History of the
Midlands Research Station
1951 - 1993

BG Technology

Gas Retired Employees Association, London HQ Branch

History of British Gas Research Stations

British Gas was for many years a major world gas company. A large part of its position was its activities in research and development (R & D).

There were five research stations

- Engineering Research Station (ERS)
- London Research Station
- Midlands Research Station
- Watson House
- On Line Inspection Centre (OLIC)

In 1995 at a time of major change in the structure of R & D, British Gas Technology published histories of the four of the research stations of British Gas. Unfortunately, there was no similar history published of OLIC although it is partially covered in ERS report.

This document is one of those histories.

These documents were never put into the public domain even though they were fascinating records of a key part of the gas industry. A full set of the reports was made available by Eric Francis, a former Director of the Midlands Research Station and the London HQ Branch of the Gas Retired Employees Association decided to fund their scanning so that they could be put into the public domain.

The London HQ Branch of the Gas Retired Employees Association is an organisation of British Gas pensioners who worked for all or part of their careers at the London headquarters of British Gas

At the time of publication of the reports British Gas had moved its R & D, renamed Research & Technology (R & T), to Loughborough.

When British Gas plc demerged in 1997 into BG plc and Centrica plc, R & T stayed with BG plc.

In 2000, a further demerger of BG plc took place into BG Group plc and Lattice plc. Lattice included Transco, the UK gas transportation company, and Advantica Technologies, the new name for BG Technology.

In 2002 Lattice merged with National Grid. At about the same time Advantica bought Stoner Technologies to broaden its reach to the US and to prepare the company for sale.

In 2007, Advantica with its 660-world staff was sold to Germanischer Lloyd.

In 2009, Germanischer Lloyd merged with Noble Denton to form GL Noble Denton and in 2010 they sold the equipment testing business inherited from Advantica to BSI.

Finally (?), in 2013 GL Noble Denton merged with DNV (Det Norske Veritas) to form DNV GL. DNV GL has a turnover of about £2 billion with around 14,000 employees world wide of whom about 1,000 are British. There is still an office in Loughborough.

OLIC has gone in a different direction. It was sold to GE and remains in Cramlington where there is the world headquarters of PII Pipeline Solutions a 50:50 joint venture between GE Oil & Gas and Al Shaheen

Holding, a wholly owned subsidiary of Qatar Petroleum. It has 11 locations globally and employs over 650 people.

While it is true that the vestiges of British Gas R & D survive after all these mergers we must ask why did it decline so dramatically?

The answer broadly lies in the competitive gas market which in Europe at least was initiated in the UK. Before this the world thought, and in parts still does, that gas was a natural monopoly; gas on gas competition was inconceivable, even illogical. That was the gas industry view, but politicians thought otherwise. In fact, the only part of the gas chain which is a natural monopoly is transmission and distribution.

British Gas as a nationalised monopoly industry could have a long-term perspective and some blue sky thinking to drive the industry forward in strong competition with the electricity industry and to a lesser extent oil. Technology was at the heart of this and the industry was more or less left to invest in R & D without external financial pressure and with a captive customer base to fund it.

If we look at the three demerged elements of British Gas plc in the context of our liberalised gas market, we can see how different the R & D demands are.

BG Group focussed on exploration and production and latterly became an extremely successful player in the LNG market. So successful that Royal Dutch Shell took them over. In terms of R & D the last BG Group annual report shows R & D at $33 million of which $19 million was with Brazilian third parties. Quite a contrast to the internal R & D with British Gas.

National Grid Gas Transmission has a continuing need for R & D support but is limited by the regulator OFGEM as to what expenses can be passed through in customer charges. For example, the most high-profile research currently is Project GRAID (Gas Robotic Agile Inspection Device). This is a National Grid project in conjunction with three British Small Medium Enterprises (SMEs) to develop ways to accurately assess the condition of its pipework assets that cannot currently be inspected via conventional Pipeline Inspection Gauges (PIGs). It secured £5.7m of Ofgem funding.

The third element is Centrica, the marketing company. Much R & D for marketing by British Gas plc and its nationalised predecessors was to compete with electricity. It also was a monopoly. Now Centrica through its British Gas brand sells electricity as well as gas so why should it spend on competing with itself? The other is that any developments funded by Centrica to improve gas could be taken up by its competitors. So, the type of R & D funded in the past is no longer economically viable.

In conclusion, the gas R & D landscape has changed remarkably since the 90s. However, we must not let the past be forgotten. It is right to celebrate the real achievements of British Gas and its predecessor companies. The publication of these reports is part of that celebration.

Rowland Sheard
March 2018

BG Technology

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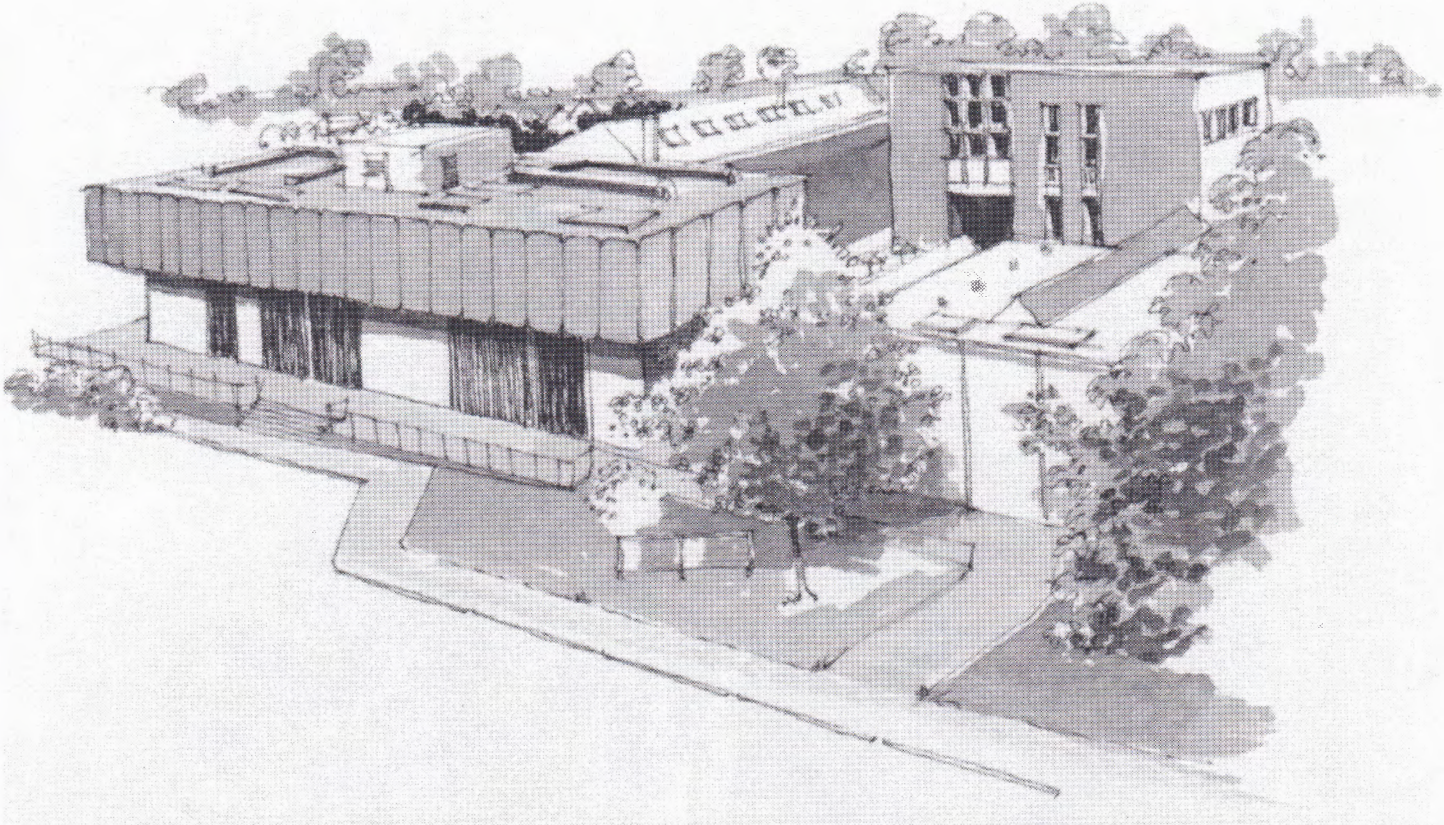

HISTORY OF THE MIDLANDS RESEARCH STATION
1951-1993

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Foreword

The decision to close down the British Gas Research Stations in London and Solihull was taken in the mid 80s, but it was some years before it became clear that Loughborough was to be the site of the new Station to replace them. When the reality of a definite closure date began to loom, it was Lawrence Conway, I believe, who put forward the notion that the demise of MRS should not pass without the recording of its achievements over the forty or so years of its existence. This idea was expanded by the R & D Programme Committee to encompass the writing of Histories of all four Research Stations.

Thus it was that I was approached late in 1991 by Lawrence Conway and Malcolm Hoggarth to assist with the production of a History of the Midlands Research Station. The initial plan was that there would be a first part setting down the major events and milestones in more or less chronological order, a second part dealing with some of the personalities who were most influential, and a third which would contain brief records of the technical achievements in the main fields of research for which the Station was responsible. This plan has been fairly closely followed, although some overlap became inevitable in the interest of providing coherent stories. I undertook to write the first part and edit the rest, which was to be largely contributed by past and present staff from the Station and its successor.

I must express my grateful thanks to all the many people who responded with contributions and whose authorship has been acknowledged wherever possible in the text. In places the editing may have been fairly ruthless in the interest of achieving a reasonably uniform approach, particularly in Part 3, and apologies are in order if anyone feels aggrieved at the result. Particular thanks are due to John Lacey and Brian Thompson for filling in some of the detail of the gasification work in the 60s.

Inevitably there will be errors and omissions, even perhaps a personal slant, and for this the editor must take full responsibility. In defence it can be said that the records are patchy, particularly in tying down the precise dates of events and the personalities involved. It is not that there is any shortage of records, there being nearly 700 External Reports and several thousand Internal Reports, although the latter have not been used to avoid problems of confidentiality. It seemed possible to check on some early events by means of the monthly progress reports, but it soon became evident that the results were not commensurate with the effort required to plough through them.

Thanks are due to Leslie Jones and Sue Pickerell for supplying the many Reports to which reference has been made, and to Janet Mortiboys for searching photographic archives and coordinating the production of this book. Lastly, I am grateful for the support of Malcolm Hoggarth, my principal contact at the Research Station and and for his many helpful comments.

W.E.Francis

December, 1995

PART 1: Origins, Establishment and Major Milestones

CHAPTER 1

Establishment of the Station

Chapter 1

Establishment of the Station

The Midlands Research Station (MRS) may be said to be a child of the Gas Act 1948, since this identified responsibility for Research as one of the main specific duties placed upon the new Gas Council. To assist it in the discharge of that duty, one of its first acts was to set up in June 1950, a high level permanent Research Committee to advise it on all matters connected with research. On the advice of the Committee, it was decided, as a first step, to establish two Research Stations, one in London (the Fulham Laboratories of the North Thames Gas Board) and one in Birmingham at the Nechells Works of the West Midlands Gas Board. The Director of the Birmingham Research Station was to be Dr. F.J.Dent, formerly Assistant Director of the Gas Research Board at their Poole Laboratories, working mainly on complete gasification of coal.

Research into complete gasification of coal had become of great importance in view of the shortage and high price of coals suitable for carbonisation and the high cost of imported gas oil for enriching water gas. The Gas Council indicated that complete gasification would be given first priority in its research programme and would constitute Dr. Dent's chief immediate task. The emphasis of the new Station was thus very clear from the outset.

The Gas Research Board had become a typical cooperative Research Association, funded partly from contributions from its members (gas undertakings, absorbed into the Area Boards, plant and appliance makers) and partly by the Department of Scientific and Industrial Research. Given the responsibility for research placed upon it by the Gas Act, the Gas Council (now the main financial contributor to the GRB) considered that it needed directly to control the principal areas of the work, and that this was not compatible with support for an independent cooperative Research Association. In May 1950 the Chairman of the Gas Council, Sir Edgar Sylvester, attended a Meeting of the Council of the GRB and indicated that it would not be possible for the Board to continue in its existing form and work parallel with any research organisation which the Gas Council might establish. However there should be no interference with the continuity of the GRB work. In particular, it was arranged that the work on complete gasification of coal, carried out at Poole under the direction of Dr. Dent, would be continued as part of the Gas Council's programme. The five scientific staff and the eight experimental staff at Poole were transferred to Gas Council employment in September 1951.

At the end of 1951 there were 10 GRB scientific staff at Leeds University on Joint Research Committee projects and the remaining 12 were sited in Laboratories at Beckenham in Kent (Fig. 1.1), and were mainly involved in research into the utilisation of gas.

Fig. 1.1 The Abbey, Beckenham, Kent. Occupied by the Gas Research Board 1949-53.

After discussions with the interested parties, the Gas Research Board was voluntarily wound up on the 26th, June, 1952 and the work and assets transferred to the Gas Council.

One or two interesting episodes from this time of some uncertainty for the people concerned are worth recording. Around the time of the decision to close the Beckenham laboratories, there was a meeting of the scientific staff addressed by the Chairman of the South Eastern Gas Board, Mr. K. W. (later Sir Kenneth) Hutchison, who explained the demise of the Gas Research Board and the Gas Council's proposals for the establishment and work of the new Birmingham Station. He explained that utilisation work would continue but would be focussed on industrial applications of gas, the Birmingham location in the industrial heartland of the country being ideal for this purpose. The news was not received with great enthusiasm, and Mr. Hutchison was questioned vigorously on whether the proposed work would be short term development or of a more long term nature. What could not perhaps be foreseen was the considerable influence Sir Kenneth would have on the future MRS; he was already Chairman of the Research Liaison Committee and as Deputy Chairman of the Gas Council would have an even more central role.

Another occasion was rather more entertaining. The Gas Council hosted a dinner at the Park Lane Hotel for the scientific staff from Beckenham and Poole, at which were present some very senior figures in the Gas Industry. There was some speculation as to whether the occasion represented a celebration, for the entry into the Gas Council's domain, or a wake following the demise of the GRB! Nevertheless, a good time was had by all.

It was also an early example of the involvement of the Gas Council at the highest level in Research affairs, and of the access of research staff at relatively low levels to people of great influence in the Industry. Over the years ahead this was to prove of very great importance.

Out of the 31 scientific staff in the GRB in 1951 the following small band made the changeover to the Gas Council and eventually to the MRS at Solihull.
From Poole:, Dr. F.J. Dent, Dr. L.A. Moignard, Dr. D. Hebden, Dr. F.C. Wood, G. Percival, R.F. Edge, J. Buckley, K.W. Stewart . Two workshop technicians, Alan Ross and Leslie Jones, also eventually moved to Birmingham (Fig. 1.2). From Beckenham: W.A. Simmonds, W.E. Francis, P.G. Atkinson P.A. Cubbage.

Fig. 1.2 The staff at Poole around the time of the takeover of the Gas Research Board by the Gas Council in 1951. Those who eventually joined the MRS at Solihull are, in the front row from the left, George Percival, Frank Wood, Leo Moignard, Fred Dent, Dennis Hebden, Alan Ross, second row fourth from the left, Ron Edge next to Jim Buckley and Ken Stewart, back row second from the right Les Jones.

In the years that followed, this select group collected one FRS, three OBEs, one MBE, two Fellowships of Engineering, one Presidency of the Institute of Energy, two IGE Birmingham Medals, eight IGE Gold Medals and several other Awards as well as providing four Research Station Directors and three Assistant Directors.

These MRS pioneers may have had mixed feelings about the demise of the GRB and the move to Birmingham, but in retrospect, being brought into main stream of the Industry, with the availability of resources to work on a substantial scale was of tremendous benefit. As Dr. Dent was to write in his 1965 Melchett Lecture, "The cost of operating on such a scale calls for a fairy godmother and ours has been the Gas Council."

1952-1955 Nechells and Poole

Gasification

The need to continue the pilot scale programme on the hydrogenation of coal, already started at Poole, where there was a facility for production of hydrogen at high pressure, meant that much of the effort would remain there for several years (Figs. 1.3 and 1.4).
An investigation of the effect on the efficiency of water gas production of using preheated air and steam was being completed by George Percival, and Dr. Moignard was finishing his definitive study of the operation of iron oxide purifiers for the removal of hydrogen sulphide from towns gas.

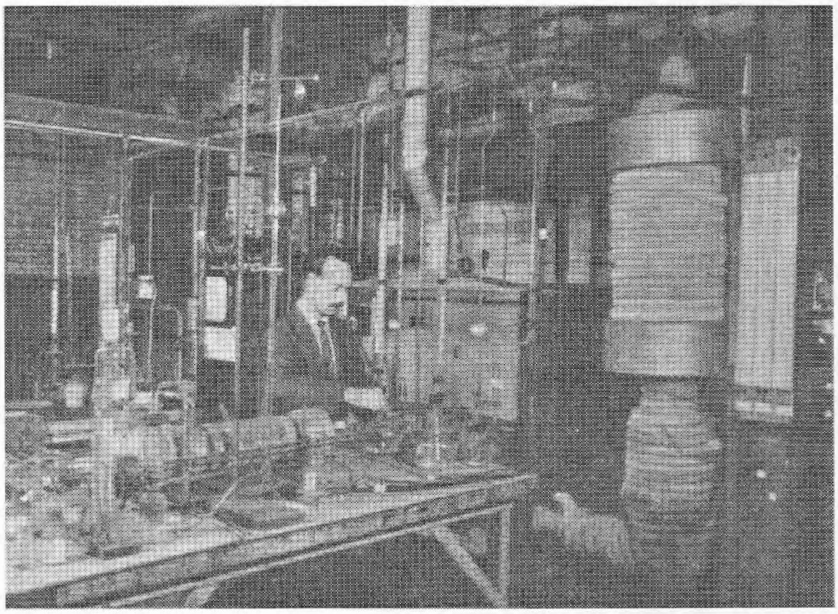


Fig. 1.3 A laboratory at Poole for small pilot plants, showing Jim Buckley with, on the bench, a number of small "Edwards bottles" for controlling gas flows.

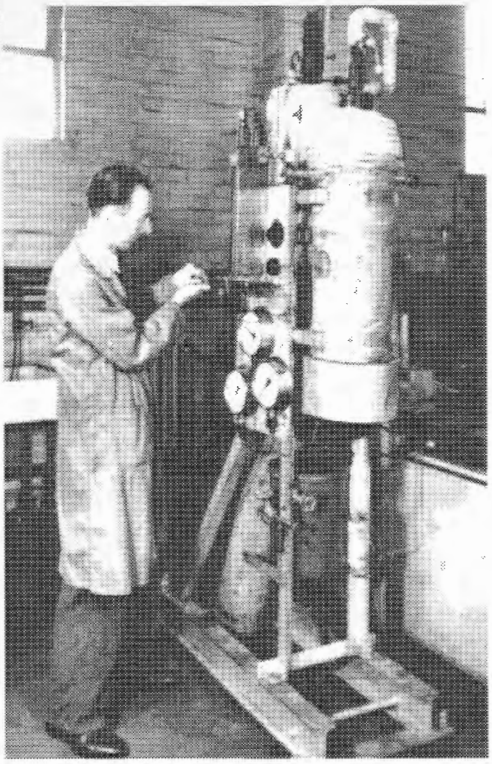


Fig. 1.4 Ken Stewart with a steam/coke reactivity rig, Poole 1952.

Meanwhile a temporary base was established at the Nechells Works of the West Midlands Gas Board, pending the acquisition of a suitable permanent site for the new Station. Laboratory and office space was made available on the top floor of the WMGB Central Laboratories, a multi-storey building overlooking the Saltley Viaduct and the main railway line from Birmingham to Derby and the North-East. Some components of a small Lurgi gasifier had been acquired by the GRB some years earlier and had been lying at Poole. This plant was now erected on the Nechells Works site at the far end near Duddeston Mill Road (Fig. 1.5). Dennis Hebden and Ron Edge were principally involved with this and were joined by Kevin Foley, a New Zealander capable of a particularly fine flow of invective on occasions.

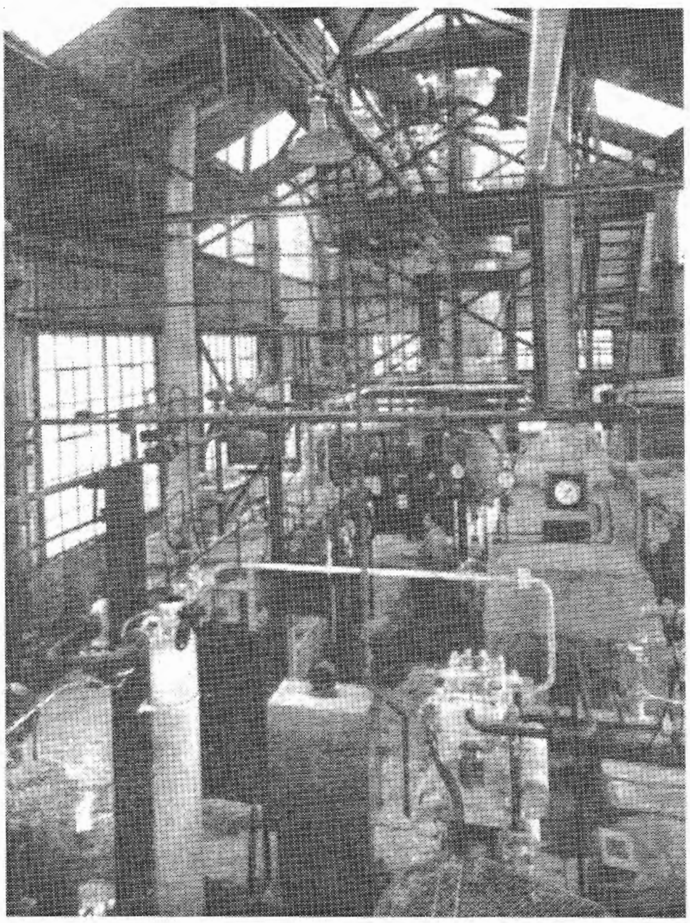


Fig. 1.5 The pilot high pressure gasification plant at Nechells Gas Works, Birmingham, in 1953 showing the ancillaries in the foreground and the generator in the background.

While waiting for the completion of this plant, opportunity was taken to test several weakly caking British coals in a small 1 sq. metre cross-section Lurgi gasifier at Holten in Germany. The gasifier was equipped with rotating knives to break up expected agglomerations and the results from these successful tests were to influence the programme for the Nechells plant. The most important aspects to be studied were the mechanism of methane production in the upper zone of the fuel bed and the scope for economy in the use of steam.

Operation of the Nechells gasifier was quite arduous, for example the grate was hand operated and had to be shaken periodically on a standard schedule. Up to four days continuous operation was possible because of the large ash containing chamber below the grate. The results were reported at the IGE Autumn Research Meeting in November 1954, one of the most important conclusions being that methane formation was mainly from direct hydrogenation of the carbon in the fuel bed. Also conclusions were drawn on the improvement in the effectiveness of steam utilisation that would result from slagging operation.

The question of enrichment of the synthesis Gas available from the standard Lurgi generator had to be addressed. One possibility, catalytic methane synthesis, had already been demonstrated at Poole, and was the first option for any projected Lurgi plant likely to be erected. Dr Dent's other proposal was through the direct hydrogenation route.That direct hydrocarbon of carbon took place in the top of the bed in a Lurgi generator seemed to be demonstrated by the results of the Holten tests. At one stage it was proposed that the Nechells plant would be modified to increase the partial pressure of hydrogen at the top of the fuel bed, but this was never put into practice. Instead, effort was concentrated on hydrogenation of powdered coal in a separate generator vessel.This reaction had already been studied on the pilot scale in GRB days in a static bed, but the reaction was not controllable, and the yields of methane were limited by the exothermicity sending a wave of high temperature advancing rapidly through the bed. The answer was to use a fluidised bed of coal, and this had been demonstrated at a laboratory scale, for which work Frank Wood received his doctorate from Leeds University. During 1952 the pilot plant at Poole was modified for fluidised operation (Fig. 1.6).

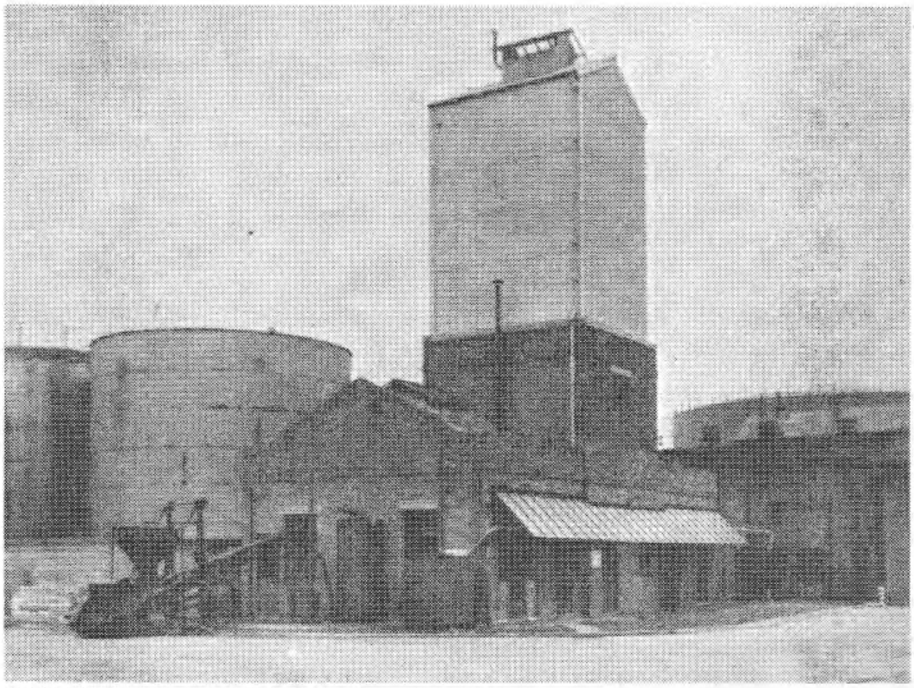
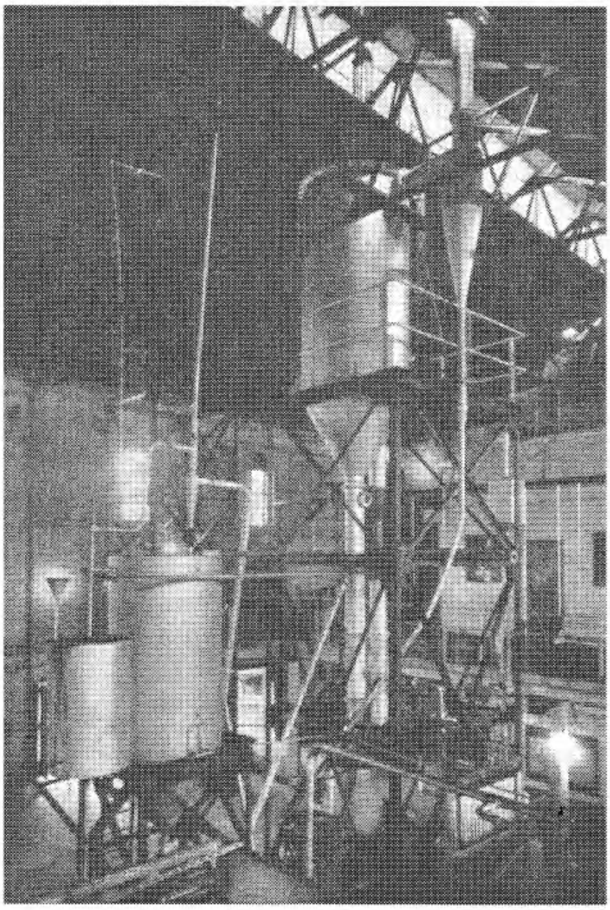


Fig. 1.6 The hydrogenation plant building at Pitwines Works, Poole in 1953.



The coal hydrogenator was also to be the first stage in Dr. Dent's vision of an all powdered coal route to town gas. Since the hydrogenation reaction only gasified part of the coal and left a "char", a second stage was needed to gasify the char in steam and oxygen to produce hydrogen for the first stage. Such a reactor would also be necessary for a powdered coal gasifier. Agglomeration of the powdered fuel was feared to be a potential problem in the hydrogenation stage, and it was planned to use forced circulation of the fluidised bed to increase the rate of mixing and to aid temperature control. To investigate the flow of gases and solids in such an hydrogenator a full scale cold model was constructed in an old horizontal retort house at Nechells (Fig. 1.7). A second such plant was erected in the retort house to simulate a powdered fuel gasifier combining a slagging cyclone with a fluidised stage and recirculation leg.

Fig. 1.7 Apparatus for the study of recirculation from a fluidised bed, in an old retort house in Nechells Works, 1953.

A newcomer, Bob Stuart, a jovial Scotsman, operated these fluidised bed plants, and not without incident! One day an unforeseen circumstance shot the contents of the plant out through the roof of the old retort house and from the top floor of the Central Laboratories we observed Saltley Viaduct disappear in a vast cloud of black dust. As Bill Simmonds later wrote[Eureka No. 20, Nov. 1982] " This incident took place in the 50's when the first impact of coloured immigration was being felt in areas like Saltley. Some people were upset by it, and there was a certain amount of racial feeling. Imagine the consternation of a white lady who was pushing a white baby over the viaduct in a pram at that time and emerged from the cloud pushing a black baby!"

Another newcomer at Nechells was Dr. R.G.Cockerham, who was already working in the Central Laboratories for the WMGB, and moved over to research on the analytical side, mainly in support of the gasification programme. Catalytic conversion of CO with steam was being studied by Fred Landau, and Reg Bott, later to return to Birmingham University, was working on static bed coal hydrogenation.

The Hydrogenation Pilot plant at Poole

The first runs were made with semi-coke as feedstock in May 1953, producing a gas of 430 B.Th.U./cu.ft. However there were difficulties in maintaining temperature at the desired feed rate of coal, leading to the provision of various preheating arrangements. A successful run was carried out in late 1953, but perhaps because of the low utilisation of both coal and hydrogen, no further runs were carried out. In January 1954 there was the first mention of a plan to use heavy fuel oil in the pilot plant.

Dr. Dent's plans for gasification research often had to be modified as a result of the rapidly changing fuel situation. Oil was becoming more plentiful and less costly and objections to the use of an imported feedstock were receding, at least for peak load purposes, although an all coal process would still be a long term objective, so the tests on coal hydrogenation at Poole were abandoned in favour of oil hydrogenation in the same pilot plant. Initial tests were with heavy fuel oil and a "topped" crude using high temperature coke in the fluidised bed. Various modifications to the plant were made during 1954/55 to avoid agglomeration and improve temperature control, including lengthening of the bed and using baffles to simulate multiple beds. Real success had to await the incorporation of overall bed recycle, first mentioned in March 1954, but not implemented on the plant until February 1956.

Utilisation

While the gasification programme was able to build on the long tradition of Joint Research Committee and GRB work, the utilisation side had to start almost from scratch. Contact was made with the Industrial Department of the WMGB; at that time it had offices and a development laboratory situated in Brasshouse Passage off Broad Street in the centre of Birmingham. H.R.Hems was in charge and one of the senior engineers was J. Waight, who was very helpful in indicating problem areas worthy of investigation. Unfortunately, Jack Waight was taken seriously ill and died shortly afterwards, but his successor, Les Walker proved to be very supportive of the subsequent research.

Bill Simmonds became a member of the Industrial Gas Development Committee, a Gas Council body responsible for coordinating the development of the industrial market, and this too became a source of information on potential research topics.

One problem area was the design of explosion reliefs for industrial drying ovens. About 12 deaths per year occurred from explosions in these ovens, sometimes from gas

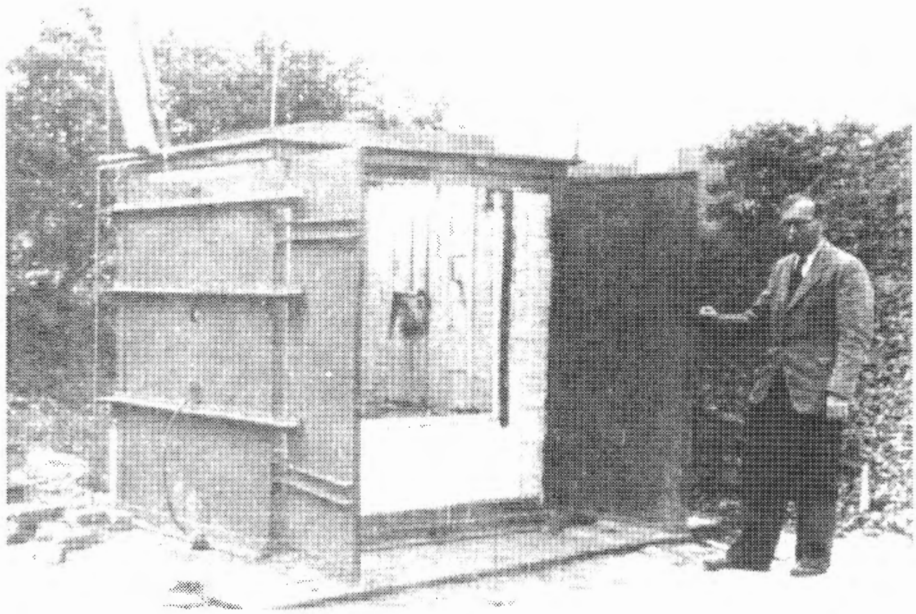


Fig. 1.8 Peter Cubbage standing by an experimental box oven on the coke dump of Solihull Gas Works around 1954. An investigation of explosion reliefs began here before the MRS was built.

explosions but also from ignition of flammable solvent vapours from paint drying or curing, whatever the method of heating. The Factory Inspectorate was leaning on the Gas Industry to do something about this problem, and with Bill Simmonds war time experience of explosives research, this seemed an ideal initial project. So Peter Cubbage found himself blowing up ovens on the coke dump at the Solihull Gas Works (Fig. 1.8).

Another problem which was said to be inhibiting the use of rational design methods for industrial gas plant was the uncertainty in the accuracy of the physical properties of the products of combustion of gas, particularly at high temperatures. W.E.Francis began a series of theoretical studies on the transport properties of gases at high temperatures, using the results of recent work on intermolecular forces in gases by Hirschfelder and his co-workers. This culminated in a new formula for viscosities of gas mixtures and in reliable data for the physical properties of combustion products first available as one of the earliest MRS Internal Reports IR3.

Control and instrumentation was a third area of work regarded as important. Experimental investigations of heat transfer in industrial gas plant often required the measurement of flue gas and combustion chamber gas temperatures. Suction pyrometry was the standard approach, but available instruments were of a size suitable for power station boilers or steelworks furnaces. Peter Atkinson set about developing small instruments suitable for gas fired equipment.

Meanwhile, Bill Simmonds was writing up two pieces of work left over from the GRB. The first was the study of wind stresses on spirally guided gasholders, for which he was awarded a Ph.D from London University. The second concerned the prediction of air entrainment in "atmospheric" bunsen type burners. This turned out to be very significant, since Eric Francis was to use the same basic injector theory and generalise it for a wide range of jet pump devices which would be applied in many subsequent MRS projects, both utilisation and gasification.

An early study on heat transfer from flames was interesting as an example of a project which was unsatisfactory in its primary aim, but served to indicate a more profitable line of investigation for the future. It was an attempt to measure the increase in direct flame radiation from a diffusion flame when the air supply was preheated, a subject in which J.F.Waight was particularly interested. The flame was confined in a water cooled calorimeter vessel with thermopiles fitted in the walls, but the heat transfer was found to be dominated by the convection caused by the strong recirculation within the chamber. The lesson was not lost and the subjects of recirculation and convection were to figure extensively in the future programme.

Life at Nechells 1952-55

Conditions at Nechells were hardly ideal. The top floor at the Central Labs. became seriously overcrowded as staff numbers began to build up. On the utilisation side the scale of the experiments was becoming larger. Some heavy pieces of equipment, the air preheater for example, had to be brought up suspended underneath the lift. On the other hand, being on a gas works site had the advantage of access to a range of facilities; there was a paint-shop, a tinsmiths, a refractories section and of course within the Birmingham area there were many small engineering firms willing and able to do one-off jobs.

Being administered by, and employees of, the WMGB meant that we were members of the Social and Recreation Club. Several of the staff (mostly ex-Beckenham) were soon playing in the "Gas Officials" cricket teams.

At that time there was a good supply of research assistants, usually undertaking part-time study at the local Tech., many of whom would subsequently be on Dip. Tech. courses at Aston College of Advanced Technology. Among the earliest were Roger Hancock and Dave Moppett. The first assistant, however, was a young lad from Cleobury Mortimer, with a thick Shropshire accent, who was unfortunately rather accident-prone. When asked to coat the calorimeter vessel with matt black paint, he managed to put more paint on himself than on the vessel.

It was not so easy to recruit and retain graduate staff. R.H.Gough had come up from Beckenham and was seconded to work with the WMGB Industrial Dept., monitoring forge furnaces in local factories, but the experience was presumably too much for him since he left soon after.

Housing for staff relocating to the area was a problem at first. The WMGB bought a large house called "Cora Lynn" in Solihull, on the corner of Warwick Road and Manor Road, and converted it into four flats, occupied initially by Dr. Dent, Ron Edge, Alan Ross and E.P.Hotchen (an ex-IGE Arthur Duckham Fellow who came and went fairly quickly). This house was to prove an embarrassment to the Station Management in later years. Solihull was always the preferred area in which to live, and after about 1953, when licensing restrictions on new houses were lifted, there was a tremendous increase in the availability of houses in the area, so from then on it was not a problem.

During 1953/4 a site adjoining the Solihull Gasworks was acquired for the new Research Station; construction of the buildings was begun and the first was ready in March 1955. It was time to move!

CHAPTER 2

Solihull 1955-1960 The Early Years

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The Wharf Lane site was an almost ideal situation in 1955. The area was designated for industrial use. There was housing on only one boundary and the Grand Union Canal formed another with open fields beyond. On the North-West side was a small industrial estate. The space available seemed more than adequate at the time, and for a while it appeared we could emit noise, effluent, smoke and dust with impunity, since the small Solihull Gasworks (3 million cu. ft. per day from continuous vertical retorts) was already there and could receive all the blame for environmental problems (Fig. 2.1)

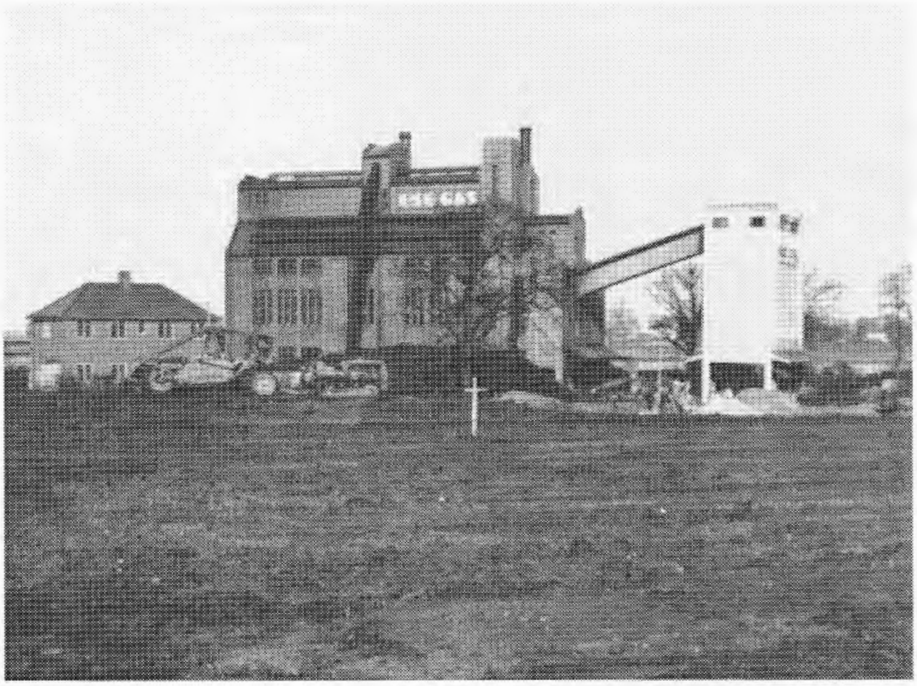


Fig. 2.1 The Solihull Gas Works 1954/5, with the site cleared for the first MRS Buildings.

Fig. 2.2 The pub at the end of Wharf Lane.

The canal was still in use for commercial traffic and there was a wharf at the end of the road from which it got its name. A pub existed at the wharf (Fig. 2.2).

The first building to be occupied was that later designated as Davy Building, and comprised offices at the front, chemistry, physics (utilisation) laboratories and a machine shop, with offices also along the South side, (Fig. 2.3). The chemical engineering building (Brunel) was ready for occupation in 1956, and even while it was being built two large pilot plants were being erected inside. One was a Lurgi gasifier modified for slagging operation while the second was a gasifier with a deeper bed aimed at promoting more methane production.

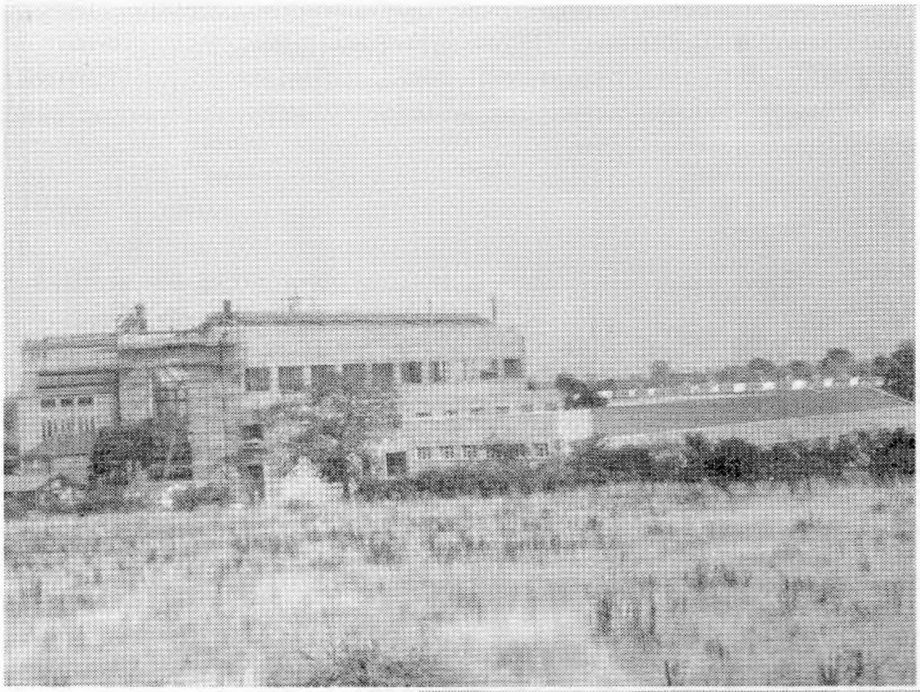


Fig.2.3 The first two MRS buildings, circa 1955, with Solihull Gas Works in the background, viewed from the other side of Wharf Lane, which was still just an open field.

A prominent feature of the chemical engineering building was the huge window running almost from top to bottom of the Wharf Lane elevation. This end of the Building had an analytical laboratory on the ground floor, but above it was a room of such height from floor to roof that some unknown wag suggested that the only possible use was for breeding giraffes, so it became known ever after as the Giraffe Room (Fig. 2.4).

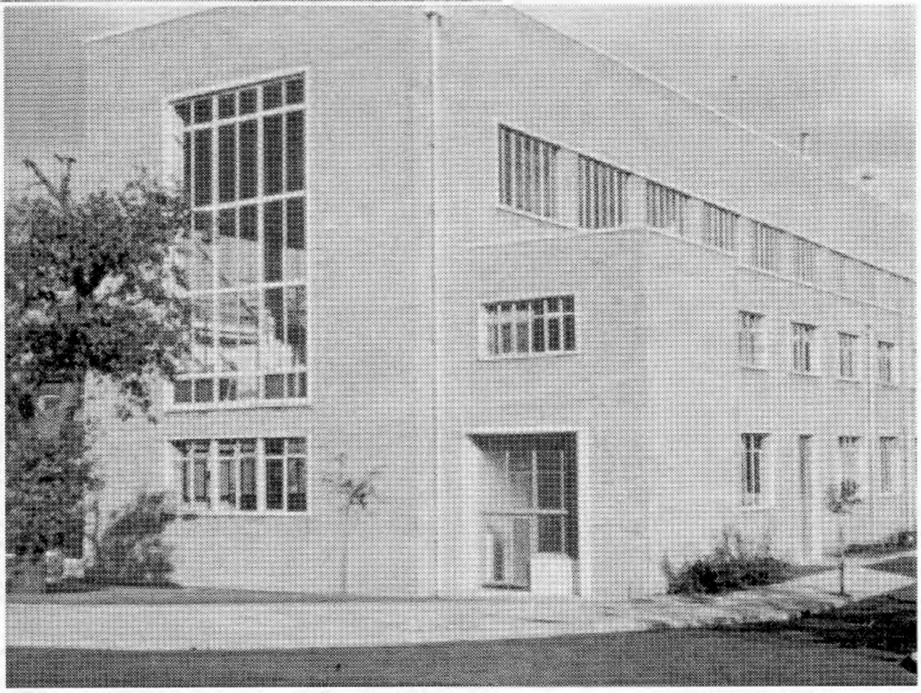


Fig. 2.4 The chemical engineering lab., later called Brunel Building, showing the huge "Giraffe Room" window.

The laboratories were heated by steam, through overhead radiant panels about six feet long by about three feet high; one remembers a continuous noise from the steam, the clacking of steam traps and networks of pipes overhead and around the walls carrying steam, water, gas, compressed air, nitrogen, hydrogen etc. The floors were of a bituminous material supposedly resistant to oils, heat, acids etc, but unfortunately heavy equipment gradually sunk into it over the years. The roof also contained bitumen which was later to catch fire after a mishap on the oil hydrogenation plant.

Staff numbers were slowly building up so that on 31st March, 1957 they were reported as follows:

Senior and Scientific Staff	23
Research Assistants	26
Workshop & Laboratory Staff	28
Administrative Staff	6
Staff Totals	83

At about this time there was an influx of graduate staff from the Indian Sub-continent, mostly chemical engineers working on the pilot plants. P.S.Murthy, Benoy Majumdar, O.Figueiredo, B.K.Deb and R.M.Contractor were among the earlier recruits. The proportion was so high at one time that it was rumoured that Dr. Dent had a recruiting office in Calcutta! The Leeds University connection was further enhanced by the arrival of Dr.B.H.Thompson, like Dr.Dent a former IGE Research Fellow, to work on hydrogenation under Frank Wood.

The official inauguration of the Station took place on April 1st,1958, by Sir Cyril Hinshelwood, a member of the Research Committee and at that time President of the Royal Society. The event was commemorated by a bronze plaque, eventually prominently placed in the foyer of Murdoch building.

The gasification programme was dominant in the Station's activities, if only because of its scale. The major pilot plants required a large team during an experimental campaign, with a shift rota to ensure 24 hour coverage. Besides the main pilot plant under investigation, there were a number of essential ancillary plants to be manned, such as a butane reformer for hydrogen production (Fig.2.5), CO_2 scrubber, oxygen and nitrogen supplies, steam boilers, the tank farm, compression facilities etc. During such campaigns, all available staff were engaged, often to the detriment of their own projects. Senior staff often slept on site in makeshift beds in offices, and one toilet was converted to a bedroom for Fred Dent who insisted on being present at critical moments.

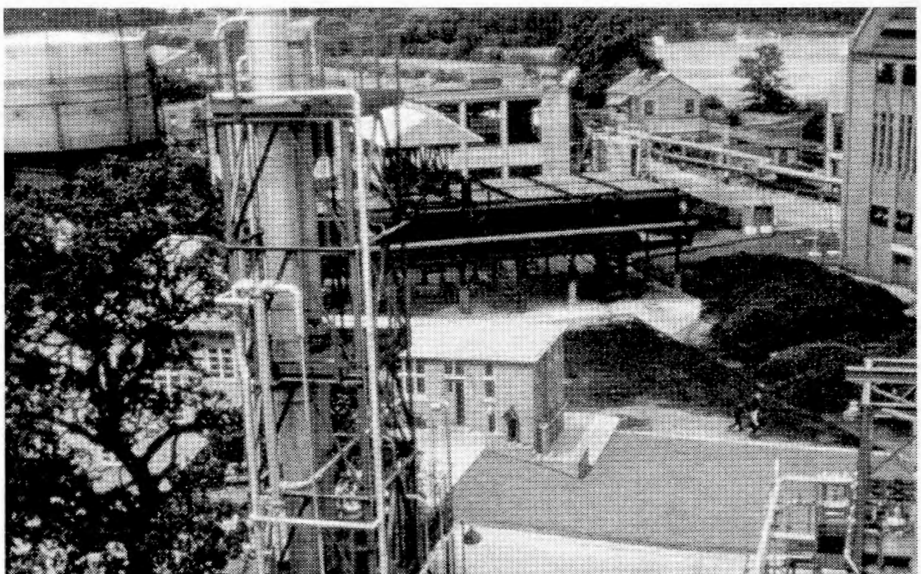


Fig. 2.5 LPG Reforming Plant for hydrogen production, 1960, with the Gas Works in the background.

Construction of major pilot plants were undertaken by established contractors such as Humphries and Glasgow or the Power Gas Corporation. The limited engineering and workshop facilities of the Station were reserved for modifications, repairs and the stripping down and refurbishment after runs. Alan Ross was initially in charge of these activities, to be followed later by Derek Mitchell. Even for this limited role the permanent staff numbers were inadequate, and were supplemented by the semi-permanent presence of contractors, particularly IPI (pipe fitting) and Atack (electricians), coupled with extensive overtime working

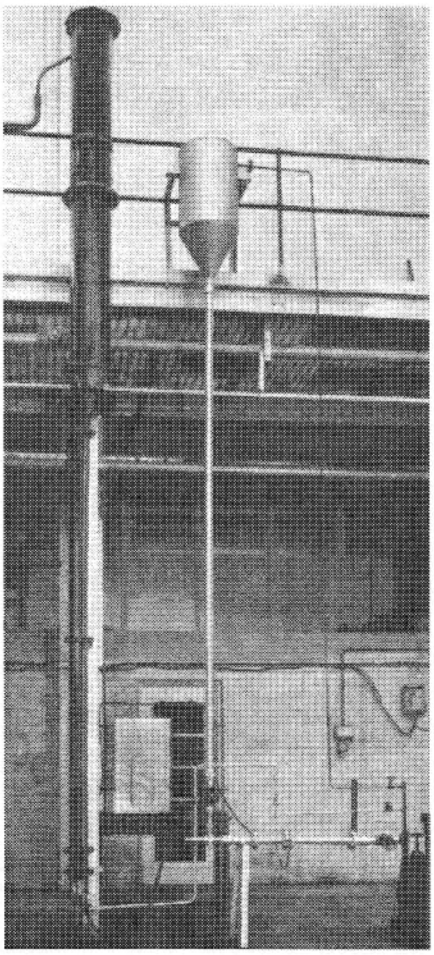
The Gasification Programme

Dr. Dent's strategy for gasification research was now more complex. The long term aim of an all coal system remained, with the Lurgi process as the already proven option for plants in the immediate future. Two plants were planned, one in the West Midlands and one in Scotland. Improvements to the existing process centred on slagging operation to reduce steam consumption and deepening the fuel bed to increase methane formation.

However, the changing fuel supply situation meant that oil was receiving increased attention, initially as a source of enrichment for Lurgi gas, then for peak load purposes and finally even as a source of base load supply.

Tests with the hydrogenation pilot plant at Poole had been continuing. In late 1955, light distillate and gas oil were successfully gasified in a fluidised bed of coke at 32 bar and about 750°C. These feedstocks could be vapourised and preheated prior to entering the reactor, but crude oil and HFO had to be directly injected into the fluidised bed and gave trouble with agglomeration until a bed recycle system was incorporated, allowing the oil to be atomised into a high velocity dense phase ascending in a riser pipe.

A full-size perspex model of the system had been built in the chemical engineering block at Solihull (Fig. 2.6) to optimise the recycle conditions so that the oil feed would be sprayed into a substantially greater weight of hot coke particles. The pilot plant at Poole was adapted to this system and successful runs took place through the Spring and Summer of 1956. A gas of high calorific value was produced and oil hydrogenation displaced methane synthesis as the preferred option for enrichment of Lurgi gas. This work was reported at the IGE Autumn Meeting in November 1956 and won the Institution Gold Medal for its Authors.



The final tests on the Poole pilot plant took place in March 1957, and was on light distillate at 10 bar producing gas of up to 1000 B.Th.U. to demonstrate the suitability of this feedstock for the enrichment of Lurgi gas. The programme and associated laboratory studies had involved most of the staff on the gasification side and a good deal of commuting from Solihull to Poole, so it was a relief to some when the final withdrawal from Poole took place in April 1957. Fred Dent and Denis Hebden may have had mixed feelings, since their sailing interests were still centred on Poole!

The further development of the fluidised bed oil hydrogenator was to take place by the planned erection of a full-scale (7.5 m. cu. ft./day) plant at Partington by the North West Gas Board, and in a 1m cu.ft./day plant at Solihull. The Poole plant was to be rebuilt at Solihull as a coal hydrogenation unit.

Fig. 2.6 Perspex model of the coke recycle system used in the fluidised bed hydrogenator in the new chemical engineering building.

The coal gasification programme was continued at Solihull with the erection of two new plants, investigating improvements identified as desirable from the tests on the Nechells gasifier. The first was a slagging gasifier, aimed at improving the efficiency of steam utilisation (Fig. 2.7), and the second was a more standard Lurgi type gasifier with a mechanical grate, increased depth of bed and facilities for injecting a hydrogen rich gas into the upper part of the bed.

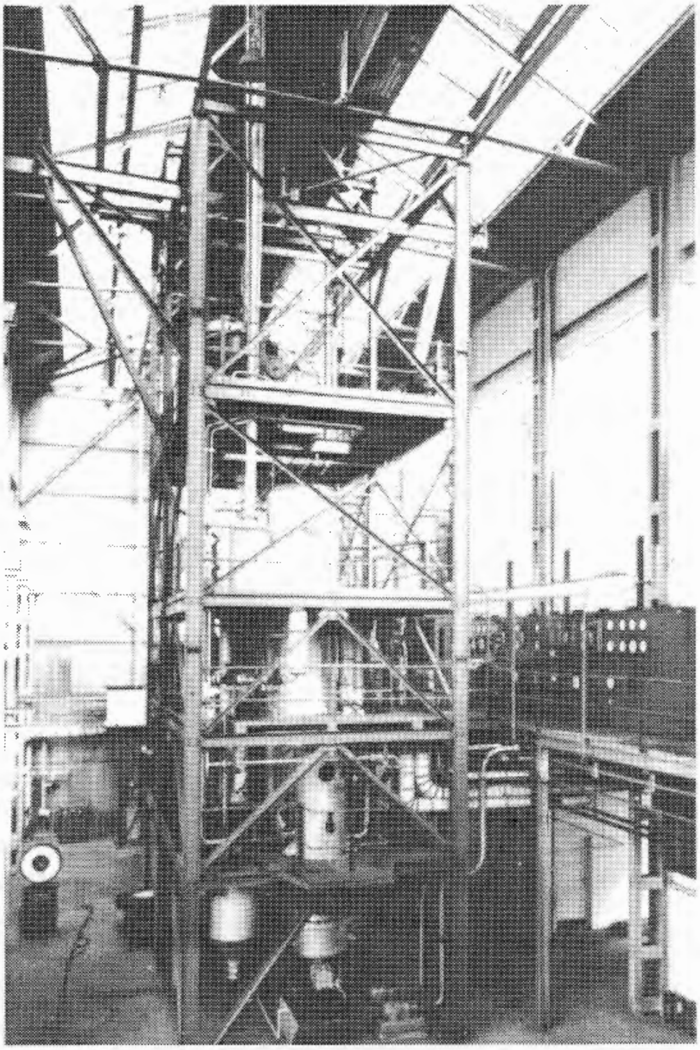


Fig. 2.7 The Slagging Gasifier, the first major plant to be erected in the new chemical engineering building at Solihull in 1955/6.

The slagging gasifier unit had been built and operated by the Lurgi Company and Ruhrgas at Holten, but the work was discontinued and the plant was purchased by the British Ministry of Power, who arranged with the Gas Council for it to be erected at Solihull and operated as part of the MRS programme (Fig. 2.8). This was the first large plant to be built in the new Chemical Engineering building and became operational early in 1956. Initially there were many difficulties in controlling molten slag flow through the refractory tapping tube without freezing or the formation of "stalactites" in the quench vessel. A system was devised of holding back the flow of slag and keeping the tap tube hot by means of a high velocity burner firing up the tube, and then tapping intermittently at high flow. This enabled successful runs to be carried out with coke in the fuel bed, and demonstrated the higher efficiency and output to be gained from slagging operation.

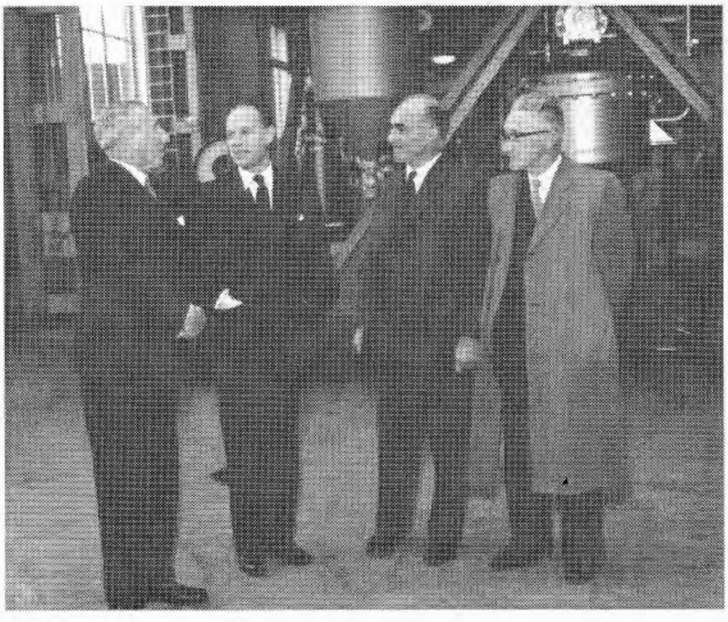


Fig. 2.8 Visit by the Minister of Power, Mr. Aubrey Jones, shown between Sir Harold Smith, Chairman of the Gas Council, and Dr. Fred Dent, standing at the base of the slagging gasifier rig, around 1956.

The project was monitored on behalf of the Ministry of Power by Brian Locke ("the man from the Ministry"). On one occasion clumsy loading of the tundish above the fuel feed lock hopper led to a large quantity of coke falling over the side of the structure on to the head of Brian Locke standing on the slag tap viewing platform. He eventually saw the humourous side of the event.
The second gasifier was known as the "gasifier with mechanical grate", and was also fitted with an agitator in the upper part of the bed and a gas offtake scraper for use with coal in the fuel bed. It was started up in December 1956, but was beset with mechanical problems in the early stages, and in view of the priority given to the slagging gasifier, progress was slow.

Catalytic Oil Gasification

Meanwhile, the economics and availability of oil products were forcing an increasing emphasis on their use as feedstocks initially for enrichment or peak load use, and this was affecting the balance of the research programme. In particular the availability of what was variously known as light ends, naphtha or light distillate fraction, easily vapourised and with relatively low sulphur content made it an attractive feed for a peak load plant. However some of the first experiments involved the use of methanol as a feedstock.

The idea was that large capital intensive plants such as Lurgi coal gasification should be run continuously as a base load plant and that at times of low demand, the output could be used to produce a storable liquid product, methanol, which could be gasified in a relatively cheap plant to satisfy peak load requirements.

Fig. 2.9 Visit of a TUC Energy Committee, showing George Percival talking to George Woodcock. Also in the picture is believed to be Mr. Sidney Greene of the NUR, standing behind George Percival, with Bob Cockerham in the left background.

George Percival (Fig. 2.9) began the laboratory scale experiments on both methanol and light distillate in late 1956. After some abortive attempts using a fluidised bed of catalyst, success was obtained using a fixed bed of powdered nickel-alumina catalyst in a 0.5" tube at 25 bar, gasifying light distillate in steam at an outlet temperature of 500°C. The gasification stage was followed by a CO conversion section to demonstrate the production of compatible town gas, after removal of carbon dioxide. The type of apparatus shown in Fig.2.10, was typical of the small scale experiments conducted on catalytic gasification and was unchanged in essence right through until recent years, although the control and instrumentation has changed radically.

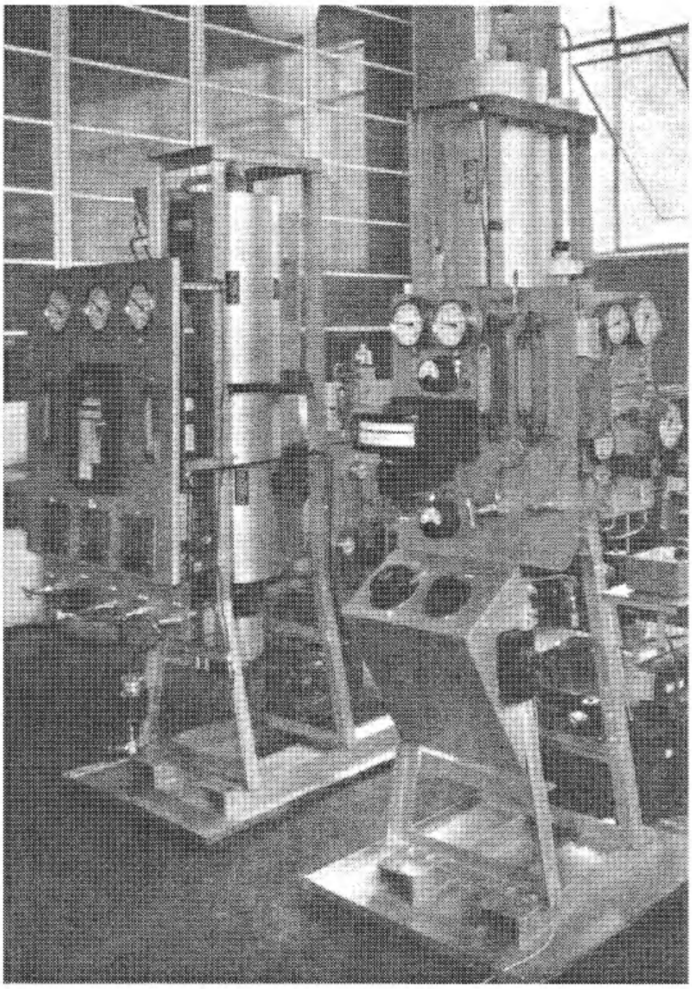


Fig. 2.10 Laboratory apparatus for catalytic gasification of methanol and light distillate, 1957.

Light distillate contained about 0.04% by weight of sulphur, which was about 500 times as much as the reactive nickel catalyst would tolerate, so the material had to be purified before it was able to be gasified. This process was demonstrated, again at the laboratory scale by Bob Cockerham.

The work on both methanol and distillate was reported very quickly in a Paper by Cockerham and Percival at an IGE Meeting in November 1957. It was the start of a successful line of development, initially known as the "peak load process", but subsequently as the Catalytic Rich Gas or CRG Process, which was in its various forms to be a major MRS activity right through to the early 80's.

Utilisation Research in the late 50's

During this period the utilisation work was rather overshadowed by the much larger scale (and at the time more important) gasification programme. Progress was slow due to the limited staffing and generally low priority for Station resources such as workshop facilities. However the little group was beginning to make its mark. The work on explosion reliefs for industrial ovens was reported in IGE Papers in 1955 and 1957, and the results were implemented quite quickly, through the support of the Factory Inspectorate and one or two enlightened oven manufacturers. Reg Broomer of H.J.Ballard Ltd. was a particularly enthusiastic supporter of the work and included the new design of relief in an updated series of ovens. Peter Cubbage then went on to work on the design of improved flame traps for use in fully premixed air/town gas supplies, and the results of this work was also taken up very quickly by Amal Ltd.

J.R.Hargreaves joined Peter Atkinson on the development of small suction pyrometers and Brian Jackson came from Leeds University to work on combustion. One of his first jobs was to study the possible use of a Lucas gas turbine combustor on town gas, at the Brasshouse Passage laboratory of the WMGB, then subsequently he cooperated with Eric Francis on the development of tunnel burners.

Another new arrival was Hilde Roughton (later Mrs Toth), the first mathematician in the Station. Her early work was on properties of combustion products necessary for heat transfer calculations, subsequently published as IGDC Special Reports, and she later headed a small but very effective mathematical services group. During her career she was to use the whole range of computing equipment, from the hand cranked mechanical calculator such as the Brunswega (often used by Dr. Dent), through electrically operated machines like the fast but excessively noisy Munro, the early electronic desk calculators including the unreliable Anita and of course the whole range of main frame digital computers. MRS originally relied on access to the WMGB's series of ICL machines, then on an Hewlitt-Packard mini acting as an intelligent terminal to the LRS computers and finally a DEC super mini. Hilde presided over all these changes and provided advice to the less mathematically able members of the Station.

Eric Francis was working on both jet and fan driven recirculation in ovens and furnaces, reported at the IGE Autumn Meeting in 1956. Applying the technique to hydrogen and feedstock preheaters for the gasification programme showed a need to improve the efficiency of the currently available jet burners and this led to the development of improved tunnel burners. The results were to shape the nature of the industrial R and D for many years to come and also led to a number of new applications in conjunction with both manufacturers and Area Boards (Fig. 2.11).

Fig. 2.11 Members of the Industrial Gas Technical Committee; some of the Regional members were very influential in applying early MRS developments in burners, furnaces and control systems. From L. to R., Bill Smirles (WMGB), R. Perrin, (NWGB), Les Walker (WMGB), Ken Greenway (SGB), Ken Ernest (Wales GB), Trevor Ward (NEGB), E.A.K.Patrick (Watson House), Bill Simmonds, Eric Francis.

Malcolm Hoggarth joined the team in 1959 and his work on the stability of tunnel burners opened the way to the design of much larger burners, widening the range of applications (Fig. 2.12). One of the more curious applications was for entrained calcination of china clay. A plant was built in the 'Giraffe Room', and unfortunately there were occasional problems which resulted in the venting of a cloud of fine white dust which drifted over to the neighbouring industrial estate. At other times the situation was not helped by the ejection of a cloud of black coke dust from the FBH plant next door, prompting irate phone calls from one particular factory occupant indicating that, black or white, the dust was considerable nuisance.

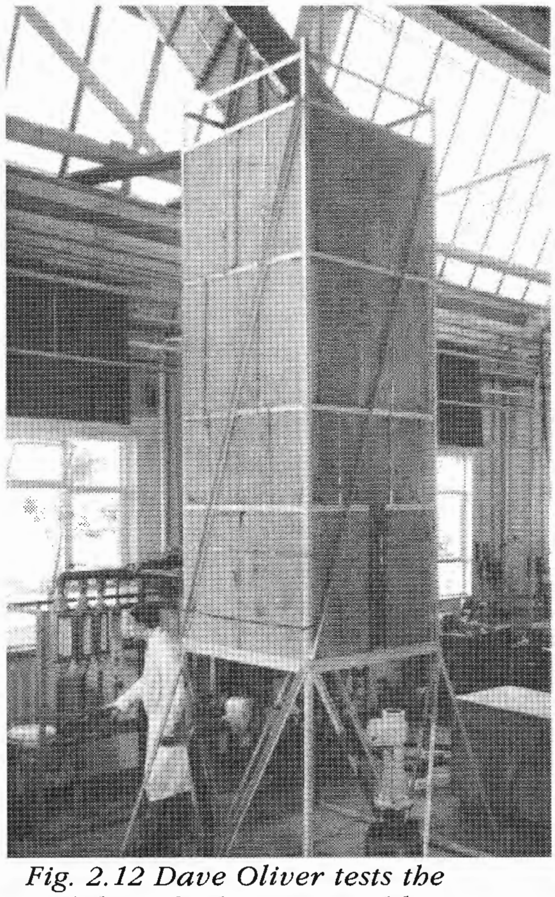


Fig. 2.12 Dave Oliver tests the stability of a large tunnel burner in a silencer in the utilisation lab. in Davy Building around 1959.

The need for safe and automatic control of the new generation of high intensity tunnel burners prompted Peter Atkinson and his group to take a close look at the requirements of such systems, particularly ignition. Some of the components in the early systems were not entirely satisfactory for the large heat releases involved and this led later to critical examination of the requirements, especially for safety shut off valves.

CHAPTER 3

1960 - 1967 The Station Grows

Chapter 3

1960-1967 The Station Grows

The early 60's were a period of significant growth in the size of the Station in terms of manpower, expenditure and in erection of new buildings and facilities (Fig.3.1). The growth in expenditure can be seen from Fig. 3.2, from small beginnings in 1952/3 to nearly £1million in 1967.

Fig. 3.1 The MRS main entrance in 1963, now complete with Gas Council sign.

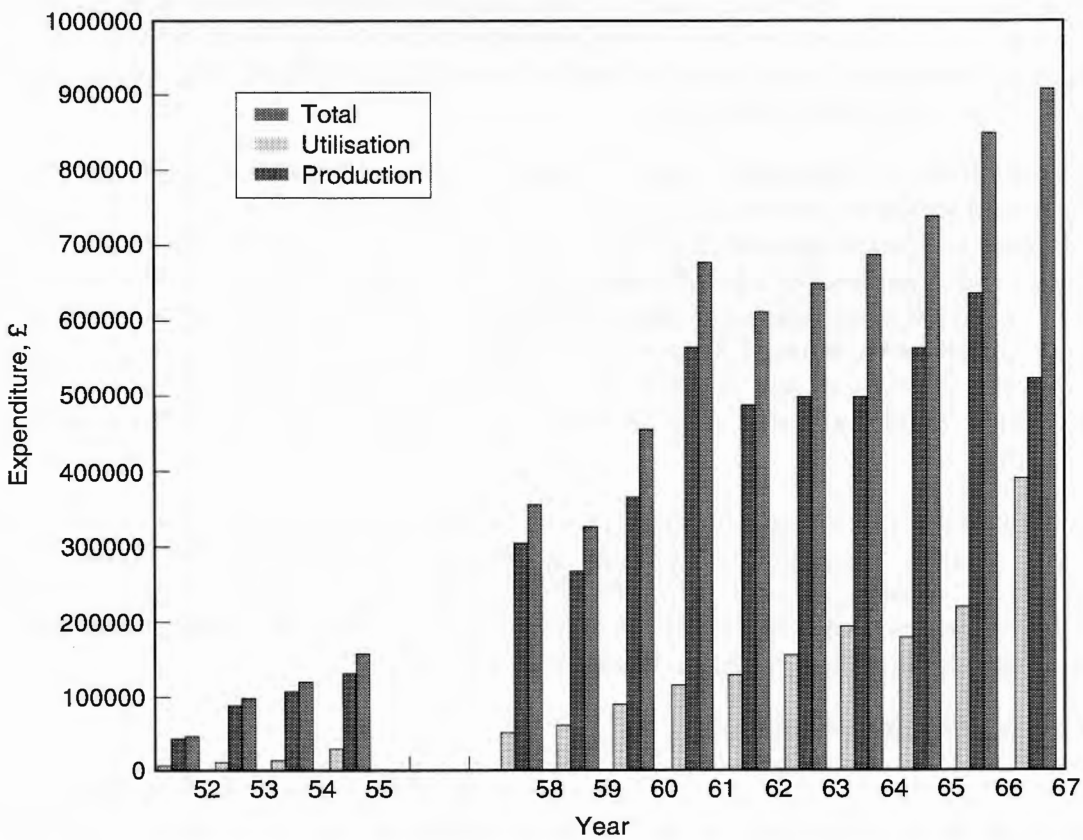


Fig. 3.2 The growth in expenditure from the early years.

In 1961 a much needed new building to house the Industrial research was erected, now known as Joule Building. This was purposely designed for the operation of fairly large combustion plant, having a main laboratory running the whole length and at the full height of the two storeys (Fig. 3.3). The floor was of heat and chemical resistant ceramic tiles, and attention was paid to the internal appearance by housing the extensive services pipework inside benches along the walls. The heating was a break from then current MRS practice.

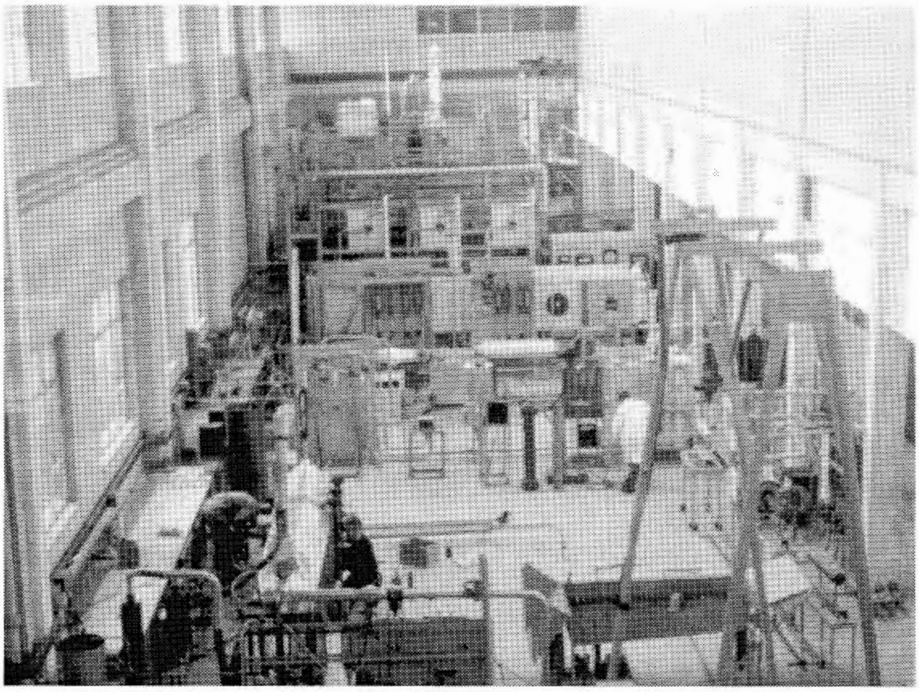


Fig. 3.3 The Utilisation laboratory in Joule Building in the mid 60s. At the far end is a series of metallic radiant tube furnaces. In the left foreground is an early rapid heater and a recuperative burner test furnace is on the right. Piped supplies of air and gas etc. were below the red formica topped benches on the left.

The main lab. was heated by a ducted warm air system, supplemented by overhead radiant heaters, although the prime heat source was still steam from the central system, a matter of some embarrassment in later energy conservation conscious years. Another novel feature was the addition of a separate combustion laboratory, acoustically lined and virtually sealed against the egress of noise from the high intensity burners which were a main item of study and which were getting ever larger.

Administration of the Station was still largely in the hands of the WMGB, who provided the Personnel function, payment of salaries, payment of invoices and overall financial control, although L.H.Taylor was responsible for accounts and budgetry control on the site. In the early days, organisation was minimal, since Dr Dent was able personally to supervise the projects on the production side and the utilisation effort was still very small.However, by the early 60's there were over 100 graduate scientists and engineers and a similar number of support staff and a degree of administrative organisation became imperative. In 1963, Dr. Moignard and Dr. Hebden, who had been Chief Chemical Engineer, were appointed Assistant Directors.

Recruitment was the factor limiting the rate of expansion so Dr. Moignard and Dr. Simmonds began the time consuming task of visiting Universities on a "milk round", and also cultivating particular Departments with which the Station had a special relationship, such as the Houldsworth School at Leeds. These efforts eventually paid off, although turnover of graduates in the mid-60's reached as high as 10-15%.

The Gasification Programme 1960-67

Towards the end of the 1950s rapid changes were taking place in the UK energy supply situation; the availability of traditional gas making coals was decreasing and the price was escalating. Light petroleum distillate was becoming available in increasing quantities at low cost as a surplus product from the many new refineries built to supply the gasoline and fuel oil markets. New gas making technologies were required to exploit this situation. There followed a period of intense activity in which process concepts based on Dr. Dent's ideas were brought to fruition. The Catalytic Rich Gas Process (CRG) and the Gas Recycle Hydrogenator (GRH) were developed to the stage of commercial implementation and the Fluidised Bed

Hydrogenator (FBH) for heavy oil feedstocks and the Slagging Coal Gasifier were successfully operated at the large pilot plant scale during this time.

The CRG Process

The feasibility of purifying light distillate from sulphur and gasifying it in steam over a nickel/alumina catalyst had already been demonstrated in the laboratory (Figs. 3.4 and 3.5), but data was required from larger scale reactors using commercial sized catalyst for the design of full size plants. To this end, larger laboratory test rigs (2 inch diameter reactor tubes) were operated and a pilot plant (Fig. 3.6) with a throughput of 200,000 cu. ft./day of town gas was built in the back yard of the pilot plant building (Brunel). This plant incorporated stages of purification, primary and secondary reforming and CO conversion. Various formulations of catalysts for testing in these plants were made in a production facility consisting of six Hoovermatic twin-tub washing machines. Round the clock working was de-rigeur!

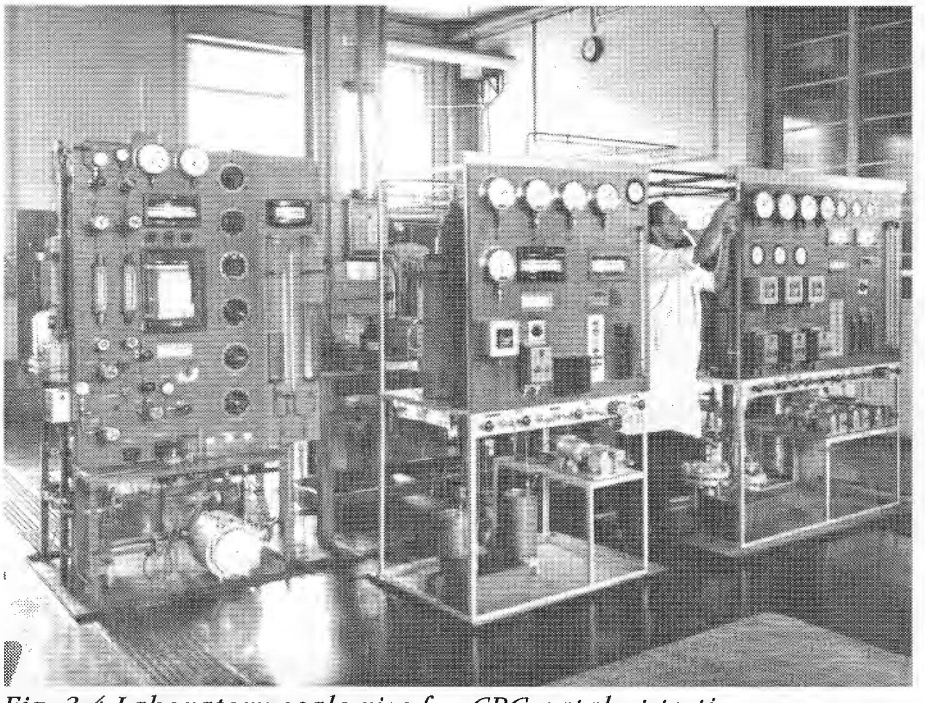


Fig. 3.4 Laboratory scale rigs for CRG catalyst testing.

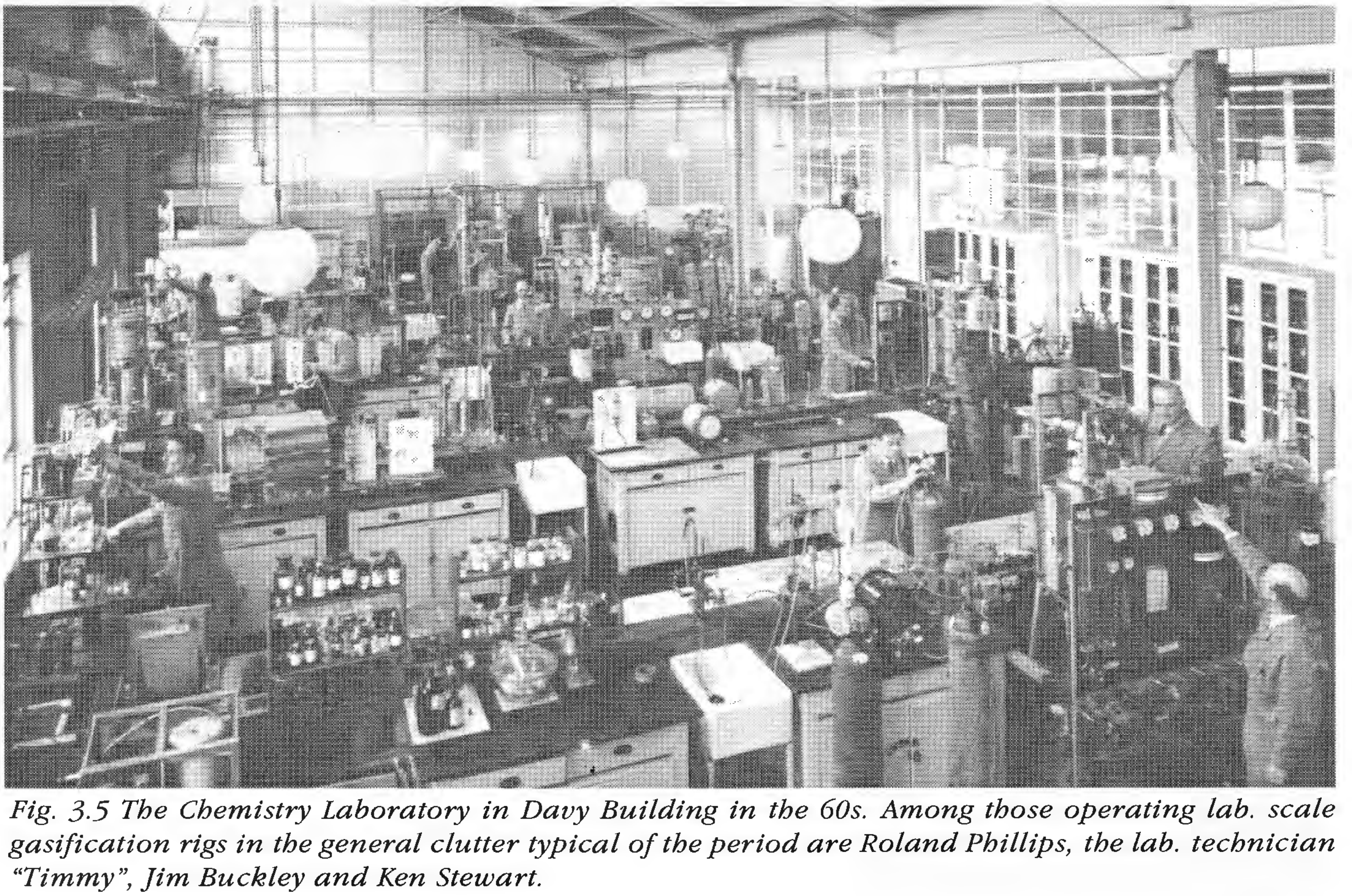


Fig. 3.5 The Chemistry Laboratory in Davy Building in the 60s. Among those operating lab. scale gasification rigs in the general clutter typical of the period are Roland Phillips, the lab. technician "Timmy", Jim Buckley and Ken Stewart.

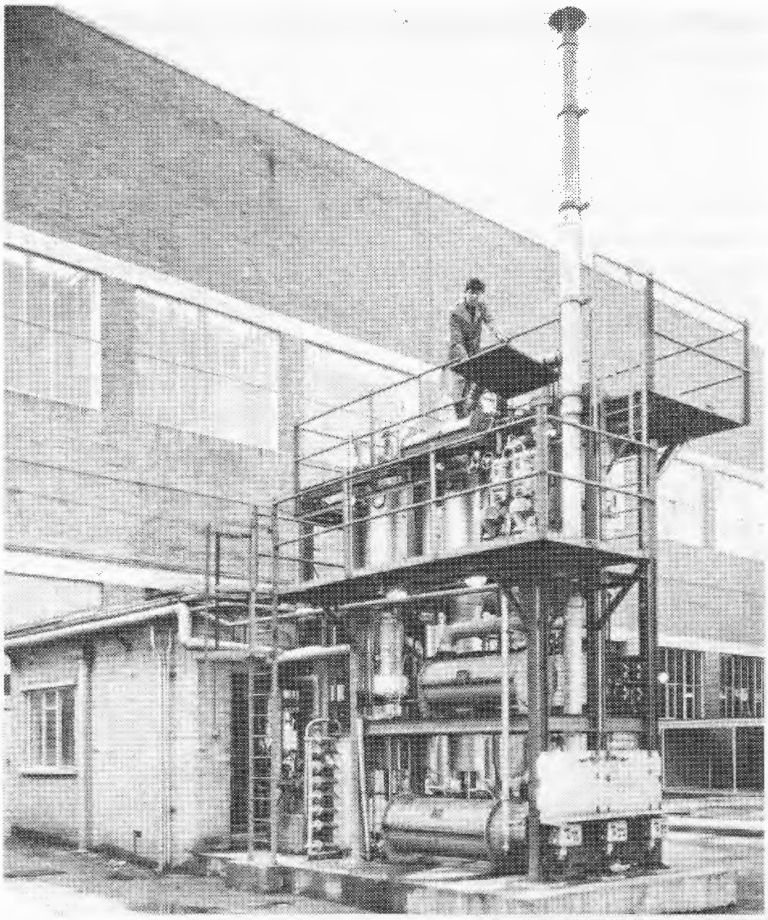


Fig. 3.6 The pilot scale CRG plant, known at the time as the "Peak Load Plant" in the Brunel Building backyard, around 1964.

One unsubstantiated claim was that the strongest and best catalyst contained Guinness accidentally added during the precipitation stage.

George Percival was responsible for the pilot plant until he left to join Woodall-Duckham, one of the main licenced contractors for the process, when the work was continued by Kelvin Humphries. Haydn Davies was in charge of the investigations of catalyst performance and process parameters using the 2 inch reactors (Fig. 3.7).

The first commercial scale plant was built at the Bromley-by-Bow works of the North Thames Gas Board and was commissioned in August 1964 (Fig. 3.8).

Fig. 3.7 The small scale CRG pilot plants used for catalyst testing and process development in the mid 60s. This temporary building was later demolished and the plants re-erected in Brunel building.

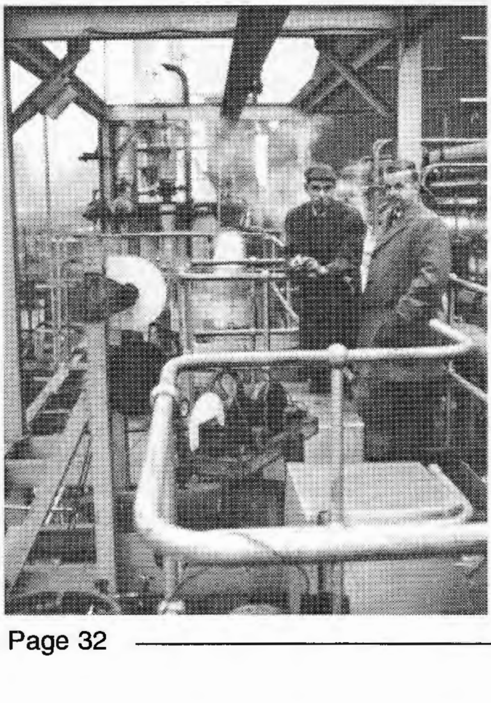


Fig. 3.8 D.A.Percy and D. Hebden at Bromley by Bow CRG plant, probably around 1964/5.

Larger plants were then built at the Toyoshu and Negishi works of Tokyo Gas. Subsequently, around 50 plants were erected for town gas production in the UK and overseas, and this success was recognised by MRS winning a Queen's Award for Technological Innovation in 1967 (Fig. 3.9).

Fig. 3.9 Sir Henry Jones, Chairman of the Gas Council, receiving the Queen's Award to Industry on behalf of MRS in 1967.

The GRH Process

The hydrogenation of oils had been already demonstrated by using a circulating fluidised bed of coke to bring the reactants rapidly to a stabilised reaction temperature and avoid problems with carbon deposition. With the availability of low cost light distillate, the question was raised as to whether the fluidised bed was necessary in a "distillate only" process. Rapid mixing of reactants with reaction products and stabilisation and control of reaction temperature was achieved by recirculation of the gases in a cylindrical reactor with a central coaxial "draft tube". The circulation was driven by the jet pump action of the hydrogen and distillate vapour injected through a nozzle along the centre of the draft tube.

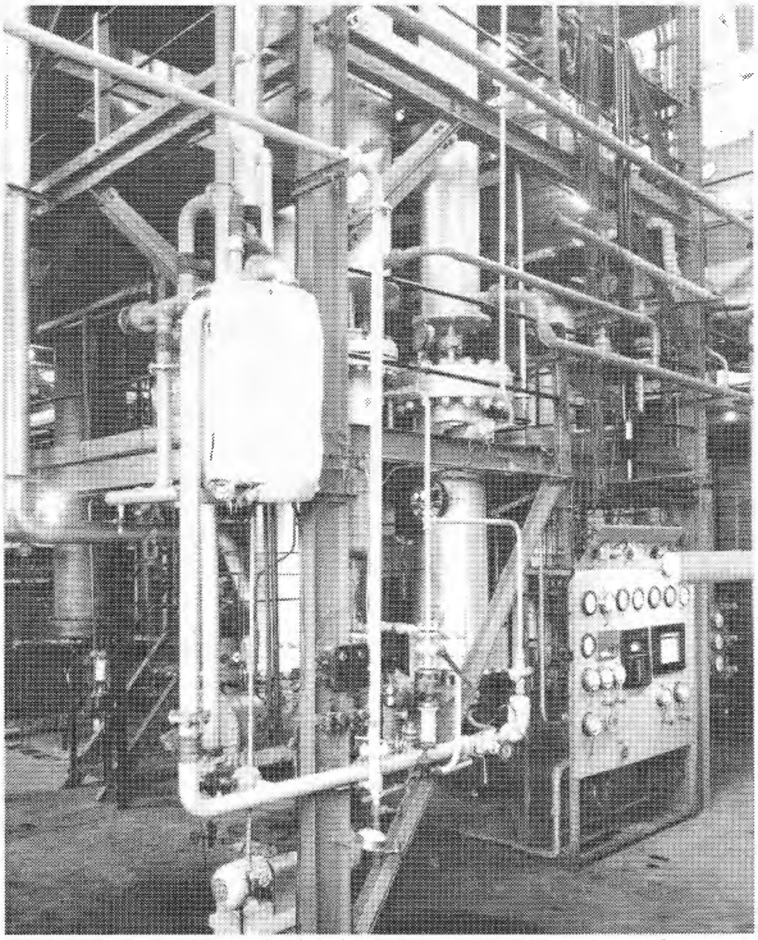


Fig.3.10 Gas recycle hydrogenator pilot plant for gasifying light distillate.

A large pilot plant with a 1ft diameter reactor and a throughput of 700,000 cu. ft./h at 30 bar pressure was built to demonstrate the process (Fig. 3.10). The work was highly successful and there was an immediate market for its application to enrich the lean gas produced by the ICI reformers which were being installed in large numbers by the Area Boards.

The first commercial plant was built in Speyer, Germany in 1964, but shortly after commissioning the reactor filled with a massive deposit of carbon. Dennis Hebden and Brian Thompson found themselves at the sharp end, and were despatched to Hanover armed with a Bone and Wheeler gas analyser just small enough to get on the plane. After a clever piece of investigative work they concluded that the carbon was caused by the catalytic activity of the reactor internals on the purified naphtha feedstock - a smidgen of sulphur in the feed provided a simple and effective solution.

A plant at the Avonmouth works of SWGB followed in 1965 and was the first of 46 units in the UK and a further 10 units were installed in Europe, giving a total capacity of 1400 million cu. ft. of gas per day.

The Fluidised Bed Hydrogenator (FBH)

The concept of the FBH had already been proven by the work at Poole and Solihull in the 50s, and was still seen as the solution for heavy oils with non gasifiable constituents, such as crude oil and HFO. Brian Thompson led a team operating a large pilot plant with a throughput of 1 million cu. ft./day at 70 bar pressure with the aim of optimising the reactor design (Figs. 3.11 and 3.12). The complex arrangement for bed recirculation via an external downcomer was replaced by a simple concentric riser tube, with the oil atomised and hydrogenated within the rising stream of particles in the central tube and the bed particles recycling down the outer annulus.

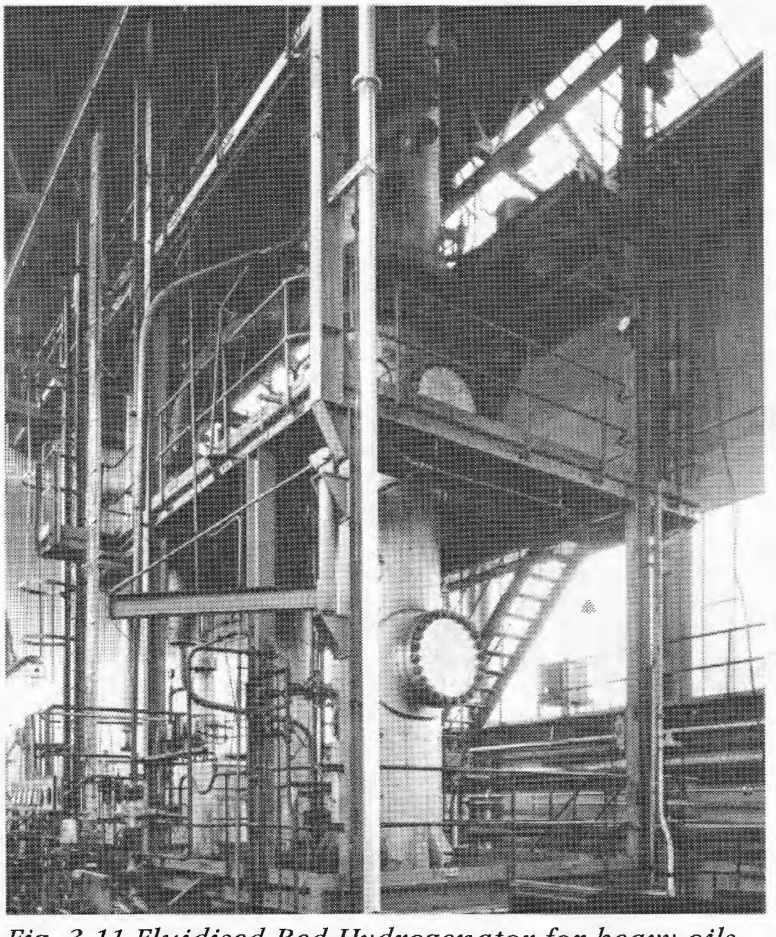


Fig. 3.11 Fluidised Bed Hydrogenator for heavy oils, typical of mid 60s pilot plants in Brunel Building.

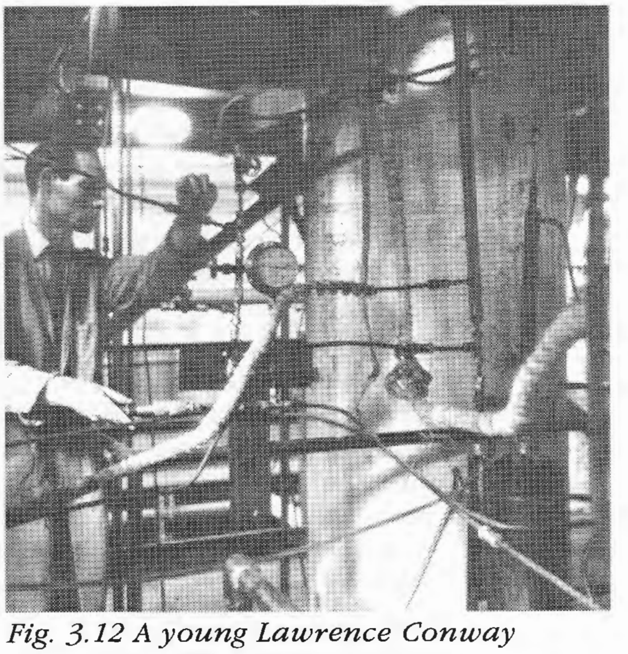


Fig. 3.12 A young Lawrence Conway operating a Hydrogenation pilot plant, 1964.

This simplified reactor worked well, particularly with light crudes and was envisaged as a base load process. However, the availability of cheap distillate for reformer and CRG based plants and later the importation of LNG and discovery of North Sea gas meant that there was no window of opportunity for exploitation of the FBH process for town gas. However further development of the FBH was assured by the negotiation of an agreement with Osaka Gas in 1967, resulting in a 5 million cu. ft./day semi commercial plant, with a 3 ft. ID reactor being built at the Hokko Works, Osaka.

The Slagging Gasifier

The pilot plant work on gasification of coke carried out during 1955-58 had demonstrated the potential efficiency advantages of slagging operation. During 1961 and 1962 the slagging gasifier was modified and re-erected by the Woodal-Duckham Construction Co. Ltd. on a new site to the East of Brunel Building (Fig. 3.13). At the same time a new building originally called the Slagging Gasifier Services Building was erected, later designated Trevithick Building (Fig. 3.14), housing the main gasifier control panels at the front and also boilers, air compressors, nitrogen pumps etc.. The building had an 18 inch thick reinforced concrete wall that projected above the roof and was supposed to protect the houses in Alston Road from blast and projectiles! At the far end there was a specially reinforced test cell for very high pressure hydrogenation of coal (1000 bar), studied by Dr. Fred Moseley and D.J.Pattison.

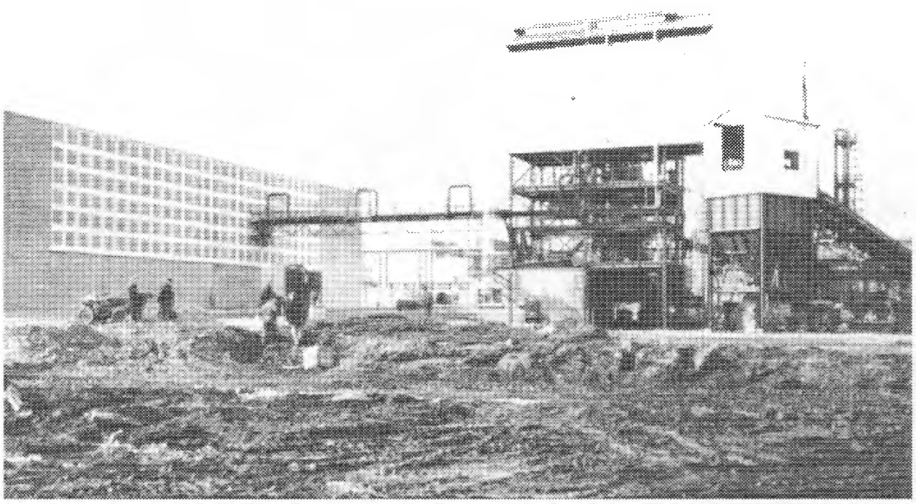


Fig. 3.13 The second Slagging Gasifier, erected in 1962 for operation on coal at 20 bar pressure, prior to the construction of the tank farm on the foreground.

Fig. 3.14 View from the top of Brunel Building around 1965/6, showing in the centre, the slagging gasifier control and support building, later named Trevithick. In the foreground is a temporary building housing Stores and Admin. and in the background, similar constructions housing small pilot plants and work on furnaces, later to be the site of Telford Building. The close proximity of the houses in Alston Road is evident and across the canal in the left distance, a new housing estate is in course of construction.

At about the same time, the somewhat notorious flare stack was built at the far N.E. corner of the site next to the canal (Fig. 3.15). Unlike conventional flare stacks, the gas was burnt in an acoustically lined chamber at the base of the 120ft high chimney. The stack was to prove an annoyance to the inhabitants of a housing estate subsequently built across the canal. Shortly afterwards, the tankfarm was built adjacent to the East boundary next to the canal.

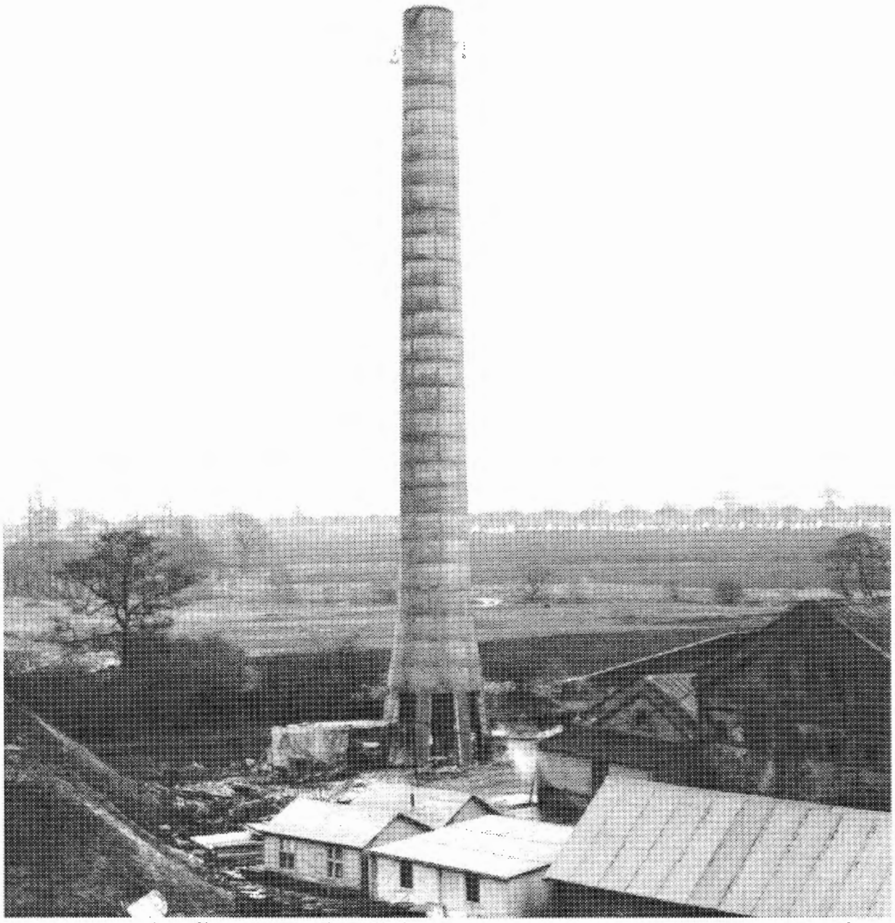


Fig. 3.15 The flare stack under construction in January 1962. Some of the old Solihull Gas Works buildings are still present and there is still an open outlook across the canal to a row of prefabs in the distance.

The gasifier was modified for operation on coal; it was fitted with a stirrer at the top and a refractory hearth with a central water-cooled slag tap at the bottom. Commissioning of the plant started in February 1962 and the programme was completed 47 hectic runs later in September 1964.

Technology for the slagging gasification of coals involving discharge of molten slag at 1400°C was developed and the data confirmed the potential advantages over the conventional Lurgi process. However by 1964, alas, coal gasification could not compete with distillate based processes for town gas and scale up and further development had to wait another 10 years for favourable circumstances. The work was reported to the IGE Autumn Meeting in 1965 by Dennis Hebden, John Lacey and Alan Horsler (GC112).

Operation of the plant at this scale caused a number of environmental problems,even though the estate on the far side of the canal had not yet been built. Apart from the lorries laden with coal, liquid nitrogen, etc trundling down Wharf Lane, the unavoidable release of gases (now called fugitive emissions), disposal of liquor etc made it very evident to the nearest neighbours that the plant was running. At high operating rates coal had to be charged to the gasifier through a lock hopper every ten minutes and the depressurisation of the lock gases into the line to the flare stack caused a pressure surge that lifted the flare to the top of the 120 ft high stack with a roar somewhat like that which comes from the airport. Each morning Leo Moignard nobly acted as the PR man and defended our activities from the irate phone calls of some of our neighbours. The indefensible eventually happened - tar entrained in the product gas was dispersed from the top of the flare stack over cars at the nearby Rover works! There were many re-sprays!

The cameraderie engendered during the long hours of shift work encouraged Alan Horsler to form an informal debating club which met every Thursday evening in the "Gentlemans Only" bar at the George Hotel in Solihull. Founder members were Alan Horsler, Derek Mitchell, Les Taylor, Mike Harvey, John Arnold, Les Jones and John Lacey, to be joined Later by Haydn Davies, Harry Blinkhorn and Derek Knowles. The vigorous debates on policy issues formulated at the meetings helped to assuage the post coal depression of the late 1960s.

Coal Hydrogenation

In one of the process concepts of Dr. Dent for methane production from coal, the powdered coal was to be reacted with high pressure hydrogen at 850°C leaving a residual char which would be gasified with steam and oxygen in another fluidised bed to produce the hydrogen required in the first stage. It was important to determine the rates of circulation within the fluidised beds envisaged for this process and to enable this to be done, a large scale physical model was built by a small team headed by Alan Horsler.

The results from the model enabled a large pilot plant to be built in 1965, next to the slagging gasifier, to study the char gasification stage. Construction of the plant was completed and it was beautifully painted just in time for the axe to fall on the coal programme (Fig. 3.16). Had the plant been operated it would, in all probability, have provided an unchallengeable lead in coal gasification technology in the next decade.

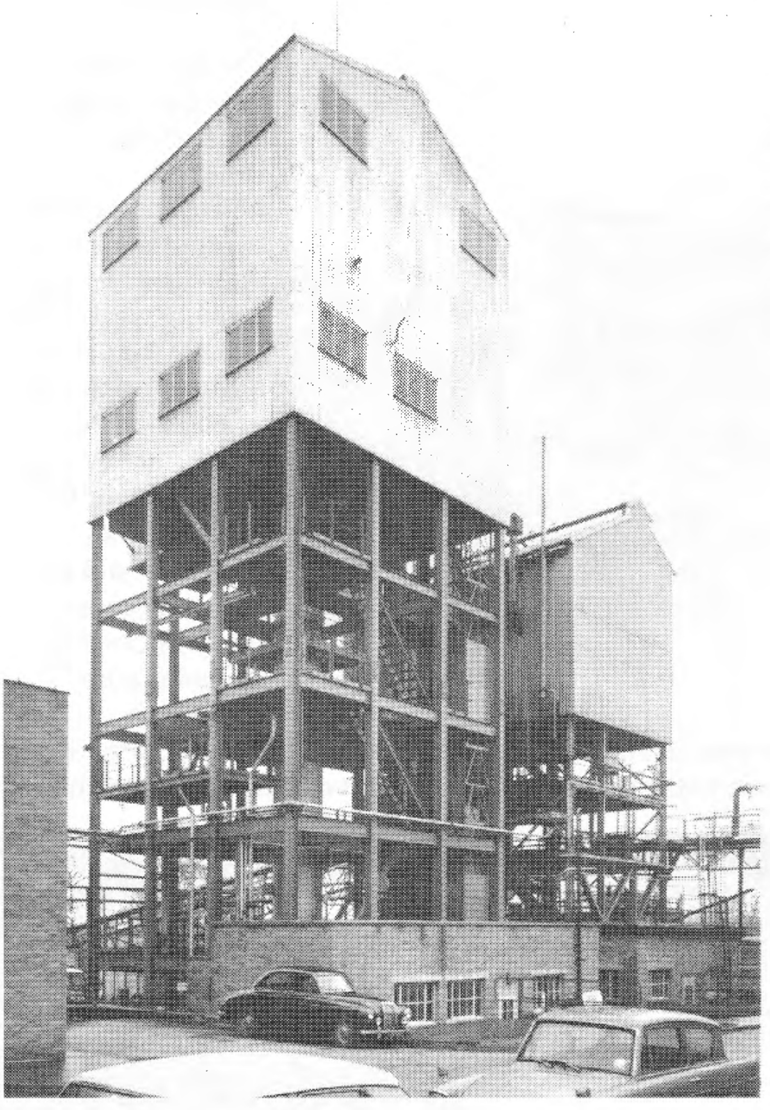


Fig. 3.16 The ill fated fluidised gasifier, which was never run, after construction next to the slagging gasifier in 1967.

1964 - Industrial Research Centralised at Solihull

In 1964 the Gas Council, anticipating increased gas sales due to new production processes from distillate feedstocks and potential natural gas supplies, decided to expand the research effort on utilisation. To facilitate this, Industrial R and D was to be concentrated at MRS, leaving Watson House to concentrate on domestic and commercial utilisation. Dr. Simmonds was appointed Director of Industrial Research, which was organised in three Departments, Combustion and Heat Transfer, Automatic Control, and Industrial Processes, headed by Eric Francis, Peter Atkinson and Peter Cubbage. As one result of these changes, Beryl Yardley joined MRS from Watson House to continue her work on mathematical modelling of furnace heat transfer by Hottel-Cohen methods.

To house the expanding staff numbers on the industrial side, Brindley Building was erected in 1964, for the controls work, followed by Darby Building in the following year for furnace and process work. (Fig. 3.17).

In the early 60's, many of the main themes of industrial research which were to last through two decades were put in place. Combustion work revolved around the development of high intensity tunnel burners, of increasing size and range of application.

Fig. 3.17 Darby and Brindley Buildings with the Link Block soon after construction.

The availability of a new generation of high velocity burners led to an investigation of the effect of their use in high temperature furnaces. A slot forge furnace for bar end heating was made available at the Brasshouse Passage Laboratory of the WMGB. Mike Lawrence and an Irish newcomer, Gerry O'Connor, carried out the experiments, involving a good deal of strenuous manual labour lifting billets in and out of the furnace and into a quench bath. The results showed little benefit from the high velocities in a conventional design of furnace and this set off a series of studies into flow patterns in furnaces, heat transfer modelling and eventually to the concept of rapid heating of metals.

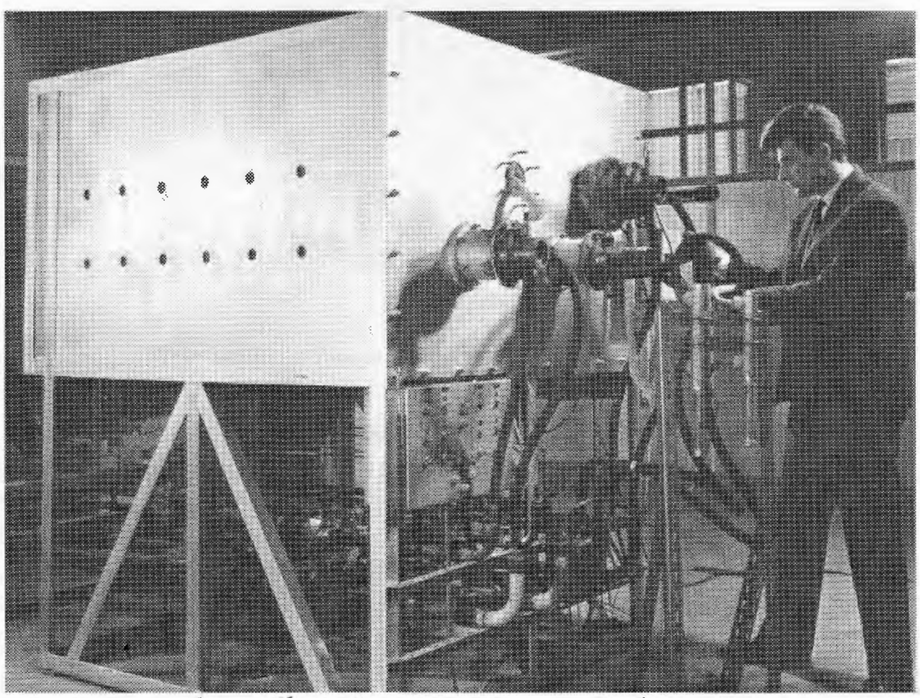


Fig. 3.18 Graham Chatwin operating an early recuperative radiant tube test furnace, mid 60s.

Malcolm Hoggarth was involved in the development of a practical design of high intensity nozzle mixing burner. Among its several advantages was the ability to be used with preheated air, which opened up the possibility of more effective waste heat recovery systems.

The concept of the self recuperative burner was being studied as early as 1964, although the first practical version was incorporated in a "single ended" radiant tube. John Bridgens and Graham Chatwin worked on this development.(Fig. 3.18)

Similar principles to those used for the nozzle mixing burners were applied to the development of large gas/oxygen burners suitable for assisted melting and fumeless refining in steel melting furnaces.(Fig.3.19)

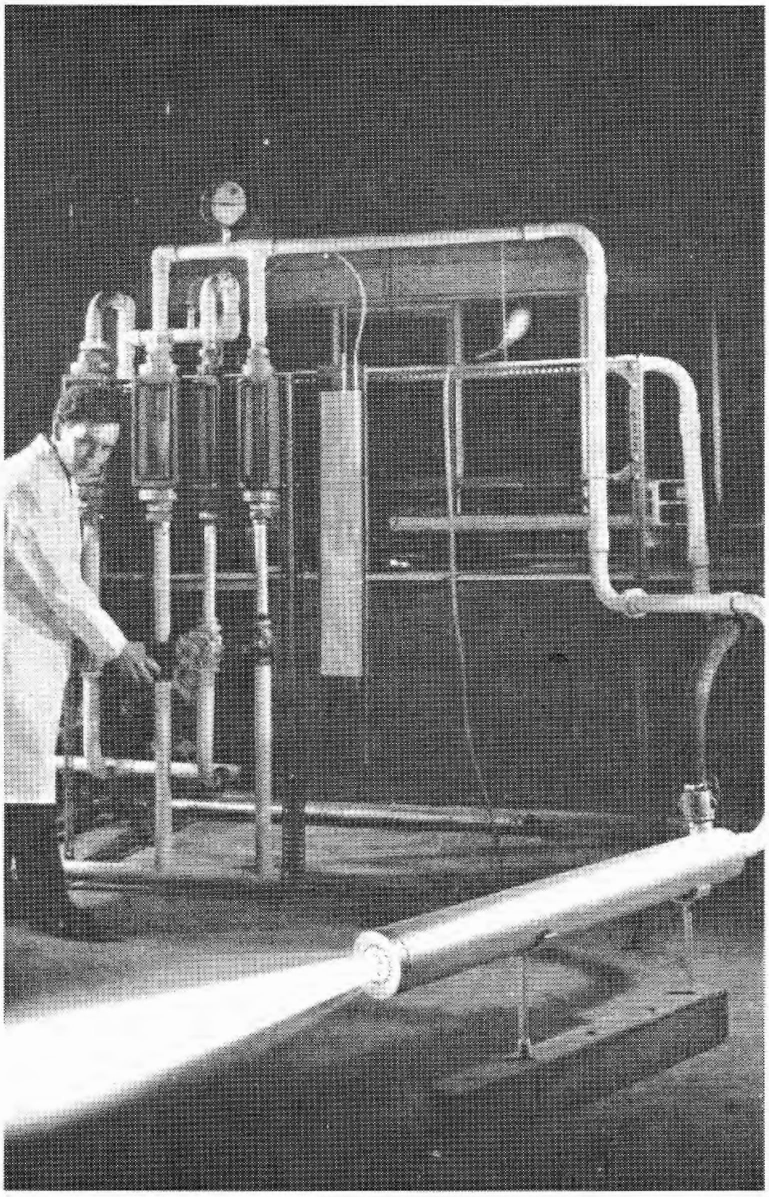


Fig. 3.19 Gerry Arnold operating an oxy-gas steel melting burner, late 60s.

Attempts to fire high intensity burners into small diameter tubes for immersion heating of water always seemed to result in acoustic oscillations, so it appeared a natural progression to use pulsating combustion, as a self aspirating system. This was technically successful, but it proved uneconomic to silence the larger versions needed for industrial use, and the project was (probably wrongly) abandoned.

Peter Cubbage and his group were working on atmosphere generation and the general area of heat treatment, including vacuum heat treatment. Later, a considerable effort went into non-ferrous metal melting, in a tower melter, a concept started originally by Watson and Glen at Watson House. Several Area Boards were also involved, but industrial application proved elusive.

In the early 60's the increased competitiveness of gas as a fuel led manufacturers of packaged oil burners to enter the gas burner market, some with little appreciation of the safety aspects of gas combustion. The Industrial Gas Committee felt that guidance was urgently needed on the essential safety aspects of automatic burners, and a drafting panel of W.A.Fitzsimons (Gas Council), G.W. Robertshaw (NWGB) and P.G.Atkinson produced the "Standard for Automatic Burners", published in 1966 by the Gas Council. This was a milestone in setting rigorous standards of performance for the critical components of the system, and its provisions were also later adopted by other countries. It had been preceded by studies at MRS on safety shut off valves, control unit logic and energy release criteria for safe ignition on start-up.

1965-Preparing for Natural Gas

In late 1964, the regular importation of liquefied natural gas from Algeria began into the Canvey Island terminal, for regasification and delivery to seven of the Area Boards, initially for enrichment of lean gas from ICI reformers. There was also considerable drilling activity in the North Sea, culminating in 1965 with the discovery by BP of natural gas in the West Sole field. The direct use of a high CV gas began to seem more and more possible and attractive, and Dr. Simmonds decided it was very desirable to explore the combustion of methane on an industrial scale. The early experiments, probably around 1964, by Malcolm Hoggarth and others were carried out using gas derived from sewage works (Mogden and Minworth), supplied in high pressure cylinders. This was clearly not satisfactory for the larger industrial burners and a more substantial continuous supply was needed.

The WMGB was one of the participants in the use of Algerian methane, with a spur off the high pressure methane pipeline terminating at the Coleshill Works. Frank Harvey, who was then Manager of the Coleshill Works readily agreed to allocate a piece of land adjoining the Gorsey Lane boundary for the erection of a small laboratory, with pressure reduction facilities suitable for flows up to at least 100,000 cu. ft./hr. of both town and natural gases.

This facility (Fig. 3.20), set up in 1965, became invaluable when it shortly became apparent that there was sufficient North Sea gas available to justify the complete conversion of the gas supply to natural gas. The MRS role was to study the principles of conversion on typical examples of the great variety of burners used in industrial practice and transfer this information to the industrial engineers of the Area Boards. Many demonstrations were arranged for Area Board personnel at Coleshill, in some cases with initial shock at the realisation that some of their favourite burners would not work on natural gas. A large demonstration was mounted at the Industrial Gas Conference at Cranfield in 1966. It became clear that the great majority of industrial plants could be converted with little trouble, and the detailed work required for individual types of burner and plant was taken up by the Area Board Development Laboratories and equipment manufacturers.

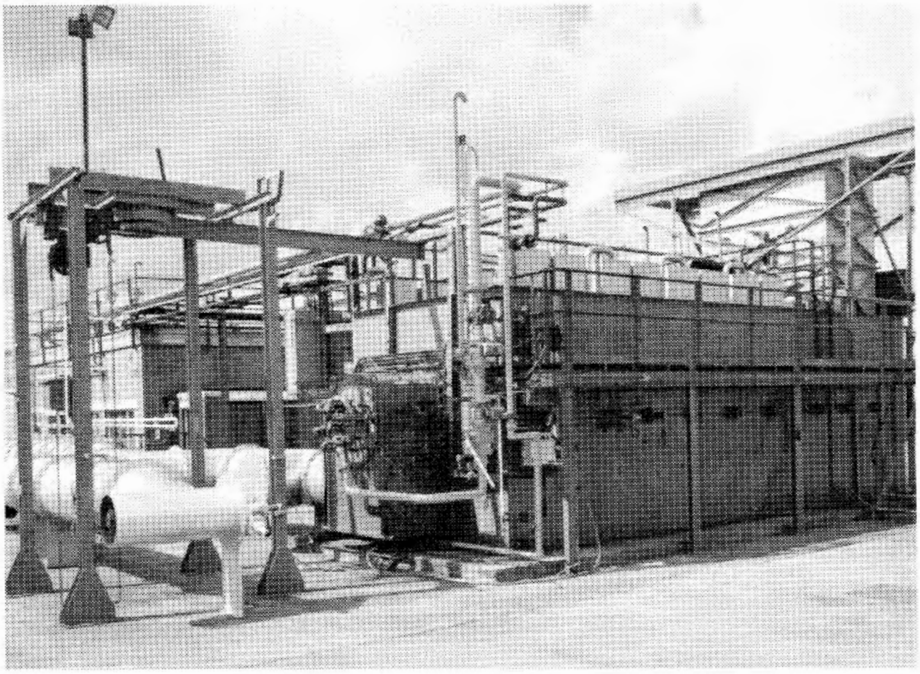


Fig. 3.20 The Coleshill Burner Test facility, showing a burner used for water tube boiler firing set up for test in the water cooled chamber. In the left foreground is the multistage Woods fan assembly for air supply in front of the governor house.

MRS involvement was then reduced to investigating particularly difficult conversion problems, such as the small burners used for glass working, brazing etc., particularly where there were a number of factories all over the country, those of the Metal Box group being a good example, and provision of technical service in the case of the very few post-conversion problems.

There was however a project on the design of aerated bar burners for natural gas which had its origins in a somewhat farcical incident involving the much respected Industrial Gas Manager of the WMGB, Alfred Jennings. He was visiting his Development Laboratory and while examining a box oven fired by a converted bar burner, managed to extinguish the flames by slamming the oven door shut. This incident threw doubt on the stability of natural gas bar burners and MRS conducted a thorough investigation of their design, even including a standard door slam test. Dave Reay, Chris Goodwin and Malcolm Hoggarth described the work in Research Communication GC165, a fine example of good science applied to an apparently mundane industrial problem.

Industrial conversion was achieved remarkably smoothly, and the early MRS activity at Coleshill made a significant contribution to this.

CHAPTER 4

1967-All Change! - Into the Natural Gas Era

CHAPTER 4

1967-All Change! - Into the Natural Gas Era

The introduction of North Sea natural gas was causing major changes in the Industry and this was reflected in significant changes in the direction, organisation and thrust of the programme at MRS. It was clear that gas production research would need to be drastically curtailed and the chemical engineering and other expertise diverted to supporting a big sales drive into the industrial and commercial markets.

Dr. Dent retired in April 1967 (Figs. 4.1 and 4.2), having seen the successful implementation of the CRG and GRH processes, recognised by the Queens Award for the CRG process, and his election to Fellow of the Royal Society. The Station had already seen the departure of Dennis Hebden the previous year to become a coordinator in the new Department of Research Administration set up under Mr.G.U.Hopton at the Gas Council.

Fig. 4.1 The retirement of Dr. Fred Dent, 1967.

Dr. W.A.Simmonds was appointed Station Director with the initial task of integrating the two sides of the Station more closely than had been necessary previously. The diversity of projects now meant that a more formal management structure needed to be implemented. Dr. Moignard continued as Assistant Director in charge of Administration and the Engineering Services function. Mr.W.E.Francis was appointed Assistant Director (Research), with responsibility for Combustion, Heat Transfer, Controls and Chemistry Divisions and in 1968 Mr.P.G.Atkinson was appointed Assistant Director (Development) in charge of Production, Furnace and Commercial Heating Divisions.

Fig. 4.2 The retirement of Dr. Fred Dent. Bill Simmonds handing over retirement present.

A new Materials Division was set up containing the analytical function, but with a wider brief to cover materials studies, metallurgy and ceramics, with Dr.R.G.Cockerham as Manager, reporting to Dr. Moignard. A Chemistry Division was created, with Dr.Fred Moseley as Manager to study chemical aspects of natural gas utilisation.

Fig. 4.3 Murdoch Building with the new Materials Division Laboratory in the foreground.

The last major additions to the Station buildings took place in this period. A much needed new administration block (Murdoch Building) was built along the Wharf Lane frontage in 1968, its outside appearance attracting some derisory comparisons with a railway carriage, despite the winning of a Civic Award (Fig. 4.3). It enabled the Directorate and the main administrative functions to be brought together, and also provided meeting rooms, a Library (Figs. 4.4 and 4.5) and a home for the new

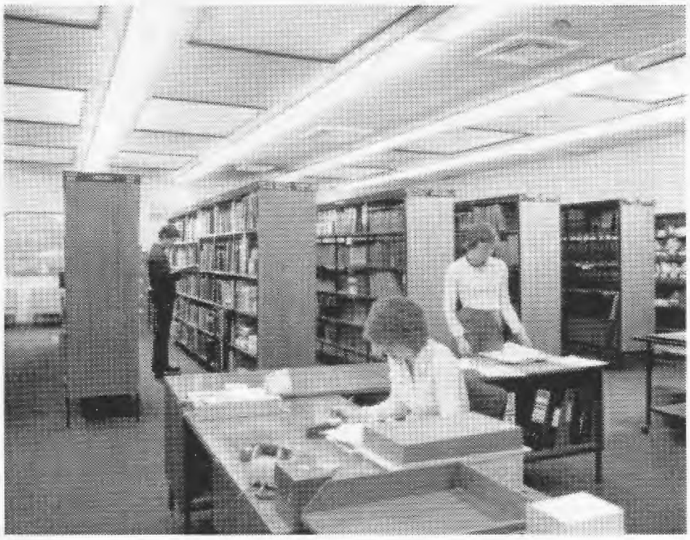


Fig. 4.4 The Library in Murdoch Building.

Fig. 4.5 Part of the foyer in Murdoch Building, showing the plaque commerorating the inauguration of the Station.

Materials Division. A "link block" was built across the fronts of Darby and Brindley Buildings (Fig. 4.6), incorporating a Lecture Theatre, and finally Telford Building (Fig. 4.7) was built to house the Engineering Services Division.

Fig. 4.6 The Link Block, which housed the School of Fuel Management and the Theatre.

Dr. Simmonds was keen to improve the external appearance of the Station, which was marred by one or two fairly unsightly temporary buildings which tended to proliferate during times of tight restrictions on new building, the West Midlands not being classed as a development area, and also the extensive network of overhead piped services and pipe bridges. All of this was eventually swept away and the piped services were put underground in what became known as "Ron Edge's ducts", which were quite successful except at the tank farm end where they tended to get waterlogged with unfortunate consequences for steam usage.

There was of course a substantial change in the balance of the work of the Station, from about 25% utilisation in 1966 to about 75% in 1970, with a substantial curtailment of gas production effort. All work on the gasification of coal was stopped, which meant that a large scale plant which had just been completed for the fluidised gasification of powdered coal was never run. In 1967 an agreement was reached with the Osaka Gas Co. of Japan for the construction of a semi-commercial scale fluidised bed hydrogenator at their Hokko Works. This was the start of a cooperation with Osaka which continues to the present day. Lawrence Conway was dispatched to Japan to assist with the project, and as a result of his efforts, he is still much respected in Osaka Gas! Apart from supporting the Osaka project, all work on FBH at Solihull was stopped.

Fig. 4.7 Early stage in the construction of Telford Building, with Trevithick, Darby and Brindley Buildings visible with Alston Road on the right.

This left work on CRG catalysts and processes as the main gasification activity necessary to support the many plants still in operation and to monitor the performance of commercially produced catalysts. Also during this period, the foundations of process schemes for production of substitute natural gas (SNG) were worked out.

Management Systems

The Station had experienced considerable changes in the late 60's and more formal management systems were necessary, not just because of the growth in numbers (250 in 1970), but also because of the number and diversity of individual projects and the pressure for greater accountability from Gas Council HQ.

In each Division a supervisory structure of Group and Section Leaders responsible for small numbers of graduates provided a promotional ladder. Detailed project planning and control was exercised with the aid of project sheets and work schedules, the latter with very variable degrees of realism. A small section was set up to carry out market studies and project evaluations. The market studies have proved quite valuable, but evaluations, based on questionable data and assumptions, have always been difficult to justify.

A feature of MRS life since the Nechells days had been the need for each research scientist or engineer to write a monthly progress report on his project. These records provide a unique and sometimes detailed account of the research activities, the problems encountered, the changes of emphasis etc. On the Utilisation side, these "blow by blow" descriptions were supplemented by "Internal Reports" usually when a significant stage of the work had been reached. These were often the source material for published papers and other external reports. The system was now applied to the whole Station, with a short monthly meeting of Assistant Directors (the Classification Panel) devoted to assigning a confidentiality class and initial distribution.

Progress on each project was reviewed twice a year by means of a presentation by the project staff to the Assistant Directors at weekly Project Review meetings, which were an ordeal to some, but had great merit in revealing talent and leadership potential in the more junior graduates.

R.J.Kightley had been taken on as Research Secretary, though it very soon became clear that his chief priority was to be recruitment and other personnel matters.

Relationships with the "end users", principally the new Marketing Division of the Gas Council, were also changing. Brian Clegg had become Director of Industrial Marketing and from the outset took a personal interest in the R and D at MRS. He was anxious to ensure that there would be no technical impediment to the vastly increased sales necessary into the larger scale applications of the industrial market. To ensure adequate liaison the Industrial Development Committee was set up, which Brian Clegg chaired, in theory jointly with Bill Simmonds, consisting of senior representatives from Marketing, the Regions and MRS. This was a prototype for the "Interface Committees" which followed later.

Changes were also taking place at R and D HQ. A study by consultants McKinsey had made a number of recommendations aimed at formalising the relationships with end user Divisions, implementing common procedures and generally making R and D more clearly accountable (the " six principles"). Dr. J.A.Gray succeeded Mr.K.L.Stretch as Director of Research in September 1971 with the immediate objective of carrying through the recommendations. In common with the other Stations, MRS had to adhere to a complex planning cycle, starting about 15 months ahead of the particular financial year, and including a rolling Five Year Plan, the latter probably quite beneficial in avoiding too violent fluctuations in effort.

Natural Gas Utilisation

Many of the staff had to change from production to utilisation related work and it says much for their flexibility and positive attitude that this was accomplished with few problems. The new activities were mainly concerned with large scale applications of gas, steam raising in water tube and shell boilers, steel melting, power generation (including "total energy" CHP schemes), many of them involving change-over from oil firing. Two new large combustion rigs were constructed at Coleshill, one a water cooled furnace for studying heat transfer and change-over, and the other for short term ignition tests. The latter was inadvertently built right over the high pressure pipeline carrying natural gas into the works, which created problems later with adherence to proximity and encroachment criteria.

Also at this time the commercial market was becoming of increasing importance as the larger establishments such as hospitals, schools, department stores etc. turned away from oil and solid fuel to the now competitive gas. Since the heating equipment was similar to industrial heating plant, it was appropriate that MRS should become overtly involved in this side of the business, so Peter Cubbage found himself Manager of the Large Commercial Heating Division. The "Large" designation was an attempt to avoid overlap with the Watson House interest, but it was a source of friction right up to the closer integration of the 90s. One of the early activities resulted from the coke replacement programme, involving provision of explosion protection and changeover technique for sectional boilers (Fig. 4.8).

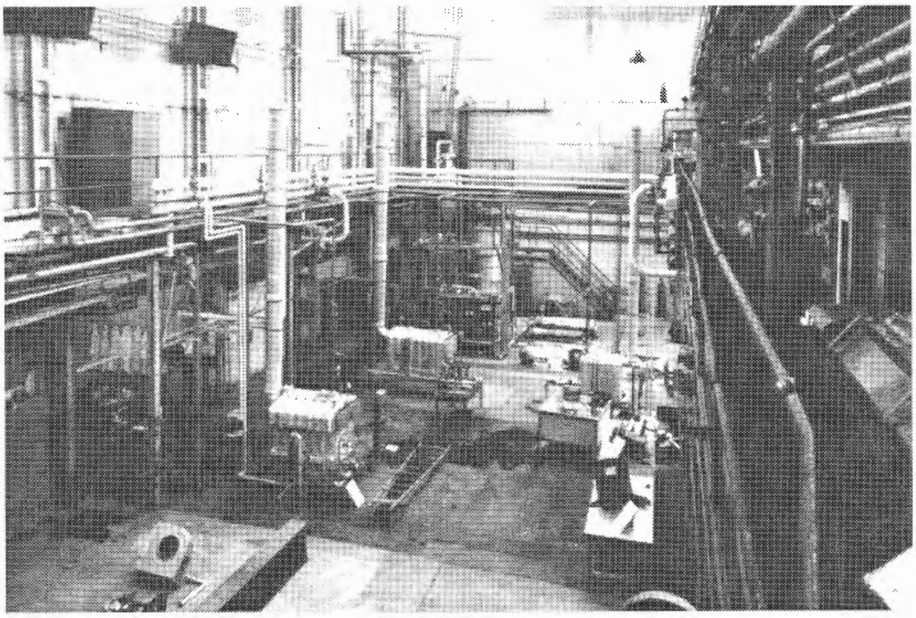


Fig. 4.8 Work on sectional boilers during the coke replacement campaign soon after the introduction of natural gas. This work was undertaken in Brunel building before this part was occupied by the CRG pilot plants.

A Testing and Certification Scheme for safety shut off valves and burner control units was inaugurated in March 1968 and announced to the manufacturers on the occasion of a memorable visit to MRS by BOGFEMA (The British Oil and Gas Firing Equipment Manufacturers Association). Roy Hayman, who was Industrial Gas Officer for the Gas Council at the time, announced the intention to begin testing controls and burners for compliance with the recently published Standard for Automatic Burners. He then promptly left the meeting for an appointment in London, leaving Bill Simmonds and Eric Francis, who had been sharing the platform, to face the resentment of some of the manufacturers at this unilateral action. However, some of them soon realised the commercial advantage of Gas Council certification for their products and samples were soon rolling in for test.

Peter Aris and Geoff Butler both moved over from the Production side to work on the testing programme and Dave Knaggs has been another long time member of the group. The existence of the scheme has undoubtedly contributed to the good safety record on the industrial and commercial side of the industry and in PR terms was a clear demonstration of a commitment to safety.

Brian Clegg had introduced interruptible gas contracts and was concerned that the technology for rapid switchover between oil and gas could be achieved safely, succinctly summed up in the phrase ".. I do not want an industrial Ronan Point!.." This led to the setting up of an Industrial Safety Committee, initially chaired by W.E.Francis, which oversaw the drafting of a series of Codes of Practice and Standards for Industrial and Commercial plant. MRS staff were extensively involved in this activity, building on the experience gained with the "Standards for Automatic Burners".

The School of Industrial Gas Engineering/School of Fuel Management

Although not strictly a part of MRS but within the Training Dept. of Personnel Division, the SIGE resulted from an initiative by Bill Simmonds and Ken Manuel (WMGB) in 1966 and started operating in 1967, just in time to make a significant contribution to the success of industrial conversion. It had an impact on life at MRS, particularly after the 1973/4 energy crisis, when it was renamed the School of Fuel Management with Peter King as Head, since from time to time it made urgent calls on engineering and other resources and MRS staff provided lecturers and lecture material. Bill Simmonds has described how it was set up in an article in "Eureka!".

CHAPTER 5

The 70's - Energy Crises and the Supply/Demand Situation

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The euphoria over the apparently vast supplies of gas from the Southern Basin of the North Sea was relatively short lived, as new industrial and commercial sales were achieved, conversion got under way and natural gas displaced distillate as the feedstock in many of the remaining town gas plants. There began to be worries that the growth in demand would outstrip future supply, particularly in possible "1 in 50" or "1 in 20" Winters. Non Premium loads became unattractive, except as interruptibles, and energy efficiency and premium enhancement was the order of the day. Many of the then current industrial projects at MRS, e.g. waste heat recovery, rapid heating, fitted this scenario admirably and others were added to the programme. The first oil crisis of 1973/4 and the possibility of late arrival of Frigg gas added emphasis to this situation.

The other affect of the supply/demand situation was sharply to reverse the downward trend in effort on gasification. This had reached a low ebb in 1970 at little more than 10% of the projected expenditure. Indeed, at a meeting of the Industrial Development Committee during a discussion on the draft Programme, the Marketing side held the opinion that the production work should be stopped! Dr. Simmonds realised that any more loss of effort would make the gasification programme non-viable. He therefore appealed to the Member for Production and Supply, Denis Rooke, who convinced the Research Committee to agree to a reactivation of gas production research, principally to ensure a credible SNG (substitute natural gas) option.

The effect of these changes on the balance of effort can be seen from Fig. 5.1, which shows expenditure over the period 1967-74. The swing back to production was achieved mainly through an overall growth of the Station's effort, most of the staff who had redeployed to utilisation staying with this work. Hence most of the work on SNG, as distinct from town gas, has been carried out by the team built up under John Lacey, who had taken over as Manager of Production Division after the departure of Brian Thompson to Economic Planning Division, H.Q.

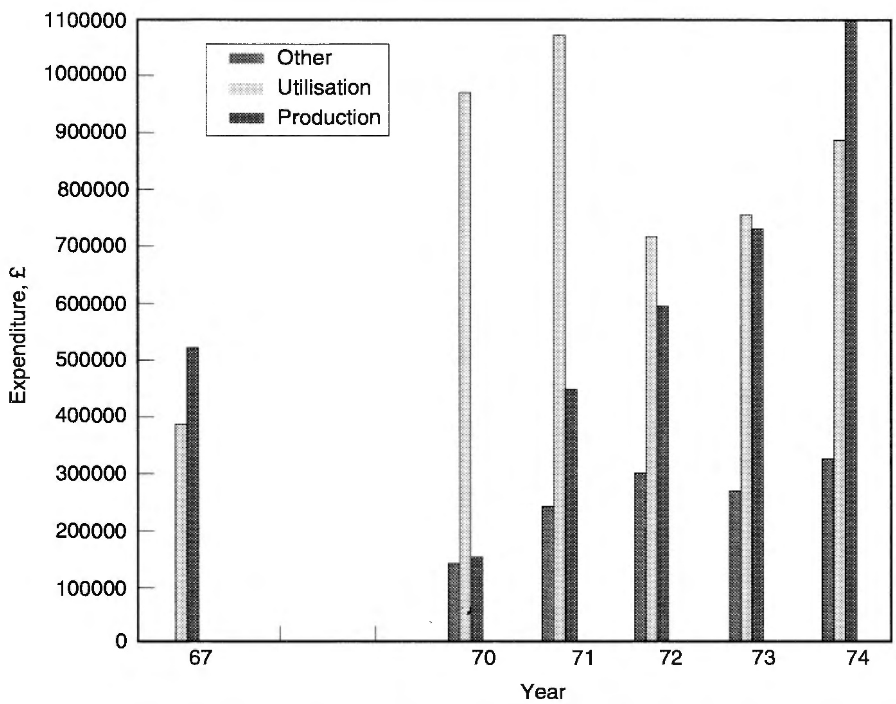


Fig 5.1 Expenditure 1967-74, showing the fall between 67 and 70 of the production effort and its subsequent rise again in the early 70s. Figures for 68 and 69 are unfortunately not available.

Supply / demand considerations were a constant background to discussions on the MRS programme through the 70's and early 80's. Marketing attitudes tended to reflect the current situation; sometimes sales were being promoted, sometimes there were restrictions, especially during the "flight from oil" following the second oil crisis of 1979. Brian Clegg, however, warned that while he would be "tacking" from side to side, R and D should not attempt to follow his short term manoeuvres, but pursue a steadier course! Regarding SNG, there were recurrent debates concerning the projected costs and availability of feedstocks, particularly oil, and the necessity and timing of the programme. There were factions in the HQ Divisions who were overtly hostile to the SNG concept, and R and D were fortunate to have the backing of a strong and influential champion in Denis Rooke.

The MacRobert Award, 1971

The outstanding achievements of Dr. Dent and the original gasification team were recognised when they received the prestigious MacRobert Award in 1971 for the development of the CRG and other processes for gas manufacture. Dr. Dent came back from his retirement on Malta and together with Dennis Hebden, George Percival, Brian Thompson and Ron Edge, received the Award from HRH Prince Philip at the Palace on the 16th December, 1971 (Fig. 5.2).

Fig. 5.2 The MacRobert Award Winners 1971. From left to right, Brian Thompson, Ron Edge, Sir Henry Jones (Chairman of the Gas Council), Fred Dent, Dennis Hebden and George Percival.

1974-More Changes at the Top

By late 1974 SNG had become a major commitment of R and D, with the need to support the International Consultancy Service (ICS) effort in selling Gas Council processes in large plants in the USA and other overseas markets, the conversion of a number of town gas plants in the UK and the need to overcome problems in the commercial manufacture of CRG catalyst. These were sensitive issues and it was thought desirable to strengthen the management of the programme.

Coincidentally, Dr.Gray wished to introduce changes at R and D HQ, so the key to the re-organisation was the departure of Eric Francis on a six month secondment to take up the new post of Chief Coordinator. Peter Atkinson relinquished responsibility for SNG and John Lacey was appointed Assistant Director SNG. Cyril Timmins, who had been at R and D HQ, but had previous experience on production plants in an Area Board, was brought in as Manager, Production Division.

On his return early in 1975, Eric Francis had a broader role as the deputising Assistant Director, with responsibility for programme planning, Engineering Services and the increasingly important field of work on Hazards. This was mainly carried out in a new Division with the euphemistic title of Special Projects, under Peter Cubbage as Manager.

Engineering Services were re-organised into an "operations"side under Geoff Billings, dealing with the day to day deployment of the technician staff on rig modifications, maintainance of services etc., while John Anderson was enticed back from Westfield as Assistant Manager in charge of design, drawing office, contracts and procurement.

Another major change occurred in 1975 in the status and working conditions of the craftsmen in Engineering Services. Until then, they had been classed as manual employees, and the pay structure was such that it was difficult to attract the highly skilled trades, such as electricians and pipe fitters with high pressure experience, without offering excessive overtime possibilities. Hence overtime and Saturday and Sunday working had become endemic, with the permanent shift team sometimes working so many hours that it was difficult to make out when they ever saw their wives! In addition, as many as 50 semi-permanent contractors staff were on site to cover for the inability to recruit.

Following fairly protracted negotiations, all the suitably qualified craftsmen received graded staff status and were classified as Technicians. A degree of job flexibility was agreed, 12 hour shifts were reduced to 8 hours, and of course they were no longer subjected to "clocking on", which was to cause problems later on when "Flextime" was introduced. Their agreed normal working hours, 8.00 a.m. to 4.30 p.m., were unfortunately out of line with those of the other staff, and it was many years before these were reconciled.

The change allowed overtime working to be controlled and when later there was industry wide pressure to reduce dependence on contractors, an increase in establishment was granted and they were gradually replaced by permanent staff.Administration was under the overall control of Leo Moignard, with Les Taylor as Manager and also looking after the details of budgeting. Harry Blinkhorn was responsible for the accounts and financial control, with Pauline Skett (later Skett-Taylor) in charge of the typing pool and Roger Frost dealing with travel arrangements, expenses etc. Until he moved to HQ, David Reay looked after the Library, later to be followed by Alan Yarwood. Local personnel matters were dealt with by Ray Kightley until Personnel Division mounted a take over bid and installed a succession of their own Senior Personnel Officers; after a few months they tended to go native so turnover was high.

An important event in July 1975 was the introduction of the Scientists/Engineers Classification Scheme to MRS,LRS and ERS, for the professionally qualified research staff. Watson House foresaw too many problems with this restriction and declined to join the Scheme until many years later. The existing Group Leader/Section Leader structure at MRS assimilated fairly easily into the new scheme. Many MRS staff benefited substantially from the change, which for the first time introduced a recognised career progression within R and D.

Utilisation in the 70's

The period from 1967-1972 showed a concentration on large scale, relatively new applications (for the UK) of natural gas, particularly steam raising. An intense effort was put in to ensure that the technology for gas and dual fuel firing of both shell and water tube boilers was well understood and that there would be no impediment to marketing in this sector from either safety or thermal performance aspects.

Shell boilers presented a particular problem, since there had been one or two instances of failure at the end of the fire tube on the tube plate at the entrance to the convective section. Some of these could be put down to poor feed water treatment or poor burner design in misguided attempts to simulate oil burner characteristics, but some intensively fired boilers remained a problem and required investigation.

Malcolm Hoggarth, Kevin Pomfret and their colleagues had already examined the smaller packaged burners and with the aid of new fire tube rigs at Coleshill turned their attention to the larger versions up to 30MW heat release. Alan Horsler led a team which conducted tests on actual boilers both at MRS and in a large number of field trials. The whole exercise was backed up, as usual, by extensive physical and mathematical modelling in which Dave Lucas and Hilde Toth figured prominently. The work was reported in a series of definitive Papers presented at the IGE Autumn meetings in 1971 and 1972 which largely wrapped up the problems.

So from about 1972 onwards these technologies were well understood and the marketing emphasis shifted to the firm premium sector of the market. MRS activity therefore reverted to its traditional role of improving efficiency, safety and the enhancement of premium value, a situation which has continued into the 90s. The need to increase the efficiency of gas applications received added emphasis from the energy crises of 73/4 and 79.

In respect of rapid heating of metals and of recuperative burners, the principles had already been established by the late 60's, but it took a number of industrial trials, often involving difficulties and setbacks before the techniques could be claimed as accepted practice (Fig. 5.3).

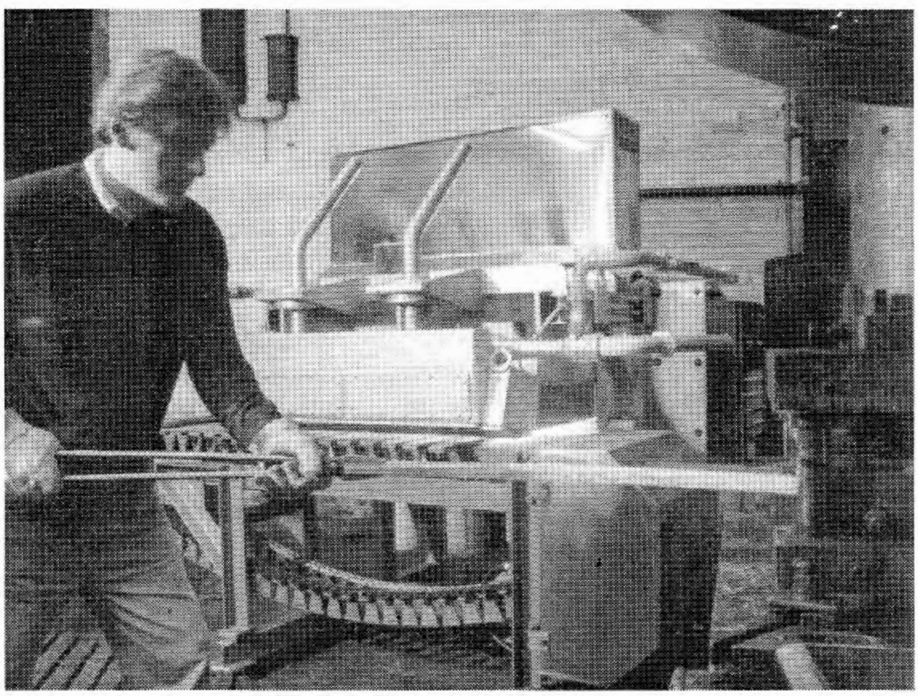


Fig. 5.3 Small front fired bar end heater built by Fairbank Brearley.

Great perserverence and a conviction in the basic correctness of the approach was needed by both management and the staff involved at the sharp end to ensure eventual success. The combination of mathematical and physical modelling, laboratory testing and finally field trials were used in these projects and had become the norm.

The principle of the recuperative burner had already been established, but it was not until the early 70s, after attempts to use them on a single cell rapid billet heater, that a practical design was established. There followed four important field trials, a crucible furnace, a forge furnace (at British Rail, Derby), and ceramic kilns at Royal Doulton and Gimsons (Stoke-on-Trent) (Fig. 5.4) which proved the industrial viability of the design. Then in 1975, possibly as a PR exercise to emphasise British Gas commitment to energy efficiency, RADEX was set up by Aubrey Lloyd-Dodd, Industrial Manager at HQ, specifically to exploit the recuperative burner. Jeff Masters of MRS and Peter Chester of EMGB were seconded with the remit to get 100 burners manufactured and installed through the Regions, to find manufacturing Licencees and to generate publicity. With engineering help from P & S Division and modelling and design back-up from MRS, this goal was largely achieved. Somewhat to the disappointment of Jeff and Peter the exercise was wound up after a year.

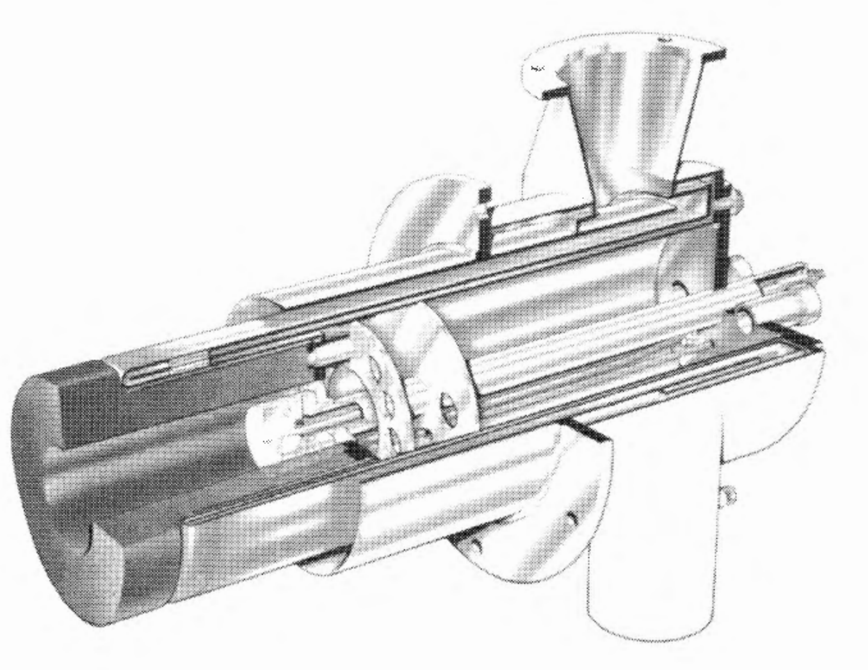


Fig. 5.4 Cut-away of recuperative burner.

The development of a small bore immersion tube for liquid heating in vats and tanks came about as a result of the study of steam usage in the industrial market. Access was obtained to data from a Load Assessment Survey conducted by the WMGB, which showed the uses to which centrally generated steam was put in typical manufacturing industry. Very little was used as process steam, but mostly as a convenient low temperature heating medium for space heating, drying, water heating for washing, pickling etc. at an appallingly low overall efficiency.

Almost all of these applications could be achieved at high efficiency by direct gas firing at point of use, but the tank heating really needed high rates of heat release in a small bore immersion tube. Old hands such as Eric Francis and Malcolm Hoggarth had tried this in the 60's but had always encountered combustion oscillations. Their advice was fortunately ignored by the following generation, and Bob Cox and his collaborators developed a system that was to prove highly successful (Fig. 5.5). This work was reported to the IGE Meeting in November 1975 and the Paper (IGE Comm. 977) earned the Authors, M.L.Hoggarth, R.W.Cox and D.A.Jones, the IGE Gold Medal.

Serious efforts to apply gas fuelled prime movers were mounted in the 70's, both for electric power generation and for direct drive motive power. In the early days of natural gas the concept of "total energy", a form of CHP was promoted, and one or two installations took place, notably at John Player in Nottingham.

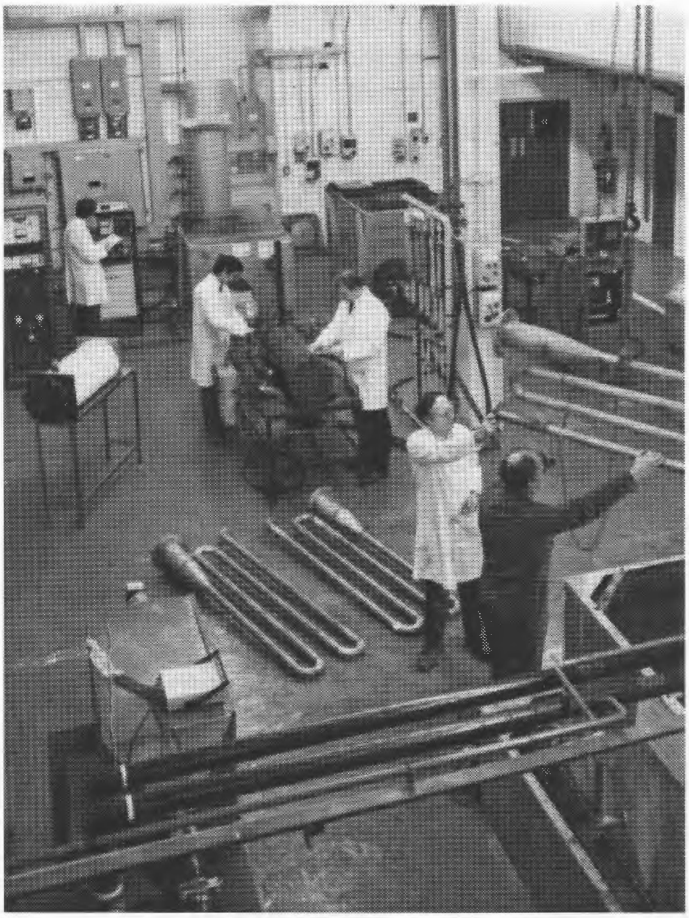
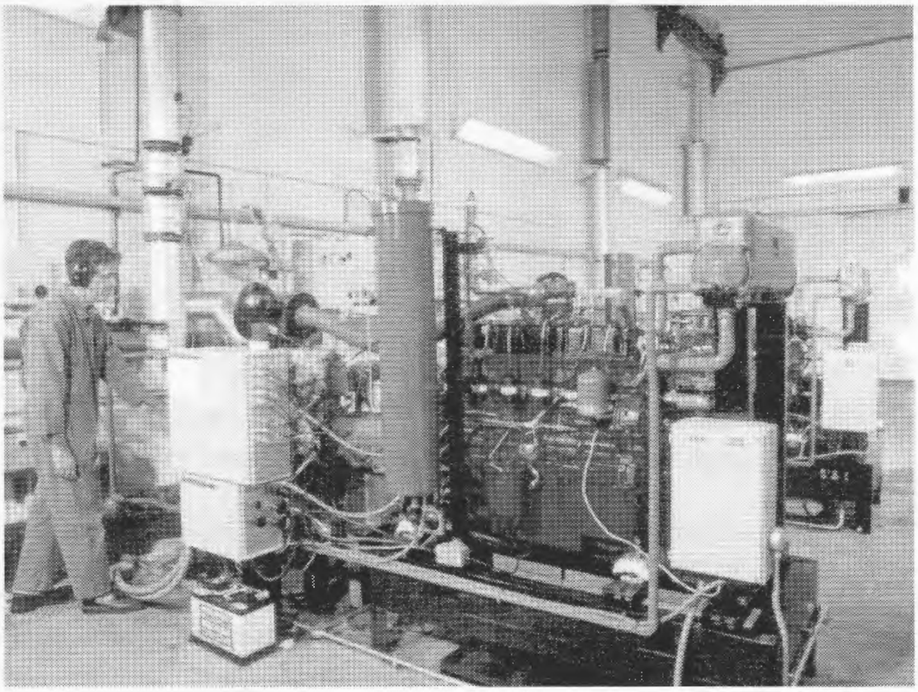


Fig. 5.5 Trevithick Building, showing small bore immersion tubes for tank heating, with Derek Jones in the white coat supervising the fitting of a tube.

Fig. 5.6 Engine test Cell in Trevithick Building.



MRS constructed a demonstration unit based on a gas turbine in a small building between Trevithick and Brindley Buildings, supplying power and heating to these and the theatre block. Frequency stability was not its strong point, which led to Controls Division staff arriving late for meetings and jokes about "Total Energy time".

The old high pressure cell in Trevithick which had been used for Fred Moseley's hydrogenation experiments was converted to an engine test cell (Fig. 5.6), for checking performance of automotive type engines converted for gas fuelling. This facility has been valuable in the rather slow process of gaining acceptance of gas fuelled engines as economic and practical in such applications as direct drive for pumps and compressors, small scale CHP and heat pumps.

Controls and safety

In the early 70s Controls Division were caught up in the efforts to ensure successful penetration of the large industrial market. They were involved in the drafting of Codes of Practice for Large Gas and Dual Fuel Burners and in conducting tests, particularly checking safe ignition, for compliance with these Codes.

With the basic safety standards well established, Controls Division activity was able to turn to burner control systems aimed at improving efficiency, particularly to overcome the problem posed by air/gas ratio control for the recuperative burner. This resulted in the low cost governor based system marketed as the J121 by Jeavons and later a more sophisticated electronic ratio controller (ERC).

Another activity was process automation, with one of the early tasks being to refurbish and update the control of the many continuously operating CRG test plants, which were beginning to look sadly old-fashioned from a control point of view. This exercise enabled the duties of the "boilermen" who manned the 24 hr. shift system to be drastically reduced.

The rapid advances in electronics meant that burner control systems were increasingly using integrated circuits and later computer technology. This meant problems in assessing conformity with safety standards for Certification purposes, but also great opportunities for improvements in the capabilities of overall heating process control, which was to keep Controls Division busy for years.

Development of SNG Processes

Some attention had been paid to processes for manufacture of substitute natural gas as early as 1966 in Dr. Dent's time, and a Paper in Nov.1968, Research Communication GC155, set out a series of process routes for a variety of oil feedstocks, using CRG, GRH and FBH reactors, even some experiments with cooled methanators. Process routes were well enough developed for The International Consultancy Service (ICS) to take advantage of a shortage of natural gas in the USA to sell the processes for a number of very large plants using distillate feedstocks. However this proved to be a one off opportunity, and came to an end when distillate feedstocks became scarce and natural gas supplies in the USA were deregulated. The capacity of the units sold in the USA exceeded the total town gas manufacturing capacity of the UK Gas Industry.

In the UK there were conversions of old town gas plants as a contingency to cover problems with Winter peak supplies in 1974/5, but again this was a one off situation. However a long term strategy for SNG process development began to evolve.

The CRG routes, both with methanation and the more efficient hydrogasification modes were demonstrated on full scale plants at Portsmouth and Stoke-on-Trent in 1972/3. Higher boiling feedstocks were shown to benefit from recirculation of product gas around the first CRG stage. The practicality of using a jet pump driven by the process steam for inducing the necessary recirculation was demonstrated first in the laboratory and then in 1975 on a large scale at the Killingholme works of the East Midlands Region. These techniques and improved catalyst formulations, particularly that designated CRG-F, pushed the feedstock capability to kerosine and even gas-oil.

Laboratory studies included an attempt to produce a "single stage" process at a temperature low enough to ensure that only methane and carbon dioxide appeared in the equilibrium products.This was based on a catalyst containing ruthenium, and showed some success , but doubts about the availability and expense of ruthenium in the quantities that might be required undermined faith in the viability of the project. In hindsight, it was probably an example of applying very questionable economic evaluations too soon in the life of a very long term project.

The GRH process was pushed to its limits with heavy distillate feedstock, ultimately with the aid of a system of sparging of the feed with hydrogen. From 1972 to 1975 the gasification of very heavy Monogas crude oil (solid at ambient temperature) was investigated in a small pilot plant in a joint project with Air Products and Chemicals. The products from a sparged vapouriser were passed to a GRH reactor to make SNG. However by 1975 SNG had become economically unattractive in the USA.

Heavy oils, from crude through to residual, were regarded as the province of the Fluidised Bed Hydrogenator (FBH). In 1977 a new start was made with a 10" diameter reactor, thought to be about the smallest capable of giving viable results. This was successfully operated over the next few years with attention also given to high grade heat recovery and the provision of offtake scrapers to deal with carbon deposition. The Japanese connection was renewed with an agreement with Osaka Gas to provide some of the funding of the project.

The gasification programme at MRS was underpinned by the setting up of a Process Studies Group in the early 70s, initially under Henry Stroud and later Keith Tart. This group looked at the performance and economics of overall process schemes and was able to specify optimum process conditions and pinpoint research needed on reactors and other aspects of the plants.

The Long Term SNG Programme

In 1978 a comprehensive 20 year programme of research, development and demonstration was prepared to give British Gas the option to use viable and proven processes for making SNG from any of the main fossil fuels, should the need arise. Distillate based processes were envisaged for seasonal peaks (LNG covering the short term needs), with heavy oil or ultimately coal for base load. At that time there was great uncertainty about natural gas supplies in the mid 90s when the original Southern Basin reserves would be running out and about problems with the depletion of the Frigg field.

The programme included proposals for the demonstration of an automated 100 million cu. ft./day CRG plant, the development of the FBH for heavy oils, completion of the slagging gasifier project and development of a coal hydrogenation process, the whole backed up by supporting research activities. The programme, at an estimated cost of £350-400 million, was approved by the Board, largely due to the strong support of the Chairman, Sir Denis Rooke.

Coal Gasification and Methanation

Interest in SNG from coal was revived by the demonstration at Westfield in 1973 of the production of SNG by methanation of Lurgi gas, sponsored by a consortium of 16 US Companies, using a gas recycle system to control temperature rise in a bed of CRG catalyst, much along the lines of the original Gas Research Board experiments in 1946.

Westfield was retained as a development centre (Fig. 5.7) for coal gasification under the operational control of Production and Supply Division and with Dennis Hebden as Programme Director for R and D, succeeded by John Lacey in 1980. One of the gasifiers was converted to a 6ft dia. slagging gasifier and a development programme began in

1975 running until 1983, initially supported by US companies, but subsequently funded by British Gas.

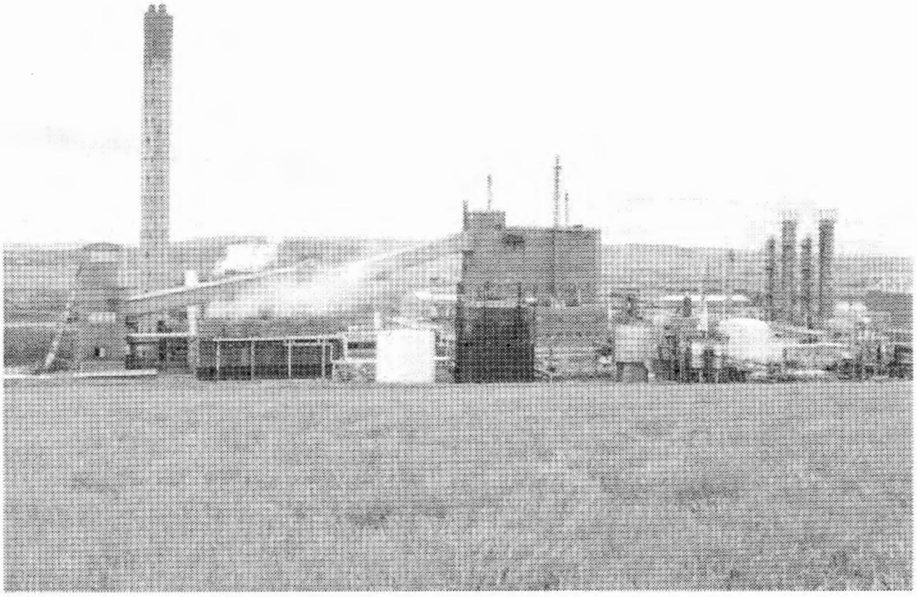


Fig. 5.7 The Westfield Development Centre.

The MRS contribution to the gasifier development was mainly concerned with modelling of slag flow and of heat transfer in cooled reactor components, and help with controls and instrumentation.

The main MRS contributions were concerned with the downstream processes, methanation, gas treatment and effluent treatment. Methanation of gas from a slagging gasifier was a much more severe duty for the catalyst than for CRG or Lurgi gas, but the "CRG team" at MRS rose to the challenge by inventing a new variation of the process called "HICOM", and from 1978 onwards a significant effort, also involving LRS and Westfield, was devoted to this. Initially the scheme was based on the use of the existing CRG F catalyst, and this proved successful.

The Emergence of Research on Hazards

From the start there had been work at MRS on explosions in industrial ovens and later on flame traps, but the rise in importance of research on hazards relevant to gas supply really began in the late 60's. Each increase in effort devoted to this field of work tended to result from some major incident, sometimes not even directly involving the Gas Industry.

The first of these was undoubtedly Ronan Point in 1968, in which the partial collapse of a system built tower block of flats was attributed to a gas explosion. Bill Simmonds has recounted that, following the incident, the then Deputy Chairmen announced to the Station Directors that he was employing an outside expert since there was no expertise within the industry. In vain did his fellow Directors protest that Bill had spent years researching on explosives and gas explosions. There is no doubt that Bill was annoyed by this decision, but fortunately there were influential people who were aware of the MRS reputation in this field. The B.Ceram.R.A. asked MRS to carry out work funded by the Brick Development Association, aiming to show that a conventional brick built multi-storey building suffering an internal gas explosion would not exhibit progressive collapse as happened at Ronan Point.

The work was carried out at a disused quarry at Potters Marston near Hinkley, a site now traversed by the M69. The work was rapidly and successfully completed and reported in 1969, and the site was used by MRS for many years to carry out research to improve our understanding of the behaviour of buildings and building components during gas explosions (Fig. 5.8).

This research was to prove valuable as a background expertise for incident investigations and also in providing part of the British Gas evidence to the King Inquiry into Serious Gas Explosions which took place in 1977 as a result of a spate of incidents during early January (the four "Bs"- Bristol, Brentford, Beckenham and Bradford).

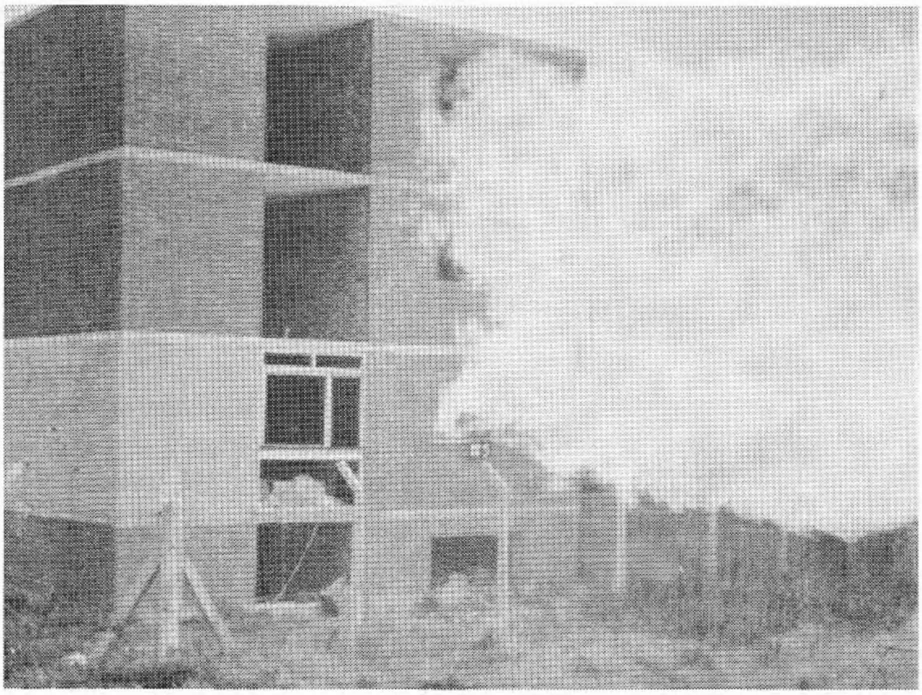


Fig. 5.8 Potters Marston. Explosion in the multi-storey brick building of a rich natural gas-air layer.

Most serious explosion incidents occurred in domestic or commercial property, but in 1972 there was a unique incident at the Effingham St., Sheffield works of the EMGB, in which an explosion took place in an underground storage tank, originally used for light distillate, which was being converted to store gas oil. MRS was asked to coordinate the scientific investigation, which involved LRS providing analytical support and ERS on the structural aspects of the tank failure. Peter Cubbage and Dave Moppett took turns as on site observers of the months long recovery of the debris in the tank, while a team at Solihull including Mike Marshall, Dave Lucas and Margaret Day carried out experiments and theoretical studies to elucidate the causes of the incident. Effingham St. was notable for the scale of the event, the tank was 100ft in diameter and the lid, weighing 1800 tons, was hurled into the air and landed upside down over the edge of the tank, and also that it was the first time we had attempted to produce a computer simulation of an explosion, in this case of distillate vapour. There was much debate on the effect on the flame speed of turbulence caused by the array of stanchions supporting the roof. From what we know now it was probably significant!

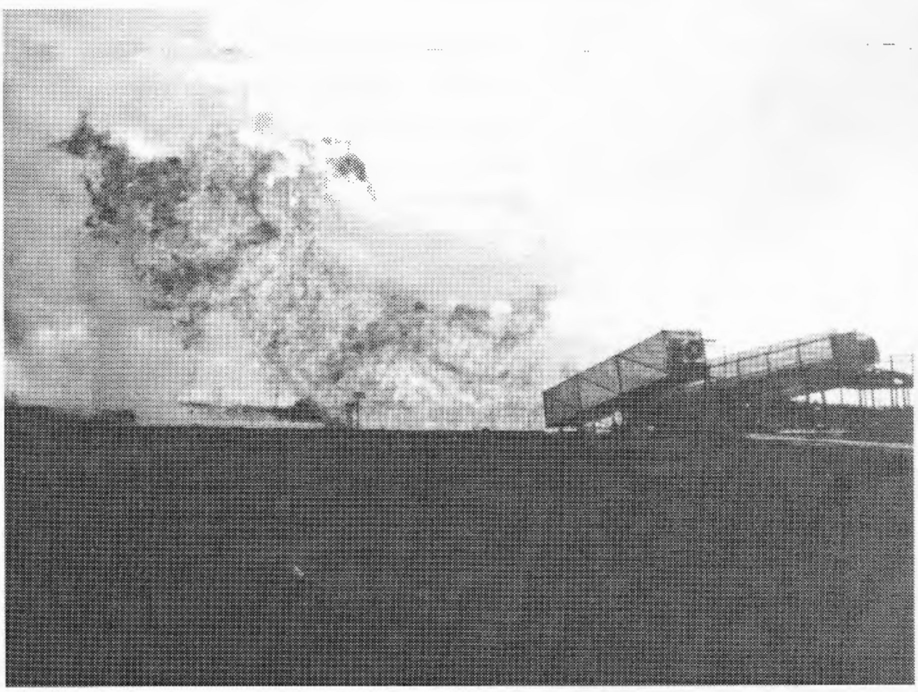
Research into pipeline fires started as early as 1970, at the request of ERS, who were much concerned with producing a Code of Practice for high pressure transmission pipelines, part of which involved proximity distances, based on size of flames and radiation levels resulting from a line puncture. At high pressures the flames were pretty fierce even from small orifices, and it was soon clear that even the Coleshill lab was not suitable. Fortunately permission was obtained to use part of the Safety in Mines Research Establishment site at Harpur Hill near Buxton, which at 1500 ft up on the Derbyshire moorland was reasonably isolated and in any case people round about were used to explosions and other strange events. Some surplus pipeline was borrowed to form a high pressure store fed from a small LNG tank, and Jim Thomas and his team were able to produce quite spectacular flames from orifices of a few inches diameter (Fig. 5.9).

Conditions at the Buxton site could be bleak. Malcolm Hoggarth and Eric Francis were once visiting one of the huts used by Sheffield University on the site, and were unable to enter because a layer of ice on the door knob made it impossible to turn. Snow in Winter and mist at any time were frequent occurrences.

Fig. 5.9 Early picture of pipeline fire work at Buxton.

The first experiments on LNG spillages and fires were also performed at Buxton, to demonstrate the integrity of earth bunding arrangements for the proposed LNG storage facility at Hirwaun. Subsequently, large scale tests were carried out at the ex-airfield site of the Fire Services Technical College at Moreton-in Marsh from 1973-77 (Fig. 5.10). LNG was transported to the site from British Gas storage facilities by tanker operated by a private contractor. On one occasion, the delivery valve on the tanker would not close completely, and MRS staff were horrified to see the tanker driver proceeding to attack the valve lever with a heavy hammer in a vain attempt to shut it!

Fig. 5.10 Picture of LNG work at Moreton in Marsh.



The next important event to have a major influence on the developing hazards programme was the explosion of a vapour cloud of cyclohexane at the Nypro works at Flixborough in 1974. The significant factor in this incident was the belief that the ignition of an "unconfined" cloud of vapour had resulted in high enough overpressure to destroy much of the plant and cause damage to property well outside the plant boundaries. It soon led to official concern about the safety of any installation with large inventories of flammable material, and the gas industry clearly had many of these. The Advisory Committee on Major Hazards (ACMH) was set up and eventually led to a whole new regulatory regime under the Health and Safety Executive (HSE) which could potentially place severe restrictions on operation and siting of plants.

It was essential to discover the extent, if any, to which natural gas or LNG vapour could be involved in explosions of the Flixborough type, so MRS began the long struggle to understand the phenomenon of unconfined explosions. From the outset there was strong personal interest and support for the programme from Denis Rooke, by then Deputy Chairman, and W.J.Walters, who were also both involved in promoting international cooperative efforts in this field, with MRS playing a technical coordination role, focused on Dave Lucas.

The unconfined explosions programme had many facets including mechanisms of gas evolution and dispersion, conditions for ignition, flame propagation, overpressure development and response of structures. Although progress seemed painfully slow at first the effort began to pay off when in 1976 the HSE began their investigation of hazards in industrial operations on Canvey Island, and MRS were able to provide informed advice to feed into the British Gas evidence relating to the LNG Terminal. Canvey figured again in 1982 when there was a major Public Inquiry into the safety of the LNG terminal.

In the early stages, hazards work was carried out at a variety of sites - Buxton, Potters Marston, Moreton-in-Marsh, and it was becoming clear that it would be better to concentrate on one more suitable site controlled by MRS. ERS were also at the time looking for a replacement for the Otterburn site for pipe fracture testing. The outcome was the acquisition in 1977 of ex-MOD sites at Fauld near Burton on Trent (Fig. 5.11), for the smaller scale explosions work of MRS and an extensive remote area at Spadeadam in Cumbria, an old rocket research site, managed and staffed by ERS, for the larger scale work (Fig. 5.12). Eventually a lot of the work at Spadeadam was on MRS projects, and after some initial problems centred round particular personalities on both sides, a good liaison was maintained between the two sets of staff.

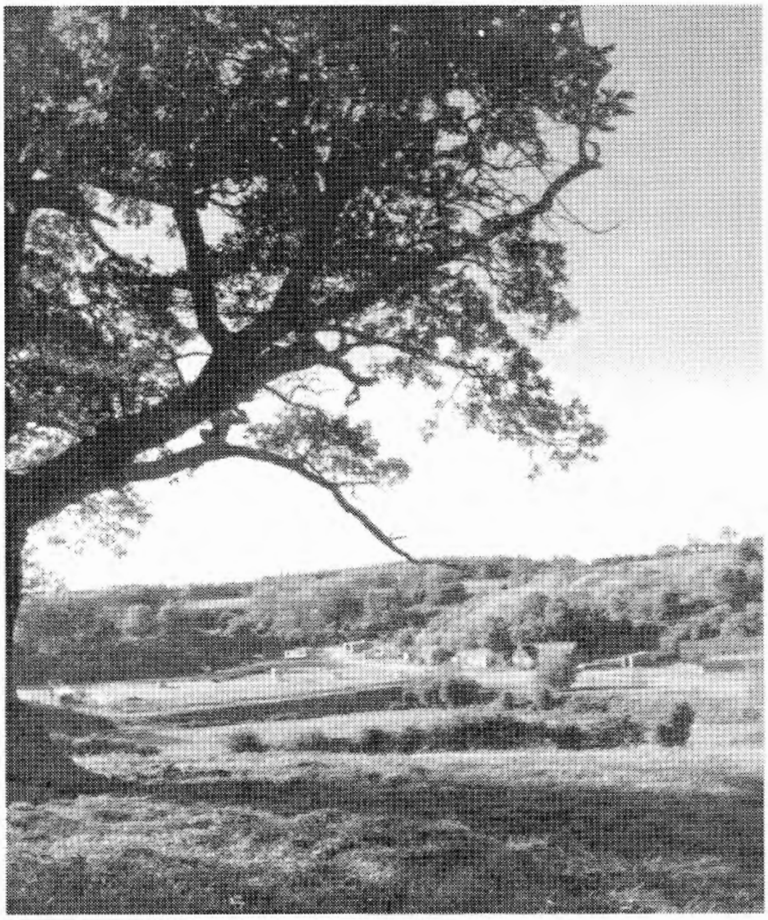


Fig. 5.11 The test site at Fauld.

Coordination of the hazards work was initially through a rather informal "Unconfined Explosions Meeting", which later developed into a formal Interface Committee, the "Hazards Interface Meeting", chaired by Bill Walters, which uniquely reported to both the Production and Supply and Resources and External Affairs Interface Committees. Dr. J.H.Burgoyne had been retained as a consultant and gave wise counsel and support for many years through his attendance at the HIM and Explosions Meetings.

In the early 70s, MRS had begun to study methods of quantitative risk assessment and also systematically to collect incident statistics of gas explosions in the UK and major incidents of interest to the gas industry world-wide. The Research Stations eventually got plugged in to the Industry's formal incident reporting and investigation system, and a group of experts were identified at MRS so that a two man team could be sent off at short notice at the request of a Region to assist in the investigation of an incident.

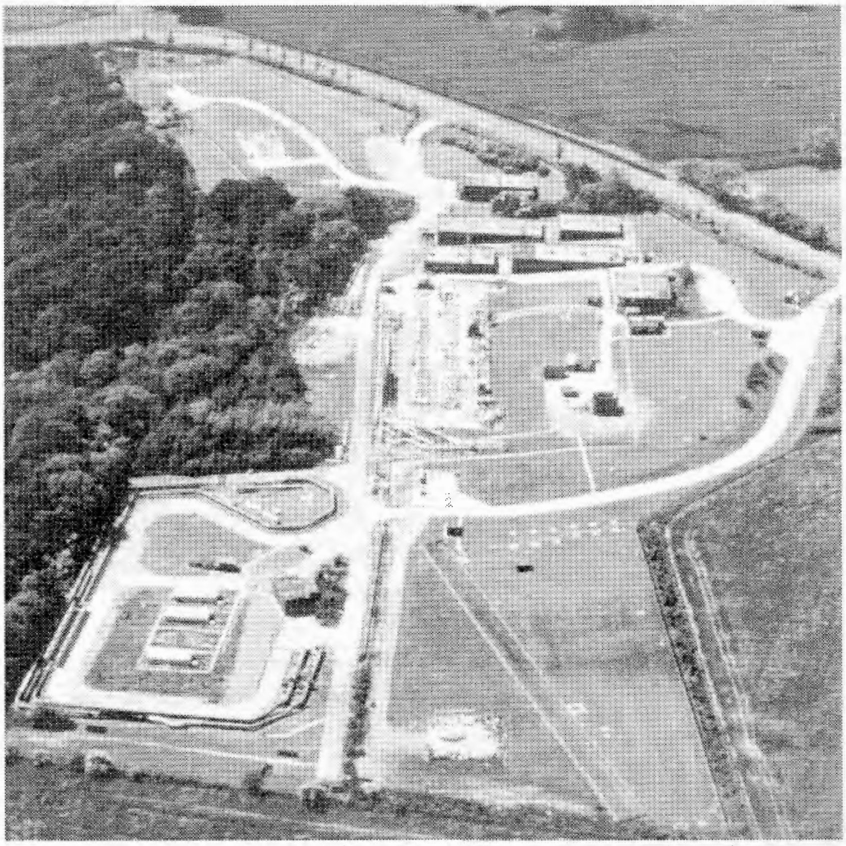


Fig. 5.12 The facilities at Spadeadam.

The risk assessment work was centred round a small group including Dave Moppett and Harry Hopkins, who also ran a defect investigation scheme for the industrial and commercial markets. The studies also took in comparative levels of acceptable risk in other industries and everyday activities, and led to an R and D initiative attempting to quantify the value of safety related research. A Panel involving all four Stations produced a Report which eventually reached the Research Committee and the Executive Committee and was recognised as having implications for the whole industry. Quantitative risk assessment continued to be an MRS interest, not least because its use in the HSE's Canvey Report of 1978 established that this approach would be used extensively in official site assessments.

Balance of effort in the 70's

With the rise in importance of the hazards work and the re-establishment of gasification research, the programme reached a sort of stability by the early 70's, having the three main but unequal sectors. This pattern persisted through to the mid eighties until the run-down preceding the end of the major part of the SNG programme.

"Fringe Activities"

There were one or two projects which are worth mentioning which fell outside the three main fields of work. The design of gas jet boosters was a spin off from the theoretical work on burner injectors, followed by an experimental study at Coleshill which gained an M.Phil for Malcolm Hoggarth (Fig. 5.13). Design of boosters for the Regions of British

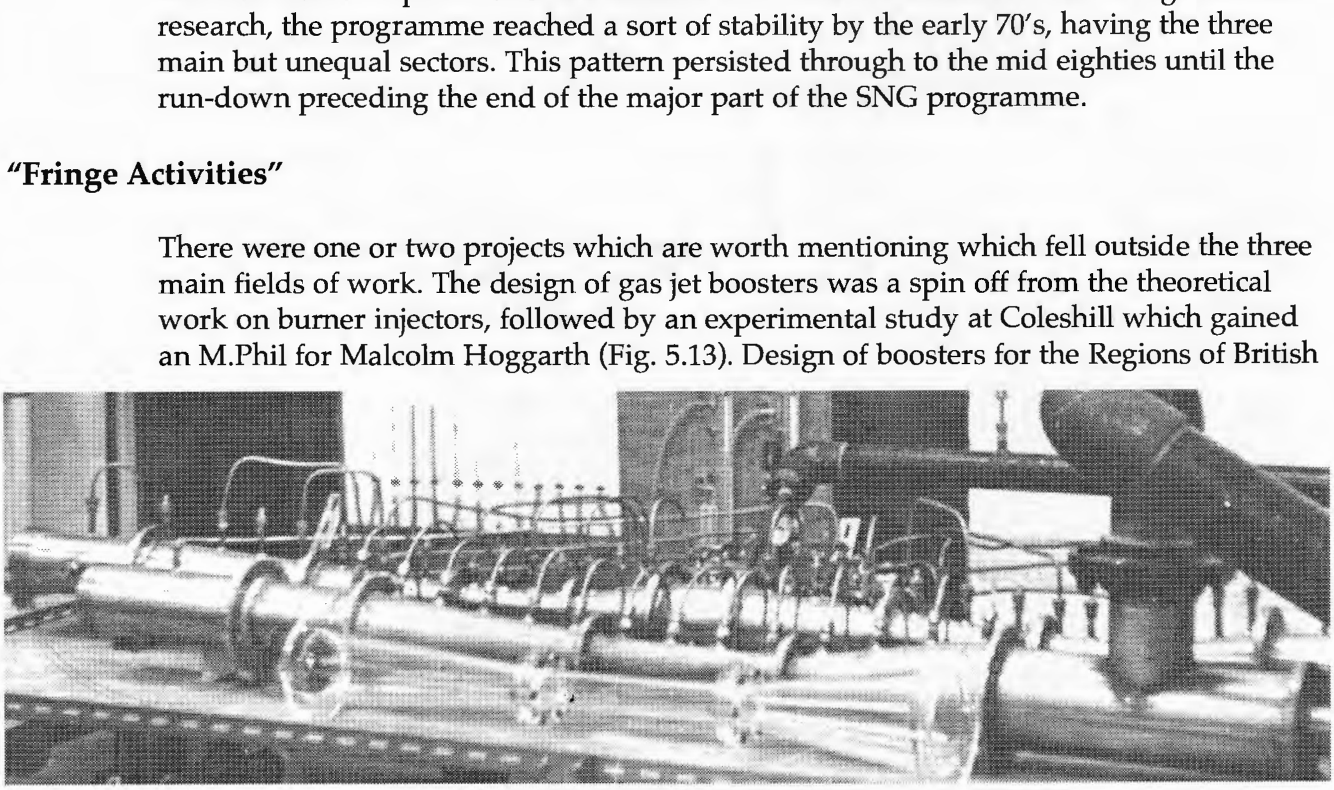


Fig. 5.13 Experimental gas jet booster.

Gas was taken on by John Templeman in the late 60's and early 70's, with the West Midlands being one of the best customers.

Prepurification of the gas feed to liquefaction plants at LNG storage sites involved removal of water vapour and carbon dioxide in absorbent towers containing molecular sieve material. The availability of gas at transmission line pressure enabled a test facility for absorbents to be built at Coleshill for checking performance against manufacturers claims (Fig. 5.14). This activity eventually resulted in a better understanding of the factors influencing packed bed absorber performance and to significant improvements in the absorb / regeneration cycle, also applied later to natural gas processing. Roger Wyatt was involved with this project almost from the start.

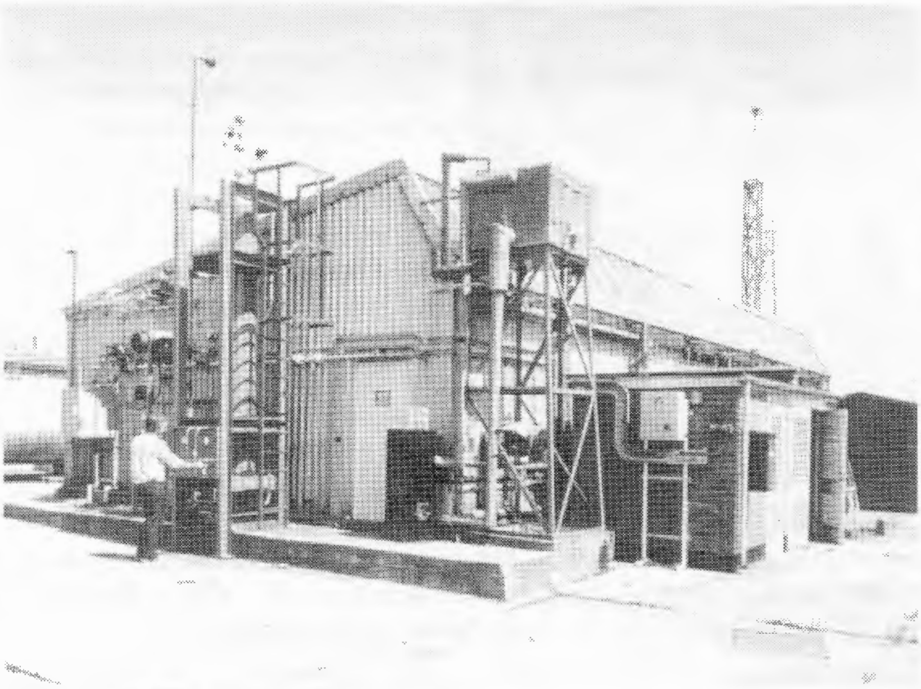


Fig. 5.14 The natural gas treatment laboratory at Coleshill.

A curious example of one part of the industry not knowing what another part was doing, concerned the performance of the water bath heaters used for preheating gas from the transmission system prior to pressure reduction. MRS first got involved as a result of an explosion incident (Luxborough Lane), but it soon became clear that their reliability, efficiency and safety left significant room for improvement. The requirement for independence of mains electricity at usually remote sites meant that they relied on natural draft and had a simple control system based on thermo-electric flame detection, despite having large heat inputs. An intensive effort from Controls, Combustion and Special Projects Divisions resulted in re-rating heat inputs,improved main and pilot burners, a radically redesigned control system and the writing of a new design specification (Fig. 5.15). The activity took place in the late 70s and early 80s and was coordinated by Neil Fricker.

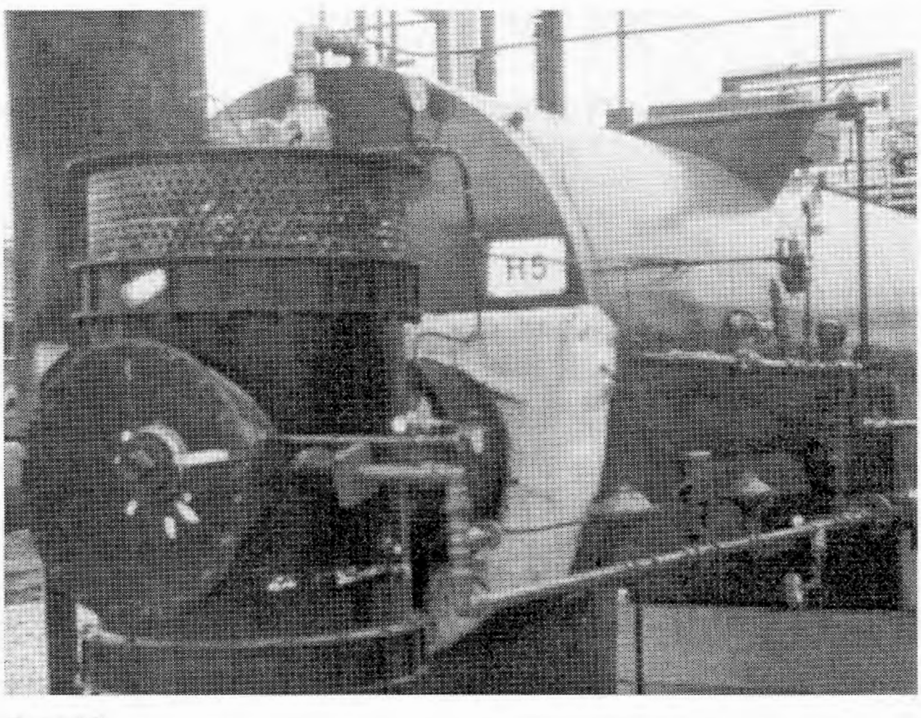


Fig. 5.15 Picture of water bath heaters on test at Coleshill..

1979 - Administrative changes, the end of an era

After a long career in gas research going back to the Leeds University days, in 1979 Leo Moignard retired to his much loved Yorkshire Dales. He had latterly been Assistant Director in charge of Administration. He also took a personal interest in the pursuing of applications for patents and had guided many MRS staff through the labyrinthine procedures. As Chairman of one of the monthly Managers Meetings, he was also responsible for "Good Housekeeping" and particularly achieving economies in the use of services such as electricity, gas and other piped services such as compressed air, hydrogen, nitrogen, steam and mains water. It took years to achieve adequate measurement and monitoring of the usage of these services, which was an acute embarrassment in a time of emphasis on energy conservation. Sometimes the only explanation for a high usage would seem to be an open-ended pipe somewhere on the Station! However persistence eventually paid off and replacement of steam heating, removal of unused services and other measures resulted in significant cost savings.

As the post of Assistant Director, Administration did not rate highly in the eyes of Personnel, it was decided not to have a replacement. Instead, John Barrett was recruited as Manager of a new Administration Division, including the Library, personnel services, typing pool and the print room (later Reprographics). This set up remained in being to the end of the Station.

Also in 1979, Ron Edge became Manager, Gasifier Design Project aimed at consolidating knowledge of slagging gasifiers, particularly the mechanical aspects. John Anderson became Manager of Engineering Division.

1979 also saw a somewhat belated recognition of the role of Trade Unions in the Station. There was already a Joint Consultative Committee (JCC), chaired initially by Leo Moignard, but its terms of reference was restricted. A Management-Unions Liason Committee (MULC) was set up to ensure regular contact to discuss potential or actual IR issues in the Station.

CHAPTER 6

The 80's - Adopting a Higher Profile

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The 80's - Adopting a Higher Profile

If for most of the 70's there was a relative stability in the Directorate (Fig. 6.1) and Divisional Managers at MRS, the 80's were marked by a veritable merry-go-round of

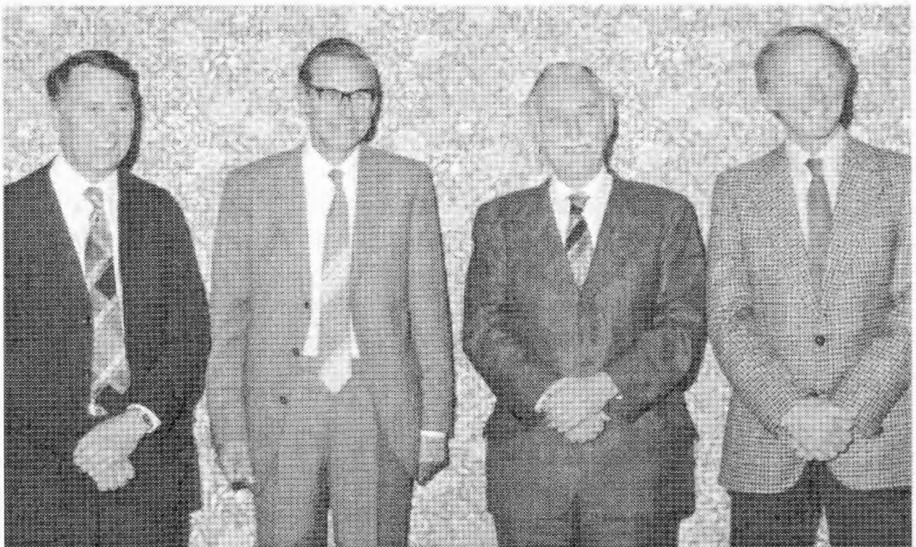

Fig. 6.1 The MRS Directorate at the time of Dr. Simmonds retirement in October 1982.

Fig. 6.2 W.E.Francis and W.A.Simmonds in October 1982 at the occasion of Bill Simmonds retirement.

change. In October 1982, Bill Simmonds retired after 15 years as Station Director (Fig. 6.2), having presided over a doubling in the size of the Station, in terms of staff numbers. He was succeeded by Eric Francis, hence maintaining a continuity back to the original Gas Research Board team.

In 1981 Dennis Hebden retired, severing another GRB link, and John Lacey took over the position of Programme Director, SNG whilst still remaining a member of the MRS Directorate. On taking over in 1982, Eric Francis achieved a restoration of three functional Assistant Directors to reflect the importance of the main fields of research, SNG, Industrial and Commercial utilisation and Hazards (sometimes under the euphemism of Safety Studies). Lawrence Conway was appointed Assistant Director SNG and Dave Lucas became Assistant Director, Safety Studies, while Peter Atkinson remained in charge of Utilisation. Henry Stroud became Manager of Production Division and Colin Bradley took over the coordination of International cooperative research on hazards.

Publicity and the Station Image

On his appointment as Station Director, it was made clear to Eric Francis that MRS had a reputation, whether deserved or not, for being somewhat secretive and aloof in its dealings with HQ and the outside world. One of his main objectives was to change this perception and give the Station a much higher profile in publicising its activities both inside and outside British Gas and to improve relationships with R and D HQ and the other HQ Divisions.

Several initiatives were needed to ensure that the image of the Station was enhanced. The appearance of the Station had to be improved, the standard of presentational material upgraded and positive steps had to be taken to make more effective contacts with potential users of results of MRS work.

In the main foyer of Murdoch Building the stairs were reoriented to improve the reception area and allow much of it to be available for publicity displays. All the Divisions were encouraged to produce visually attractive display material to the same basic pattern. Phil Sims was persuaded to take charge of a Reprographics Section and proved adept at organising the production of display material and other forms of publicity.

The first occasion on which the new displays were used occurred in September 1983 when the Research Committee met at MRS (Fig.6.3). This was a preview to using the hazards related material for the launch of the "Explosions Monograph", written by Bob Harris, at the Fourth International Symposium on Loss Prevention at Harrogate. This proved to be the first of a series of British Gas Applied Science Monographs produced by the Research Stations, with the strong backing of the Chairman.

Fig. 6.3 Dr. D.M.Lucas, Sir Denis Rooke and W.E.Francis in front of a display on hazards research during a visit of the Research Committee, September 1983.

The meeting rooms in the front block were refurbished as were the visitors dining facilities. The theatre was more or less gutted and refitted with new theatre style seating (to replace the original "schoolroom desk" type), a new platform area, H and V system and audio-visual facilities.

In terms of permanent staff numbers, the Station was still growing; indeed an all-time peak of 462 was achieved in November 1986 (Fig.6.4). In some ways the Station was bursting at the seams, but a complete new building, although often included as a fallback in the Five Year Capital Programme, was difficult to justify because of the changes in the nature of the work. Most of the experimental studies for the Hazards work were carried out at Fauld or Spadeadam, and the rest tended to be computer simulations. Field trials on customers premises represented a large proportion of the utilisation programme and some of the larger scale SNG work was carried out at Westfield or Coleshill. The upshot was that there was less need for large open laboratory areas and a lot of pressure to convert them into offices and small labs.

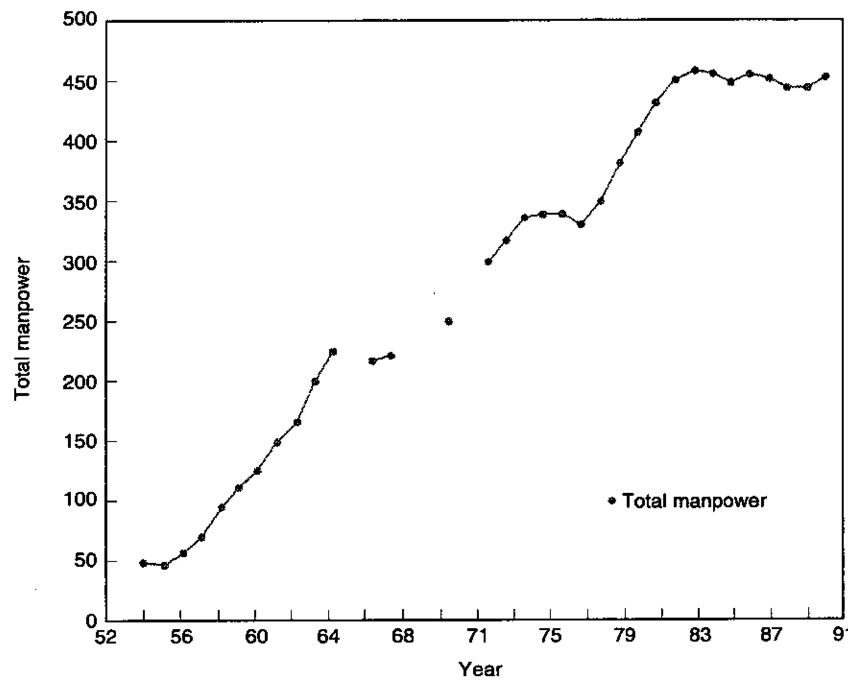

Fig. 6.4 Growth of manpower from the early days to the late 80s.

The biggest change was in Joule Building, which was chopped into a series of offices, small labs and storeroom's for equipment used for offsite hazards work, a rather sad demise for a fine laboratory purpose built for industrial utilisation research. More successful was a refurbishment of the back end of Brindley Building as an open plan office for Controls Division. The top floor of the Workshop building was also converted to open plan for the Design function, its effectiveness helped by the introduction of a Computer Aided Design system.

Exploitation of Industrial Utilisation Developments

On his appointment as Station Director, it was made clear to Eric Francis by the Chairman that he wanted to see a more robust effort to exploit MRS developments in the marketplace. It was also clear that MRS would have to rely on its own resources if it was to achieve any success; no other departments of British Gas, including Marketing, were likely to give more than tacit approval and support.

It was necessary to work through Manufacturers, so this involved licensing, sometimes joint developments and a need for frequent liaison with licensees, or potential licensees. R and D HQ provided a service on the legal and administrative aspects of licensing, but there was still a need for a great deal of effort at MRS to keep tabs on all the contacts and make sure that problems were speedily dealt with. Bob Cox was persuaded to head up a Technology Transfer Section on which all this activity could be focussed.

One of the keys to success was to ensure adequate publicity for the range of developments already proven or in the pipeline. A newsletter called "Industrial Gas Research News" had been introduced by Bill Simmonds in January 1964, and had been useful in disseminating information on the industrial programme in the form of short news items. Apart from a change of name to "Gas R and D News", it had continued unchanged in basic format and style. However it was now too restrictive for the more overt purpose of conveying technically slanted publicity material to British Gas Regions, equipment manufacturers and interested personnel in other research organisations and Universities.

A new publication called "MRS Relay" was launched in September 1983, again introduced to the Chairman and the Research Committee at their meeting at Solihull. Extensive use of colour in diagrams and illustrations and the ability to supplement short news items with longer technical articles and industrial case histories gave the new magazine a good impact, and it was generally welcomed. Alan Yarwood had the job of editor and for the initial production had valuable assistance from Tony Manos of Watson House. The general format of one or two longer articles, "Asides" for news items, "Inside Industry" for case histories and "Rostrum" for publications was still retained until the last issue of October 1993 . Manufacturing Licensees were particularly pleased to see "Ideas in Action", showing a list of licensees for various products highlighted by miniature reproductions of their sales brochure covers.

It was heartening, in view of the effort that went into making "Relay" visually attractive and effective, that in 1984 it received two Awards from the British Association of Industrial Editors, the Costain Group Trophy for small circulation internal magazines for providing "proof that technology does not have to be boring", and the Monotype Trophy for the most outstanding journal of all circulation categories.

1983 also saw the start of regular Seminars and laboratory visits by large groups of senior managers from the equipment manufacturers. These became a regular feature, usually involving short papers by MRS staff on a particular area of the work followed by informal demonstrations and discussions in the laboratories. Industrial development engineers from the Regions also attended these Meetings and there were separate Seminars for Regional personnel organised in conjunction with Marketing Division.

The Energy Management Games

In 1983 a National Energy Managers Competition was initiated by members of Heating Plant Division, based on computer simulation of energy use within a typical engineering production factory ("Midland Fabrication"). The competition was open to Energy Management Groups, who had to make a series of investment decisions over a simulated six year operating period, the winner being the group showing the greatest financial saving.

With an admirable sense of occasion, the final computer key press to indicate the winning group was carried out by the Secretary of State for Energy, Mr. Peter Walker during a visit to MRS in October 1983 (Fig. 6.5), and the prizes were presented at the National Energy Managers Conference in November. Several contests were run subsequently, including one for the commercial sector, with the School of Fuel Management taking over the administration.

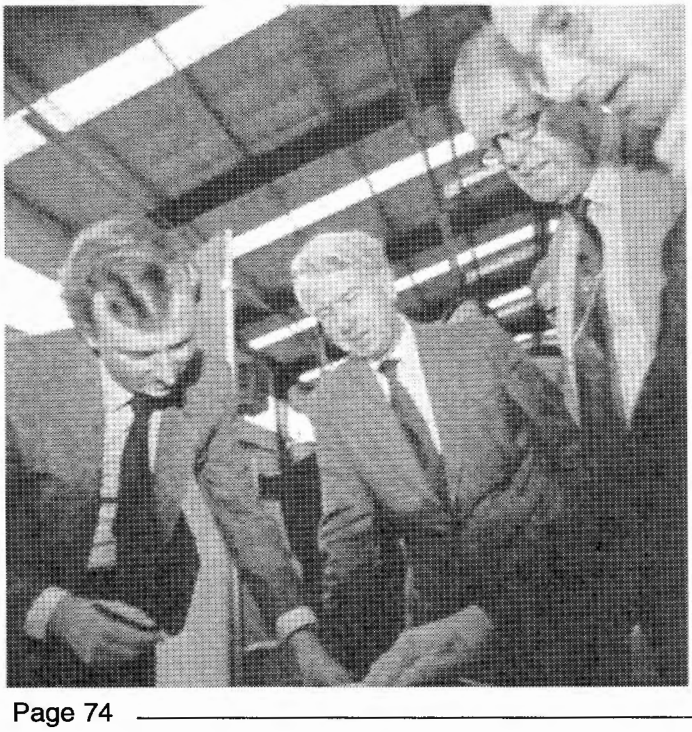

Fig. 6.5 Mr. Peter Walker, Secretary of State for Energy, accompanied by Sir Denis Rooke, about to initiate the print out of the final results of the National Energy Management Competition during a visit to MRS in October 1983.

The Royal Society Esso Energy Award

The Royal Society Esso Award for 1983 was won by Jeff Masters and Roger Webb for the development of the recuperative burner for gas fired furnaces (Fig.6.6). The Award is given annually for outstanding contributions to the advancement of science, technology or engineering, leading to the more efficient mobilisation, use or conservation of energy resources. This gave national recognition to a most successful MRS project; by then the licensed manufacturers had installed over 2000 units.

Fig. 6.6 Jeff Masters and Roger Webb with Sir Andrew Huxley, President of the Royal Society (left) and Mr. A W Forster, Chairman of Esso (right), following the presentation of the Royal Society Esso Award for 1983.

Administrative changes, Secondments, Retirements

As part of a deliberate attempt to encourage mobility and career development, during the mid-80s there were a large number of secondments, within the Station, and to other parts of HQ and to the Regions. These gave opportunities, through acting positions, for many people to gain further managerial experience. Bob Cockerham retired in 1984 as Manager of Materials Division and spent his final year on secondment to carry out a review of the British Gas Analytical Methods Handbook (BGAM) for the Scientific Services Panel, on which for many years he had been the MRS representative. Rowland Phillips became Manager (at first "acting") of the Division, which was reorganised and renamed Chemistry Division, taking in that part of SNG work which was laboratory scale. This gave the Division a direct stake in the R and D Programme and hence not wholly a service Division.

Many of the administrative changes during this period continued the gradual drift away from local responsibility towards control by HQ functions. Most personnel functions were already carried out by a Senior Personnel Officer based at MRS, and a very significant change was the severance on April 1st, 1986 of all remaining administrative links with the West Midlands Region, after 35 years. The main changes were being for the first time on the HQ payroll and adherence to HQ procedures for orders, invoice payments, expenses etc. The changes took place very smoothly, largely due to a task force at MRS centred round Jeff Jackson.

Other apparently minor changes could cause initial consternation among the staff, such as the phasing out of the traditional serving of tea and coffee by the "tea ladies", and replacement by vending machines! Rationalising the hours of work also proved to be a difficult issue. For a variety of historic reasons, various groups of people worked different hours and many had no desire to change. From a management point of view this led to inefficiencies and a uniform system was highly desirable. A majority of the staff were on flextime, introduced in the late 70's, and involving a computerised system of clocking in and out. The engineering technicians, having achieved staff status in 1975 were opposed to any reversion to a clocking system, but had earlier start and finishing times than other staff. They also had a commitment to shift working when required, which was deemed to preclude flextime. A small group of the scientific staff enjoyed a "personal betterment" of a longer lunchtime which went right back to Dr. Dent's time. After protracted negotiations and the buying out of the "betterment", a rationalising of the working hours was achieved.

The need for a permanent shift team had diminished by the gradual phasing out of the old CRG pilot plants and their replacement by a few highly automated new plants for catalyst performance tests, mainly in connection with the methanation project. In the end a single manned shift was introduced with mainly site security duties.

The gradual improvement in the effectiveness of the site services continued through the setting up of a Site Energy Working Party (SEWP), under the Chairmanship of Jeff Masters to carry on the good work started by the Good Housekeeping Committee. Many redundant plants and services were stripped out and the goal was finally achieved of eliminating space heating by steam, so by and large MRS was now practicing what it preached in the field of energy efficiency and showing significant cost savings.

In 1986, Dave Lucas departed to R and D HQ as Chief Coordinator and Malcolm Hoggarth succeeded him as Assistant Director, Safety Studies, hence freeing the "log jam" to promotions in Heating Plant, enabling Jeff Masters to become Manager of Heating Plant Division.

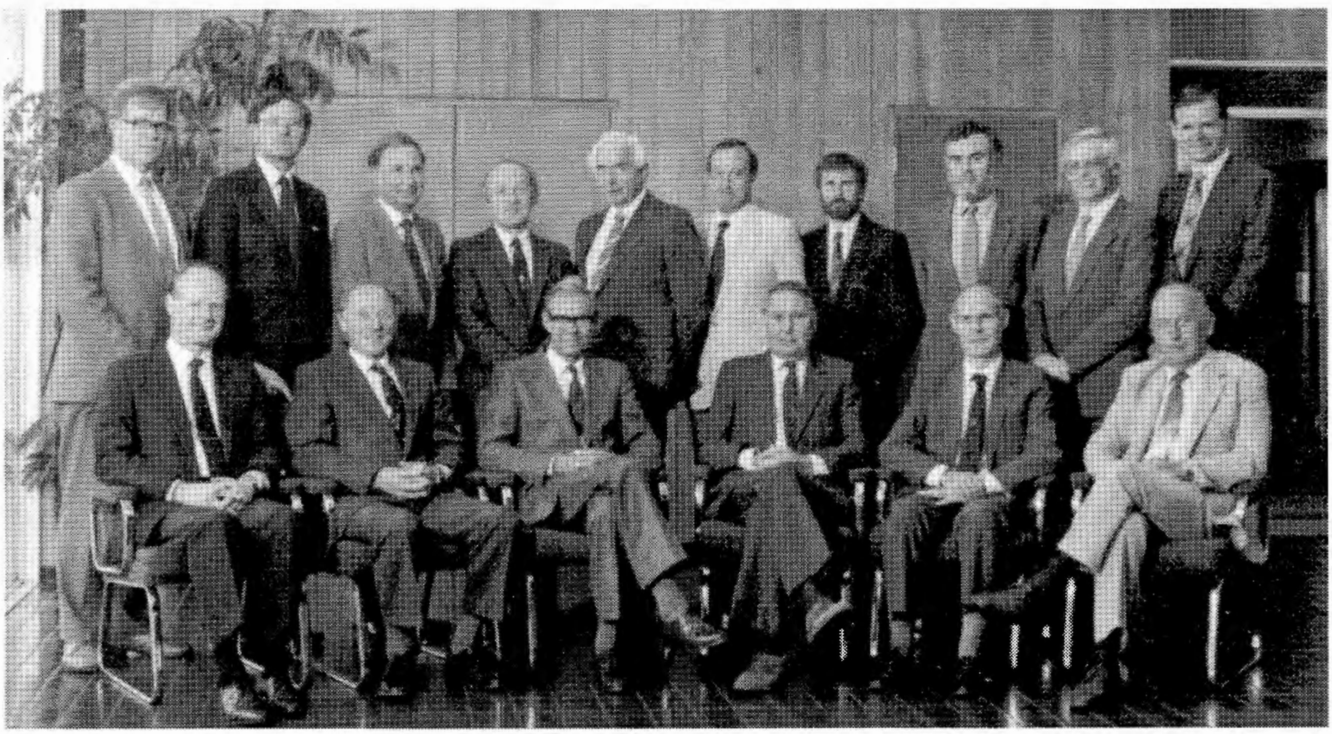

Fig. 6.7 Attendees at a Managers Meeting in the mid 80s. Seated left to right, Roger Hancock, John Lacey, Eric Francis, Peter Atkinson, Lawrence Conway, Peter Cubbage. Back row, Dave Moppett, Henry Stroud, Tony Cross, Colin Bradley, Jim Cornforth (School of Fuel Management), Jeff Masters, Keith Adams, Mike Davies, Ray Kightley and Jeff Jackson.

The New Station Decision

John Gray retired as Director of Research in early 1983 and was succeeded by Gerry Clerehugh. One of the first issues addressed by Mr. Clerehugh and his Station Directorate of mostly new incumbents was the unsatisfactory situations of the London Stations and MRS. The deliberations culminated in an announcement in 1986 of the decision to close the three Stations and relocate in a new Station in an as yet unchosen site in the "South Midlands".

The decision to relocate led to a series of changes in the MRS management. Dave Lucas took over responsibility for the New Station Project and the resulting gap in the HQ Chief Coordinator's position was filled by secondment of Lawrence Conway, which allowed Henry Stroud to act as Assistant Director SNG. John Anderson also joined the New Station team and his place as Manager, Engineering Division was taken by Keith Adams. The retirement in September 1987 of Peter Atkinson allowed the appointment of Jeff Masters as Assistant Director, Utilisation and of Neil Fricker as Manager, Heating Plant.

In December 1987, after 40 years in Gas R and D, and in the knowledge that he would not be participating in the New Station, Eric Francis retired and Lawrence Conway was appointed Acting Station Director. Within a year or so, all the remaining ex-Gas Research Board people, Ron Edge, Peter Cubbage, James Buckley and finally Ken Stewart had also retired, perhaps appropriately the end of an era coinciding with the impending incorporation of MRS into the New Station.

Lawrence Conway, who was later confirmed as Station Director in March 1991, had hardly settled his feet under the Directorial desk when he was whisked off again to R and T HQ and Malcolm Hoggarth took over as Acting Director, with Bob Harris, who had become Manager, Special Projects Division, acting as Assistant Director, Safety Studies. This enabled Malcolm Wickens to manage Special Projects and Martin Vasey to head a new Division of Safety Modelling. The retirement of Roland Phillips resulted in Tony Cross succeeding as Manager of Chemistry Division. Thus MRS was able to face the uncertainties of the 90's with a new generation at the helm, albeit all "home grown" and with a proven track record of success.

SNG in the 80's - The Seven Year Programme

The Long Term SNG Plan was subject to updating each year and in the early 1980s came under very close scrutiny as confidence in future natural gas supplies increased. Drastic cuts were made in a revision approved by the Executive in 1984; the costs were halved and the more sharply focussed objectives of demonstrating the production of SNG from coal using the slagging gasifier and proving the technical feasibility of coal hydrogenation were to be completed in 7 years, i.e. in 1991. Furthermore Management Consultants were brought in to ensure tight control, with the inevitable result - a plethora of multi-divisional committees for strategy, policy, management and for technical matters blossomed forth! The revised programme under the direction of John Lacey was completed within budget (£193 million) at the end of 1991, despite the loss of two years due to an explosion at Westfield in 1985.

The first task for the MRS production side in the 80's was to complete the FBH pilot plant programme, part funded by Osaka Gas. A three year project was started in 1981 to define the conditions for a SNG process from residual oil feedstocks, involving pilot plant tests on the 10 inch dia. reactor at Solihull and scale up information from the large fluidised bed "model" at Coleshill. These tests were successfully completed and were supplemented by a plant engineering study to determine feasibility and costs for a full scale SNG production plant.

Commercial FBH plants for base load SNG would need to be 10 times the size of the pilot plant, so attention had to be paid to scale up, not straightforward with fluidised beds. The "Large Fluidised Model" was constructed in 1980 at Coleshill (Fig. 6.8), comprehensively instrumented to give unique data on the behaviour of large diameter, deep beds.

Fig. 6.8 Large fluidised bed model of FBH at Coleshill.

The final report on the FBH development was presented to Osaka Gas in April 1984 (Fig.6.9). This was not the end of the Osaka connection however, since they were persuaded to cooperate in a new attack on the long standing challenge of coal hydrogenation.

There are good theoretical reasons why direct hydrogenation of coal to methane should be potentially more efficient than steam/oxygen gasification. In the latter, large amounts of energy have to be provided for the endothermic production of hydrogen and carbon monoxide; this energy is subsequently released again in the highly exothermic methanation stage and has somehow to be recycled to maintain a reasonable overall efficiency. With direct hydrogenation this problem is much reduced.

Fig. 6.9 Presentations of the final report and a commemorative plaque by Mr. Yoshida of Osaka Gas and Eric Francis, Director of MRS in April 1984, to mark the completion of a cooperative programme to develop the fluidised bed hydrogenator for production of SNG from heavy oils, using the pilot plant reactor at Solihull and the large model at Coleshill, to the stage of an engineering design study.

However the development of a practical coal hydrogenator had eluded many researchers worldwide, including Dr. Dent's team in the 60's. Undaunted by this experience, the MRS team decided that a fully entrained reactor stood most chance of success, controlling the temperature rise from the slight exothermicity by using product gas recirculation a la GRH. Before venturing to an actual pilot reactor, extensive modelling, theoretical and physical were undertaken, together with laboratory scale reaction studies closely simulating the expected reactor conditions and contact times. In the laboratory, a high pressure heated grid apparatus was used and supplemented by studies of coal constitution by maceral analysis.

In Brunel Building, a coal fines gasification rig (CFG) was constructed around a 1" dia. 4-6 metre long reactor tube, down which fine coal dropped in contact with hydrogen. This was undoubtedly the most expensive "test tube" ever used at MRS, operating at up to 90 bar and 1000 C (Fig. 6.10)

Osaka Gas joined the project in 1986 and carried out complementary studies in Japan. The pilot plant reactor (Fig. 6.11) was commissioned in September 1987 and was successfully operated in batch mode through to October 1988. Having proved the concept, further phases involved higher loading and continuous running (Fig.6.12).

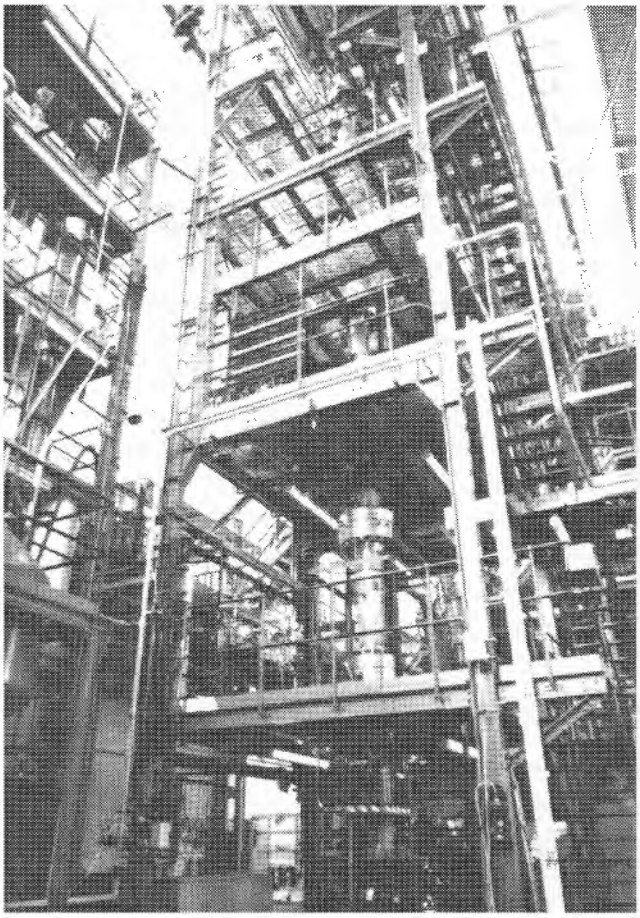

Fig. 6.10 Coal Fines Gasification rig.

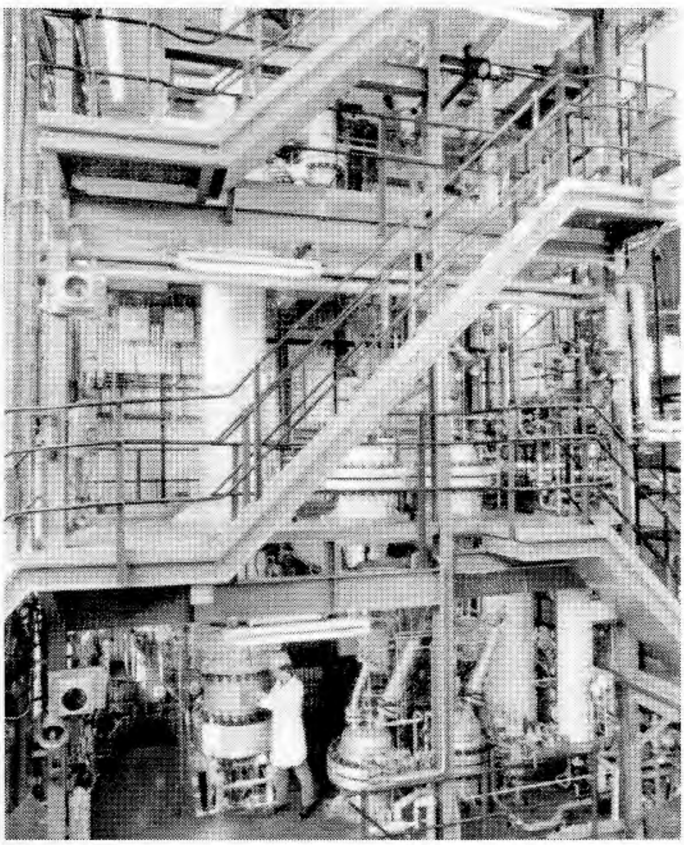

Fig. 6.11 Coal hydrogenation pilot plant (CHPP), first operated in 1987, later refurbished for long duration tests, shown during recommissioning run in 1990 as part of a cooperative development programme with Osaka Gas.

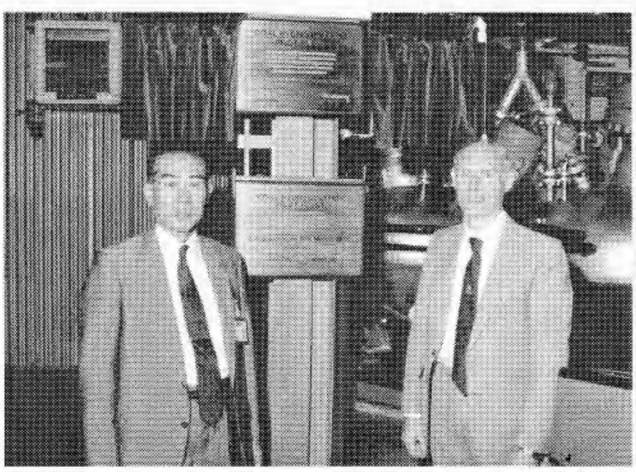

Fig. 6.12 CHPP commemorative plaques, with K. Ishimaru (Osaka Gas) and Lawrence Conway, June 1990.

Support for the Westfield programme

The main SNG from coal programme, centred round the full scale Westfield facility, was revised in 1984 to a 7-Year programme aimed at providing a fully proven viable process. Operation of the "8ft dia. extended gasifier" was to be the main activity supplemented by a higher pressure smaller "experimental gasifier"

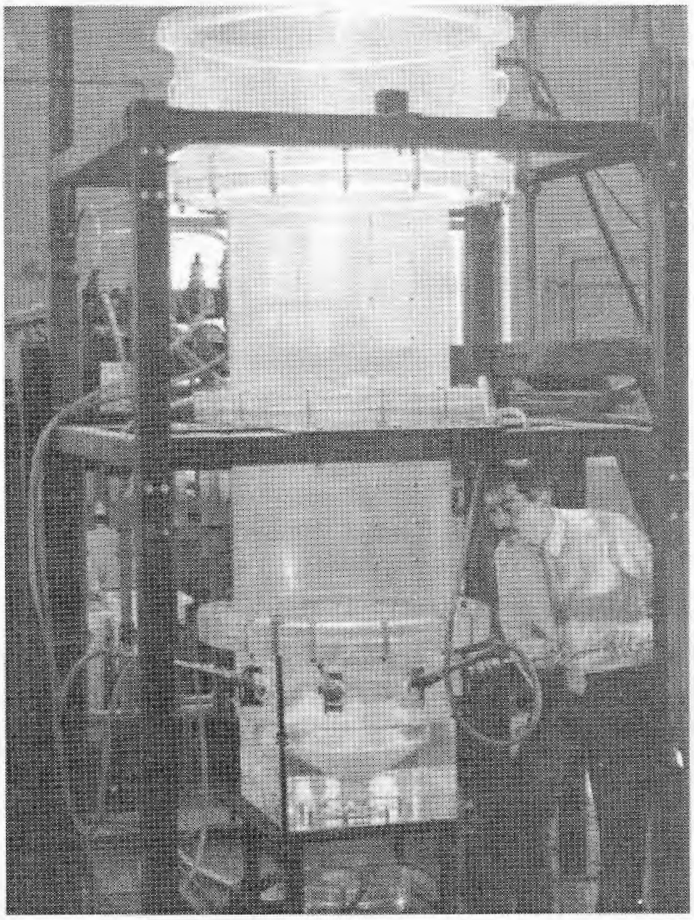

Fig. 6.13 Slagging gasifier flow visualisation model, 1986.

Direct support for the gasifier development was provided by Engineering Science Division and Process Studies Group. Several aspects of solids and slag flow were studied (Fig. 6.13) and eventually a detailed mathematical reactor model was developed, which proved valuable for performance predictions and understanding of gasifier behaviour.The principal MRS contribution was still concerned with methanation and improvements to the HICOM process. This meant developing a catalyst which would withstand more severe conditions than would CRG-F. In conjunction with LRS, many candidate formulations were laboratory tested and the best were selected for extended pilot plant runs (Fig. 6.14). These entailed a continuous supply of a simulated slagger gas and to this end a plant was erected to an MRS process design in an existing structure in Brunel backyard. The contractors seriously underestimated the complexity of the job and were probably financially disadvantaged by the deal, but the plant performed according to plan.

The best of the candidate catalysts, designated LH, was shown to be suitable for the "Advanced Hicom" conditions and was used in the final pilot plant test at Westfield with actual slagger gas.

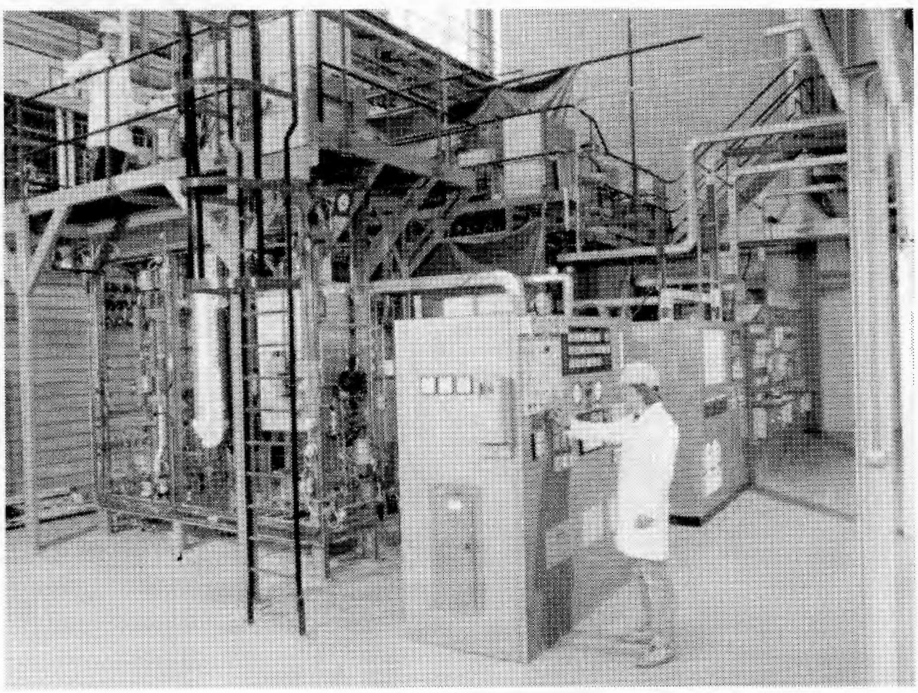

Fig. 6.14 HICOM pilot plant, typical of the highly automated catalyst test rigs of the late 80s.

Most of the work on methanation was carried out at Solihull, but it was realised that eventually all the stages of the conversion of the slagger gas to SNG would have to be proved on the actual gas produced, sometimes using sidestreams. To this end it was felt essential to have an MRS presence at Westfield, so in 1981 a Westfield Division was set up, initially with Jim Garstang and later Haydn Davies as Manager. Eventually a separate Laboratory for the MRS staffed activities was erected at Westfield. Relationships with the local management, which was rather bureaucratic and not very cooperative, were sometimes most difficult; engineering work had to be carried out according to P & S Operations procedures, and priority was difficult to obtain with relatively small projects, so life was often fraught for the MRS staff. Nevertheless a young and enthusiastic team of mainly local graduates was built up. It was not until 1990 that the Chinese Wall between the P & S and R & D establishments at Westfield was finally breached.

The Westfield Division was responsible for work on the downstream treatment of the gas from the gasifier, i.e. acid gas removal, demonstration of methanation on the actual gas from the gasifier and on purification of the aqueous liquor. They were also involved in various aspects of the design and operation of the high pressure (70 bar) experimental gasifier (Fig. 6.15). A 1 million SCFD Acid Gas Separation Pilot Plant was built at Westfield and used to demonstrate the suitability of solvents such as Selexol, Purisol and selefining for naphtha and/or sulphur removal. Liquor purification was demonstrated on a 1 ton/day plant, including the novel use of reverse osmosis for the final stage to produce a very pure water, suitable for re-use within the plant.

Fig. 6.15 Experimental gasifier vessel being hoisted into position.

The HICOM process was eventually demonstrated in 1989 at Westfield over a period of 60 days operation using product gas from the slagging gasifier purified using the Rectisol plant; it confirmed the high performance expectations.

In 1990, a demonstration of the use of the slagging gasifier at medium pressure for the gasification of power station coals was successfully completed during 40 days of tests in a project supported by the CEGB and British Gas. The final task in the development of the slagging gasifier was to commission and operate a new Experimental Gasifier over the pressure range 25 - 70 bar with a view to optimising the SNG process route.

The work at Westfield was completed at the end of 1991 and Haydn Davies and his staff returned to Solihull in 1992.

Utilisation R and D in the 80's

Significant effort was still needed to consolidate the position of already proven developments in the market place, such as recuperative burners, rapid heaters and vat and tank heaters. Increasingly though, these could be left to the Licensees, one of whom, Fairbank-Brierley, won the Queens Award for Export of rapid heaters in 1990 (Fig. 6.16). Although the uptake of rapid heating was relatively slow, there was sufficient progress for Kevin Pomfret and John Waddington to win a second Royal Society-Esso Award for MRS, a remarkable achievement (Fig. 6.17).

Fig. 6.16 Looking towards the burners in a rapid heating furnace.

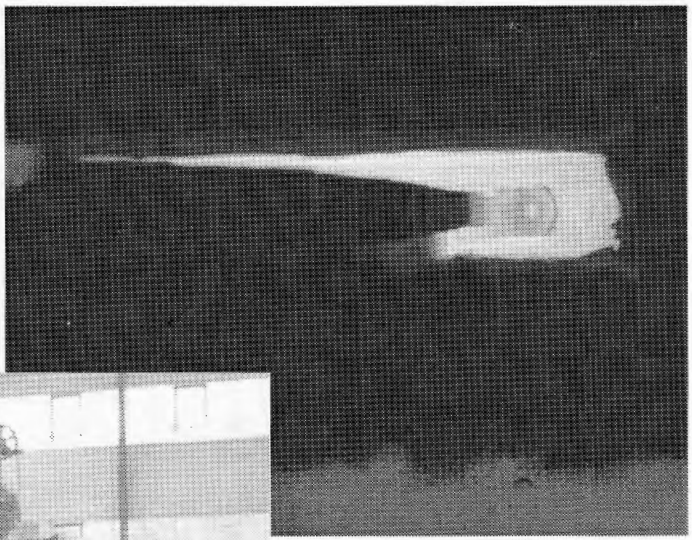

Fig. 6.17 Kevin Pomfret and John Waddington, winners of the 1990 Royal Society/Esso Energy Award for their work on gas-fired rapid heating furnaces, standing in front of the experimental walking beam billet heater in Darby Building.

Power Generation

Much of the newer work has been in the general field of power generation. There had been studies on gas fuelled prime movers at MRS since the late 60's, but with only limited success. In the early 80's small scale CHP was beginning to be viable, both with gas turbines and spark ignition engines. In the commercial sector, small engine driven CHP or "cogeneration" systems were finding application in "Institutional" establishments, where high annual running hours were the norm, such as swimming pools and other leisure centres, hospitals, prisons and also in hotels. MRS contributions were in assisting regions to assess the economic viability of schemes, in many field trials, and using the engine test cell facilities to check and improve engine conversions and performance.

Later in the decade, CHP schemes in the Megawatt range based on turbines were becoming common and further applications of engines, such as engine driven air compressors and engine driven chillers and chiller/heaters were becoming viable.

Engine driven heat pumps appeared to offer potential for significant energy savings. There were some notable installations in the industrial process sector, for example in malt drying. Application to space heating for the commercial sector proved more difficult. In the early 80's MRS managed and monitored a programme involving seven installations in Regional premises, with strong support from Marketing HQ. The installations covered a variety of engine/refrigerant compressor/heat exchanger combinations from several installers, and were overseen by the local Regional engineers. Performance was monitored over a complete heating season, and although one or two of the heat pumps performed well, the overall results were not brilliant. Some of the installers did not inspire confidence and the performance of some of the components, notably in the refrigerant circuit, did not measure up to manufacturers claims. The conclusion was reluctantly drawn that Marketing could not confidently support a sales campaign for engine driven heat pumps at that time. However much useful experience was gained and pointers provided to the further development of components and systems.

Natural gas fuelled vehicles have been in operation in various overseas countries for many years, and in the early 80's, the idea was floated at the Research Committee that MRS should explore the possibilities in the UK, but were firmly warned off. By the end of the decade attitudes had changed and MRS, LRS and ERS were all involved in a programme initially aimed at fleet use.

Fuel cells were another means of power generation that had attracted researchers since Bacon demonstrated his original hydrogen/oxygen cell. Both MRS and Watson House were interested in fuel cells, since they appeared relevant in all sectors of the market. By the mid-80's, phosphoric acid fuel cells had been developed in the USA to the stage where extensive field trials of pre-production units were being planned, and although overtures were made, there did not seem to be an appropriate role for British Gas. Solid oxide cells were at an earlier stage and were particularly attractive for direct use of natural gas. After much discussion and several papers to the Research Committee, arrangements were made to purchase an experimental cell from the US developers, but for reasons which were not clear, no cell was forthcoming. This left molten carbonate cells, which involved severe materials problems, but had inherently the highest potential efficiency. A facility for testing small molten carbonate cells at up to 10 bar pressure was built at MRS mainly for investigating the possibility of direct reforming (Fig. 6.18). Bob Carpenter was persuaded to leave Engineering Science and the hazards work to lead the fuel cell team and was joined later by Andrew Dicks from Chemistry.

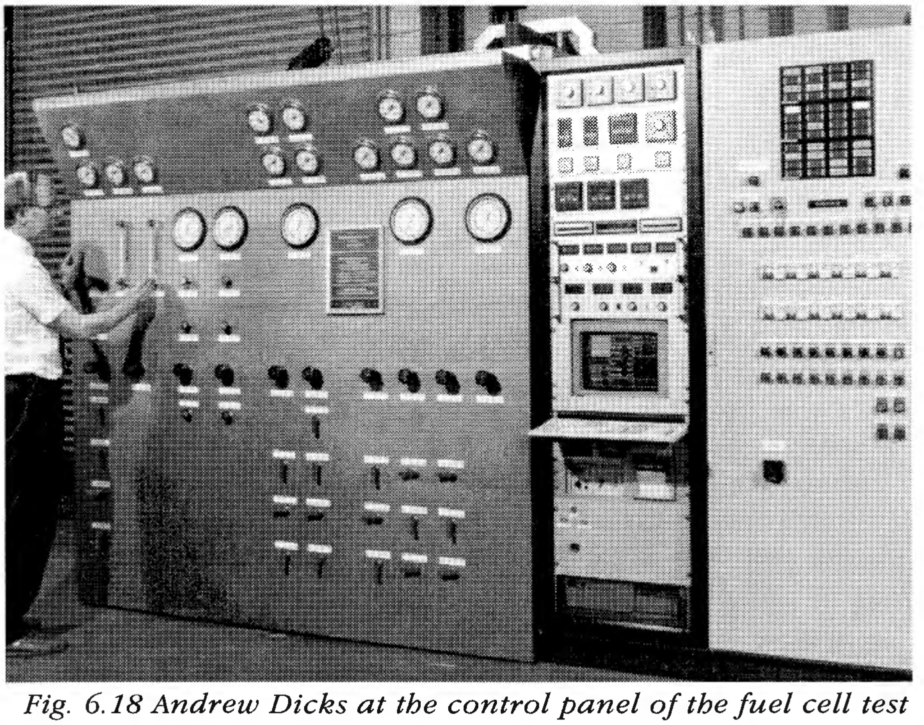

Fig. 6.18 Andrew Dicks at the control panel of the fuel cell test facility, 1989.

Low Temperature Processes

In the low temperature heating field, a spin off from the tank heater was the direct contact water heater, which offered very high efficiencies for once through cold feed applications. There was initial success in the tanning and dyeing industries, but the first cost proved too high and the concept has recently been redesigned for lower cost production.

Dehumidification became a new application for gas in the UK as a result of a joint development with Munters Ltd. using a dessicant system based on the Munters wheel, with the dessicant regenerated by a burner operated with high excess air to give a temperature of about 110°C. The first application was achieved early in 1990 at an ice rink in Forfar, and there is great potential in situations where controlled conditions of temperature and humidity are required.

High Temperature Processes

The great success story in the high temperature field was the development of a compact regenerative heat recovery system. Recuperative burners had been, and are still being, successfully applied to a wide range of furnaces, but the need to limit metal temperatures in the heat exchanger put a severe restriction on the air preheat and hence the overall efficiency. In the early 80's a system was devised using a pair of regenerator beds packed with small ceramic spheres, with a fast switch-over cycle using a novel valve arrangement. It was soon obvious that very high efficiencies were attainable and this early progress was the subject of a small item in the last edition of "Gas R and D News" before it was replaced by "Relay". This was seen by Trevor Ward of Hotwork, who immediately realised the potential and soon paid a visit to Solihull to see the device under test. The upshot was a Joint Development Agreement under which Hotwork very quickly produced a prototype for field trial on a glass melting "pot" furnace - a demanding duty. The trial was successful and showed that the device could deal with dust laden gases.

Subsequent commercial exploitation proceeded rapidly and within two years 220 burners had been sold, including some very large installations within British Steel. The regenerative burner enabled gas to be introduced into the bulk melting of aluminium, with its attendant very harsh operating conditions. The development culminated in Hotwork and MRS jointly gaining the Queen's Award for Technological Achievement in 1992 (Fig. 6.19).

Fig. 6.19 Jeff Masters receiving the 1992 Queens Award for Technological Achievement from the Lord Lieutenant, the Earl of Aylesford. The Award was won jointly with Hotwork Ltd. for the development of the regenerative burner.

Although the recuperative burner could be regarded as a mature technology by the 80's, there was scope for a more cost effective version for the lower temperature heat treatment range 700-1100°C. A new radial plate heat exchanger was developed jointly by Nuway Ltd and MRS, which is just beginning to be commercially exploited.

The development of a ceramic radiant tube capable of indirect heating at process temperatures up to at least 1200°C had been an objective since the 60's, when the recuperative "single ended" metal version had been introduced. Progress since then had been painfully slow, with a number of setbacks due to tube failure, often when success seemed within reach. In the early 80's, however, improvements in the production of large diameter silicon carbide/silicon nitride tubes and a new method of mounting the tubes in the furnace resulted in acceptable life and performance. Plain tubes were used with a sealing plug at one end spring loaded to maintain the tube under compression.

An application breakthrough came in 1983 with the installation of a furnace at Craelius Ltd. for the heat treatment of diamond tipped drills in a hydrogen or nitrogen atmosphere at 1100°C (Fig. 6.20), and this was followed by other applications including the important one of production of glazed ware in the pottery industry.

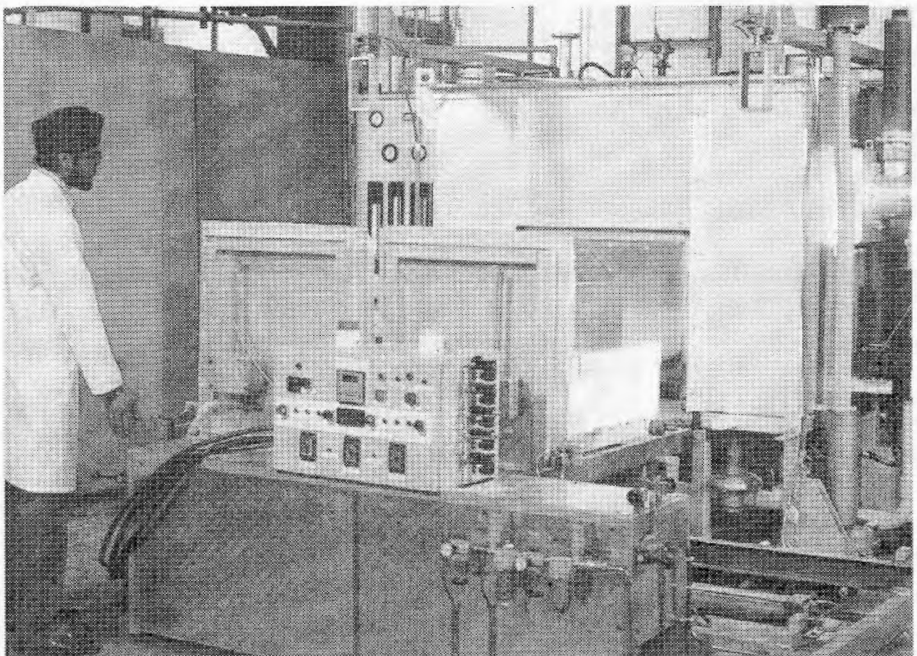

Fig. 6.20 A furnace heated by ceramic radiant tubes on test at MRS before delivery to the Craelius Group for heat treatment of diamond rock drill bits.

A similar firing technique was adopted for ceramic immersion tube heating of molten metals, such as zinc for galvanising and aluminium for the die-casting industry (Fig. 6.21).

An important early field trial was conducted on zinc melting in 1980 at ISC Alloys, with the cooperation of West Midlands Region. Burns Engineering supplied the tubes for this and many other of the early installations, becoming the principal Licensee and building up a significant export trade. By 1990, some very large multitube installations had been achieved, notably at Tinsley wire for galvanising and ISC Alloys, showing significant advantages in efficiency and productivity over conventional methods.

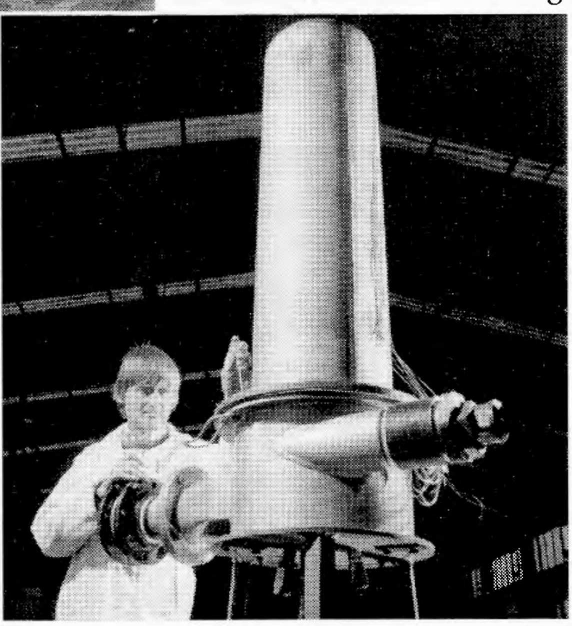

Fig. 6.21 Ceramic immersion tube prior to installation, R. Bridson in attendance.

Mathematical modelling continued to provide support for many of these programmes, and the MRS contribution was underlined by the publication in 1991 of a British Gas Monograph on the subject written by J.M.Rhine and R.J.Tucker.

Controls and Automation

Fig. 6.22 Controls Division 1987, showing mainly Certification Test rigs.

The Certification activity continued at MRS (Fig. 6.22), but increasingly it came under the aegis of the National and International Standards organisations. Testing of safety shut off valves (Figs. 6.23 and 6.24) to BS5963 began in January 1985 and a further significant step was the recognition of the quality of the facilities by NAMAS accreditation, leading on in 1992 to the ability to test to EC standards for British Gas as a "Notified Body" for the EC Gas Appliance Directive.

Testing techniques needed to take more account of the increasing use of microelectronics, with control sequencing and logic incorporated in software. Automated testing of the effect of bit corruption in software was developed in the early 80's and an improved version for general use implemented on an IBM compatible PC in 1988.

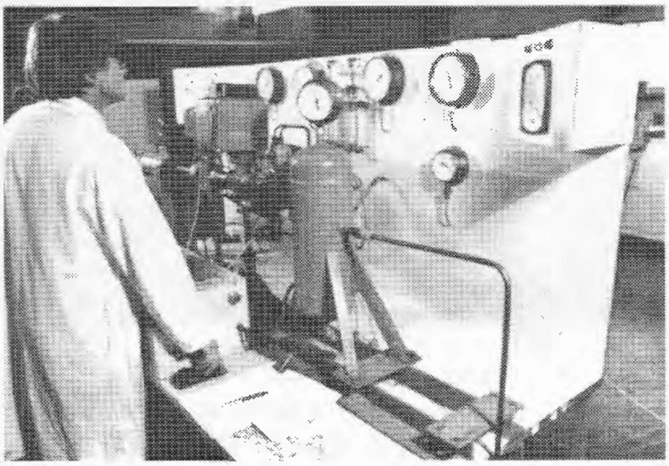

Fig. 6.23 Dave Knaggs operating a safety shut off valve test rig.

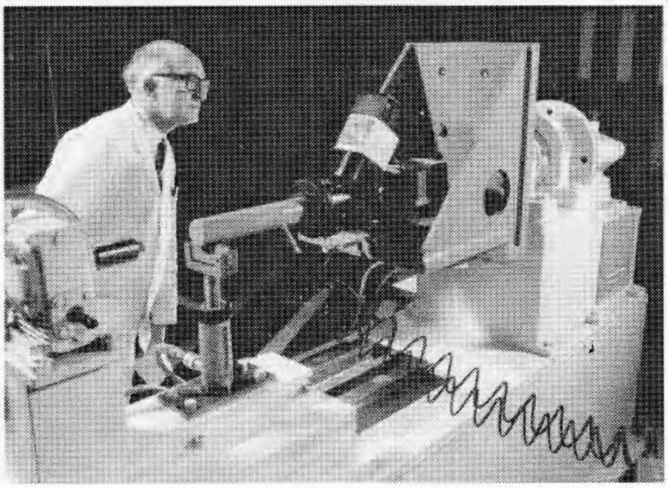

Fig. 6.24 Geoff Butler operating the safety shut off valve bending test rig.

Microelectronics and particularly microcomputer technology was introduced to upgrade many aspects of burner and process controls, such as air/gas ratio and combustion quality control (Fig. 6.25), programmers and flow control (using "silicon chip" pressure and flow sensors).

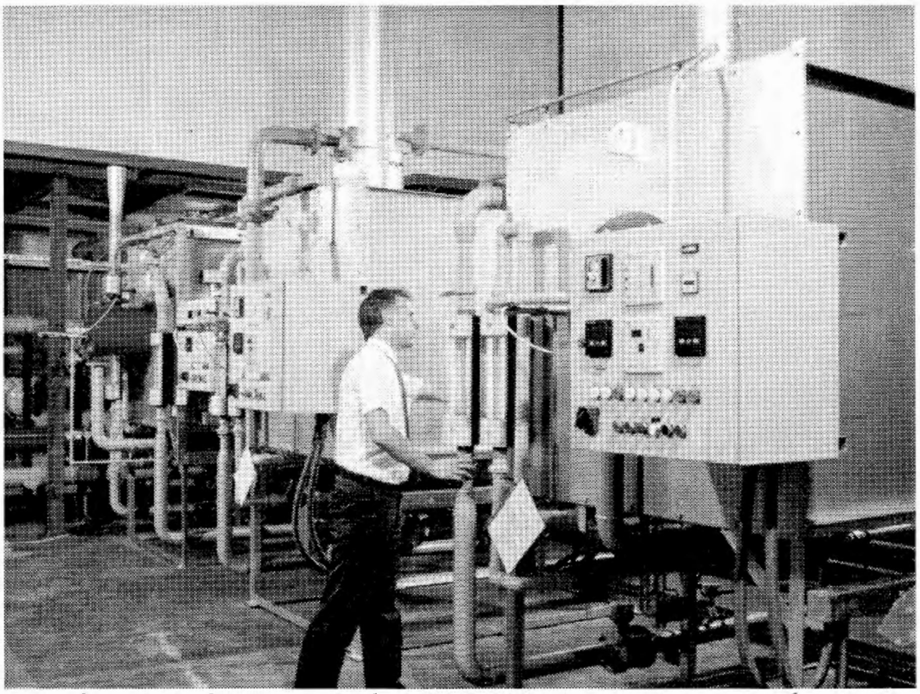

Fig. 6.25 Rigs for testing electronic air/gas ratio control systems (ERC) and various furnace atmosphere control systems.

Mention should also be made of "Mathilda", an instrument for logging gas loads and for energy management in customers premises. It incorporated a portable programmable calculator for easy downloading of data, and although soon overtaken by the availability of commercially produced instruments, it performed valuable service for Regional Engineers in the early 80's.

Another feature of the 80's was the increasing popularity of programmable electronic systems (PES's) in conjunction with burner systems. This gave anxiety about their potential failure modes in safety critical applications, and led to the introduction of "SaM", an independent safety monitor, which can act as a watchdog on the safety critical outputs from the PES.

Hazards Research in the 80's

A major event in 1982 was the decision to hold a Public Inquiry into the continued operation of the Methane Terminal at Canvey Island, following on from the HSE publishing a reassessment of their 1978 study of the risks. MRS was involved in providing evidence on the consequences of various projected gas and liquid releases, backed up by experimental and theoretical studies. The effort was coordinated by Dave Lucas, who also led the team briefing the Counsel for British Gas at the Inquiry, Andrew Rankin Q.C. and Michael Howard Q.C. (later a Cabinet Minister). The outcome of the Inquiry was that the risks of continued operation were regarded as acceptable, and it also reinforced the importance of hazard studies and risk analysis.

A second major event was the Piper Alpha offshore platform disaster in July 1988, the implications of which impacted on British Gas as a significant offshore operator. The incident threw the spotlight on consequences of flammable releases in the very congested conditions on production platforms. Fortunately, good relationships had already been established with the Exploration and Gas Production functions as part of a deliberate attempt to diversify MRS activity into other areas as the effort on SNG was planned to run down in the late 80's. A programme of work was started involving theoretical and wind tunnel studies together with explosion experiments at Spadeadam on representations of offshore modules, with ERS contributing studies of structure response. The results were fed into a new hazard assessment package called CHAOS (Consequence and hazard assessment of Offshore Structures), and several recommendations were made for mitigation of risks.

Following the Cullen Report on Piper Alpha, and the need for offshore safety cases to be made, this area of work is continuing to be of great significance for R and T. The strong position of MRS in this field was recognised by the Dept. of Energy placing a contract for an expert review of the offshore explosion problem.

Fig. 6.26 20m dia. LNG pool fire at Spadeadam.

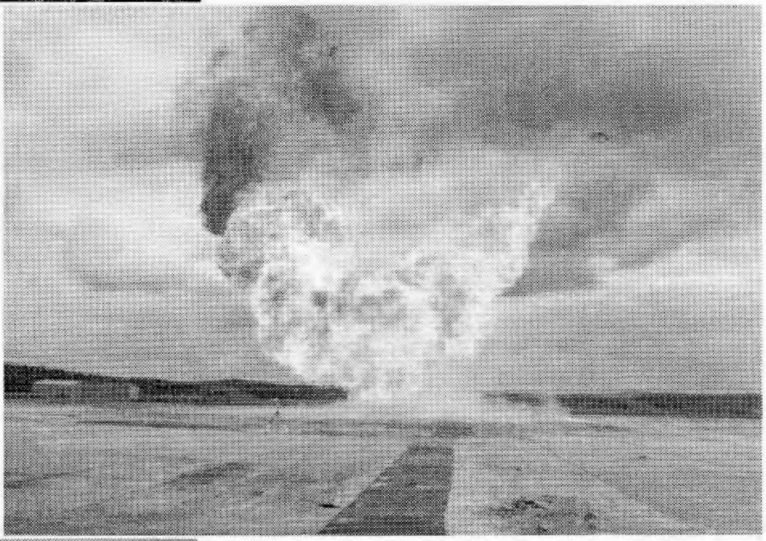

Fig. 6.27 High pressure pipeline fire. Double ended crater release.

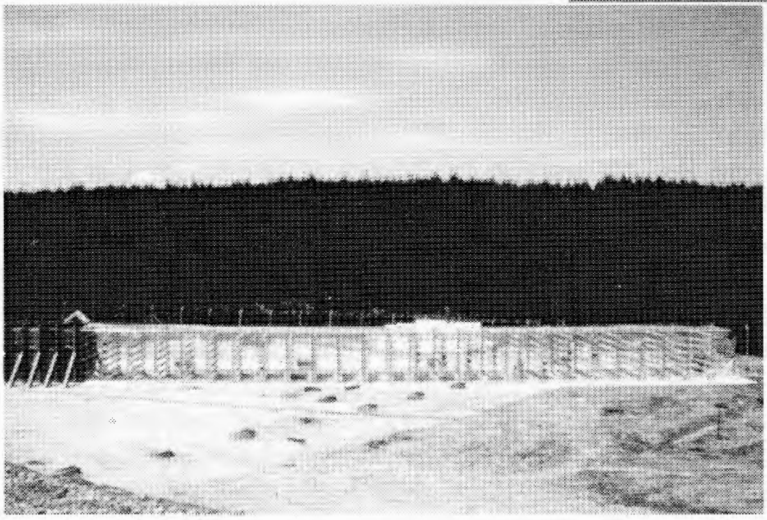

Fig. 6.28 VCE rig at Spadeadam, showing a confined ignition chamber at the left followed by the "unconfined" section with repeated obstacles to simulate the effect of congested plant.

In the hazards research generally, the pattern in the 80's was one of experiments on an increasing scale on fires, explosions and dispersion (Figs. 6.26, 6.27 and 6.28); because of the expense, inter-company and international cooperation became almost essential for the largest tests, even though MRS may have been the operating contractor and Spadeadam often the test site A good example was the collaboration between British Gas, Shell and Elf Aquitaine in conducting 6 and 10m diameter LNG pool fire tests. This led on in 1987 to a consortium of 6 companies staging the largest LNG pool fires ever attempted, 35m diameter, at Montoir in France, with MRS measuring the fire characteristics. The new data was fed into improved predictive models.

By the mid 80's, after nearly 10 years of effort, the work on vapour cloud explosions had at last yielded a good understanding of the mechanism of high overpressure production. It had become clear from the early work that strictly unconfined conditions did not produce high flame speeds and pressures, and that some degree of confinement or plant congestion was a characteristic of known incidents. The definitive experiments were carried out at Fauld in a 3mx3mx45m long polythene covered enclosure in which repeated obstacles, simulating pipe racks, gave rise to flame acceleration to about 600m/s and pressures high enough to eventually destroy the rig, necessitating a move to Spadeadam (Fig. 6.29). It was found that natural gas needed severe congestion to produce these high flame speeds, whilst cyclohexane or propane could readily exhibit detonation under less severe conditions.

Fig. 6.29 Result of a particularly violent VCE in the rig at Fauld. The work was transferred to Spadeadam forthwith.

The results eventually enabled useful recommendations to be made on plant layout and design to reduce the risk of major incidents, and modified the overpressure calculation method for natural gas releases which greatly diminishes the perceived risk and in many cases allow vapour cloud explosions to be discounted. A paper describing this work by Bob Harris and Malcolm Wickens in 1989 gained them the Institution of Gas Engineers Gold Medal.

Gas dispersion studies were aided by the deployment of a unique measurement tool - LIDAR (LIght Detection And Ranging) using the Raman scattering of a powerful pulsed laser beam for remote measurement of methane concentrations in experimental or operational gas releases (Fig. 6.30). This was first used in 1983 and later further improved in accuracy and facility of use by better data acquisition and processing. Natural gas concentrations down to 1% at distances of 50-1000m can be measured with a spatial resolution of about 1.5m. The possibility of extending the technique to measuring ppm levels of toxic gases using the differential absorption Lidar (DIAL) method is currently being pursued.

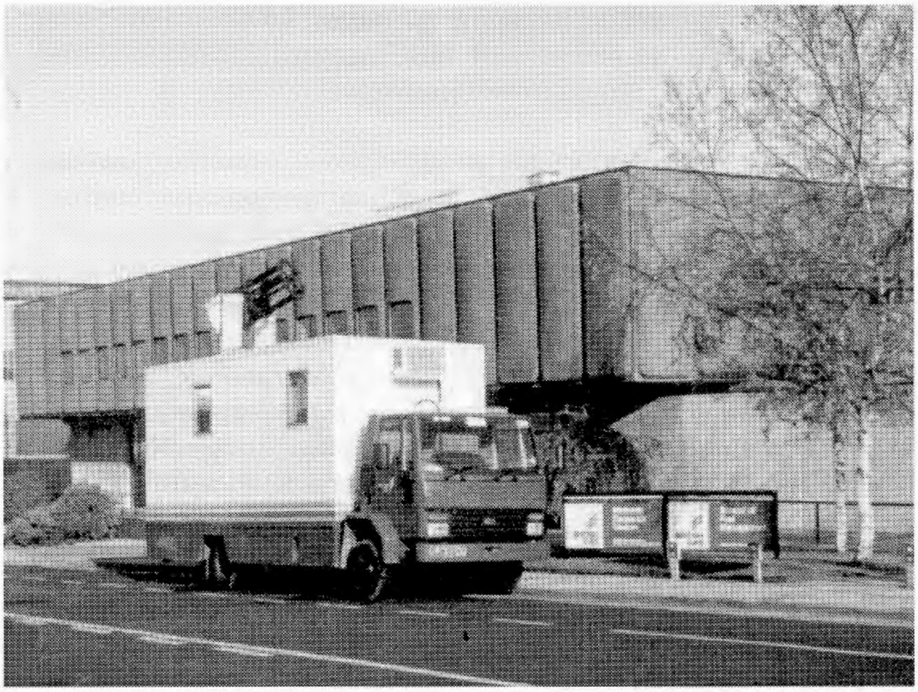

Fig. 6.30 LIDAR for remote measurement of gas dispersion. The LIDAR vehicle with telescope extended outside MRS.

Physical modelling of both fires and gas dispersion was helped by the building of an environmental wind tunnel at Fauld(Fig. 6.31). Previously, large scale wind tunnel studies had to be contracted out, as for example the work at the National Maritime Institute (NMI) simulating dispersion of an LNG spill at the Canvey Island Terminal, carried out for the Public Inquiry.

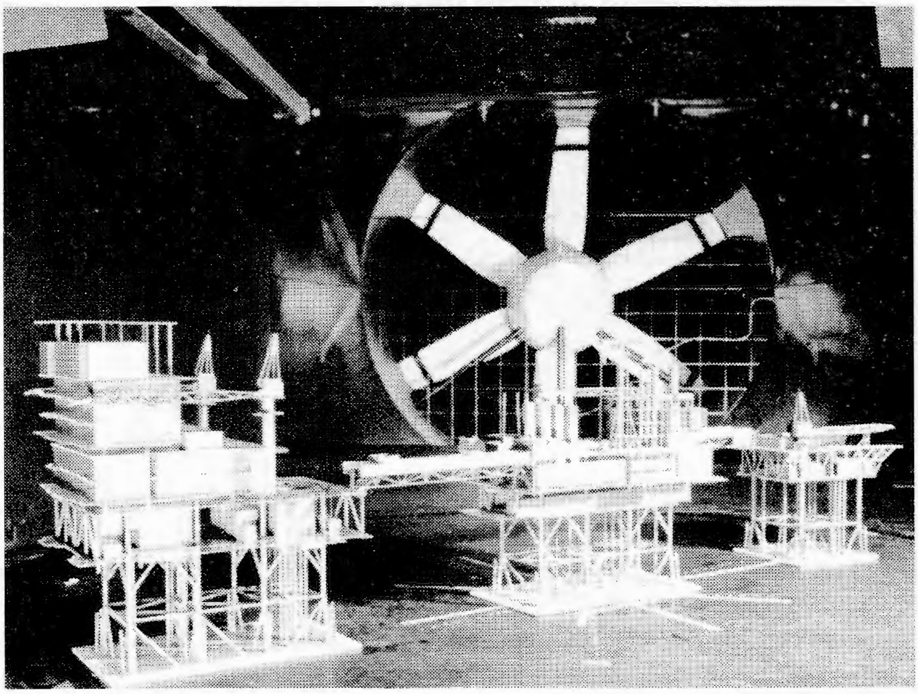

Fig. 6.31 1:100 Scale model of the Rough B complex in the wind tunnel at Fauld.

The increasing need for producing safety cases, substantially enhanced by the impact of the CIMAH Regulations (Control of Industrial Major Hazards) in 1984, has led to the production of a whole series of user friendly computer packages for predicting consequences of releases. This was made easier by the advent of powerful desktop PC's and workstations. As with the CHAOS package, these could be linked in to plant CAD and process models.

The availability of greater computing power also meant that predictive models could be more fundamentally based on numerical solutions of the underlying fluid dynamic equations. At present these Computational Fluid Dynamic (CFD) models, because of the computer power and run time requirements, may remain as research tools.

Process Automation

The expertise on process automation and safety analysis, gained by Controls Division work on the MRS plants and at Granton, was increasingly deployed in other British Gas plant activities. The performance of pre-purification units at LNG liquefaction plants was improved by the provision of microcomputer control coupled with mathematical modelling of the absorption process, the first system being commissioned at Avonmouth in 1988.

MRS also played a significant role in a cooperative venture to apply expert systems to the real time control of chemical process plants. This came out of the ALVEY initiative and led in 1987 to the setting up of COGSYS (for COGnitive SYStems), a club of 35 industrial sponsors for the building and demonstration of a fully engineered real time system for general process application. One of the two demonstrations was on the methanation gas production plant at MRS. The system is now being commercially exploited by a new Company, COGSYS Ltd., part jointly owned by British Gas, Salford University and SD-Scicon Ltd.

Direct help for plant operation was provided by studying techniques of alarm handling, in an attempt to avoid the "Three Mile Island" situation of the operators being swamped with information at critical times. This work has culminated in the development of LORA (LOgical Reduction of Alarms), a suite of programs designed to present operators with an uncluttered and filtered view of the alarm status of the plant, showing only those alarms which are important at a given time.

Prepurification and Packed Bed Absorption

The work on prepurification of natural gas by absorption of unwanted components in packed beds had been started in the 70's as a service to LNG liquefaction plants by John Templeman and Roger Wyatt. During the 80's the expertise on absorption has paid off handsomely as it has been used on LNG plants to uprate existing installations to cope with gradually increasing carbon dioxide levels in the incoming gas,and so avoid further capital expenditure on new plant. The efficiency of absorption and bed regeneration has also been increased through a better understanding of the processes.

Support was given to P and S Division for an uprating of the plant at Easington Terminal for the control of the hydrocarbon dewpoint of the gas coming from the Rough Storage Field. As a result of modifications stemming from the MRS work, the plant is now capable of processing three times the original design gas volumes, with greater efficiency of fuel usage. Absorption has also been chosen for new dehydration plant for the Hornsea salt cavity storage facility.

The mathematical models developed for absorption, regeneration and process optimisation are now incorporated in a design package called ADAPT (Advanced Development of Adsorption Process Technology). Over the last few years this technology has saved British Gas costs amounting to tens of millions of pounds.

HISTORY OF MRS

PART 2: Personalities and Perceptions

The progress and achievements of the Station are the result of the efforts of the many hundreds of people who have made contributions over the forty or so years of its existence. However, some of the more senior people involved in the management of the Station have had a more significant impact. Pen-pictures of some of these are set out in this part of the history, together with some very personal perceptions of events and personalities largely in the contributors own words. There is perhaps a bias towards the founders of the Station, especially those now retired.

Chapter 7

The Founders

Chapter 7

The Founders

Dr. F.J.Dent O.B.E., F.R.S.

Fred Dent's ideas on gasification dominated the first 15 years of the Station's existence (Fig. 7.1). It is difficult to do justice to his career and achievements in the short space available here and the reader is referred for a more thorough account to the excellent Royal Society Memoir by Sir Kenneth Hutchison FRS and Dennis Hebden (Biographical Memoirs of Fellows of the Royal Society, 20 (1974)). There is also Dr. Dent's own account of his experiences in gasification research in the Melchett Lecture for 1965 published in J. Inst. Fuel, May 1966.

Fig. 7.1 Dr. Frederick James Dent, Director of MRS until 1967.

Some idea of Fred Dent's character and of the experience of working with him may be gained from the following extract from the "Memoir", written by Leo Moignard.

"In his professional life, Dent was dominated by the ambition to understand the gasification and hydrogenation of coal and, after the mid-fifties, of oil as well and, on the basis of this, to design viable gas-making processes. He was too unassuming to seek authority for its own sake, but realistic enough to know that he needed command of substantial resources to gratify his ambition. Accordingly the sequence of appointments, and the recognition that he did secure in research, gave him deep satisfaction. He often referred to the generosity of the financial support which he had received throughout his career; he had had a"fairy godmother" in the gas industry.

"It followed from this approach to his tasks that, from first to last, he was wedded to science and technology. He was a remarkable example of a man who remained outstandingly productive until he retired: he was nearly 60 when the patent application for the most advanced form of his invention of a fluidised-bed oil hydrogenation process was filed. He was convinced that in the last analysis the wellbeing and reputation of his Research Station, and of its people, depended solely on its fertility in research and development results, and he never tired of impressing this on his staff. He made no moves towards the administrative or managerial kind of scientific life and indeed was impatient of administration in most of its forms. The minimum, in terms of staff recruitment, financial control and similar matters, was done, and as much as possible was delegated to his senior staff. For similar reasons, he played little or no part in the work of the professional institutions.

"Dent was richly endowed with intuitive perception into the cause of observed events which were, for him, the foundation of all technical progress: observations were the one thing which no practising scientist could ever afford to neglect, and should make personally. He was never happier than when in the laboratories, giving enthusiastic and detailed instructions for experiments to be performed and then waiting, rather impatiently, and fervent with speculation, for the outcome. Facts, once established, were accepted and the challenge then was to incorporate them into the speculation which underlay the next conceptual adventure. He never ceased to regret the need to delegate practical work, and indeed was a man whose practical skills (which he put to good use in his hobbies) matched his exceptional intellect. With a tinge of resentment, he would remark that an outstanding surgeon was not expected to sit in an office while lesser surgeons did the operations!

"Insofar as he thought about staff organisation at all, it was this outlook which led him to prefer a radial to a hierarchical type of structure. He liked all his men, above the level of assistant, to report to him personally, and had this been truly workable, great benefit would have accrued from the influence of his personal teaching spreading more widely than it did. Some time elapsed before he accepted that to work by this method would limit the Research Station to a size at which it would be unequal to its tasks, but he always regretted the need to delegate the direction of research and would complain that the Station was getting too large.

" He was convinced of the importance of training minds to be capable of appreciating the significance of good observations. His was a receptive mind, powerfully capable of original thought, quite unabashed at challenging the "conventional wisdom" of the moment, and well able to lead and inspire the men who worked with him, some for many years. To engage in a technical discussion with Dent was a salutary and even humbling experience, because of the breadth of his knowledge, his command of the experimental results and the intricacy and perceptiveness of the reasoning with which he interpreted them. It was notable that his imagination was most acute in the physically visual sense rather than in the vein of pure ideas. It was the thinking of a particularly gifted engineer, even when the subject was chemistry or physics.

"He exploited these gifts with an outstanding capacity for hard, rapid and effective work. The needs of the hour dictated his daily schedule: a harassed and tired member of his staff once remarked that Dent's best results were always obtained at two in the morning; but Dent would be there to see them emerge. He supported the results of experiments with detailed and exhaustive analyses of the material and thermal aspects of process steps, filling notebook after notebook with numerical calculations. He accustomed himself to this practice as a young man,in the days before computers or even serious mechanical calculators were available. To watch him solve five simultaneous equations, eventually by trial and error, using twelve significant figure numbers, by long division and multiplication, at high speeds without mistakes, was an impressive experience. In our family circle, a "Freddy calculation" is the name of the cool arithmetical operation which upsets the heady guesses of the enthusiastic speculator.

"He made serious demands of his staff in terms of energy, industry, time and application, but never of a kind that he was unwilling to supply himself. In this sense, as in others, he was an exceptional leader, whose influence by example was often decisive when the tired and disheartened troops would waver in the face of yet another breakdown or setback. In other senses, he expected much less-as regards intellect, for instance, or originality. These he knew he could supply; it was enough for him that a man should work with single-minded devotion to the need of the development in hand. He would forgive almost anything but laziness or indifference, and would give more credit than was often deserved to those who had diligently helped him, with dedication, to see the work through. He was anxious for the welfare of his staff, not only in the material sense, and particularly in ensuring that they had opportunity to work at a productive topic.

"In work with Dent, excitement was never lacking; if there was disappointment today, something would be thought up leading to the prospect of good news tomorrow. But periods of comparative calm would alternate with times when he felt that results were not forthcoming quickly enough, and there would ensue a tempestuous period when frantic efforts were made to retrieve the situation or fill up a pitfall that had suddenly appeared at our feet.

"When the time came to prepare work for publication Dent brought to the task a masterly command of English; his scientific and technical writing was a model of conciseness, clarity and accuracy. This quality was not easily achieved; he took immense pains over writing and the final product was often the result of several revisions, argued over at length with members of his staff."

Dr. D. Hebden O.B.E.

Dennis Hebden (Fig. 7.2) joined Dr.F.J.Dent as a research student at the University of Leeds in 1941, being awarded his Ph.D in 1945. He moved to Poole in 1944 as one of Dr. Dent's newly formed Gas Research Board team, where he worked on many of the pilot plant studies, including coal hydrogenation, methane synthesis and the breakage of coke. After the take over by the Gas Council he was involved in the Lurgi plant trials at Nechells, hydrogenation of oil at Poole and after 1955 particularly in the slagging gasifier programme at Solihull. He was appointed Assistant Director in 1963. In 1966 he moved to R and D HQ in a Coordinators role, but was soon mainly concerned with the SNG Programme, becoming Programme Director. He was one of the team to receive the MacRobert Award in 1971, was elected F.Eng in 1978, awarded the OBE in 1979 for services to R and D in the Gas Industry and the Birmingham Medal by the IGE in 1981. He retired in the same year to live at Wareham near the shores of Poole Harbour, where he has been able to indulge in his lifetime interest in sailing.He has contributed the following reminiscences of his career in gas research.


Fig. 7.2 Dr. Dennis Hebden outside the Palace after receiving the O.B.E.

"After about 18 months of uncertainty following the nationalisation of the Gas Industry, Col. Harold Smith, then Deputy Chairman of the Gas Council, came to Poole in the Summer of 1951 to advise us individually that they were taking over the Gas Research Board and that no staff would be "thrown onto the street". Those who wished to go and join Dr. Dent in Birmingham to establish a new research station would receive every assistance to make the move. I, later to be joined by Ron Edge, was the first to move and was provided with a desk in Bob Cockerham's office on the top floor of the Central Laboratories at Nechells.

"Between 1952 and 1954 we constructed and operated the experimental high pressure steam/oxygen gasifier on the Duddeston Mill Road pipe storage site, adjacent to Nechells Gasworks. During this period I commuted weekly between Poole and Birmingham, living in various hotels, guest houses and digs. Bob and Barbara Cockerham provided me with some excellent accommodation for a spell until an increase in their family necessitated my moving on. Bob also suffered my setting up a camp bed in his office for a time for use during plant runs. Leo Moignard shared two memorable digs with me, the first landlady had a phobia about electricity consumption, insisting on lights out by 10 pm. The second, in Bearwood, was a homely soul with a gay son and friend, two pleasant lads who, we understood, made up the front and rear ends of a cow during the pantomime season. Leo moved house sooner than I, who was restrained by selling regulations on a new house in Lilliput. There was also a lack of enthusiasm for exchanging Poole Harbour for Nechells Gasworks and commuting was becoming a habit. The family eventually moved into 81 Silhill Hall Road, Solihull, in August 1954, an event in which I took little part, having grabbed a table and chair off the removal van on its arrival and retired to the attic to continue work on a paper for the Autumn Research Meeting [GC14]. N0. 81 was a good family home with a big garden and a large playroom attic. They say "new house - new baby" - or was it commuting ? - but one year later No. 2 son arrived.

"During 1954-55 time was mainly occupied in re-erecting the gasifier from Nechells in the new "Chem Eng Block" and installing alongside it the experimental slagging gasifier. Also work had been continuing under Dr. Frank Wood at Poole where a 0.5 ton/day fluidised bed coal hydrogenator was being converted to operate on oil. In October 1955 Dr. Dent asked me to take over from Frank and return to Poole - a proposition which puzzled the family who had so recently been uprooted from there. While back to commuting it was not as frequently as previously, the plant turn-rounds being well organised by Alan Yarwood and Les Jones. On 10th April 1956 P. S. Murthy joined us direct from India - literally. He landed in this country, spent a couple of days at Solihull and was then packed off to Poole. He took the cultural shock with stoicism, accepting without comment the twelve-hour shifts and bunking up in the old laboratory stores which he had turned into a dormitory. He turned out to be a brilliant asset to our team, going on later to make major contributions to the development of the gas recycle and fluidised bed hydrogenator programmes.

"The work at Poole coincided with the Suez Crisis and petrol rationing. To supplement our ration for the Solihull/Poole car trips, Jim Buckley used to run some stills in the laboratory to separate benzene from the aromatic hydrogenation condensate. This high grade benzene was mixed 50/50 with petrol and performed excellently in a Standard 8. We tried using light distillate and benzene but this was not a success - all highly illegal of course! The Poole plant was finally shut down in March 1957 and the workshop disbanded in May.

"Shortly after completing the first slagger programme in June 1958 I was fortunate to accompany Dr. Dent on a visit to the USA primarily to attend a Gordon Conference on Coal Science and Utilisation. One highlight was that we travelled out to the States first class on the Queen Mary, each of us in our own stateroom with our own personal steward. Soon after leaving Southampton Dr. Dent received a sheaf of congratulatory telegrams - that morning his name had appeared in the Birthday Honours List as a recipient of the OBE - we duly celebrated. The Conference was notable in retrospect by the freedom with which information was exchanged - very different from later years when commercial security changed all that. We met and made many friends on that trip, most of whom have now passed on into history; not least Martin Elliott who died only recently and Reichel, then of Pittsburg Consolidated, later of Conoco and who kept in touch with Westfield, I believe. The return trip contrasted unfavourably with that on the QM - an 11 hour flight at under 19,000 ft from Idlewilde to London in a Constellation with a severe case of tail wag. I was met by the family who scoffed at my American-style bow tie and insisted on a trip on the Thames and a visit to the Cutty Sark.

"The next two or three years were occupied with process studies, designing and building divers pilot plants, not least trying to get the next experimental slagging gasifier project approved. Oil processes, however, took priority and we were having problems running all the plants, models etc which we were building. Indeed the first

GRH pilot unit was completed and ready to start up several weeks before the staff could be made available to operate. it. However, not long after the first results were available from that plant, Mr. Chester, Chairman of the SWGB, ordered a unit to enrich ICI reformer lean gas at Avonmouth. While the first order for a GRH was placed in the UK, the first to be commissioned was in Hanover. Indeed the first commercial CRG plant was destined to start up at the Toyosu Works of the Tokyo Gas Company. The first, admittedly semi-commercial, FBH unit was also built abroad, by Osaka Gas. Will the first commercial BG/Lurgi slagging gasification plant be built in the USA ?

"Among the pilot plants being built was of course the 20 atm slagging gasifier. With much outside interest from the Ministry and on recommendations in the Wilson Committee Report on Coal Derivatives, the Gas Council was encouraged to proceed with the project and allocated over £0.5 mill. However, delays arose for one reason or another, mostly political and while we had already completed all the preliminary designs of the gasifier and specified the auxiliary plant it was not until late January 1961 that the order for the construction work was placed with Woodall-Duckham. At about this time John Lacey joined me and took most of the management of the project off my back, and we eventually got the plant away for its first run in March 1962. I recall the "slagger" days as quite exciting, and with a grass roots plant, a pleasant change from the "shoe string" and primitive conditions we had had to cope with on the oil hydrogenator plant at Poole. It was a good team on which many of the gas production section substituted from time to time and we had noble support from Derek Mitchell's workshop fitters. The experience John Anderson gained on the project proved invaluable when we went to take over and convert the Lurgi plant at Westfield to slagging operation and successfully complete our contract with the US sponsors.

"Apart from the engineering work I spent much time at Dr. Dent's elbow carrying out innumerable calculations analysing CRG, GRH and FBH process routes. Until the computer arrived at Aston University (or College of Technology ?) calculations were done long-hand with bi-quadratic equations being solved by trial and error. Often square roots had to be calculated by the classical long-hand method to thirteen or more places in order to determine significant but small differences. Our only aid was the old Brunsviga which had come originally from Leeds and which I learnt to operate by touch. With Hilde Roughton's (later Mrs. Toth) and the Aston computer's help this all changed; equilibrium gas composition calculations which had once each taken 1 to 2 hours to do were done in the time it took to type out the result. Dr. Dent, while overjoyed at the relief from mathematical marathons, was not interested in pursuing the computer's capabilities further as a process analysis tool. He preferred a 'hands on' approach to maintain close contact with all the factors which would influence process or reaction steps and the end results.

"I consider myself as most fortunate and privileged in having been a student under Dr. Dent and subsequently having worked with him over a period of 25 years and enjoyed his and his family's company for over 30 years. Our common interest in sailing, to which I introduced him on Poole Park in 1944, when with Dr. W. H. Blackburn we were commissioning the static bed coal hydrogenation plant at Pitwines Works, was a major bond between us. Often in the midst of some discussion on budgets, contractor problems or similar mundane subjects he would divert into talk about some contemplated modification to "Blue Jay", his Albert Strange ketch. Bought in 1947 he renovated her while we were still at Poole and continued with modifications after the move to Solihull. He built a new mizzen mast, gluing its box construction in his lounge at home in "Cora Lynn" and then shaping and planing it in the "Giraffe Room" in the Chem Eng block on the Station. He did all his own work on the boat; he was an accomplished craftsman with unbounded patience and attention to detail. He sailed in the Western Channel visiting Brittany, the Channel Islands and the West Country. A day after he departed from MRS in 1967 he sailed with a local couple from Cobb's yard at Hamworthy and headed for Spain where Jean joined him in Vigo. They sailed on into the Med. where they cruised for the next six years from their base in Malta, where he died after a brief illness in October 1973.

"Although on leaving Dent expressed some disappointment that due to the advent of natural gas, his processes were not going to realise the future he had hoped for them, he lived to hear about the success of the CRG process for SNG production in the USA and of the world-wide interest in his other processes. He made only two visits back to the UK, one to receive the Birmingham Medal in 1968 and the other to receive the MacRobert Award in 1971.

"In the two years before Dr. Dent retired, commercial CRG and GRH plants were being installed at home and abroad, and I became heavily involved in working with the contractors on flowsheet and reactor designs and later in acting as a consultant and witness at the commissioning of plants. The first CRG plant was one built in nine months by H&G/Hitachi at the Toyosu works of Tokyo Gas and I attended its start-up in company with Malcolm Wesley. The first GRH start-up was at Hanover which I attended with Brian Thompson - his first trip abroad. Both gave us testing problems which we solved on the spot with the minimum of delay to the plants which passed their guarantees on schedule without penalty. It was all very interesting and challenging but the future of gas production R&D looked bleak; even the commercial outlook seemed certain to be limited. In 1966, knowing he was going to retire the following year, I discussed my future with Dr. Dent and intimated that I would like to seek fresh fields. Later I had a proposal from Sir Kenneth Hutchison, then Deputy Chairman of Gas Council that I should join G.U. Hopton who had been given the task of setting up a centre for administering the Gas Council's R&D programme. Shortly after I arrived at 199 Knightsbridge, Hutchison told me that my first job was to see that all the new CRG plants went away successfully and I was to call on LRS for commissioning teams to support the operation. Although now living in Guildford I was to remain closely involved with MRS not only in connection with the commercial CRG plants but also other projects involving the Contractors' Club. During a brief lull in activity around 1968-70 I reluctantly got involved with administration matters but with the support of MRS we managed to keep the CRG programme alive through the SNG Working Party and were well prepared to meet the demand from the USA for processes to produce SNG.

"From 1970 until I retired in 1981 I was back working closely with MRS firstly in connection with the promotion of the CRG SNG processes in the USA and with the subsequent technical support to the licensees and operators, secondly in seeking opportunities for our other processes and finally in getting sponsorship for the development of the slagging gasifier at Westfield. Westfield was a marvellous opportunity to get back to the hardware and finally to escape from "co-ordination". There was an enthusiastic team at Westfield managed by Jim Scott but led by Terry Brooks, a man similar in many ways to Dr. Dent and almost as talented. I was very fortunate to see my time out at Westfield and take part in the final confirmation of the gasifer's capabilities. I was always delighted to hear about its subsequent progress and hope some day to hear, if not see, the first full scale integrated commercial plant."

Dr W.A.Simmonds

Bill Simmonds (Fig. 7.3) studied Physics at University College, London and started his career by carrying out research for the Ministry of Defence on blast and fragmentation effects of bombs and shells. In 1947 he joined the Gas Research Board, taking charge of a group working in London on domestic utilisation of gas. It is a tribute to his qualities of leadership that he managed to get useful work out of a small group of talented but rather eccentric people, while having to cope with a series of moves from one unsuitable location to another.

Fig. 7.3 Dr W.A. Simmonds speaking on his retirement in 1982.

As well as supervising the utilisation work, Bill was also running his own project, which was measuring the wind loadings on spirally guided gasholders. This was a unique piece of work which involved building a hut on top of a gasholder at Brentwood, Essex, in which the pressures developed by dozens of pitot tubes were recorded. Very few experimental measurements had ever been taken on structures of this size and Bill was later awarded an external Ph.D by the University of London for this work.

In 1952, after the take over of the GRB by the Gas Council, Bill had to start again from scratch in an entirely new field, that of industrial utilisation. It is typical of the way that Bill went about the task, in that he very soon forged very good personal relationships with the senior staff of the West Midlands Area Board Industrial Department, and through his membership of the Industrial Gas Development Committee (Fig. 7.4), with the Industrial Managers of the other Area Boards. This enabled an insight into the nature of the technology and the problems of the industrial market which in those days had its centre in the West Midlands.

Fig. 7.4 The Industrial Gas Development Committee on a visit to Watson House, probably in the late 50s or early 60s. Among those present, from left to right in the back row, Arthur Higgs (WMGB), Roy Hayman (Industrial Gas Officer, Gas Council), Bill Simmonds, Leslie Andrew (Director ,Watson House), E.A.K.Patrick (WAtson House, later Director), Walter Howell NWGB). In the front row at far left, Gwyn Thomas (EGB), at far right Aubrey Lloyd-Dodd (SGB, later Industrial Sales Manager, Marketing Division HQ and one of MRS principal contacts)and fifth from left Bill Tarn (Wales GB).

It was a hard struggle to build up a team at a time when the Gas Industry was not highly regarded as a career prospect and when the overwhelming priority of the Station was the gas production research. However there were sufficient achievements in industrial utilisation research for this to be concentrated at Solihull in 1964, with Bill as Director of Industrial Research; up until that time there had been a separate industrial research group at Watson House.

Bill's recruiting policy at that time included taking on female staff, mostly as assistants, and who by chance happened to be sufficiently attractive to result in several marriages to the male graduate staff; the effect was that there were strong incentives for those graduates to stay at MRS, and some were still on the strength when MRS ceased to be a separate entity.

In the mid 60s, a new factor emerged in the shape of methane importation as LNG. Bill was quick to see the potential for direct use of methane, and built a laboratory at the Coleshill Works of the WMGB where the spur main terminated which supplied methane for reformer gas enrichment. Again typical of Bill's methods, he was on very good terms with the local Area Board Engineering staff and chatted up the Manager of the Coleshill Works to acquire a piece of land for the new lab. This action meant that before any of the North Sea gas discoveries, MRS was examining the characteristics of industrial burners on natural gas. Consequently, when it became clear that a large scale conversion exercise was likely, Bill was able to demonstrate to a large number of the industrial engineers the inadequacy of their favourite burners on natural gas. This early awareness may have contributed significantly to the smooth progress of conversion on the industrial side.

When Bill was appointed Director in 1967 he had the brief of unifying the Station and concentrating its efforts on natural gas exploitation. This involved persuading many of the staff to transfer from production to entirely new work on the industrial side. It is a tribute to Bill's ability to deal with people that this was achieved with a minimum of problems and few, if any, losses of key staff.

Much of the eventual appearance of the Station was owed to Bill's efforts around this time. He felt that it was not necessary for the Station to look like the back yard of an oil refinery, with all the pipe bridges and other plant excrescences, and the run down in production gave him the opportunity to sweep these away together with a number of temporary buildings. These were eventually replaced by Brindley, Darby, Murdoch and Telford; it was also his idea to name them after eminent British Engineers, mostly connected with gas or energy in some way.

Though normally showing an urbane and unflappable demeanour, when provoked, Bill could be very forthright, especially with certain groups of people which he held in no great regard. In no particular order of demerit, one may list accountants, full time Trade Union officials, chemists, most Headquarters people and of course Personnel. Nevertheless he remained on good terms with almost everyone he met and was very approachable by people at all levels in the Station. He always seemed able to find time to listen to people with difficulties and gave real help in cases where there were domestic or other personal problems.

It is difficult to understand how Bill found the energy not only to cope with the problems of running the Station, but but also to be actively involved with important outside interests including prominent positions in the Institute of Energy, becoming President in 1979/80. Another of his lifelong interests has been in the Scout movement, culminating in a position as County Commissioner for Solihull, being awarded the Silver Acorn for "specially distinguished service" in 1982. Scouting was a family tradition, since his father was also a County Commissioner and his wife Betty, County Secretary, received the Medal of Merit.

In 1982, Bill was elected to the Fellowship of Engineering. He has contributed the following personal reminiscences.

Memories of MRS - W.A.Simmonds

An occasion which was amusing in hindsight, although not at the time, was a strike called by NALGO. There was a dispute within the Gas Board (as it was then) about which we knew little at the Research Station. One branch of NALGO covered the Board and us (despite the fact that we were a Headquarters outfit). This dispute boiled up into a strike, which in those days could be called suddenly. The first that MRS knew about it was when two Committee Members of the Union came into my office and told me there was to be a strike and that they had looked round the Station, concluded that there were no safety hazards, and that we could be shut down completely with no maintenance staff on duty. I said "Just hang on a minute while I write that down", and started to do this. After a while one of them asked what I was doing. I told them that I was writing down exactly what they had said and then we would all three sign and date the statement. What is the point of that?" they asked. "Well", I said, "at an Inquest I can produce it for the Coroner". Without a word they got up and walked out. Actually, the hazard was considerable in view of the size and nature of our pilot plants, two of which were running at the time. Twenty minutes later, three of my own staff knocked at the door and said "Could they come in and discuss arrangements for putting the pilot plants on standby, and for staffing during the strike". They were, if anything, even more relieved than I was that they could deal with the safety of their plants.

During the same strike we had to pass a picket to get to the Research Station. For many years I had played cricket for the Board Cricket Club but had given up (due to old age!) about two years before this event. Going home past the picket one evening, I saw a member of the team amongst the picket, so I pulled over to the kerb about 25 yards past the picket, and this friend came over, and we started talking about members of the team and his young son — who used to come to many of the matches, so I knew him quite well—most of whom I had not seen for two years. At this point his minder, who was 6'6" tall and weighed about 16 stone came strolling over with a very belligerent look on his face. I can still see the look of disgust on his face when he realised the kind of conversation that we were having.

Another amusing incident has remained in my mind. Every year there used to be a meeting of the Chairman with the General Secretaries of the major Trade Unions in the industry. This was followed by lunch and a tour. One year the tour was to the then WMGB and MRS. Consequently I was invited to the lunch. The Secretary I was sitting next to (and I honestly don't know his name) turned to me and very condescendingly said "What are your problems, my man?" No-one likes being patronised and I could hear the missing words "trivial" problems and "my little man". So I said "I don't think you would like to hear them". In retrospect that was a mistake because he could not resist making sure that he heard my answer. I gave in and told him that I had two problems with regard to industrial utilisation research. The first was with managements of industrial firms who were very interested in our work and keen to see it succeed and to take advantage of it as long as they were the second firm to try it but were not prepared to be the first. The second problem was the shop floor who were not prepared to accept any change at all. Whereupon he turned to talk to the chap on his other side and never spoke to me again. Yet what I had said (and remember that this applies some time ago—say in the mid and late sixties) was accurate, although fortunately it did not apply to all firms, only to a large majority.

When the two parts of MRS were combined into one in 1967, the original remit to me from the Research Committee was to run down the work on gas manufacture because of the impact of natural gas. Whilst there was some sense in this at the time, the remit was not rescinded until the rundown had reduced the effort to such a level that any more losses would have made it non-viable. The situation was only retrieved by my appealing to the then Member for Production and Supply, Denis Rooke, who went to the Research Committee and got the whole situation changed in the course of just one meeting. The reader will no doubt note the difference between this and our modern Programme Planning system. This at least taught me something which subsequent events wholly justified. It is perhaps appropriate here to point out that one consequence of this run-down is that all of the work on SNG as distinct from town gas, has been carried out by John Lacey and his present team, and considerable credit is due to them for their achievements.

In the mid-50s, as we were moving MRS on to its Solihull site, one of the programmes being worked on was concerned with the design of explosion reliefs for industrial drying ovens. This is a good example of the way that the Factory Inspectorate used to work, and has lessons for HSE. The Factory Inspectorate, by studying accident reports and statistics, determined that an identifiable group of accidents (about 12 deaths per year) occurred from explosions in industrial drying ovens.

These are very common pieces of equipment and most factories have at least one. They are used for drying, curing etc and involve evaporation of flammable solvents, so there is a possibility of explosions whether they are heated by electricity, oil or gas. However, the Factory Inspectorate pointed out that the only people with the expertise in combustion and explosions were the research staff in the gas industry. They persuaded us to carry out the work because, if we did not, then they were going to do it themselves, and asked us to imagine what dreadful restrictions on oven design they might come up with. However that may be, the work was done at Solihull, and was carried out in the coal dump at Solihull Gas Works, because the mounds of coal provided screening for the blowing up of simulated ovens. The screening, however, cannot always have been as effective as we should have liked, because one day, when Peter Cubbage was happily getting on with this work, he looked up to see a lady who lived in the road adjoining the site bearing down on him, brandishing a carving knife from her kitchen and swearing blue murder that she was going to stop these noises. Since Peter is still with us, and still has his head, you may take it that she did not catch him!

Dr.L.A.Moignard

Fig. 7.5 Dr. L.A. Moignard at the retirement of Margaret Wiggins, at one time secretary to Dr. Dent.

Leo Moignard (Fig. 7.5) was born in Jersey, where he attended school, subsequently reading Chemistry at Jesus College, Oxford, going on to gain a D.Phil in 1938. He then joined Dr. Dent's team at Leeds University and then afterwards with the Gas Research Board at Poole, where he worked on many projects but was particularly known for his definitive study on the removal of hydrogen sulphide from town gas using iron oxide.

After the takeover of the GRB by the Gas Council he moved to Nechells in 1953 and to Solihull in 1955. In 1963 he was appointed Assistant Director, looking after much of the smaller scale laboratory work and also administrative matters. He continued as Assistant Director under Bill Simmonds until 1979, when he retired and has since lived in Wensleydale in Yorkshire. The following are his reminiscences of life and work at Solihull.

"The building now named Davy housed the first arrivals on the Solihull site, and Dennis Hebden, Bob Cockerham and I somehow fitted ourselves (with our desks) into the room below Fred Dent's office. Maybe we were known as "The Three Fat Men": we toyed with the idea of an eating competition, but contented ourselves with competitive weighing; strangely, Dennis was always the heaviest.

"Soon we went our several ways and I was left in occupancy of the room. Increasingly, as Fred rightly concentrated on technology, I was led into "management", which included staff recruitment, at first jointly with Bill Simmonds - a difficult activity then, as the public image of the industry was unhelpful, and not encouraged by Fred, who once refused to offer jobs to five young graduates whom we had managed to attract, on the ground that the staff was getting too numerous. At times there were long sessions with Fred, often late into the evenings, when Autumn Meeting and other papers were being written - he liked me to comment on the work as it first flowed, sometimes viscously, off his pen end. He took great trouble over papers for publication. In those distant days, when more copies of a typescript were needed than carbon paper could provide, a secretary would "cut a wax" to be fitted to the roller of a machine which she would turn by hand. A secretary had a right to assume that when a wax was cut the text had reached finality; but not with Fred. He would ask for, and alter, the carbon of a wax. We once had an elaborate and difficult passage to write; Fred could not be satisfied, and when he had amended a page at the "wax" stage for the fourth time he must have felt he could not face his secretary, then Mrs. Lomas, and sent me in with it. She cut my apologies short: "Never mind! One thing is certain: Dr. Dent will never commit suicide - he couldn't keep his mind made up long enough!" So intent was Fred on seeing that his staff got credit for their work - maybe more than they deserved - that he would put their names on papers, even without the formality of telling them, so that the first one man heard of being an author of an Autumn Meeting paper was when the galleys arrived on his desk.

"There were occasional sudden crises. Once I returned from a recruitment trip and, wishing to see Fred, looked into the secretary's office, to find it stripped bare. The incumbent had upset Fred in some way, and had been summarily bundled into a room in the wooden hut across Wharf Lane, accommodation then thought sufficient for such encumbrances as accounts, clerks, secretaries and typists, and all those not engaged in getting "Bloody results".

"The time came when our masters promoted Dennis and myself to be Assistant Directors. Fred summoned us to break the news and said: "They seem to think I need assistance!" - not a wholly welcoming start to new commitments.

"One new responsibility was to take charge of the interests of the Gas Production research team in patents, and this soon developed into my becoming the intermediary between inventors and the Patent Agents employed by the Corporation, an arrangement which persisted until the appointment of an in-house Patent Agent. I dealt with Abel and Imray (No A. or I.), Boult, Wade & Tennant (no B., W. or T), and after a while, when Bill had accepted my offer to act also for the Utilisation side, with Barker, Brettell & Duncan (no B. or B., but a partner related by marriage to D.) I found myself converting inventors' notes, or even discursive and poorly systematised verbal explanations, into reports which could reasonably be offered to Patent Agents and their drafting staffs as raw material to enable them to identify what the alleged invention really was and then to prepare the texts of provisional and later of complete Specifications, and especially of the all-important Claims, an activity which gave plenty of scope to my inveterate tendency to write convoluted sentences of inordinate length, such as are especially to be found in the patent literature, which are not to be confused with structures which are the result of employing the device of cobbling together two (or more) sentences by means of one (or more) colon(s). (I still can, you see.) One morning I had gone to the Surgery to lie quietly under the infra-red lamp while I read "The Official Journal", assuaging an attack of back pain, and was invited by the then Surgery Attendant, Jim Marklew, to try some tablets, for additional relief. I had arranged to see George Percival later in the morning to hear about a CRG development. When he arrived I was beginning to feel a little strange; I listened with all the attention I could muster and soon made what I thought was an intelligent comment, but was concerned to see a look of surprise pass across George's expressive face. I must be a bit cleverer next time, I thought, but a few minutes later when I ventured another remark, George broke off: "No, Leo, its not like that at all!" So I had to explain that I had taken a couple of Marklew's pills and was feeling decidedly woozy. In the hope that I would recover - which I did by the end of the morning - we agreed to meet later. When next I saw Marklew I reported the matter: "Ah!" says he: "that's very interesting. Those are the pills we give to the girls to help with their monthly pains!"

"An instructive activity was the arrangement of visits, sometimes, rewarding, sometimes not. Alas! it is the latter kind that sticks in the memory.

"There were the major events, entailing much preparation (and delay of work), cleaning up, writing brochures, drilling staff, such as that arranged to occupy the afternoon after the lunch to mark the presentation of our first Queen's Award. A large contingent of the great and the good attended the ceremony and the lunch; just four of them came round the Station. Once when the British Association was meeting in Birmingham our arm was twisted to arrange a visit on a Saturday, specially for school teachers, and I had to nominate a good many volunteers. Those who came made no attempt to display interest - any more than did the then Solihull MP., who did not try to conceal the fact that his object in visiting us was to show himself to his constituents.

"Constant scribbling, with much alteration, rearrangement and scissors-and-paste mucking around with texts led to such deterioration of my handwriting that I took to doing the patent work by dictating texts to a tape recorder. This was the occasion of Jean Abbiss's entry on to the MRS scene, as she responded to an advertisement for a secretary accustomed to audio work.

"The opening of the canteen was followed by the catering contractors trying to take over the tea-trolley service, the province of our "cleaning ladies", who obviously preferred purveying tea or coffee to cleaning. We rebelled, by way of thermos flasks: the contractors gave way, saving face by stipulating that there must be no more of people (like me) getting two cups of tea or coffee. Mrs. Smethurst, the dear old soul who looked after Davy Building, got round that. She found an enormous cup which more than provided the accustomed volume. I gather it became known as "Dr. Moignard's chamber pot".

"Fred's concluding years, though happily crowned with brilliant personal successes, were a little overshadowed by the impact of natural gas on the future of production R&D. On his retirement the right decision was made, to redirect the whole Station's effort towards the opportunities that natural gas offered in industrial utilisation, under the leadership of Bill.

"This led to the most marked change in management style that I experienced. Bill was set a difficult task: to close down, or seriously to scale down, activities cherished by the production staff in charge; to lead these folk to take up totally different projects; to overcome the attitudes of misunderstanding or even disdain that had existed between some production and utilisation people; and to introduce a more formal and hierarchical staff structure. He managed to persuade our masters, at the height of the euphoria that natural gas generated, that some production research should continue. The new staff structure did at least enable everyone to know who it was he worked for!

"Bill attached importance to meetings and committees as a means of reaching agreed decisions (or agreeing to reached decisions!) and of imparting information. He and I chaired alternate fortnightly meetings with Divisional Managers, the intention, soon somewhat eroded, being that my meetings should deal with the "administrative matters". The intervening Monday mornings were take up with Bill's sessions with the Assistant Directors, sessions known as "The Directors' Meetings".

"These changes were timely, and indeed serendipitous, in view of the stricter control of R&D which the Corporation was able to put into effect with the appointment of John Gray as Director of Research. We would have been ill-equipped without them to conform to the changes he introduced. I was appointed to several committees and in due course to chair some of them. I mention them, in no particular order. There was the so-called Certification Advisory Panel (CAP), which authorised (whom did it advise ?) the issue of certificates of performance to the manufacturers or vendors of components of automatic gas burners, in the light of reports by the testing staff in Controls Division, who had inspected the items and submitted them to accelerated life tests. I suspect that I was chosen after a while to chair this panel because I manifestly knew nothing about automatic burners, and would therefore be impartial. Meetings were whole-day, with representatives of HQ and Regions, and I strove (usually just succeeding) to get the panel back into the conference room after lunch by 14.05. It was only right at the end of my time that I discovered that Pete Aris, in charge of Testing, had persuaded the waitresses to see that I got my coffee last and that it was boiling hot. I developed the necessary asbestos gullet.

I took over the chair of the Station Safety Committee in 1974, at about the time that the Health and Safety at Work Act was coming into force. Whether we were merely lucky it is hard to say. Our one major disaster (and that still in Fred's time) was to blow the roof off part of Davy Building, landing five people in hospital, an incident traced to the breakage of a sight glass on a vessel containing butane when the isolating taps on the glass had not been closed. There were near misses of course, many of which may have gone unrecorded. There was the chemist who had the bright idea of replacing the iron sulphide and acid in a Kipp's apparatus with aluminium sulphide and water - he was carried out into the open air and recovered. There was the engineer who opened the bottom valve on the oil hydrogenator lock hopper without first closing the top valve. There was also the affair of the lead bath, of which more anon; it led me to an inconvenient minority opinion. Much of our on the whole good safety record was probably due to people knowing what they were doing, as with the Bone and Wheeler gas analysis technique, so dangerous that - when it was safely superseded - I once said that as Chair of Safety Committee I should have advised forbidding its use.

"Alas! I must here record a grotesque failure of judgment. I once wrote a training manual for Boning and Wheelering, stating in the introduction that this technique should be learnt as it would not readily be superseded. Bob Cockerham and his analytical team were beavering away superseding it at the time. However, the report was charitably received at the classification meeting, and even accorded the distinction of starting a new class: Historical.

"I also chaired the R&D Divisional Safety Committee, a meeting of representatives of the Stations and of the HQ Safety team, which met at the (then four) Stations in turn.

"Yet another Committee was that which supervised the School of Industrial Gas Engineering (SIGE): I chaired the panel which reviewed the syllabuses of the various courses which the tutors had compiled - another example of ignorance ensuring impartiality. This went on until our masters decided to turn the School into a PR exercise (as the School of Fuel Management) under Peter King, who quickly dispensed with technical advice.

My brief chairmanship of the JCC - we were, I was told, the last outfit in British Gas to be without one - was I believe free of incident either positive or negative. It was earlier that we learnt a little about Trade Union procedure. One of Fred's legacies was the longest lunch break in British Gas, not unnoticed across the road, and the Directors sought to take the opportunity presented by a shortening of the working week to correct this. I wrote a notice which Bill signed, and when it was issued there was uproar. At the height of the furore Ken Stewart, formerly prominent in NALGO, came to see me and pressed a paper into my hand: "If you had written the notice like this", he said, "you would have had far less trouble." What he had written was without question better than my version. Horses for courses!

"The other change of management style occurred when we ceased to be administered by West Midlands Gas and became an HQ out-station. Put in the most charitable terms, the new scheme took time to become efficient.

"My personnel involvement had moved from recruitment to salary administration. I would sit, twice a year, to listen to the observations and recommendations of Managers, for whom, at this time, all their geese were swans. Compromises that I thought I could justify to the Directors' meeting were reached; those proposals that passed through that sieve were reported briefly to the personnel people in West Midlands, who wisely recognised that we knew our staff better than they did.

"When HQ Personnel took over, this was far too casual. A form had to be filled in for each proposal; a space of half an A4 page was left for a brief essay in support. I often felt when I had written these that my middle name must be : Mendacity.

"The first occasion on which this drill was followed was an April round, for senior officers. I had taken great care to get everything done in good time and from the middle of March I was expecting a package of letters to issue to managers for their staffs. In the last days of March I was daily on the telephone to HQ and the carpet outside my door was worn down by managers eager for comfort for their people. But one day, well into April, I was assured that the letters would be on my desk next morning and, sure enough, a large envelope arrived. It contained the letters for the ERS senior officers. Brian Thompson ('Big Fat' - as distinct from Brian Thompson of MRS - 'Little Fat') and I exchanged suitable remarks - and the packages, as quickly as possible.

"I cannot recall a single recommendation being refused, or even amended!

"The procedure was not without pleasing incidents, though. Roger Hancock once came to discuss his swans with a view to their recognition, at 16.30 as arranged, but explained that an experiment was being prepared that he really ought to see. Would I mind if he went down when his people phoned? He would only be gone ten minutes or so. At 16.50 he was summoned, and at 17.15, still waiting, I strolled down to Controls to see what had become of him. I found him bent double with his head inside a wire-netting cage, open at the top, with a little group of his staff standing around. After a few minutes he stood up and, seeing me, grinned a not very abashed apology. I reassured him that he had got his priorities right (though his staff might not have agreed). A man after my own heart!

"Another feature of the change to HQ status concerned safety. One morning, as I walked down from the car park (before the days of our "railway carriage pressings" Admin. building) I was greeted with solemnity by Geoff Billings and Normal Weaver. There had been an accident in the night: a stainless steel coil immersed in a lead bath had burst, and molten lead had been blown around a fair-sized space in the pilot plant building. No one had been hurt; advice was needed on cleaning up. This I got at very short notice by consulting the Safety Officer of West Midlands Gas in person, just across the road. This experience was prominent in my mind when, soon afterwards, it became clear that transfer to HQ would mean that safety advice would come from a group in Manchester. Despite my misgivings, Bill chose not to oppose this change and happily no untoward circumstances resulted.

W.E.Francis

After an education at Poole Grammar School, under the influence of a talented Chemistry teacher, F.J. Whitelock, Eric Francis (Fig.7.6) went to Exeter College, Oxford, graduating in 1947. Through contact with R.F. Strickland-Constable, who was doing work for the Gas Research Board in the Physical Chemistry Laboratory at Oxford, he joined the GRB.

Fig. 7.6 Eric Francis.

"In the complete absence of any joining instructions, I presented myself at the GRB Labs. at Pitwines Works in Poole, to the surprise of Frank Wood and George Percival (all the senior people being still on holiday)".

The next day he was sent to join a group working on utilisation problems in borrowed accommodation in the City and Guilds College, South Kensington, headed by Bill Simmonds, who had arrived a few weeks previously.

Work on the corrosion of water heaters was undertaken in the next few years in a series of unsuitable locations, including a lab. at the top of the Imperial Institute tower, the factory of Main Water Heaters in Thornton Heath, The Abbey, Beckenham and a six month spell in Fred Dent's lab. at Poole. This latter experience gave close contact with chemical engineers and was a very useful influence.

Following the take-over by the Gas Council, Eric was the first to move from Beckenham to Birmingham on the 6th December, 1952, the day of a severe smog in London, when it was impossible to see across the platform at Paddington Station. The few years at Nechells enabled a start to be made on industrial utilisation problems, and in particular a lesson was learned on the importance of recirculating gas flows and convection in governing heat transfer mechanisms in gas fired combustion plant, which was to influence MRS work during the whole of its existence.

On moving to Solihull in 1955, the work on recirculation was consolidated and led to applications which highlighted shortcomings in the performance of high intensity burners. The development of improved tunnel burners established a whole new range of applications and research projects which would keep M.R.S. busy through the late 50s and early 60s. It is perhaps hard to realise now how isolated and out of step with the established combustion research community in the UK and Europe the Gas Industry was. The conventional wisdom was concentrated on enhancing radiation from flames for use in large scale plant such as steam boilers, steel works and glass melting furnaces. By the late 50s MRS. had sufficient experience and confidence to be able to ignore all this as irrelevant to the majority of smaller scale gas fired plant. In particular, the realisation that large furnace volumes very necessary for oil and coal combustion were not needed for gas, enabled a totally new approach to furnace design, in which use of high intensity tunnel burners freed the designer from combustion considerations and the furnace chamber could be tailored to suit the nature of the load being heated.

A corollary was the need for a more thorough understanding of gas flow patterns in furnaces, for quantifying convective heat transfer rates and integrating these in an overall heat design calculation with interzonal and non luminous gas radiation. The key to this was modelling and in the 60s flow visualisation heat/mass transfer analogy and theoretical modelling were all started. Better recruiting ability attracted a series of talented people to work on these topics some of whom stayed with R&D to push the projects through to application and eventual wide scale exploitation. Some of the people involved with the work who came in around this time, such as Malcolm Hoggarth, Dave Lucas and Jeff Masters, have since gone on to senior positions at MRS. and then Loughborough.

The techniques developed during this very productive period stood MRS. in good stead when the introduction of natural gas brought the need to support conversion and, perhaps more seriously from a technical point of view, changeover from oil in a variety of large scale applications not associated with gas in the UK. By 1967, with Fred Dent's retirement and Bill Simmonds becoming Director of MRS., Eric found himself as Assistant Director with a much wider brief than hitherto and unfortunately less able to maintain close "hands on" contact with the research projects. The Station was getting larger and much work was needed to integrate the gas production and utilisation sides and to put in some organisation where there had previously been very little. This time also coincided with John Gray becoming Director of R&D Division and the implementation of greater accountability, the planning cycle and closer integration of the Stations with HQ.

"I was involved much more with administrative matters - necessary but hardly enjoyable. Fortunately when things became unbearably boring, one could wander down into the labs and talk to bright young scientists and engineers who were doing real work! This period brought me into contact with a wider range of technologies, such as controls for which I was now responsible. A spell as Chairman of the newly formed Industrial Gas Safety Committee saw the introduction of the Codes of Practice for Large Gas and Dual Fuel Burners in 1970 and the inauguration of work on a number of other codes for industrial plant."

"A closer involvement with the growing hazards work came about since at this time research on pipeline and LNG fires was carried out by Malcolm Hoggarth's Combustion Division. This interest was enhanced in 1972 when the explosion at the Effingham Street Works, Sheffield took place. Having quickly dispatched Mike Marshall to assist with any investigation, it became increasingly clear that it was a very serious incident, and it was necessary to view the sight at first hand. The scene which greeted me was of a group of people looking disconsolately down into a huge tank full of pipes, stanchions and other ironmongery with tons of gravel strewn everywhere and a pervading smell of light distillate. I found myself responsible for coordinating the R&D contribution to the scientific part of the investigation".

This investigation was of prime importance both from the scale of the effort and for the range of experimental and theoretical studies which were carried out.

As part of "career development" and to aid a number of changes in postings which John Gray wished to make at MRS. and HQ, Eric now had a spell on secondment as Chief Coordinator at R&D HQ in late 1974/early 1975, commuting every day from Solihull on the early train.

"Towards the end, one of the regular dining car attendants commented that I had eaten more BR grilled kippers than anyone else he knew".

The experience at HQ gave a valuable insight into the very different world of HQ and the requirements of presenting an acceptable face of R&D to the Corporation top brass. He returned to MRS. as Assistant Director with a wider brief and the "deputising role".

During his time at HQ, the concern about LNG safety and unconfined explosions came to a head after the Flixborough incident in 1974. He was summoned to a meeting with Sir Denis Rooke and Bill Walters at which the possibility of an international cooperative effort was discussed, since LNG users around the world were getting nervous of severe restrictions to their operations due to a lack of quantitative knowledge of the risks. In the event British Gas was the lead Company and MRS. had the task of technical coordination as well as conducting its own programme. Our effort was focussed on Dave Lucas as technical coordinator. From this time the hazards work grew in importance and has been strongly supported from the top.

Also in the mid 70s Eric had been encouraging Dave Moppett and Harry Hopkins to study risk assessment techniques and collect incident statistics. All the Stations claimed to be interested, so he was given the task of chairing a Working Party on Safety Guidelines to see how far risk analysis could be used to aid in evaluation of R&D Safety related projects. Of course it had wider significance and after presentation to the Research Committee he was told to take the report to the Policy Committees and the Executive, who all signed on to the principles and a subsequent industry Working Party drew up Guidelines which were adopted.

On Bill Simmonds retirement in October 1982, Eric was appointed Director.

"The next five years were possibly the most rewarding of my time at MRS., since I was in a position to make things happen. Many of the projects that I had started had come to fruition and were receiving recognition as a result of more extensive commercial exploitation".

"It was a great privilege to be in charge of such a large number of talented scientists and engineers, most of whom were relatively young. Each generation seemed to be more able than those they succeeded. It was interesting to see how the newer people managed to solve problems which had eluded the older generation. The newcomers quickly absorbed the existing technology and in two or three years were making significant contributions. In five or six years they had often become the Industry expert in a particular field".

"In hindsight the uptake of some of the industrial developments has seemed painfully slow. In the early days we had to rely on the Area Board Industrial Development departments and individuals such as Ken Ernest (Wales), D.J. Davies (North Thames), Trevor Ward and Cyril Rann (North East), and Les Walker and Ken Manuel (West Midlands).

Certain individuals in the plant manufacturers were also very supportive and influential: Reg Broomer (Ballards, later Stordy), Clive Denning (Incandescent Heat), Maurice Roper (Amal) and John Thurley are worthy of special mention. As a result of their efforts, use of recirculation, tunnel burners and injectors were taken up quite quickly, though not as widely as we would have liked".

"In the 70s and onwards, when our formal interface was with Marketing HQ, there seemed to be only half hearted support for developments aimed at improving performance and efficiency. Marketing seemed unable or unwilling, to work out ways of getting benefit from the exploitation of MRS. developments, and support seemed little more than grudging acceptance except at those times when energy crises made it expedient from a PR point of view. When I was appointed Director in 1982, the Chairman made it clear he wanted to see more vigorous commercialisation of developments, and I took this to mean that it was up to MRS. to use its own endeavours in this regard. These are recounted in Chapter 6, and the results have been heartening. I was able to retire at the end of 1987 with the satisfaction of seeing many of the techniques I had set out to develop become standard practice".

"The work that has given me great satisfaction has been the theory of injectors, the results of which permeated much of MRS. activity, including the GRH, fired heaters, jet boosters, coal hydrogenation, even CRG as well as the obvious ones of tunnel burners and flue gas ejectors. This well illustrates the evolutionary approach, tending to build on previous knowledge, which seemed to be part of the ethos in all parts of MRS.

Compared with conditions for gas research now in the late 90s life at MRS. was relatively straightforward. Funding may have been tight in later years, and we were always fending off the bean counters, but support from the top was strong and I believe we had a regime, which allowed creativity to flourish. The results recorded in Part 3 prove it".

"As I have remarked several times to Bill Simmonds, we had the best of it".

George Percival O.B.E.

George Percival (Fig. 7.10) joined the Gas Research Board at Poole in 1946 as a Research Assistant, while still studying part time at the Bournemouth Municipal College, and participated in many of Dr. Dent's laboratory and pilot plant studies, notably one on the effect of preheating the air blast to a water gas plant (Gas Council Research Communication GC3, 1953).

Fig. 7.10 George Percival.

Following the move to Birmingham, he was involved in a number of pilot scale projects, but his major contribution was the study of the catalytic steam gasification of methanol and light distillate in what was later to become known as the CRG process. He was responsible for building and running the so-called "peak load plant" erected behind Brunel Building. The results were reported in Research Communication GC106, 1964 and won him the IGE Gold Medal (with Bob Cockerham and Alan Yarwood).

In 1965 George left MRS to become Chief Process Engineer with Woodall Duckham Ltd., one of the licencees of the Gas Council processes. He returned to Gas Council as the first Coordinator, Production and Supply in the newly formed Department of Research Administration under Gerry Hopton. From 1973 to 1978, George was in the USA as Director of the International Consultancy Service, with a mission to promote the sale of British Gas processes and technology, for which activity he was awarded the OBE in 1978.

George returned from the USA to re-enter R and D as Assistant Director at Watson House, becoming Director in 1981, but that is another story. He has contributed the following recollections of his time in gas research.

"Early membership of the GRB installed certain qualities of dedication in staff that became so important in the later years during upheavals in the Gas Industry and great uncertainty about the future of research and its location. It was, in present-day management terms, almost an idyllic existence, although working conditions were as tough as they could be; scant facilities, long working hours, poor accommodation. This is a description of the lifestyle at Poole and yet there was a freedom scarcely to be experienced again. The management structure was not clearly defined and yet everybody knew what their objectives were, a feature of small teams and powerful technical direction. One was expected to do all that was necessary (within reason) to prosecute the work, such as glass blowing, pipe fitting, constructing apparatus from component parts, operating the Bone & Wheeler (of which more later), writing reports and producing artistic diagrams for inclusion in printed reports and to explain investigations to influential visitors. We were all "driven by Dent" whose watchword in a changing world was "Its the results that matter, not the politics".

"The team of Fred Dent, Dennis Hebden, Blackburn (later replaced by Leo Moignard), originated from the team working at Leeds University under the aegis of the Joint Research Committee of the Institution of Gas Engineers and the University where much of the fundamental work on coal gasification mechanisms had been carried out. This formed the basis of larger scale work at Poole after the Gas Research Board had taken over this work and such staff as were prepared to move. Dent believed in moving quickly to the largest scale possible and sorting out any outstanding problems alongside in the laboratory. He carried this doctrine through to the MRS where his dream of sufficient money, sufficient space and sufficient staff were fulfilled"."As has been said, the management structure in the GRB was not too clearly defined. At Poole, Fred Dent was in charge and Dennis Hebden and Leo Moignard were his lieutenants, after that it was largely a matter of length of service and origin. Being at Leeds was a big advantage; it would mean that you ought to be a good fit in the team and would understand the language! Success would bring immediate responsibility and then direct access to Fred. Results and future work would be discussed with him and he kept in touch with every aspect of the programme in this way. This arrangement worked well with a small team and Dent kept it up as long as he could at MRS even when staff numbers were more than ten times that at Poole. This one-to-one contact engendered a feeling of full involvement in the development task with immediate reaction to success and failure; these "highs" and "lows" being regular features of existence. As Dent used to say, "Its a grand feeling, laddie, when you kick a goal". Being able to operate the Bone & Wheeler constant volume gas analysis apparatus had its advantages and disadvantages. Apochryphal tales are told about the fate of individuals who smashed the equipment, fell asleep while at the controls, or accidently lost a vital gas sample, thereby wasting weeks of work. Staff were divided into two camps, those that could and those that couldn't. There were some that wouldn't on some pretext or other, but they were regarded as "beyond the pale".

"Nationalisation was the key step in the salvation of the Gas Industry and of the research function associated with it. At the same time it produced a period of extreme uncertainty among GRB staff, particularly after the end of 1951, when it was clear that the Gas Council intended to wind up the GRB. Politics seemed to figure much more in the day to day work and it became more evident that the industry was doomed if it tried to adhere to its traditional processes, whereas the Government was insistent on its continued use of high grade coal to help support the sensitive mining industry which had also been nationalised. Dent summed up the situation with the remark "They won't help the coal industry, they'll just kill off the gas industry".

"The work continued apace, however, with more digressions into existing process problems and improvement, such as studying the effect on efficiency of preheating supplies to a water gas plant, the hardening of oxide in purifiers, and crushing of coke. Fortunately the work on new processes had always concentrated on producing an ideal gaseous fuel from whatever source. Free from sulphur, non-poisonous and available at high pressure to facilitate transmission over long distances were the chief objectives. These standards were to prove invaluable in the changing scene ahead".

"Uncertainty persisted and depression accompanied the announcement of a move to the Birmingham area, located initially within Nechells Works. It was believed at the time that this was to be the final resting place. In 1953 the writer moved to what was officially described as the Birmingham Research Station, offices being located on the fourth floor of a laboratory block, with pilot plant dotted about the extensive works. It is astonishing how much was achieved in a short space of time at this unpromising location. The "Physics Section" as it was called, joined the Gasification Section of the old GRB at this site. It was the first time that the two "sides" had come together. Much doubt was expressed about the viability of the gasification work because of the unsuitability of the laboratory building. Great inconvenience was caused to the original occupants of the building, who were "dyed in the wool" Works Chemists,working 9-am to 5-pm quietly and reverently, with minimum noise. On the other hand, the crowd on the fourth floor used the personnel lift to carry gas cylinders up and down constantly and furthermore they had found a way of bypassing all the intermediate floors in spite of the waiting crowds. There were the inevitable floods from water services to equipment that was left running overnight, but because of the way the building was constructed, water never collected in the fourth floor but ran down vertical stanchions and flooded one of the lower floors. On one occasion water penetrated the Chief Chemist's office and filled a briefcase which had been left overnight leaning against a stanchion".

"The decision had been taken to build a new Research Station on a site next to Solihull Gas Works, and building had begun. The Chairman of the West Midlands Gas Board, George le B. Diamond, had been sufficiently far-sighted to realise that to attract the type of staff required to man a station of the proposed size, it would be necessary to choose a site in an area which would also satisfy the social aspirations of the professional family man".

"The writer will always remember the first visit to the Solihull site on a cold and foggy morning early in 1954. The Workshop Block, as it was called, was almost complete, a single storey building which would shortly become home for the whole of the staff located at Nechells until the remainder of the Station was completed. The steel structure of the Chemical Engineering building was being erected and one or two vertical columns reared upward almost out of sight in the fog. It was an exciting visit because we knew that all our hopes would be fulfilled and that a new life and a stable job situation extending far into the future was in prospect. We began to look for houses in the locality".

"Around Easter 1954, the move began, the single building available having been divided into three sections of about equal area from front to back, housing the gasification section, physics section and workshop respectively. It is recalled that the writer was fortunate to squeeze a desk into a room set aside for storing glassware. Fred Dent had an office on the first floor with a rear window overlooking the gasification laboratory. There were murmurings of "Big Brother is watching you", which must have had their effect because in a short time, the clear glass in the window was replaced by the frosted variety. Building continued apace, pilot plants were erected, staff numbers grew and elementary budgeting began, and one was more conscious of the influence of the Research Committee, now consisting of four University Professors, four Area Board Chairmen, and the President incumbent of the Institution of Gas Engineers. A great deal of support was received from Professor Garner of Birmingham University, both from the technical side in Committee, and from the staff side. His departments produced a stream of post-doctoral graduates in Chemical Engineering to expand the scope of the gasification work at Solihull. Some tolerated Dent's management style, some didn't, so there was quite a turnover. As previously mentioned, Dent persisted with his "hands on" approach; men were expected "to get their hands dirty" and not sit around until someone else was able to get round to doing the job even though it may have been mainly manual labour. This attitude did not appeal to a proportion of professionally trained men in their first job.

"The influence of academics in the Research Committee was felt in other ways. The "grand plan" was being pursued in the development work: very large, high pressure coal gasification units located close to pit head and feeding a high pressure gas grid as base load, backed up by many small, low cost, high pressure peak load plants strategically located at terminal points. Because of the need to base the whole operation on coal, methanol was selected as the feedstock for the peak load plants gasified catalytically. The methanol was to be manufactured year round at one of the base load units. When this was considered by the Research Committee, one academic pure Chemist casually remarked that it was ridiculous to use methanol, a fine chemical, very valuable in the chemical industry, expensive, and quite unsuitable for making gas, of all things. He probably hadn't realised we were going to make our own. Fortunately, Dent ignored the advice to shut the methanol work down, which came from the Committee, and continued to fund it from another programme. When naphtha became widely available, the methanol gasification work provided the foundation of the CRG process"."With the rapid changes in feedstock availability, the work became more competitive and there was an emphasis on patenting and reports were now subject to severe scrutiny. Process licensing and relationships with licensees developed. An international flavour was given to the exercise by invitations from abroad to present technical papers. We all became much more commercial in our outlook and dealings and made increasing use of plant control technology. More use was made of the expertise of our colleagues in the "Physics" Section, who designed burners, burner management systems and analytical and thermal measuring equipment for pilot plants. The Bone & Wheeler still held sway, however, and continued to do so until the 1970s. One final incident is recalled that highlights the fact that men were often left on their own on night shift to tend working plant. On this occasion an assistant had had the misfortune to break the burette of the Bone & Wheeler whilst attempting a gas analysis. There were plenty of spares in stock, however, and instead of leaving the repair for the day man, he decided to attempt the job himself. By the time his relief arrived, every spare burette had been broken. One can only imagine the reaction of Leo Moignard, whose staff were responsible for maintaining chemical equipment. The young man achieved a notoriety unmatched by previous workers, and entered mythology, almost. Actually, he died in tragic circumstances while on holiday in Switzerland later, but no connection can be made. There were perhaps a higher than average number of deaths for such young staff before 1965; Dr. David Percy and Mr. Kelvin Humphries, two dedicated engineers, died in harness.

Dr. F.C.Wood

Frank Wood (Fig. 7.11 joined the staff of the Joint Research Committee (of Leeds University and Institution of Gas Engineers) after spells with W C Holmes and Babcocks. He was seconded to the GRB at Poole in 1946 and carried out research there for a Ph.D under Dr Dent on fluidised bed coal hydrogenation. The rest of his career with the GRB and the Gas Council was concerned with hydrogenation of coal or oil.

Fig. 7.11

A lighter moment in the late 50's, with Dennis Hebden, Les Taylor, Frank Wood and P.S. Murthy.

Alan Yarwood writes - " I recall the apparatus he used in the lab at Poole and that it came down from Leeds. The reactor was a sturdy pressure vessel. My first contact with Frank (working with him) was probably during university vacations when he was running this apparatus. Quite quickly I came to realise that he was a competent, energetic and cheerful person who often whistled in the lab. Even now, I sometimes recall that I first heard a tune from, say a Beethoven symphony, or from Schubert's 9th, being whistled round the lab. (downstairs) as he went about his work.
The key to success in the hydrogenator was Fred Dent's brilliant conception of a fluid bed recycle system to control the effect of exothermicity and avoid agglomeration by the oil feed. To optimise recirculation , mixing rates etc. a transparent full size cold model was built at Solihull. It worked like a charm so had to be demonstrated to Gas Council luminaries led by George Diamond (then Chairman of WMGB) who were visiting the new Research Station. Unfortunately a large split developed in a major acrylic test section during the demonstration, rapidly followed by a cascade of several tons of powdered coal onto the aghast spectators, assisted by a powerful air blast. The visitors fled the building.

From 1955 he was dealing with Humphreys and Glasgow on the design, and erection and commissioning of a much larger plant to be erected in Brunel Building. In July 1958, Frank was engaged, with H&G, in commissioning the beast. During Alan Yarwood's first few weeks in Solihull, one Sunday afternoon, the unmistakable sound of a major leak was clearly audible in his lodgings in Hampton Lane.

Frank reports- "The leak heard by Alan Yarwood was, in fact, a blow-out and fire in the coal hydrogenator resulting from attempts to raise the bed temperature to autogenous level by adding "a smidgin of oxygen" in Dr Dent's favourite phrase. The blast took the roof off the building and could be heard a good deal further away than Hampton Lane. Fortunately, no-one was hurt but I'm sure the experience taught us all a timely lesson, namely that "Festina Lente" is to be recommended when venturing into unknown territory."

At the end of 1959 Frank left MRS for Winfrith, working for the AEA on the Dragon project. The move to the Midlands had so affected his wife's health that he felt obliged to return to Dorset (a good move whatever the reason, of course). Frank stayed with AEA until 1974 then joined an International Consulting Engineering firm, based in Hong Kong and London, specialising in desalinisation, finally retiring in 1988. Frank received the Institution of Chemical Engineer's Morton Medal in 1966.

P.A.Cubbage M.B.E.

Fig. 7.12 Peter Cubbage MBE, seen outside the Palace after receiving his award.

Peter Cubbage (Fig. 7.12) studied at Queen Mary College, University of London following service in the Royal Navy. After gaining a B.Sc. degree he joined the Gas Research Board at Beckenham, working on corrosion of water heaters. He transferred to Birmingham with the new Gas Council Research Station in 1953 initially working on development of effective explosion reliefs for industrial ovens. For most of his subsequent career he was involved in work in the hazards field, with brief excursions into atmosphere generators and commercial heating. Latterly he was Manager, Special Projects Division and was for many years associated with the Flame Lectures as presenter. He was awarded the M.B.E. in the New Years Honours List in 1987. After retirement in 1988, he has maintained an interest in the hazards field becoming Chairman of the U.K. Explosion Liaison Group.

He has contributed the following reminiscences of his time at MRS:-"My first impressions of the Midlands, after moving from The Abbey in Beckenham initially to the Gasworks in Nechells and then on to the site earmarked for MRS at Solihull Gasworks, were definitely of coming to the Black Country.

"As the first person to work at Solihull, I set up a test facility between the then Coal and Coke heaps and started blowing up ovens, in reality boxes, filled with different gas air mixtures. Mr. Steve Downs, Manager of Solihull Gasworks allowed us to use their laboratory, where we were assisted by J. Goode and J. Playford, later to become Commercial Manager in London and Director of Engineering, East Midlands Gas Board/Southern Gas Board respectively, to carry out gas analysis and electronic repairs, otherwise we were in a wooden garden shed surrounded by coke and coal, dust and slurry. There was a row of houses that backed onto the coal heaps, and on one occasion an RSPCA inspector called on us and started by insisting that we should stop our activities as we were causing distress to the dogs in the neighbourhood. Only when we explained that the work was aimed at saving human lives did she change her attitude and agree we had to continue, and that she would explain this to the dogs' owners. During the construction of the first laboratory, the nightwatchman was attacked and robbed and the caravan of one of the site construction engineers exploded - my first introduction to explosion investigations, that in later years were to become a regular call on MRS services. The construction completed, the then staff from Nechells transferred to Solihull, and the idyllic life we had enjoyed changed. Library, Workshop, Typing and Management Services arrived. Order was established!! New buildings appeared at regular intervals and the staff increased quickly.

Following the completion of the explosion relief programme, an investigation into designing flame arresters started. The Giraffe Room housed the initial rig of a 1" pipeline some 25 ft. long. The assistants soon learned that it was not a good idea to put one's hand near the end of the pipe when a detonation occurred. The rig was banished to the backyard because of the noise (or was it because of Dr. F. Dent's mast), and work extended to 2" and 4" pipes. Although a sandbagged "silencer" was built, the noise of a 4" gun pointing at the Chairman's office in the new WMGB offices recently built across the road was too much, and the work had to be abandoned. The need for a proven design of flame arrester for pipelines greater than 2" still remains, particularly for offshore, where large diameter pipelines carrying higher hydrocarbons than methane exist protected by unproven arresters. A low pressure loss arrester suitable for hydrogen has also not been designed and proven.

"The first drying oven fitted with an explosion relief brought to MRS was installed in the workshop. The explosion relief was protected by a steel plate for protection during transport. I was told that this was not to be removed after delivery because "the relief, being a fragile part of the oven, needed to be protected from the workshop staff"!!!

"Another story of the resistance to explosion reliefs met early on from industrialists is the case of the factory owner who had a slight explosion and when approached would not talk to us. A second explosion had no effect on his attitude, but a third, all within a few weeks encouraged him to invite us in and give us a blank cheque!

"After the Ronan Point explosion, the Brick Development Association (BDA), part of BCRA, built a 3 storey block of flats at Potters Marston in which they wished to show that with brick construction there is a bridging over effect and that progressive collapse as occurred at Ronan Point would not occur. AWRE were asked to provide the instrumentation and carry out the explosions. As gas was involved AWRE did not feel able to do the explosions and we were called in. After the work for BDA was complete, we were offered the continued use of the site and facilities which we accepted and stayed there until the construction of the M69 adjacent to the site made further work there unpracticable.

"Searching for a new site meant travelling to the far north of Scotland, Chivenor in the South West, and many points between. Spadeadam was visited but deemed too large for our immediate needs! At. W. Freugh we were offered use of a site on Mondays, Tuesdays and Wednesdays, as the RAF used it for bombing practice at the end of the week!

"Much of the initial work on LNG pool fires and high pressure gas release fires was carried out at Buxton on the SMRE site (now the HSE site). It is ironic that following the acquisition of a Spadeadam site by ERS we transferred the later very large fire and explosion work there, having previously not thought it suitable (actually an adjacent area of Spadeadam).

"My first sight of Fauld was on a dank, misty day, and although it looked about the right sort of size, the facilities were very poor, but as a remote site it obviously had potential. Only after negotiating the initial lease did we learn of the site's history - the place where the largest explosion of solid explosive (bombs) had taken place in about 1943/4. It took us some little effort to convince the local inhabitants that our work was safe and that we weren't likely to repeat their previous experience.

"The Fauld test site was an old Gypsum mine, and the spoil from the mine had been used to flatten an area on which the brick buildings had been erected. It was not difficult to see the reason why after about 3 years we found the floor of one building sinking, and on further investigation discovered a hole large enough to drop a car into, having been leached away under the Gents!

"Much of the narrow gauge railway track on the Fauld site was donated to the Railway museum at Ripley, where it is now in use."

R.F.Edge

Ron Edge (Figs. 7.13 and 7.14) joined the Gas Research Board at Pitwines Works, Poole in June, 1948, with a first impression that he was approaching a prison; this turned out to be the blast proof wall of the static bed coal hydrogenation plant. It also happened to be the day that Dennis Hebden returned from his honeymoon, and Ron was assigned to work under him on a project called "The breakage of coke by mechanical means", consisting of pouring dustbins of coke through a two roll breaker, dropping single lumps from the top gallery of a retort house or levering them apart with a screwdriver.


Fig. 7.13 Ron Edge.

In the next few years Ron was to work on a number of different projects, often involving 10 hour night shifts. After the take-over of the GRB by the Gas Council, he was sent to Nechells Works in 1952 to supervise the erection of the Lurgi coal gasifier and assisted in its operation until it was re-erected at Solihull in 1955. He was not finished with Poole, though, since he took part in the first fluidisedbed oil hydrogenation project and was one of the authors receiving the IGE Gold Medal in 1956.

During the next few years he was working on the mechanical design aspects of various gasification plants and in 1966, following Dennis Hebden's move to HQ, succeeded him as Chief Engineer. He continued to be responsible for engineering services when Dr. Simmonds became Director, taking the post of Manager, Engineering Division in 1971. Also in 1971, he was one of the recipients of the MacRobert Award for work on gasification processes.

<u>The Great Fire of MRS</u> Ron gave an account of this memorable incident in the Nov. 1982 ssue of "Eureka!""A long time ago (circa 1968) on the site now occupied by Telford Building stood its predecessor containing a group of plants used for testing CRG catalyst. One feature of the plant was the injection of a controlled amount of hydrogen at high pressure via a measuring device using a glass tube called a Flowrator.

"In the early hours of one morning the flowrator tube of the plant furthest from the door, and closest to steel drums filled with naphtha, burst. Unfortunately hydrogen (also helium but no other gas) heats up when suddenly reduced in pressure. This caused it to ignite. A further misfortune was that the instrument panels were made of varnished plywood!

"The plant operator called out the Fire Brigade, Haydn Davies and myself. As I arrived at MRS in my car, a police car raced past me, leaving the Station. I had no reason at the time to think any more of this.

"On the plants themselves the main difficulty was found to be faulty isolation valves outside the building preventing shutting off the hydrogen. This necessitated allowing the hydrogen to continue to burn as the safest course of action until an alternative solution could be found but at the same time to prevent the naphtha-containing drums from heating up to an explosive level. The Chief Fire Officer required a lot of convincing to persuade him to use his hoses to cool down the drums but to make sure he did not extinguish the fire (firemen don't think that way!).

"Eventually we succeeded in putting out the fire by diverting a high pressure supply of nitrogen into the hydrogen system and the fire brigade continued to spray water where required until everything had been cooled to a safe level.

Fig. 7.14 Retirement of Ernie Green, for many years in charge of the stores. Also in the picture are John Anderson, Bob Norgrove, Les Taylor, Derek Mitchell and Ron Edge.

It was much later that we discovered that the occupants of the aforementioned police car had quite unnecessarily evacuated about 100 families from the area without telling us. This produced a gross over-reaction by the media. The BBC Home Service (Radio 4 these days) in its early morning news gave the impression that the entire Research Station had been razed to the ground.

"Now it so happened that Dr. Simmonds was to attend a Research Committee Meeting in London that morning. He rose, dressed,and went off to catch his train without switching on his radio. He missed out via the newspapers because although the Birmingham Post carried the story the fire happened too late for the nationals.

"When he arrived at the meeting, the Chairman, Sir Henry Jones, asked him about the fire and of course he knew absolutely nothing of it. He promptly rang me at MRS wanting to bleep! bleep! bleep! know why I hadn't rung him at his home in the wee small hours to tell him what was happening. I don't think he really believed me until he returned to Solihull to see for himself that the fire was too small for it to be really necessary for me to disturb his well earned "kip"."I think it can probably be said that this was the biggest shock he received in his long reign as Director."

Alan Yarwood

Alan started working for the Gas Research Board in 1949, after leaving Poole Grammar School, situated just across the playing fields from Pitwines Works where the GRB had its Laboratories. He was employed in dissolving sulphur from spent oxide using carbon disulphide and on other unpleasant and smelly things to do with purifiers. With a grant but no place at University he spent a year working with George Percival on the water gas plant.

After University in 1953 he then began full time work with the Poole team, which curiously for a while called itself the Research Department of the West Midlands Gas Board. He worked with Frank Wood on the coal hydrogenation pilot plant, which was being converted to fluidised operation. As Alan recalls - "the day came when we were to inject oil into the reactor to see what would happen. This was at the instigation of one of the oil companies who had more of some of their products than they knew what to do with. We had been sent three forty gallon drums - one of light distillate, one of recycle oil (akin to gas oil/lubricating oil) and one of heavy fuel oil (thick, black and mobile only when heated). I recall a few frantic minutes while we were running on recycle oil - the plant was running well and I had gone into the control room to speak to Frank. Dr Dent came on the phone from Birmingham, anxious to know what was happening. Hardly had Frank answered his first question than pressure gauge needles began to dance and I had to dash back to the oil pump and shut it down. Water had contaminated the oil. That wasn't the only excitement, however, for we soon realised that we had experienced the birth of oil hydrogenation."

This life style must have taken its toll on Alan, for in 1956 he had a spell in a sanatorium, rejoining the team, by then all at Solihull, in 1958, working with George Percival and Bob Cockerham on what became the CRG process (Fig. 7.15. He was involved with the design of the "peak load plant", but subsequently was more concerned with catalyst formulation, preparation and testing on the laboratory scale. In the early 60's, attempts to use commercial catalysts were unsuccessful, so Alan set up means of preparing catalyst in sufficient quantity for the peak load plant, making use of a domestic washing machine as part of the "production line". Continuing improvements and expanded testing facilities eventually enabled Peter Spence to go into commercial production of catalyst in time for the Bromley-by-Bow plant.In 1965

Fig. 7.15 IGE Medal Winners of 1964. L. to R. Henry Chapman (WMGB), Alan Yarwood (MRS), Bob Cockerham (MRS), John Prigg (Watson House), John Harris (Watson House), George Percival (MRS).

Alan set up the "Catalyst Preparation Lab." in Brunel Building, large enough to make pilot plant charges, and did the lab testing which led to the "double methanation" route to SNG.

After the run down in production work in 1968 he was appointed Publications Secretary, was seconded to assist Dennis Hebden in London in 1972 and spent 3 months in Baltimore in 1975 helping to establish Laporte-Davidson Inc. as a manufacturer of catalyst for the SNG plants being built in the USA.

When Leo Moignard retired in 1979, Alan took over the patents work and joined the Management Services Division under John Barrett, looking after publications, and the Library. He made a major contribution to the inauguration of "Relay" in 1983 and has acted as its editor.

K.D.Stewart

Ken joined Gas Research Board at Poole in late November 1946, as an assistant experimental officer after completing full time studies and worked as a member of the team on the high pressure methane synthesis run. After the conclusion of this he moved to work on oxide purification of town gas and was closely involved in the full scale testing on a "stream of purifiers" at Pitwines Works. He achieved some notoriety during a very hot spell of weather in 1948 when he was working in bush shirt and shorts and was told by the Works Superintendant that seeing someone dressed for hot weather made him feel even hotter as he had to be in formal dress in case of having to receive visitors. On completion of the oxide programme, Ken was then assigned to work on steam-coke reactivity, which he was still doing when he moved from Poole initially to Nechells and then to Solihull (see Fig. 1.4 in Chapter 1).

A spell of work on hydrogenation of oil fractions under pressure replaced the steam-coke work culminating in an investigation into the effects of progressive increase in light oil feed rates during hydrogenation when considerable quantities of benzene were synthesised. However the benzene market collapsed so no further work was done on the process. However, part of the plant was used as an alternative method of treating of tar factions by removal of unsaturated compounds.

Work on the hydrogasification of light distillate was being expanded and Ken next moved onto this project and with which he remained, apart from a 7-year period working with Jim Buckley on carbon monoxide conversion, until he retired in 1991.

Ken always considered himself fortunate in that he was able to continue doing experimental work until he retired, and considered one of the most rewarding experiences was to get a small scale jet booster to work.

P.G.Atkinson

Peter Atkinson (Fig. 7.15) obtained an Honours degree in Chemistry in 1949 at the Woolwich Polytechnic, then a College of the University of London. He joined the Gas Research Board at Beckenham in September of that year, but after only a few months was called to National Service in the R.A.F., having been an active member of the Air Training Corps at school.

Fig. 7.15 Jeff Masters, Peter Atkinson and Bill Simmonds in 1979.

He returned to the GRB at the end of 1951 and worked on several projects, including the removal of sulphur from spent oxide in a fluidised bed, before moving up to the Birmingham Research Station at Nechells in 1953. He had a lifelong interest in electronics, having been known to convert war-surplus air command receivers (BC454) to the medium waveband and a surplus radar set to a television receiver-although he had connected the vertical deflection plates incorrectly, leading to an upside down picture, the results were to encourage his father-in-law to buy his first television set.

The interest in electronics naturally led to him working in the field of instrumentation and control. He designed a pressure transducer that enabled fluctuations in fluidised bed conditions to be monitored, and started his best known early work on gas temperature measurement. The result of this was the Atkinson metal suction pyrometer, much used in MRS and by engineers in the Regions and plant manufacturers.

At Solihull he set up an instrument laboratory to serve both production and utilisation activities. The existence of this facility got to the ears of the Chairman of the WMGB, George Le B. Diamond, who was a keen Hi-Fi audio adherent and used to seek advice from Peter on his equipment, being the possessor of an early Leak "Point One" amplifier.

Also at Solihull, the work on industrial burner safety and automation was started. The performance of the large solenoid valves of that era shocked Peter when he discovered that they would open if merely laid on their side. He was heard to say - "this is all that lies between us and the graveyard". This work led to the design of much safer valves and to the Standards for Automatic Burners.

One of the first explosion investigations carried out by MRS fell to Peter in 1961, following an incident on an American machine at Smiths Crisps in Gt. Yarmouth, resulting in recommendations for improved safety procedures. Persuading people to invest in safety improvements was always difficult, and one of Peter's gambits was to ask if anyone would buy a substandard parachute.

One of Peter's less successful projects was for the determination of steam/oxygen ratios for the slagging gasifier by measuring molecular cross sections using a radiation cell with Sr 90 as the source. After weeks of effort with high impedance electrometer circuitry, drift and instability remained. However, the cell eventually got used for a time in a chromatograph marketed by Pye.

One day early in 1963 Peter took to his bed with a fever, began day-dreaming about electronic ignition circuits and had the presence of mind to write one of them down; on recovering he could not follow the theory, but built the circuit, using automotive type ignition coils and it worked, was patented and has been sold throughout the world, particularly on bakers ovens.

Good communications with the Regions were vital for the implementation of research results and one example of the ultimate in conciseness is worth recalling. In 1968 MRS was carrying out technico-economic investigations of total energy schemes and had completed a study for Eastern Gas. The prospective client was AEI-GEC and the Industrial Sales Manager was Gwyn Thomas. Following the negotiations he wrote:-

Dear Mr. Atkinson,
A.E.I.-G.E.C.
T.E.
R.I.P.

Sincerely,

GET

Chapter 8

Some Newer Recruits

Chapter 8

Some Newer Recruits

Dr. T.R.Phillips

Rowland Phillips (Fig.8.1) joined MRS from the Atomic Energy Industry and did laboratory scale work on gasification and catalysts in the early 60s. He later followed Bob Cockerham as Manager of the Chemistry Division. His contribution is interesting as a view from someone not having his career almost wholly in gas research.

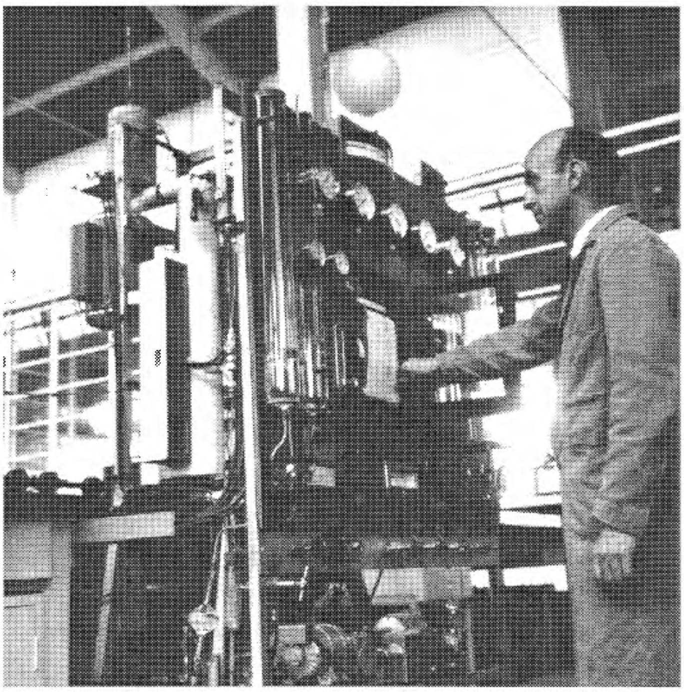

Fig. 8.1 Rowland Phillips operating a typical laboratory gasification rig in 1964.

"When I attended my interview for a job at MRS, I was seen by a Dr. Moignard, who asked the usual searching questions and then put on a fairly shabby raincoat and gave me a rather bewildering tour of some impressive large bits of chemical engineering. I did not enquire too deeply about my role in the organisation but I understood that I would be working on catalysis; it sounded interesting, and so I took the job that I was subsequently offered. I thus found myself in what is now the Davy Building, which was not really what I had expected, and I confess to being somewhat disappointed. Instead of the high-tech which I had seen, I found a laboratory in which a few reasonable-looking small test rigs were wedged in between benches of dust-encrusted apparatus, more reminiscent of the 40s than the mid-60s. The former, which were mainly under the control of Messrs. Percival and Yarwood, were the items with which I became involved. The latter, I eventually discovered, were the domain of a small group who seemed to work directly on trouble-shooting problems for the Director, Dr. Dent. When one problem was finished or when another more pressing one appeared, the existing apparatus was discarded and another built on a new bit of bench, but the old was retained "because we might have to come back to it, old man". Thus, space was not readily available to this new upstart, and I think it must have involved a fair bit of behind-the-scenes activity by Dr. Moignard and George Percival to get me settled in. In comparison with the Atomic Industry from which I had come, the level of support in that laboratory in the way of assistants, fitters, cleaners etc, was mainly of poor quality and there was not much of it. The basic trouble was that the workshops were really geared up to support large scale plants, but for the laboratory plants there was little available. The best of the bunch was Vic Morris, who was at least a well-trained instrument engineer; N. Timmins, a one-time greengrocer, made up in willingness and enthusiasm for his lack of formal training. In the summer months, however, they were frequently engaged on problems of a nautical origin since there were some boating enthusiasts amongst the senior staff.

"I shared an office with Dr. Alan Williams. I had little contact with Dr Dent apart from a "Good Morning" on good days, to a quick nod or less on bad ones. I think that Dr. Moignard and George Percival acted as a sort of shield to enable us to continue a reasonably coherent programme of work, whereas others were changed around projects with a sometimes surprising frequency.

"One of Dr.Moignard's responsibilities was dealing with all aspects of Patents: writing them, renewing them, rebutting oppositions etc. Possibly because Alan and I were in a nearby office, he would often drop papers in and ask us to comment on oppositions, and on one occasion I appeared to have found an answer to a particularly awkward objector, so I left a note on his desk with my suggestions. He appeared at our door shortly after with a contented smile on his face and said "Phillips, you should wear a wig." I was almost as bald then as I am now, so Alan and I burst out laughing.

"Dr. Moignard became bright red in the face and proceeded to apologise profusely, whilst trying to retreat to cover up his embarrassment.

"The most traumatic experience of my time in MRS was the day that an LPG leak blew the roof off the Davy Building, seriously burning several members of staff. I was in the building at the time but not in the section in which a sight glass on a modified copper central heating tank broke and the LPG which it contained spread over the laboratory in which there were several hot furnaces. An attempt was made to throw it out through a window but before it was achieved, there was a loud explosion followed by a tremendous roaring noise. The injured managed to get out, since fortunately none had been seriously hit by the falling roof beams, but there was general chaos until Dr. Hebden appeared and brought about a modicum of order. One of my lasting memories was of a fitter, Roy Handy, on top of a ladder trying to extinguish a flame on a high pressure gas main because no-one knew where to turn it off. This event eventually led up to the introduction of substantial changes in the attitude of the Station to safety matters, and the realisation that the proper design of small plants could be as important as for larger ones.

L.H.Skett-Taylor

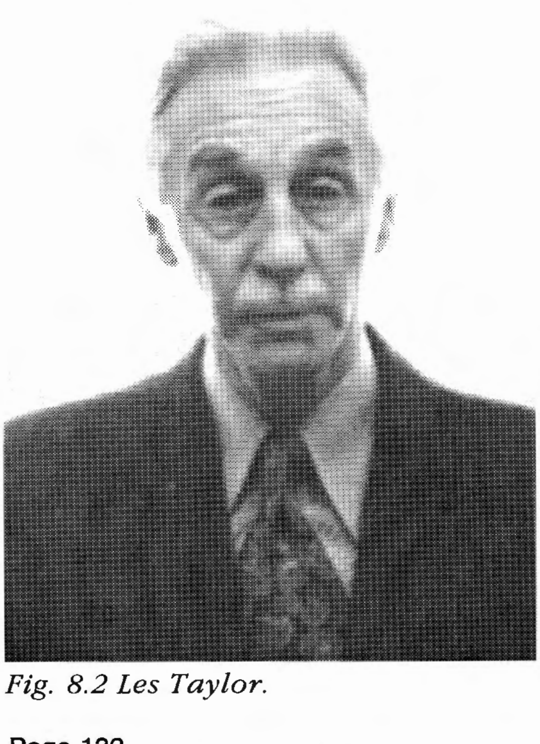
Fig. 8.2 Les Taylor.

After wartime service as a pilot on operations in Europe and Burma, Les Taylor, as he was then, started with a firm of chartered accountants in 1947, but soon left to join the newly formed NHS, rising to become assistant to the Chief Finance Officer of the United Birmingham Hospitals.

He joined the Birmingham Research Station in June 1954 as Chief Clerk with responsibility for clerical and financial services (Fig. 8.2). He set up the system of accounts and costing for the research projects then being carried out at Nechells, for monitoring against budgets agreed with WMGB, who were responsible for MRS financial matters, payments, salaries administration etc. As late as 1968, the official accounts were being signed off by the WMGB Chief Accountant, W.G. (Bill) Jewers, later to be Managing Director, Finance of British Gas.

After the Station moved to Solihull Les was appointed Administrative Officer under Dr. Dent and was responsible for finance, costing, clerical, typing and printing services, and foreign travel.

Dr. Dent's approach to budgeting was fairly simplistic - to define some broad areas of work, get them enshrined in the programme and then ask Les to go round the various project leaders to get an idea of large items of expenditure and the likely manpower and to produce a budget, often within a few days of a deadline. In those days money was not the limiting factor on progress and the items were large enough to give Dr. Dent the flexibility he needed to concentrate on the specific project he considered to be of major importance to the Industry at the time.

As an example, the first Gas Recycle Hydrogenator was built and commissioned extremely quickly, funded by the budget for the FBH. Some accounting rules had to be slightly bent to accomplish this! Les's role was to keep the accountants and other "grey people" at HQ or WMGB off Fred's back and let him get on with the real work. As Leo Moignard was wont to tell Les, all that he did in the administrative field would count for nothing; it was the research results that mattered!

He had occasionally to act as general trouble-shooter, as on the occasion when Dennis Hebden's efforts to increase the output of the slagging gasifier resulted in emission of droplets of tar and soot from the flare stack. Les had to negotiate with Directors of firms in the adjacent industrial estate, all of whom wanted their cars resprayed.

Following Dr. Dent's retirement, Les became Manager, Planning and Administration under Dr, Moignard with wider responsibilities under the more formal structures instituted by Dr. Simmonds, including acting as Secretary to the regular Directors' Meetings.Later as the Finance and Planning Manager, Les became more involved with the formulation and costing of the R & D Programme and the Capital and special revenue items. He became adept at rapidly re-jigging the costings at short notice to reflect the decisions of Interface and other Committees, with the aid only of a pocket calculator.

Brian Oeppen

Brian Oeppen is a Cambridge engineer, getting his D. Phil for work on vibration of spur gears in 1964. He joined MRS in 1966 as leader of a Furnace Section, progressed to Assistant Manager in Process Heating Division and became Manager of a newly created Furnace Division in 1970.The Furnace Division was concerned with the development of rapid billet heating, recuperative burners and recuperative radiant tubes, as well as the exploitation of natural gas in large scale furnace applications.

Brian was perhaps most associated with the development of automatic heating machines for forging and metal forming. In 1972 he left MRS to form his own Company, R.H. Furnaces, to manufacture and sell rapid heating furnaces under licence from British Gas, specialising in heaters tailor made to customers particular requirements. He has kept in close touch with MRS ever since and from the mid-80's, as a licencee for the ceramic radiant tube, has been involved with several important "breakthrough" applications, such as the Craelius furnace for diamond drill heating and ceramic kilns for glazed ware firing.

Dr. R.A.Hancock

Roger Hancock (Fig. 8.3) was one of the earliest recruits to the utilisation side at Nechells as a Research Assistant, and since he subsequently rose to become Manager of the Controls Division has been able to see life at MRS from a wide spectrum of positions in the management chain, as the following comments reveal.

Fig. 8.3 Roger Hancock.

"I joined MRS in August 1954 as a Research Assistant in the Central Laboratories at Nechells and moved to Solihull in 1955. At the time I joined, the gas industry was certainly not seen as a growth business and the view was expressed that it might survive long enough to see my career out. The graduate scientist (Phil Hotchen) for whom I first worked left some 12 months later to join the UKAEA and his advice at the time was that there would be little future in gas unless natural gas were to be discovered in the UK.

"A feature of the early days was the small size of the whole operation, a dozen or two people in total and projects were handled by individual scientists plus some research assistance. In my first job I was assisting with work aimed at enhancing flame radiation (of towns gas flames) so as to improve radiant heat transfer. The ultimate goal, I seem to recall, was to fire glass tanks. The project didn't in fact last long, whilst one could greatly increase emissivity it was at considerable cost in terms of flame temperature and consequently prospects didn't look too promising.

"Other themes on which I worked in the early days included convective drying in a recirculating dryer and the reduction of combustion noise, particularly noise from tunnel burners. I recall being pleased to obtain a patent for a porous castable refractory. Whilst this material effectively eliminated resonance in tunnel burners it was a rather messy and complex process to produce it and didn't catch on. Unfortunately simpler casting materials were less effective.

"An interest in electronics and controls led to my working on the ignition and control of tunnel burners and the work led in due course to R&D in the wider area of controls, safety and the control of plant and processes undertaken within Controls Division at MRS. This work included studies of the functions of ignition, air/gas ratio control, safety shut-off valve design and performance and studies relating to control unit logic, details of which are described elsewhere.

"A feature of utilisation work at MRS has been the rapid implementation of research in industrial processes on customers' premises. I recall a number of "interesting" visits to manufacturers' works to sort out application difficulties. One such job entailed a visit to works of a printing machine manufacturer in Wiltshire where an air blast "slot" tunnel burner of MRS design and customers manufacture was being used on a colour printing machine to dry the ink by direct impingment on the rapidly moving web. Imbalance across the slot caused scorching of the paper in places and inadequate drying in others.

"It was satisfying, and something of a relief in view of the cost of starting and stopping the machine, to be able to identify correctly the cause of the problems as poor machining of the burner air nozzle.

"Another occasion entailed the control of an indirect air heater at Filton on a rig being used to simulate high altitude flight for engines under development and later destined for the Concorde. Such was the confidence of the Company in the heater that they required fire officials to be in attendance when it was lit up. Reliable start-up and operation was soon achieved without the need for their services.

"Work in the laboratory was also frequently 'eventful'. Experimental rigs for utilisation research were generally designed and built by the graduates concerned with technician support. Whilst people were safety conscious the approach was less formal than it is now and some practices were followed in the laboratory that I'm sure would no longer be regarded as acceptable.

"For example, Peter Cubbage in carrying out work on flame traps in the laboratory, would have a whistle blown to warn staff just prior to each detonation. This gave people time to put their fingers in their ears and to move away from the vicinity of the rig.
"Work on fan premix burner systems and their use on furnaces in the laboratory also produced some rather noisy 'light-backs'. One gentleman destroyed several fan-cases whilst determining the"safe"'lengths of downstream mixture pipework. Fortunately his work was undertaken out of doors.

"There were also occasional incidents on plant which with hindsight were amusing but which could have had serious consequences. Once Peter Aris was converting a small Stone Vapour steam generator to gas firing and experienced what might be described as a severe delayed ignition of the main burner. The resulting "bang" turned the rectangular sectioned flue into a circular section and temporarily deafened all within earshot. One might say that it was no accident that the main theme of the work of Controls Division at MRS was that of designing systems to be safe in operation and in investigating the reasons for failure where industrial and commercial customers' plant suffered damage.The team approach was very effective in providing advice to customers and in bringing expertise to bear on problem solving. This was possible because individuals developed their specialised expertise which collectively allowed systems problems to be addressed, for example in the late 60s early 70s, the late Steve Hutt's expertise on Safety Shutoff Systems, Keith Stein on Governors, Richard Grimsey on Control Units and Peter Spittle on Systems. Over the years many individuals have contributed to the work of Controls Division and to that of MRS as a whole.

Fig. 8.4 The Fire and Rescue team in 1974 on the occasion of an inter-Regional competition in Scotland, including the late Steve Hutt, John Ford and Jeff Pearson.

"The Station had a strong RF&A (Fig. 8.4) team and its own Red Cross detachment which supported local events. On one occasion, the team staged a demonstration outside the NatWest Bank in Poplar Road, Solihull, to aid a Red Cross flag day. The staged "accident" was the collapse of scaffolding resulting in numerous "casualties" amongst the "workmen" working on the bank and "passers-by". The plan was that some members of the team in uniform would render first-aid and that the casualties would be collected in the Red Cross ambulance. In the event, the conductor from a passing bus saw the "accident" and telephoned for an ambulance, which arrived quickly together with the Police. The make-up was so good that despite protests the "injured" were rushed to Solihull Hospital, where they were received with some annoyance by the awaiting emergency staff.

"Although the Police had been informed of the event in advance, clearly the message had not been passed on!"

D.J.Moppett

Dave Moppett (Fig. 8.5) was one of the first Research Assistants taken on at Nechells in 1952 and since equipment had not arrived from Poole, spent his first few weeks seconded to the Central Labs. When a box of bits did arrive he was involved with experiments on water gas shift catalysts at high pressure. This work expanded on moving to Solihull in 1955.

Fig. 8.5 Dave Moppett.

During this period he was continuing his education on day release, and received a severe ticking off from Leo Moignard for failing a chemistry exam., with the result that he was put on a Dip. Tech. Applied Physics sandwich course (6 months at college, 6 months full time at MRS).

It was regarded as more appropriate that he worked in the "Physics Section" as the utilisation side was then known, and found himself working on tunnel burners for Eric Francis, testing a "Mach 2" C-type burner, exploring the limits of Eric's theory of tunnel burner design. Running off the compressed air line gave a reputed noise level of 140 dB, with a note similar to the exhauster alarm at the Solihull Gas Works, to the annoyance of the works engineer, Steve Downes, who kept going up to the top of the retort house only to find no fault.

Dave was a very strong lad and found himself helping with the arduous task of heaving steel bars in and out of a forge furnace at the WMGB Lab at Brasshouse Passage, with Mike Lawrence and Jerry O'Connor. In 1961, after graduating with his Dip. Tech., he moved over to work for Peter Cubbage on atmosphere generators, where his talent for overcoming obstacles and getting things done was used to rescue projects that seemed to be floundering. Weaker spirits tended to wilt under the Moppett regime!

In 1965 Dave moved to Controls Division under Peter Atkinson, where he carried out definitive work on safety shut off valves which was an essential precurser to the Standards for Automatic Burners. He was subsequently involved in the setting up of the Industrial Defect Reporting Scheme for monitoring problems with safety related controls. Appointment as Assistant Manager under Roger Hancock gave him a broader remit in the Division.

In the 1970's Dave found himself with Peter Cubbage again in the Special Projects Division working on hazards, with a particular interest in risk analysis and incident investigations. Later he took these functions into a separate small unit and was responsible for monitoring safety adherence in the whole Station (Fig 8.6). For many years he has organised the Defect Investigation Panel (DIP), overseeing the Reporting Scheme for whole industry.

Fig. 8.6 First Aid Team. Back Row, left to right, Dave Moppett, Mike Thorley,Diane Broomhall,Helen Hogg, Reg Banks, Lawrence Morrison, Tony Collins.

Lawrence Conway

Lawrence Conway (Fig. 8.7) started his career in the gas industry as a Student Gas Engineer with the Northern Gas Board. His first six months were spent getting his hands, and everything else dirty on a gas works using the latest design of horizontal retorts for coal carbonisation. He was fascinated by the science and practical engineering of these and the newer methods of gasmaking then appearing. This led him to Leeds University where he obtained a degree in General Fuel Science in 1960. Instead of returning to Tyneside, however, he was recruited by a team of enthusiasts who were developing new gasification processes at the Midlands Research Station in Solihull. There he was soon involved in large scale pilot plant operations on hydrogenation of coal in multiple fluidised beds, on the fluidised bed hydrogenation of crude oils (FBH) and on the gas recycle hydrogenation of light oils (GRH) working under Dr Dent, Brian Thompson and P.S. Murthy. There was a great sense of urgency ("time is our greatest enemy") and, with relatively few automatic systems, the work was physically demanding and, in retrospect, sometimes unsafe. At that time engineering designs were often close to their limits for high pressures and temperatures involved. "We became used to dealing with crises in the middle of the night!". All of the experimental work required extended shift operation but he set a record when, having been placed in charge of the FBH pilot plant, he set up a camp bed in the office and during one particularly fraught week spent 120 hours on the plant. There were also papers to the IGE and visits to the Patent Office but there was a real sense of achievement when the GRH was commercialised in Britain and Germany

Fig. 8.7 Lawrence Conway

when the Osaka Gas Company decided to build a semi-commercial scale FBH plant in Japan to further the development of the process, and of course when the Station won the MacRobert Award in 1971.

Lawrence was fortunate enough to be sent to Japan in 1968 to train the staff and help commission the FBH unit (see chapter 10.4 and Fig. 10.4.2). He spent several long periods there over the next few years and took a great interest in the people and their customs and made friendships which last up to the present.

With the discovery of natural gas in the North Sea, interest in gas production waned and he became involved in experimental work and field trials on the use of natural gas in boilers and industrial processes. However in 1971 anxieties about long term availability of natural gas led to a revival of work on gasification, now aimed at producing a substitute natural gas (SNG).

He took over from Cyril Timmins as Manager of Production Division and, in 1984, he became Assistant Director SNG working with Dr John Lacey at the height of the SNG Programme (Chapter 6). This involved providing technical resources in both Solihull and Westfield and he reorganised the Station's engineering and financial systems to improve their effectiveness. This work was interrupted by a long course at the London Business School and a short secondment to R&T HQ in London. With the retirement of Eric Francis in 1987 he was appointed Acting Station Director, MRS. Two years later he was back working with Gerry Clerehugh at R&T HQ replacing Dave Lucas who had taken on the management of the design and construction of the New Research Station. This secondment was most rewarding, despite the almost daily commuting, giving a very different perspective to the work and practices of the different Research Stations and of the preoccupations of the Company as it adjusted to privatisation.

Meanwhile he was able to maintain contact with the technical work as Chairman of Working Committee B (Production of Manufactured Gases and Hydrogen) of the international Gas Union(IGU).

Lawrence was appointed Director of the Midlands Research Station in March 1991 and, at the end of that year became General Manager of the Gas Research Centre responsible for completing its construction, fitting it out, transferring staff and equipment from the three Southern Stations and, sadly for closing them down and handing over the keys to the Property unit.

Malcolm Hoggarth

Malcolm Hoggarth (Fig. 8.8) having gained an Honours degree in Gas Engineering at Leeds University, joined the Midlands Research Station in 1959, where he became involved in studies of high intensity combustors. His scientific interests have, over the years, developed into a wider range of research activities associated with combustion, heat transfer, and thermodynamic applications and in fire and explosion hazards.

In those early days when there were few scientific staff in the utilisation area young graduates had frequently to be thrown in at the deep end to solve tricky technical problems. "Advising a manufacturer's director, old enough to be one's father, rip out the inside of his furnace to eliminate120 dB(A) resonant noise to get the factory back to work, was not to be undertaken lightly". Such salutary experiences did, however, prove valuable to those confronted with them.

During these early years there was much change in the industry, one of the most

Fig. 8.8 *Malcolm Hoggarth*

important being the introduction of natural gas to replace town gas and to displace oil and coal in low grade heating processes. Malcolm and colleagues were heavily involved in enabling R&T to provide advice to support the Regions in a rapidly expanding market.

At about this time Malcolm gained a M.Phil degree for work on Gas Jet Booster Design and Performance which was later used extensively in the Regions.

In 1969 he was appointed Manager of the Combustion Division where he supervised work on burners for large shell and watertube boilers and commenced studies of large scale hazards such as pool fires and jet fires from pipeline fractures at Harpur Hill near Buxton. This site was renowned for it's severe weather conditions (reputedly 90 days snow and 120 days below freezing each year!). Once, after a sceptical reception to a request to Leo Moignard for furlined boots for staff working at the site, a test which Leo was attending was "accidentally" delayed. The request was quickly granted.

With the management reorganisation in the early 1970's Malcolm became Manager of the Heating Plant division with responsibility for utilisation R&D. This was a particularly rewarding period with much contact with International Gas Companies, Gas Regions, Manufacturers and Customers. Numerous field trials were undertaken and some 40 licences were granted to manufacturers. In 1986 following the customary 6 month's as acting coordinator at R&T HQ he was appointed Assistant Director with special responsibility for Safety and Hazards. This was a particularly stimulating period, when, because of a number of incidents such as the Piper Alpha Accident much emphasis was placed on hazards research either as in house or as collaborative ventures.

At this time Malcolm was Chairman of an International Technical Committee on Hazards with membership from Canada, Europe and Japan. This impressed on him the difficulties that must confront such organisations as the European Union when attempting to obtain a consensus on sensitive National issues.

Perhaps the most interesting activity was, as part of a three man team, reviewing the safety of British Gas offshore installations following the Piper Alpha Accident.

This provided an insight into a wide spectrum of safety activities including safety procedures, permits to work, fire and explosion, diving, helicopters, and security. Involvement with the bomb squad, and Special Boat Squadron makes one grateful that they are on our side. Their advice in the event of being involved in a highjack was "to lay back and enjoy it; don't try to help us by picking up a gun as we can't know whether you are friend or foe".

By 1991, when Lawrence Conway having been appointed as Station Director was whisked away to become General Manager of the embryo GRC, Malcolm was made acting Station Director a post that was to last almost two years.

As the move to the GRC approached the planned matrix management system began to emerge and he was appointed "Technical Controller Physical Sciences' in November 1992 with responsibility for staff relating to research on combustion, heat transfer, thermodynamics, and hazards for the research programme. This responsibility continued at the GRC after MRS closed in 1993.

Jeff Masters

Jeff Masters (Fig. 8.9) joined the Midlands Research Station in 1965, after completing a student apprenticeship and obtaining a 1st class Honours degree in Mechanical Engineering from the University of Wales.

He joined ostensibly to work on fluidised beds, but was beaten to the post by one week by another recruit and started to work on rapid heating machines. The work involved combustion, heat and mass transfer, fluid flow materials, mathematical and physical modelling and experimental techniques. To give a flavour of the period, hot wire anemometers were home made by butt welding two wires with a pulse of d.c. voltage using silver cigarette foil as a fusable switch. Despite the home spun technology the results were pretty good.

Fig. 8.9 Jeff Masters

The work rapidly moved on to field trials in the drop forging industry in places such as the Black Country and South Yorkshire. In these locations the images of a Dickensian past breathed new life, but we did have considerable success. Licences were signed and the technology became established.

Growth combined with staff turnover led not just to promotion but to rapidly increasing responsibility. This latter is often the case when there is growth in a new activity. Individuals have the freedom to expand their boundaries. The work soon embraced heat recovery and general high temperature process technology. During this period we established an excellent rapport with Regions, customers and manufacturers. We had a marvellous time collectively developing the technology, operating field trials, providing consultancy and commercialising the technology. This was to stand us in good stead for the next phase.

In 1975, the time of the energy crisis, British Gas needed to demonstrate it's commitment to energy efficiency. Jeff and Peter Chester, from Marketing Division were seconded to form a group called Radex to establish the technology of recuperative burners. Within one year one hundred recuperative burners and their associated systems were designed, and his team at the Midlands Research Station and the Regional TCS units who managed the field trials locally. The work ultimately led to the Royal Society Esso Award.

On his return to the Midlands Research Station Jeff requested a change to low temperature process heating, including combined heat and power. This soon involved a major national field trial programme on heat pumps again involving Regions and ably assisted by Jeff Pearson and his team. A paper on heat pumps was awarded the IGE Gold Medal.

In the 1970's the Energy Manager Groups were very active. Jeff hit on the idea of developing a computer based energy management competition along the lines of a business game. Robert Jones the Energy Conservation Coordinator supported the idea and the game was launched and ran for two years. In the first year the teams of three made energy management investments on an industrial site. The second year related to eight commercial buildings. Each month a league table was published with a sporting commentary by Jeff to maintain momentum. Prizes were given by the Minister at the Annual Energy Management Conference.

In 1986 Jeff became Manager of Heating Plant Division. The quality and effectiveness of the technical work continued to be paramount but more attention was paid to strategy, the business impact of technology, communications and developing even closer links with user Divisions in British Gas.

This work bore fruit following Jeffs appointment to Assistant Director in 1987. Links with Marketing Division were very close, the work was valued and investment in utilisation R&D increased steadily. Programmes on power generation, energy in buildings and air conditioning were initiated. The job also involved responsibility for Controls Division and safety work concerned with operating a NAMAS accredited laboratory and the associated testing, certification and defect reporting operation. In taking over the reins of this activity, Jeff had unstinting support from Roger Hancock and his team.

During this period Jeff represented R&D on the Research Coordination Council of the US Gas Research Institute, the Japanese Exchange, the European Gas Research Group, being a programme Committee chairman for four years, and the International Energy Agency. Also MRS received the Queens Award with Hotwork International for the development of regenerative burners.

It was clear that changes affecting British Gas would impinge on R&T. To ensure that the staff were prepared and the organisation appropriate Jeff initiated a management and culture change programme called Towards 2000. This was highly successful and led to a significant shift in appreciation of the challenges facing R&T and a change in structure. This was due in no small part to the efforts of the coordinator of the exercise, Neil Fricker.

When the new structure was announced prior to the move to the GRC. Jeff was appointed Programme Controller for Industrial and Commercial Utilisation. The company continued to change and what had been one customer became eight customers with very specific needs and limited budgets. This led to further changes but perhaps that story should be reserved for another 'history'.

Sport and Recreation

One of the first sports in which members of the Research Station actively engaged was Cricket. At least 5 of the staff played regularly for the Gas Officials Cricket Club 1st and 2nd XIs in the early 1950s (Fig. 8.10).
The earliest recorded involvement in the Wilkes Cup Competition, an inter-departmental cricket competition that had been initiated in 1928 within the West Midlands Gas Board area was in 1953 when a number of MRS staff joined the Central Laboratories team and won the Cup. By 1956 the staff levels at MRS were sufficient for its own team to be entered but not at that time of sufficient strength to win. Although MRS won the West Midlands Regional six-a-side Trophy in 1976, it was not to be until the early 1980s that the MRS name finally appeared on the coveted Wilkes Cup Trophy. During this period MRS appeared in the final four times and won the Trophy twice.

Building on this success, MRS have competed regularly in midweek matches against local teams, including Midland Bank, Powergen, Lyndworth, Jeavons, DHSS, and British Leyland. There has also been an annual fixture against RAPRA, who are based in Shrewsbury. The team, captained by Jim Thomas, has been very successful with notable victories over strong sides.

The story regarding football is of players from MRS joining the many local teams in and around Solihull. This situation has been the same as far as Rugby is concerned, but some MRS staff joined the Birmingham Gas Officials who later changed their name to Solihull Gas Officials (about 1975).

There is little on record concerning MRS football teams until 1983 when three MRS five-a-side teams reached the quarter finals of an interdepartmental competition. The original entry of 24 teams from WM Gas and MRS was won by MRS "B". By 1986 MRS teams had won the competition four times out of the seven years it had been run.

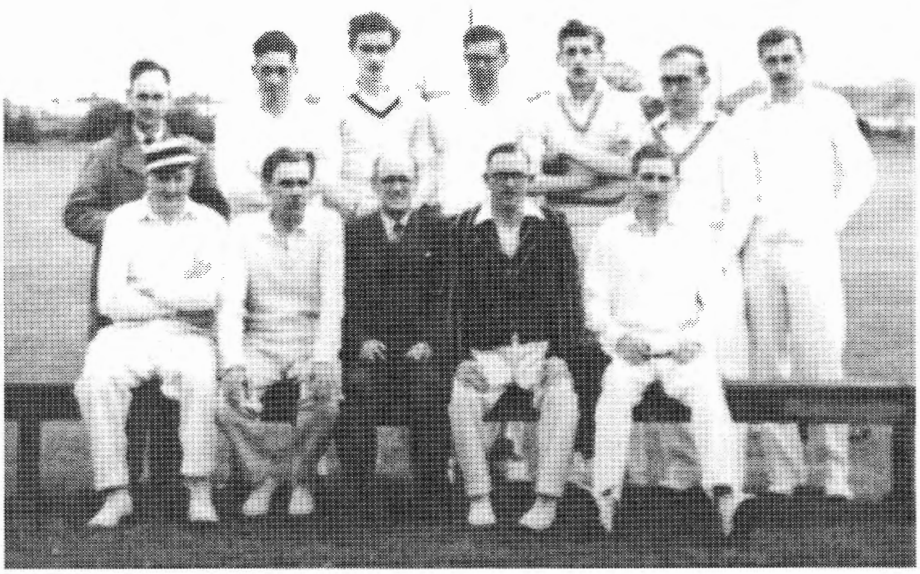

Fig. 8.10 The "Gas Officials" 2nd X1, around 1955. Among those standing in the back row are Stuart Burton, Eric Francis, Peter Cubbage and Les Taylor, all of MRS.

Athletics has been another sport in which many MRS staff have taken part. The London Marathon attracted runners as early as 1987, many entrants were sponsored and over the years many £000s have been raised for charity. At least 14 full marathons have been completed and approaching 100 half-marathons.

In 1988 the MRS Thriathlon was inaugurated: this involved an 800m swim, 15 mile cycle ride and 4 mile run. Twelve teams of 3 each took part. In 1989 a biathlon was added to the year's activities - being held in the winter, the swim was excluded. The individual winners were Dave Painter (men) and Dr. Rachel Palmer (ladies). With the move to Loughborough in mind, 8 staff entered the half-marathon there in 1990, 13 in 1991 and 12 in 1992. All recorded excellent times for the arduous event.

Competitors from MRS have entered a number of events organised by the local Branch of NALGO. In 1986 MRS had a team of 3 in the 6 mile Interbranch Road Race held at Great Barr, coming in 8th. In 1987 and 1988, they came second.

Although most of the sporting activities were for men, this merely reflects the large preponderance of men to ladies on the staff. The ladies however had a football team that played charity events as early as 1975. Solihull Gas Netball Team got off to a promising start in 1984.

Badminton provided the sport where international honours were achieved by Wendy Massam in 1986. Having reached the finals of the doubles in the English National Championships, she was chosen to play for England in the World Team Championships in Indonesia.

The first social event organised at the Research Station was a Bonfire and Firework party on 5 November 1955. This was most successful, and as one would expect at a Research Station, saw the launch of a novel firework, of which Guy Fawkes himself would have been proud. It consisted of a balloon filled with hydrogen attached to a rocket and squib so arranged that the balloon did not ignite until it was well up in the air. A loud explosion, appreciated by the crowd, was the end result. The firework extravaganza was followed by a meal that is recorded in the WMGB Magazine as providing "enough food to last our stomachs for days".

Although there were Fireworks parties in subsequent years, building on the site in Wharf Lane soon meant that there was insufficient open space and by 1962 these enjoyable occasions had to stop.

The first Staff Dinner of the Research Station was held in January 1956 and was repeated on an annual basis for many years. A wide variety of other events, canal trips, theatre trips, car rallies etc. have been organised over the years.

Membership of the WM Gas Social and Recreation Society provided the finance and impetus for the many activities available to MRS staff. The facilities at Hollyfield, Lord St. and elsewhere were all on offer and the debt owed to West Midlands Gas for providing these facilities is gratefully acknowledged.

There are many other activities that although not mentioned above were taken part in by MRS staff and space restricts detailed accounts. For instance, bellringing and sailing.

CHAPTER 9

The Flames Lecture

Chapter 9

The Flames Lectures

Introduction

The Institution of Gas Engineers had been organising annual Christmas Lectures since 1952, and in January 1964 Bill Simmonds, Peter Cubbage and Dave Moppett attended a Flames Lecture, at Coventry Technical College, given by Mr Jimmy Cooper of East Midlands Gas. This was the last Jimmy Cooper was to give, since he decided to give it up and had persuaded Bill Simmonds to take over the role of Lecturer. Bill told Dave Moppett that he had less than 12 months to make the necessary demonstration equipment for a revised lecture he was about to write. The theme of the the lecture was to be "What is a Flame?", the answers illustrated by suitably spectacular demonstrations (Fig.9.1).

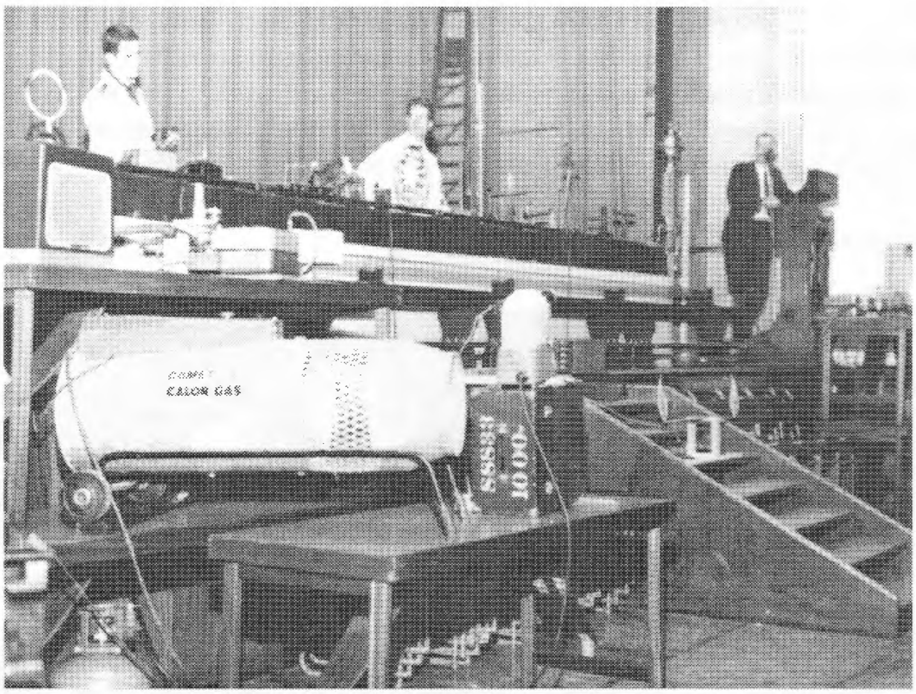

Fig. 9.1 Science of Flames. Bill Simmonds at the rostrum, John Newby and Dave Moppett demonstrating, circa 1965/6.

The first of the MRS lectures was given in 1965, in London, and in the intervening years, over 100,000 people, mostly schoolchildren, have seen one of the lectures and over 400 have been given. Peter Cubbage gave a full account of the lectures in his Chairman's Address to the Midland Section of the IGE (Gas Eng. Man. 1979.19.603), and Dave Moppett has brought the story up to date. Only a brief account is possible here.

The Lecture Content

The lecture was designed to be both entertaining and educational, and in order to hold the attention of schoolchildren for any length of time had to be visually exciting and fast moving. Accordingly the script was illustrated by a series of demonstrations, and sometimes by film clips. The general themes remained constant although the emphasis has varied over the years, presenting the chemistry and physics of flames, the combustion of solids, liquids and gases, but concentrating particularly on the latter of course. Safety and control in the use of gaseous fuels was also a strong content and in recent years there has been an emphasis on energy conservation.

Noisy and spectacular demonstrations were essential. Tunnel burners, pulsating combustion and rocket motors and a traditional small gas engine were all used. Flame propagation through tubes was used to illustrate the concept of flame speed, culminating in a detonation, and a series of gas explosions in balloons ended with a gas-oxygen explosion which was usually a "show stopper". On one occasion, this item resulted in a cloud of dust descending from the roof of the auditorium reducing visibility almost to zero. However the lecture continued and when the lights went up it became obvious that only by the application of a lot of soap and water and hair shampoo would anyone present ever be clean again.

Flashback was illustrated by a flame lighting back through a hole in the base of an upturned treacle tin full of air gas mixture, the tin being projected into the air by the exploding mixture. In an early lecture at the old Birmingham Technical College in Suffolk Street, the experiment went so well the treacle tin chipped a flake of plaster off the proscenium arch.

Rocket propulsion was demonstrated with the aid of a model plane powered by a Jetex solid fuelled motor, flown from the stage along a nylon cord stretched to a balcony above the audience, where it was to be caught by a member of the team. On one occasion he failed, the model bounced back, burned through the thread and fell to the polished parquet floor, where the burnt outline is still visible.

The Lecturers and Demonstrators

Bill Simmonds acted as Lecturer for the first few years (Fig. 9.2), and then handed over to Peter Cubbage in 1967 (Fig. 9.3). Dave Moppett was engaged from the start in preparing many of the experiments and in acting as demonstrator. His selection for this task was due partly to the fact that his hobby was and still is, stage managing amateur dramatics, and also to his known ability to overcome obstacles and get things done no matter whose toes were trodden on.

Fig. 9.2 Science of Flames. Early lecture c. 1965/6 with Bill Simmonds surrounded by young admirers.

The Cubbage/Moppett team were responsible for over 100 lectures in the period up to 1980, when they were joined by Steve Hammond as demonstrator (Fig. 9.4), who was present on another 50 occasions until he left the Company in 1989. From 1983, it was decided to use a closed circuit video system, usually operated by Dave Moppett, to project an enlarged image of the bench experiments on a screen to make some of the smaller items more visible to audiences.

Fig. 9.3 Science of Flames. Peter Cubbage with more young admirers and some of the demonstrations, including the famous golden syrup tin which illustrated flame flashback.

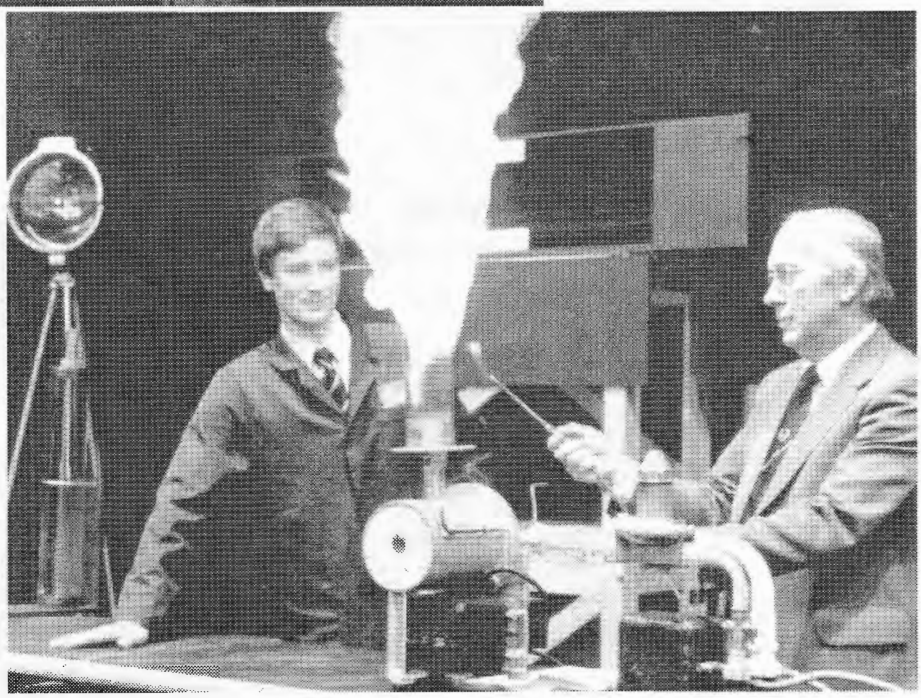

Fig. 9.4 Science of Flames. Cardiff 1974 or 76. Peter Cubbage with Steve Hammond. Steve and Dave Moppett shared most of the demonstration duties for lectures in the 70s and 80s.

After Peter Cubbage retired in 1989, the running of the lectures was bequeathed to his successor as Manager of Special projects Division, Bob Harris and more recently to Malcolm Wickens (Fig. 9.5).To spread the load, Malcolm has inaugurated a team of lecturer/demonstrators, including among others, Barbara Lowesmith and Phil Sims,with the camera work shared by R.W.Hill, C.S.Hawkins and M.G.Toy.Mention should be made of the contributions of the fitters, one of whom was often included in the team to assist with setting up the equipment, enough to fill a removal van, before each lecture and breaking it down afterwards. H. Kirby, L. Henry, F. Paul and R. Beeks were among those who assisted.

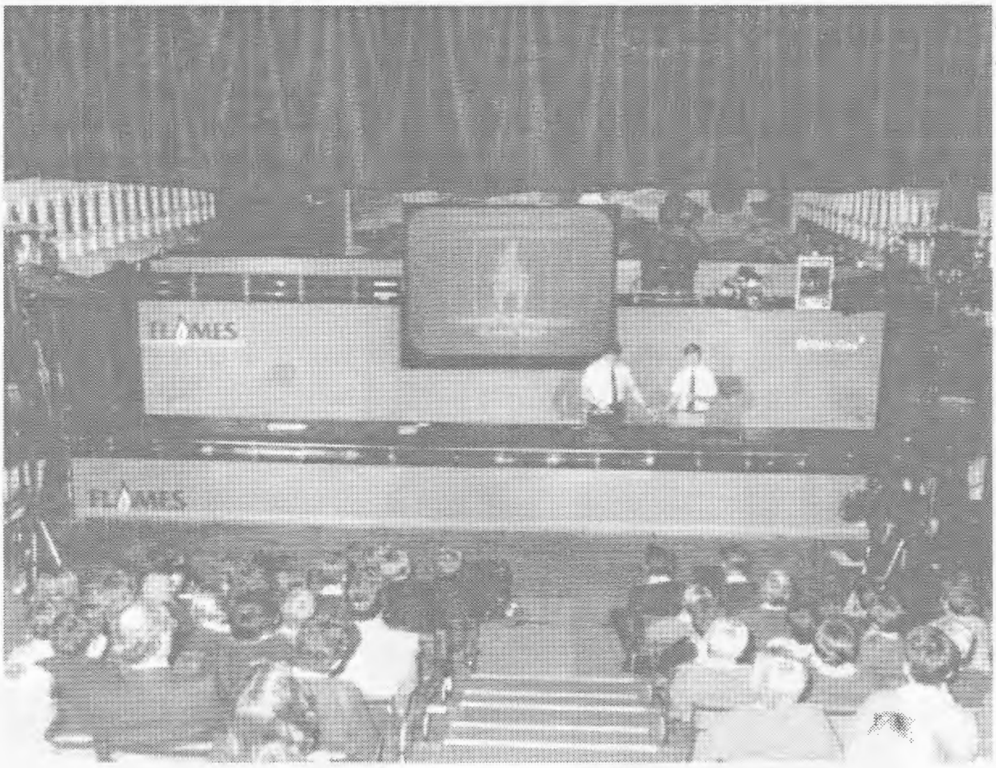

Fig. 9.5 Science of Flames. The format in 1990.

Prestigious Events

Most of the lectures in the earlier years were sponsored by the IGE Sections, principally the Midland, Scottish and Manchester and District Sections and held in a variety of types of venue, including a circus ring and a gymnasium, with a stage consisting of two wrestling rings.

In 1981 Sir Denis Rooke was President of the Association of Science Education (ASE) and requested that the Flames Lecture be presented as an adjunct to his Presidental Address to the ASE Annual Meeting at the University of Kent in Canterbury. This was the first time that a video camera and screen were used to enhance the show, which was presented three times to audiences of 350 or more. Dr. John Gray and the R and D Directorate attended one of the shows.

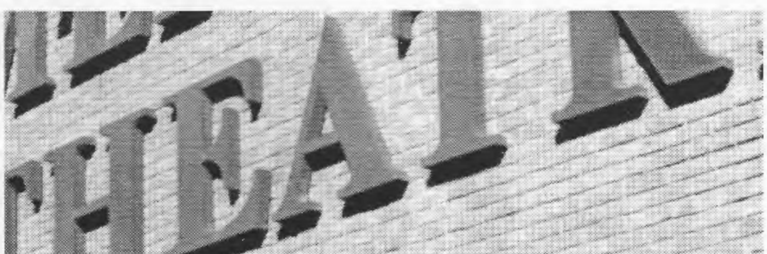

Fig. 9.6 Science of Flames at the Molecule Club, 1983.Peter Cubbage, Steve Hammond, Bill Simmonds and Sir Bernard Miles pose outside the Mermaid Theatre.

In late 1982, Bill Simmonds was brought out of retirement to present a special performance at the instigation of Sir Denis.

In 1983, Bill was also recalled for a performance at the Molecule Club in the Mermaid theatre on the Embankment (Fig. 9.6). This was memorable in that Sir Bernard Miles took over the rehearsal and gave Bill some free lessons in the dramatic art of voice projection.

1986 saw the first of two visits to the USA at the invitation of the US National Science Teachers Association, to take the lecture, which they had seen at the ASE Meeting, to the NSTA annual meeting in San Francisco. A lot of practical problems had to be overcome, such as the different mains frequency and voltage, different video standards and different gas cylinder threads, but these were all solved and the lecture was successful enough for them to be invited back again the following year to the meeting in Washington D.C.

The Packaged Lecture

Another outcome of the ASE lecture was the recommendation that a packaged version should be prepared which could be readily taken round to any School venue and presented by Regional personnel selected for their technical knowledge and presentational skill. A prototype kit and script were prepared at MRS and presented to an audience of high level Regional representatives (Deputy Chairmen), who were impressed enough to give a commitment to support the idea.

Fifteen sets of equipment were then constructed and the task begun of training pairs of demonstrators from the all the Regions. A performance assessment took place with very variable results, but some Regions got off to a good start. Although the commitment from the Regions has been as ever, very variable, the exercise was reasonably successful and in some areas the lecture is still on offer to schools.

HISTORY OF MRS

PART 3: THE TECHNICAL ACHIEVEMENTS

A feature of R&D at MRS has been an evolutionary approach, whereby certain long term aims have been pursued by further development of techniques which have already been used in a series of shorter term objectives. This has provided a valuable continuity of technology and scientific background.

For example in the field of gas production, the long term aim has been the efficient conversion of fossil fuels to gas of an appropriate quality. The technology has involved large scale high pressure chemical reactors, and the scientific background is in chemical reactions at high temperature and pressure, catalysis, analytical techniques and modelling for scale-up.

In the field of Industrial Utilisation of gas, the long term aim has been the improvement of efficiency and ensuring safety. This meant covering the great variety of heating processes employed in industry and commerce, eg. furnaces for metal and ceramic treatment, melting, water heating, steam raising, air heating, drying, power generation etc. The common scientific background is in combustion, heat transfer and aerodynamics.

In this Section the aim is to cover the principal technical achievements by a series of narratives which follow the progress of a particular line of R&D from its inception to the present day. Each contribution has been written by one of the senior researchers who has been intimately involved with the project.

CHAPTER 10

Gas Production

10.1 Slagging Gasification

J.A.Lacey

Background

In the 1950s, the manufacture of towns gas was largely based on the use of coal. There were many small gas works in use because the integration of gas production into larger, more efficient units had only just begun. The industry was severely handicapped both by the high price of coking coals and the poor financial return from by-product coke and breeze. Complete gasification of coal offered a solution and plans were well advanced to build Lurgi plants at Westfield and Coleshill, with the expectation that they would do much to restore the image, the prestige and the profitability of the industry.

The Lurgi process enabled weakly caking coals to be completely gasified with steam and oxygen at pressure under non-clinkering conditions so that dry ash could be discharged via a grate at the bottom of the gasifier. A large excess amount of process steam had to be used to prevent the ash from fusing and this adversely affected the efficiency. Investigations using a small pressure gasifier at Nechells showed that the efficiency and the throughput of a gasifier could be substantially increased by operating without the excess steam, such that the ash melted to form a liquid slag(1).

The idea of a slagging gasifier was not new. Lurgi had built a pilot plant slagging gasifier at Holten, Germany, in 1953, but abandoned the work without making significant progress. Their experimental unit was purchased by the Ministry of Power and, in view of the Gas Council's interest in slagging gasification, it was installed at MRS in the pilot plant building (Brunel).

The gasifier comprised a refractory-lined pressure shell, about 6 m high with an internal diameter of 1 m with a slag tap branch at the bottom of the vessel, through which slag flowed into an adjacent quench chamber. This unit was used, from 1956 to 1958, to gain operating experience on slagging gasification at 5 bar pressure, using coke as the feedstock(2).

The plant was modified to operate on coal at 20 bar pressure and was installed in an outside location in 1962(3). The work programme was completed in 1964 and then shelved because of the advent of a new generation of processes based on the catalytic gasification of petroleum distillate with steam.

The slagging gasifier development lay dormant for ten years until the great worldwide resurgence of interest in coal gasification following the 1970s oil crises. In 1974 work on the scale-up and further development of the slagging gasifier was restarted when a group of oil, gas and pipeline companies from the United States agreed to support a project at Westfield, Scotland(4).

Technical Objectives

The initial technical objectives of the work at MRS were to show the feasibility of operating a fixed bed gasifier at pressure under slagging conditions and to identify the process and engineering problems. The second phase was to obtain performance data on coal to enable comparisons to be made with the Lurgi process and to develop the technology to the stage from which it could be scaled-up to a commercial size unit.

The Technical Approach

The pilot plant gasifier, as bought from Lurgi and installed at MRS, is shown in Fig.10.1.1. Coke was supplied to the top of the reactor through a lock hopper and a mixture of steam and oxygen was injected through tuyeres into the base of the fuel bed to create an intensely hot combustion zone in which the ash melted to form a slag. The slag collected in a refractory hearth and was discharged through a refractory tube into an adjacent chamber where it was quenched in water. Lurgi had found that satisfactory slag flow required a discharge rate of more than 450 lb/hr. To achieve this high mass flow rate, blast furnace slag was added to the coke to increase the amount of slag and it was discharged intermittently. Control of the slag flow was achieved by the use of a burner located at the end of the slag tap tube.

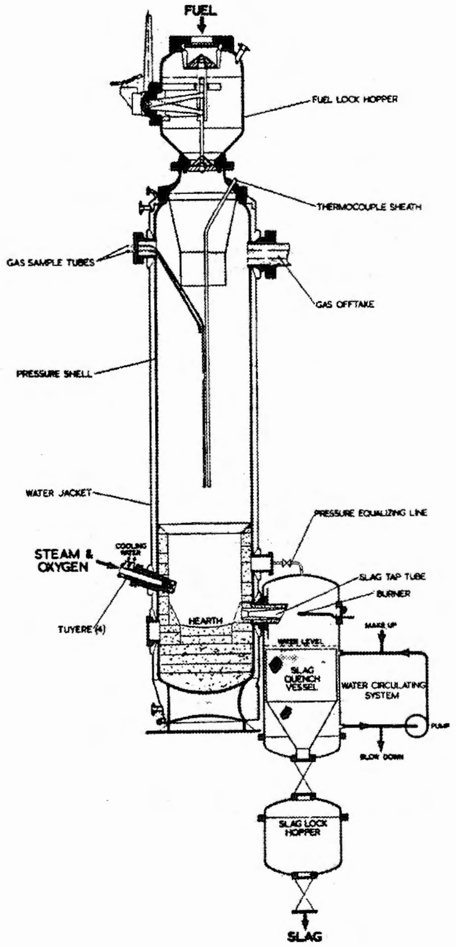

Fig. 10.1.1 Cross-section of the Gasifier, showing the first slag tap arrangement.

Several variants of the slag tap and the slag tapping system were investigated. One of the main problems was the devastating effect of liquid iron, formed by the reduction of iron oxide in the coke ash, upon the gasifier components. The final arrangement is shown in Fig.10.1.2. The hearth was lined with carbon tiles to counteract the effect of liquid iron and the slag was discharged through a silicon carbide tube. A run of 50 hours duration was achieved, proving both the feasibility of slagging operation and the concept of intermittent slag tapping.

Major design changes were then made to the gasifier and the pilot plant was rebuilt together with full supporting services to operate on coal at 20 bar pressure, at a cost of £225,000. One of the most important changes was to replace the flat hearth with a side slag offtake by a hearth that drained to a central slag tap pointing vertically downwards. The design gradually evolved to that shown in Fig.10.1.3. A water-cooled slag tap that allowed a protective layer of frozen slag to form on its surface was used.

Located below the slag tap was a burner from which hot combustion products passed upwards through the slag tap to hold back the slag in the hearth. Slag was withdrawn through the slag tap by stopping the burner and reversing the differential pressure across the hearth, the slag dropped into the quench water to form glassy frit that could be removed through the bottom lock hopper.Slag flow was stopped by re-lighting the burner and restoring the differential pressure across the hearth by directing hot gases through the slag tap. This system was developed to the point where it operated automatically and produced slag of consistent flow properties over a period of several days.

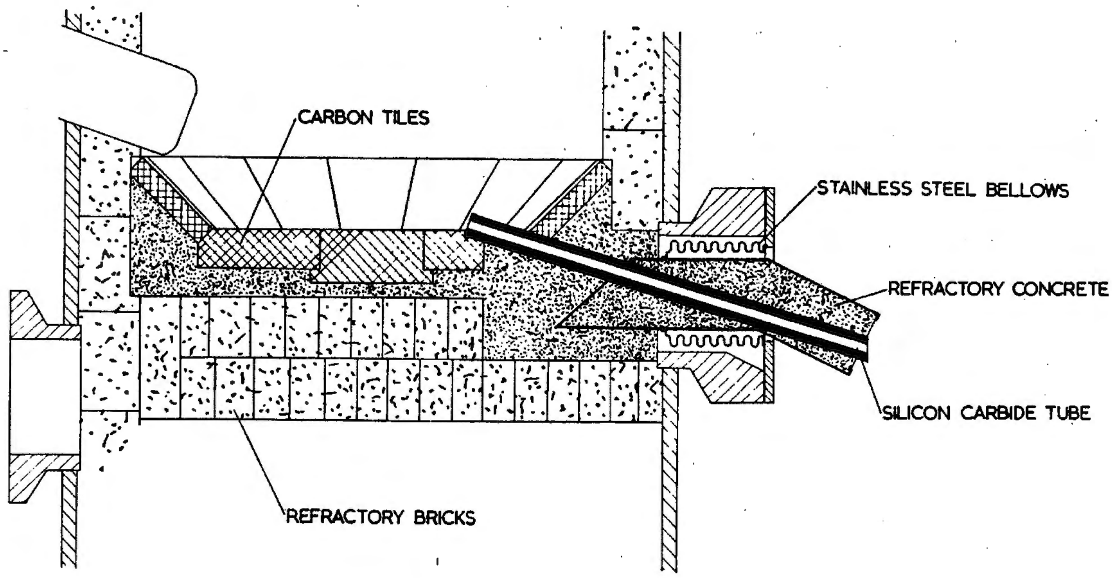

Fig. 10.1.2 Arrangement of the hearth when lined with carbon tiles.

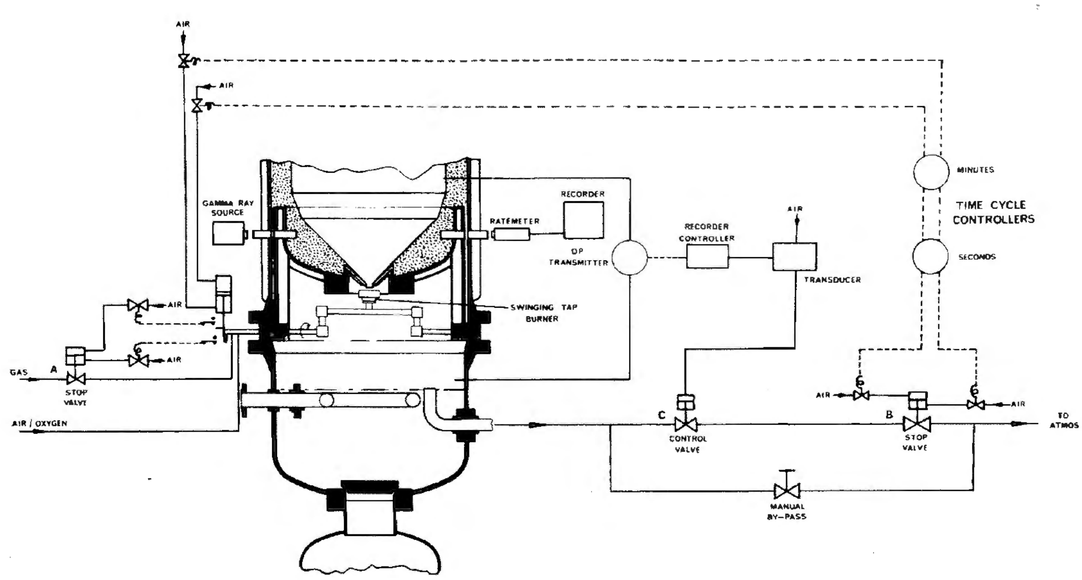

Fig. 10.1.3 The automatic control system for tapping slag.

The trials on coal at MRS confirmed the earlier predictions of the potential advantages of the slagging gasifier; the process steam consumption was reduced by more than 80% and the thermal output per unit cross-sectional area of the gasifier was four times greater than experienced on Lurgi gasifiers using bituminous coal. However, at the end of the second phase of development there were still some unresolved problems of containing very hot slag and liquid iron for long operating periods. The use of water-cooled components in the hearth region which would be self-protecting by solidifying a layer of slag on their surface offered a viable solution.

The Westfield Programme

The opportunity to continue the development of the slagging gasifier arose ten years later when a group of US oil, gas and pipeline companies agreed to support and fund a project at Westfield. One of the Lurgi gasifiers previously used to make town gas was converted to operate under slagging conditions; this involved replacing the grate by a hearth and tuyeres, reducing the diameter of the gasifier from 10 to 6 ft with a refractory lining because of the limited supply of oxygen from the air separation plant, and fitting twin gas offtakes at the top of the gasifier.

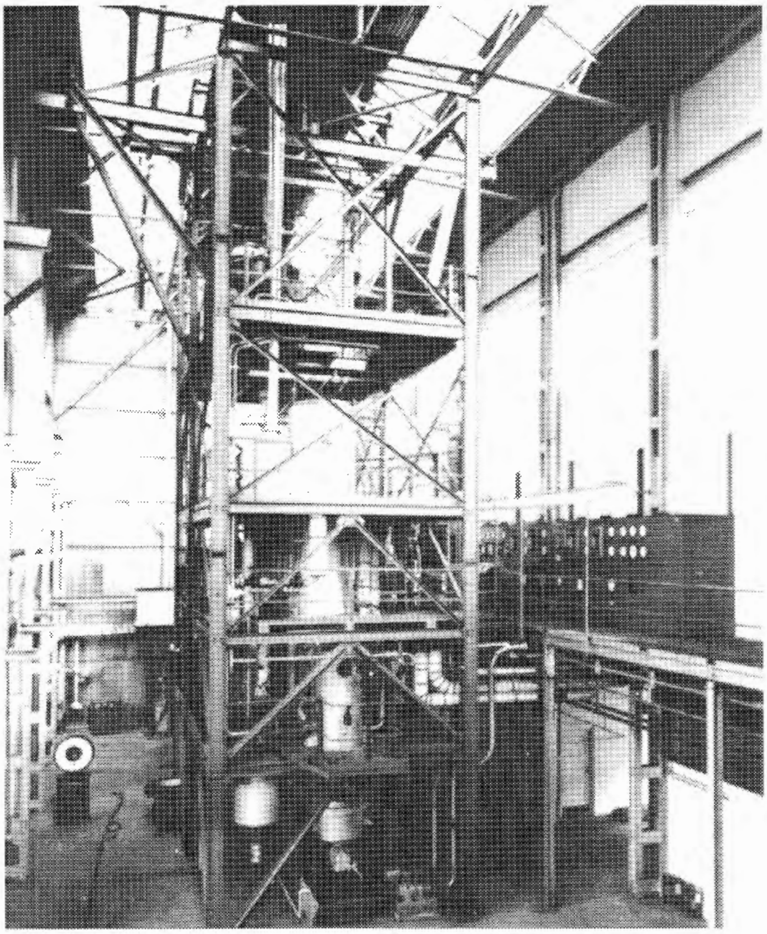

Fig. 10.1.4 Slagging Gasifier at Solihull.

The basic ideas generated at MRS were incorporated into the design of the Westfield gasifier and progressive development of the technology took place from 1975 to 1983. The performance of the gasifier on a wide range of coals was determined, techniques for gasifying fine coal, e.g. by agglomeration and by injection at the tuyeres, were investigated, and the response of the gasifier to load changes that might be experienced in power generation applications was demonstrated. Finally, a demonstration run of 90 days duration to prove the gasifier components was carried out(5).

A commercial scale gasifier with a diameter of 7.5 ft and a deeper fuel bed and a throughput of 500 tonnes/day of coal was commissioned at Westfield in 1984, and was used until the end of 1990. Two main features of the programme were: the successful demonstration, over 60 days, of gasification, gas purification and upgrading of the gas to SNG, and, a 40 days demonstration of the gasification of power station coals. Finally, in 1991, the operation of an experimental gasifier at pressures up to 70 bar, to enhance methane formation for the production of SNG, was successfully accomplished.

Exploitation/Benefits

The slagging gasifier has been developed to the stage that enables it to be exploited for commercial use for the production of a clean fuel gas for power generation, and for SNG. The cost of power generation using the slagging gasifier is already competitive with that from a conventional coal-fired plant fitted with flue gas clean up, but the large scale use of natural gas for power generation for the foreseeable future means that no new coal-fired plants will be required in the UK until beyond 2000 AD. However, there are good prospects that the technology will be used overseas in the near future. Detailed studies have shown that the overall efficiency is more than 43% when the slagging gasifier is integrated with a combined cycle power generation plant and up to 75% for making SNG, while meeting all environmental requirements. It is envisaged that commercial gasifiers will operate at 30 bar pressure and have a throughput of 1500 tonnes of coal/day.

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10.2 MRS Activities at Westfield

Haydn Davies

Background

A small team of research engineers comprising mostly chemical engineers and under MRS direction was set up at Westfield in 1981 to support the Coal Gasification Programme. It's prime responsibility was to develop the technology for the downstream treatment of the gas from the BGL gasifier viz, Acid Gas Removal, Methanation and the purification of the aqueous liquor. They were also responsible for the further development of the gasifier at pressures up to 70 bar. The work of the group at Westfield is one of MRS's success stories and provided possibly the last opportunity of direct involvement with large scale, challenging, world leading Chemical Engineering development work.

Aqueous Liquor Treatment

Process studies undertaken at MRS showed that of the three process options of catalytic oxidation, incineration and the conventional route of phenol extraction, dissolved gas stripping, biological oxidation and activated carbon absorption, the conventional route offered the cheapest option by some margin for SNG production. Process data was obtained for all routes to substantiate these findings. Lurgi and the Coal Research Establishment at Stoke Orchard did contract work to provide information on their incineration options. The Osaka Gas Co in Japan showed the capabilities of catalytic oxidation.

To demonstrate the purification of liquor by the conventional route and supply process design information, a plant of one ton/day throughput was constructed at Westfield. To ensure that liquor of constant quality was available for long periods, a three month supply of liquor of appropriate composition was stored in a Nitrogen blanketed tank. A typical liquor composition would be:

COD	20,000	mg/l
TOC	5,500	"
Free NH3	550	"
Fixed NH3	6,500	"
Phenols	5,500	"
Carbonates	7,500	"
Chlorides	1 to 5,000	"
Cyanides	100	"
Nitrates	200	"
Sulphides	3,200	"
Thiocyanates	1,000	"
Trace elements(total)	45	"

and the objective of the development work was to reduce concentrations to the extent that either the purified water could be discharged directly to a river or a "Zero Discharge" option could be followed by using the product on the plant eg boiler feed water. The conventional route described above was successful in reducing the phenols, dissolved gases and thiocyanates to low levels but the chlorides and other salts had to be removed. This was achieved by the novel and pioneering use of Reverse Osmosis which, when used as a final process stage, produced a very pure water. It was also shown that by replacing the activated carbon, biological oxidation and fixed ammonia removal stages with reverse osmosis a simpler process could be used to achieve zero discharge.

Acid Gas Removal

Before gas from a coal gasifier can be converted to methane the sulphur-containing acid gases must be removed. The well established Rectisol process, which uses refrigerated methanol, had been successfully demonstrated at Westfield for this purpose with gas from dry bottom Lurgi and BGL Slagging gasifiers. However,the Rectisol process is expensive to build and operate and process studies indicated significant savings if a physical solvent process could be used operating at near ambient temperatures.

To study these solvents and processes an Acid Gas Separation Pilot Plant was built at Westfield (AGSPP). The plant had a throughput of one million SCFD and could operate at up to 70 bar pressure. It could run either directly in line with the gasifiers or in a recycle mode. There were separate sections for naphtha and sulphur removal and different solvents could be used independently in each. Solvent regeneration in each section was effected by a combination of flashing to low pressure and steam heating. As well as the main gas, acid gases after removal could be collected and recycled.

The work was highly successful in that a number of solvents were tested and shown to be ideal for acid gas removal from Slagger gas before subsequent methanation or generation of power. Two solvents; Selexol (Di-methyl ether polyethylene glycol [DMEPEG]) and Purisol (N-methyl-2-pyrrolidone [NMP]) were shown to be suitable for naphtha removal. Purisol and Selefining (a mix of NMP and N,N-Dimethylethanolamine [DMEA]) were the two solvents tested for sulphur removal. Selefining would be preferred because it was effective in removing all sulphur down to very low levels. Purisol, however, was only able to remove about 40 to 50% of the COS leaving about 300 ppm in the purified gas. An interstage COS Hydrolysis plant would be needed with this solvent.

The plant was run whenever possible in line with one of the gasifiers. Between gasifier campaigns the AGSPP often ran in recycle mode with Nitrogen as the bulk gas spiked with H2S and/or CO2. Valuable modelling information was obtained by these means.

Methanation

The MRS Westfield team were responsible for the technical direction of the 60 day HICOM demonstration and the data retrieval and final report. A feature of the run was the sidestream unit, a 1′ inch diameter reactor which ran in parallel with the main reactor. The two vessels were therefore always on line together, for the same length of time with exactly the same feed gas and were subjected to the same conditions of start up, running and shutdown. The test proved that catalyst performance from laboratory rigs and commercial reactors are very similar and that pilot plant results can be used for scale up with confidence.

Much of the catalyst testing and screening was done at MRS but it was necessary to check catalyst performance with "real" gas from the gasifier. This was done by storing gas from a BGL Gasifier at high pressure, desulphurising the gas with solid absorbants in a small purification plant and methanating the gas in a 1′ in. reactor similar to those at MRS. It was shown that "real" gas had no determinable affect on catalyst performance.

The High Pressure Experimental Gasifier

The fourth area of responsibility was the further development of the BGL gasifier at high pressure. A highly instrumented "Experimental Gasifier" with advanced sequence and computer control, a throughput of 200 tons/day at 70 bar and purpose built for the derivation of yield information and data retrieval was designed and engineered by Westfield R&D projects, MRS and Development personnel and built by Construction department. The unit was commissioned in December 1990 and operated at increasing pressures, terminating at the end of the programme at 70 bar. The team monitored progress of construction, assisted Plant Operations where possible, especially in the sequence control of the plant and played a lead role in determining the liquor balance over the plant.

10.3 Gasification Reactor Modelling

A.R.Tait

Background

When the SNG programme got underway in the early seventies it was recognised that successful scale-up would demand a clear understanding of chemical reaction engineering principles. This need represented an opportunity for a modelling contribution to process development. Modelling at that time tended more towards the physical rather than the mathematical form. This usually involved the application of dimensional analysis to identify criteria, usually in the form of dimensionless groups, which could be used to design small scale isothermal experiments which could be carried out at room temperature and pressure. These would be used to make measurements of transport phenomena which could not be investigated on a real plant.

However, the early seventies represented the time when mathematical modelling techniques were becoming more accessible. Computing power was advancing rapidly and engineering graduates with a working knowledge of computer simulation techniques were also beginning to emerge from university departments. This complementary set of circumstances led to the application of both physical and mathematical modelling techniques to the development of gasification processes at MRS

Technical Approach

From the start a commitment was made to develop mechanistic rather than phenomenological models which, although useful, would have limited application outside a tried and tested envelope of pilot plant operating conditions. It was envisaged that these models would be a powerful tool to assist process development and the initial objective was to provide a demonstration of how reactor performance might be maintained, or even improved, on scale-up. However, as modelling techniques advanced and the application progressed from one gasification process to another, so the value of modelling was recognised more widely and it was able to play an increasingly prominent role in the overall programme.

Mathematical models cannot be generated in a vacuum. No matter how good their theoretical base they still need fundamental data and they must be validated. The mathematical models have been seen as providing the link between plant data, fundamental experiments on, say, coal chemistry, physical modelling of, say, flow patterns and, of course, basic theory, as indicated by Fig. 10.3.1 (1), These interactions represent a consistent theme which has run through all the reactor modelling at MRS.

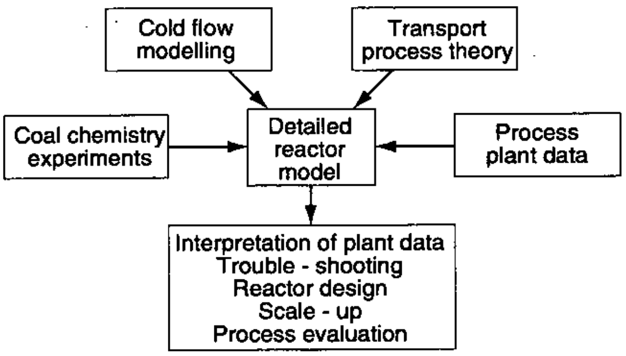

Fig. 10.3.1 The concept of reactor modelling.

Modelling the GRH Reactor

The first process to be modelled as a chemical reactor was the Gas Recycle Hydrogenator (GRH), a gas phase system with forced recirculation in which relatively light oil fractions reacted directly with hydrogen. The way in which the problem of simulating the process was approached set the scene for future modelling exercises. Although the gas flow patterns within the reactor were perceived as playing an important part in its performance the computing power required for full CFD-type simulation simply was not available. It was decided, therefore, to treat the fluid flow in a relatively simple manner and to couple this with classical chemical reaction engineering. In fact, this worked very well and it was not even necessary to combine these models in the same computer code. A simple pressure and momentum balance was used to calculate the ratio of gas recirculating around the vessel to that entering it. The validity of this approach was demonstrated by comparison with data obtained from cold flow experiments in a perspex model. Some of these results are shown in Fig. 10.3.2 (2).

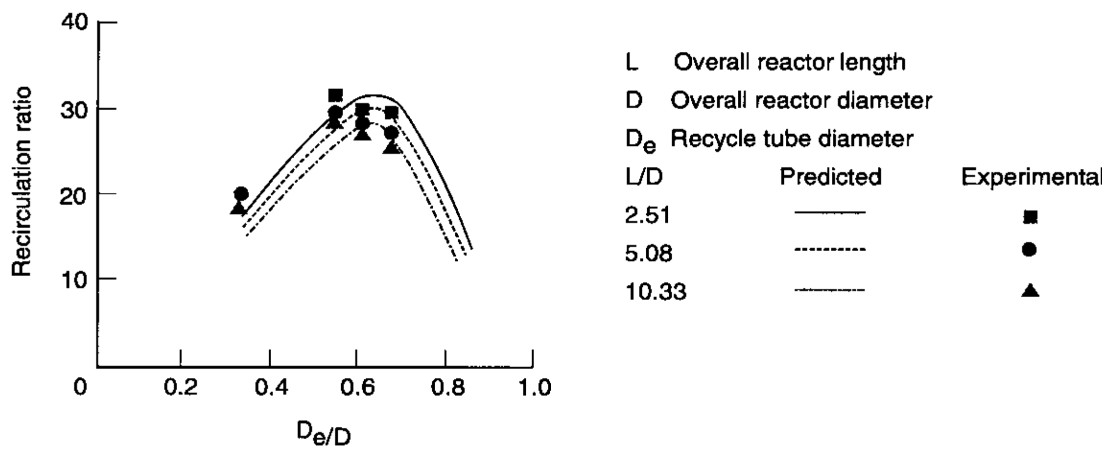

Fig. 10.3.2 Variation of recirculation ratio in a GRH vessel with recycle tube/reactor diameter ratio.

The calculated values of recirculation ratio were then used as input to a second model in which chemical reaction rate equations were solved in a linked series of well-mixed and plug flow zones. At that time it was extremely difficult to identify all the chemical species within the feedstocks and a rigorous approach to the break-up of long chain molecules was not practical. Instead, pilot plant data was used to generate empirical correlations for this part of the process. The formation of methane by the hydrogenation of the lighter hydrocarbons was dealt with in a more fundamental way and reaction rate equations were solved using published rate data.

This combination of the flow and chemistry models was tested against a range of pilot plant data and the product gas compositions were found to be in remarkably close agreement. The fact that it was shown that it was not necessary to model everything simultaneously was very significant and this "integrated" approach to reactor modelling has permeated through all the subsequent programmes. The flow model indicated that since the reactor operated with a high internal recirculation rate it was effectively a well-mixed system. The chemical reactor model demonstrated that as a result of this, combined with its highly exothermic nature, the GRH exhibited symptoms of the classic "multiple-steady states" phenomenon associated with this type of system. Furthermore, the model indicated that at the preferred commercial operating condition the reactor would be in meta-stable thermal equilibrium where the potential for temperature runaway would be high. A dynamic model was written to investigate whether conventional control systems could prevent this. The conclusion was that they could not and that there was a range of conditions inside which a commercial reactor could not operate. This was later confirmed by experience from peak load plant which operated for a short time on a few sites in the UK.

Modelling the FBH Reactor

The development of the GRH process overlapped with that of the Fluidised Bed Hydrogenator (FBH), designed for gasifying heavier oil fractions. Exactly the same approach was taken to modelling the FBH, with the added complexity that the flow model had to incorporate terms describing the hydrodynamics of fluidised beds. The flow model was validated by comparison with data from small scale fluidisation experiments. By this stage analytical techniques had improved and it was possible to incorporate a more detailed reaction scheme in the chemical model, including the break-up of multi-ring compounds in the heavier oil fractions. A thermal stability and control system analysis was carried out but in this case it was found that the large inventory of coke used to form the fluidised bed provided enough thermal inertia to prevent temperature runaway.

It was recognised that the key to the commercialisation of the FBH process would be the ability to predict how the fluidised bed would behave on scale-up. Unfortunately, fluidised beds are notoriously difficult to scale and so a decision was taken to build a large scale fluidisation facility at Coleshill. The bed was roughly 1.5m in diameter and 10m deep with an inventory of about 20000kg. It was very well instrumented and a mass of unique fluidisation data was collected on it.

Modelling of Coal-based Processes

The window of opportunity for a commercial FBH process was closed before any were built and by the end of the seventies attention had swung back to coal as a potential feedstock for gasification processes.

The modelling of coal-based processes represented the most ambitious programme of modelling undertaken up until then. The programme really got underway at MRS in response to the need for some trouble-shooting at Westfield. Gasifier operations were being seriously disrupted by the deposition of molten slag in the slag removal system. Model experiments at MRS demonstrated that the problem was caused by an unusual gas flow pattern and that it could be cured by a redesign of the internals of the slag quench chamber. These modifications were incorporated into the Extended Slagging Gasifier (ESG) which was built at Westfield in the early eighties. The success of this work prompted the decision to build a one-third scale acrylic model of the gasifier to be used to visualise and quantify gas, liquid and solids flows in various parts of the gasifier. The model is shown in Fig. 10.3.3 (2).

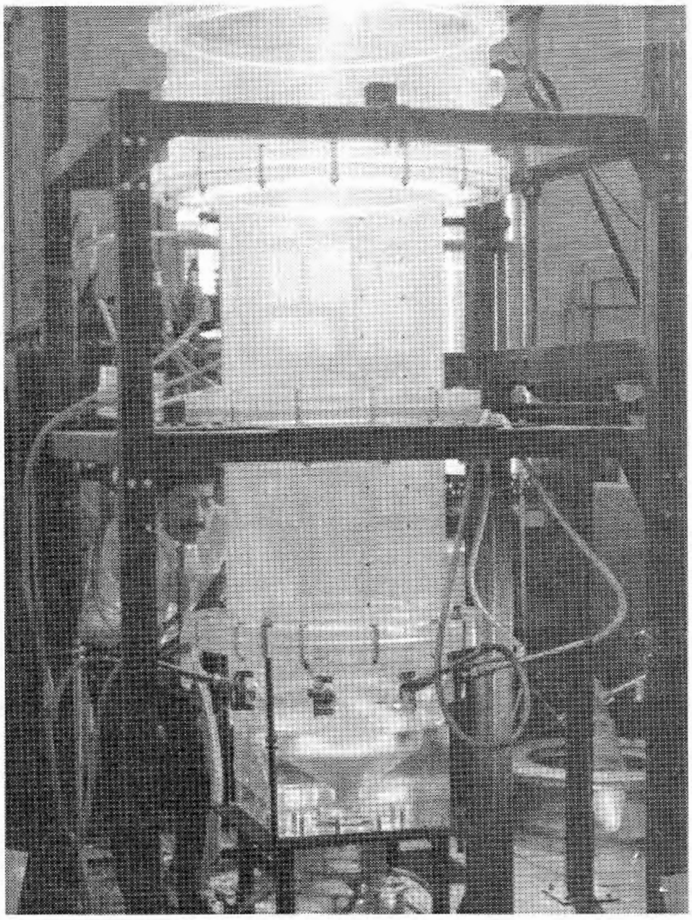

Fig. 10.3.3 One third scale model of the slagging gasifier.

In parallel with this physical approach, mathematical modelling techniques were beginning to be applied to the gasifier, initially in response to materials problems in some of the water-cooled gasifier components. It appeared that these components were suffering from local overheating, or hot-spots. In order to determine whether these defects could designed out, detailed heat conduction calculations were required. These had to be done in complex two and three-dimensional geometries. It was at this time that finite-element techniques were starting to be applied to these types of problem and a proprietry code, BERSAFE, was purchased from the CEGB to attack these problems. This proved very successful and new designs of slagtap, hearth and tuyeres were assessed before they were manufactured and installed on the gasifier. These components were shown to have very long lifetimes during the gasifier trials which followed. Work started on a detailed mathematical reactor model of the gasifier in about 1983. The first versions of the model was produced in 1985 and although this was a major achievement given the complexity of the process, nevertheless, it still contained many simplifications which had to be addressed. From this point on virtually all the modelling effort was directed towards improving the model so that it could be used for design, optimisation and scale-up. Separate programmes to investigate coal devolatilisation, char chemistry, gas flow patterns, solids residence time distributions (3), heat transfer mechanisms (4) and numerical techniques (5) were put in place at MRS, LRS and at Leeds, Exeter, Nottingham, Heriot-Watt and Cambridge Universities. These were timed to reach fruition by 1990 when the information was drawn together to form the final version of the model. The validity of this model was demonstrated by extensive comparisons with performance data from Westfield.

The key to the value of the resulting model was its ability to calculate internal gasifier temperature, composition and flow distributions as shown in Fig. 10.3.4 (1). This has enabled it to be used to analyse and explain unusual phenomena observed on the gasifiers at Westfield, to aid in the design of components for those gasifiers, to predict performance data for novel feedstocks, such as sewage sludge, and untried coals, such as those from Spain and South America. It has also been used to predict the performance of very large gasifiers proposed for power generation schemes and for optimising gasifier design.

Finally, the model equations were translated into a time-dependent form and this simulation of gas flows in packed beds has been applied to the modelling of gas separation processes, and the general principles of reactor modelling have since been applied to the simulation of fuel cell systems and methane reforming schemes.

Modelling the MRS Coal Hydrogenator

A very similar approach has been taken with regard to the simulation of the MRS coal hydrogenator. Pilot plant design has drawn heavily on extensive physical model studies of gas-solid interactions in entrained flow systems and large models have been used to investigate scale-up. By the time the flow patterns were being modelled mathematically, CFD codes were readily available and use was made of them as well as simple pressure balance models. Detailed reactor modelling began in about 1985 and it soon became clear that the model was developing along very similar lines to the slagging gasifier model. An early decision was taken, therefore, to combine the two models to produce a generalised coal chemistry code which could be applied to coal processing in fixed beds or entrained flow. The hydrogenation version had reached a sufficiently advanced stage of development by 1991 that it was being used to analyse pilot plant data and to generate performance data for flow sheeting exercises.

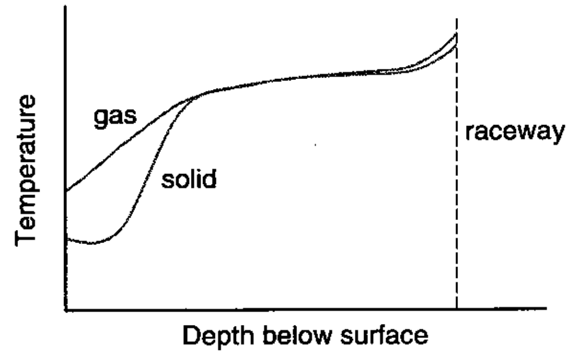

Fig. 10.3.4 Temperature profiles through the bed of the slagging gasifier.

Retrospect

Important lessons were learnt from these modelling programmes. In order to get the maximum benefit it was important to bring together a variety of disciplines so as to give a complete picture of the reactor systems. However, it was not necessary to combine everything into single all-embracing computer codes. A combination of complex numerical systems, simple corelations and experimental data were integrated together in different ways to provide answers to specific questions. Techniques were brought in from outside the field and others were recycled into quite diverse areas. For example, the original gas recirculation models were borrowed from techniques developed to describe the flow in industrial gas appliances (7). Models developed to describe the behaviour of liquid sprays in gasifiers were later applied to the analysis of the behaviour of LNG sprays, gas drying schemes and air conditioning systems. Experience gained in the dynamic model was used to simulate the response of a gasifier to fuel and load changes when operating as part of a power generating scheme, and to optimise shut-down procedures (6).

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10.4 Fluidised Bed Hydrogenation of Oil Feedstocks

M.G.Farrington

Introduction

The thermal hydrogenation of oils was originally conceived in the 1950's as a means of producing methane and other lower hydrocarbons for enriching low BTU gas produced by coal gasification processes, for distribution as "Towns Gas." Process schemes were subsequently devised for the production of "Town's Gas" and Substitute Natural Gas (SNG) from oil as the sole feedstock.

Reactor Concept

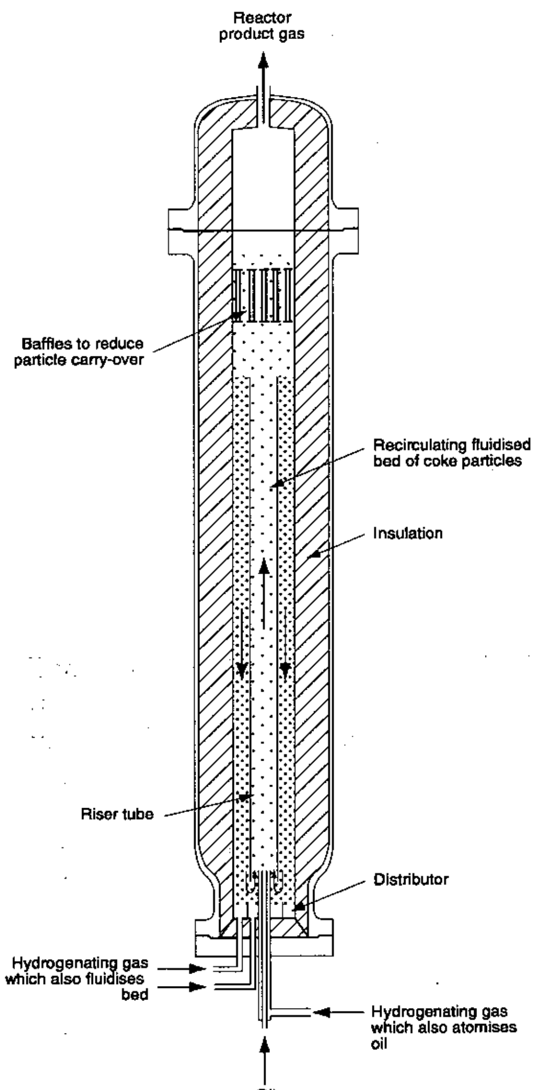

Fig. 10.4.1 Diagrammatic Layout of the fluidised bed hydrogenator.

The hydrogenation of oils is exothermic and in the case of heavy oils, ungasifiable constituents are deposited as residues. A fluidised bed reactor of fine coke particles provides an excellent means of controlling the reaction temperature within close limits and utilising the heat of reaction to raise the feedstocks to reaction temperature. It also provides a medium on which the residues can be collected in a convenient manner.

The Fluidised Bed Hydrogenator (FBH) reactor has passed through various stages of development which were designed to extend its capability to operate with any petroleum feedstock from light distillates to heavy vacuum residues. A simple gas recycle system (GRH) can be used for distillates, but for heavy oils, induced rapid recirculation of coke particles in a fluidised bed is necessary to avoid agglomeration of the particles by the high boiling residues.

The final version of the FBH reactor incorporating a central riser tube is shown in Figure 10.4.1.The Hydrogenator typically operates at 50 bar (750 psi) and at 750°C. The bed of finely crushed coke particles is fluidised by the pre-heated hydrogenating gas (about 98% hydrogen). The design of the distributor encourages the fluidised coke particles to flow up the riser tube accompanied by gas bubbles, and the more densely packed coke particles to flow down in the annular region.

Heavy oils are atomised into the base of the riser tube where, upon contact with hydrogen, a significant amount of methane is formed. The by-product carbon and mineral matter in the oil coats the coke particles and the resulting growth of the coke particles must be controlled. The product gas disengages from the bed at the top of the reactor and, after being quenched to remove aromatic tars, can then be treated and upgraded to form SNG.

Process Development

22"/16" Diameter Pilot Plants

Following extensive experimental work at Poole in the early 1950's and early work at MRS (described in Chapter 2 of Part 1 and Ref.(1)), a larger FBH pilot plant was constructed at MRS. This was capable of operation at pressures up to 70 bar with an output of 1 million s.cu.ft/d. The initial design of rector internals comprised a 22" diameter by 16ft long fluidised bed and, to prevent agglomeration, the bed was circulated through a downcomer and riser extending 15ft below the main bed, via a fluidised transfer zone. In this plant a one month test on light distillate hydrogenation was accomplished producing a gas of 850 Btu/cu.ft. at 350 psig. A gas of 1000 Btu/cu.ft. was produced by raising the pressure to 720 psig to avoid soot in the condensate. Middle East and Algerian crude oils were successfully gasified using this reactor arrangement . The work was reported by Murthy and Edge in 1962 (2).

The complex arrangement of reactor internals in the 22" reactor was subsequently replaced by the simple concentric riser tube design described above. The reactor internal diameter was reduced to 16" and it incorporated a 12" riser tube. This simplified reactor operated well in initial tests with light crude oils, reported by Thompson, Majumdar and Conway in 1965 (3). However the commercial success of the gas recycle hydrogenator (GRH) and the CRG process on light distillates for town gas production, rather blighted the immediate prospects for the FBH in the UK.

Semi-Commercial Plant in Japan

As a result of the success of the tests on the simplified reactor design, an agreement was reached in 1967 with Osaka Gas Co. Ltd. in Japan for further development of the FBH process.This included the construction and operation of a semi-commercial scale plant at their Hokko Works in Osaka. This plant which is shown in Figure 10.4.2 incorporated a 3ft diameter reactor with a capacity of 5 million cu.ft/d of product gas. This fluidised bed operated well with Middle East crude oils, although carbon deposition in the reactor offtake system caused serious operational difficulties.

In 1968 it was deduced that, with the large quantities of cheap natural gas becoming available to meet the UK needs, the work on hydrogenation of oil was no longer required. All such work at MRS was therefore stopped, although MRS personnel continued to support the operation of the semi-commercial plant at Osaka. The hydrogen production facilities required to serve the 16" FBH were demolished.

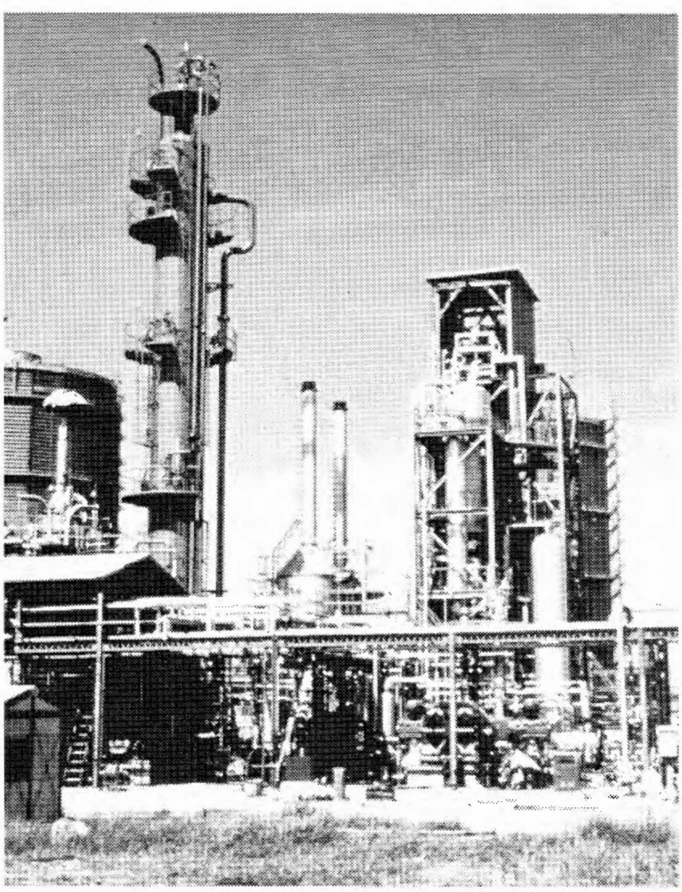

Fig. 10.4.2 The semi-commercial FBH installation at the Hokko Works of the Osaka Gas Company.

The SNG Era

In 1970 it was feared that the supplies of natural gas might be unable to meet the demands for gas in the 1990's. It was decided that alternative processes should be developed to manufacture SNG from the whole range of oil feedstocks to meet the possible shortfall. The target for the FBH process was to extend the range of acceptable feedstocks to include the cheaper heavy crudes and residual oils.

New Pilot Plant

A new smaller scale pilot plant with a 6" diameter reactor was constructed in 1971 at MRS and operated with crude oils. The small scale of the reactor caused some operational difficulties, particularly with carbon deposition in the reactor offtake.

In 1977 a new hydrogen production plant was constructed and the FBH reactor diameter and nominal throughput were increased to 10" and 10,000 cu.ft/h respectively. Over 160 tons of heavy oil feedstocks including 20 tons of vacuum residue were successfully gasified during 18 tests. The reactor throughput was also increased by 50% above the original design to a feed rate of 7 tons/d without affecting product yield (Borrill and Easterby (4)).

In addition to obtaining detailed data on the reactor products, the tests involved giving detailed attention to the problems of fouling of the gas offtake, controlling the fluidised bed particle size distribution, and of developing improved atomisers and solids mixing within the fluidised bed.

Carbon deposition in the reactor offtake remained a significant constraint to operation during the tests. However, in later tests, hydraulically driven mechanical scraping devices were successfully developed and incorporated to maintain the reactor offtake and quench inlet free from blockages.

Heat Recovery Studies

Process evaluation studies indicated that significant improvements in the process economics could be achieved by the recovery of high grade heat from the gases leaving the FBH reactor. Conventional dry waste heat boilers could not be used because they would be rapidly fouled by heavy tars in the reactor products. Major modifications to the pilot plant were made for the later tests to incorporate a novel irrigated tube boiler system to generate steam at 1500 lb/in2 (103 bar). The modified pilot plant is shown in Figure 10.4.3.

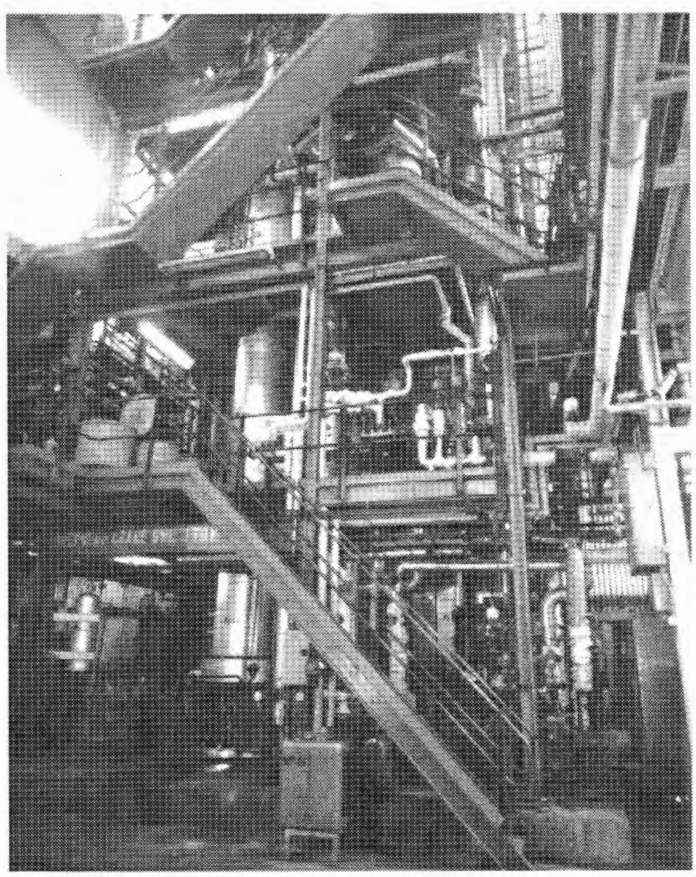

Fig. 10.4.3 FBH pilot plant including heat recovery equipment.

All surfaces in the quench and boiler in contact with the reactor product gas were irrigated with a high boiling aromatic oil. This scheme was successfully operated during the last six pilot plant tests. Performance data was obtained and no problems with deposition on the boiler tubes were evident.

Large Fluidised Bed Model (LFBM)

A consequence of using the FBH process for base load SNG manufacture is that the reactors would need to be considerably larger than any on which pilot plant experience had been gained. Typical commercial reactors could contain 10ft (3 m) diameter fluidised beds. The scale-up from pilot to commercial units has been a particular problem common to all applications of fluidised beds.

The Large Fluidised Model (see Figure 6.8 of Chapter 6), was constructed in 1980 at Coleshill to obtain detailed knowledge of factors to be taken into account in the design of full scale plants. The main components comprised a closed loop system in which nitrogen gas was circulated at controlled temperature and pressures, up to 380°C and 20 bar respectively. The operating conditions were chosen to preserve a fundamental similarity in physical properties to those in the FBH reactor, in conformity to established modelling theory. A programme of twelve runs with a total operating time of 2773 h, providing essential data, was successfully completed.

Process Feasibility Studies

In parallel with the Pilot Plant and LFBM activities, the feasibility of the FBH process for SNG production was examined from the standpoint of FBH technical feasibility, process integration feasibility and process economics. Two FBH process schemes for the manufacture of SNG from residual oils were judged by an independent process contractor to be technically feasible and practical. The study confirmed the high efficiency and modest capital cost of the process compared with the best coal-based processes.

Programme Costs

The construction and operation of the FBH pilot plants demanded major commitment and funding. From 1971 total expenditure was in excess of £15M. The work on the pilot plant and the LFBM was partly funded by a grant from the European Economic Community during the period 1979-1982. The final stages of the pilot plant, modelling and process studies were 50% funded by Osaka Gas Co. Ltd. under a new Joint Development Agreement.

Conclusion of the FBH Programme

It was concluded in 1983 that sufficient pilot plant and modelling studies had been completed to enable FBH reactors of a commercially acceptable size to be designed. The next stage of development of the process would involve the construction and operation of a development plant. The decision to advance to the development plant could not be justified at that time and all work on this process was therefore terminated.

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10.5 The Gas Recycle Hydrogenator

(Based on contributions from G. Horley and B.H.Thompson)

Background

The hydrogenation of oil feedstocks to produce gases of relatively high calorific value, suitable for further processing to town gas, had been demonstrated in the early 1950s, using a recirculatory fluidised bed of powdered coke to control temperature and collect carbonaceous deposits. The original work was reported in 1956 in Research Communication GC37 (1) and further development had continued on the process during the late 50s mainly aimed at dealing with crude and heavy residual oils. However the increasing availability and low price of light distillate focussed attention on this feedstock.

Although it had been proved that the fluidised bed process could easily deal with light distillate, it was also known from laboratory scale work reported by Moignard and Stewart in 1958 (2) that carbon deposition was not a problem with distillate. The question arose whether a process could be developed without using a fluidised bed if other means of controlling temperature could be arranged, for example by internal recycle of the reacting gases.

In industrial heating plant, jet burner driven recirculation had been used to promote good temperature uniformity and the design theory had been worked out by Eric Francis (3). Discussions between P.S.Murthy and Eric Francis took place which indicated that in a hydrogenator, recirculation ratios of between 10 and 20 would be possible with the sort of hydrogen jet pressures which would be available. On the basis of these calculations the decision was taken to try out the concept on a pilot plant scale.

Technical Approach

The recirculation calculations were first checked at pressure in an air model, and following this experiments were started in a 300mm dia. reactor vessel. The reactor comprised an insulated cylindrical pressure vessel containing a cylindrical coaxial tube inside. The vaporised feedstock and hydrogen-rich feed gas were pre-heated, together or separately, and injected at high velocity into the inner tube. This induced a recirculation (gas recycle) system down the inner tube and up the annular space between the pressure vessel and inner tube. This recirculation ensured a substantially uniform reactor temperature and rapidly pre-heated the feeds to reaction temperature (Fig. 10.5.1).

In the initial studies the Gas Recycle Hydrogenator (GRH) as it became known, was operated at 750°C and pressures up to 450 psig using preheats in the range 400-500°C with a 160°C FBP naphtha. Under these conditions 90% of the output was in the form of gaseous hydrocarbons, predominantly methane and ethane, and the rest of the carbon in the form of mainly good quality benzene and toluene. The calorific value of the gas was around 800 Btu/cu. ft., and the proportion of liquid products could be increased by varying the operating conditions.

The output from such a small plant (see Fig.3.10 in Chapter 3) was surprisingly high; in one test 0.9mill. cu.ft./day was produced, the limiting factor being the feed preheater. Under the normal operating conditions no carbon deposition occurred. These very successful studies were reported by P.S.Murthy and R.F.Edge in November 1962 (4).

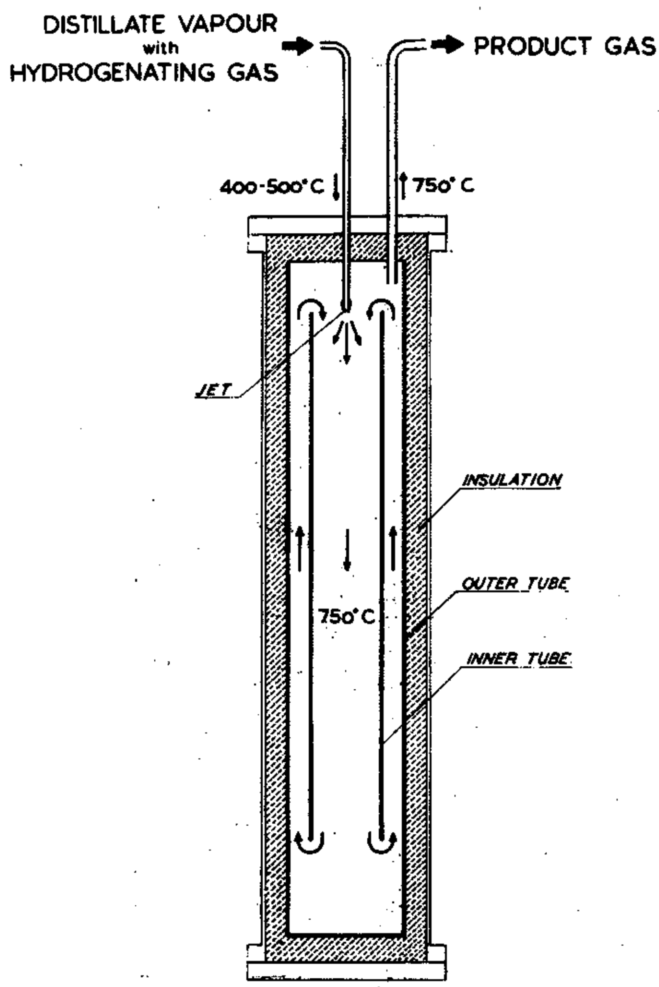

Fig. 10.5.1 Pilot scale hydrogenator for light distillate with internal gas recycle.

Commercial Implementation

The success of the pilot plant studies led very rapidly to commercial application. The first commercial GRH plant was ordered by the SWGB for enriching the lean gas produced by an ICI steam/naphtha reformer to town gas standard at the Seabank Works near Avonmouth. At about the same time Humphries and Glasgow obtained an order for a similar application at a refinery near Hanover in West Germany, and it was this plant that was the first to go to work. Soon after commissioning, temperature control of the GRH was lost and this was found to be the result of a massive carbon deposition.

The original development work was done using "raw" petroleum feedstock which contained 300ppm of sulphur compounds. In the Hanover unit, the feedstock was desulphurised before feeding to the GRH. The problem was solved by the addition of a small proportion of undesulphurised naphtha or hydrogen sulphide.

Subsequent pilot plant work, reported by Thompson, Majumdar and Conway in 1965 (5), backed up by laboratory studies showed that the presence of about 100ppm of sulphur in the feed was necessary in order to obtain extended operating times covering the range of operating conditions. The role of the sulphur was to passivate the catalytic activity of the materials of construction of the internals of the GRH and retard the carbon forming reactions. The presence of a small quantity of steam in the hydrogenating gas also assisted in giving long operating periods.

This later work also explored the use of higher boiling distillates, up to 230°C FBP, and operation at higher pressures, up to 900psig, in order to produce a gas of 1000 Btu/cu. ft. The first U.K. commercial gas making unit based on the GRH, was commissioned at the Avonmouth Works, SWGB, in 1965. In the next few years over 50 units were built in the UK and Europe for enriching reformer gases. The total gas making capacity of the installed units was 40 MM s.cu.m/day.

Later Developments

By 1967 it was clear that the future was with natural gas and GRH studies were almost wholly concerned with increasing the calorific value of the product gas and extending the range of feedstocks which could be used, with a view to production of a substitute natural gas (SNG) Experiments were run, in which product gases of calorific values in excess of 1000 BTU/scf were produced at operating pressure up to 1350 psig, using light petroleum distillate feedstocks. Some of these results were reported by Davies, Lacey and Thompson in 1968 (6) aimed at determining the extent to which existing commercial installations could be used to produce an SNG.

Middle petroleum distillate feedstocks (gas oil and heavier) cannot be completely vaporised. These feedstocks were pre-heated but were maintained substantially in the liquid phase before injection to the GRH using an atomiser. The atomising gas was pre-heated hydrogen-rich gas. This work was mainly carried out in the late 1960's but additional tests on gas oils were run in 1973/74.

The APCI Joint Work

In 1972, a small gasification unit was built at MRS, incorporating a 75mm (later 120mm) GRH, for the investigation of heavy oil gasification. This work was jointly funded by the Gas Council and Air Products and Chemicals Inc (APCI) of Allentown, Pa, USA. The feedstock was high sulphur, heavy crude oil and the unit incorporated a novel "sparged" vaporiser in which hot hydrogen-rich gas was used to vaporise the lighter fractions of the oil feed. The oil vapour and hydrogen-rich gas mixture was fed to the GRH. This work lasted about 3 years, but had only a limited success and the programme was terminated in 1975.

Subsequently, in 1976, APCI brought forward a proposal for the design of a commercial scale gasification unit based upon a "standard" Gas Recycle Hydrogenator. Although no experimental work was required, MRS provided the process and mechancial design details for the GRH and ancillary equipment. The plant was constructed at Marcus Hook, Pa, USA in 1979 and MRS staff assisted with the commissioning of the unit. This plant was shutdown in 1982.

Two factors mitigated against the GRH for SNG production. First was the relatively high flame speed of the product gas, due to the presence of ethane, without which the high CV could not be obtained, and the small excess of remaining hydrogen. Secondly, the success of catalytic schemes involving CRG/methanation and hydrogasification stages, eventually able to use almost the whole range of distillate feedstocks.

All work on the Gas Recycle Hydrogenator process ended with the shutdown of the Marcus Hook plant. However, the term "gas recycle" refers to the technique of inducing internal recirculation of hot gases from the product outlet to the feed inlet of a reactor. This method was used in the MRS Coal Hydrogenator so that application of "gas recycle' can be said to have been extended into the 1990's.

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10.6 Coal Hydrogenation

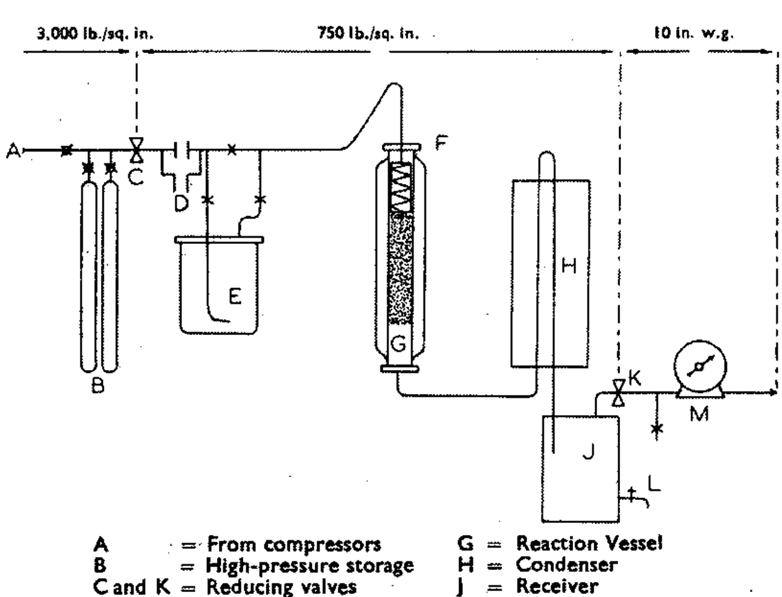
J.A.Lacey

Background

The story of coal hydrogenation began in the late 1930s following the introduction by Lurgi of an outstanding new process for the gasification of lignite, at pressure, using steam and oxygen. There was great interest in the possibility of using this process to make town gas from the less reactive British coals, and, at the instigation of the Gas Research Board, a classic programme of laboratory investigations was carried out by Dr Dent at the University of Leeds. Dr Dent first investigated the reactions that occurred in the lower part of a fuel bed simulating a Lurgi reactor, then he turned his attention to the upper part of the fuel bed, in particular to the reactions between coal and coke, with gas mixtures containing hydrogen. By passing the gas mixtures, at pressures up to 100 bar, downwards through a fuel bed contained in a 1 inch diameter reactor tube and progressively raising the temperature he obtained copious quantities of methane. He had discovered the direct reaction between the coal substance and hydrogen to make methane. It was envisaged that coal hydrogenation could be used to make methane to enrich the gas from a Lurgi, or other type of gasifier, for distribution as town gas.

The Gas Research Board Studies

In the early 40s experiments progressed to a 7 inch diameter reactor with a fuel bed 12 inches deep, the temperature of the inlet hydrogen being progressively raised to initiate the reactions at 500°C, or above (1). It was observed that a high temperature reaction zone at 1000°C moved rapidly down the fuel bed, causing the coal to agglomerate strongly and leaving a residue of relatively unreactive char. The progress of the laboratory investigations was such that an increase in scale became desirable and in 1943 the programme was transferred to the Pitwines Works of the Bournemouth Gas and Water Co. in Poole. The new experiments were in a 12 inch dia., 8 ft. long reactor (Fig. 10.6.1), and when precautions were taken to insulate the vessel, reaction zone temperatures of up to 1200°C were observed, which began to limit the yield of methane from equilibrium considerations (2).However, the problems of temperature control and agglomeration had to be overcome. A fixed bed coal hydrogenator using lump coal would clearly have been impractical on a large scale, but a fluidised bed reactor was thought to be a practical proposition.



A = From compressors
B = High-pressure storage
C and K = Reducing valves
D = Flow gauge
E = Vaporizer
F = Preheater
G = Reaction Vessel
H = Condenser
J = Receiver
L = Sampler
M = Meter

Fig. 10.6.1 Flow diagram of the fixed bed hydrogenation pilot plant at Poole.

The process route would then involve two stages; a fluidised bed hydrogenator to make methane by the partial hydrogenation of the coal, leaving a residual char that would be gasified with steam and oxygen in a second stage fluidised bed gasifier to produce the hydrogenating gas required in the first stage.

Laboratory studies in a 4 inch diameter fluidised bed reactor (Fig. 10.6.2) were undertaken by Frank Wood in the late 40s, including investigation of a pre-oxidation stage to remove the tendency to agglomeration of caking coals (3).

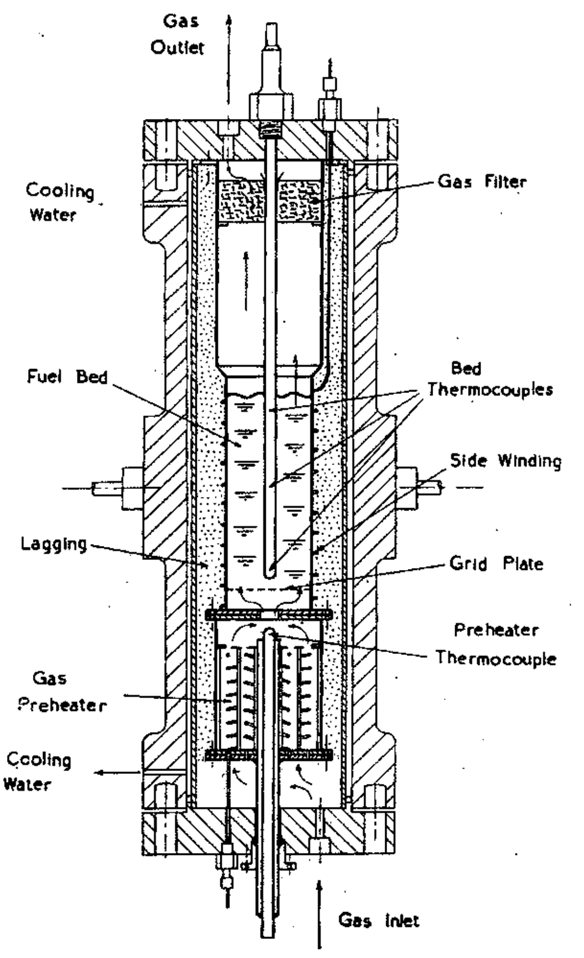


Fig. 10.6.2 High pressure reactor for hydrogenation of fluidised fuel.

The Gas Council Work

The take over of the GRB by the Gas Council in 1951 removed many of the previous restraints on progress, so the laboratory work could now be scaled up. A fluidised bed hydrogenation pilot plant with a 12 inch diameter reactor was built and operated at Poole (Fig 10.6.3, also Fig. 1.6, Chapter 1); temperature control was good and the methane yields were high, but there were

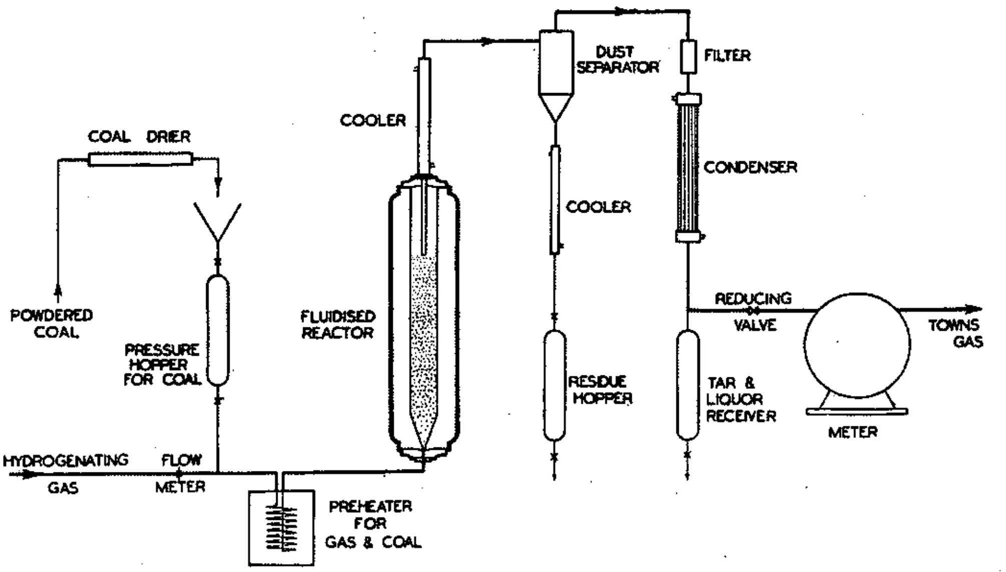


Fig. 10.6.3 Flow sheet of the fluidised hydrogenation plant for coal at Poole.

doubts that the rates of mixing would be high enough to prevent agglomeration of coal particles injected into the fluidised bed (4). Techniques for improving the bed mixing by forced recirculation of the bed material were explored, using full scale physical models, and the concept of using an entrained flow riser driven by the reactants, with a dense phase downcomer, proved effective. A number of different reactor designs emerged, but they were only used, at a later stage, for oil hydrogenation, which began to take priority over work on coal.

When the MRS was opened in the mid 1950s the fluidised bed pilot plant from Poole was installed at the east end of the pilot plant building. A few short and not very successful tests were made, and the plant then lay idle because of the greater need to concentrate resources on more urgent developments, such as the slagging gasifier, the CRG process and oil hydrogenation. Only two aspects of work on coal hydrogenation continued into the 1960s; investigations of reactions at ultra high pressure by Moseley and Patterson and the construction of a fluidised bed pilot plant (alas, never to be operated) for the gasification of coal char with steam and oxygen to make a hydrogen rich gas.

Ultra-high Pressure Hydrogenation

Fred Moseley performed some remarkable experiments on coal hydrogenation at pressures up to 1000 bar (5), using an horizontal entrained flow reactor located in a "bunker", with concrete walls 1 1/2 ft thick, in a corner of the slagging gasifier services building (Trevithick). Some extremely difficult practical problems of feeding pulverised char and hydrogen into the 1/8 inch ID by 20 ft long reactor were overcome and comprehensive data on reaction kinetics were obtained. At any particular time the rate of hydrogenation was proportional to the hydrogen partial pressure. Coal could not be used directly because of blockages in the reactor but char could be almost completely hydrogenated to a gas of high methane content, e.g., 75% methane in the produced gas, by reacting coal with hydrogen for 0.5 seconds at 1000°C and 500 bar pressure. The scientific data was first class, but any thought of developing a process at these extreme conditions was out of the question, as the estimated gas compression costs alone amounted to 30% of the cost of the gas made.

1965 - 1983 A Long Hiatus!

In 1965 all work on coal was stopped because oil was a much more attractive and cheaper feedstock for gas making, and the prospect of the availability of natural gas from the North Sea was on the horizon. There was little thought or even interest in coal hydrogenation for more than a decade, until 1979, when the long term programme for SNG was formulated. It was envisaged that the slagging gasifier would meet the medium term needs and be used for the gasification of lump coal but there would be a need, long term, for a process using coal fines because of its greater availability and lower cost. Proposals to re-start work on fluidised bed hydrogenation and fluidised bed gasification were included in the 20 year programme. But in the subsequent years the concerns about the availability of natural gas at the turn of the Century were allayed and, in 1984, the scope of the SNG Programme was drastically cut. Coal hydrogenation was to suffer yet again!

The main thrust of the revised programme was the completion of the development of the slagging gasifier; work on coal hydrogenation was to be restricted to proving the technical and economic viability of the overall process concept. A detailed review of the coal hydrogenation technology was made and the only unproven stage of the entire coal to SNG process was the coal hydrogenator;reactors for gasifying the residual char were at an advanced stage of development by Shell and Texaco, and other plant items were already commercially available.

The Rockwell Trials

Ideas about coal hydrogenation reactor technology were influenced by the work carried out by a consortium of companies headed by Rockwell to test a 1/2 ton per hour flash pyrolysis reactor. Chris Hodrien and Alistair Tait were seconded from MRS to work at the test site on the outskirts of Los Angeles. Coal was successfully hydrogenated by injecting powdered coal into a stream of hot hydrogen that flowed vertically downwards in an entrained flow reactor. The pre-heat to initiate the reaction and control the temperature at about 1000°C was achieved by burning part of the hydrogen with oxygen. Gasification was achieved with no agglomeration of the coal particles or deposition in the reactor. However, the simplicity of the reactor was offset by an adverse efficiency penalty due to the high oxygen consumption. This stimulated the idea that the use of oxygen could be avoided altogether by using the gas recirculation principle of the GRH.

The MRS Coal Hydrogenator

The new reactor concept, the MRS Coal Hydrogenator, had a central draft tube for gas recirculation, as in the GRH. Coal was supplied, in dense phase flow, to the top of the reactor and mixed with a high velocity jet of hydrogen directed along the vertical axis of the reactor such that the momentum induced recirculation of product gas at 900°C to 1000°C. This provided enough heat to initiate the hydrogenation reactions which were completed within the draft tube. At the bottom of the reactor the residual char particles passed into a collecting chamber, the product gases flowing up the annulus to the top of the reactor.

Before testing the new reactor concept, the first major step in the new coal hydrogenation programme was to construct, in 1983, a laboratory scale plant, the Coal Fines Gasifier, to obtain accurate yield data for UK coals (6). The reactor (Fig. 10.6.4), which was 1 inch diameter by 13 ft long, allowed the hydrogenation of coal at temperatures of 800°C to 1000°C, 90 bar pressure, and gas residence times of up to 25 seconds, for the production of methane, or the co-production of methane and liquid hydrocarbons. The work showed that more than 50% of the coal could be hydrogenated at 70 bars pressure and 1000°C leaving sufficient carbon to be gasified in a steam/oxygen gasifier to make the hydrogen required for the process. The overall process for making SNG was feasible.

Fig. 10.6.4 Coal fines gasifier rig.

The Osaka Gas Company also recognised the potential of coal hydrogenation as a route to SNG and other valuable products, and co-operation between the two companies, which had started much earlier on oil hydrogenation, continued into coal hydrogenation - a new Development Agreement being signed in 1986. The first phase of the joint work, to prove the design concept and performance of the MRS Coal Hydrogenator was completed in 1988. Under the leadership of Phil Borrill, a pilot scale reactor (Fig. 10.6.5) with a throughput of 5 tonnes coal/day at 70 bars pressure was used successfully to gasify lignite and the most strongly caking coals for short periods of time, with no obvious operating or technical problems (7). The operating time of the plant was limited by the capacity of the collecting chamber beneath the main reactor to store the residual char. Later the pilot plant was modified to allow the continuous discharge of char through alternate lock hoppers, and storage silos were installed to allow up to 10 days operation. The work was highly successful and demonstrated the flexibility of the reactor to make methane for SNG, or by reducing the reaction temperature for the co-production of SNG and up to 20% of aromatic liquids.

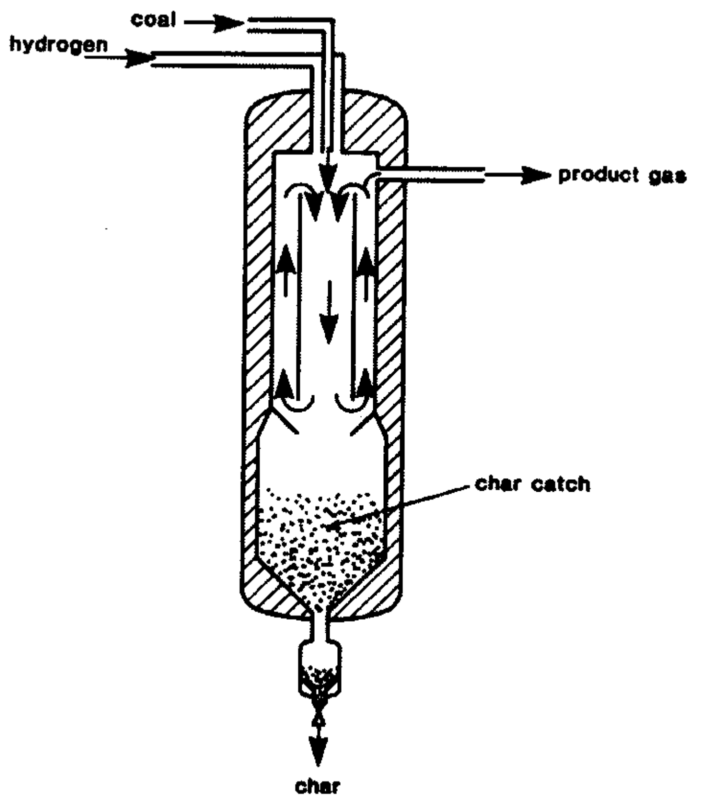


Fig. 10.6.5 Diagram of the MRS coal hydrogenator.

In parallel with the pilot plant work, a study was made by Humphreys and Glasgow to assess the engineering feasibility and costs of a large plant for making 250 million cu. ft./day of SNG. It was concluded that there were no major engineering problems in the overall process route and an incredibly high overall process efficiency of nearly 78% for making SNG from a British bituminous coal was predicted. This was about 5 percentage points above the efficiency of the slagging gasifier process route. Furthermore, the plant would have a lower capital cost.

The Future

Hydrogenation remains an exciting, challenging, and highly efficient process technology for the gasification of coal. Unfortunately, there has been no interest in pursuing the development because of the unfavourable economics compared with natural gas - even if the coal is free the capital costs would make the final SNG costs greater than natural gas. Hence there will be no incentive for further development of the technology until there is a major change in the availability, or the price, of natural gas. This could be well into the next century. Indeed, the centenary of Dr Dent's work at Leeds may be celebrated by the first commercial application of coal hydrogenation.

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10. 7 The Catalytic Rich Gas Process (CRG)

H.S.Davies

Background

During the 1950's, the gasification of coal at 25 bar pressure using the Lurgi process was considered to be the most attractive process for towns gas manufacture. The plants were expensive to build and for economy reasons were necessarily to be operated at base load. Then, as now, there is an imbalance of summer to winter load and to redress this balance it was postulated that excess Lurgi gas could easily be converted to methanol in summer months and be converted back to town gas in the winter when demand was higher. The synthesis of methanol was relatively straightforward but a process to gasify methanol would have to be developed.

Technical Approach

Experiments started at MRS in 1956 using nickel/alumina catalysts developed by Dr. Dent earlier for methane synthesis (see under "Methanation"), and showed that a process could quite easily be developed. The methanol was decomposed readily over the catalyst with or without air addition and only 0.25 lb/lb steam/methanol to produce a gas at equilibrium for CO shift and methanation reactions at about 670°C, close to the experimental outlet temperature. A second stage with a commercial conversion catalyst at 425°C reduced the CO content to less than 2%. After removal of some carbon dioxide the gas was of ideal towns gas characteristics.

The process was not developed further for methanol because at the time large quantities of relatively cheap naphtha were becoming available and work centred on how this feedstock could be utilised using a similar catalytic process. Early problems encountered were numerous. Naphtha, unlike synthesised methanol, has much sulphur which has to be removed to prevent catalyst poisoning. To maintain reaction with steam, more air would have to be added and this would make the resulting town gas more dense and also, because naphtha has no oxygen, more steam would be needed for its gasification. However, the biggest problem was the propensity of the naphtha to deposit carbon more readily than methanol and cause blockage. This was overcome by reducing the operating temperature of the catalyst to the range 400 to 550°C, when reaction proceeded with steam only, exothermically, to give a gas at equilibrium for CO shift and methanation reactions. This gas had too high a calorific value for town gas so a second reforming stage with air addition was necessary. The early work was reported by Cockerham and Percival in 1957 (1)

"The Peak-Load Plant"

Until the late 50's experiments had only been performed on small apparatus with reactor diameters about 0.5 inch, bed depths of from 6 to 12 inches and catalyst in granular form. To further development, a large pilot plant comprising a desulphurisation section, a first stage reactor of 6 inches diameter and 4 feet depth and a second reforming stage along with CO conversion, was built on the Brunel back yard. The plant, affectionately known for years as the peak load plant, had a throughput of up to 30 gallons per hour of naphtha (see Fig. 3.6 in Chapter 3) and could produce about 200,000 cu.ft. of town gas per day (Cockerham, Percival and Yarwood (2)).

This increase in capacity not only resulted in the necessity to provide several large storage tanks of various sizes for both crude and purified naphtha but also created a major challenge in the preparation of sufficient catalyst to operate the plant. It was Alan Yarwood who realised that the Hoover twin tub washing machine was ideal for catalyst preparation, being fitted with a stainless steel tub with recirculation and built-in heater as well as temperature control, for catalyst precipitation, and spin-dry facility for filtration. An order to the local electricity showroom for six machines provided adequate catalyst manufacturing capability.

The shape of the catalyst was soon found to be important and after much experiment with extrusion, impregnation and tableting, 1/8 inch equant cylindrical pellets was considered the best catalyst configuration and is still today the preferred size, giving optimum performance with regard to throughput, pressure drop, life and reactor size.

After the CRG catalyst had been activated by reduction with hydrogen, the vapourised purified feedstock was then mixed with about twice its weight of steam and passed over the catalyst at about 450°C preheat temperature and a pressure up to 25 atmospheres.

A reaction zone was set up in which the naphtha was completely gasified and the resulting gases brought immediately to equilibrium for the temperature and pressure of the system. This reaction zone was easily identified in the bed by determining the temperature profile within the bed. It is seen that the temperature initially falls slightly and then rises sharply to reach about 500°C in the first few inches and this temperature is maintained throughout the bed (Fig.10.7.1).

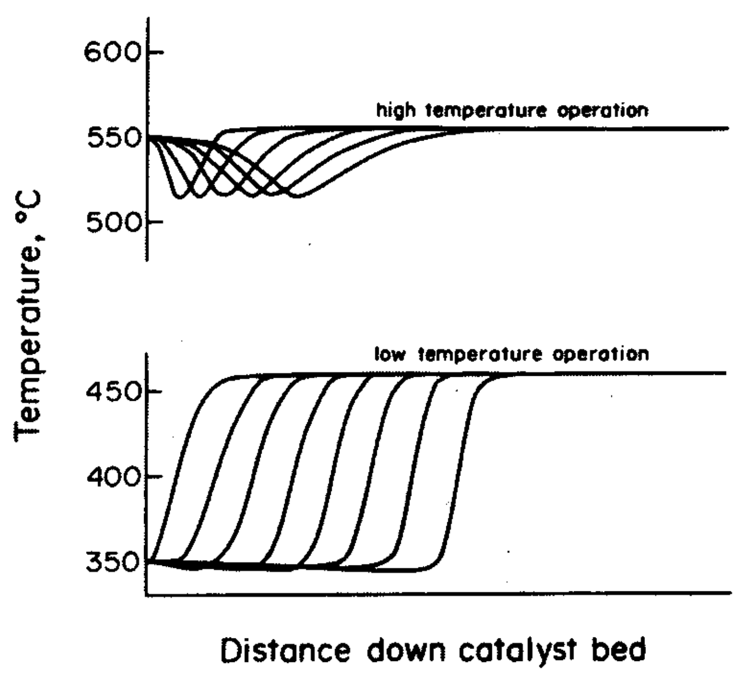

Fig. 10.7.1 Movement of reaction zones at extreme conditions of temperature.

Catalyst Life - Mechanisms of Deactivation

With liquified petroleum gas (LPG) and light distillates boiling up to 120°C, very good catalyst lives were obtained, but with higher boiling feeds, catalyst life had to be improved. This was effected by optimisation of the process conditions and improvements to the catalyst composition and methods of preparation.

Active catalysts based on nickel and alumina do not have an indefinite life as recrystalisation occurs at exposure to these working temperatures, especially above 500°C, if alkalis are present and if there is a high partial pressure of steam. This loss of activity was noticed as an extension of the reaction zone down the bed but provided that the zone did not extend out of the bed, the outlet gas composition remained constant.

The shape of the reaction zone is a very definitive indication of the condition of the catalyst bed and the change of shape with time is invaluable in determining the principal mechanisms of failure and hence the best approach to improve performance. There are three distinct mechanisms of catalyst loss of life, - namely sintering or loss of catalyst surface, poisoning by sulphur or other contaminant and deposition of a monomolecular layer of carbonaceous material "polymer" over the active surfaces. These three modes each have a characteristic temperature profile indicating which failure mechanism was responsible for loss of life. All CRG reactors have the profile monitored continuously, even when the plant is not running, so the temperature history of a bed is always known.

Sintering, because of the loss of active surface results in a stretching of the reaction zone and normally is attributed to failure because of steaming or too high a temperature at some time or other, or even just a bad batch of catalyst (Fig. 10.7.1 upper curves).

Poisoning by sulphur is very noticeable as the catalyst which has seen sulphur is permanently and completely deactivated leaving a flat-front to the temperature profile with a normal shape following further downstream.

Deactivation by polymer deposition results primarily in deepening of the initial temperature "dip". This is because the polymer normally deposits at the front of the bed where temperatures are lower allowing only the endothermic decomposition of the naphtha to take place and it is not until relatively clean catalyst is available further into the bed that the exothermic reactions proceed normally and full reaction temperature is attained (Fig. 10.7.1 lower curves).

Process conditions could be adjusted to slow down zone movement by increasing hydrogen and/or steam and raising temperatures slowly to prevent polymer formation. The immediate improvement in performance would be offset later by faster reaction zone movement due to sintering at the higher temperatures so a compromise had to be reached (Fig. 10.7.2).

The early version of CRG catalyst had up to 1.6% potassium, to promote steam/carbon reactions and hence prevent polymer deposition. Alas - sintering was a problem. After numerous trials on catalysts with 0.3 and 0.8% potassium and also with Barium oxide, catalyst with 0.6 -0.8% postassium (CRG-B) was the preferred formulation. Later developments in the mid-1970s resulted in a lower potassium content catalyst CRGF which had good resistance to sintering and polymer and this is now the catalyst used extensively.

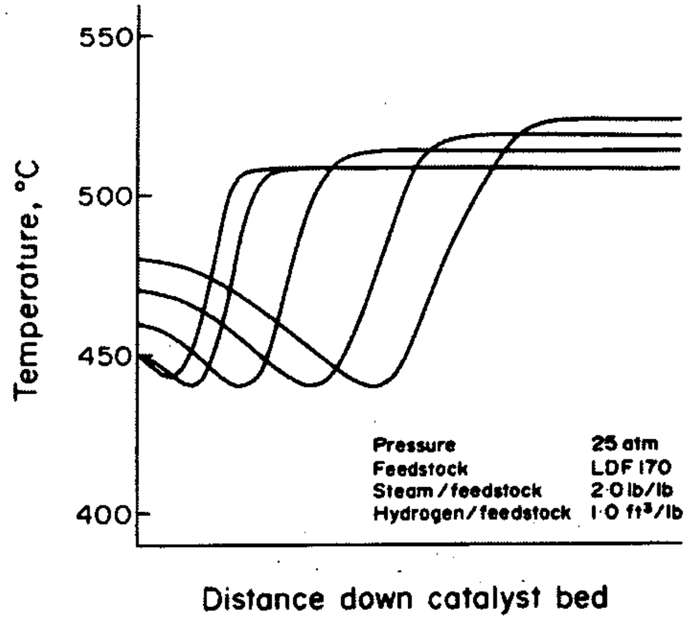

Fig. 10.7.2 Typical temperature profiles with constant minimum temperature.

Commercial Implementation for Town Gas Production

The first commercial scale CRG plant was built at the Bromley-by-Bow gas works of the North Thames Gas Board and was commissioned in August 1964. The first charge of catalyst was the Type C (high alkali) and this lasted over 2000 hours in spite of many operational interruptions (3). Although this was an undoubted success demonstrating the new concept of low temperature, adiabatic reforming, longer catalyst life was necessary. Several more plants were in the pipeline and to enable testing of the many commercial batches of catalyst which were being made by Peter Spense of Widnes (the first licenced catalyst manufacturer) and to optimise catalyst conditions, six pilot plants (the celebrated 2" tube apparatus) were built and these proved to be invaluable in the future process development (see Figure 3.7 in Chapter 3).As mentioned earlier, naphtha was freely available and the gas industry had already embarked on a massive investment by erecting many ICI lean gas reformers in every region of the UK gas industry. Some gas utilities abroad had done likewise. These plants produced a very clean, hydrogen rich gas with a calorific value of about 330 Btu/cu.ft. This had to be enriched to 500 Btu/cu.ft. with LPG before it could be distributed.

The early application of the CRG process, as at Bromley and very soon later with progressively bigger plant at the Toyosu and Negishi works of Tokyo Gas, the Bromley and Southall works of NTGB, the Brighton and East Greenwich works of the SEGB, the Killinghholme works of EMGB and Granton of Scottish Gas was to provide enrichment to the lean gas reformers on site instead of LPG. This was all very well, but when the lean gas reformers had to shutdown so did the CRG plants.

The concept of the original work by Percival and Cockerham (1)was now adopted and plants were offered to produce town gas directly by using a second reforming stage at higher temperatures. Three processes were offered, Series A, Series B and the preheat/reheat routes. The Series A route consisted of reforming part of the rich gas from the CRG stage at about 800°C in a tubular reformer and blending back into the remaining rich gas to produce a 500 Btu/cu.ft. gas. This route became highly successful culminating in a total of 68 plants being built to the present at home and abroad with an overall output of 1.4 Billion cu.ft./day. 36 of these were in the United Kingdom. The process won for British Gas the Queens Award to Industry in 1967.

The Series B route which comprised reforming all the rich gas product at a lower temperature than in the Series A route, to produce 500 Btu/cu.ft. gas directly has never been taken up. The Preheat/Reheat route involved heating the rich gas to about 800°C twice in direct fired heaters and passing the hot gas on to packed beds of reforming catalyst (3). One plant was built at the Whitehill Point Works of Northern Gas and a feature of the plant was its remarkable operating flexibility and ability to turndown from 100 to 10% quickly while still maintaining product gas quality.

Catalyst Preparation

The precursor to the catalyst was precipitated from a mixed solution of aluminium and nickel nitrates by addition of sodium carbonate and then the sodium was removed by filtration and washing of the precipitate. This co-precipitation method of preparation and also the nickel and trace element contents were optimised. Later research at MRS and LRS showed that the excellent activity and stability properties of CRG catalyst arose from the formation of a complex intermediate nickel aluminium carbonate hydrate known as 'NACH'. After controlled addition of trace amounts of potassium, calcination and reduction it gave a catalyst with the nickel very well dispersed on a modified form of alumina which has good stability in steam containing atmospheres.

The potassium was added to retard the formation of trace quantities of a "polymer" which gave rise to a slow deactivation of the catalyst when used for gasification of liquid hydrocarbons. The CRG catalyst was shown to be better for methanation than the earlier catalyst developed by Dr Dent and colleagues.

Catalyst variations

Seven variants were developed between the late 1950's and the mid 1970's. These were CRG's A, B, C, D, F, H, K and Q. All were extensively tested at the pilot plant scale. Type C was used in the first commercial demonstration at Bromley by Bow, but A and B were later found to be better. Type C was not used again and only A, B, F, and Q were used commercially. The initial variants, A, B, and C, differed only in their potassium content. A contained the lowest level of potassium and C the highest with an intermediate level in B. A was used primarily for methanation whilst B and C were used for gasification of liquid hydrocarbons by steam reforming. A and B were used commercially in the CRG processes in the United Kingdom and abroad from 1963 until the mid 1970's when they were replaced by CRG F.

CRG F was identical to A, B, and C apart from its alkali content. It was developed in 1973 to 1975 after problems were experienced with the performance of CRG B at increased pressures and temperatures for the operation of CRG processes which were then required for applications in Japan and the United States. The level of the added potassium and the residual sodium from the precipitation process were optimised to increase the stability of the catalyst at the higher temperatures and pressures of operation whilst retaining the resistance to 'polymer' formation. CRG F became the preferred formulation and is still widely applied throughout the world for methanation, CRG processes and more recently pre-reforming.

CRG D, H and Q differed from A, B, C, and F in that they each contained an additional element. D contained barium, H Chromium and Q calcium. In each case the added element was a minor constituent. The performance of D at the pilot plant scale was not consistent and thus its development was not pursued after the initial pilot plant tests in the mid 1960's. H was first developed in the mid 1970's and tested at the laboratory scale by LRS before tests at the pilot scale were done at MRS. Q was developed during a collaborative research programme with ICI during the mid 1970's. Both H and Q had good stabilities under gasification conditions and were particularly suitable for kerosene. These did not find commercial application, although Q was used commercially in one instance for the gasification of a naphtha. H is a parent of the LH catalyst developed later for the methanation of slagger gas by the HICOM process.

CRG K was developed in the mid to late 1970's for the gasification of the heavier feedstocks but like H and Q it did not find commercial application. Its composition was identical to that of F but the temperature of precipitation was lower, giving a catalyst with increased resistance to 'polymer' formation.

CRG Process Development for SNG Production

Towards the end of the 1960's natural gas had been discovered in the North Sea and the industry was considering the complete conversion of the United Kingdom from distribution of town gas to natural gas. The ability to manufacture a gas similar in characteristics to natural gas from naphtha using modified town gas plant would be useful in meeting peak demands and in ensuring long term security of supply. Research then concentrated on modifying the CRG process to make a gas containing mainly methane. The ability of CRG catalyst to bring hydrogen and carbon oxides to equilibrium at low temperatures threw up many options, two of which methanation and hydrogasification, became very successful indeed (4)(5)(6).

The Methanation process comprised cooling the gas from the CRG stage to 300°C and introducing it to a second bed of CRG catalyst (the low alkali version CRG A was best). Re-equilibrium of the gases was established at about 360 to 380°C giving a gas richer in methane; more CH4 could be made by utilising a second stage, the quantity being maximised if water was rejected before this stage. Removal of CO_2 resulted in a product gas of up to 98- 99% methane.

This Double Methanation process found immediate application in the United States early in 1970 when three very large plants was built for Consumers Power, Algonquin and Brooklyn Union Gas. Single methanation stage plants were built at Commonwealth Gas and for Ashland Oil.

A later development produced the better Hydrogasification process where further naphtha was added to the gas leaving the primary CRG stage and the mixture passed over a second bed of CRG catalyst where it was gasified. The presence of the hydrogen from the first stage enabled good catalyst life to be obtained at low preheat temperatures and because the process steam was in a way used twice, conditions could be adapted to give very low overall steam/naphtha ratios and hence very efficient reforming plant. The route was recognised as a significant advance on the methanation process and all subsequent SNG plants in the USA and Japan used the hydrogasification process, and also the UK conversions where possible.

To the present 51 SNG plants have been built, 27 in the UK, 6 in Japan, 15 in the USA and 3 in South Korea with an overall output of 1.8 Billion cu.ft/day.

Catalyst Manufacture

CRG catalyst has always been made for commercial applications by a chemical company under licence from British Gas following a strict approval procedure.The first licenced manufacturer was Peter Spense of Widnes who were taken over by Laporte Davison of Baltimore about 1970. Katalco, who were part owned by ICI were also licenced early in the 1970s to make catalyst in the United States.Today, CRG catalyst is only made by ICI at Clitheroe in Lancashire.

Heavier Feedstocks

In the early 70s, it was thought necessary to extend the range of distillate feedstocks available for the CRG process. This was achieved partly through the catalyst improvement described above ,but also by the use of product gas recirculation around the reactor back to the inlet. This resulted in a more uniform temperature regime through the catalyst bed which reduced sintering towards the outlet and, together with the presence of hydrogen in the circulated product gas, reduced polymer formation at the inlet end (Fig. 10.7.3). Pilot plant tests demonstrated the benefits in catalyst life and the ability to gasify kerosine successfully

A further innovation was recirculation by jet pump with process steam as the driving medium (Fig. 10.7.4). This process was demonstrated on the full scale at the Killingholme Works of East Midlands Gas in 1975 (6).

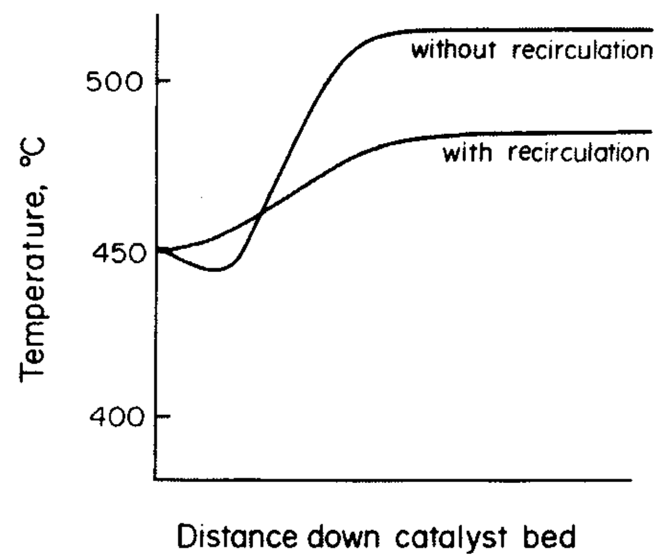

Fig. 10.7.3 Effect of recirculation on reactor temperature profile.

CRG catalyst has also been used in several locations for the derichment of natural gas and a later application for which the LH catalyst will be ideal is the preforming of feedstocks prior to high temperature reforming - a return to Series B but with hydrogen as the desired product.

CRG has been a success story. Low temperature adiabatic reforming of petroleum feedstock was a new concept and over the last 25 years or so has found very wide application at home and abroad. Competition has been intense, with Osaka Gas and Lurgi developing similar processes later, but they have not been as successful as British Gas. A combination of excellent scientific and engineering skills backing up strong technical support has enabled us to maintain our advantage.

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10. 8 Feedstock Purification

J.A.Lacey

Background

As outlined in Section 10.7, in the mid 50s MRS were engaged in the development of the CRG process for the catalytic gasification of light distillates, then becoming available in large quantities from refineries. The results of pioneering work at MRS on this process technology were published in 1957(1). The distillate feedstocks contained up to 0.05% wt of sulphur, well in excess of the amount that could be tolerated by the nickel based catalysts used in the process. Purification of feedstocks to remove sulphur to very low levels that would avoid deactivation of the catalysts and allow continuous and prolonged operation, became an urgent and important requirement.

Technical Objectives

The highly active nickel-based reforming catalysts were slowly poisoned if the distillate feedstock contained more than 0.2 ppm wt of sulphur. Methods of purifying hydrocarbons traditionally used by industry, e.g. washing with caustic soda solution, or adsorption on active carbon etc., did not allow such high standards of purity to be achieved.

Purification of the feedstocks at the refinery was not practical because of the risk of contamination during transportation to the gas works. An efficient, reliable, low cost process that would remove virtually all of the sulphur from the feedstock and operate continuously upstream of the catalytic reforming unit, was required. The process approach that was adopted was to mix the feedstock with a gas containing hydrogen and pass it over a catalyst at 300 to 400°C and elevated pressure to convert the sulphur to hydrogen sulphide which could then be absorbed by passing the gas through beds of solid absorbents.

Work was initiated first at the laboratory and then at the pilot plant scale. The objectives were, to prove the technical feasibility of the process conditions for a range of feedstocks and to establish guarantees for commercial plants.

Technical Approach

There were plenty of hydro-desulphurisation catalysts available commercially, most of which were based on molybdenum on alumina with either nickel (Nimox) or cobalt (Comox) as a promoter. Laboratory screening tests at MRS showed that Nimox had the best performance.

Two absorbents were available in commercial quantities, one based on iron oxide, known as Luxmasse, the other was zinc oxide. The former was selected because it was more readily available, it had a higher sulphur retention and was about one third the cost of zinc oxide.

The distillate feedstocks that were likely to be used had final boiling points of 125°C, 150°C, 185°C and 230°C (kerosene). Various process configurations for commercial plants had hydrogenating gas available as lean gas (80% hydrogen), town gas (56% hydrogen) and rich gas (17% hydrogen) with a requirement that the oxides of carbon should be reduced below 5% by volume.

The pilot plant programme on feedstock purification was completed in two years with a staff of three engineers/ scientists plus laboratory and engineering support. The pilot plant comprised a series of reactors operating at 30 bar pressure and 350°C of 1´ inch and 3 inch diameter, 6 feet long operating at 30 bar pressure and 350°C, in a building of outstanding architectural appeal, known as the `cow shed' which was located in the Brunel yard (Fig. 10.8.1).

Process design conditions were established and used for the construction of commercial plants for town gas manufacture and later for SNG.

The purification of the lighter distillates (FBP 125°C) was straightforward but the heavier distillates contained larger amounts of more refractory sulphur compounds and required lower space velocities and a higher hydrogen partial pressure. A two-stage process comprising Nimox/Luxmasse/ Nimox/Luxmasse was required to purify kerosene (Figs. 10.8.2 and 10.8.3).

There was a good feedback of information from plants operating in the UK. Numerous problems were encountered with the slippage of sulphur through beds of Luxmasse when they were in

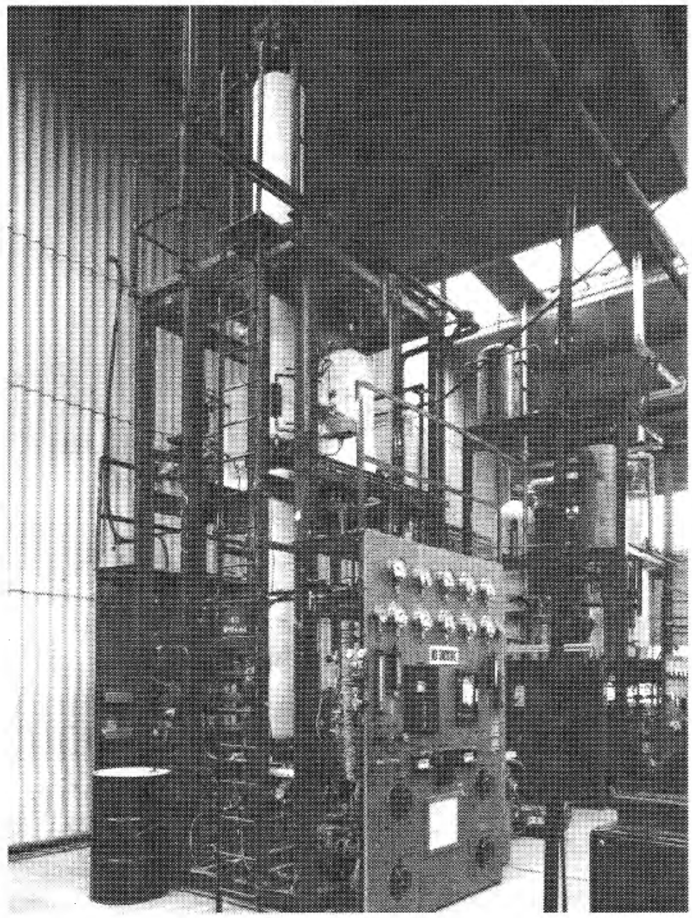

Fig. 10.8.1 Purification pilot plants.

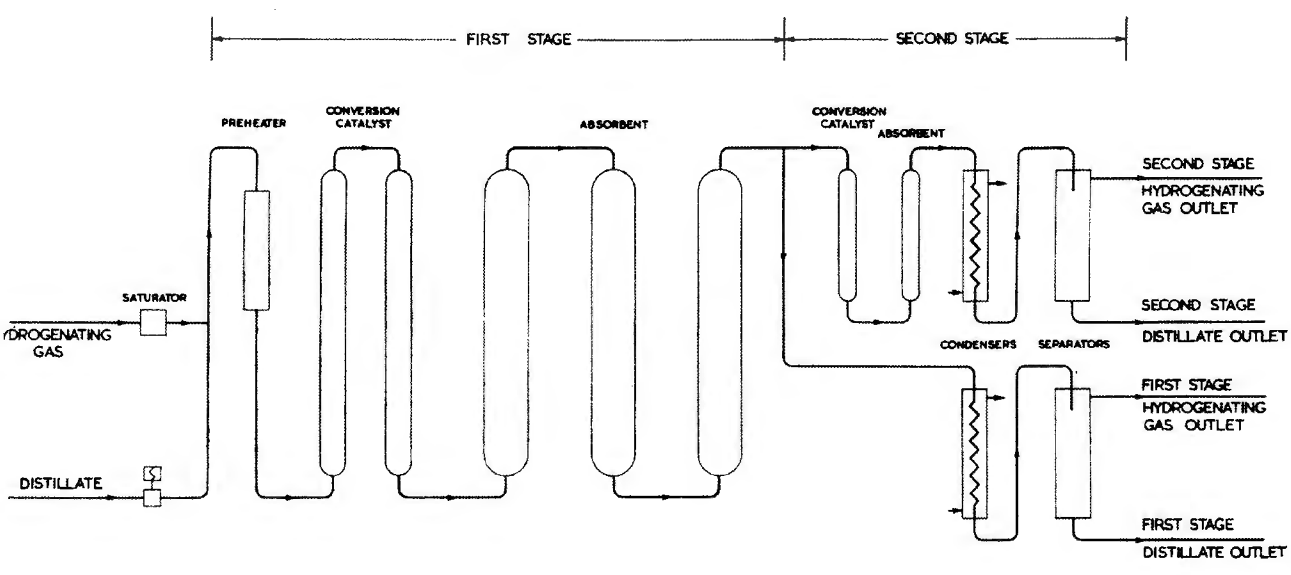

Fig. 10.8.2 Simplified diagram of a two-stage purification plant.

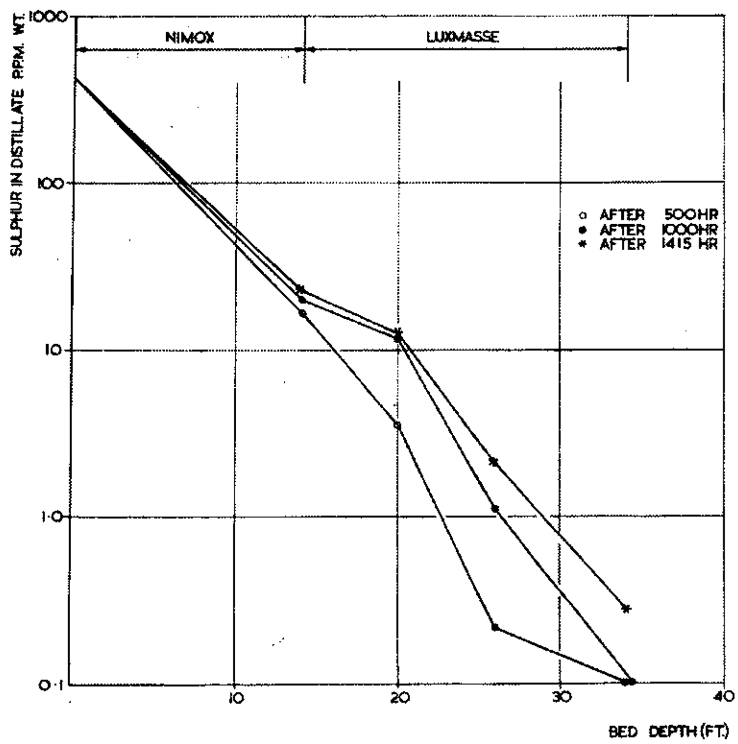

Fig. 10.8.3 The conversion of organic sulphur in LDF 170 overbeds of Nimox and Luxmasse at 375°C and 400 lbf/sq. in. gauge.

the partially sulphided state - the presence of water vapour in the product gas, originating from the reverse shift reaction of carbon oxides in the hydrogenating gas, was the principal cause. On several plants the ability of the hydro-desulphurisation catalyst to catalyse highly exothermic methanation reactions was demonstrated when hydrogenating gas, with up to 20% carbon oxides (due to the failure of the amine wash process), was circulated through the reactor; in one instance at Coleshill there was serious damage to the reactor. After a few years there was a universal move to zinc oxide absorbents as the cost was reduced and the sulphur pick up improved. A copper oxide/zinc oxide catalyst was used as the second stage when the high boiling distillates needed to be purified.

Exploitation

The British Gas fine purification of feedstocks technology was used successfully in 118 units in the United Kingdom and overseas in town gas, SNG and chemical plants, with a handsome return to the Company in process royalties.

References

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10.9 Methanation

A.Williams

Background

Methanation has been developed by the gas industry during the past half century as a means of enriching the product gases of the gasification of coal and of liquid hydrocarbon mixtures such as light distillates and naphthas to produce town gas and SNG. The main reactions to be considered are methane synthesis (methanation) and water gas shift. These are brought to equilibrium over nickel catalysts, the composition of the product being determined by temperature and pressure. Both reactions are highly exothermic and are described by the equations

$$CO + 3H_2 = CH_4 + H_2O \quad \text{.....Synthesis}$$
$$CO + H_2O = CO_2 + H_2 \quad \text{..... Shift}$$

A third reaction, the Boudouard, can occur and must be suppressed because it forms carbon. It is described by the equation

$$2CO = CO_2 + C$$

If the carbon monoxide concentration in the gases exceeds the value corresponding to the equilibrium for this reaction ,carbon will be deposited and steam must be added to limit the carbon monoxide:dioxide ratio by the shift reaction.

The development of methanation processes for the enrichment of gases produced by gasification of fossil fuels on the industrial scale presents formidable challenges to both chemists and engineers. The temperature rise resulting from the strong exothermicity of the reactions must be controlled to protect the catalyst. If not, the catalyst suffers unacceptable chemical and physical deactivation processes. Moreover, the heat released has to be recovered in order to avoid a decrease of thermal efficiency of the combined gasification and methanation processes. The catalyst must have a high activity for the reactions and have sufficient chemical and physical stability under the operating conditions to allow at least a years operation.

Early Gas Research Board Work

The foundation for the work on methanation and also gasification at MRS was provided by the pioneering developments of methanation for enrichment of gas produced by a Lurgi coal gasifier and by gasification of coke to town gas by Dr.F.J Dent and colleagues (1),(2). This work was done at Leeds University and then Pitwines Gas Works, Poole during the period 1938 to the early 1950's for the Gas Research Board. They developed the technology for operation of both the gasification and methanation at pressure which favours methane formation. Recycle of part of the product gas was used to limit the temperature rise. These technologies were later to be widely applied in the development of gas-making processes at MRS. A nickel-alumina catalyst with adequate activity and stability at the reaction conditions then envisaged was also developed by Dr. Dent's team. They also established the equilibrium constants of the reactions as a function of temperature and pressure. It is worthy of note, given the current interest in natural gas vehicles at MRS, to recall that a second objective of the work was to synthesise methane to be used as a substitute motor fuel should the need arise during and after the second world war.

CRG Catalyst Development

At the time of Dr. Dent's developments, methanation did not find a commercial application as opportunities for and advances in other methods of producing gases from fossil fuels removed the need. It was only much later that the first commercial applications for methanation were undertaken. In the meantime , following the establishment of MRS with Dr. Dent as its first director, the focus of attention switched from methanation to development of the gasification of methanol and then liquid hydrocarbon mixtures, e.g. light distillates, by the CRG process as a means of producing a rich gas. Much of the process and recycle technology developed for methanation was adapted and improved for the CRG processes. The nickel- alumina catalyst, used for methanation, was modified and improved to meet the requirement of the CRG process for a catalyst with even greater activity and stability in steam containing atmospheres at high temperature and pressures. The CRG catalyst was shown to be better for methanation than the earlier catalyst developed by Dr. Dent and colleagues. The development of the family of CRG catalysts culminated in CRG F which was introduced in 1975 and is still widely applied throughout the world for methanation and CRG processes.

Methanation of CRG Gas

The first commercial application of methanation for gas enrichment arose in the late 1960's and early 1970's when there was a need for supplies of substitute natural gas in Great Britain to augment the North Sea gas supplies and to supplement the supplies of natural gas in the north eastern United States. At that time MRS adapted the CRG processes by the addition of methanation stages to increase the methane content of the CRG gas to give a product which, after removal of carbon dioxide, was essentially methane; addition of a small amount of LPG formed a substitute natural gas (3). The catalyst used was CRG-A and the conditions were derived from the data of the earlier work at Leeds, Poole and MRS. All that needed to be done was to prove the methanation stages on the pilot plant scale using the same 2 inch diameter reactors used for testing of the CRG process. Following the unqualified success of this work, the CRG double methanation process found widespread application and has continued in use to the present. The only change during the last 20 years has been the introduction of CRG-F catalyst in place of CRG A.

Methanation of Lurgi Gas

The renewed interest in the gasification of coal which arose in the 1970's gave further opportunity for the application and development of methanation processes for the conversion to SNG of the product gases from both the Lurgi gasifier and the British Gas Lurgi slagging gasifier. The conversion of the product gas of a Lurgi gasifier to SNG after purification and the adjustment of its carbon monoxide to hydrogen ratio by the shift reaction was demonstrated on the commercial scale at the Westfield Development Centre(4). This work was supported financially by a consortium of 14 United States companies led by CONOCO and carried out by the then Production and Supply Division of British Gas Corporation with technical assistance and advice from MRS. Thus, one of the original objectives of the early work, the enrichment of Lurgi gas was finally demonstrated at the commercial scale.

Methanation of Slagger Gas - the HICOM Process

In the mid 1970's British Gas took the strategic decision to develop a coal-to-SNG process based on the slagging gasifier. It was essential to methanate the purified product gas of the gasifier in a way which did not dissipate the high thermal efficiency realised at the gasifier. Studies of the process flow sheet by MRS showed that the conventional route of shift reaction followed by methanation used for Lurgi gas was not the best one for the slagging gasifier case. An alternative, tailored to take advantage of the high carbon monoxide and low steam and carbon dioxide contents of the slagging gasifier product was selected. After addition of steam in an energy efficient manner by a saturator, the shift and methane synthesis reactions are combined in a single step to give an overall reaction

$$4CO + 2H_2O = CH_4 + 3CO_2$$

This new process was called HICOM (5),(6). Its development formed a major element of the Research, Development and Demonstration Program for SNG. The objectives were a) to demonstrate, at the commercial scale, the methanation of purified gas from the slagging gasifier by the HICOM process using the commercially available CRG F catalyst to give, after carbon dioxide removal, SNG and b) to develop a substantially improved version of the process (the Advanced HICOM) which after development of a new catalyst could be operated at higher temperatures and pressures than with CRG F. The development of HICOM was carried out at MRS, LRS and the Westfield Development centre and at the height of the development and testing of the new catalyst between 40 and 50 staff were wholly or partly employed on the project.

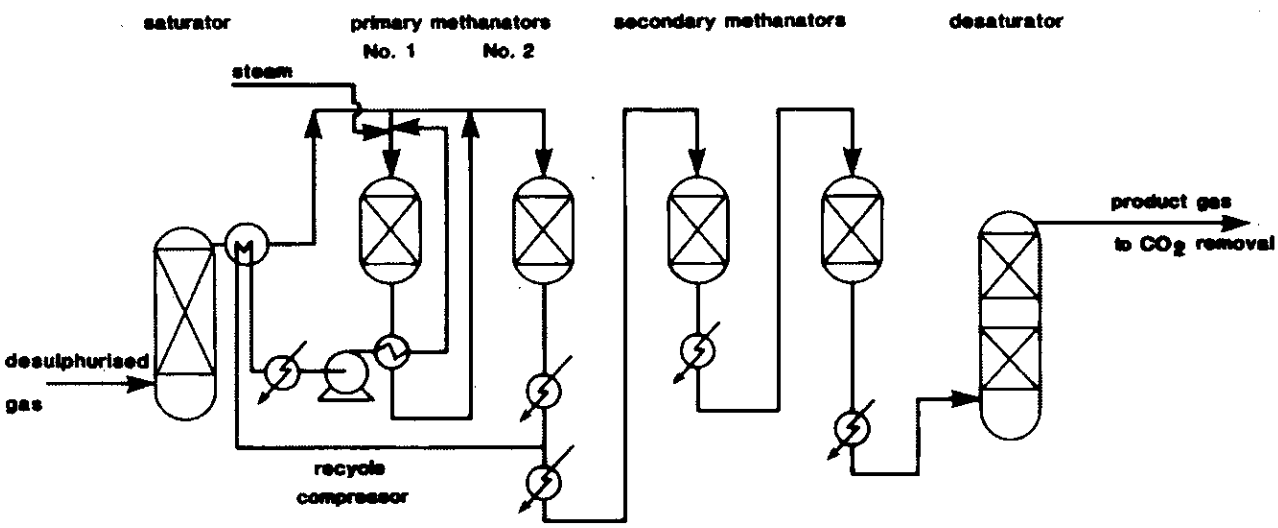

Fig. 10.9.1 Basic HICOM process flow diagram.

The process flow diagram for the HICOM process, shown in Fig. 10.9.1, shows that recycle of product gas is again used to control the temperature rise in the adiabatic primary methanation stages. Most of the steam is added by a saturator which makes efficient use of low grade heat generated within the process and which otherwise would be dissipated. The remainder of the steam is added after the feed flow is split between the two primary methanation stages. The final product from the primary methanation stages is passed to secondary methanation stages operating at successively lower temperatures. In these secondary reactors, which need no recyle for temperature control, the remaining carbon monoxide and hydrogen are converted to give a gas, which after removal of CO_2, is suitable for use as SNG. The composition of the gas passing to the secondary reactors is such that the well proven commercial technology used to convert CRG gases to SNG can be used with CRG F as the catalyst.

Process flowsheet studies identified the optimum conditions for HICOM with CRG F as the catalyst. Tests at MRS during 1978 to 1985 using laboratory and pilot scale plants, replicating the conditions for the primary methanators, gave proof-of-concept for this critical step of the process, including recycle of part of the product gas and demonstrated the suitability of CRG F catalyst. Proof of the saturator as means for steam addition had to await the demonstration of the process at the commercial scale. This was carried out in 1989 at the Westfield Development Centre by the then Production and Supplies Division of British Gas with technical assistance from the MRS division based at Westfield. The 60 day trial was successful, proving the addition of steam via the saturator, the recycle of hot gases with a recycle compressor and the excellent performance of the primary and secondary stages, producing gas of SNG quality after removal of carbon dioxide.

Advanced HICOM

Although HICOM can be operated satisfactorily with CRG F, the conditions necessary for CRG F are not the optimum for it. Operation at temperatures above the maximum allowed for CRG F benefits the thermal efficiency of the coal-to-SNG process. The recycle ratio needed decreases as the outlet temperature increases, and this would allow the size and cost of the recycle compressor to be reduced. At temperatures above 600°C it is possible to replace it with a jet booster, also developed at MRS. A benefit also exists in the high pressure steam which is raised and superheated before export to other parts of the coal-to-SNG process. However, a new catalyst was required for operation at the higher temperatures. It had to operate over the temperature range 300 to above 600°C and at pressures up to 51 bar in atmospheres with high steam and carbon monoxide contents. It was essential that the catalyst continued to do this for at least a year. The development of a new catalyst formed a major task for MRS and LRS during the period 1983 to 1991.

Over 1000 formulations were assessed for their potential to meet the requirements by a specially developed test which was a modification of one used previously to assess catalysts for the CRG processes. About 40 were selected for testing in laboratory scale plants which replicated the conditions of the primary methanator of HICOM. Six of these plants were built at MRS and LRS and the total test time achieved with them was in excess of 100,000 h. Many tests lasted more than 1000 h or more with the longest being one of 5000 h to prove the formulations finally selected.

Eight candidate catalysts were then tested at the pilot plant scale using four plants similar to those used for the CRG F tests, illustrated in Fig. 6.14 in Chapter 6. A methanation feed gas plant was specially built to supply gas which simulated that from a slagging gasifier. The test duration was normally between 900 and 1200 h and the total time of all tests was about 20,000 h. Two tests were done with a reactor cooled with high pressure water/steam in a purpose built cooled methanation plant, since it appeared that an optimum configuration might be an adiabatic followed by a cooled methanator (Fig. 10.9.2). Two catalysts met the requirements and the best of these, designated LH, has been recommended for Advanced HICOM use. It was derived from the precursor of CRG catalyst with the controlled addition of a clay and other materials to give chemical and physical stability at high temperature whilst maintaining high activity for the reactions. Although a demonstration trial of advanced HICOM was not done, the final pilot plant test at Westfield using the product gas from the slagging gasifier and LH catalyst was successful and confirmed the results of the MRS pilot plant tests.

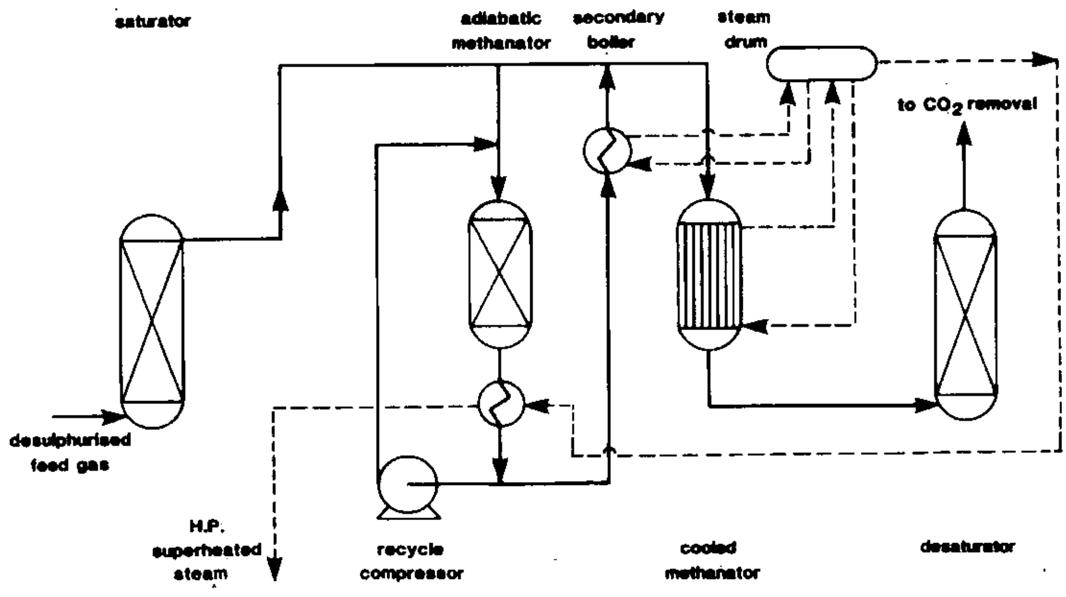

Fig. 10.9.2 Simplified flow diagram of advanced HICOM scheme.

Other tests on LH have shown that it could replace CRG F for CRG and pre-reforming of natural gas processes and would increase the range of conditions available for these. It is likely that it will find its first commercial application for these uses given the present lack of demand for SNG.

The development of HICOM and the catalyst for it represents a notable success for British Gas R & D and MRS in particular which is now ready for commercial application when the need arises.

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10.10 Natural Gas Processing

J.Templeman

Background

The Gas Industry has always been faced with the problem of storing adequate quantities of gas to meet daily demand patterns and peak demand in winter. The changeover to a natural gas based industry offered a new storage option, namely, of liquefying the gas and storing it at a very low temperature. To liquefy natural gas it has to be cooled down to around -160°C. Liquefied natural gas is stored in large insulated tanks, which typically have a storage capacity of 20,000 tons; this is equivalent to one thousand million scf of gas.

The first LNG plant to be commissioned by British Gas was at Glenmavis in 1971, and others followed at Canvey Island, Partington, Avonmouth, the Isle of Grain, and Dynevor Arms in South Wales. An LNG installation and storage site is shown in Figure 10.10.1. A block flow diagram of the LNG production and storage process is shown in Figure 10.10.2.

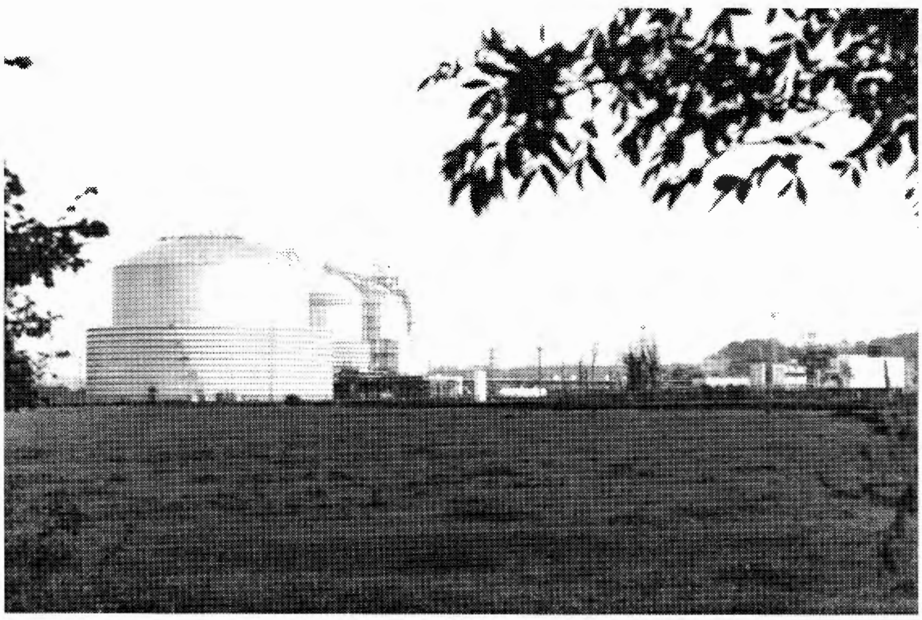

Fig. 10.10.1 A LNG production and storage site.

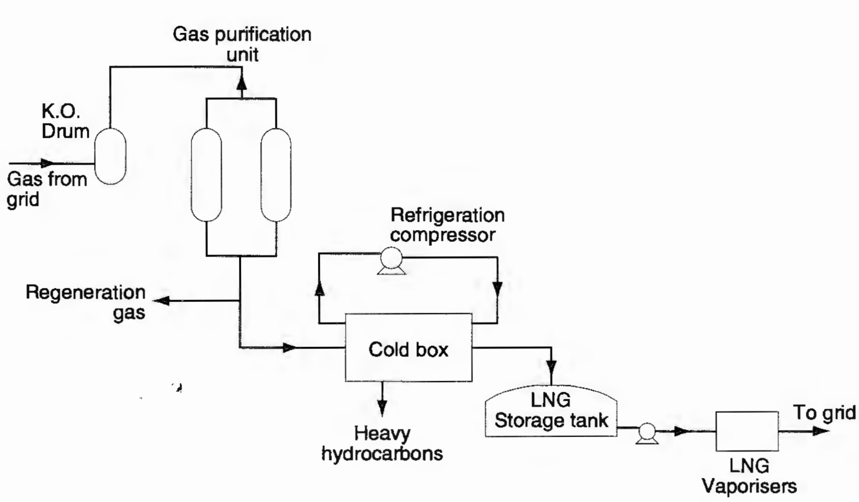

Fig. 10.10.2 Flow diagram of the LNG production and storage process.

The Research and Development Division of British Gas anticipated that this large programme of LNG plant construction and operation was likely to require R/D support. One area in particular was the purification of the gas prior to its liquefaction. The gas has to undergo a rigorous purification to remove components that would solidify and cause blockages in the low temperature heat exchangers. The process proposed by the contractors for purifying the gas was adsorption of the undesirable compounds on a bed of solid material.

Technical Approach

To obtain data on the adsorption process a natural gas treatment laboratory was established by MRS. The laboratory was situated on the Coleshill site of West Midlands Gas to take advantage of the availability there of high pressure gas from the National Transmission System. A photograph of the laboratory is shown in Figure 10.10.3 (see also Fig. 5.14 in Chapter 5).

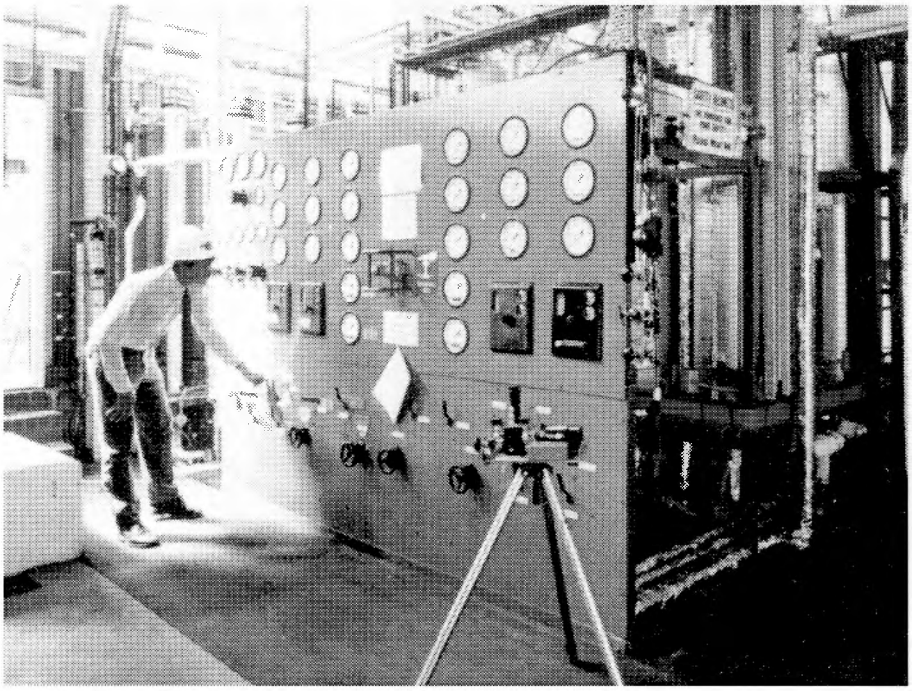

Fig. 10.10.3 Natural gas treatment lab at Coleshill. The high pressure packed bed absorption rig.

The first major item of work to be carried out at the new laboratory was in connection with the LNG plant to be built at Glenmavis. The problem to be solved was to determine whether it was necessary to remove traces of benzene (approximately 500 vpm) from the gas. One of the two contractors bidding for the job, Air Products Ltd, specified an activated carbon adsorption unit to remove the benzene; without this Air Products claimed there would be blockage problems in the liquefaction stage. The other contractor, British Oxygen, claimed there was no need for the benzene removal process. The removal step was expensive, approximately £250,000 at 1979 prices, therefore there was considerable incentive to determine whether this step was necessary. The work carried out at the Coleshill laboratory showed that the benzene removal step was not necessary, and hence British Gas was able to select with confidence the cheaper bid put forward by British Oxygen.

Molecular Sieves

One of the major activities carried out at the Coleshill laboratory was the examination of the adsorption purification process for the removal of water and carbon dioxide from natural gas prior to its liquefaction. To avoid blockage problems in the low temperature heat exchangers the concentrations of these components needed to be reduced to the low levels of 1 ppm (water) and 50 ppm (carbon dioxide). This is a critical process and at the time of the ordering of the Glenmavis LNG plant there was only one recommended adsorbent for this duty, a molecular sieve manufactured by Union Carbide. There were several other sieves on the market but their suitability for the LNG plant duty was not known. Molecular sieve is expensive and pilot plant tests were carried out at Coleshill to see if some of the other, less expensive molecular sieves, would be satisfactory for the LNG plant duty. It was also desirable to have more than one source of sieve from the point of view of supply and cost. Some were found to be capable of meeting the purification requirements and as a result they have been used on the LNG plants.

A photograph of a gas purification unit is shown in Figure 10.10.4. The performance of the purification units on the LNG plants was monitored by MRS. This has provided a useful data bank of knowledge, and has ensured that molecular sieves were not changed too early, and allowed LNG plant managers to budget and place orders for replacement material in good time.

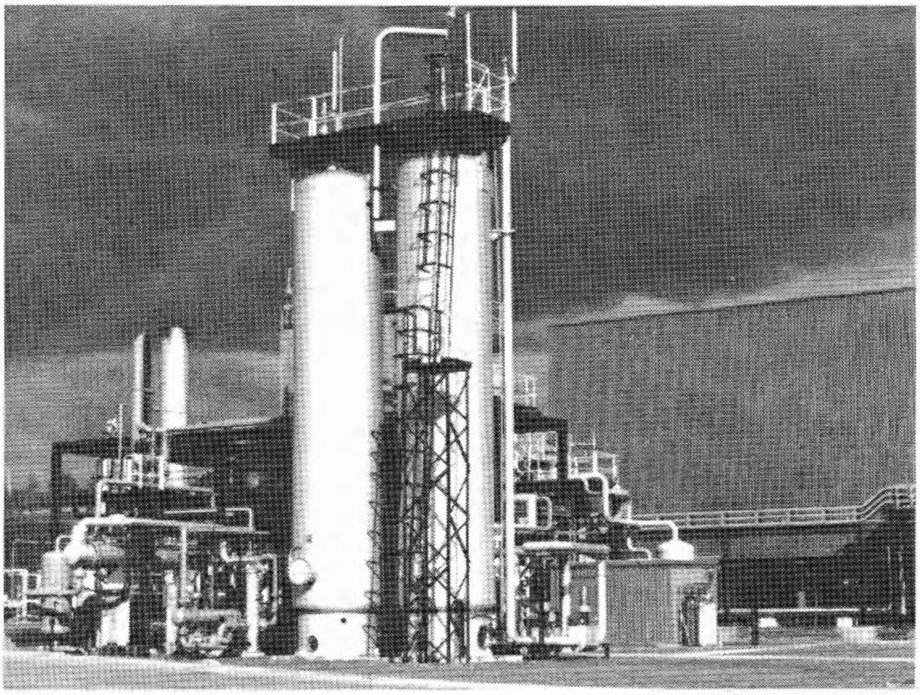

Fig. 10.10.4 A gas purification unit on an LNG plant.

Improving Tower Performance

In the early eighties a problem began to appear on the LNG plants as the result of the introduction of new sources of natural gas. The new supplies resulted in small changes in the composition of the gas in the National Transmission System (NTS); in particular the CO_2 levels increased. These composition changes caused major problems on the LNG plants.

The first LNG plants were designed to treat gas containing 0.15% v/v of CO_2 and the later ones 0.50%. However, as a result of new gas supplies, it was anticipated that the CO_2 levels in the NTS would increase and reach a level of around 1% v/v in the early nineties. Thus urgent attention was required to uprate the CO_2 removal capacity of the purification units. Consideration was given, by the then Production and Supply Division who were responsible for the operation of the LNG plants, to add further adsorption towers to solve the problem. A total of £7 million (at 1985 prices) was approved for these additional towers and their installation.

Around this time MRS had begun to investigate alternative solutions to increasing the CO_2 removal capacity that would be much less expensive than adding more towers. The thrust of the MRS investigations was to examine methods of reducing the time required for the thermal regeneration of the adsorbent; if this could be reduced it would increase the effective capacity. An obvious way is to increase the flow of regeneration gas for the heating and cooling of the adsorbent. This has the disadvantage of producing large quantities of regeneration gas that ultimately have to be injected into local distribution mains, but there is a limit to the quantities of gas that can be injected into these systems. Thus increasing the regeneration gas flow did not, by itself, provide a satisfactory solution. An effective way of reducing the regeneration time is to reduce the regeneration temperature; this was investigated at the Coleshill laboratory. The molecular sieve beds remove water and CO_2 from the gas and the regeneration temperature required is determined by water, which is more strongly adsorbed than CO_2. To remove water a temperature of 250°C is necessary, whereas pilot plant tests showed that the CO_2 is removed at a temperature of only 175°C. The concentration of water in the feed gas is very small relative to that of carbon dioxide, and only a few inches of adsorbent at the top of the bed are utilised for water removal. Thus the regeneration temperature could be lowered if an adsorbent could be found that had a good capacity for water, and that was also capable of being regenerated at a temperature below 250°C. Tests on adsorbents at the Coleshill laboratory showed that silica gel had the required characteristics.

Following these pilot plant tests a demonstration of the principle was carried out on the Partington LNG plant. A small layer of silica gel, approximately 6 inches, was put on top of the main bed of molecular sieve. The regeneration mode was changed; a pulse of heat was put into the bottom of the bed, just sufficient to ensure that the top of the bed reached 175°C. The demonstration was successful, and the plant was operated for several months in this mode without any problems arising. The gas purification units on the other LNG plants were similarly modified. This modification, plus modest increases in the regeneration gas flow, allowed gases containing up to 1.2% of CO_2 to be processed. Thus the spending on the additional towers was avoided.

Hydrocarbon Dewpoint Control

In the mid-seventies British Gas examined the concept of taking excess gas available from the NTS in the summer and storing it in a partially depleted offshore gas well. Studies showed that this could provide an extremely large, relatively cheap and environmentally acceptable means of storage. Following the design and costing studies the project was approved and led to the design of equipment for the offshore and onshore parts of what became known as the Rough Field project.

The Rough Field was a partially depleted offshore gas well about 15 miles off the Hull coastline. The onshore gas reception and processing plant was to be situated at Easington. Since the storage well was only partially depleted the injected NTS gas would become "contaminated" with the heavier indigenous Rough Field gas and as a result, the gas arriving onshore would have a hydrocarbon dewpoint exceeding the NTS specification. Thus a process had to be selected for the Easington site to remove heavy hydrocarbons from the gas to adjust the dewpoint to the NTS specification.

The process contractors examined a number of processing schemes for heavy hydrocarbon removal from the gas and concluded that the most economic, and operationally attractive scheme, was to chill the gas to remove the bulk of the heavy hydrocarbons and to remove the remaining traces using adsorption.However, selecting an absorbent for the "trim absorption unit" was a problem as there was no reliable performance data on which to base the design. As a result, MRS were asked to carry out pilot plant test to identify a suitable adsorbent. Three adsorbents were examined for their heavy hydrocarbon adsorption and regeneration characteristics, silica gel, activated carbon and molecular sieve. Silica gel was found to have the most suitable overall characteristics, i.e. a good adsorption capacity and ease of thermal regeneration. Subsequently silica gel was installed in the adsorption towers at Easington (Fig. 10.10.5). However, this was not to be the end of MRS involvement in this project.

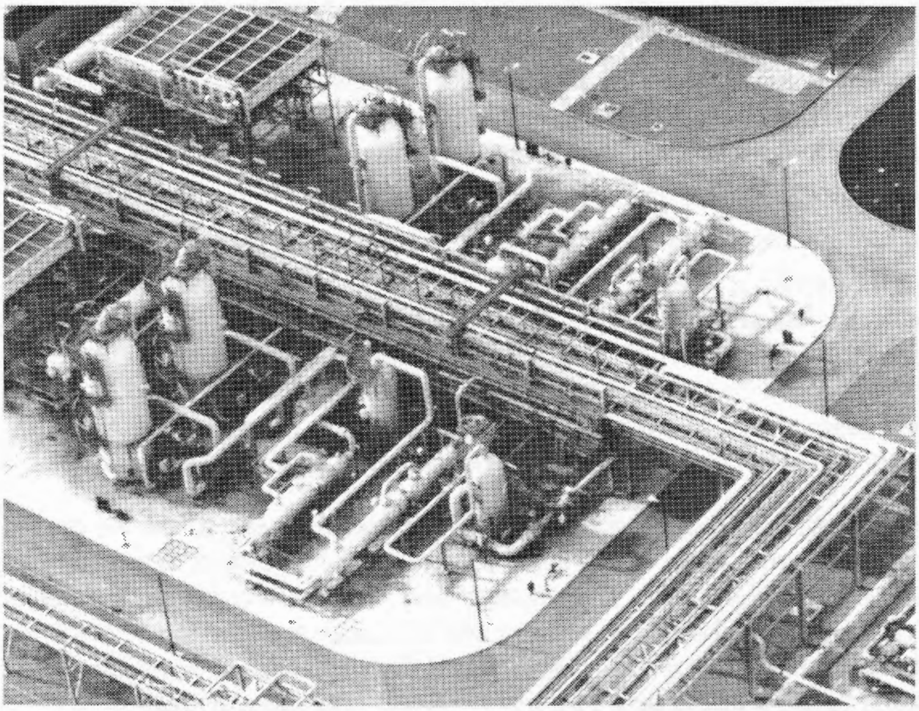

Fig. 10.10.5 Easington Terminal, the gas treatment section.

The Rough Field complex was commissioned in late 1985 and MRS carried out trials on the Easington adsorption unit in 1986. The plant performed well and analysis of the data collected gave indications that the adsorption unit had a capacity well in excess of its design value. MRS developed a mathematical model of the adsorption of hydrocarbons on to beds of silica gel and also a mathematical model of the removal of the hydrocarbons by thermal regeneration. The models were used to study the performance of the Easington "trim" adsorption unit. The predictions from the models also indicated that there was potentially a larger than design processing capacity at Easington. It was predicted that the adsorption unit alone (ie with the chilling unit off-stream) could process the full range of anticipated gas compositions from the Rough Field, at flow rates of up to twice the design value. These predictions were confirmed in trials carried out in 1987.

As a result of this work the layout of the Easington plant was altered to take full advantage of this "unlocked" capacity. Originally there were two gas processing trains at Easington, each consisting of a chilling and a "trim" adsorption unit in series. The chilling and adsorption units now operate as four independent streams; the gas processing capacity is three times the original design value.

Morecambe Field

Following the decision by the Company to develop the North Morecambe gas field MRS were involved in studies connected with the gas processing requirements. Data were supplied to the North Morecambe Project Team to allow them to assess the benefits of using adsorption technology to meet water and hydrocarbon dewpoint specifications. The studies identified that adsorption had lower costs and more flexibility of operation than the alternative processes of refrigeration and turbo-expansion. The capital costs (1988 prices) for the adsorption and refrigeration processes were £6.2 and £7.2 million respectively with operating costs of £0.4 and £0.6 million/year. Turbo-expansion had higher costs than these. Adsorption was selected to meet the processing requirements of the North Morecambe gas, and the detailed design and construction of the adsorption units is being carried out by John Brown Engineers and Constructors Ltd. MRS have supplied data to enable the detailed design of the adsorption plant to be carried out.

Commercial Exploitation

It was recognised that there was a potential for exploiting the adsorption technology developed by MRS. This is now well underway. The technology has been given the name ADAPT (Advanced Development of Adsorption Process Technology), and a comprehensive brochure produced and sent to all the major companies who have an interest in natural gas processing. Papers have also been given at International Conferences. This is now starting to pay off with enquiries received from a number of companies. The first paid design study has recently been completed for Nederlandse Aardolie Maatschappij (NAM) who are the operational side of the Dutch Gas Industry. The MRS study provided process design data for NAM's NORG project, which is similar in scope but larger than the Rough project. The NORG project has now proceeded to the detailed design phase which is being carried out by the process contractors, Fluor Daniel. MRS are supplying additional information during this phase.

MRS will soon be undertaking a second paid design study for NAM for the processing of gas from their Grijpskerk field. Later on, further process design studies for NAM will be carried out in connection with the revamping of the gas treatment facilities for Groningen gas.The indications are that the interest in this technology will continue to increase and it will generate a substantial income for the Company.

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10. 11 Jet Boosters

J.J.Templeman

Background

Gas Compression has always been an important process in the Gas Industry; since it is a fairly expensive operation, means of reducing compression costs are continually being sought. The jet booster offers a means of making large savings in these costs.

The move towards higher distribution pressures, already underway as a result of integrated networks and fewer larger production plants, was accelerated in the early sixties with the introduction of high pressure gas manufacturing plants. These plants delivered gas into transmission mains at pressures of up to 300 psig (20.7 barg). It was at this point that 'jet boosters' began to be installed to compress low pressure holder gas, quite often replacing mechanical compressors.

When high pressure manufactured gas became available it made sense to locate pressure reduction stations at holder stations or old works sites. To reduce costs there was a need to maximise the use of low pressure holder facilities, to minimise the use of expensive mechanical compression and to somehow utilise the considerable pressure energy available in gas supplies. The jet booster was ideally suited to take advantage of this situation as it can use the high pressure energy in gas supplies, that would otherwise be wasted, to boost the pressure of holder gas and deliver it into local distribution systems. Furthermore the jet booster has a low capital cost, no running or maintenance costs and thus offers a very inexpensive means of gas compression.

Technical Approach

In the 60s there was only one Company supplying gas jet boosters, and their prices were high. As a result MRS was encouraged to develop jet booster design methods. This work started from quite a good position as there was close similarity between the proposed work and the gas burner design theories and techniques that had already been developed by MRS (1)(2).

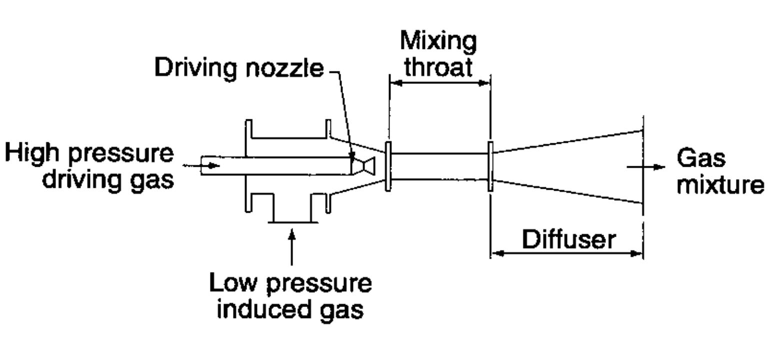

Fig. 10.11.1 Diagram of a simple jet booster.

The jet booster (Figure 10.11.1) is a simple device having no moving parts. The high pressure driving gas expands through the nozzle, the pressure energy is converted into kinetic energy and the gas emerges as a high velocity jet. There is a considerable velocity gradient between this jet and the surrounding gas and as a result it is entrained into the jet. The mixture enters the mixing throat where the process of momentum exchange and mixing are completed and some pressure recovery may occur. The mixture then passes into the diffuser where further pressure rise takes place as the velocity falls.

It is important to draw a distinction between compressible and incompressible flow situations. Gases can be considered to be incompressible if there are no substantial absolute pressure differences over the booster. The dividing line between these two states is not precise; for engineering purposes the flow is generally considered to be incompressible if the absolute pressure ratio of the booster exit gas to the entrained gas is 1.2 or less. In some cases there is a high pressure difference across the nozzle, but the pressure lift of the mixed flow is only small and can be considered as incompressible flow. These are referred to as "semi-compressible" jet boosters. Design methods were developed for all three types, ie incompressible, semi-compressible and compressible.

The design techniques developed by MRS were based on the equations of continuity, momentum and energy and the procedures allow optimised designs to be arrived at, i.e. maximum outlet pressure for a given injection ratio, as well as providing the ability to predict the performance of the booster at conditions away from design.

The existence of high pressure supplies of both town and natural gas at the Coleshill Laboratory enabled the design methods to be tested on a reasonable scale (3). The work earned Malcolm Hoggarth an M.Phil (4). Later the theory was extended to two stage boosters and tests were carried out on a full scale prototype two stage unit which was installed at the Coventry, Foleshill Road, holder station of West Midlands Gas (5). The agreement between the theoretical and measured results was good.

Commercial Implementation

This successful experimental work led to a total of 89 jet boosters being designed for various Regions of the Gas Industry by MRS. These jet boosters are listed in Table 1.

Table 1 MRS Designed Jet Boosters

Region	Number of Jet Boosters
Wales Gas	26
Northern	4
North West	7
South West	9
West Midlands	22
South East	10
Scottish Gas	9
North Thames	2
Total	89

The total equivalent horse power of these jet boosters is 13,030 and the total power savings per year based on electricity at 7.5 pence/kW and 16 hours/day operation is £4.25 million. The largest in terms of gas throughput was one in the Bristol distribution system which used 24.7 million scfd of gas at 175 psig (12.1 barg) to entrain 4.8 million scfd of holder gas at 8 in.wg (19.9 mbarg) and deliver the mixture at 30 psig (2.1 barg). A photograph of the MRS designed jet booster at Hinckley is shown in Figure 10.11.2.

The jet booster design work carried out by MRS proved to be very effective, the total amount of effort spent being around 1 to 1.5 man years. It resulted in considerable

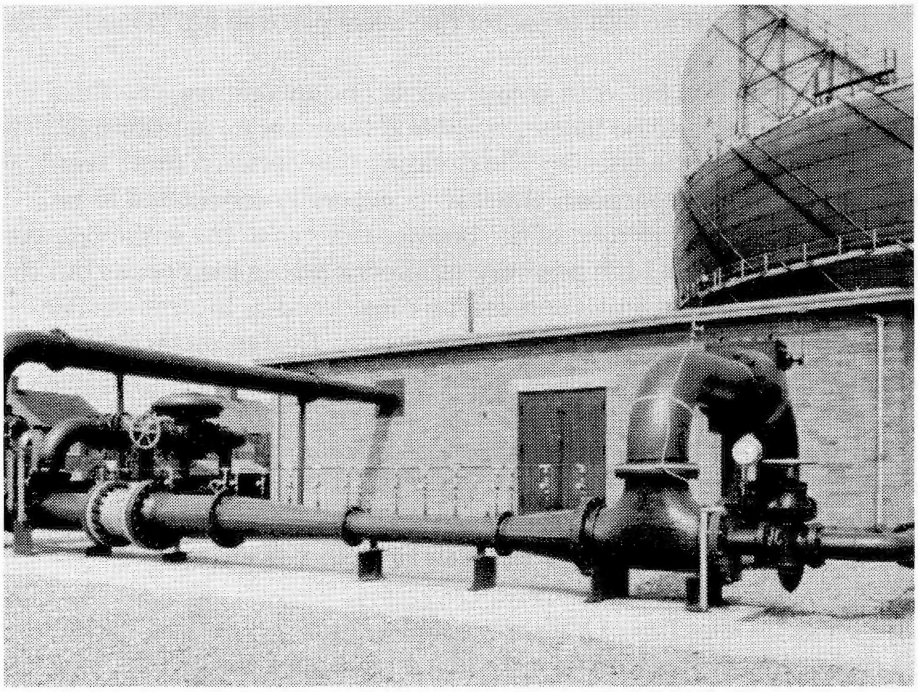

Fig. 10.11.2 Jet booster at Hinckley.

savings in energy costs and also it gave the industry the capability of meeting its own design requirements. The units themselves were frequently manufactured in Regional workshops and only cost about 25% of those of proprietary design. Moreover the total costs of installing a conventional diesel driven gas compressor are about 10 times greater than that of a jet booster for the same duty.

As well as being used to design jet boosters for gas distribution systems, the design techniques were successfully used in other applications. One of the most notable was to achieve recirculation in the Catalytic Rich Gas (CRG) process (see Section 10.7).

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CHAPTER 11

Burners and Heating Plant

11.1 Injectors, Jet Pumps and Recirculation

W.E.Francis

Background - The Atmospheric Injector

The injector has been of importance to gas utilisation since the introduction of the atmospheric injector in the shape of the Bunsen burner in the mid 19th century. It is somewhat surprising that a comprehensive theory of its action was not developed until the mid 20th century.

The MRS contribution, as with so many other topics, derives from Gas Research Board work, in this case started by R.S.Silver, then Assistant Director. He attempted an energy balance approach to predicting the air entrainment in an atmospheric injector of the type used on most cooker burners. However he omitted the "enlargement loss" associated with the increase in cross section of the mixed air and gas stream as it fills the mixture tube by recirculation of the mixture, causing a rise in static pressure. Consequently, Silver could only match experimental results by the use of empirical coefficients.

Subsequently some careful air entrainment measurements were carried out at Beckenham by A.D.S.Tantram in 1950-52, supervised by Dr W.A.Simmonds, who developed a comprehensive theoretical treatment at Nechells in 1953-4 (1), verified by using Tantram's results and those from actual cooker burners taken by J.W.Wood for the Joint Research Committee at Leeds some years earlier. Simmonds used a force-momentum balance to include the "enlargement loss" and was able to account for the effects of friction losses, contraction and discharge coefficients of nozzles, heating effects and buoyancy for both laminar and turbulent flow conditions.

Jet Driven Recirculation

In the early 50's, some furnace manufacturers (The Incandescent Heat Company, under the direction of John Fallon, in particular) began to appreciate the benefit of recirculation of combustion gases to provide uniform temperature conditions in furnaces, air heaters and radiant tubes. Recirculation was in some cases provided by the jet pump action of tunnel burners. The significance of recirculation and its effect on the balance of heat transfer between convection and radiation in heating plants had been brought home to W.E.Francis by attempts to measure the effect of air preheat on radiation from a town gas flame. Convection from copious recirculation in the calorimeter chamber masked the radiation effects.

Eric Francis was using an Incandescent Heat Co. jet burner fired air preheater for the experiments and realised that injector theory could predict the recirculation ratio and hence the convective heat transfer and the temperature uniformity.

The predictions were verified by measurements of recirculation ratio on the air heater, a radiant tube and experimental tube circuits in which the pressure losses could be more accurately defined.

Jet driven recirculation is particularly suitable for high temperature plant, but with normal burner supply pressures recirculation ratios were limited to about 5.

Recirculation could be equally beneficial in lower temperature plant, and hot gas fans could be used to achieve very high rates of recirculation. The efficiency of drying processes particularly could be improved by the use of fan driven recirculation. An experimental forced convection oven was operated (in the "Giraffe Room" Fig. 11.1.1) drying a stack of wet fibre boards to demonstrate that high humidity levels generated by almost 100% recirculation was no impediment to efficiency and the achievement of good drying rates. The standard humidity charts were modified for the particular case of direct gas fired drying.

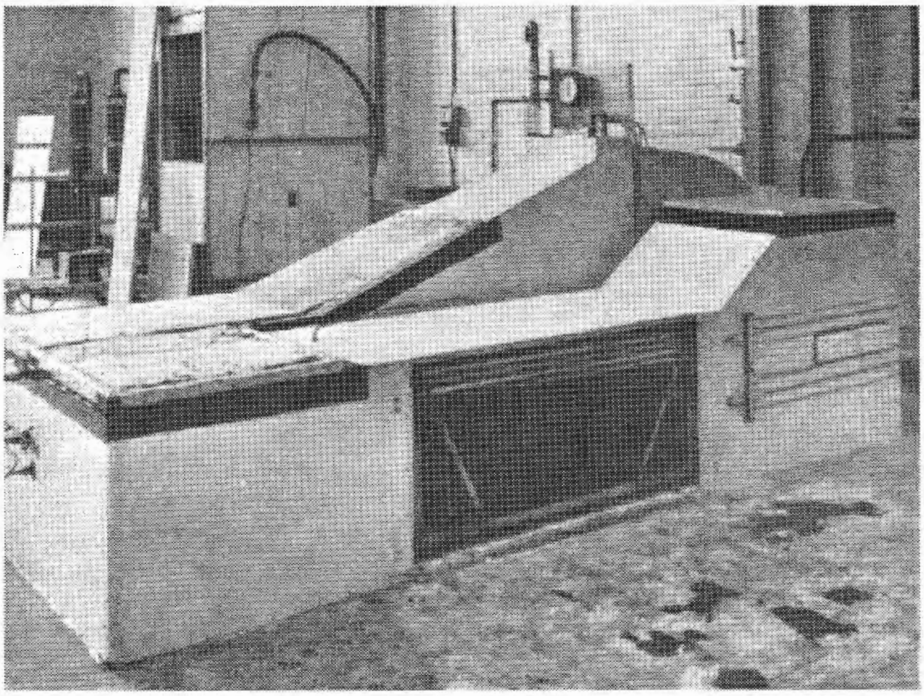


Fig. 11.1.1 Experimental drying oven with fan driven recirculation, showing the wet fibre board load.

Applications of Recirculation

This work on recirculation was presented at the IGE Meeting in November 1956 (2). Some manufacturers were quick to take up the ideas, in particular Reg Broomer of F.J.Ballard. For example, he installed a series of ovens at the Armstrong Cork Co., for drying acoustic ceiling tiles, which were in essence larger versions of the experimental fibre board dryer (Fig. 11.1.2). He also redesigned the company's tin printing ovens to make better use of recirculation and cooperated with MRS in developing an efficient plate type cross-flow heat exchanger for use in indirect fired air heaters and ovens.

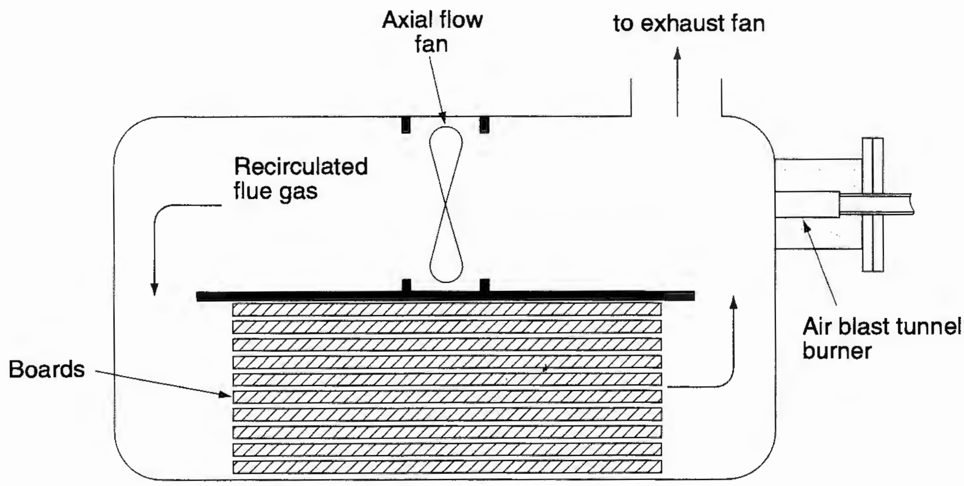
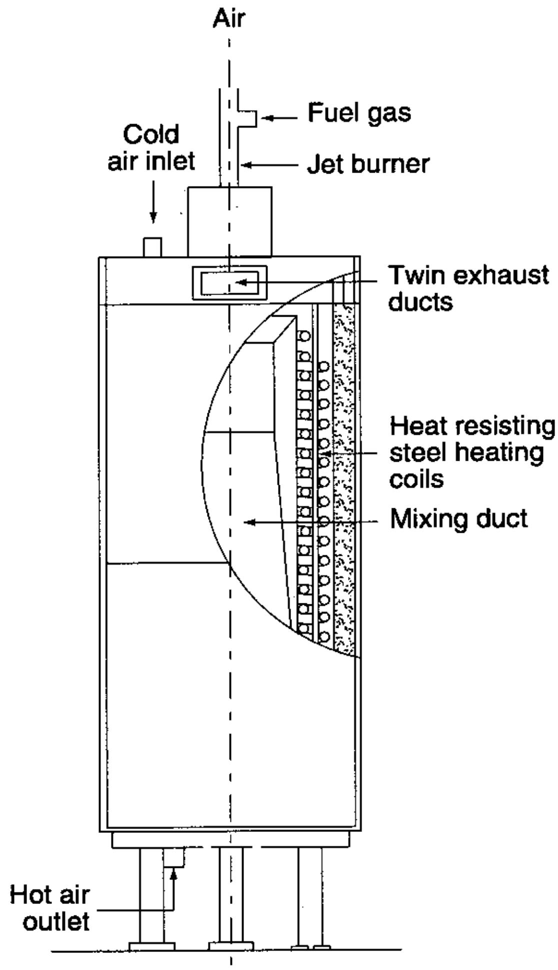


Fig. 11.1.2 Schematic diagram of drier for insulated board manufacture.

One of the most successful applications of jet driven recirculation was in preheaters for hydrogen and oil feedstocks required for the gasification projects at MRS, which required close control of maximum tube temperatures, since at high pressures the materials were working close to their limits. Coiled tube heaters fired with tunnel burners to produce recirculation were designed for this purpose and proved quite effective (Fig. 11.1.3). However, efforts to increase the outputs of the heaters required excessive air pressures and showed up the limitations of the current design of tunnel burners. A study of the design of air blast tunnel burners, again using injector theory, led to new configurations with optium exit velocities.

Fig. 11.1.3 Coiled tube high pressure air heater using jet driven recirculation.



High Velocity Burners

The availability of the new generation of high velocity burners was a spur to further applications of jet recirculation. Clive Denning of the Incandescent Heat Co. took up the coiled tube heater design and supplied many to the aircraft industry for high pressure, high temperature air for turbine testing. Several more were supplied to MRS three on the CRG peak load plant (see Fig.3.6 in Chapter 3).

Trevor Ward and Cyril Rann at the NEGB Industrial Development Laboratory proved particularly adept at finding applications for jet driven recirculation, applying it to glass tank preheating, stress relieving of pressure vessels, heating of embossing rolls and a variety of heat treatment processes where temperature uniformity was important (Fig.11.1.4).

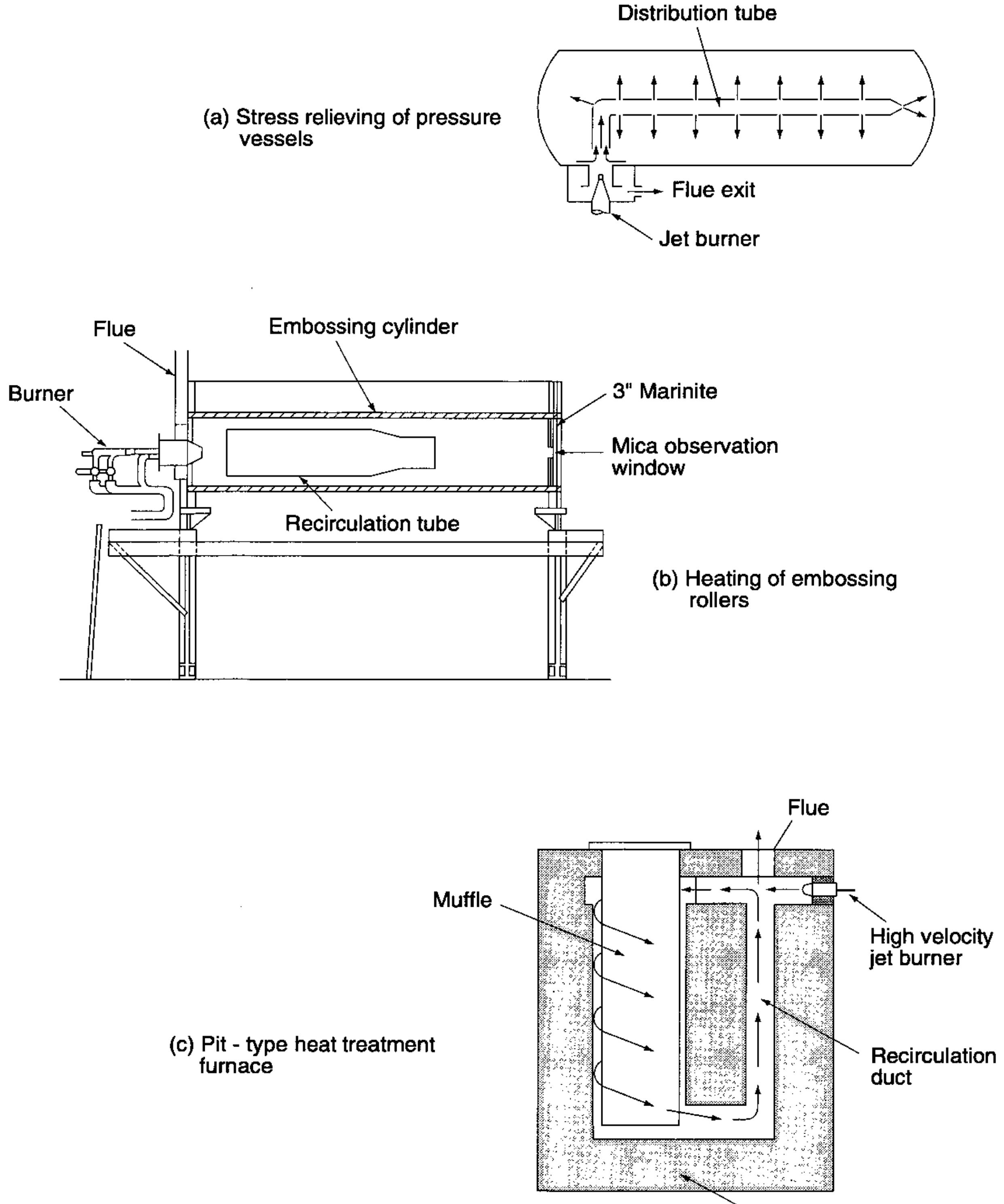


Fig.11.1.4 Examples of jet driven recirculation applications.

A Generalised Jet Pump Theory

By the early 60's, enough experience of various jet pump devices had been gained to give great confidence in the basic theoretical approach, so it was possible in 1963 to generalise the theory for the optimum case of maximum mixed fluid pressure (3). For turbulent conditions with no phase changes and incompressible flow in the mixing throat and diffuser, the design equation takes a very simple form, which could be applied to most of the situations of interest to the Gas Industry, for example, atmospheric and air blast injectors for burners, flue gas ejectors (of importance in the first generation of recuperative burners) and simple gas jet boosters.

Simplified design charts for industrial use were published as an Industrial Gas Development Committee Report and presented at one of the early Industrial Gas Conferences at Ashorne Hill in 1960.(4)

Over the years there have been many diverse applications of jet pumps and jet recirculation associated with MRS projects. Malcolm Hoggarth and John Templeman went on to extend jet booster design to cover high pressure multistage devices (Section 10.11). The design of industrial bar burners for natural gas were studied by Malcolm Hoggarth and Dave Reay to overcome perceived problems in conversion of industrial ovens (5). Radiant tubes and ceramic immersion tubes relied upon jet recirculation for temperature uniformity.

Some of the most interesting applications have been in the gasification field. The first and commercially the most successful was the gas recycle hydrogenator (GRH), first reported in 1962 by Murthy and Edge (6), in which a high velocity jet of hydrogen and vapourised light distillate, preheated to about 450°C was directed into a simple cylindrical vessel fitted with a concentric inner draught tube. In the 80's, this technique was employed again for the hydrogenation of coal. A jet of hydrogen provided the momentum for product gas entrainment and for rapid mixing of the pulverised coal feed, producing methane and hydrocarbon liquids, with a powdered char falling out at the base (7).

In developing the CRG process for heavier distillate feedstocks, and even kerosine, it was found that recirculation of the product gases from the steam gasification stage was beneficial in reducing catalyst deterioration. The recirculation could be achieved by a jet pump driven by the process steam (8). A similar technique of recirculation of product gas by steam jet pump was adopted in the HICOM process for methanation of gas from the slagging gasifier (9).

The Coanda Injector

In seeking improvements to the water bath heaters used in pressure reduction stations for gas preheating, attention was focussed on injectors using the Coanda effect, since these appeared to offer some noise reduction with high pressure gas. Investigation showed that the injector efficiency was little different from a well designed conventional coaxial jet injector, and that the same design theory could be applied.

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11.2 High Velocity Jet Burners

M.L.Hoggarth

Background

High velocity gas burners have played a central role in the development of a wide range of industrial heating processes at MRS over the last 40 years. Jet driven recirculation, rapid heating of metals, recuperative burners, ceramic radiant tubes and immersion tubes have all derived from the original interest in high velocity burners in the mid-50s.

The incentive for using high velocity jet burners in the 1950s derived from the demand for increased productivity in industry which necessitated the development of gas fired heating methods that could keep pace with the general speeding up of the manufacturing process as a whole. It was recognised that high velocity air blast tunnel burners or jet burners could provide higher convective heating rates for local heating processes and that the high velocity streams of combustion products emerging from burner tunnels could be used to drive recirculation and to provide uniform temperature conditions in furnaces, air heaters and radiant tubes.

A variety of different design configurations were devised by development engineers such as Jim Palser(1), John Waight(2) and Bill Smirles(2) of the West Midlands Industrial Department, who employed single mixture ports or nozzles. Trevor Ward(4) of NEGB Industrial Development Centre and Graham Robertshaw(5) of the NWGB Development Department pioneered multiple mixture port burners formed by drilling arrays of holes in metal plates. Air/gas mixture was supplied from separate Venturi injectors. The design of these burners relied on a combination of features partly derived from theoretical considerations such as mechanical energy balances (Waight(2)) and practical experience.

Spectacular improvements in heating rates were achieved and several successful examples of the utilisation of high velocity combustion products to drive recirculation were demonstrated(4). The limitations of these existing air blast jet burners were shown up by the design calculations for equipment using jet driven recirculation (6). The air pressures required seemed excessive and could not be generated economically. As a result, Eric Francis and Brian Jackson embarked on a systematic study (7) of air entrainment and pressure losses through a range of typical configurations of premixed tunnel burners using air blast injectors.

Technical Approach

The evolution/development of jet burner design comprises several distinct features and major advances. These include the efficient use of air supply pressure, the adoption of the inherent self proportioning characteristics of the injector system to achieve accurate air/gas ratio control over the operating range, the need to ensure a stable flame free from lightback, lift and blow off on both town gas and natural gas, and finally, the requirement to operate with highly preheated air.

To provide a criterion against which to assess whether the available air and gas supply pressure was utilised effectively, Eric Francis and Brian Jackson (7) introduced the concept of a "pressure efficiency" which they defined as the ratio of the dynamic pressure.

of the combustion products at the burner exit to the available air supply pressure at the air nozzle. A theoretical examination of tunnel burner design was undertaken in which the pressure efficiencies of a range of conventional and optimised burner designs were determined from the pressure changes occurring through the entire burner-injector system taken as a whole (Fig.11.2.1). The pressure efficiency of conventional burners was shown to be very low, about 7 to 8 per cent.

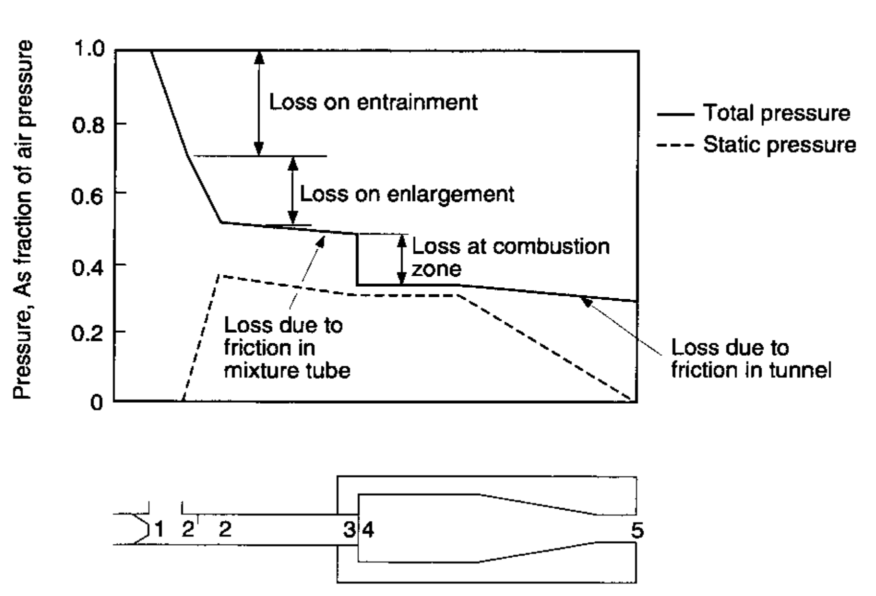

Fig. 11.2.1 Pressure changes in an air blast tunnel burner.

The theoretical maximum pressure efficiency using air blast injection in a completely frictionless system with optimised cross-sectional areas was shown to be about 70 per cent. A series of optimised burner designs were produced by summating the static pressure changes through the burner. Calculations were made for a range of different burner configurations including various combinations of parallel and venturi injectors firing into parallel or convergent tunnels. The equations incorporated terms for continuity, conservation of energy and momentum, and parasitic losses such as friction. Account was taken of energy release on combustion and the corresponding expansion of gases caused by the seven-fold increase in absolute temperature. The final expression relating cross-sectional areas, air/gas ratio, temperature ratios and frictional losses was differentiated to determine the optimum burner dimensions and corresponding pressure efficiencies.

Experimental verification of the theoretical predictions showed close agreement indicating that pressure efficiencies of 20 to 30 per cent could be achieved for parallel mixture tube burners and up to about 45 or 50 per cent when venturi injectors were employed.

Since the burner design is based on fixed ratios of the cross-sectional areas the air nozzle, mixing port(s) and tunnel, it was evident that a range of different burner sizes and configurations (eg burners with tunnels in the form of long slots Fig. 11.2.2) could be constructed. Early investigations (8) were confined to 1 to 2 in. diameter tunnel exits though burners with up to 6.0 ins. diameter tunnel exits were later manufactured and operated in customers' premises. While these burners operated satisfactorily in most respects, turndown ranges were severely reduced with the bigger burners. Although turndown could be improved by operating the burner with excess air at low flow rates this was not regarded as an satisfactory solution. Turndowns for the larger burners at stoichiometric was no more than 2:1 compared with the 5 to 10:1 for smaller burners.

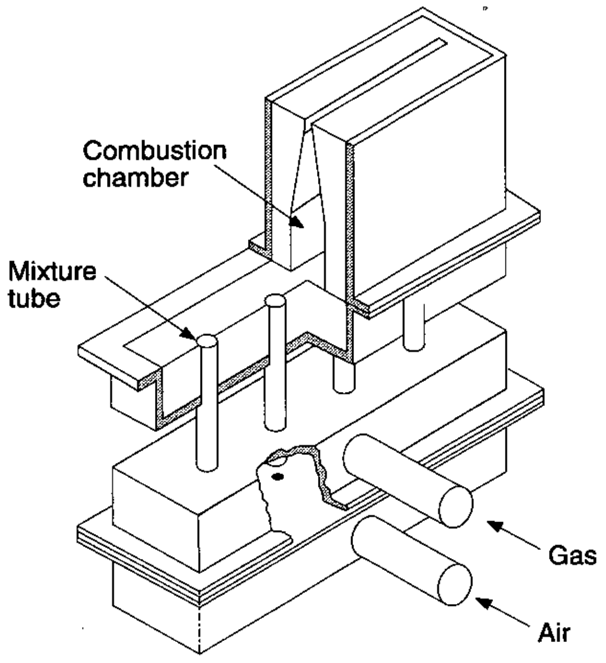

Fig. 11.2.2 Construction of a high velocity burner with a long slot exit.

A systematic investigation of lightback by Eric Francis and Malcolm Hoggarth (9) revealed that the mixture velocity at lightback could be correlated with the critical boundary velocity gradient (CBVG) theory of lightback. This parameter is constant in the laminar flow region but increases in the turbulent region as the Reynolds Number increases. Consequently the tendency to lightback could be reduced by lowering the Reynolds Number and turbulence levels in the mixture ports. Two ways of achieving this were explored, one involved the use of multiple mixture tubes or multiple drilled burner ports while the other employed an annular mixture port. The multiple mixture tube/or multiple drilled ports eventually proved to be the more practical and flexible solution (Fig. 11.2.3).

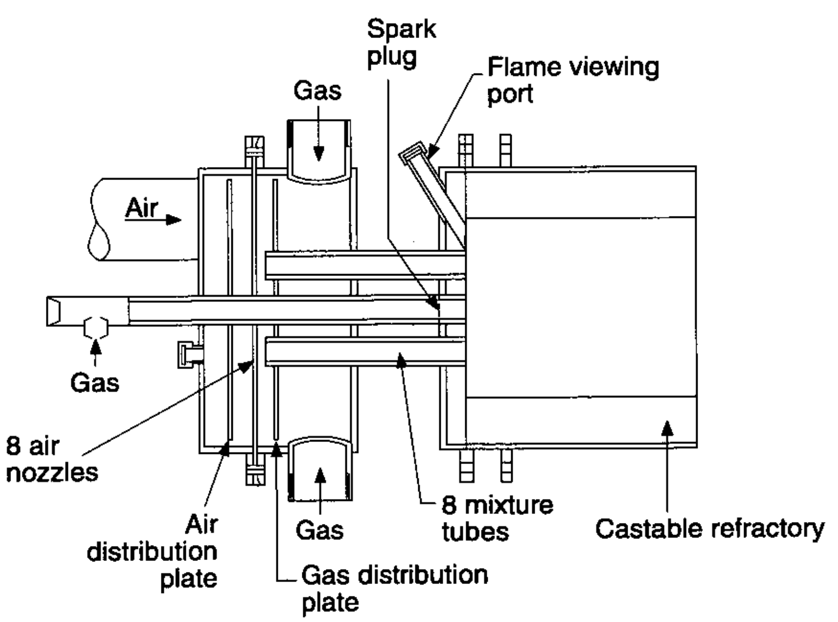

Fig. 11.2.3 Diagram of a 10 million Btu/h tunnel burner.

Multiport or tube burners achieve the maximum throughput of the large burner while retaining the turndown of a small burner (Fig. 11.2.4). They were manufactured and used successfully with heat releases up to 100 therms (3MW) (10).

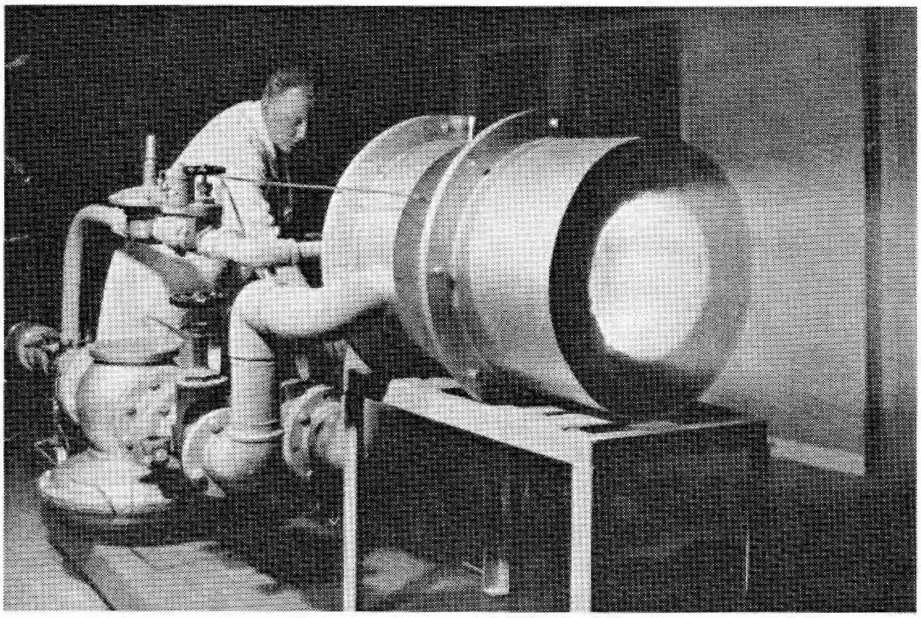

Fig. 11.2.4 Malcolm Hoggarth operating a large tunnel burner around 1968.

Conversion to Natural Gas

The prospect of the introduction of natural gas in the late 1960s changed the emphasis on flame stability from lightback to flame lift and blow off. Experiments were conducted at the MRS to determine how sensitive air blast tunnel burners were to blow off with natural gas. Although it proved possible to operate premix tunnel burners on natural gas, they were less resistant to blow off. Single port burners were shown to be more prone to blow off than multiple port burners. These features were demonstrated to Gas Board Engineers by David Moppett and Malcolm Hoggarth at the Industrial Gas Conference at the College of Aeronautics, Cranfield in 1964, using bottled methane gas from the Mogden and Minworth Sewage Works. Piped natural gas supplies were not yet available. While premixed jet burners supplied with methane displayed increased resistance to lightback, their markedly increased susceptibility to blow off encouraged the already growing interest in nozzle or tunnel mixing burners that were used widely in the USA. In these burners that displayed very good flame stability characteristics, air and gas is fed directly into the combustion chamber or tunnel where mixing and combustion take place simultaneously.

Nozzle Mixing Burner Development

Nozzle mixing tunnel burners were also proving attractive for use with preheated air since they operated, in effect, in a permanently litback condition. The added ability to resist blow off made them doubly attractive. These characteristics had rekindled interest in an until then, little studied variant of the jet burner, a self-proportioning nozzle mixing tunnel burner, the E-type burner, described by Eric Francis and Brian Jackson in 1957.

Peter Aris and Malcolm Hoggarth (11) investigated the design and operation of self-proportioning nozzle mixing burners in the early 1960s, placing particular emphasis on the improved range of flame stability with both town and natural gas and operation with highly preheated air. Relatively short flames with good stability characteristics were obtained by adopting a ring of small air nozzles drilled in a back-plate surrounding a central gas entry tube (Fig. 11.2.5). A range of different design configurations emerged capable of operating with heat releases from 50,000 to 5 Mill Btu/hr (15kW to 1.5MW). The larger versions used multiple gas inlets each surrounded by a ring of air holes. The tunnel exit cross-sections could be tailored to match the shape and size of load to be heated. These burners were employed in many diverse applications

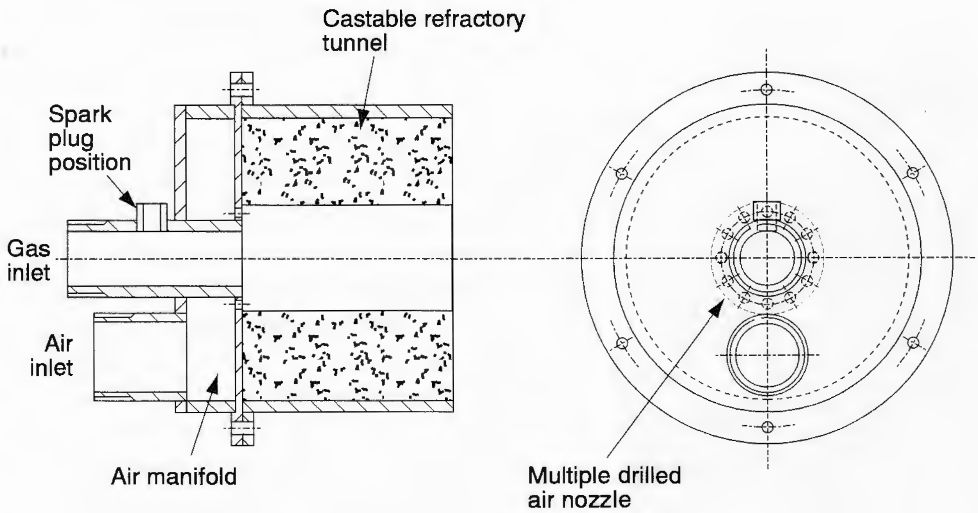

Fig. 11.2.5 Diagram of a simple nozzle mixing burner.

Applications of Tunnel Burners

The results of the above research began to be applied very soon after the first paper had been published, and several small sized burners were installed. By 1959 the demand for burners with heat releases up to 2.5 million Btu/hr (0.75MW) was becoming apparent. Once the principle of multiple mixture tubes firing into a single refractory lined tunnel had been established (10), there was a rapid increase in demand for burners which exploited the ability to produce large heat releases (ie up to 10 million Btu/h) in small spaces in a controlled way (Fig. 11.2.6).

Fig. 11.2.6 Tunnel burner for steel ladle preheating at Beardmore Steel Works, Glasgow.

Some of the applications of recirculation were perhaps the most interesting. Jet Burners were used to fire high pressure, high temperature air heaters for the aircraft industry (Fig.11.2.7), combining high efficiency with the ability to control the maximum tube wall temperatures by recirculation of the flue gases (10). The Industrial Department of the North Eastern Gas Board (4) proved particularly skillful in applying jet burners to stress

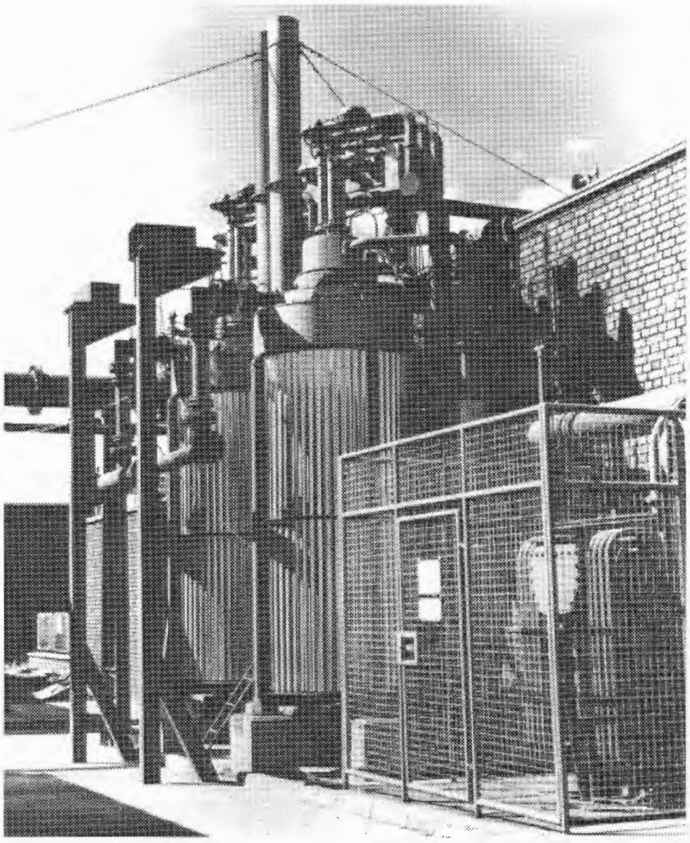

Fig. 11.2.7 High pressure air heaters, probably those at Bristol Syddeley, Filton. Fired with early versions of large tunnel burners.

relieving of pressure vessels, heating embossing rolls, glass tank preheating and various heat treatment applications where temperature uniformity was important. At lower temperatures where hot gas fans where employed to produce massive recirculation, Wales Gas in the South Wales aluminium industry (12) employed large tunnel burners in slab reheating and homogenising furnaces and in plate annealing and billet preheating for extrusion (Fig. 11.2.8). These processes were traditionally carried out either by oil fired radiant tubes or electricity, due to a perceived problem of metallurgical deterioration by direct contact with flue gases. MRS carried out some key experimental demonstrations of direct heating as a prerequisite of these applications. The majority of aluminium heating in the UK is now carried out by gas.

The ability of high velocity tunnel burners to produce increased convective heat transfer was employed to overcome the perceived disadvantages of the low emissivity of gas in such processes as steel billet reheating, glass melting, aluminium melting and even boiler firing. Although initial experiments in 1961 carried out with West Midlands Gas (13) in a slot forge furnace showed no advantage for high velocity burners in a conventional furnace chamber, this study did demonstrate that radical changes in

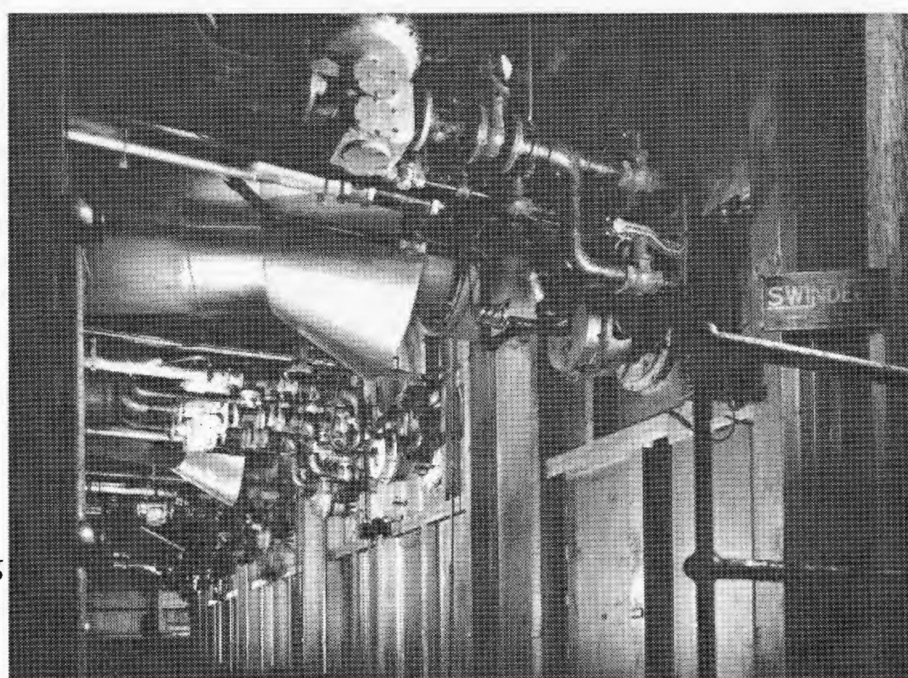

Fig. 11.2.8 Aluminium heat treatment furnace, South Wales. Fired with large tunnel burners.

conventional furnace design was necessary and that a much greater understanding of the flow patterns in furnaces would be necessary to predict the interaction of convective and radiative heat transfer and the effect on overall furnace performance. The appreciation that to exploit the characteristics of high intensity gas burners required a different approach to furnace design led to the concept of rapid heating of metals (14). As a result of developments in this area, high velocity burners are incorporated in a range of commercially available furnaces produced by British Gas Licensees (15).

While the introduction of rapid heating required a radical change in furnace configuration and operating practices, significant improvements in the thermal performance of conventional furnaces can be achieved by reducing flue gas losses by employing some form of heat recovery. While the desirability of recuperation or regeneration with an high intensity burner was recognised very early on, its implementation had to await the development of a burner which would be capable of operating on preheated air. The advent of the nozzle mixing tunnel burner in the early 1960s met this requirement well, providing compact heat sources, capable of operating on town and natural gas, with preheated air up to about 1000°C. The simultaneous development of air/gas ratio control enabled variations in back pressure due to variable preheat temperatures to be accommodated (11,16). Subsequent development and exploitation of integral recuperative and regenerative burners have proved to be one of the major successes of the Midlands Research Station in the industrial field culminating in the Royal Society Esso Energy Award (17)in 1983 and a Queen's Award for Technology in 1992.

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11.3 Atmosphere Generation

Background

The generation of controlled atmospheres from town gas, mainly for use in metallurgical heat treatment or as a source of inert gas, was a relatively small load, but strategically important because of the often critical nature of the application in industrial processes. In the late 50s, problems due to variations in the characteristics of the gas produced were beginning to increase, since many of the simple control systems in use on atmosphere generators relied on receiving a relatively constant gas composition. As a result of increasing integration of works and distribution networks and the greater variety of gas production processes, gas quality variations were becoming more common.

MRS was asked to investigate methods of control of atmosphere generators and Peter Cubbage led a small group which began work on so called lean exothermic generators, producing an atmosphere with little oxygen or combustibles by combustion near to stoichiometric.

Technical Approach

A generator was built with flexibility to use both premix and nozzle mixing burners and the primary cooling to about 300°C was obtained by firing into a radiant tube free-standing in the laboratory. Further cooling by a water jacket reduced the temperature to about 20°C and the gases were led to an oxygen analyser.

Various control methods were investigated:
(1) Controlled flows of gas and air.
(2) Control by measurement of the oxygen content of the atmosphere.
(3) Control of the wobbe index of the air/gas mixture.
(4) Control of the wobbe index of the town gas at a lower level by injection of air into the gas.

Variations in gas quality were obtained by introducing additions of the main town gas constituents to change the Wobbe number by one gas group (about 10%). At first the Wobbe number of the incoming gas from the adjacent Solihull Works varied appreciably until this was demonstrated to the disbelieving Works Manager, Steve Downs, who soon had the Works producing a straight line on the Wobbe recorder as well as on the CV recorder.

The results were reported by Cubbage and Whiteside (1) in November 1961 and showed that controlling on oxygen content of the atmosphere could be to better than ±0.05%, control of Wobbe number of the gas gave ±0.3%, Wobbe number of the air/gas mixture ±0.5% and simple control of air and gas flows gave ±1.2%. Thus a range of methods of varying cost and complexity had been demonstrated and their performance quantified so that a selection could be made to suit a particular application.

It was appreciated that the quality of a lean exothermic atmosphere was also dependent on the completeness of combustion emerging from the burner. Some work was initiated to measure the performance of a variety of industrial burners in this respect and to check against the theoretical calculations by then available from Francis and Toth in IGDC Special Report No. 2 (2). Experiments were conducted with a rapid quench by means of the Atkinson water cooled suction pyrometer, and by a series of controlled cooling methods to equilibriate the products at lower temperatures to ensure recombination of dissociated species. This work was reported by Cubbage and Ling in November 1963 (3).

The quenching experiments showed good agreement with theory for fully premixed tunnel burners, with nozzle mixing and other burner types departing from the ideal in varying degrees. The best practical method of minimising the total of oxygen plus hydrogen plus carbon monoxide from a stoichiometric mixture was by recirculation cooling at temperatures between 1200 and 1300°C, from which combustibles plus oxygen was below 0.2%.

By 1965 the range of gas production methods was becoming quite wide, with the introduction of ICI reformers, Lurgi generators with various enrichment sources, as well as the conventional coal carbonisation plants and a range of oil based peak load plants. Dave Moppett produced IGDC Special Report No.4 (4) setting out calculated compositions of atmospheres prepared from a range of gas compositions including Algerian natural gas, and also covering the endothermic atmosphere range.

Endothermic atmospheres were mainly used for metallurgical heat treatment such as carburising, and was conventionally produced by reacting a very rich mixture of gas and air over a nickel based catalyst in an externally heated retort. These were a common source of control problems and also suffered from carbon deposition on the catalyst. Dave Moppett developed an alternative approach by starting with the much more tolerant rich exothermic atmosphere and stripping the water vapour and carbon dioxide by means of a molecular sieve.

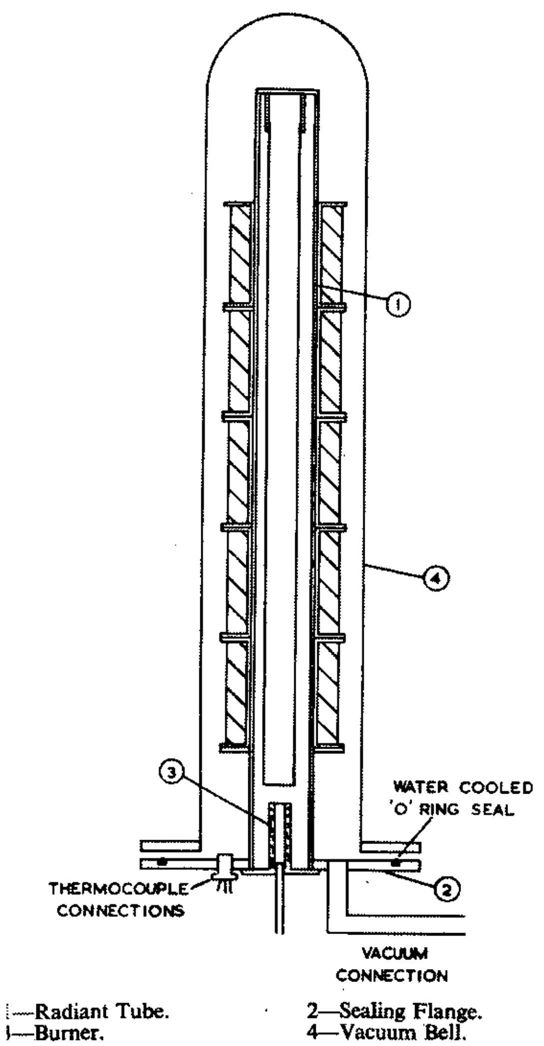

Fig. 11.3.1 Single tube vacuum annealing furnace.

A laboratory demonstration plant was built using the single ended recuperative radiant tube to generate the atmosphere and an AEI-Birlec molecular sieve absorber to remove water vapour and carbon dioxide to very low levels. The advantage of the recuperative system was that with preheated air the normal rich combustion limit could be exceeded by a wide margin to obtain very reducing atmospheres. Oxygen free atmospheres could be produced with amounts of hydrogen plus carbon monoxide from 1.5% to 35% with a dewpoint in the region of -80°C, hence covering the whole range of conventional rich exothermic and endothermic atmospheres. Tests with this generator of heat treatment of both ferrous and non ferrous metals showed its suitability for a variety of processes such as annealing, hardening, malleablising and gas carburising (5).

Vacuum heat treatment was becoming increasingly used in industry and was almost invariably electrically heated. Stuart Burton was involved in developing a gas fired vacuum furnace for heat treatment of copper wire held on steel bobbins. The bobbins were threaded onto a single ended radiant tube in the centre of a cylindrical vacuum bell (Fig. 11.3.1). The work was reported by Burton and Cubbage in November 1965, and the advantages claimed were lower capital cost and much reduced operating cycle compared with existing furnaces.

Commercial Implementation

The expertise gained by the work on atmosphere generation was mainly useful in technical service activity, assisting Regions in solving problems experienced by customers. Several stripped rich exothermic atmosphere generators were installed in industry, but many of the problems experienced in the town gas era disappeared with the advent of natural gas and its relatively constant quality.

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11.4 Gas Fired Rapid Heating

N.Fricker

Background

The successful development of high velocity burners led to high expectations that their use on conventional gas fired furnaces would promote convective heating within the furnace and hence improve heating rates and furnace efficiencies. This was of particular value given the relatively high price of gas compared to competing fuels (oil in the early sixties, increasingly electricity in the seventies and eighties). What better way to demonstrate this potential than by fitting such burners to a slot forge furnace(1)?

The result was a disappointment; there was no significant effect on heating times of the steel stock or on furnace efficiency. Like many other unsuccessful experiments, understanding why the effect was so small provided the keys to many of today's gas fired rapid heating machines. It also formed the basis for a long series of advances relating to the development of mathematical models of high temperature furnaces and of physical modelling to gain an understanding of the flow patterns and processes of convective and radiative heat transfer in such furnaces.

The "Single Cell" Furnace

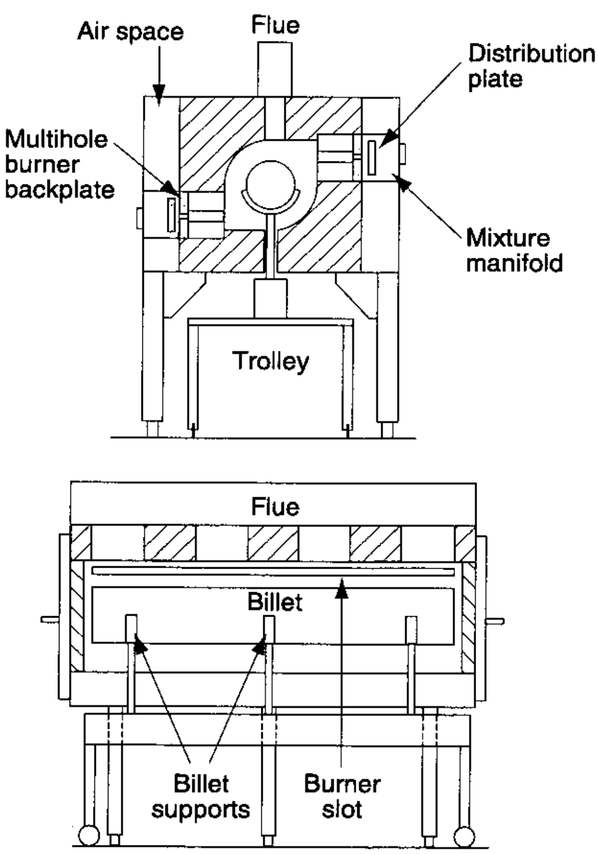


Fig. 11.4.1 "Single cell" high speed heating furnace.

It was clear that simply bolting high velocity burners onto an existing furnace would not yield the potential benefits sought. In order to achieve high heating rates, much higher flow velocities were needed over the surface of the stock. These could be achieved either by direct impingement of burner jets on to the metal or by reducing the dimensions of the heating chamber to match those of the material to be heated. In order to avoid problems with uniformity of heating, earliest endeavours followed the latter line, leading to the development of the so called 'single cell' furnace in which round stock was surrounded by a circular section heating chamber, and high velocity burners were fired tangentially into the chamber to generate a highly circulating flow of gases. Recirculation rates were to be high enough to provide a stream of uniformly heated high velocity gases around the stock, hence ensuring rapid but even heating over the whole circumference.

The initial experiments were carried out in the early 60s by Mike Lawrence and John Spittle (2) on tangentially fired furnaces for heating cylindrically shaped billets, mainly aluminium and copper (Figs. 11.4.1 and 11.4.2). Enough was done to demonstrate that the technology was viable, and that in the case of aluminium, that there was no metallurgical deterioration. A similar technique, but employing direct jet impingement, was employed in a commercially available furnace, the Granco, for aluminium billet heating for extrusion.

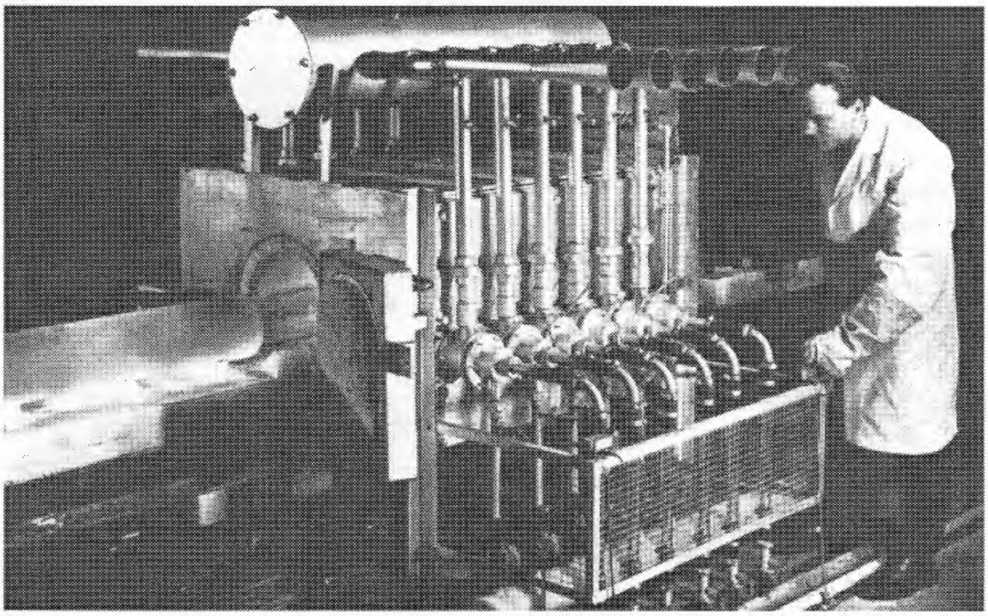


Fig. 11.4.2 John Towler operating a recuperative single cell billet heating furnace in the late 60s.

Brian Oeppen and co-workers in Furnace Division set out to engineer the furnaces and in particular to search for improved refractory materials that would have the qualities of low thermal inertia and high thermal shock resistance which rapid heating tests (and a number of catastrophic material failures) identified as necessary. The result of such endeavours were machines capable of heating circular and square sections of steel and aluminium billets uniformly and quickly. A large single cell furnace for heating steel billets, fired from one side only with 25 recuperative burners was built in 1973 and probably represents the culmination of the effort on the single cell Fig. 11.4.3).

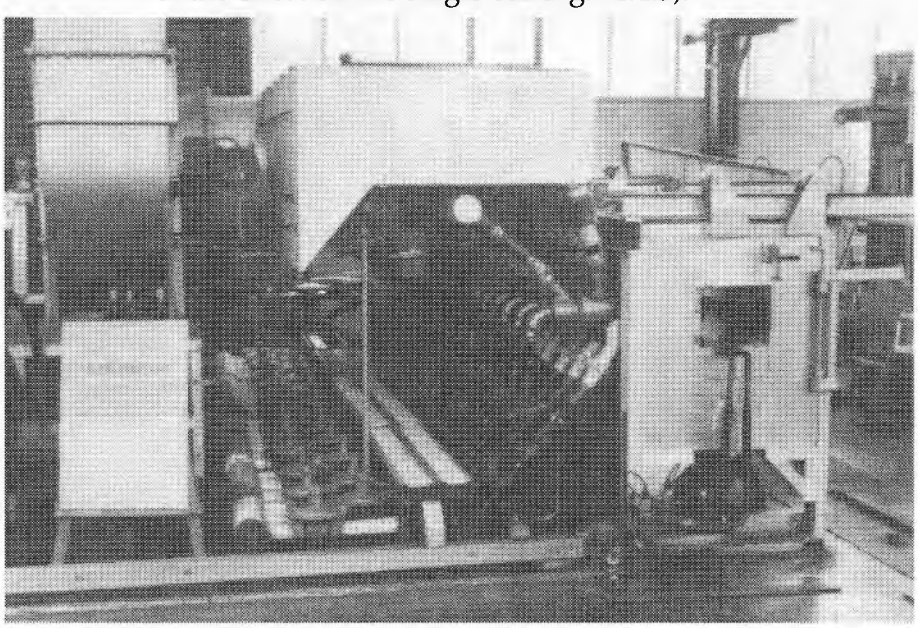


Fig. 11.4.3 A single cell furnace fired by 25 recuperative burners.

Modelling Support

The practical realisation of single cell rapid heaters were supported by model studies of flow patterns and new information on radiative and convective heat transfer to and between surfaces of annular cavities. Beryl Moppett and Geoff Read (3) carried out flow visualisation studies using water flow in perspex models exploring variations in burner and flue offtake configurations. In a classic series of experiments, Dave Lucas (Fig. 11.4.4) and colleagues in the then Combustion and Heat Transfer Division developed and then applied heat and mass transfer analogies to determine convective heat transfer rates

Fig. 11.4.4 Dave Lucas with apparatus for heat transfer measurement using the electrolytic model technique, late 60s.

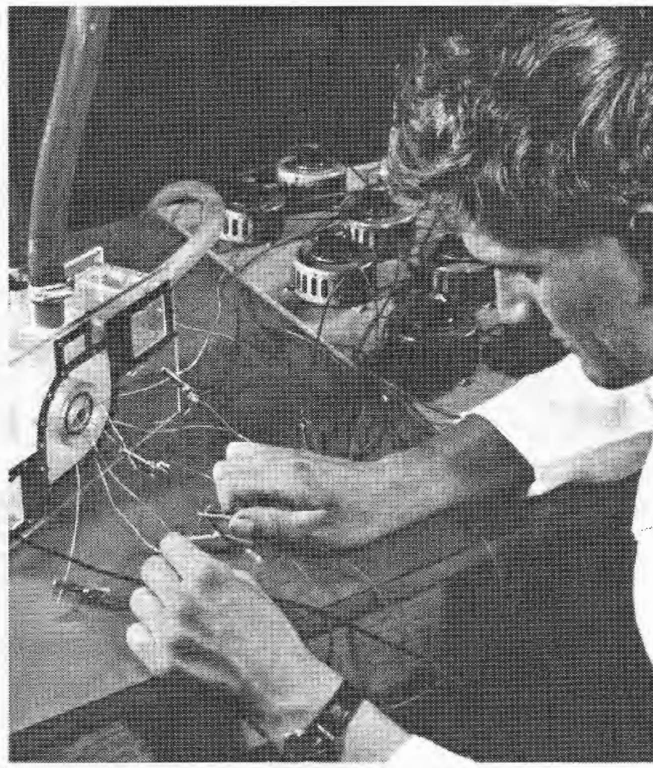
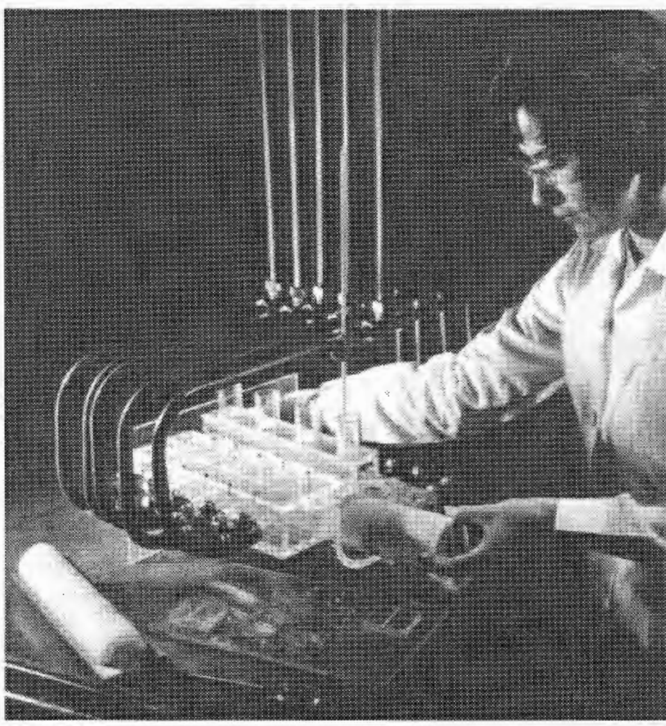


Fig. 11.4.5 Ann Galsworthy using the naphthalene sublimation technique in a single cell heater model.

using air models (naphthalene sublimation technique, Fig. 11.4.5) and water models (electrolytic technique)(3)(4).This was the start of the tradition of furnace modelling built up at MRS and later greatly refined as described in another Section.

Continuous Counterflow Furnaces

In cooperation with the WMGB, a continuous counterflow pusher furnace was developed for heating small square section billets to about 900°C prior to final heating to 1200°C in an electric induction unit,



combining the low capital cost and good efficiency of the gas furnace with the speed of the induction heating at the higher temperature to minimise scale formation (Fig. 11.4.6). The 700 lb/h unit consisted of a tangentially fired forcing zone followed by a preheat zone, leading to an improvement in efficiency over the single cell. The success of this unit encouraged the building of a 2000 lb/h continuous counterflow furnace for heating steel billets to forging temperature entirely by gas, billet transport being by pushing on air cooled metal rails (2).

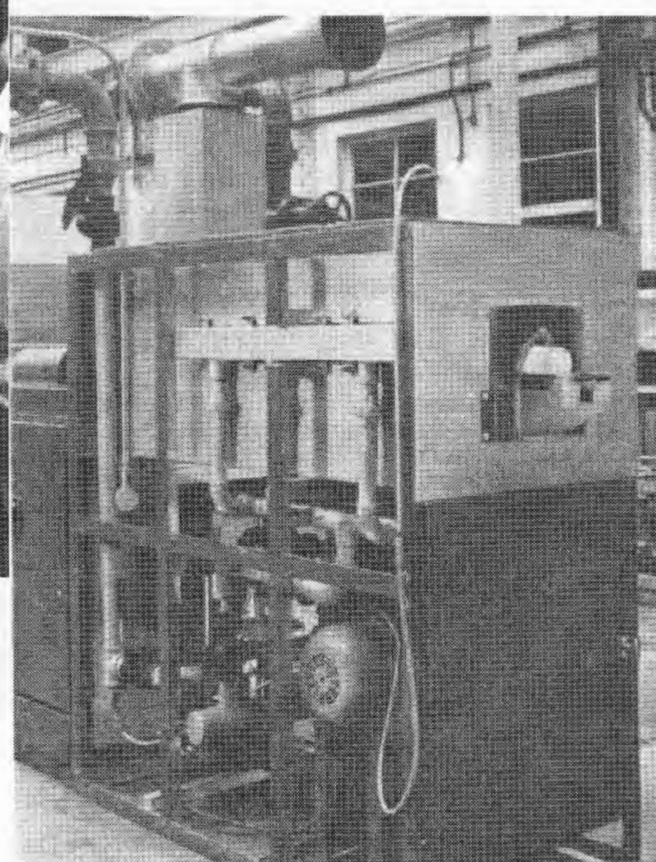


Fig. 11.4.6 WMGB 700 lb/h continuous counterflow furnace.

This was the start of a long struggle to perfect the continuous counterflow rapid heater, in the early stages by Brian Oeppen, Jeff Masters, Phil Wong and many others in the Furnace Division of the late 60s and in the later Heating Plant Division of the early 70s. Designs in which cut billets were pushed end to end along skid rails gave good thermal performance and could be made to work well in the laboratory. However trials in the rather rugged conditions of a forge, such as those at Clydesdale Stamping and at Firth-Derihon were never fully satisfactory (5)(6).

There were two main problems. End to end pushing of the billets required a good quality of cut and even then, the jamming of a billet could be disastrous and build up of scale caused problems. These problems led to various attempts to improve the method of stock support, including ceramic rails (which eventually dissolved in the scale from the steel!), "hover" transport, which demanded an unresolvable compromise between firing rates for hovering and heating as well as posing some awful pulsation problems, and the indirectly cooled skid rail, which was the most successful and remains in service to this day for certain licensed designs of rapid heater.

Secondly, the furnace ideally required a steady work rate to suit the forge capacity; this was totally at variance with the traditional practice of the workforce, operating conventional oil-fired furnaces batchwise, alternating furious activity with frequent rest periods. Also their concept of the temperature required for forging was distinctly on the high side. In the social climate of the late 60s and 70s, managements seemed reluctant to tackle these problems in pursuit of better productivity and the good product quality offered by rapid heating.

The breakthrough came with the adoption of broadside on pushing of billets or bars on a flat hearth, with ejection at the hot end; this was the concept which became known as the "whole bar heater".

Whole Bar Heaters

The whole bar heater concept was developed by Jeff Masters and his colleagues in the early 70s (5)(6). These were end fired, originally with high velocity burners, over the top of the stock with minimal clearance to the roof. Their early efforts were rewarded with some horrendous noises from organ pipe type flame resonance. (There was a point at which all such furnaces were known as "Oeppen's Organs"!) This ultimately led to the development of a fish tail lower intensity high velocity burner by Neil Fricker, Clive Hughes and John Waddington.

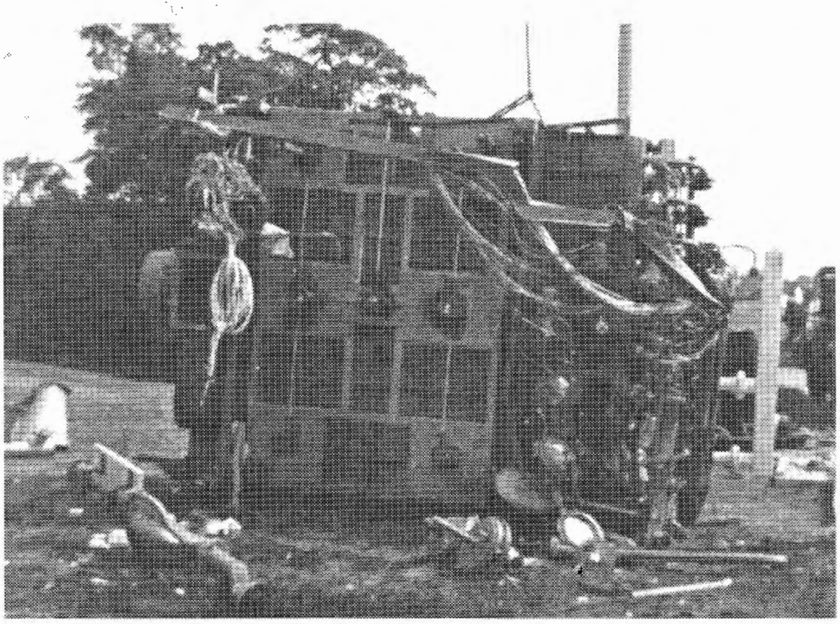


Fig. 11.4.7 Wreckage of the 4.5 tonne/h furnace lying by the side of the road.

The 1973 paper describes successful small machines e.g. for 600lb/h and in 1976 the development culminated in full scale laboratory trials of the largest prototype furnace ever built at the MRS (7). This was a 4.5 tonne/h steel bar heater designed to heat 2.4m long billets of 50mm to 125mm square section to 1200°C. Only short runs were possible in the laboratory (the steel produced in one hour contained enough heat to warm a house for a week!). The furnace was therefore moved to the Sheffield rod rolling mill of Sanderson Kayser on a "sale or return" basis for extended trial. This provided the occasion for one of the more bizarre and spectacular mishaps (Fig. 11.4.7) when the furnace fell off the transporting lorry while negotiating the Stonebridge roundabout (all the obvious jokes were made at the time!).

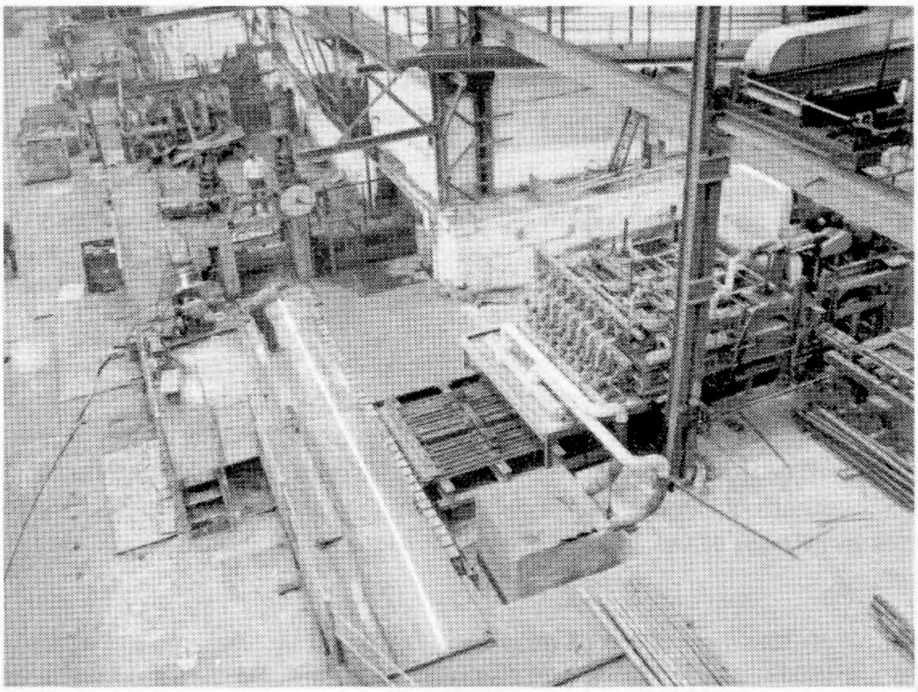


Fig. 11.4.8 4.5 tonne/h bar heater in operation at Sanderson-Kayser, Sheffield.

Following a rebuild the trial finally began and, after the usual teething troubles, was so successful that the whole factory output was dependent on the furnace, which was purchased by the company and was in continued use at least eight years later (Fig. 11.4.8). Tahri Dhanjal spent a year of his life at the factory ensuring things went smoothly. There was a mysterious series of problems and stoppages occurring until a new pay rate was negotiated with the operators, when the problems seemed to vanish.The success of the Sanderson Kayser furnace gave the development team great confidence in the technology, and later improvements involved a walking beam stock transport, a longer preheat zone and extensive use of ceramic fibre linings.

Part Bar Heaters

There are many applications where a part of a metal bar, usually the end, is required to be heated for subsequent bending or forging. The rapid heating technology leant itself to the development of small heating machines for part bar heating, consisting of little more than the combustion chamber, where the stock was passed close to or in the tunnel of a high velocity circular or slot burner. The low thermal inertia meant that it was brought into use in minutes and therefore only using fuel when hot metal production was required. Productivity advantages were achieved through the ease of applying mechanical handling with any desired degree of automation (8) (Fig. 11.4.9). These units were developed and already being successfully applied in 1971. They were quickly taken up by manufacturers and have been supplied in increasing numbers and variety ever since.

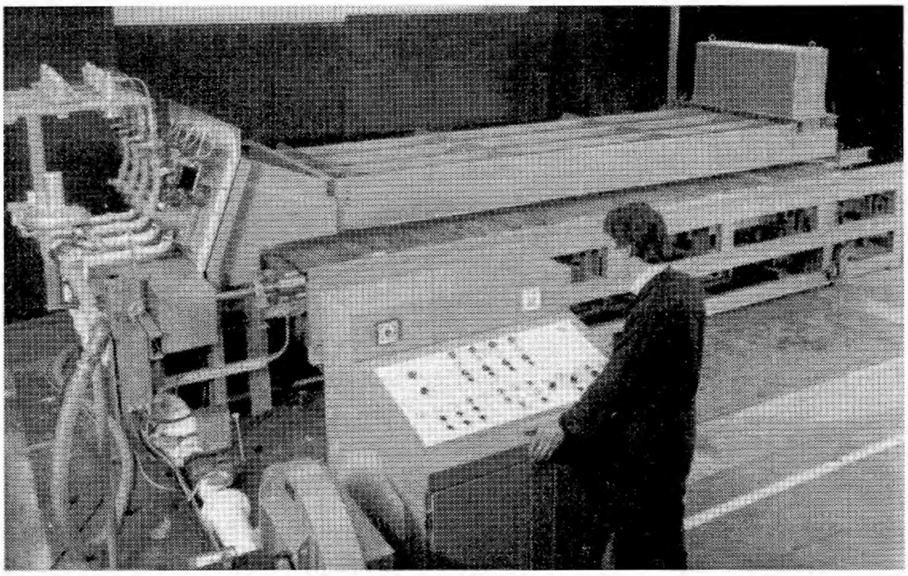


Fig. 11.4.9 Automated continous bar end heater by Fairbank Brearley.

Technical Advantages

(1) High heating rates and low thermal inertia mean fast start up times measured in minutes, thus easily coping with work stoppages without wasteful "standby" operation.
(2) The high heating rates mean that metal temperatures are above 900°C for only a short time ,so that oxidation and decarburisation are minimised and often negligible.
(3) Because of the low thermal inertia, stock temperature can be controlled directly with a suitable pyrometer, rather than on furnace temperature, avoiding temperature overshoot and also helping to minimise metal deterioration.
(4) Environmental conditions around the heater are good.
(5) Ease of automation means high productivity and good integration with other operations.

Commercial Implementation

Adoption of rapid heating technology involved a complete break from traditional furnace design. It was therefore perhaps no surprise, but nevertheless disappointing that the established furnace manufacturers showed no interest in taking up rapid heating. It was left to two newcomers to exploit the possibilities.

In 1972, Brian Oeppen formed his own company, R.H.Furnaces, to make rapid heaters and has pursued this objective through good times and bad ever since, producing many successful examples.

Some of the earliest examples of part bar heaters were installed in the spring making industry. One user, frustrated by the limited availability of the equipment, set up his own manufacturing facility in a subsidiary, Fairbank Brearley, who since being licenced in 1973 have sold several hundred units. Many of these were sold overseas and in 1990 resulted in Fairbank Brearley gaining a Queen's Award for Export Achievement.

Exploitation in North America was pioneered by Fairbank Brearley from 1985, and their success generated interest from U.S. companies, so that there is now an additional licencee, Rapid Technologies Inc. of Newnan, Georgia.

From all of this work, gas fired rapid heating has now firmly established itself in the furnace business with over 450 units sold by three licences in twenty countries; efforts of the MRS team were recognised with the award of the Esso medal to Kevin Pomfret and John Waddington in 1991.

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11.5 Recuperative burners

R.J.Webb

Background

Historically, combustion air pre-heating was mainly used to raise flame temperatures to the levels needed for glass and steel melting. More recently, the economic and environmental benefits of heat recovery have been appreciated and both energy suppliers and equipment manufacturers have devoted substantial resources to meeting the market demand.

In the late 50s, it was recognised that the more widespread use of waste heat recovery by air preheating in smaller scale gas fired furnaces was very desirable. However, existing recuperators were large, expensive, prone to leakage and burnout and not very effective. By incorporating burner, recuperator, flue offtake and air jet driven flue gas eductor into a single device a lot of the objections to the use of recuperation could be avoided. There was no external ducting of hot air and flue gases, minimising losses, the complete unit could be retrofitted in place of an existing burner and the existing flue system dispensed with. The resulting recuperative burner system proved to be a milestone in the drive towards improving the energy efficiency of high temperature industrial processes.

The Technical Approach

Before significant progress could be made on the development, a burner of reasonably high exit velocity and capable of operating with preheated air was required. This was provided by the work of Malcolm Hoggarth on nozzle mixing tunnel burners, reported in November 1964 (1). The arrangement of a ring of air orifices surrounding a central gas entry firing into a short refractory tunnel proved reasonably robust and was initially used for direct firing with an external concentric tube recuperator. This proved the concept was viable but it was thought easier to implement in a single ended metallic radiant tube, with the heat exchanger and burner inside and concentric with the tube, all within the furnace wall.

This basic design, incorporating a concentric annular tube heat exchanger, was reasonably successful and the radiant tube had a limited application in heat treatment furnaces up to about 1000°C in the late 60s (see Section 11.7). The development and performance of the tube was described by Chatwin, Francis, Harrison and Lawrence in November 1965 (2).

The annular tube design of recuperative burner was applied at much higher temperatures to a single cell rapid billet heater, significantly improving its performance, not only by the recovery of waste heat but also due to the improved flow of gases within the furnace. These results encouraged a more thorough study of heat transfer in the recuperator so that the design could be on a rational basis and scale up to larger sizes was facilitated. This work was reported in November 1969 by Harrison, Oeppen and Sourbutts (3).

There were two further improvements to the design. First, the advent of natural gas had necessitated altering the burner nozzle arrangement to give shorter and more stable flames, described in Patent Applications by Masters and Harrison. Secondly, the experience with direct firing at temperatures of upwards of 1200°C had highlighted problems with the mechanical stability of the refractory burner quarl. This was overcome by extending the combustion air annulus over the quarl, forming a cooled sheath to hold the refractory in place.

The unit which emerged from the extensive development and laboratory testing consisted of a high velocity air blast tunnel burner surrounded by a countercurrent, concentric tube heat exchanger made of heat resisting steel capable of delivering air pre-heats of up to 600°C and fuel savings of around 30% (Fig. 11.5.1).

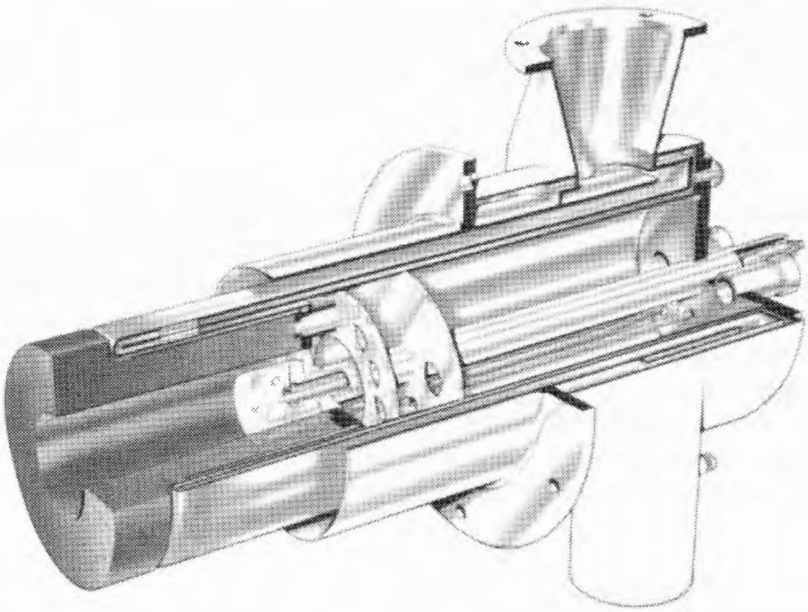

Fig. 11.5.1 Cut-away view of recuperative burner.

The variation in air temperature and back pressure which occurred as the burner heated up had also necessitated the development of an appropriate ratio control system. For the smaller radiant tube burners, the dual valve system described by Hancock (4) was used, in which constant pressures were maintained across the air and gas control valves by backloaded governors. This system was impractical for the larger burners and a double diaphragm governing device was developed which was introduced by Jeavons Engineering as the J121. This maintained constant pressures across fixed metering orifices in the air and gas lines, independently of downstream conditions, and the availability of this relatively inexpensive device contributed to the subsequent practical application (see Chapter 12).

Commercial Implementation

Extensive laboratory testing and evaluation of the recuperative burner were followed by four field trials on customers' premises arranged through the Regions, which took place between 1972 and 74. These were on a crucible furnace, a forge furnace at British Rail, Derby (Fig. 11.5.2),

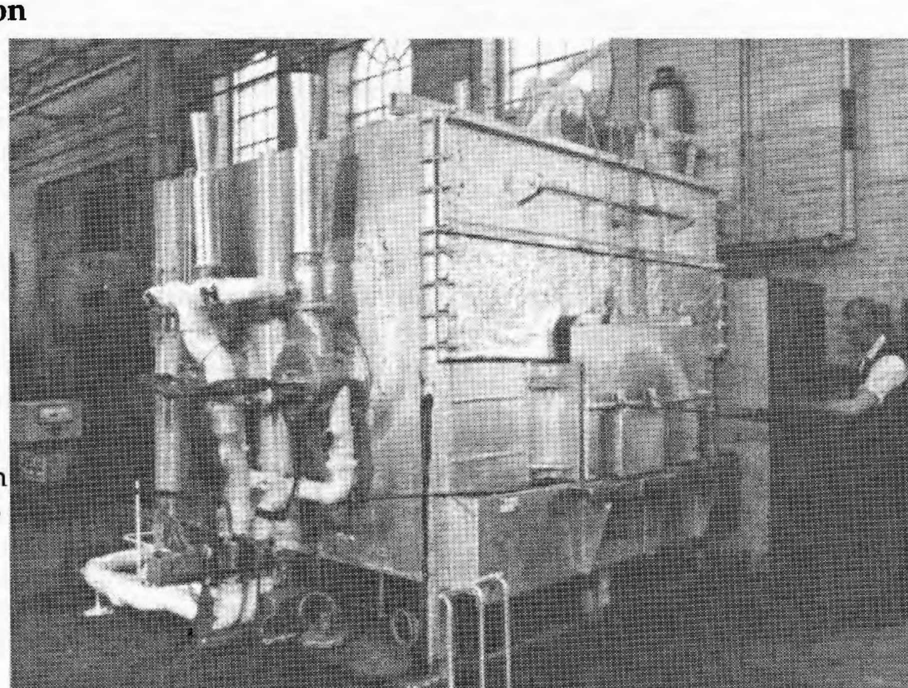

Fig. 11.5.2 Forge furnace at British Rail, Derby.

and two ceramic firing kilns at Royal Doulton and Gimsons (the two latter through the good offices of Eddie Blankley, then Industrial Manager for the North Staffs Area, and familiar with MRS from a previous spell as Lecturer at the School of Fuel Management). The performance of the installations was carefully monitored (5), so that the fuel savings could be determined, and the Regional personnel kept an eye on them so that any problems could be quickly overcome. The ceramic kilns (Fig. 11.5.3) were particularly critical installations since the firing arrangements had been drastically altered after modelling at MRS had shown that the number of burners could be reduced and the flow patterns improved. The temperature uniformity requirements in the kilns were particularly stringent and set operating cycles had to be adhered to.

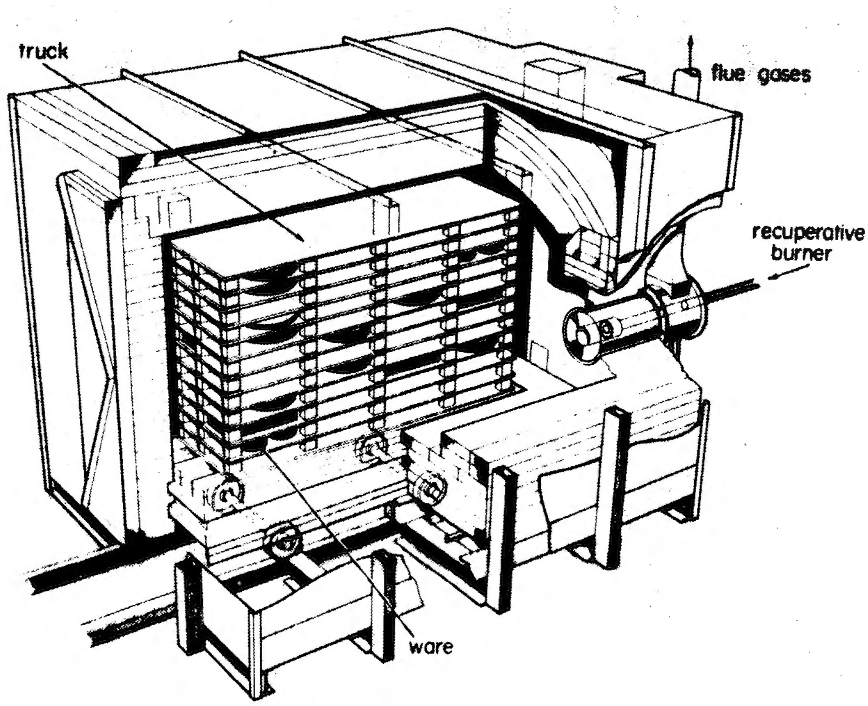

Fig. 11.5.3 Intermittent kiln fired by a single recuperative burner installed at Royal Doulton Tableware Ltd.

"RADEX"

The success of these trials gave confidence to proceed to a wider, but still carefully controlled exploitation through the Regions via the RADEX scheme during 1975-76, during which 100 burners, produced by a Licencee (IPI) strictly to the MRS design were installed. All the components were sourced through P&S Division, with IPI carrying out the fabrication. The Regions were responsible for finding the applications and through a nominated contact in each Region the proposals were vetted and approved by MRS, who had produced a manual of installation. The whole exercise was organised and supervised by Jeff Masters (MRS) and Peter Chester (Marketing HQ) seconded to "RADEX" for a year and installed in an office in WMGB HQ at Solihull.

The objectives were largely achieved, although there were inevitably problems to overcome. Burner quarls experienced cracking and there were individual problem installations, notably a magnesium alloy crucible furnace in NWGB, an aluminium crucible in EGB and a furnace with a mysterious "explosive quarl" at British Leyland.

Licencing

Following this, the now essentially full-developed product was licensed to four manufacturers, Hotwork, Stordy, Laidlaw-Drew and Nuway, who gradually began to evolve their own individual designs. A high degree of market acceptance was rapidly achieved and in 1983 gained the Royal Society Esso Energy Award (5), which is given for 'outstanding contributions to the advancement of science, technology or engineering leading to the more efficient mobilisation, use or conservation of energy resources'.

In the next few years recuperative burner installations featured in many GEM Award nominations and winners (Fig. 11.5.4)

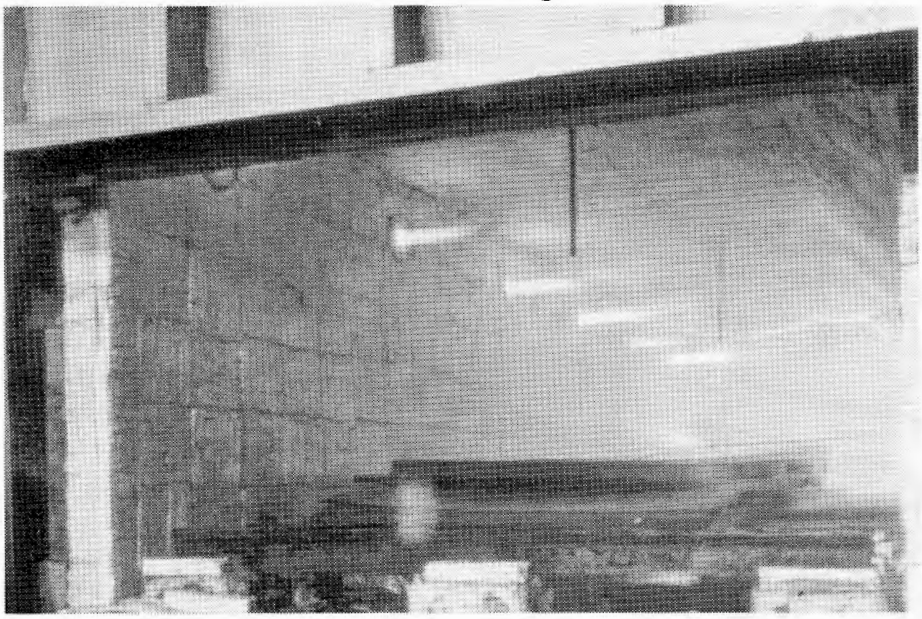

Fig. 11.5.4 Furnace at Spartan-Redheugh.

The Conical Recuperator

It is axiomatic in R&D that few concepts are so good that they cannot be improved. This was certainly true in the case of the recuperative burner, further development yielding the second generation conical recuperator (Fig. 11.5.5) and a system which was more durable, needed less maintenance and offered the option of a separated recuperator to increase versatility. This stage of the programme also marked a substantial shift in the approach towards commercialisation. Rather than handing a proven product to a licensee for manufacture, MRS realised the value of involving a manufacturer (Nuway Ltd.) at an early stage and conducting all of the work beyond proof-of-concept jointly. This reduced timescales, ensured that the product is targeted on the real needs of potential users and allowed expertise in manufacturing to be applied at a beneficially early stage.

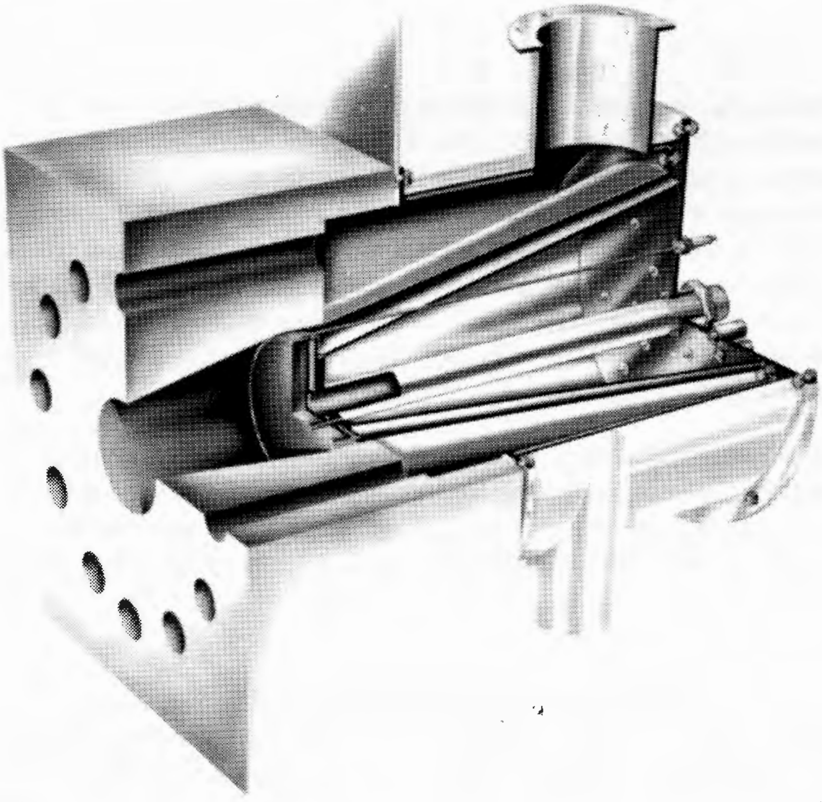

Fig. 11.5.5 Conical recuperative burner.

The conical burner (6) has proved to be highly successful, continuing the market acceptance of the earlier burner to a stage where many furnace manufacturers and users specify recuperative burners as standard equipment for both new plant and refurbishment projects. Around 3000 units of the two designs have now been sold. Whilst this is clearly now a mature technology, it is by no means outmoded, as continuing successful installations show. To take an example, the design specification for a furnace used for slab heating, plate reheating and heat treatment at temperatures ranging from 550 to 1300°C included six burners and three separate conical recuperators, demonstrating the ability of this system to reduce the number of burners required to achieve even heating throughout large furnaces. The furnace, at Spartan Redheugh yielded a reduction in energy consumption of 43% and is claimed to be one of the most versatile ever constructed in Britain.

The Radial Plate Recuperator

Such applications strengthened British Gas' view that recuperation warranted continued attention and the latest product of the programme was launched in 1991. This radial plate recuperative burner (Fig. 11.5.6) was designed to deliver improved thermal and economic performance in the many applications operating at temperatures between 700 and 1100°C. It therefore complements the earlier burner, which can be used at furnace temperatures up to 1500°C. The development of the radial plate unit (7) carried forward two existing themes - extensive use of mathematical modelling and joint development with a manufacturer (Nuway Ltd.) - and added a new one in gaining financial support from the Energy Efficiency Office. Such involvement not only assisted in keeping the development on schedule and correctly focussed but provided valuable support to the essential task of disseminating information on new developments to potential customers.

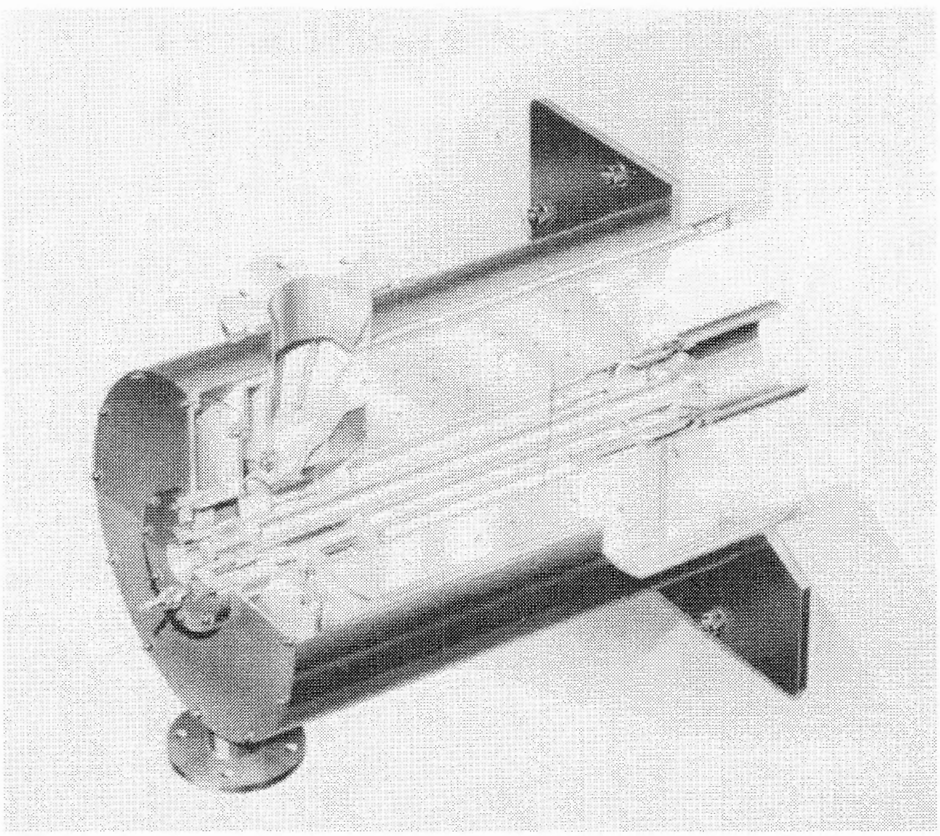

Fig. 11.5.6 Radial Plate Recuperative Burner.

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11.6 Regenerative Burners

R.J.Webb

Background

The heat recovery effectiveness - heat recovered as a proportion of the theoretical maximum - of metallic recuperators, and hence the fuel savings obtainable through their use, are limited by the maximum service temperatures of the metals used in their construction (Fig. 11.6.1). To increase effectiveness beyond the levels obtainable from recuperative burners (see the previous section) requires the use of ceramics, together with design concepts which recognise the limitations of these materials.

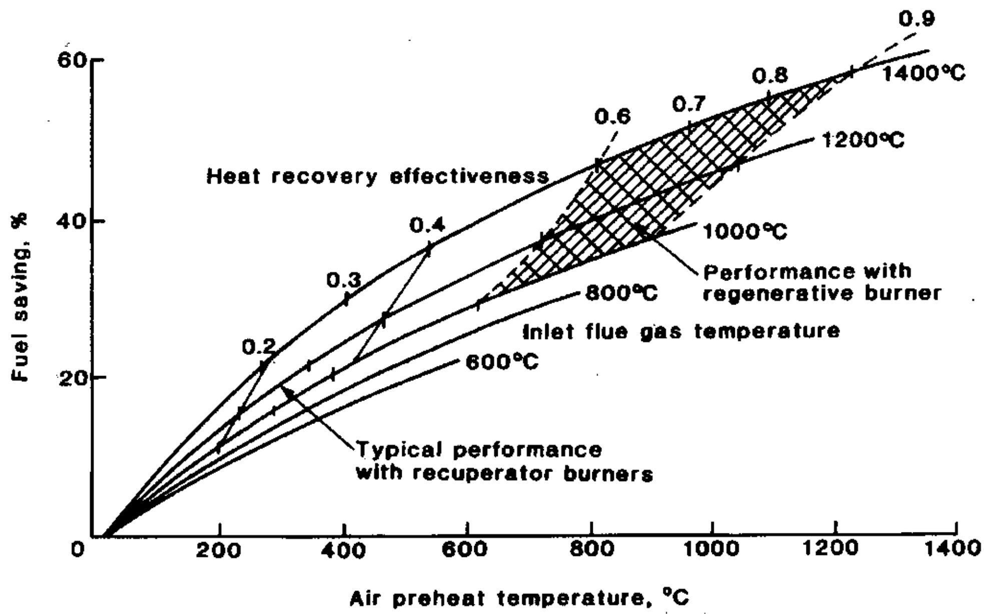

Fig. 11.6.1 Fuel savings, furnace temperature and air preheat.

By the late 1970's, whilst the recuperative burner programme was still in progress, the Midlands Research Station was committed to the substantial increases in energy efficiency which it was thought could be obtained through the use of ceramic reversing regenerators. This was, of course, not a new concept as such systems had been in use in the glass industry for many years. The technology was, however, not applicable to other processes because of its bulk and cost. British Gas therefore set out to develop a compact, cost effective concept which, like the recuperative burner, could be applied with equal ease to new or existing plant.

Technical Approach

The system which was devised consists of two burners, each with an associated heat store. The burners fire in sequence, their combustion products leaving the furnace through the heat store of the other burner in the pair. On reversal, cold combustion air is now drawn into the burner through the hot storage medium and is pre-heated.

The prototype unit (Fig. 11.6.2) which was produced to test the concept used zirconia cylinders or Raschig rings as the heat storage material. The system worked well, and following a procedure which was then fairly novel but has since become almost standard procedure, MRS began to collaborate with a manufacturer (Hotwork Development Ltd.) very early on, in about late 1981 when the regenerative burner had been no more than an idea only two years earlier. This collaboration advanced the work rapidly, one of it first

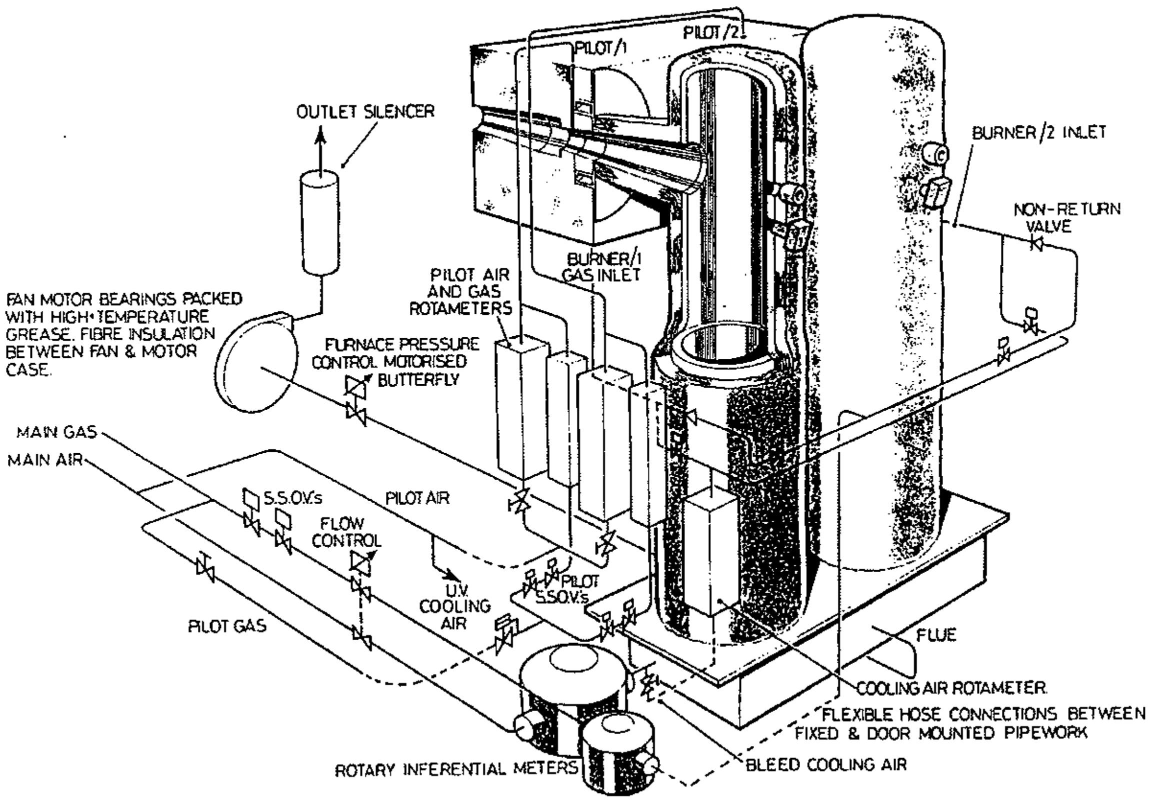

Fig. 11.6.2 Diagram of prototype regenerative burner.

consequences being the switch from Raschig rings to alumina balls for the heat stores. This produced a slight increase in the pressure drop across the storage beds but gave valuable reductions in bulk and cost and also made the system easier to use as the material can simply be poured into its container rather than needing to be carefully stacked.

The development of the regenerative burner and its translation into a marketable product presented formidable technical challenges:

(1) The high flame temperatures - around 2200°C - produced by the use of combustion air pre-heated to 1000 - 1200°C necessitated development of a burner fabricated wholly in refractory materials.

(2) Transient heat transfer within packed beds was a largely unknown area for British Gas. To assist in optimising the bed design a contract for mathematical modelling work was placed with Leeds University. Such contracts are, assuming that their terms are specified carefully and they are well managed, an excellent way of shortening development timescales by providing access to specialist expertise. British Gas continues to use them extensively. In-house modelling also contributed significantly to the development and, in line with a trend which has become firmly established, was employed from an early stage.

(3) High temperatures and rapid (1-2 minutes) cycling made great demands on the control system. Purpose-designed schemes were developed in parallel with the burner and heat stores.

Commercial Implementation

Hotwork quickly developed a production prototype which on test showed improved performance from the use of alumina balls as the packing (Fig. 11.6.3). The first field trial

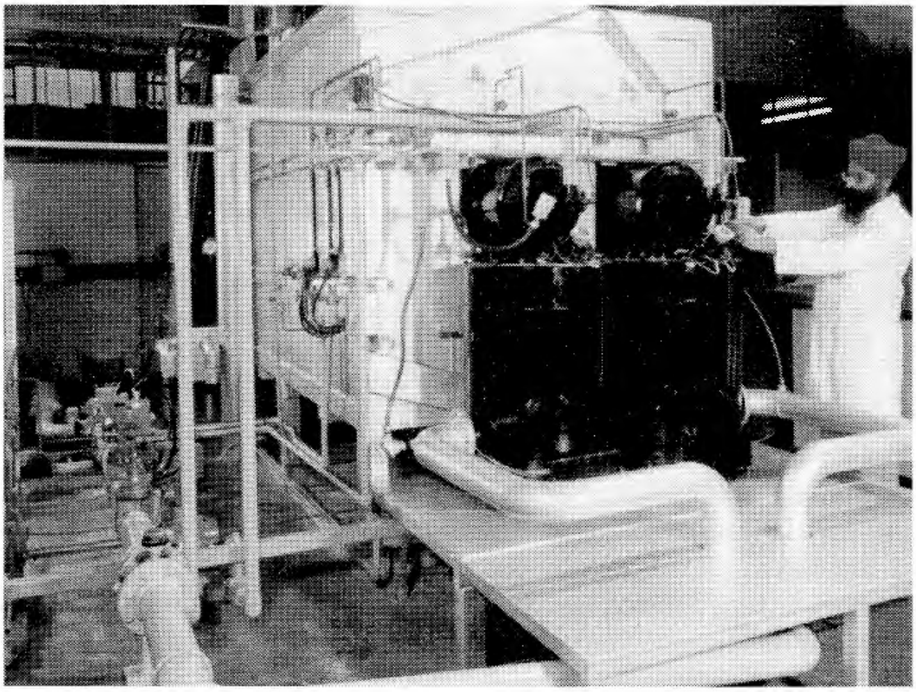

Fig. 11.6.3 Furnace with regenerative burner on test in Derby building.

was on a soda lime glass pot furnace used in the production of lampshades, with a maximum furnace temperature of 1400°C and very dusty conditions providing a stringent test of the robustness of the system. Information obtained from this installation confirmed the performance predictions and by the end of 1983 detailed designs for a range of sizes had been produced. The first commercial sales were made, to British Steel, around this time and their success can be judged from the fact that British Steel remain among the most enthusiastic users of regenerative burners (Fig. 11.6.4).

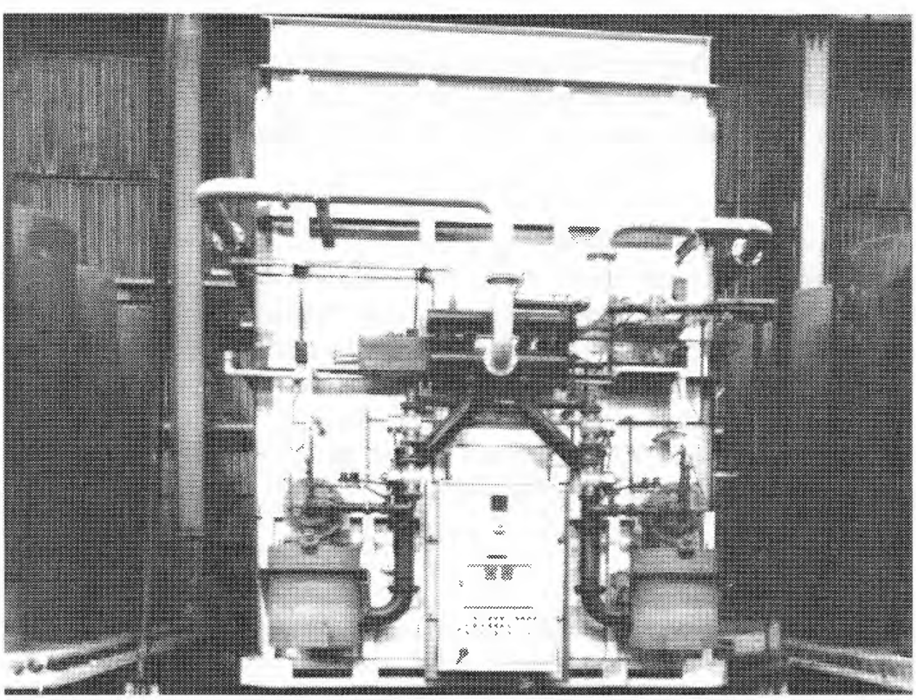

Fig. 11.6.4 One of nine coil annealing furnaces at British Steel, LLanwern, showing one of the two pairs of 1.3MW burners.

Use of the system was extended to aluminium melting in about 1985. Such 'dirty' processes, where the flue gases are heavily contaminated, cannot take advantage of recuperative heat recovery because the flow passages within recuperative burners would quickly become corroded and blocked. In contrast, regenerative burners are highly suitable as the heat storage material can readily be removed for cleaning (Fig. 11.6.5).

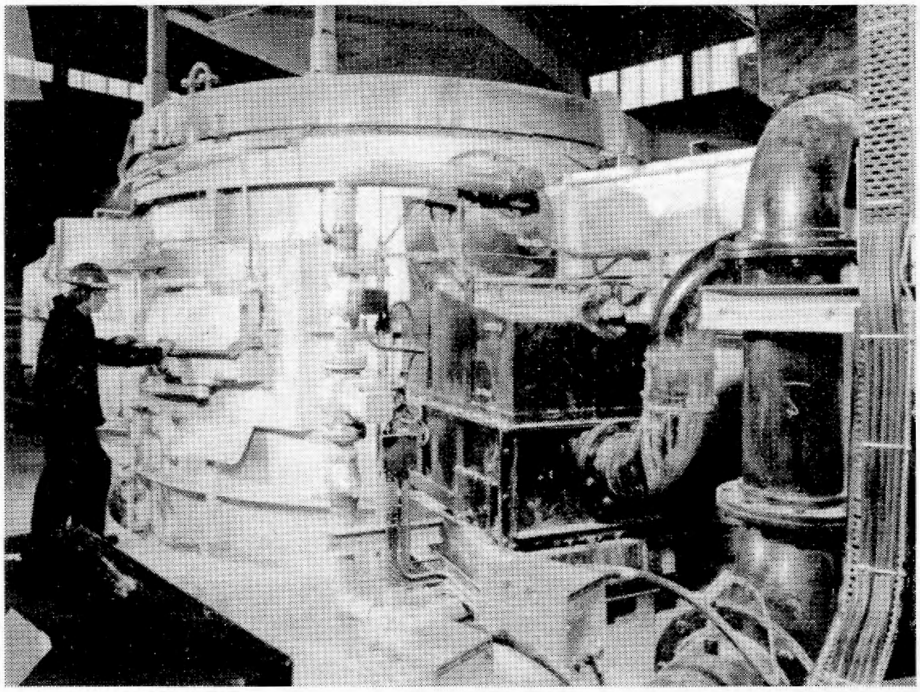

Fig. 11.6.5 One half of the 210kW regenerative burner system on an aluminium melter at Dolgarrog.

Regenerative burners have a heat recovery effectiveness of 90%. The cost savings which this exceptional performance can produce are shown by the 64 burner installation which won the 1990 Gas Energy Management (GEM) Award for new technology. The installation yielded a reduction in annual fuel consumption of 4.4 million therms which was the largest single saving in the history of the competition. The system continues to enjoy considerable commercial success, having been exported to 14 countries, and in 1992 British Gas and its manufacturing partner, Hotwork Development, were joint winners of the Queen's Award for Technological Achievement.

Development of "Low-NOX" Version

The work which has been carried out on regenerative burners during the late 1980's and early 1990's has been largely concerned with a theme which has become vital throughout the whole R&D programme - the environment. Increased public awareness, backed by a rapidly expanding body of legislation, has demanded a close examination of means of reducing the environmental impact of combustion processes. This work has posed particular difficulties in the area of high temperature heating, where air preheating leads to elevated flame temperatures and in turn to increased output of oxides of nitrogen (NOx).

After an initial examination of catalytic reduction techniques, which proved to be too costly, British Gas and Hotwork concentrated on staged combustion and flue gas recirculation, gaining support for the programme from the Energy Efficiency Office. The first stage of the project was to model the effect of variations in burner design by the use of a computational fluid dynamics (CFD) code called FLUENT, after checking the code predictions against measurements on a prototype 600kW burner. As a result of the model work, a 3MW version was tested at Coleshill (3). The product of this programme, the "low NOx" regenerative burner, was launched in 1992.

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11.7 Radiant Tubes

P.Wedge

Background

Furnaces for industrial manufacturing processes which require an inert or controlled atmosphere to protect the stock must be heated by an indirect means. When using electricity as the energy source, resistance elements or induction coils are normally used. The options with gas firing include externally fired muffles and radiant tubes.

Radiant tubes often span across the furnace above and below the stock to provide even heating. When metallic tubes are used, constructed from heat resisting nickel chrome alloys, it is possible to achieve furnace temperatures approaching 1000°C, but the alloys are then working near their operational limit. The tasks of the radiant tube are: to provide a very uniform temperature along the tube length, to operate at a high temperature without distorting and premature failure, and to provide a high thermal efficiency.

Technical Approach

A number of tube designs were evolved by manufacturers in attempts to satisfy all of these requirements. Tube types included straight through firing or 'I' shape, 'O', 'P', 'W' and 'U' shapes using burners with slow lambent flames. The MRS single ended tube developed in the early 1960s used a high velocity (C-type) burner firing into an inner tube which recirculated the hot gases by jet pump action a number of times to promote convective heat transfer. A very uniform temperature was achieved and by exhausting the hot gases at the burner end, the tube could be inserted into the furnace through one hole for simplicity of mounting (1). Despite these advantages it was not a sufficient improvement to attract commercial implementation.

It was made clear by manufacturers that a higher efficiency version would be much more attractive. A number of different types of radiant tubes had large external recuperators fitted to preheat the air for combustion by cooling the exhaust gases. With the MRS single ended radiant tube it was possible to fit a tubular shaped recuperator within the radiant tube in the unheated portion which passed through the furnace wall. To achieve this the premixed C-type burner had to be replaced by a nozzle mixing E-type burner which had been developed in the meantime, in order to use preheated combustion air at 6-700°C. The heat exchanger consisted of concentric tubes, forming narrow

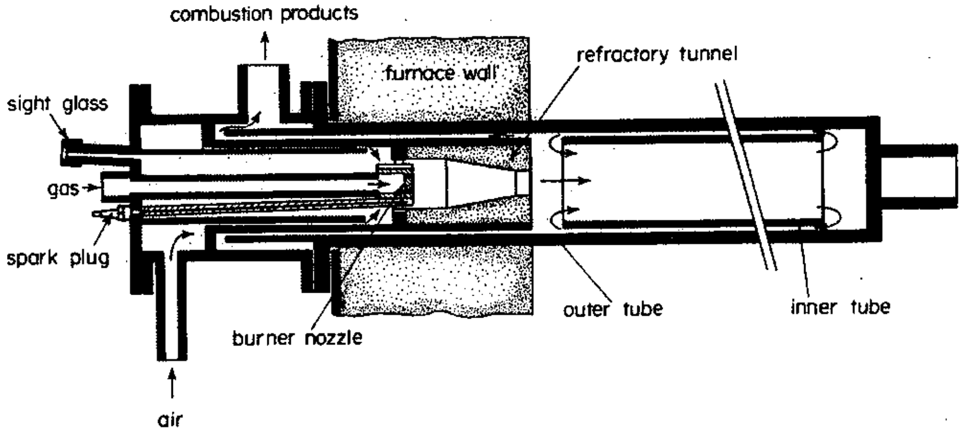

Fig. 11.7.1 Single ended metallic radiant tube.

annuli (1/8 inch on the air side) with a high length to hydraulic diameter ratio resulting in a high heat transfer effectiveness in a relatively short overall length (2). This was the first commercial embodiment of the recuperative burner (Fig. 11.7.1), improving the thermal efficiency from 40 or 50% to around 60 or 70%.

Ceramic Tubes for Higher Temperature

Work on using ceramic tube materials to overcome the temperature limitations of heat resisting alloys was carried out in the late 60s and early 70s. The possibility of achieving furnace temperatures up to 1250°C was attractive because it could open up a new range of applications including sintering, firing of pottery and ceramics, and heat treatment of stainless steels.

The properties required from ceramic tube materials were high emissivity, good thermal conductivity, low porosity, good resistance to thermal shock and oxidation, availability in relatively large tube sizes and, a realistic cost. Work was carried out with the British Ceramic Research Association at Stoke on Trent to evaluate possible materials (3). From the many materials evaluated, silicon carbide emerged as the most likely solution. Several different forms of silicon carbide existed but one bonded with silicon nitride gave the best overall balance including availability and cost.

To use ceramics instead of metals in the radiant tube design involved more than simply replacing one material with another as early laboratory tests on full size tubes soon revealed. Ceramics are far better in compression than tension and shapes must avoid rapid changes in cross section. Reproducing the mounting arrangement as used in the metallic tube meant that the underside of the tube was always in tension. A design was eventually produced using plain open ended tubes suitably plugged at one end and mounted in compression between the furnace walls (Fig.11.7.2). This allowed for thermal expansion, reduced tensile stresses and sealed the tube while ensuring that all parts of the tube remained in compression.

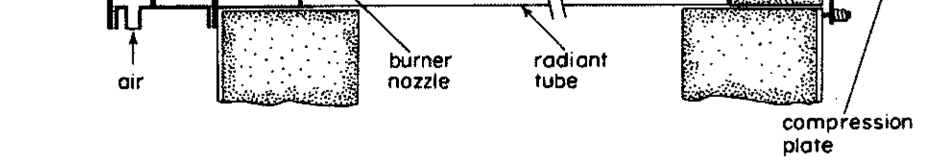

Fig. 11.7.2 Ceramic radiant tube.

In the mid 1970s, many advances in furnace design were taking place and the use of thin wall lightweight ceramic fibre insulation instead of thick, heavy brick walls gave many advantages including a fast heat up time. An experimental furnace was designed and built at MRS incorporating ceramic tubes, ceramic fibre insulation and a burner control system giving proportional control of the firing rate. The unladen furnace and radiant tubes could reach 1250°C from cold in less than one and a half hours, opening up the possibility of high temperature gas fired indirect heating and fast firing cycles in batch furnaces (Fig. 11.7.3).One years continuous operation was established as the life of the silicon carbide tubes and this proved to be economic against the higher energy cost and maintenance cost of competing electric resistance element furnaces.

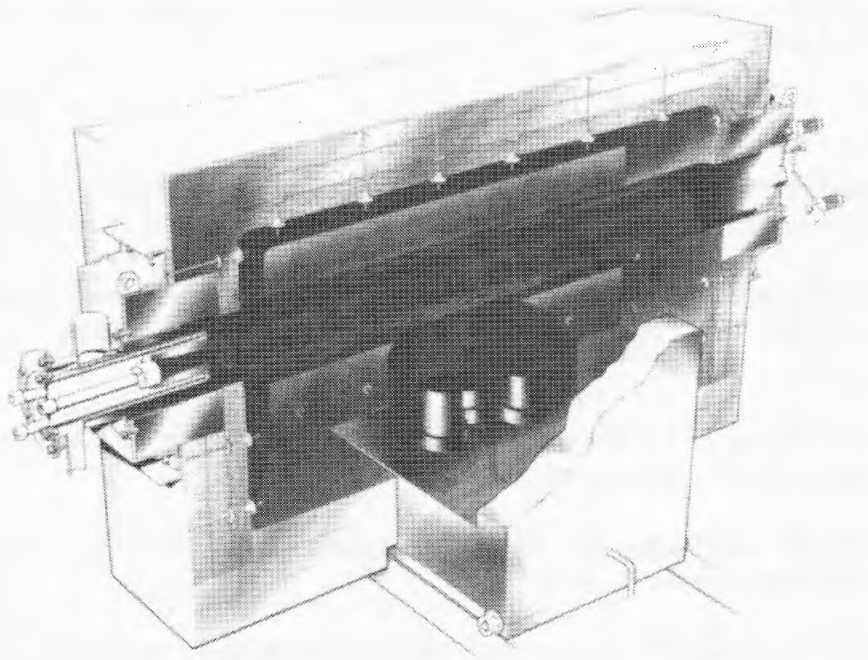

Fig. 11.7.3 Ceramic radiant tube.

Exploitation of Ceramic Tubes

A number of ceramic radiant tube furnaces were built for field trials using an atmosphere of air or protective gases to suit the process. In each case, the furnace assisted the customer to improve and develop his product and heating process.

The manufacture of diamond impregnated core drills for mining and exploration work at the Craelius Company was an outstanding example of this and received worldwide coverage in technical journals. The process involved setting diamonds in a fine powder and bonding them in a matrix by melting a copper alloy into the powder.

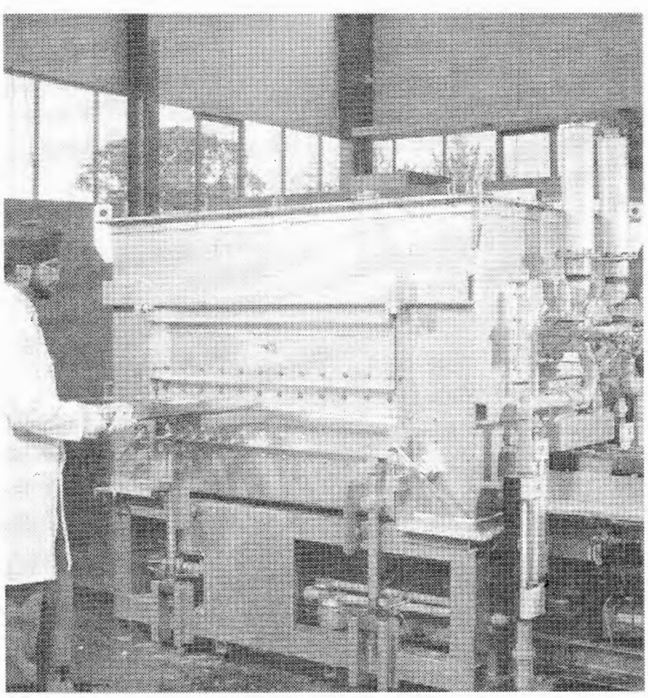

Fig. 11.7.4 Billet heating furnace with walking beam stock transport.

Temperature and atmosphere were critical. Any moisture or oxygen would ruin the powder, slightly too high a temperature would soften the diamonds, too low a temperature prevented infiltration of the copper alloy. The ceramic radiant tube furnace gave a better product with a faster output at much lower energy cost than the more expensive electric induction furnace in use prior to the field trial (see Fig. 6.20 in Chapter 6).

As the development was licensed to manufacturers, radiant tubes were supplied for demanding applications such as the manufacture of turbine blades for aero engines and the fast firing of ceramics and tiles. The ability to reach 1200°C brings advantages also for billet heating, especially in being able to deal efficiently with a range of stock sizes and shapes (Fig. 11.7.4).

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11.8 Ceramic Immersion Tubes for Metal Melting

P.Wedge

Background

Strong competition from electricity in the non ferrous metal melting market, during the 1970s and 80s, resulted in work on improving the performance of gas fired melters. The main requirements were for high thermal efficiency, low metal loss, and accurate control of temperature. Many gas and oil fired melting furnaces used direct combustion of the fuel above the surface of the metal in a reverberatory chamber operating at high temperature, typically 1000°C or more. Other methods involved containing the charge metal in a highly conductive crucible or kettle externally heated by either radiant or high velocity burners. In this system the products of combustion are isolated from the charge metal and this ensures that oxidation and gas pick up into the metal are kept to a minimum.

The concept of using ceramic immersion tubes to heat molten metals originated with aluminium producers who wanted to hold metal at temperature, typically 700°C, prior to casting into billets for subsequent rolling to aluminium foil. The aluminium had been melted in a large gas fired reverberatory furnace and then degassed by passing it through a filter bath. It was essential to ensure that the metal did not pick up any gases which would result in porosity and holes in the final product.

Technical Approach

Molten aluminium is particularly aggressive and the choice of materials for lining the holding baths is limited. Various forms of silicon carbide were considered for the immersion tube since metal tubes would react quickly with the aluminium. Early trials were carried out with British Alcan using single ended ceramic tubes immersed vertically into the aluminium. The method of firing was taken from the MRS single ended radiant tube using a high velocity burner with integral recuperator and an inner recirculating tube to ensure uniform heating (Figs. 11.8.1 and 11.8.2).

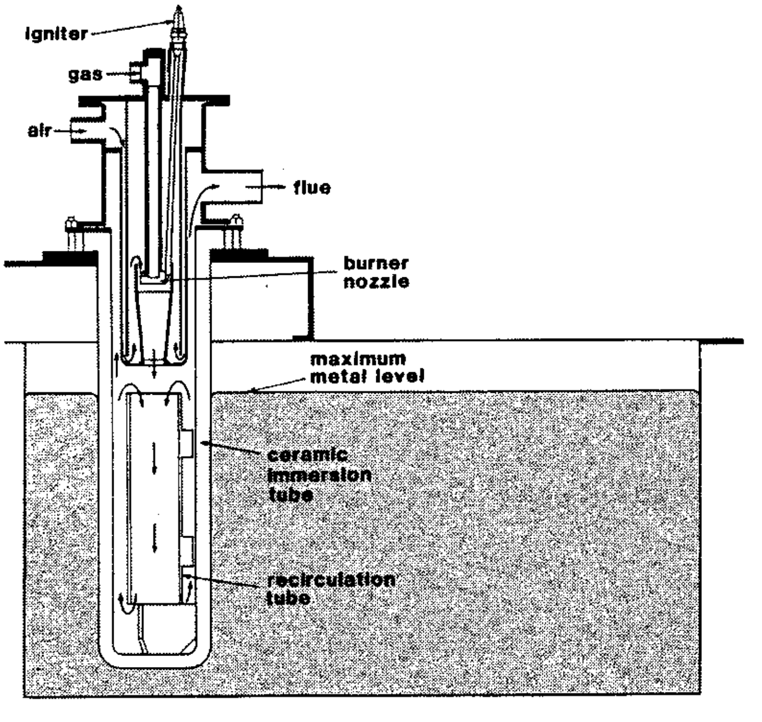

Fig. 11.8.1 Diagram of ceramic immersion tube for metal melting.

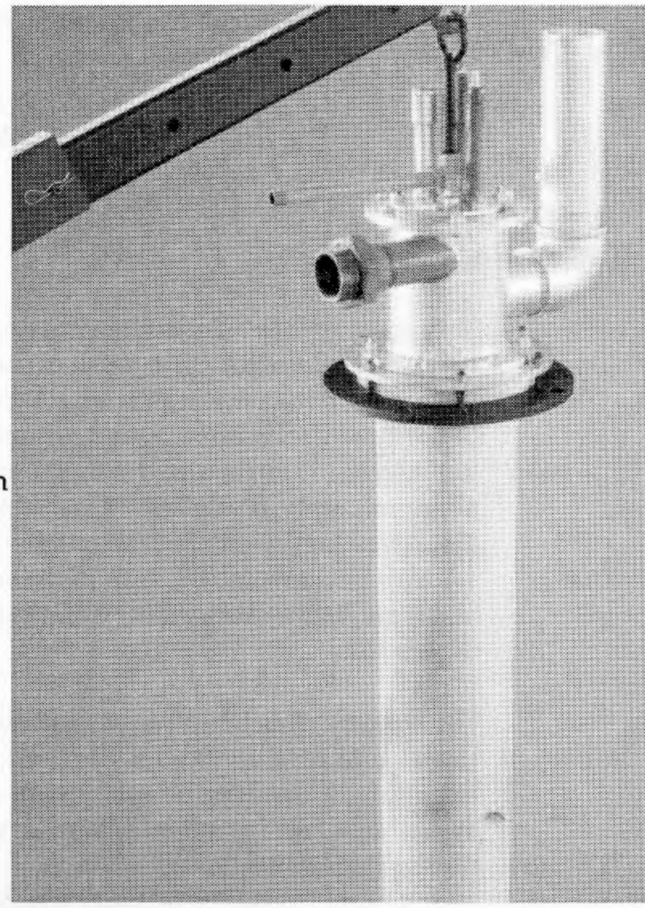

Fig. 11.8.2 Ceramic immersion tube.

The trials showed that the combustion products were totally isolated from the molten aluminium and there was no pick up of hydrogen gas. The immersion tube created very uniform temperature down through the aluminium and thermal efficiency was high. High thermal conductivity between the ceramic tube and molten aluminium resulted in the tube operating just a few degrees hotter than the metal. Oxidation of the aluminium was negligible (Fig. 11.8.3).

The challenge was to establish economic and consistent lives for the ceramic outer tubes which were in contact with the molten metal. Silicon nitride bonded silicon carbide proved to be the best material with acceptable lives of 3 months being achieved in the early stages.

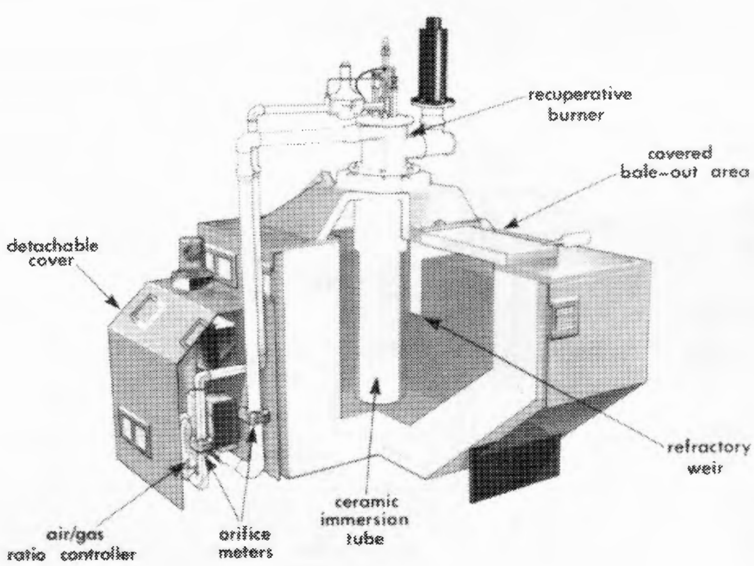

Fig. 11.8.3 Illustration of aluminium bale out bath.

The development then progressed to other applications with a number of field trials being carried out. The BNF Metals Technology Centre were carrying out research into high temperature galvanising and were looking for more efficient ways to heat baths full of molten zinc at 550°C for the galvanising process. A field trial was carried out with ceramic immersion tubes which showed that temperature uniformity was improved, energy consumption was reduced by around 25% and output from a given size of bath could be increased.

Commercial Implementation

Manufacture of the ceramic immersion tube was licensed to Burns Engineering in the UK and galvanising baths proved to be a popular application with many ceramic immersion tube systems being exported to Canada, the USA and South Africa. The conversion of existing wire galvanising baths to immersion tube firing gave up to 40% increase in production capacity. Usually the output from the galvanising bath limited production from the rest of the wire handling plant. With extra heat available after conversion, the whole wire producing plant could be uprated giving tremendous benefits. A six tube installation at Tinsley Wire in Sheffield was backed by the Energy Conservation Demonstration Projects Scheme in 1983 and proved highly successful (Fig. 11.8.4).

In the UK, zinc refining and alloying processes also benefited from the use of ceramic immersion tubes. The manufacture of zinc diecasting alloys was carried out by melting zinc at 450°C in externally heated iron pots. High purity zinc is needed and the iron pots gradually reacted with the zinc to give unwanted iron impurities. By constructing a ceramic lined bath heated by several immersion tubes the problem of contamination was overcome and an increased thermal efficiency was achieved. Similar benefits resulted on a zinc powder production plant and in the refining of zinc containing cadmium. The zinc applications were less aggressive on ceramic materials than was molten aluminium and hence ceramic tube lives of one year or longer were often achieved.

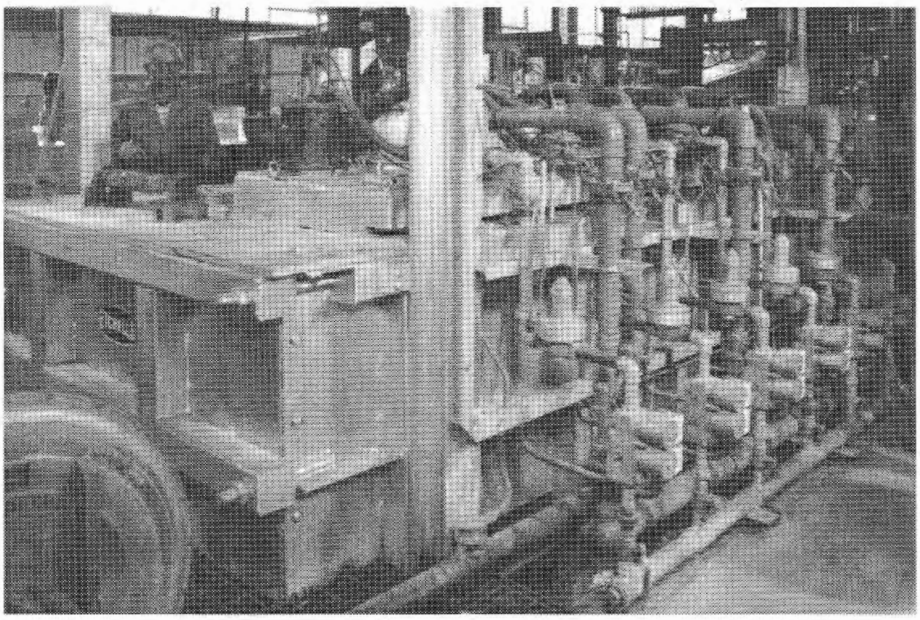

Fig. 11.8.4 Six tube wire galvanizing bath at Tinsley Wire.

Later Developments

For aluminium, further work was carried out to improve ceramic tube life. The early silicon carbide tubes were produced by ramming silicon carbide into a mould and then nitriding the green shape in a kiln at high temperature. The consistency of the material was variable and in service, oxidation of the silicon carbide resulted in a loss of strength and reduced resistance to attack from the molten aluminium. When a new method of ceramic tube production became available using isostatic pressing, a considerable improvement in tube life was achieved. Work was carried out with the tube manufacturer to develop material compositions to suit specific conditions. Tube lives were improved to around 9 months in aluminium (Fig. 11.8.5).

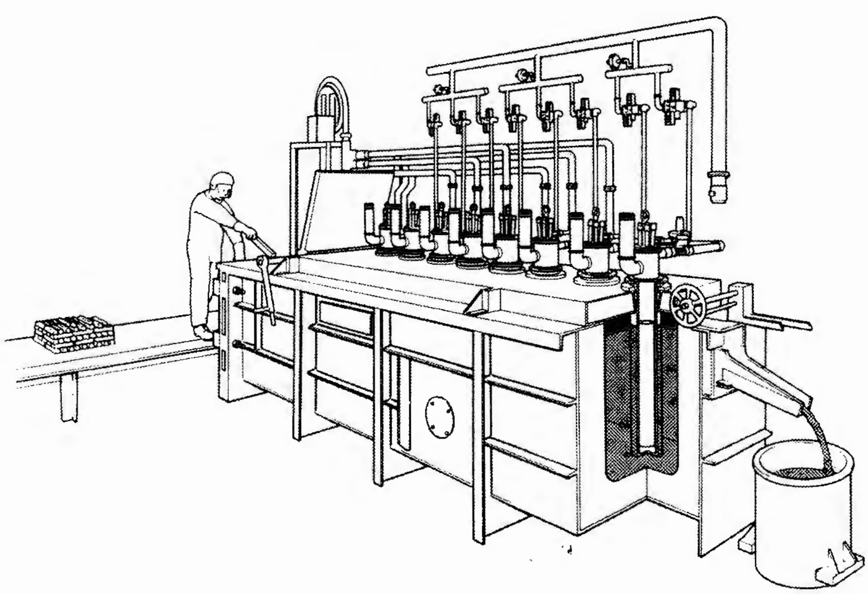

Fig. 11.8.5 Illustration of eight tube aluminium melter.

Early in 1990 the market was felt to be expanding enough for a second licensee to be announced, now known as Process and Technology Ltd, part of the Hi-Draw Group, specialising in the wire galvanising industry (3)

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11.9 Furnace Modelling

J.M. Rhine and R.J. Tucker

Background

Furnace modelling began at the MRS in the early 1960s as a result of attempts to apply high velocity burners to furnaces such as the slot forge furnace (1). Later, in order to compete effectively in the industrial sector against other energy sources, notably oil and electricity, more efficient gas-fired processes were being developed at MRS. Examples included the recuperative burner, recuperative radiant tubes and rapid heating furnaces. With the introduction of natural gas in the late 60s and early 70s, the programme of changeover of large scale processes such as steam raising and glass melting from oil firing to gas gave a new impetus to modelling as an aid to ensuring a satisfactory changeover.

The transfer of new technology into existing industrial processes, or the change from one fuel type to another, always involves some commercial risk. The risks include lost or decreased production due to equipment failure, reduced output, reduced efficiency or reduced product quality. Furthermore, industrial heating processes are by their nature very diverse in design, mode of operation and temperature and the rules and experience gained are not easily transferable from one application to another. In many cases the scale or nature of the process precluded experimental tests either in the laboratory or on the plant, and predictions from modelling became the only practical means of assessing performance. The Regional gas engineers were therefore increasingly looking to MRS for this type of technical support.

These new opportunities and the problems they created coincided with some significant advances being made by researchers world-wide in the techniques for modelling combustion plant. Of particular significance was the zone method for the modelling of radiation transfer based on the technique developed by Hottel (2) at MIT. The pioneering work of Spalding and co-workers (3) at Imperial College on the modelling of turbulent combusting flows was also laying the foundations for modern day CFD (computational fluid dynamic) models now used for furnace design and simulation. These advances in mathematical modelling were also assisted by the advent of increased computer power, initially on mainframes but later with desktop machines.

New physical modelling techniques for studying flow related problems on combustion plant were also emerging. Many of these techniques such as flow visualisation and acid-alkali techniques are still in use, being applied to solve problems which are still too complex to handle by current day mathematical models.

Technical Objectives

Ideally, modelling will lead to the prediction of output, specific energy consumption or efficiency and sometimes more detailed information such as heat flux distribution and temperatures in the load and plant structure, since these may affect plant integrity. To meet these objectives, models must accurately predict heat transfer (radiative, convective and conductive) along with flow, mixing and combustion within the furnace enclosure. It is also often important to consider non-steady state plant operation such as a cold start-up or interrupted production. This has led to the development of transient models.

Technical Approach

Mathematical Modelling: Zone Method

The zone method involves subdividing the radiating enclosure into isothermal volume and surface zones. Total energy balance equations are then written for each surface and gas zone to include radiation, convection, enthalpy transport and combustion heat release in each zone. These equations are solved to yield the temperature field and heat fluxes to the surface.

In its simplest form, which was often used in the early days of furnace modelling, the enclosure is consider as a single well stirred zone, and this is still adequate for many types of batch furnace.

Continuous furnaces, such as counterflow rapid heaters, required the development of a one dimensional long furnace model. Other situations could be adequately described by a combination of well stirred and plug flow (long furnace) regimes. Several early applications of this technique were described in 1971 by Davies, Lucas and Toth (4), including air heaters, rapid heating furnaces, reverberatory furnaces and recuperative burner applications. One application of importance to the penetration of natural gas into the industrial market was to simulate a shell boiler firetube (5).

Zone models utilised to simulate metal treatment furnaces often also incorporate transient conduction routines which enable them to be used to predict temperature gradients through the load (Figs. 11.9.1 and 11.9.2). Particular MRS developments in the zone method have focused on the representation of the radiating gases, for example non-gray gas models for combustion products, and mathematical procedures, such as the Monte Carlo method (6), to calculate radiation paths and exchange areas in complex geometries.

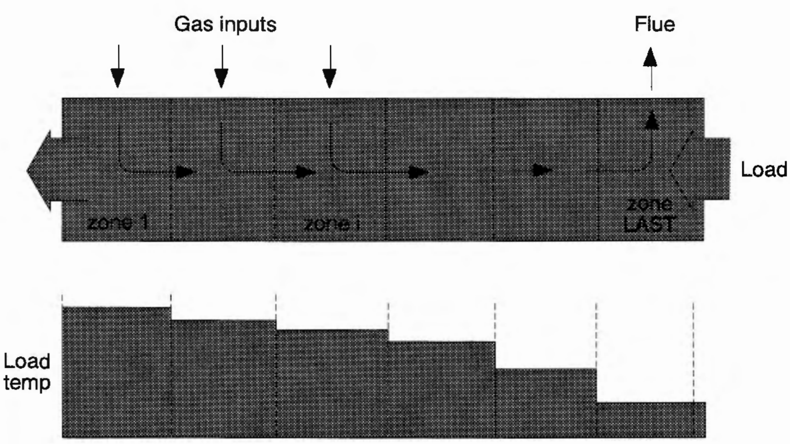

Fig. 11.9.1 Zoning arrangement in a long furnace model of a steel reheating furnace.

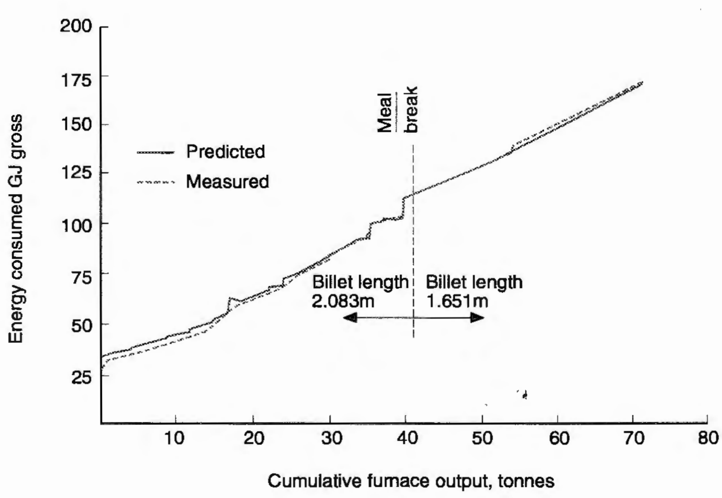

Fig. 11.9.2 Prediction of gas consumption on a steel reheating furnace using a long furnace zone model.

Mathematical Modelling: Computational Fluid Dynamics (CFD)

For the most part, furnace modelling applications utilising CFD techniques have concentrated on developing and extending general codes which are commercially available. In the furnaces area FLUENT, marketed by FLUENT Europe, has been extensively used. MRS developments have again concentrated on radiative heat transfer aspects. In addition, in-house improvements to the input and output data have made the code more "user-friendly" as well as providing data-transfer links with other mathematical models, such as a version of the zone model which predicts the performance of glass melting furnaces (Fig. 11.9.3). Another important development has been to formulate "post-processing software" to predict emissions, particularly the formation of oxides of nitrogen (NOx).

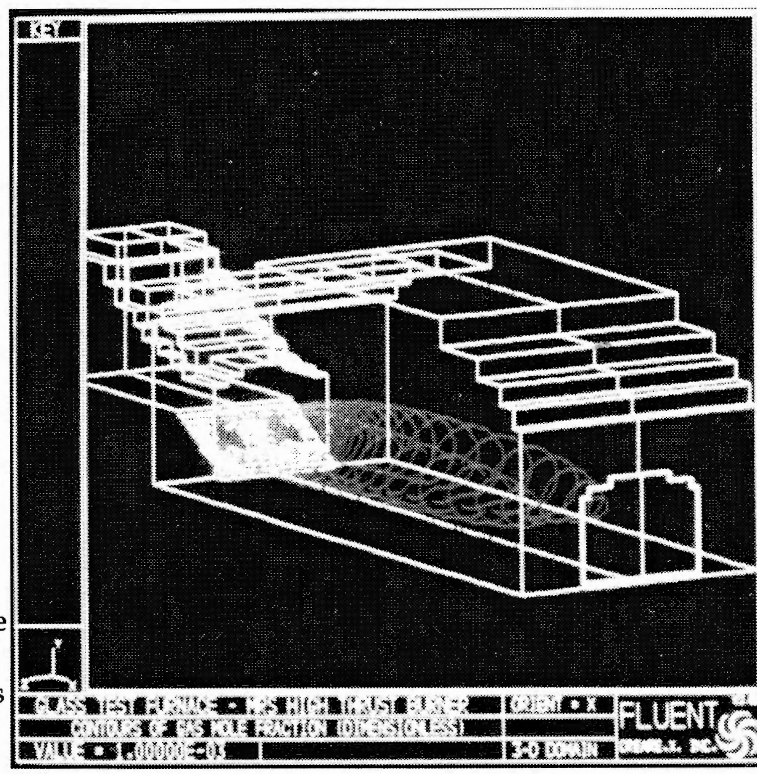

Fig. 11.9.3 Computer simulation of combustion in a cross-fired glass melting furnace using computational fluid dynamics.

Physical Modelling: Flame Simulation

It is well known that in a turbulent diffusion flame the rate of mixing of the fuel and air controls the rate of combustion and hence the flame length. It is possible to study fuel/air mixing in an isothermal scale model using the acid/alkali technique. Here the fuel and air are represented by dilute solutions of acid and alkali respectively. The alkali contains an indicator which becomes clear on neutralisation, after mixing with the dilute acid, resulting in a vivid visual representation of the flame. A study was undertaken at MRS when the technique was used to simulate flame length data obtained in a full-scale combustion rig. Excellent agreement was achieved between the actual flame lengths and those "predicted" in the acid/alkali experiments (Fig. 11.9.4).

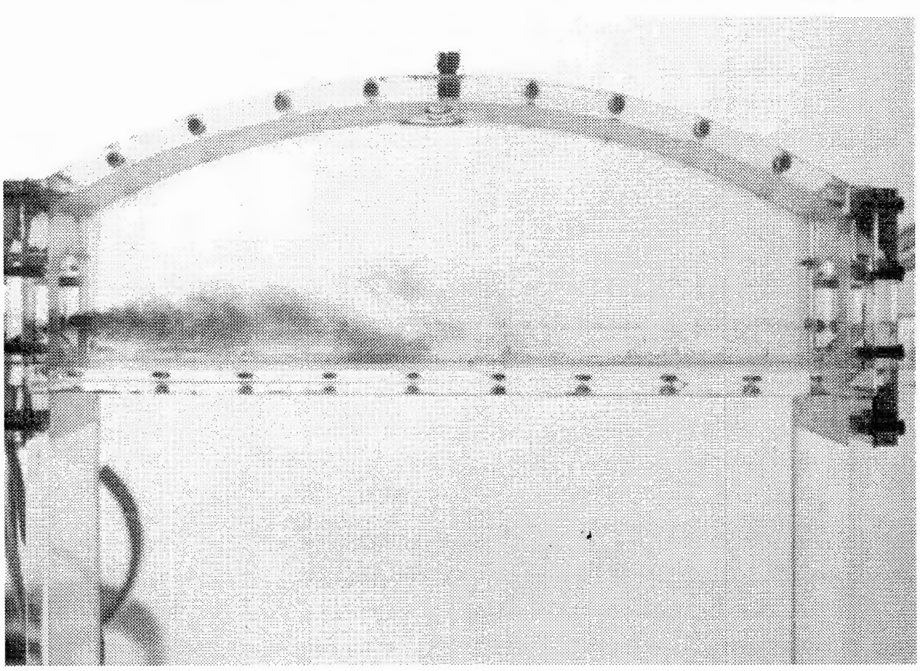

Fig. 11.9.4 Physical modelling of a cross-fired glass melting furnace using the acid-alkali technique.

The technique is now validated and established as a quantitative method of determining flame characteristics in boilers and furnaces, and particularly glass melting tanks (7).

Physical Modelling: Determining Convection

In many gas-fired industrial plant the heat transfer by convection is significant and often a critical input to the thermal design. Unfortunately, convective heat transfer coefficients are not available for many of the flow regimes and geometries occurring in practice. In the 1960's physical modelling techniques were applied which used Chilton-Colburn analogy for heat and mass transfer to determine convective heat transfer. This approach enables the convective processes to be isolated from other heat transfer mechanisms by eliminating or greatly reducing the radiative transfer. Two well established mass transfer techniques have been extended and applied at Midlands Research Station to a wide variety of furnace and boiler problems. These were the naphthalene sublimation technique and the electrochemical reduction of potassium ferri-cyanide in the presence of sodium hydroxide (8).

Average or local coefficients were obtained using these mass transfer techniques and considerable research was undertaken to optimise both approaches (see Figs 11.4.3 and 11.4.4). However, it was always recognised that mass transfer techniques were very dependent on the skill of experimenter. In the early 1980's new, non-intrusive, surface temperature measurement techniques were applied to physical models to obtain convective data. The first technique utilised the developments in infrared thermography for determining local surface temperature. The device, with careful calibration, is very accurate, but the basic instrument is rather costly. The second method, which is much cheaper, exploits cholesteric liquid crystals which respond to changes in temperature by scattering white light incident on them through the visible spectrum. The colour change is completely reversible and independent of the heat source. Considerable work was undertaken at MRS to develop experimental procedures to utilise these new temperature measurement methods. Particularly emphasis was placed on producing uniformly heated test sections and automating data analysis. In the case of the liquid crystal technique a fully automated method, which systematically analyses a video record of the colour changes to give local convective coefficients, was developed. The system uses state-of-the-art digital image processing technology, developed, primarily, for medical scanners and was produced with staff from the Dept of Mechanical Engineering at Nottingham Polytechnic (9).

These "low-temperature direct methods" have, for most applications, superseded the mass transfer techniques. However, in the future it is expected that CFD codes will be sufficiently developed to eliminate much of the need for this type of experimentation.

Exploitation and Benefits

Modelling techniques for furnace design are now in constant use by several groups within R&T. Modelling is also used by some of the British Gas furnace and burner licensees. The benefits to British Gas are a reduction in design and development cost. The benefit to the customer, is a reduction in plant operating cost together with potential for improving product throughput and quality. Not least however, are the benefits to the environment through reduced emissions and fuel usage.

Rapid heating technology is one example in which these benefits have all been realised. Rapid heating furnaces are manufactured under a license from British Gas. Because of the diversity of applications, mathematical models were written to assist in the thermal design of each heater, to determine the internal geometry and required burner capacity.

Both steady-state and transient long furnace zone models were developed to cover intermittent through to continuous operating requirements. Accurate convective heat transfer correlations are an essential requirement in these models, and these were obtained from isothermal physical modelling experiments.

The development cost of these models is very difficult to estimate since the models incorporate expertise and knowledge acquired over many years. These models also represent one of a whole range of models developed from the same techniques. Discounting the development costs, the thermal design of a typical rapid heater using established models, is unlikely to consume more than £500 in labour and computing costs. The value of the heater may vary from ten, to several hundred, thousand pounds. The value to the customer in terms of energy saving can pay for the modelling in just a few days. Modelling has enabled a fast turn-around of customer enquiries, and has enabled the manufacturers to offer thermal efficiency and performance guarantees to their customers.

British Gas's expertise in furnace modelling has been recognised world-wide through numerous publications, through the sale of software to other gas companies and most importantly through the success of commercial developments.

Further information on the theoretical and experimental modelling methods mentioned in this section can be found in the British Gas Technical Monograph "The Modelling of Gas-Fired Furnaces and Boilers" by J.M. Rhine and R.J. Tucker, published by McGraw-Hill, 1991.

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11.10 Pulsating Combustion

D. Reay

Background

In 1960, MRS began investigating the possibility of using the pulsating combustion principle in industrial gas heating equipment. Previous investigation of this phenomenon had been mainly concerned with the pulse jet engine, developed in Germany in the 1930s, which led to the production of the V1 flying bomb. However Lucas Rotax of Canada had produced an experimental gas fired water heater and had claimed very high thermal efficiencies. Another stimulus was provided by F.H. Reynst, who was a pioneer in the pulsating combustion field and whose many papers on the topic were collected and edited by Professor Thring in a book published in 1961.

The objective of the MRS work was to produce a compact, high efficiency, high output immersion tube liquid heater. The attraction of the pulse combustor was the combination of combustion intensities and heat transfer rates similar to those attainable with forced draught, with the simplicity and convenience of self aspiration.

Principle of Operation

A pulsating combustor fundamentally consists of an air inlet pipe with inlet valve, a combustion chamber and a resonating exhaust tube of the same or smaller diameter several feet long (Fig. 11.10.1). Gas is admitted into the combustion chamber and ignited by means of a spark plug. An explosion occurs, the air inlet valve shuts and the exhaust gases are driven by the pressure increase through the exhaust tube. The inertia of the moving gas column creates a decompression in the chamber, the inlet valve opens and more air and gas are drawn in. Ignition follows from the previous combustion phase and the cycle recurs at a frequency of between 50 and 200 Hz depending on the dimensions of the unit.

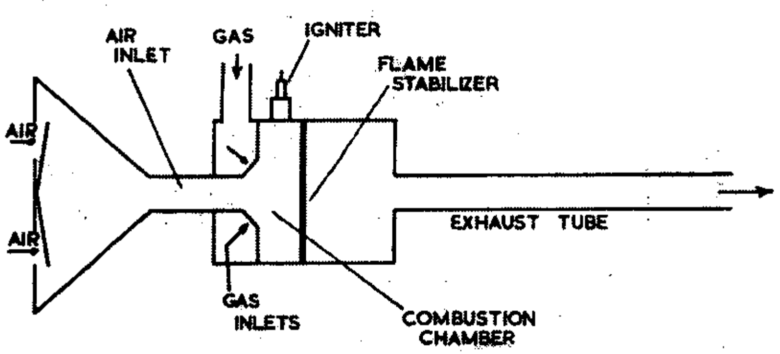
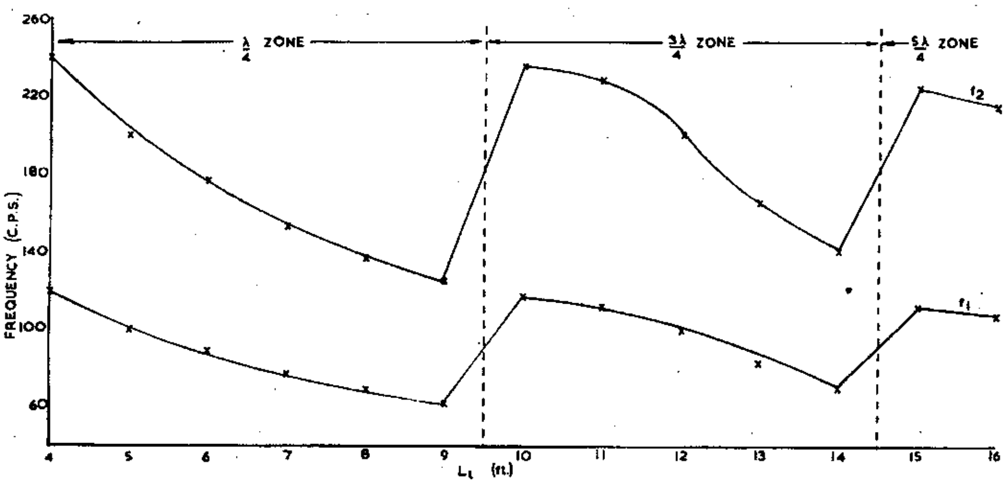


Fig. 11.10.1 Diagram of a Helmholtz type pulse burner.

Preliminary Investigation

The preliminary study of gas-fired pulsating combustors was carried out by David Reay, Malcolm Hoggarth and Eric Francis in the early 1960s (1). There are many types of pulsating combustor, but it was expedient to begin with designs derived from discussions with Max Watt of the Gas and Fuel Corp., Melbourne, Australia. He had been operating types of tubular pulse units with long exhausts, particularly suitable for immersion tube heating, designated at MRS as "Schmidt" and "Helmholtz". In the Schmidt burner the combustion chamber and exhaust tube are of the same diameter whilst in the Helmholz burner the exhaust tube is of a smaller diameter.

It was found that a short Schmidt burner resonated as a quarter-wave tube, setting up a standing pressure wave with a pressure antinode at the flame and a pressure node at the exit. As the tube was lengthened however, frequency jumps occurred to give 3/4 and 5/4 wave resonance, with the fundamental frequency of operation remaining in the range 40 to 150 Hz (Fig. 11.10.2).



$L_a = 10$ in. $D_a = \frac{3}{4}$ in. $D_t = 3$ in. $Q_g = 100$ ft^3/h.

Fig. 11.10.2 Variation of fundamental and first harmonic frequencies with exhaust tube length.

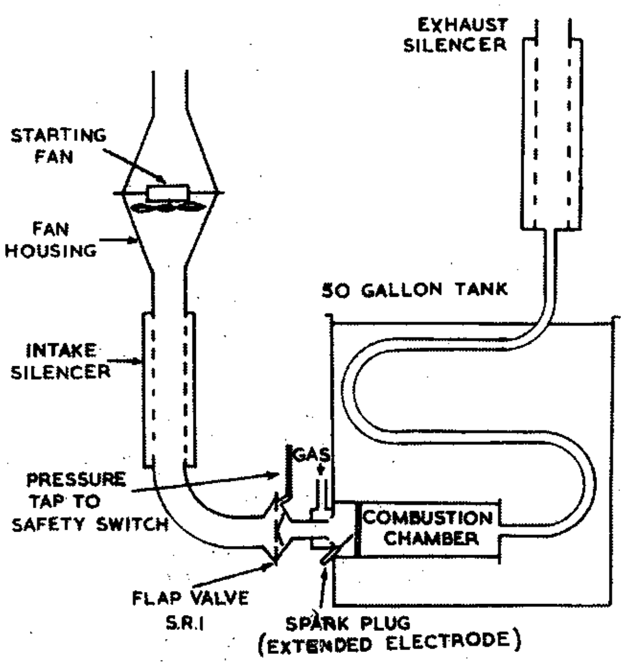
The frequency of the Helmholz burner was mainly determined by the resonance of the air inlet pipe and combustion chamber volume acting as a Helmholz resonator, with a smaller diameter exhaust tube ideally tuned to resonate as a quarter-wave tube at the same frequency.

Combustion quality was found to be very good, providing good air and gas mixing was promoted by using multiple gas nozzles of small diameter. These nozzles were directed at a small stabilising bar, which seemed to act as a bluff body stabiliser. Turndown ratios of up to 5:1 were achieved.

Several designs of air inlet valves and valve materials were investigated. A circular vibrating reed of thin rubberised material (nitrile nylon) formed the most promising mechanical valve. Aerodynamic valves of the Borda mouth type were used, but suffered the disadvantage of a considerable reverse flow of combustion products.

The major disadvantage of pulsating combustion is the inherently high noise level produced. Some success in noise reduction was achieved using simple commercial "straight - through "silencers on the air inlet and exhaust pipes.

Heat transfer rates from gases to exhaust tube wall were investigated. Due to the scrubbing effects of the pulsations in the exhaust gases, heat transfer rates much higher than for conventional natural draught fired tubes were measured.



A small prototype immersion tube unit was operated with fully automatic ignition and control including pulse-failure protection by means of a pressure switch, fed from a combustion chamber tapping through a small "rectifying valve" which produced a significant negative pressure when the burner was pulsating correctly (Fig. 11.10.3).

Fig. 11.10.3 Experimental immersion tube unit for tank heating.

Later Work

Later work (2) (3) was devoted to investigating in more detail the heat transfer characteristics of pulsating combustors, and developing silencing methods and fully automatic control.

It was found that thermal efficiencies under pulsating flow conditions were from 30 to 50 % higher than those theoretically predicted for steady flow. Local heat transfer coefficients were substantially increased and some correlation was found with local particle velocities.

Noise reduction techniques were applied to 2 and 3 therm pulsating combustors using all-absorptive silencers, bringing noise levels down from 125 dB to around 80 dB. When the level of 80 dB had been achieved however, more noise was being emitted from the burner casing than from the inlet and exhaust ducts, and it was thought that any further attenuation would be difficult to attain, due to the multiplicity of noise sources.

Immersion tube heaters of 7, 11 and 13 feet were tested and found to have thermal efficiencies of about 75 %. The 7ft tube was operated under fully automatic control (4), with on-off operation controlled thermostatically, using negative pressure derived from the combustion chamber for flame detection. The control provided a purge period of 30 seconds, during which time an air inlet fan operated, prior to ignition. The control system also provided a limited trial for ignition period, several attempts to ignite if the first was unsuccessful, and finally a lock-out condition on flame failure or failure to ignite after several attempts. The 7 ft tube operated successfully for extended periods but the 11 and 13 ft tubes were unreliable, exhibiting a mysterious combustion instability causing random and unexpected failure after several hours operation.

Stroboscopic observation of the combustion zone indicated that the combustion was of a continuous sinusoidal nature, rather than the discrete series of "explosions" that was commonly held to be the case.

Conclusion

In the mid-60s, natural (North Sea) gas was arriving, all industrial burner equipment had to be converted and there was therefore a pressing need for experimental resources to be devoted to this end. The work on these fascinating pulsating combustion devices had therefore to be abandoned.

An assessment can be made of the work undertaken. The primary aim of the research was to produce a compact, high efficiency, high output immersion tube liquid heater. This was achieved, but the final unit was rather noisy and expensive, in comparison with the conventional Temgas immersion tube heaters of that time. Heat release rates per unit area of immersed tube were however considerably higher than for equivalent Temgas units, allowing much more compact heating tubes to be used . However, pulsating combustion failed to break through into practical industrial tank heating and this appears to be still the case, at least as far as the UK is concerned. Some years later, high efficiency condensing boilers based on pulse units (Lennox) were available from designs produced in North America. No further work on pulsating combustion was done at MRS.

It is fair to say that no fully satisfactory design formula had been evolved and the effect of the many dimensional and other parameters on combustion stability was still not completely clear. There was therefore much scope for further research into this fascinating topic. Pulsating combustion is particularly suitable for university research and subsequently projects in the field have from time to time been sponsored at universities.

In the early 70s all the objectives of the pulse combustor project were achieved by the development of the forced draught small bore immersion tube (see Section 11.11 below).

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11.11 Small Bore Immersion Tubes For Vat and Tank Heating

R.W.Cox

Background

In the early 1970's the Large Commercial Heating Division headed by Peter Cubbage was formed. One of the first tasks of this new division was to identify those market sectors, in the industrial and commercial sector, where most fuel was used. The market analysis indicated that, second only to space heating, was the use of fuel for heating liquids in vats and tanks, estimated at some 2,000 million therms per annum. Heat in this sector was predominantly supplied through steam, as an intermediate medium, often generated from coal or oil in a central boiler house. The overall efficiency of fuel usage was thus very low and an opportunity clearly existed for point of use gas firing technologies of higher efficiency.

Conventional gas fired systems (undertank firing, drop in heaters or large bore immersion tubes) were themselves either inefficient or very bulky, and certainly did not compare with the simplicity of a small bore tube carrying steam immersed within the tanks being heated. Heat was transferred readily from such tubes due to the high steam side heat transfer coefficient resulting from condensing steam.

Technical Approach

The initial work was to try to develop a burner capable of firing at high intensity into a small bore tube, possibly into the existing steam tube. This concept proved impracticable. However, work continued to fire burners into a 1" nominal bore tube (1). A number of parameters proved important. The design had to be nozzle mixing to allow wide limits of flame stability. It was found to be critical to divide the airflow into two streams, primary and secondary, the ratio between them was also most important. Gas pressure had to be converted across small ports into energy for mixing and turbulence. The relative position of air ports and gas ports was crucial and finally the combustion chamber diameter and length mattered. A 14° taper section followed to match into the small tube being fired (Fig. 11.11.1).

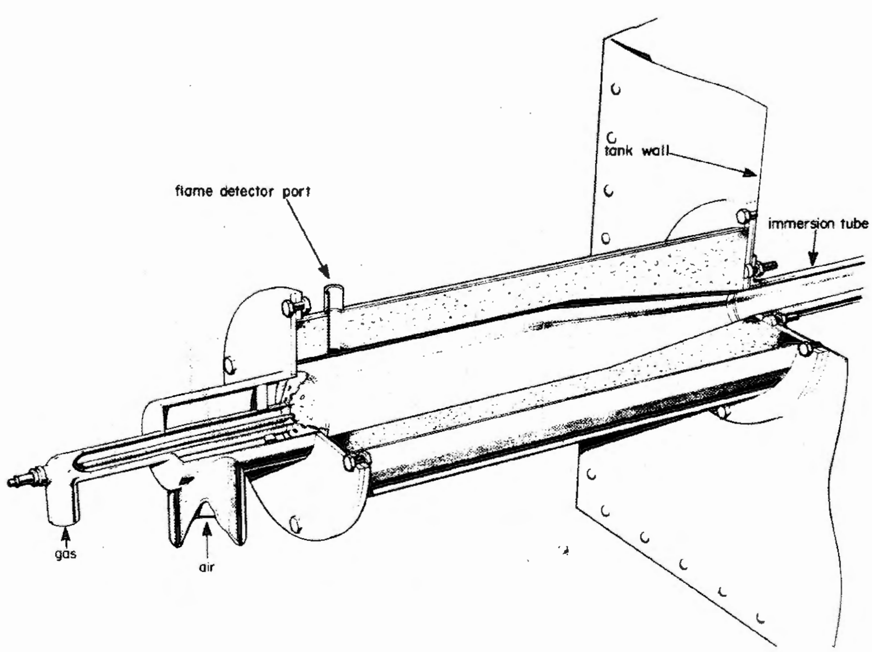


Fig. 11.11.1 Illustration of the original version of the immersion tube burner.

A series of laboratory experiments produced the first design which allowed adjustment of the primary to secondary air ratio through the adjustment of a cone. Up to 100,000 Btu/h heat release was possible with good combustion quality and stability firing into a 1" tube some 15-20 feet long. Development led to larger sizes and all metal immersed combustion chambers (Fig. 11.11.2). By 1978 a 600,000 Btu/h version firing a 3" bore

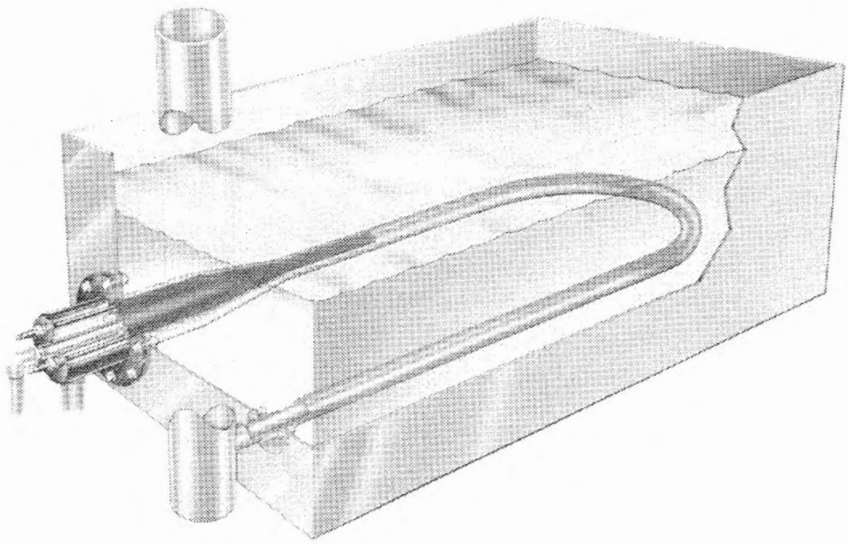


Fig. 11.11.2 Later version of the immersion tube system.

tube was available. A further significant advance was the introduction of fixed primary and secondary air ports to control the ratio of primary to secondary air rather than the original cone system which was always difficult to adjust. Indeed this development is still the version sold today by licensees on behalf of British Gas plc. The adjustment allowable in the current design is the relative position of air and gas ports to optimise flame stability.

There were surprisingly those who insisted that firing at high intensity into a long small diameter tube was not possible and, even if it were, the system would resonate. However, it was possible and resonance was never a problem.

The overall efficiency of small bore systems is typically 85% based on gross calorific value and maybe much higher at start up on firing a cool solution when condensation occurs, hence also removing the latent heat from the combustion products.

Commercial Implementation

To introduce the system to the market place required a number of field trial sites to prove the development under industrial conditions. The first trial was in a rinse tank for drill bits at Edgar Allen Tools in Manchester in October 1973. The system still operated many years later having outlived the original wash tank into which it had been installed.

Other significant early installations were at British Gas East Midlands Litchurch Lane site in Derby, at Thomas Bolton, Cheadle Staffs and at the J. Allen Rubber Company at Lydney. Many fascinating hours were spent at these sites with quite a rapport being built up with the locals. At Thomas Bolton, copper products, tube, wire and plates were manufactured. The stock held at the factory in the form of large copper billets was very valuable and very heavy. The site itself was situated either side of a canal. The site manager at that time, a former opening batsman for Staffordshire, who once faced West Indian fast bowler Gilchrist and never forgot the first ball he received, often recounted the tale of the night of the planned theft of copper billets. The canal was the access and a barge the escape vehicle. Unfortunately, for the thieves, they were undone by their greed. The weight of the large amount of billets stolen was such that the barge sank.

At J. Allen Rubber company another enthusiastic engineer of the old school, Fred Pace, ensured the success of the installation. The company manufactured rubber gloves (Fig. 11.11.3), balloons and other rubber products, while the formers for rubber gloves and balloons were readily available for experimental purposes, those for the "other products" were surprisingly not.

The result of the field trial activities was a very successful product being sold initially in the UK through three licensees, Stordy, Wellman and Aeromatic. The licensees have since changed and systems are now available for firing tube sizes up to 8" nominal bore and at high supply pressures (1 psig). The most successful outlet is into North America through Eclipse Inc. with many hundreds of burners sold. The UK market is, of course, not as large but the high intensity tank heater development sparked off competing systems from other companies such as Lanemark, the result being total sales of all systems into the 1,000's.

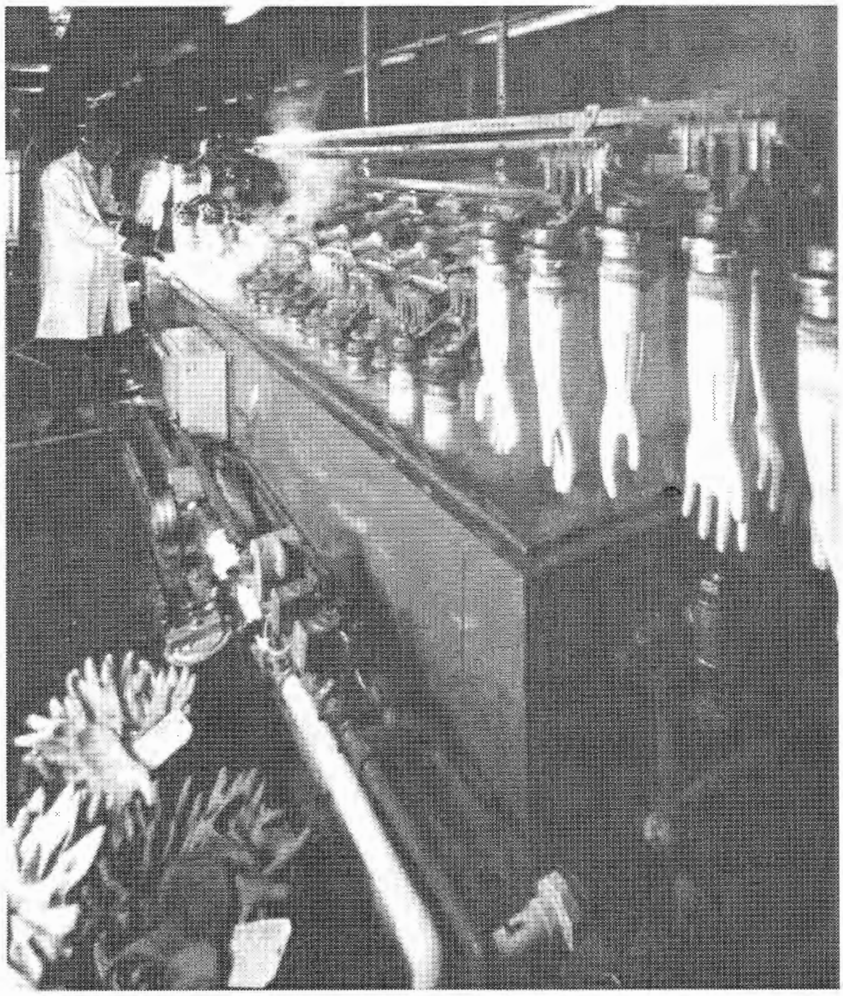


Fig. 11.11.3 Tank heater for washing of rubber gloves.

Another variation marketed by the licensees was a multitube in-line water heater particularly suitable for provision of hot water services in commercial premises.

Direct Contact Water Heater

A bulk water heater, the direct contact water heater, was developed to take advantage of the possibility of recovering latent heat of the water vapour in the products of combustion. It is basically a counterflow system with cooled combustion products coming into contact with incoming cold water thereby reducing the combustion products temperature below their dewpoint. A simple direct contact system has a limitation on liquid temperature of about 89°C at which point all of the input heat evaporates water rather than raises its temperature. However the novel use of a two stage device with direct and indirect sections allows both high efficiency and high water temperatures to be achieved.

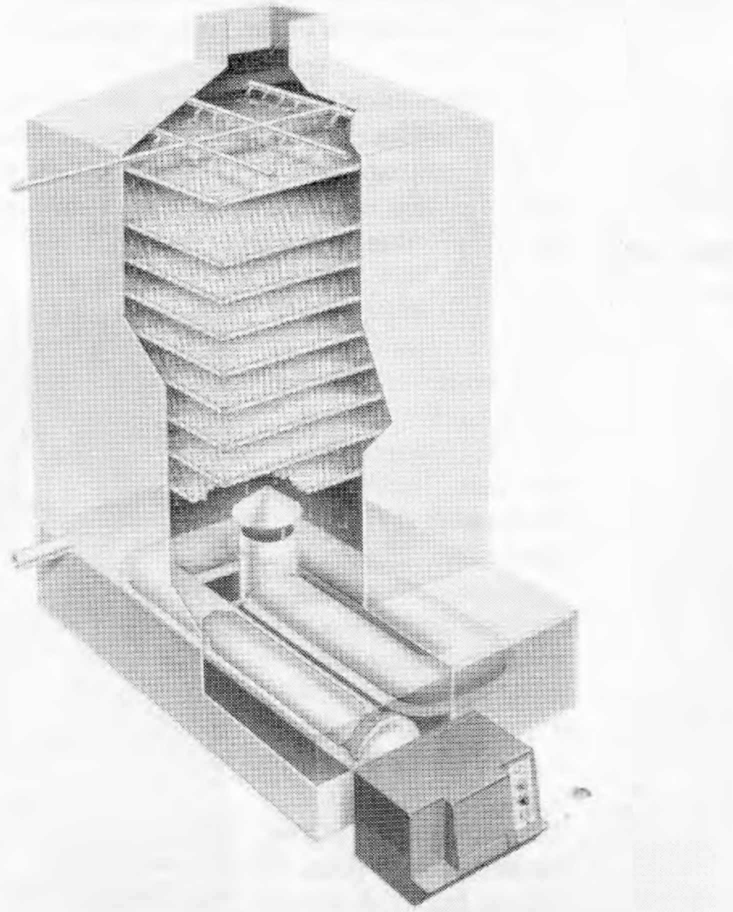
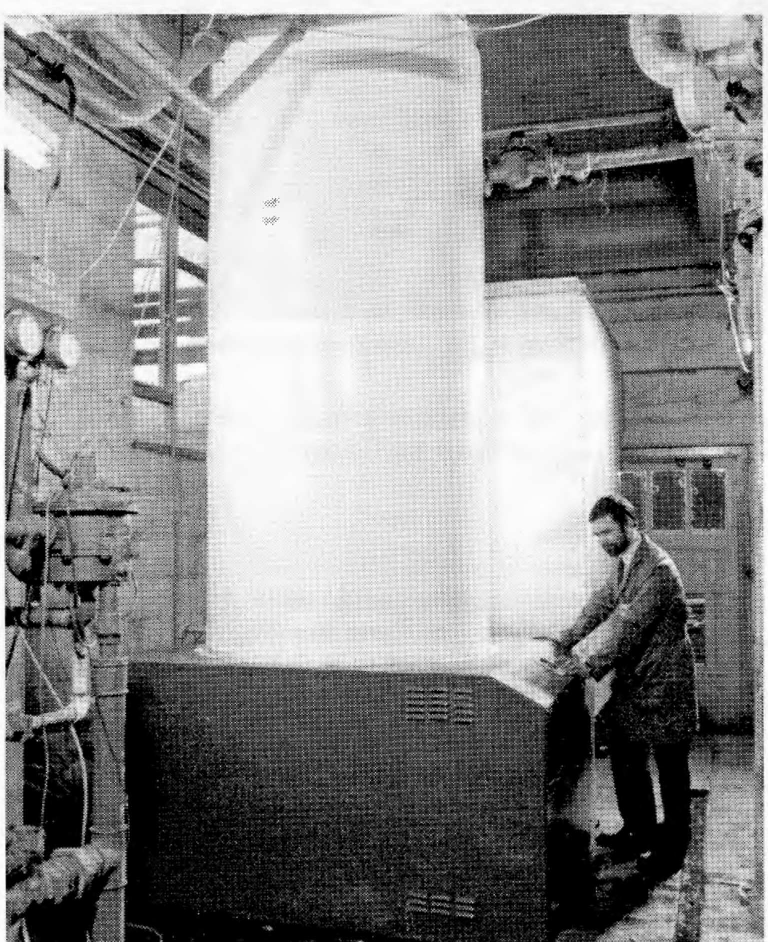


Fig. 11.11.4 Original version of direct contact water heater.

The original version (Fig. 11.11.4) developed in the early 80s consisted of a tower into the top of which cold water was sprayed and trickled down over a series of grids in counterflow to the combustion products from the indirect section; this was a bath heated by a simple immersion tube, fired by a standard packaged burner, in which the preheated water from the tower section could be raised to temperatures of up to near boiling.

This version of the direct contact water heater was available from licencees and has found many applications for bulk water heating, particularly in tanneries.



Recently, a redesign has taken place (2), leading to a unit consisting of a two part cylindrical tank resting on a rectangular base section; the lower tank housed a vertical immersion tube and the upper tank contained a packed bed onto which cold water was sprayed (Fig. 11.11.5). The base section housed ancilliary equipment with a control cabinet at the front. The new unit has proved to be cheaper to build, is more attractive in appearance and takes up less floor space while retaining the high efficiency of the original (Fig. 11.11.6).

The work over the years has produced a whole range of liquid heating equipment capable of satisfying the varying demands of the market place and offering a high efficiency option.

Fig. 11.11.5 Redesigned direct contact water heater.

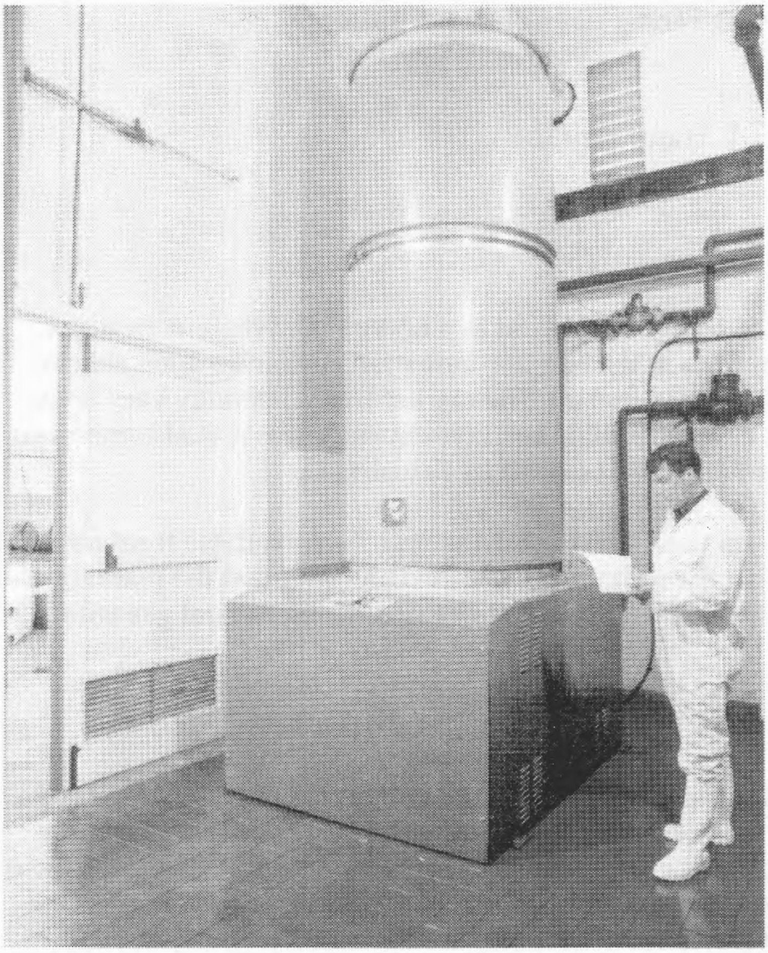


Fig. 11.11.6 1.2 MW direct contact water heater at Oris Ltd., Sunderland.

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11.12 Natural Gas Firing of Industrial Boilers

J. Hammonds

Background

During the 1950's coal began to be replaced by oil as a boiler fuel. When natural gas became available in large quantities in the late 60s, industrial customers were able to consider gas firing as an alternative to fuel oil. The market was potentially very large, had a good load factor, could be interruptible and consequently was a vital component in the expansion of the industrial market planned by British Gas.

Since dual fuel burners had been used for boiler firing and were available from the USA, it was reasonable to assume that the technology was available and that the market would be price lead. In this climate boilers began to be fired using natural gas with fuel oil as the stand-by fuel.

Technical Objectives

After a time some boilers which were being fired for much of the time by natural gas were found to be failing; this was generally picked up at the annual inspection of the boiler. It was in the light of this that a study of boiler firing using dual fuel burners was started at the MRS with the objectives of finding out the problems associated with the gas firing of boilers and to offer solutions. It was necessary to quantify any changes in thermal performance, heat transfer and temperature distribution that might arise because of differences in fuel properties.

Technical Approach

The performance of smaller packaged burners up to 400kW had already been evaluated, particularly for their compliance with the "Standards for Automatic Burners" and reported in 1971 by Hoggarth, Jones and Pomfret (1). This was a useful precurser to the work on the larger burners used for steam boiler firing, gas and dual fuel up to 30MW. Dual fuel burners were tested initially at Solihull but then the investigations were moved to purpose built test furnaces at the Burner Test Site at Coleshill. Water cooled fire tubes of 2 and 8 MW capacity simulated conditions in shell boilers (Fig. 11.12.1) and a larger furnace was used for burners up to 30MW suitable for water tube boiler firing.

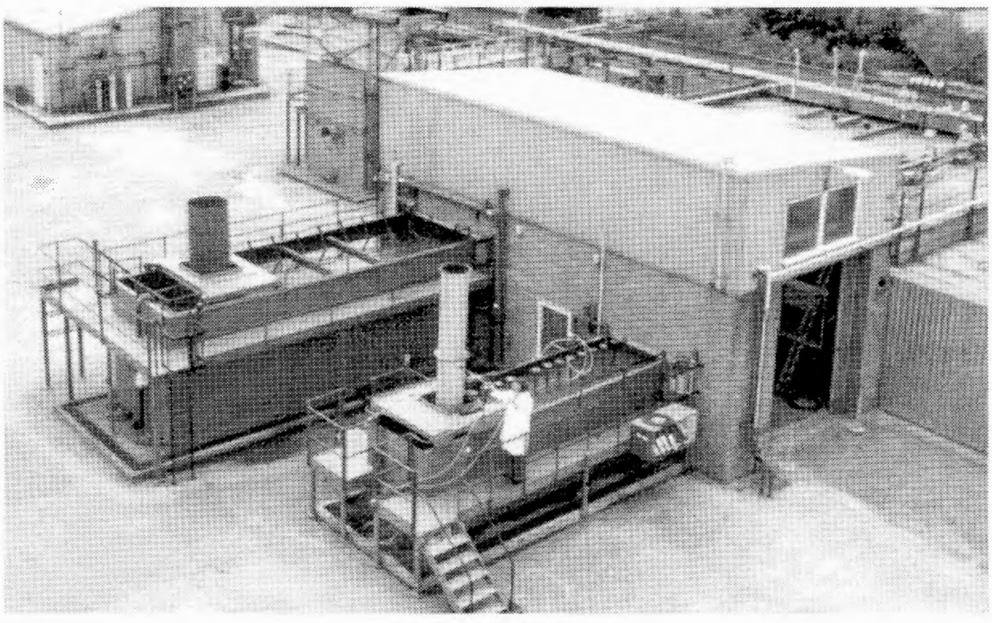

Fig. 11.12.1 The fire-tube rigs at Coleshill.

There was also a special furnace which could be used to investigate burner light-up and identify any ignition and instability problems. This work was reported in 1972 by Hoggarth, Pomfret and Spittle (2).

The other part of the programme was the field testing of boilers with the emphasis on trouble shooting, so most of those which were tested had had some problems after changeover to natural gas. The experimental programme was supported by the development of mathematical models. A model for shell boilers was developed which predicted heat transfer and temperature distributions in the fire tubes and reversal chambers.

Manufacturers supplied burners which were used for boiler firing and each was fired on one of the three test furnaces. Measurements were made of flame length and shape, and of burner stability as well capability of safe and reliable ignition. In-flame measurements and flue gas analysis showed the degree of flame burnout and carbon monoxide level; the latter was subsequently to be one of the most important parameters that were used to determine the performance of a burner on an actual boiler.

There was some controversy as to the effect of the application of natural gas to shell boiler plant specifically designed for oil firing. The main area of contention was the effect that higher temperatures of the combustion products of natural gas leaving the fire tube would have on the tube plate. Consequently, the programme of field testing was initiated in 1970 to examine the relative effects on metal temperatures of oil and gas firing in sensitive parts of boilers.

During a field trial the fuel, feed water and steam rates were measured by conventional calibrated instruments. As the tests were primarily concerned with combustion products and metal temperatures, and the effect on these of excess combustion air levels, additional instrumentation was directed towards the measurement of these parameters.

Combustion products were analysed using para-magnetic oxygen analysers, Orsat apparatus for carbon dioxide and Drager tubes for carbon monoxide. Combustion product temperatures were recorded using a water-cooled Atkinson suction pyrometer and metal temperatures were measured using sheathed thermocouples brazed onto metal surfaces within the boiler (6). In order to obtain reliable data, once steady conditions were established a test of about one hour's duration was needed. This time was required because traversing was needed; spot readings could be unreliable.

Around 50 field trials were carried out over a period of about 5 years, providing complementary information to that obtained under laboratory conditions at Coleshill. The main results were reported in 1972 by Horsler and Lucas (3) and highlighted the importance of proper boiler feed water treatment and showed that downrating on gas was only justified in a very few cases of plant with very high firing densities. The paper also used heat transfer and temperature calculations based on the "well stirred/long furnace" models (4)(5) and showed that these could be used with reasonable confidence to predict performance.

Benefits

The programme of work was pursued intensively over the period 1969-1972, with several of the staff having transferred from the production side and thus with experience of large plants. The practical result was a more or less complete methodology for changing over boilers to natural gas, so eliminating the initial failures of some combinations of boilers and burners.Out of the work also came better burners due to the comprehensive testing which was carried out at Coleshill. Burners could be matched to particular boilers, so optimising performance.The ultimate result of this research effort was to enable owners of boiler plant to have confidence in the use of natural gas as an alternative to fuel oil. This of course led directly to greater sales into what was then a new market for gas.

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11.13 Natural Gas Firing of Glass Melting Tanks

J Hammonds

Background

Glass melting furnaces, known as tanks, can be fired by a variety of gaseous fuels such as natural gas, coal gas, liquefied petroleum gas and certain substitute gases. The use of producer gas manufactured in the glass works itself is now a thing of the past. However, the most common fuel that is used in the UK is heavy fuel oil (HFO). In contrast, in the United States natural gas is most commonly burned and HFO is used as the stand-by fuel.

So, as natural gas became available for industrial use in this country, a market that looked attractive was that of glass melting. The container sector (bottles manufacture) was of immediate interest, the size of this market is about 200M therms per annum and it has a high load factor. The aim was to win this market as an interruptible load for natural gas, where HFO would be the stand-by fuel, a similar position to that existing in the USA.

Technical Objectives

Existing furnaces were designed to fire HFO and glass makers had had many years experience to optimise the firing technique for this fuel. There was an in-built resistance to change and the almost invisible natural gas flame, compared to the luminous HFO flame, was considered inferior by many operators. Control was thought to be more difficult because a NG flame was not as easily seen and it was believed that only a luminous one was able to melt glass effectively.

Early change-over attempts were based on trying to reproduce the luminosity of an oil flame by delaying mixing of air and gas to "crack " the gas forming carbon particles. Any benefit in emissivity was offset by overlong flames, with combustion continuing into the regenerator, and consequent reduced flame temperature.

The research objective was hence to produce a burner design optimised for gas and to try and match the output and efficiency achieved with oil.

Technical Approach

The approach adopted was the traditional MRS strategy of combining mathematical and physical modelling, large scale laboratory experiments and field trials of promising designs on customer's plant(1).

At the MRS there was considerable expertise in the use of ZONE mathematical models (Hottel type) and such a model was developed for a reverberatory glass melting furnace. This model needed validation and this was achieved using data from field trials and from glass makers themselves. The validated model may be used to determine the thermal performance of a furnace by treating it as a series of well stirred reactors (2).

To predict the properties of the flame, a much more sophisticated kind of mathematical model is required. Such a model is a computational fluid dynamics code (CFD). This may be used to investigate flame shape and position, recirculation within the furnace, temperature distribution and ultimately the rates of production of pollutants such as oxides of nitrogen. These codes also needed to be validated and this is an on-going activity.

The acid/alkali technique was used to visualise the flame shape and burn out characteristics for various gas nozzle designs. In an acrylic model of the glass furnace, suitably scaled, acid is used to simulate the air and alkali mimics the fuel, with an indicator to show show the presence of unreacted "gas" (3). This technique was validated at Coleshill by comparing real flame measurements to those of model simulations of the flames (Fig. 11.13.1). Now models of both cross-fired and end-fired (horseshoe) tanks are used in investigations of natural gas and oil firing. New ideas may be tried on such models before going to more expensive experiments using actual burners or trials on melting tanks themselves.The model work indicated that a short flame was required with a high heat release in the early stages, and which will cause little additional recirculation of combustion products (4). Full scale tests indicated that twin hole nozzles with an included angle of 22° between the jets, operated at medium pressure (240mbar) gave the best compromise between complexity and reduced flame length (Fig. 11.13.2). This type of nozzle was applied on an actual glass tank with significant improvement in efficiency (5).

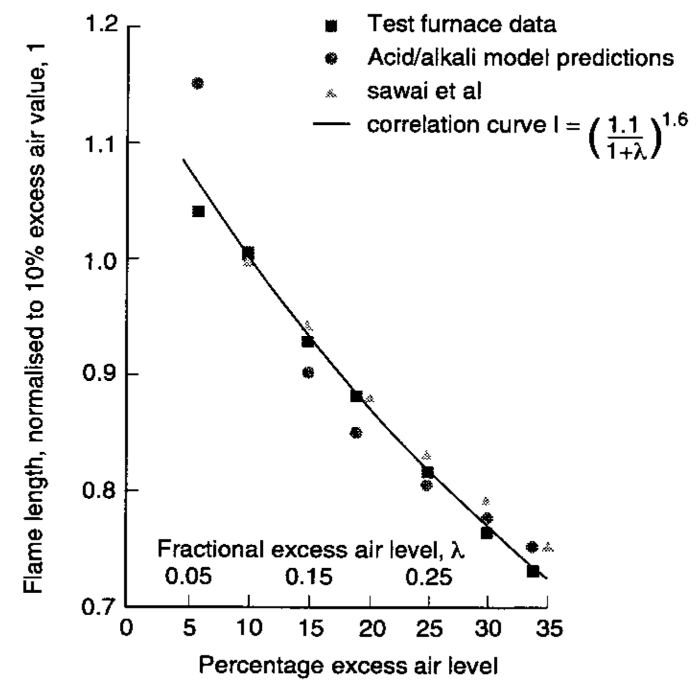

Fig. 11.13.1 Comparison of predicted and measured flame lengths.

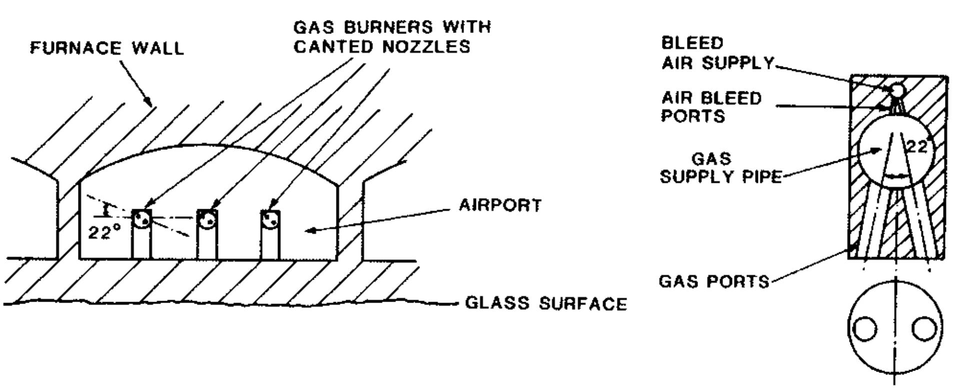

Fig. 11.13.2 Burner nozzle design and position in the air intake.

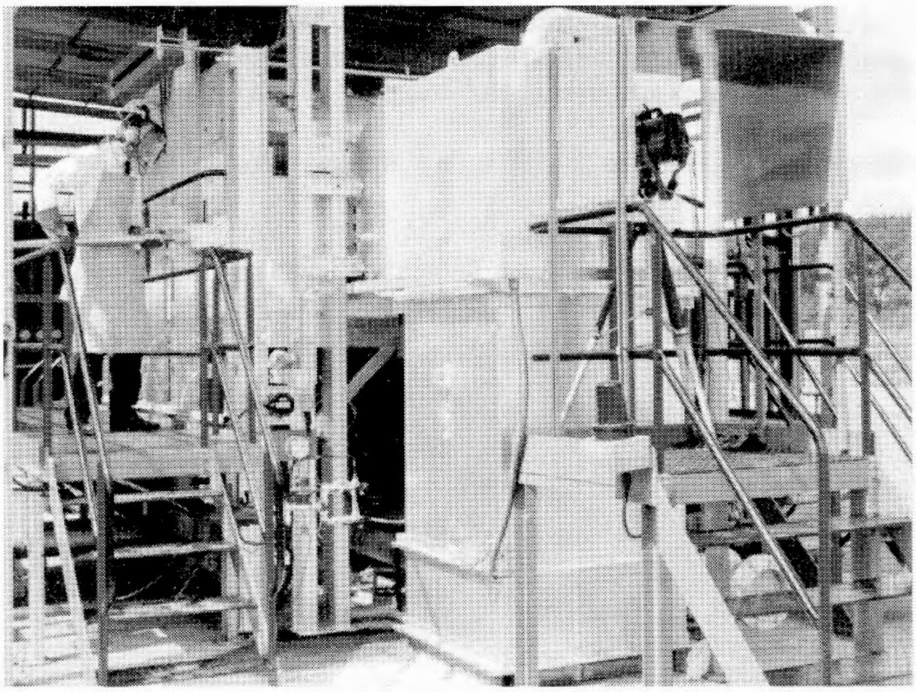

Fig. 11.13.3 Glass melting furnace at Coleshill.

More recently, a "hot" model of a glass melting furnace has been built (Fig. 11.13.3), at 40% scale, of a cross-fired glass melting furnace where experimental natural gas and fuel oil burners can be tested. This furnace is regenerative, simulating a real glass tank and operates at 1600° C using air preheated to 1200°C to attain this high furnace temperature. Experimental runs lasting three weeks of continuous operation allow extensive investigation of furnace performance and burner systems. The experimental data from such trials can be used to validate both ZONE and CFD models and this forms an integral part of the research programme. Such trials are used to prove the performance of burner systems under conditions closely paralleling those existing in a real glass melting furnace.

This particular project has led to a world-wide collaboration on the topic between British Gas and companies from the Continent of Europe and Japan.

Implementation and Benefits

Using all of these techniques it has been possible to offer support and advice to glass manufacturers to help burn natural gas more effectively and efficiently. To date a number of glass melting furnaces have been changed over to natural gas from HFO using techniques developed at MRS. Ultimately if all of the research work is successful better burner systems should become available which produce lower levels of pollutants such as NOx.

The expertise gained in the topic of physical and mathematical modelling on this project has been used on other combustion related studies. The availability of reliable experimental data for model validation proved useful for other CFD users at MRS.

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11.14 Total Energy and CHP

B. D. Mugridge

Background

Total Energy was a concept introduced in the early seventies in which gas constituted the only energy source for an industrial or commercial site, centred round a combined heat and power system. The idea was to expand the use of natural gas by using a gas fuelled prime mover to develop mechanical power, using the waste heat from the generator for process or space heating, supplemented where necessary by direct gas firing. In its most common form this power is used to generate electricity via an alternator or similar device. Fuel tariffs in the UK have never been such as to make it economically viable to use gas solely for electricity production The combined generation of electricity and heat, hence the term CHP, has therefore been the norm and research into this topic has been towards improving the efficiency and reliability of gas fired CHP systems and making available a wider range of prime movers.

Early examples of the Total Energy concept included a gas turbine system installed at John Players factory (1) and several large dual fuel reciprocating engines at National Westminster Bank in London. Both schemes used prime movers generating more than one Megawatt of electricity and MRS provided technical advice on the efficient use of these systems.

In the 70s marketing policies and tariffs were not particularly encouraging towards large scale power generation from gas. This limited the scope of any research in this area and meant a concentration on small scale systems, although a gas turbine based TE system was constructed,as a demonstration of the technology, to supply Darby and Brindley Buildings (2). During the 1980s the research carried out by MRS was therefore confined to small scale CHP, mainly small reciprocating gas engines, which could be used in the commercial market where gas tariffs compared more favourably with electricity. Typical applications for small scale CHP were swimming pools, hospitals and old peoples' homes where a 24 hour energy supply was needed.

Technical Approach

The MRS research was initially concentrated on evaluating the performance and reliability of automotive petrol engines converted to gas. In this context it helped produce effective air-fuel ratio controllers, investigated more reliable ignition systems and tested a range of different valve materials and designs which were less prone to the excessive wear on valves and valve seats that characterises the use of a 'dry' fuel. Using its dedicated engine test cell facility, a number of production petrol and diesel engines were successfully converted to gas firing. Cooperative projects with companies such as Leyland, Ford, Power Torque and Perkins enabled low cost engines to be made available for CHP applications (3).

Direct Drive

MRS pioneered the modern concept of using the prime mover shaft power for direct drive applications. Whilst having a smaller market potential, the system avoided the loss of efficiency associated with converting mechanical power to electricity. Early successes came with field trials of a direct drive reciprocating air compressor at a Birds Eye factory and a water pump drive in a local swimming pool (Fig. 11.14.1). In both cases heat recovery was used for process hot water. A major advance came with a joint project between MRS and CompAir BroomWade, a large manufacturer of industrial air compressors. This collaboration resulted in the design and production of a 40kW rotary compressed air package which was successfully used in the textile and chemical industries (4).

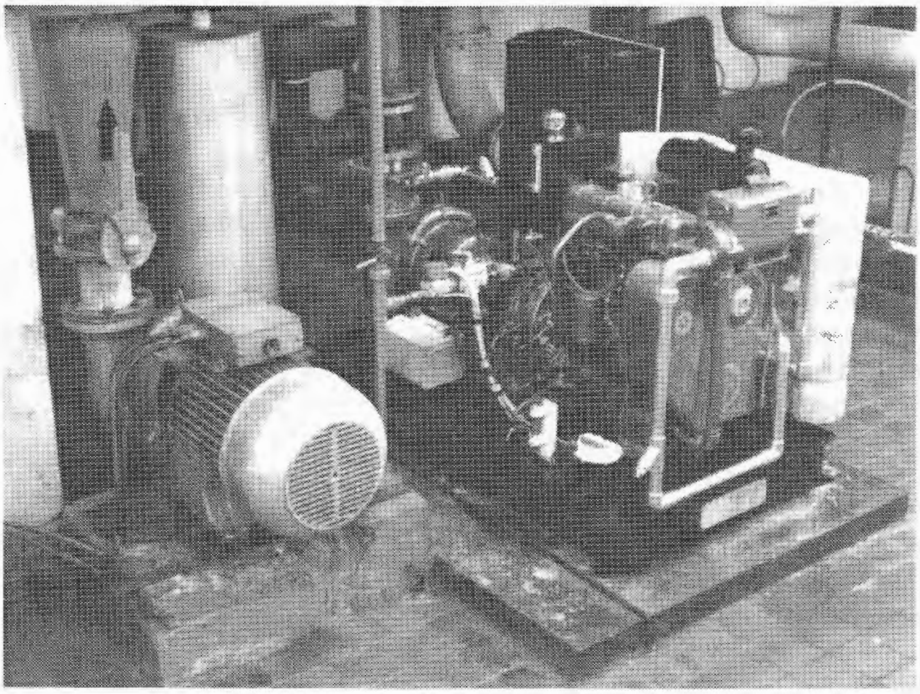

Fig. 11.14.1 Gas engine driving the main water pump at Tudor Grange Swimming Pool. Engine heat recovery heated the pool.

Co-Generation

Whilst direct drive systems opened up a new market, the main emphasis has always been in the use of engines for electricity generation. In the late 1980s a number of companies emerged specialising in the supply of small CHP systems for electricity and hot water production, sometimes called co-generation systems. These commercial packages invariably used engines which had been part of the earlier MRS research programme. MRS continued with its engine evaluation work (Fig. 11.14.2) providing basic support to the growing CHP market which was being fed by the output of these CHP equipment suppliers. However it also saw a need to help educate both the commercial world and British Gas sales and engineering staff on the value and application of CHP.

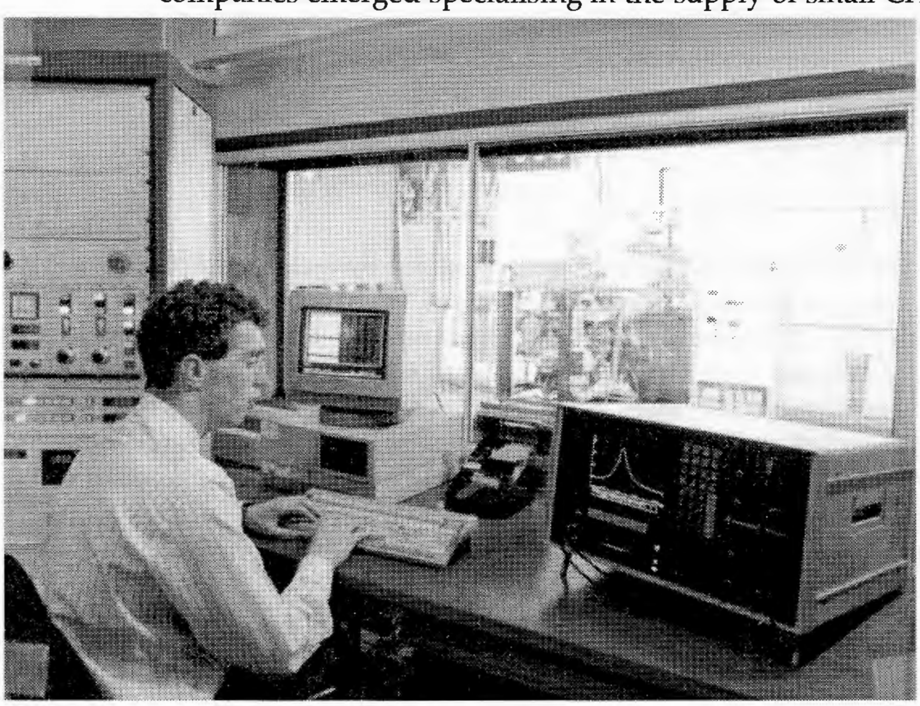

Fig. 11.14.2 Engine undergoing trials in the test cell at MRS.

A major effort of the MRS team was therefore devoted to this latter task and this technical advisory role continues today in the more active power generation market. Computer aided design spreadsheets now exist to help a customer to evaluate the merits of CHP for his company and to choose the best system for his energy requirements.

Current Position

The 1983 Energy Act removed all operational and institutional restrictions by the Electricity Boards to the use of CHP and enabled connections to, and use of, the grid for load balancing purposes. By 1990, it led to more than 350 small scale packaged systems (up to 150 kW) and 10 large scale gas turbine driven systems over 2 MW to be installed (5). Large scale CHP (Fig. 11.14.3) and Combined Cycle technology, where in the latter both gas and steam turbines are used to maximise electricity generation, are now firmly established in the market place mainly because of the improved performance and reliability of turbines and large reciprocating engines. At the smaller end, the full potential of CHP has still to be realised. The main drawbacks have been mechanical reliability and high capital costs. The MRS research programme attempted to address these problems through the development of more novel technology. This included work on both rotary and two stroke engines, neither of which use troublesome valve gear. Early failures of these engines under test undermined progress and both engines programmes were halted. However, the two stroke engine still offers considerable potential if the problem of methane slippage can be contained. Current efforts are directed towards the development of a British Gas design of small gas engine CHP package aimed at a lower capital cost.

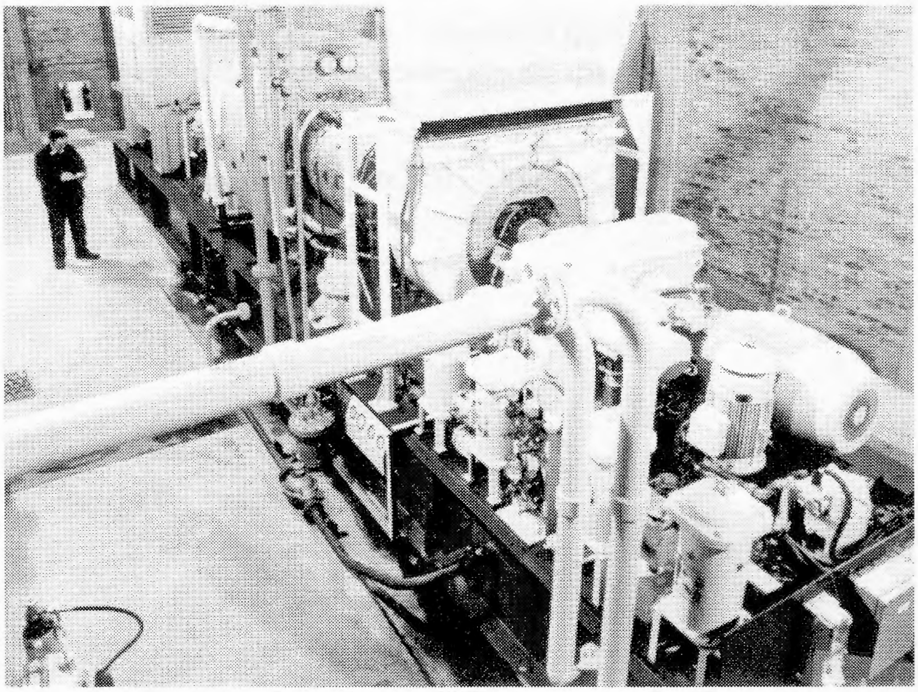
Fig. 11.14.3 Gas turbine driven CHP system at a distillery.

The research carried out over the years at MRS into gas engine development is likely to pay dividends in other areas of application. The commercial market for air conditioning is dominated by electric chillers but a current project on gas fired chillers using gas fuelled engines shows considerable promise. Gas engine technology will also make a considerable impact on the emerging market for natural gas vehicles.

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11.15 Heat Pumps and Air Conditioning

J.Chapman

Background

Air conditioning has only become a significant energy market in the UK over the past five to ten years, but during that time its growth has been rapid. Now the load is estimated to be the equivalent of about 1000 million therms of gas per year. A further attraction of the air conditioning market, which is of course currently dominated by electricity, is that it is mainly a Summer load.

The origins of the air conditioning research at MRS went back to the work of the Prime Movers Section led by Jeff Pearson. One of the uses to which a gas engine could be put was to drive a refrigeration compressor to produce chilling. Several early installations were carried out to investigate the technology, including one at MRS which provided cooling for the administration block (Fig. 11.15.1). This ran for seventeen years and demonstrated the technical feasibility of the approach (1).

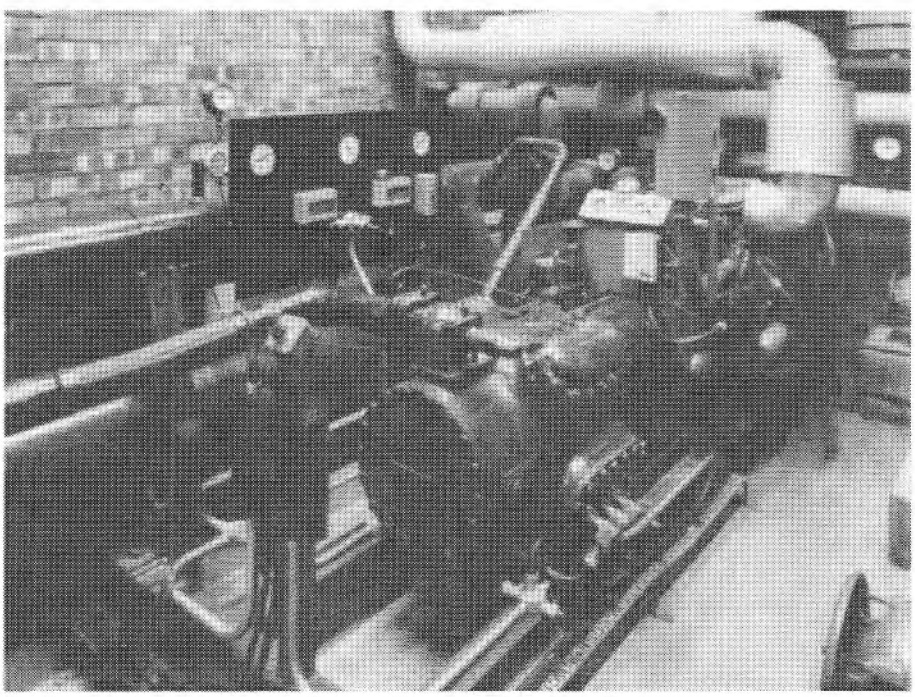

Fig. 11.15.1 The engine driven air conditioning plant serving Murdoch building.

At the time of this early work at MRS a gas engine without heat recovery could be cheaper to run than an electric motor because the latter incurred high maximum demand charges. Unfortunately this situation did not persist. Electricity tariffs changed and it became uneconomic to run a gas engine without using the heat that could be recovered from it.

Heat Pumps

The energy crises and consequent higher energy costs of the 1970s placed renewed emphasis on energy efficiency. This, coupled with the fact that the air conditioning market at that time was small, led to great interest in the opportunities for heat pumps. So in the late 70's and early 80's the focus of the engine driven vapour compression research moved away from chilling towards heat pumps for heating and heat recovery applications.

It was recognised that gas engine driven heat pumps offered two inherent advantages over the electric competition - heat recovery from the engine could be used to top-up the output of the machine, and the variable speed capability of the engine provided additional operating flexibility.

Opportunities were identified in certain industrial process applications where custom-built heat pumps would operate for high numbers of hours per year. MRS provided technical consultancy and performance monitoring expertise for a number of these including industrial applications in malt drying and textile dyeing, and also commercial applications in swimming pools (2). Several of these schemes received financial support from the Energy Technology Support Unit and an essential requirement of the grant was that full monitoring should be carried out to determine economic and technical performance. To do this MRS developed a data-logging system based around the Commodore PET microcomputer. Special attention was paid to achieving accurate measurements by the use of high specification instruments and good measurement practice.

Probably the most successful installation was that at the Louth maltings of Associated British Maltsters. This system which comprised a heat recovery run-around coil together with a gas engine heat pump and kiln microprocessor controller, became fully operational in March 1981. Monitoring showed that it's capital cost of £426,500 would be recovered by the energy savings in a payback period of 3.7 years and this installation did in fact go on to complete many years of useful service.

Space Heating Field Trial

Space heating of commercial and industrial buildings was also seen as a potential market. Here mass produced standard packages were thought to have prospects for success, provided that capital costs could be kept low. To explore this opportunity BG undertook a field trial programme to obtain information and assist in the formulation of a marketing policy.

This exercise was probably the largest field trial programme ever organised by MRS (3). It involved eight installations, each in BG premises and each within a different BG Region. Five manufacturers were involved and each of the eight units was different. This enabled a wide range of engines, compressors control systems, and heat pump configurations to be included in the field trial matrix.

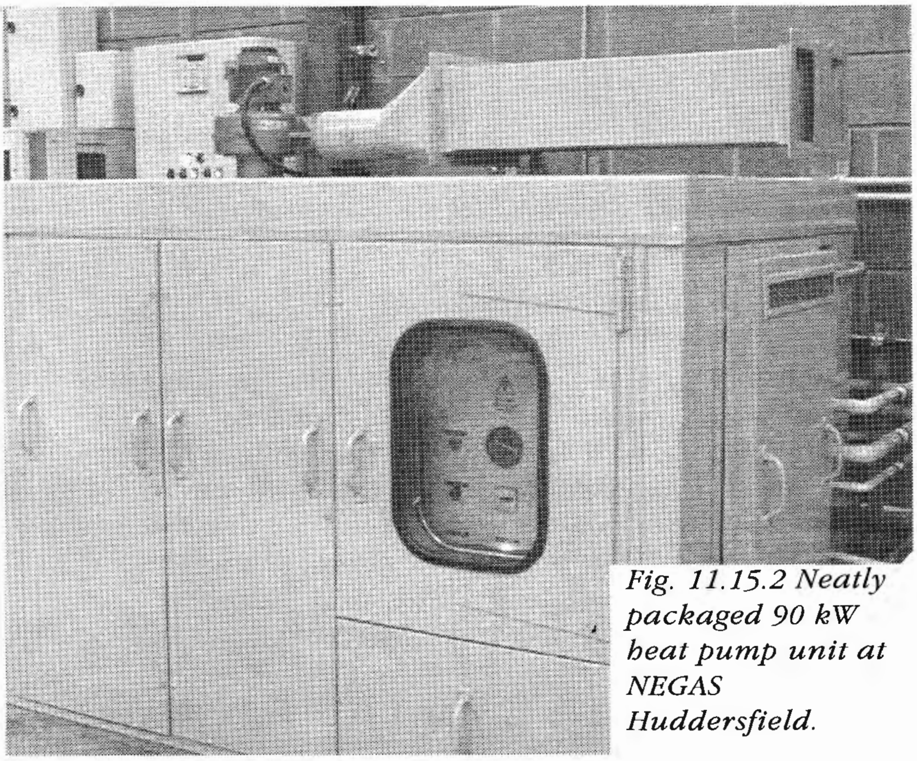

Fig. 11.15.2 Neatly packaged 90 kW heat pump unit at NEGAS Huddersfield.

The first heat pump, which was at Huddersfield, commenced operation in 1983. The heat pumps and the buildings were extensively monitored for two heating seasons producing a comprehensive volume of information covering the detailed operation and performance of each site together with full details of the monitoring and data analysis systems employed. The machine at Huddersfield (Fig. 11.15.2) was still in service at the time of writing.

The programme concluded that reliable, high performance packages could be produced provided that attention was given to design and to development testing, but that such units were not yet commercially available and a marketing effort was therefore not justified. By this time the air conditioning market in the UK was beginning to grow and the decision was taken to develop a chiller/heater.

Chiller-Heater Development

The knowledge gathered during the heat pump field trial proved invaluable in the development that followed. Now at the time of writing, two models of gas engine chiller heater have completed laboratory testing and are being installed on field trials. These designs, both producing 20TR (70 kW chilling), incorporate some of the more successful heat pump technology seen in the earlier trials, particularly in the use of a rotary sliding vane compressor in preference to reciprocating types (4).

Absorption Chillers

In the past five years, the emphasis placed on environmental issues has given a spur to research on clean air conditioning technologies. Conventional chillers use the CFC refrigerants that are responsible for depleting the atmospheric ozone layer. Furthermore they are driven by electricity whose generation in coal-fired power stations produces the greenhouse gas carbon dioxide together with the sulphur dioxide and nitrogen oxides which cause acid rain.

One available solution to this problem is the gas-fired absorption chiller which does not use the environmentally damaging CFC refrigerants at all. Over the last two decades efficient, "double effect" absorption chillers have been developed extensively in Japan. During the mid-1980's several of these units were installed by MRS in BG premises, which included our own administration building at MRS, in order to determine capital cost, performance and operating characteristics at first hand.

It was found that high capital cost was a barrier to selling these units. The manufacturers' claimed coefficient of performance of 0.95 could be achieved provided care was taken in the design of the installation, particularly over providing sufficient cooling water at a low enough temperature. Subsequently this was found to be quite a problem in the UK where many customers do not wish to use wet cooling towers because of the Legionella hazard. The use of air blast dry coolers, possibly with spray assistance on hot summer days, is one of the topics in the current research programme on absorption chillers.

Building Energy Modelling

Traditional rule-of-thumb methods of assessing the chilling and heating requirements of buildings tend to overestimate the maximum load and so the plant is often oversized by a large margin. Work in the mid-80's applied advanced building energy models, which rigorously simulate the dynamic energy flows in buildings, to various buildings in order to investigate the optimisation of plant sizing (5).

The administration building at MRS once more became a test bed for new technology. Using a dynamic building energy model the maximum chiller requirement was obtained. Then by running the model with chillers of lower capacity the effect of not meeting the maximum load could be estimated. It was predicted that if the chiller were undersized by 20% then on the hottest day of the year the building temperature would be a mere 0.3°C above the set point. Such a unit was installed and has operated successfully for four years with good client satisfaction.

The work advanced to the point where the expertise and dynamic modelling facilities based at MRS are offered to customers through the Technical Consultancy Service departments in BG Regions. Another important output of the work was the Energy Audit software package which was produced in collaboration with BG North Western. This PC software simulates dynamic conditions and is designed for use by TCS departments and Regional engineers for application to smaller, more straightforward buildings.

Dessicant Dehumidifiers

An important development in air conditioning has been the joint work with Munters Limited on a gas fired desiccant dehumidifier. This development began in about 1987 with laboratory work to convert Munters existing products to gas firing (Fig. 11.15.3). Humidity is usually only considered a secondary parameter in the comfort conditioning of humans but for industrial products in storage it is of prime importance. Successful field trials in areas as diverse as curling rinks, pop corn manufacture, swimming pools and the National Film Archive have demonstrated the usefulness of this development.

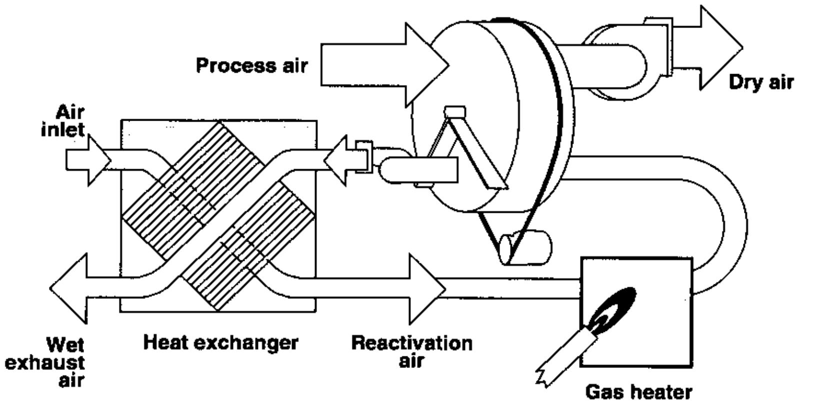

Fig. 11.15.3 Schematic of dessicant wheel with heat recovery.

In today's research programme, desiccants are seen as having the potential to offer clean, low cost air conditioning (6). They take an important place place in the programme alongside gas engine chiller heaters, absorption chillers and building energy modelling. There is no doubt that the modern concern with the protection of our environment has given an important impetus to our work and a promising future in a large market is foreseen.

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Chapter 12

Controls and Instrumentation

12.1 Suction Pyrometers

R.A.Hancock

Background

The accurate measurement of gas stream temperature particularly flue-gas temperature, is crucial to heat balance calculations and efficiency measurement on both industrial and process plant. In the mid fifties it was recognised that the work of Industrial Gas Engineers, Appliance Manufactures, and Research Laboratories was handicapped by the lack of a suitable instrument and this problem was addressed by Peter Atkinson and his colleagues.

Any type of thermometer measures only its own temperature and this is determined by the conditions in which it is being used. A simple thermocouple inserted into a gas stream, for example, will indicate a temperature dependent upon both the gas temperature and, because of radiation effects, on that of the surroundings. If these two temperatures are significantly different large errors can occur in the measurement of gas stream temperature using such a sensor. It was known that the use of a suction pyrometer, in which the gas is drawn rapidly across a thermocouple housed within a tube, could reduce such errors by virtue of the increased convective heat transfer between the gas and the thermocouple and by the radiation shielding provided by the tube.

Suction pyrometers available at the time were large water cooled devices quite unsuitable for use in small scale town gas fired plants.

Technical Approach

Peter Atkinson's work led first to the development of a compact metal suction pyrometer aimed at providing accurate measurement of gas stream temperature and suitable for use up to 1100°C (1). This instrument used a chromel-alumel thermocouple within a 1/4 inch stainless steel shield (Fig.12.1.1).

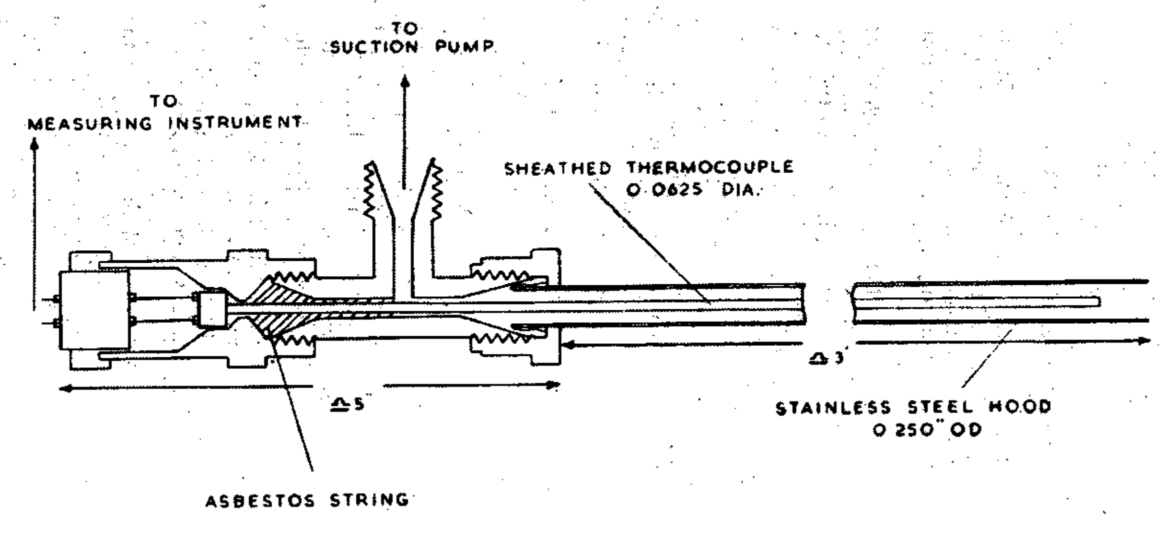

Fig. 12.1.1 Diagram of the metal suction pyrometer.

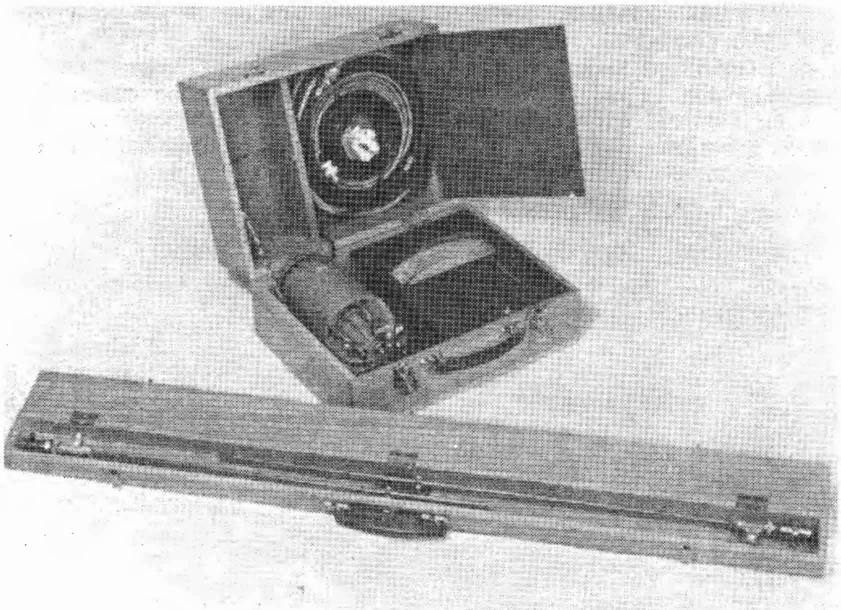

Fig. 12.1.2 The Atkinson metal suction pyrometer.

The complete pyrometer (Fig. 12.1.2) consisted of a probe assembly and an instrument case containing a moving-coil temperature indicator and suction pump. For ease of carrying the case also housed the connecting leads and suction hose. In order to compensate for the residual error mentioned above, the unit had a facility to take temperature measurements under suction and no-suction conditions. This allowed the "Efficiency" of the pyrometer to be determined and an accurate measure of gas temperature to be obtained by a simple calculation or reference to a chart. The complete unit provided an extremely portable and convenient instrument which was later produced commercially and used widely.

Vital to the success of this development was a laboratory test rig in which prototype and later production pyrometers were calibrated. A heated hood suction pyrometer allowed the true temperature of gas streams up to 1600°C to be determined. This design consisted of an alumina sheathed Platinum/Platinum-Rhodium thermocouple mounted within an alumina tube which was wound with a platinum heating element to form the hood. By taking readings with and without suction and adjusting the hood temperature by altering its heater current, so that there was no change in thermocouple reading between these conditions, the true gas temperature was indicated.

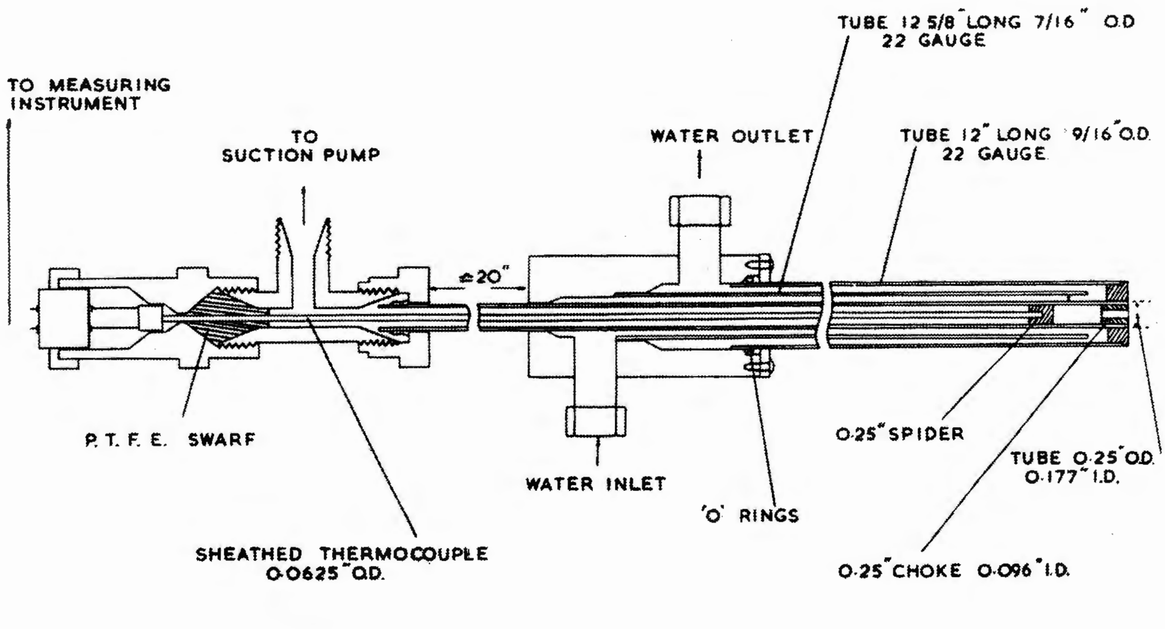

Fig. 12.1..3 The water cooled suction pyrometer.

During the development programme very many measurements were made over a wide range of gas stream temperatures in order to optimise and verify the design of the pyrometer.

As indicated above, the metal pyrometer was suitable for use up to 1100°C. In order to allow higher temperatures to be measured on industrial plant a water cooled pyrometer (2) was developed as an accessory to the portable suction pyrometer set (Fig. 12.1.3). The water cooled pyrometer had an outside diameter of only 9/16in and, like the uncooled version, used a chromel-alumel thermocouple. The key to this design lay in the way the thermocouple was mounted within the suction tube. Hot gases were drawn in through a small orifice and cooled before impinging on the thermocouple tip. Thus with a gas temperature of, say, 1300°C, the thermocouple indicated around 800°C.

Each water-cooled pyrometer was calibrated in the test-rig up to a temperature of approximately 1600°C, the "trimming" of the calibration being achieved by adjusting the location of the thermocouple. The instrument was suitable for measuring gas stream temperatures up to 1800°C.

Commercial Implementation

In the early days of the Atkinson Suction Pyrometer all the "Production" units were manufactured in the instrument laboratory at MRS, the boxes, suction pumps and other material being bought-in. Later the units were manufactured by the Industrial Pyrometer Company although calibration of the water-cooled pyrometers continued to be carried out at MRS. This led to refinement of the calibration rig so that the temperature of the hot gas stream could be measured both with a heated-hood probe and also by Sodium D-line reversal using a tungsten lamp source. This combination allowed accurate temperature-measurement up to stoichiometric flame temperature.

The water-cooled pyrometers were also produced commercially and used widely in research studies.

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12.2 Ignition, Safety Shut-off Valves and Control Units

R.A.Hancock

Background

In the late fifties there was an increasing need for the automatic control of industrial burners both to give the customer the advantages of "Push button control" and to allow burner systems to be readily integrated into automated processes. This led to R&D into burner control which was initially directed at the automatic control of air-blast tunnel burners.

Initially burners were fitted with commercially available flame-detectors, glow-plug or high-tension spark ignition, electrically operated solenoid gas valves and automatic supervision was provided by a programming burner control unit. Early work at MRS was concentrated upon achieving safe and reliable ignition and operation. This led to studies aimed at achieving a more thorough understanding of the necessary design parameters for the control equipment. For example the required spectral and frequency response of flame detectors, the spark energy required for ignition and the characteristics required of electrically operated valves in order for them to be reliable in operation (1).

Ignition

The ignition energy requirements of gas/air mixtures was studied using an electrically charged capacitor/inductor-bank as an energy source and determining the power dissipated in the ignition-spark by the measurement of current and voltage transients with a high speed oscilloscope. Happily it was established that practical ignition sources, such as mains driven HT transformers generated more than sufficient energy to give reliable burner ignition, typical spark-energies being an order of magnitude greater than the minimum required.

A practical ignition system for tunnel burners was provided by a mains driven HT transformer and spark plug with connections suitable for rugged industrial service and safe operation in the presence of a potentially lethal 10kV. A lot of work was carried out to determine the optimum positioning of the spark plug on the mixture tube of the burner to ensure that the initial flame was swept forward and stabilised in the normal place in the tunnel (1). Also in 1967, an electronic ignition system was described by Atkinson and Arnold, using automotive ignition coils, which was particularly suited to multiple burner systems (2).

Flame detectors based on infra-red flicker from flames were in use, but the frequency response was not optimum for tunnel burners. Measurement of the cell output from practical burners showed the optimum detector response should be 70-90 Hz.

An air blast burner fitted with a "zero governor" on the gas supply and a suitable throughput control valve on the air side had an inherent self-proportioning action, the air/gas ratio remaining reasonably constant over the turndown range of the burner. Thus with the addition of spark ignition and flame detection, an automatic system was available and there were very many installations for a wide range of applications during the late 50s and early 60s.

Citeria for safe ignition

The ignition phase of burner start-up is critically important to reliable and safe operation, consequently the subject received extensive study over a number of years and particularly at the time when natural gas was being introduced (3)(4). During a burner light-up sequence the ignition source is energised, gas flow commences, builds-up and after a short interval ignites. If it doesn't, action is taken to shut off the gas supply. Research aimed at establishing criteria for smooth and safe ignition was directed at determining the effect of ignition delay. Studies were undertaken in a pressure vessel of approximately 0.14cu.m. in volume, in which a "pocket" of stoichiometic mixture contained in a balloon was ignited and the pressure rise measured. This experiment paralleled the situation within a plant combustion chamber in which the delayed ignition of accumulated mixture might occur. The results confirmed a relationship between pressure rise and energy release per unit volume of chamber which formed the basis of the "energy release criterion" in the Standards for Automatic Burners referred to later.

An alternative approach to achieving safe ignition suited to nozzle mixing burners was also studied. In this case the rate of gas flow into the burner, relative to the combustion air flow, was limited so that the bulk mixture was below the lower limit of flammability although a zone of combustible mixture existed in the vicinity of the burner nozzle. This approach became known as the "dilution criterion" and was also included in the Standards which, when the criterion was first introduced, limited the start-gas rate at ignition to 10% of the stoichiometric gas rate for the proved air flow.

Subsequent operational experience using the dilution criterion suggested that it might be possible to relax the limits without reducing safety. A re-examination of the approach was therefore undertaken using an experimental arrangement designed to explore the limits of safety under simulated but realistic plant conditions. The investigations took the form of delayed ignition experiments performed under the most unfavourable conditions likely to be encountered in practice. Associated theoretical work was also carried out.

Laboratory experiments were undertaken both with commercially available burners of 60kW and 470kW rating and with a range of burner heads purposely designed to give poor mixing. In order to ascertain the influence of combustion intensity and chamber shape, the burners were fired into cylindrical "fire-tubes"' of different dimensions and also into a box-shaped chamber with vertical flue exit. A common feature of the fire tubes was an explosion-relief end-wall so that the consequences of delayed ignition could be studied in safety. The experimental work included the determination of the "critical concentration" i.e. the gas/air ratio above which delayed ignition resulted in significant pressure rise, and also, for various flammable mixture ratios, the ignition-delay that could be tolerated. In addition the effects of venting, firing intensity, scale, throughput, burner mixing characteristics, temperature and fuel-gas type were studied.

Large scale experiments were also undertaken in an Ignition test Furnace at the Coleshill Laboratory that could accommodate burners up to 30MW heat release. The test furnace was approximately 9m long, 2.5m high and 3m wide at its roof, which comprised a lightweight explosion relief. The burner used for the test programme was a proprietary multi-nozzle register-type burner of 30MW rating. Experiments over this wide range of burner and combustion chamber size led to revision of the "dilution criterion" in Industry Standards and it was later included in British Standard BS 5885. On one occasion the inherent safety of this approach was most impressively demonstrated to a group of overseas visitors visiting Coleshill. The visitors, members of a European

Standards Committee and familiar with burner design and operation, showed some signs of alarm when told that un-ignited gas had been flowing through a large 'power-station' type burner for several minutes and that it was about to be ignited. The burner lit up smoothly!!!

Safety Shut-off Valves

Early work on electrically operated gas valves correlated the closing force of valves with their likelihood of failure, evidenced by the valve sticking-open or letting-by. Subsequent standards, described later, included a requirement that valves should close "with sufficient closing force as to ensure tight shut-off under operating conditions" as well as other essential characteristics.

In the early 60s, a large number of commercial solenoid and other valve types were examined to determine the forces available to keep the valves closed and the maximum forward pressure against which they were capable of opening (5). Closing force was easily measured by the reverse pressure to cause leakage. As a result of this work, new criteria for SSOVs were suggested which were subsequently embodied in the "Standards for Automatic Burners". Many of the existing larger sizes clearly could not meet them, but manufacturers quickly cooperated in developing new designs of solenoid, electro-hydraulic and electro-mechanical actuated valves with much improved performance.

Even though such valves could be well designed and thoroughly tested it was recognised that there remained a small chance of mal-operation and studies were made of valve systems designed to avoid the consequences of failure of a single valve.

Multiple valve systems ranged from simply installing two valves in series, through double-block and vent configurations to systems comprising double-block valves with automatic leak-testing equipment. A system was developed at MRS which relied upon the creation and monitoring of a partial vacuum between two closed valves in series in the gas line (6). Other systems relied upon pressuring the space between the valves. Prior to about 1968 the general practice had been to rely upon a single valve but the consequences of failure, coupled with the development of reliable "valve-proving" systems, led to the wider use of multiple valve shut-off systems and their being specified in Codes and Standards.

Control Units

The design of burner control units was also the subject of fundamental study in 1966/67. Consideration of the actions of a skilled operator controlling a manual burner enabled the functional requirements of an automatic burner control unit to be defined for the first time in terms of logical propositions (7). Boolean analysis was then used to design burner logic for on/off and modulating burners which was suitable for implementation in electromechanical, solid-state or fluidic logic. The engineering aspects of electromechanical and solid state control unit design were also addressed and basic design principles were established that have continued to influence practice to the present day.

An essential feature of the work on burner control was the emphasis on safety, including safety under fault conditions. Throughout the sixties and early seventies burner control units almost invariably employed electromechanical logic and timing and such equipment could readily be designed to respond safely to component failure. Furthermore, analysis of system safety was relatively straight forward.

The advent of electronic and microelectronic systems introduced both new opportunities for providing advanced burner control and also a new challenge as regards fail-safe design of both hardware and software. Techniques for fail-safe design were investigated, developed and patented. A prototype microelectronic burner control unit was developed at MRS which embodied many safety features and was arguably the first of its kind in the world. This led to the development and commercialisation of a microprocessor-based control system for application to multiple dual fuel installations. Advanced test techniques for checking microprocessor-based burner controls for the effects of software corruption were also developed.

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12.3 Standards for Automatic Burners

R.A.Hancock

Background

In the early 60s automatic gas burners were being introduced by manufacturers of packaged oil burners, some of them unused to gas utilisation practice. Later, the supply of gas from high pressure gasification processes and the availability of large quantities of natural gas enabled the gas-industry to expand into new markets. Manufacturers of oil and coal burning equipment entered the industry supplying gas systems to fuel users unaccustomed to burning gas. Guidance on safety requirements for automatic burners was urgently needed at this time.

Research on the performance of safety shut of valves, ignition criteria and control logic had been carried out at MRS and provided the basis for The Gas Council to take an initiative in publishing, in July 1966, " Standards for Automatic Gas Burners", which specified fundamental requirements for safe burner design. Its content was based upon experience with the design of automatic burner systems, including that gained at MRS, and took account of practice in other European countries and North America.

Technical Specifications

The characteristics specified included a proved air purge to clear the combustion space of any flammables prior to ignition, the provision of efficient flame detection and performance requirements for safety shut off valves.

A critical phase of burner start-up was recognised as being the interval between gas being admitted to the burner and the instant when satisfactory ignition of a pilot flame (or main flame at low rate) is detected by the flame detector. A feature of the Standard was the inclusion of an energy release criterion such that if a delayed ignition occurred during this period then the resulting pressure rise within the combustion chamber would be insufficient to cause damage. This criterion was based on the release of no more than 2 Btu per cu. ft. of combustion chamber volume, which had been shown to produce a maximum pressure rise of about 2 psi, a pressure which was known to be unlikely to cause serious damage to an appliance. Emphasis was also placed upon the need to ensure rapid and smooth ignition of a main flame from a pilot flame.

The publication of "Standards for Automatic Gas Burners" established a bench-mark for the design of burner systems at a time of very rapid expansion of the Industry and demand was such that it was reprinted in 1968.

In 1970, with advancing knowledge arising from continuing studies, the Standards were revised and a second edition published. This work was undertaken in collaboration with equipment manufacturers and agreed jointly by the Gas Council and the Society of British Gas Industries.

This second edition included two important areas of change which related to the requirements for safety shut-off valves and to the criteria for energy release at start-up. The safety shut-off valve specification was modified so as to remove some constraints on operating-times. In addition, a requirement for two valves to be used in series for burners larger than 600kW, introduced shortly before as an amendment to the First Edition, was strengthened with a reminder that in some circumstances, for example because of large thermal input or location, a multiple valve system should be installed, preferably in a self-checking system or in a double-block and vent configuration.

At the ignition phase of the burner the energy-release options were also increased with the introduction of the "Dilution Criterion" in addition to the previous "Energy Release Criterion". This allowed a start-gas rate not exceeding 10% of the proved air-flow at the time of ignition (1). This criterion was especially applicable to nozzle mixing burners, which, following the widespread introduction of Natural Gas, were much more widely used than pre-mix burner types.

A Third Edition was published in 1977. This took into account further field experience, advances in technology and new research into burner ignition undertaken at MRS. The scope of the document included burners from 60kW to 2MW thermal rating and it represented the agreed requirements of British Gas, the SBGI and the British Combustion Equipment Manufacturers Association. This had a much more complete specification of valving requirements, namely two valves in series (One Class 1 and one Class 2) for burners in the range 60-600kW and two Class 1 valves in series in the range 600kW to 1MW. For burners between 1 and 2MW, two Class 1 valves with a "System-check" was specified, the checking system being achieved using either switches on the valves to confirm closure prior to start-up or a pressure-proving system to verify the leak-tightness automatically.

In the light of MRS research into burner ignition, the permitted gas rates at start-up were also increased, namely, for Natural Gas, to 25% of the stoichiometric gas rate corresponding to the proved air flow. The third edition also dealt more comprehensively with other aspects of burner design such as purging, the gas-flow controls and electrical equipment. It also introduced guidance relating to air/gas ratio control on high/low and modulating burners and on the performance of self-checking flame safeguards where a burner may be firing continuously for long periods.

The fundamental criteria and safe design features embodied in the "Standards for Automatic Gas Burners" later formed the basis of a British Standard, BS 5885 and more recently have influenced the formulation of a draft European Standard for Gas Burners which, if agreed, will be adopted in all the countries of the EC.

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12.4 Testing and Certification of Controls

R.A.Hancock

Background

In order to encourage the development and use of safe and reliable control equipment on Industrial and Large Commercial plant, a Testing and Certification scheme for electrically operated safety shut-off valves and burner control units was established in 1968. The scheme was introduced to give recognition to those manufacturers whose equipment complied with tests designed to assess conformity with the Gas Council's Standard for Automatic Gas Burners. When equipment passed the tests, the manufacturer was issued with a Certificate and the equipment included in a Certificated Equipment List, published twice yearly. The list grew over the years and became in effect a "Buyers guide" used both by burner and equipment manufacturers and by British Gas Engineers in selecting and recommending components or when undertaking safety-surveys of customer's plant. The scheme has continued to the time of writing with periodic revisions to take account of the introduction of new British, and latterly European Standards.

The equipment falling within the scope of the Certification Scheme comprised the two most important safety-related controls associated with automatic burner operation, namely the safety shut-off valves and the Burner control unit with its associated flame monitor.

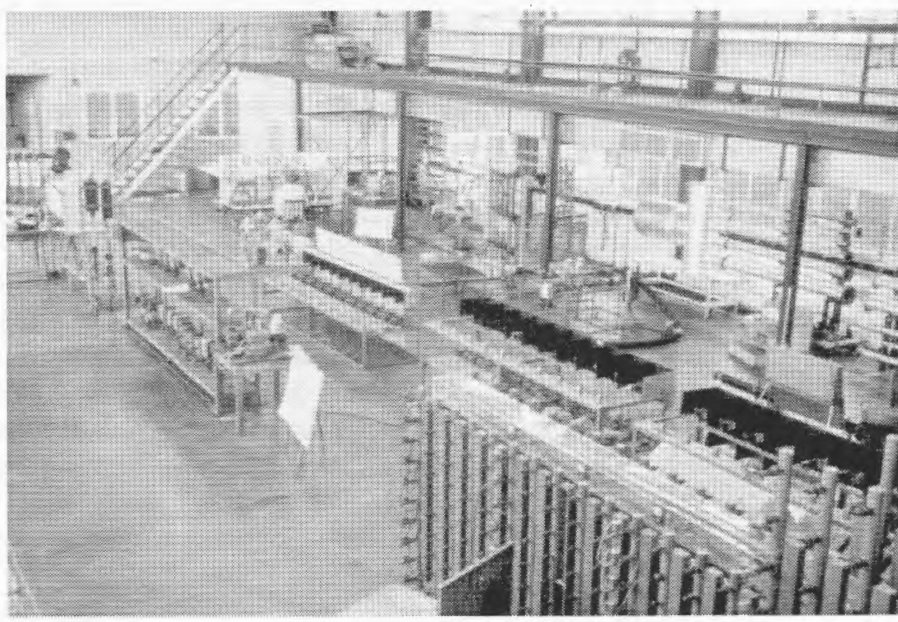
Tests on Safety Shut -off Valves

The actual tests carried out on safety shut-off valves, and the number of test samples examined, were dependent upon the valve type but fell broadly into four areas, an examination of mechanical and electrical construction, performance, flow tests, including where appropriate measurement of opening and closing characteristics, and a life test. Purpose built rigs were used to measure the ability of the valve to open and close correctly under the appropriate range of pipeline pressures with the valve mounted in whatever orientation the manufacturer's instructions allowed and when operated over its range of electrical supply voltages. These tests included tests for gas-tightness with the sample in its closed position, tests for any external leakage and a measure of the ability of the valve to remain closed when subject to reverse pipeline pressures. The propensity to subtle causes of failure such as magnetic hysteresis were also examined. Flow capacity measurements were also made on all valves and in the case of slow opening valves, and valves incorporating high/low or proportioning action, the opening and closing characteristics were determined. For this purpose there was a flow rig driven from a bank of axial-flow fans which could deliver around 100000 ft3/h of air at about 20in. w.g., flow measurements being made initially with orifice plates and later with hot-wire flow meters. When necessary, higher pressures could be obtained from a large centrifugal blower also connected to the rig's plenum chamber.

An important part of the test programme was the life test in which a sample comprising a number of valves were cycled on/off, or, for high/low valves through a more varied cycle, for an extended period (Fig. 12.4.1). The number of samples tested, and the duration of the test was dependent upon valve-type and the prevailing standards. For example, for many years, the test applied to small fast-acting solenoid valves required a sample of 10 valves to be tested to 1 million operations. For larger motorised valves the test required 3 samples to be cycled to 250000 operations.

Valves tested under the scheme ranged in size from 6mm (1/8in.) to 150mm (6in.) and these generally had either a solenoid or electrohydraulic actuator. Over the years more complex designs emerged which combined pressure-control or air/gas ratio control functions within the valve assembly. The safety-implications of these various additional features were addressed during the test programme and the performance of these functions checked against the manufacturers declared data.

Fig. 12.4.1 General view of Certification test area in Brindley Building, solenoid valve and other life test rigs in the foreground.



Tests on Burner Control Units

Burner control units were, in the early days, generally of straight-forward electromechanical design which allowed the logic to be readily assessed and the performance tested.

The test programme for control units comprised a study of the circuit-logic, an examination of mechanical and electrical construction, measurement of the unit's operating sequence and timings and a life test (Fig. 12.4.2).

Fig. 12.4.2 Control units on life test.

For the latter, a sample of three units were set-up on a rig where they each controlled a small gas burner and on which the terminal loadings of the unit could be set to specified values of current and power-factor by additional inductive and resistive loads. The life test comprised 100000 operating cycles with regular checking of the safety-lock-out function of the unit. The test required that no mechanical or electrical failure should occur up to the first 25000 operations and that thereafter no failure likely to cause a dangerous situation should occur.

The flame detector associated with the burner control unit forms an important element of the burner control system. These detectors were generally either of the flame-rectification (ionisation), ultra-violet radiation or infrared radiation types and some, intended for burners firing continuously for long periods, had built-in self-checking features. The examination of flame-detectors included an assessment both of the performance and the extent to which the unit design was fail-safe.

The technology of control unit design is one that has seen significant changes over the years, moving from electromechanical logic to complex microelectronic designs. Those units currently using electromechanical logic have become very much more compact, using printed circuit and surface-mounted technology. To address the challenge of adequately testing these more complex designs, especially microprocessor-based units, specialised test methods were developed at MRS. Of particular importance was the development of an EPROM Emulation technique REMUS which allowed the effect of software corruption within microprocessor-based units to be investigated.

The Results of Testing

Experience over the years has shown life testing to be very searching and a wide variety of design deficiencies have been revealed and rectified as a consequence. Whilst some items have sailed through the test programme others have been modified and re-submitted several times before the required performance has been achieved.

In the early days the tests exposed many weaknesses. For example, of the first 30 samples of solenoid valves in the range 1/8 to 1in BSP submitted, only seven proved satisfactory. Failures were due to both design faults and to poor quality control.

The contribution that the testing scheme has made to the availability in the UK of safe and reliable control equipment is indicated by the number of items currently listed, over 2000 from more than 30 manufacturers, and by the good safety record achieved in the field. Whilst manufacturers have hardly been pleased when equipment has failed the tests, many have expressed appreciation at the final outcome, conscious that field problems, sometimes of a potentially serious nature, have been avoided.

Monitoring the Scheme

Throughout the operation of the scheme there has been an element of evaluation and investigative experimental work although latterly this has diminished as test requirements have become more closely specified within British and European Standards. Because of this element of assessment and engineering judgement there has been since the inception of the scheme, a Certification Advisory Panel (CAP) consisting of engineers from Headquarters, Watson House, The Regions as well as from MRS. The main role of CAP was to adjudicate on the issue of certificates on the basis of test results and taking account of relevant field experience. It also advised and agreed on any special tests or conditions of Certification that were deemed necessary. In performing its role the Panel also provided an element of "Quality Auditing" of the testing scheme.

Feedback on the safety and reliability of equipment in the field was provided through a Defect Reporting and Investigation Scheme also operated from MRS. Failures of certificated equipment and unsafe incidents such as explosions within industrial plant were reported by Regional Engineers to MRS where the results were collated. Where appropriate such failures and incidents were investigated in detail by MRS staff, both on-site and in the laboratory, and such investigations provided both insight into failure-modes of equipment as well as data aimed at avoiding a recurrence of specific incidents or required for litigation.

Data from the Defect Reporting Scheme allowed the overall safety record of industrial and commercial plant to be monitored and enabled any areas of weakness in either equipment design or operating procedure to be identified and addressed. Such information contributed to the formulation of standards and to the testing of equipment as indicated above.

The Future

At the time of writing this account the whole subject of testing and certification is under review as a consequence of the introduction of European Directives. These will lead to European-wide certification and the issue of "CE" marks by government appointed "Notified Bodies". In order that the test laboratory at MRS should have the necessary credentials to be able to participate in this activity, it sought, and was granted, accreditation by NAMAS, The National Measurement and Accreditation Service of the DTI. This necessitated a more clear separation of the testing activity from the research function at MRS and the introduction of a formal Quality Management System including calibration and traceability of measurement standards.

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12.5 Codes of Practice for Large Burners

P.Spittle

Background

The period from about 1969 to 1974 saw an enormous growth in the use of gas in industry, increasing from less than 2000 million to over 7000 million therms/annum, and corresponding to the introduction of North Sea natural gas. This period also saw a large increase in the range of plant fired by gas, to include shell and water tube boilers, cement kilns, glass tanks and other large high temperature furnaces. The thermal ratings of individual burners also grew dramatically from about 1-2MW to, in some cases, more than 60MW.

The attention given to safety by both the equipment manufacturers and the gas supply side of the industry has always been paramount. During this period of rapid growth, safety was given added emphasis by an element of enlightened self interest, in that the large quantities of gas from the offshore producers was taken on a take-or-pay basis and the then Gas Council could not allow the industrial equivalent of a Ronan Point to hinder its marketing activities.

It was against this background that in 1970 the Gas Council published the first part of the Interim Code of Practice for Large Gas and Dual Fuel Burners (1), in order to give guidance to its customers, its own engineers and equipment suppliers, in what were then new fields of application. This was followed over the next 18 months by parts 2, 3 and 4 so that eventually single and multiple burner dual fuel installations were all covered.

Scope of the Codes

The scope of the documents covered low temperature plant (with a normal operating temperature insufficient to re-ignite the fuel, taken as 750°C) and included individual burners greater than 3MW and multiple burner installations with a total thermal rating over 3MW. Guidance was given on fuel supplies, combustion air supplies, flame detection, purging, safety shut-off systems and fuel/air ratio control. Another important section covered the allowable energy release during the critical pilot or start gas ignition phase.

The very high firing rates of some installations required the supply of gas at higher pressures (several bar) than the 20 mbar hitherto considered normal. Thus guidance was needed on aspects of pipework welding standards, gas velocities and filtration, and overpressure protection. This relatively new technology had to draw on experience gained from activities in the rapid expansion of the high pressure national transmission and distribution systems, although it subsequently became apparent that some of the requirements had been over engineered. However the chief engineer of one large UK customer did express his thanks that very high pipework and welding standards had been specified after a large water tube boiler had suffered an explosion. He commented that the gas supply pipework to the front of the boiler was the only thing that prevented the boiler from collapsing after the explosion.

As many installations were to be dual fuel, using various grades of oil as the other fuel (often on an interruptible basis) a major section of the Codes covered the switch over sequences need to ensure safety and to provide a "bumpless" transfer to the other fuel.

Some of the guidance was based on the previously published Standard for Automatic Gas Burners published in 1966 and on surveys of European and North American practice with a liberal sprinkling of sound common sense. However, much of the content was based on R and D studies carried out at MRS into safety shutoff valves (2), automatic control units (3) and safe ignition criteria (4).

Revision of the Codes

The Interim Codes were published unilaterally by the Gas Council in a very short space of time and to fulfil an urgent need. It was appreciated that this action could cause considerable upset to the plant and equipment suppliers (it certainly did) who felt that they had a vast store of experience and expertise to offer through their activities in the coal and oil fired fields. Despite this natural irritation the equipment suppliers did admit that at least it gave them all a common basis against which to tender. It was always envisaged that, in the light of experience and after full consultation a revised Code would be published.

To this end a joint working party was set up between British Gas, the Society of British Gas Industries and the British Combustion Equipment Manufacturers Association, and in 1976 the Code of Practice for Large Gas and Dual Fuel Burners (5) was published.

Probably the two most important changes in this document were firstly the lowering of the thermal rating of burners covered, from 3MW to 2MW, and secondly, the revised energy release criteria permissible at start up. This latter change resulted from a detailed research programme aimed at examining the extent to which start gas rates could be increased without compromising safety. The equipment manufacturers had long felt that the original energy release criterion was unnecessarily stringent. This limited the release rate to no more than 53 kJ/m3 of the combustion chamber volume for every 100 mbar pressure rise that the plant and flue ways could withstand (1 Btu per cu. ft. per psi). This in turn led to the need for separate pilot burners and the consequent requirements for careful burner design to ensure rapid and reliable cross-ignition to the main flame. The revised criterion allowed the start gas rate to be considerably higher, provided that it did not exceed 25% of the stoichiometric gas rate for the proved air flow. This led to improved safety in that there was a reduced risk of a delayed main flame ignition in the event of a shrunken or displaced pilot flame and also opened up the possibility of direct main flame ignition.

Other important changes in the revised Code of Practice covered aspects of welding of pipework, simplified requirements for multiple valve safety shut-off systems, a new section on operating data, and aspects of safety systems for multi-fire tube boilers.

The publication of these Codes of Practice clearly demonstrated the gas industry's responsible attitude to safety in large gas fired plant. At the time they were breaking new ground, but are now commonly accepted, with many of the criteria, some utilising the original wording, appearing in British Standards (e.g. BS 5885, "Specification for industrial gas burners, of input rating 60kW and above") and in harmonised European Standards only now about to be published.

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12.6 Air/Gas Ratio Control

D.Churchill

Background

Control of the ratio of air and gas supplied to industrial burners is fundamental to their safe, reliable and efficient operation. Many possible techniques exist, and these were reviewed in a paper presented by Roger Hancock in 1964 (1). By the mid 1970s increased concern for energy conservation and development of more sophisticated plant renewed interest in ratio control developments. The particular stimulus to work undertaken at MRS was for systems applicable to recuperative burners or plant employing flue mounted recuperators.

Technical Approach

Dual Valve Ratio Control and the J121

In the early 60s, high velocity nozzle mixing tunnel burners capable of use with preheated air were available which made possible the development of the recuperative burner. However, control of the air/gas ratio was affected by the changes of flow and back-pressure as the air temperature increased following start -up from cold. The problem was overcome by the development of a system which became known as dual-valve ratio control (Fig. 12.6.1), in which the differential pressures across flow controlling valves in the air and gas supply lines were maintained constant by pressure governors upstream of the valves, back-loaded from pressure tappings downstream of the valves (1).

Diaphragm operated weep-relay valves or linked butterfly valves were often used as the controlling orifices, to give a cheap practical hi-lo control. This was ideal for small recuperative burners such as the MRS version used in single ended radiant tubes. However larger burners, such as needed for direct firing of furnaces, required the use of very large pressure governors on the air side, which were either expensive or not available.

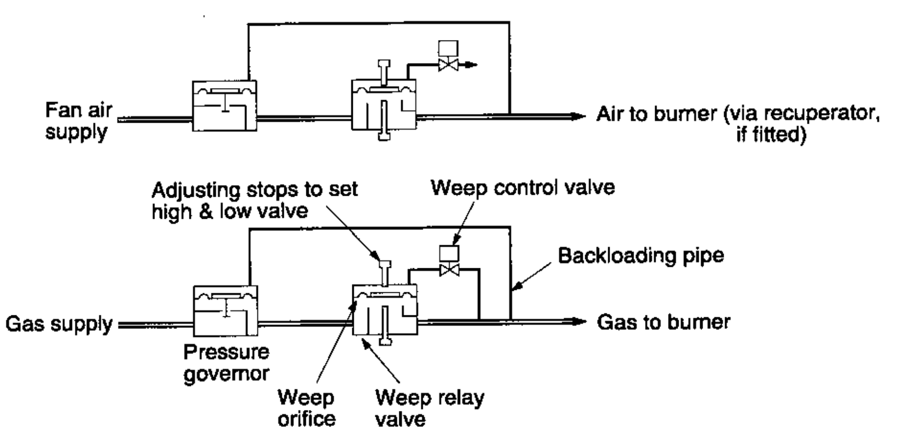

Fig. 12.6.1 A dual valve ratio controller using weep relay valves.

The problem was eventually solved by the development of a multi-diaphragm device in the gas supply line, based largely on standard governor parts, in which the air and gas pressure differentials across the metering valves were applied across the main diaphragms in opposition This controlled the gas flow to maintain roughly equal air and gas differential pressures. This system avoided the need for a large governing device in the air line (2).

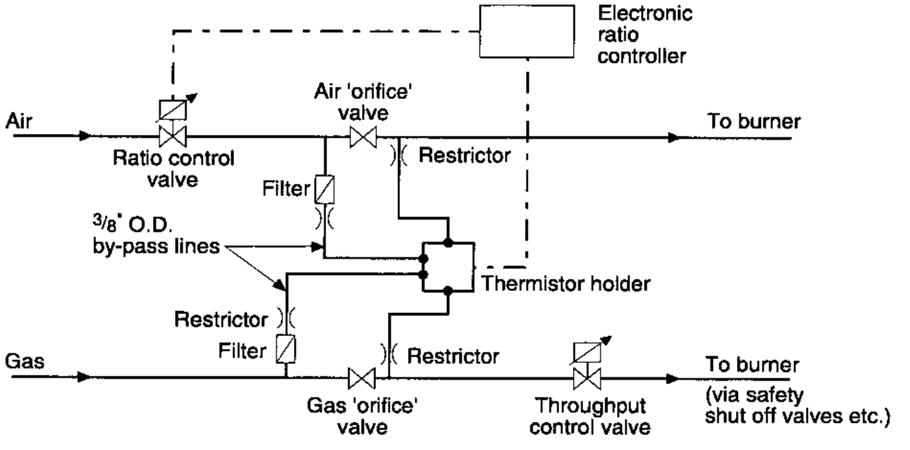

Fig. 12.6.2 Schematic of the electronic ratio controller (ERC).

Prototypes were made, proved in the laboratory and successfully field tested on a number of sites. One particularly successful installation was on crucible furnaces melting aluminium for casting at a factory which was then Europe's largest manufacturer of teapot spouts. In this case the multiple diaphragm units replaced "pressure divider" systems which were very prone to drift. The design was ultimately taken up by Jeavons Engineering and has been marketed since as the J121, and its use has contributed to the success of the recuperative burner.

Electronic Ratio Controller

In 1975 an electronic ratio controller (later known as the ERC) was developed. This system arose from a task given to an industrial trainee to investigate the possibility of producing a ratio monitor. It proved to be potentially a much better controller than the systems it was monitoring and was therefore developed as a ratio controller in its own right. The system was based on a novel application of thermistor flow sensors (2) with operational amplifier based analogue electronics operating a motorised valve.

The controller again relies on metering orifice valves in the air and gas lines, with shunt flow metering through by-pass lines using thermistor anemometers as the flow sensors. The thermistors were mounted in a transparent plastic block, and provided electrical outputs which could be compared by the electronic circuitry to give a control signal to a motorised valve to adjust the ratio (Fig. 12.6.2).A particular feature of the unit is that it is a mass flow controller when correctly installed. The system was so innovative that considerable laboratory effort was needed to prove both theoretically and experimentally the operation of the system before field trials of prototypes could be initiated. One interesting test was to confirm the integrity of the thermistors which had been criticised as being apparently fragile. Examples mounted in the their sensor housing survived fitting adjacent to a drop forge, although the "temporary" monitoring electronics used did not.

The first field trial was installed and commissioned in the summer of 1976. It was at Glacier Metals, Ilminster on a recuperative burner fired crucible furnace melting borax for the treatment of bearings. This installation was successful and a great deal was learned from it. The second trial installation was fitted in the summer of 1977 and comprised two controllers on a lightweight kiln firing ceramic ware at J.E.Heath, Stoke-on-Trent. This was again ultimately successful, although after a variety of problems most of which ultimately proved to be nothing to do with the electronic ratio controller. A paper outlining the developments (3) was presented by D.A.Churchill to the IGE Autumn Meeting in November 1979.

Commercial Implementation

Discussions regarding possible licensing of the ratio controller involved a substantial number of companies and it did not prove an easy task at that time to identify companies with the right combination of electronics and gas engineering expertise. The first licence was with Consultant Gas Engineers although, for various reasons, this arrangement did not work out. The second licence with Inter Albion of Potters Bar was signed in 1984, has proved successful. After agreeing the licence, considerable effort by both MRS and Albion, went into improving the unit (now called the ERC) cosmetically although the basic principle and thermistor arrangement did not change. In fact the thermistor housing has remained virtually unchanged since the original sketch of 1977 (Fig.12.6.3).

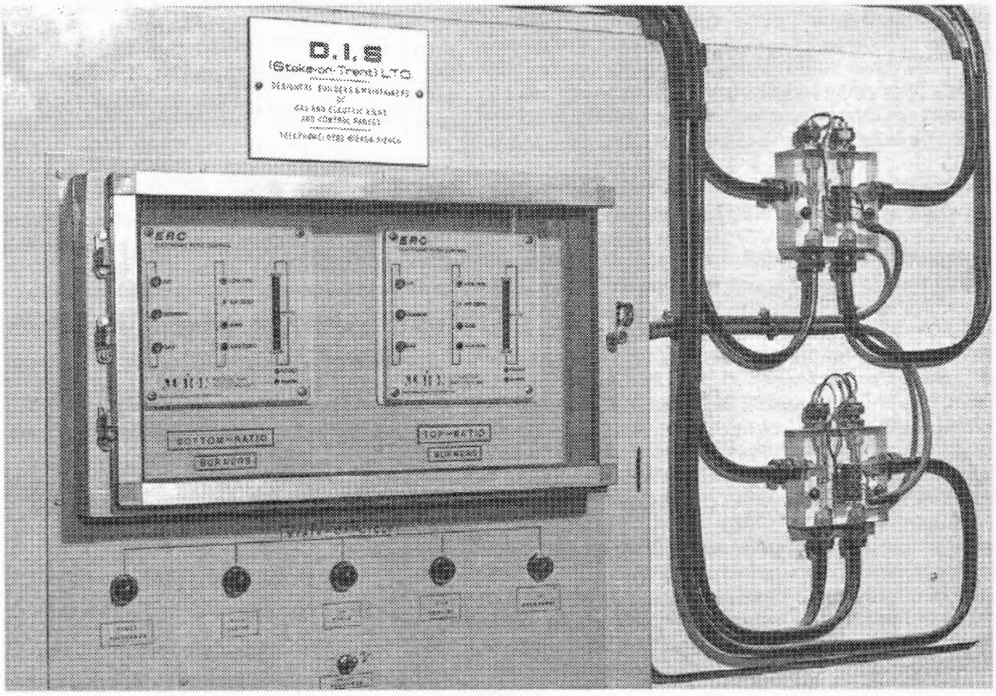

Fig. 12.6.3 A pair of ERCs controlling a ceramic firing kiln at J.E.Heath Ltd, showing the plastic encapsulated thermister blocks on the right.

Later Developments

The late 1970s were a tremendously productive period at MRS in developing to a prototype or concept stage a number of valuable enhancements to the ERC.

These included:-

Use of the controller signals to replace pressure switches
Trimming of unit from a flue oxygen signal
Options for switching ratios for atmosphere generation
Operation on fuels other than natural gas
Furnace pressure control

None of these possibilities were proceeded with at the time- introducing the ERC in its basic form to the industry was sufficient challenge- although Inter Albion have since done work in some of these areas. However, in the late 1980s the ERC became an integral part of advanced furnace controls systems developed at MRS (Fig. 12.6.4). These exploited the ability to introduce a "nudging" input into the electronics to allow changing of the ratio from external signals. These systems have been used particularly successfully in the ceramics industry (4).

Fig. 12.6.4 Components of a "high level" ratio control system showing ERC and oxygen analyser (OA), both marketed by Inter Albion.

Electronics and sensor technology have obviously advanced enormously since the ERC was originally devised. It has been part of MRS's brief to maintain contact with such changes and therefore further developments of the ERC concept have regularly been reviewed. Development of an up-dated ERC based on newer thermal sensors (like the Honeywell Microbridge) and incorporating various new features was seriously considered and, perhaps unwisely, not attempted. Instead it was decided to adopt digital techniques (which barely existed when the ERC was first devised) and the development of a Micro Electronic Ratio Controller (MERC) was initiated. By spring 1992 this had reached the stage of a laboratory demonstration prototype and potential licensees were being sought(5). MERC has attracted particular interest because of the attention which has been given to addressing the problem of easing commissioning and providing information to the commissioning engineer (Fig. 12.6.5)

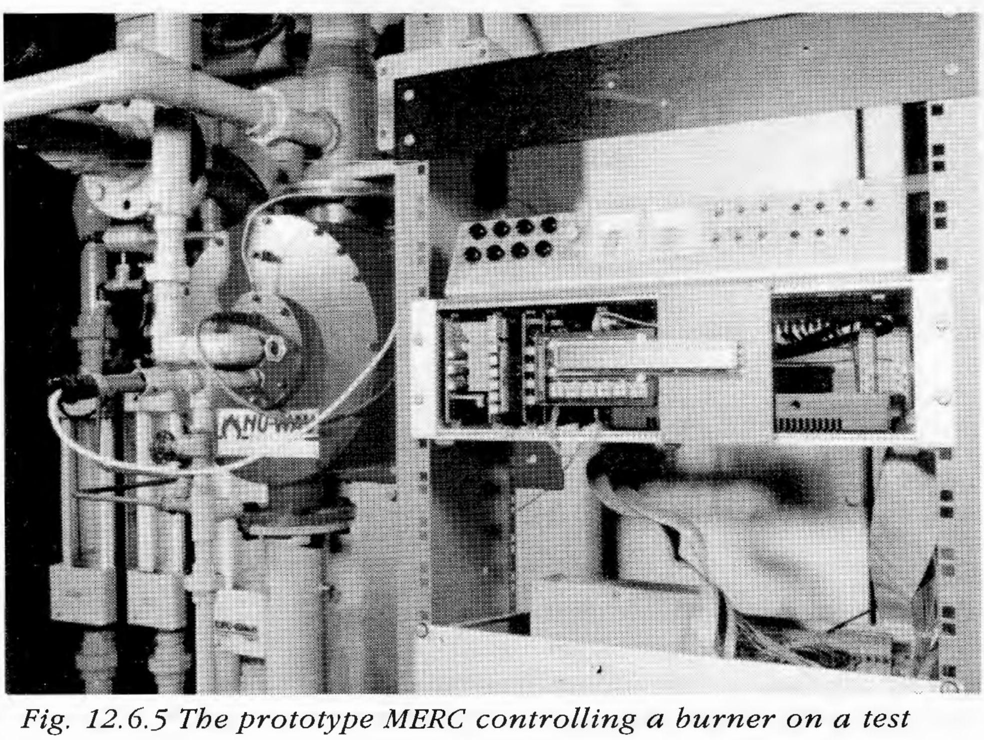

Fig. 12.6.5 The prototype MERC controlling a burner on a test furnace.

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12.7 Transients in Gas Supply Systems

David Churchill

Background

An essential requirement for any gas supply system is that its dynamic response be adequate to prevent significant fluctuations in pressure during changes in load. In most cases this does not need to be considered in detail because the system is very tolerant to large changes (e.g domestic supplies). However, because of the very different conditions and types of equipment involved, some industrial and commercial loads can create severe problems if consideration is not given to the dynamic behaviour. The larger and often more sophisticated plant which has been installed recently can greatly aggravate such problems. MRS has been providing a service to the industry regarding such "transient" problems and has given technical support on a substantial number of installations, certainly running into the hundreds, over the last 20 years. These have involved a great range of plant, including:Boilers of all sizes, from small commercial to large steam raising plant.Various industrial process plant - covering a wide range from metal melting , heat treatment, glassworks, chemical works using gas as feedstock to such specialised equipment as pig singers.CHP and power generation loads, especially industrial gas turbines which can pose special problems.

The type of problems encountered, either already occurring or anticipated at the design stage have included:

Plant which is inoperable due to pressure fluctuations tripping safety interlocks.

Wide and potentially dangerous fluctuations in air/gas ratio.

Installations which are virtually un-meterable or where very large metering errors occur.

Installations where meters are broken on certain shutdown conditions!

Serious vibration at BG equipment induced by the customers plant.

Cases where there is in fact no dynamic problem, but support has been invaluable in reassuring the customer that there is not.

MRS's support in this area has been based on three factors:-

Accumulated experience and expertise gained over the years; having been involved with such work for many years makes it quite likely that a similar situation has been seen before.

Having equipment available which allows transient pressure fluctuations to be measured on site. This has been maintained continuously for many years and has at times been quite extensively used.

Developing and using simulation software to allow prediction of the behaviour of systems and to allow design changes to be investigated on paper.

This software has involved several generations as computer availability and power has increased and has become known as DoGS (Dynamics of Gas Systems).

Technical Approach

DoGS beginning was in a project to examine low pressure governor response because of problems with pilot outage on plant. This was largely experimental but also included analytical solution of the equations describing very simplified systems. An equivalent exercise followed for rotary displacement meters which at that time were becoming more widely used and could create similar problems. This analytical approach was good for dealing with very simple systems or for indicating the relative significance of different parameters but was otherwise very limited.

Therefore a digital computer approach was adopted for solving the differential equations. This began with the RD meter and then the low pressure governor, again in very simple systems. This work demonstrated the power available and a great deal was learnt from the simple models.

At this time much experimental work was undertaken both in the laboratory and on field sites. This illustrated that in many instances it was desirable to account for the "acoustic" effects due to wave transmission within pipes rather than simply consider them as "lumped" volumes. Thus a new series of models were generated which combined a wave transmission type approach based on that used in hydraulic pipelines with finite difference type models for individual components such as rotary meters. During this period aspects of the work were described in papers presented to an I Mech E seminar and an ATG Congress (1)(2).

By about 1977 a series of programs had been written in FORTRAN which permitted, within limits, the required combinations of components to be assembled, appropriate changes in flow or pressures applied and the system response determined. (All data was inputted and outputted as numerical data, i.e. there were no graphics, and initially there was no VDU either !).During this period a considerable amount of laboratory work was devoted to characterising the range of components encountered in the supplies to low pressure industrial and commercial plant. This was needed to ensure that the base of data required to model a wide range of situations was available (Fig. 12.7.1).
The FORTRAN models required a lot of know how to use and could hardly be described as user friendly, even by the standards of the time. In the early 1980s consideration was given to ways in which the work could be made more accessible and advantage taken of the enormous advances in computer power and accessibility. The strategy adopted was to produce a series of simplified programs to deal with situations which experience had shown to be important. These were written in BASIC and were capable of running on a BBC computer. The BBC was chosen because it was a machine to which many potential users would have some access. (This was before the advent of the IBM PC). These programs employed graphics to plot output data and used both lumped volume and wave transmission models as appropriate.

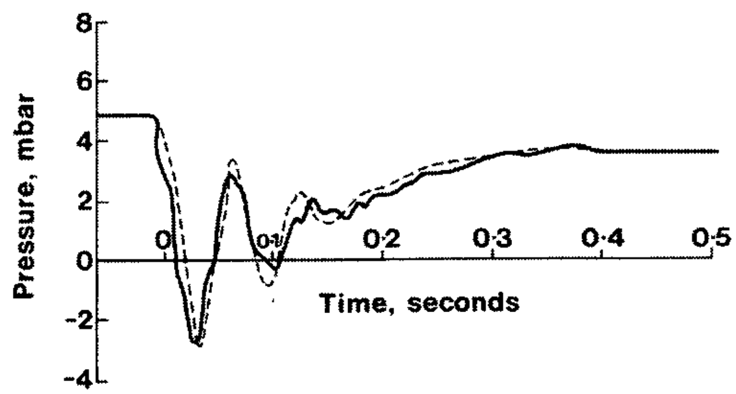

Fig. 12.7.1 Prediction (dotted line) and measured value of the pressure downstream of a governor as flow is increased.

These BASIC models were successful (3) but ultimately suffered from being system dedicated.The increasing variability and complexity of systems meant that models had to be "customised" for specific tasks, leading to a large family of variations many of which had to sacrifice desirable features because of lack of available effort and computer power.

Meanwhile, desktop computer power and availability had increased vastly and it was clear that the future was in the PC. Therefore to maintain the usability of the work consideration had obviously to be given to transferring the work to the PC and at the same time to increasing its flexibility and adaptability. After much discussion it was decided that the way forward was to adopt a WINDOWS based environment and to contract out the work to an external company, Aeon Software of Sandbach. The result is that system models can be assembled on screen with components used in virtually any desired numbers and combinations, and great flexibility is provided regarding position of outputs and parameters plotted (4) (Fig. 12.7.2)

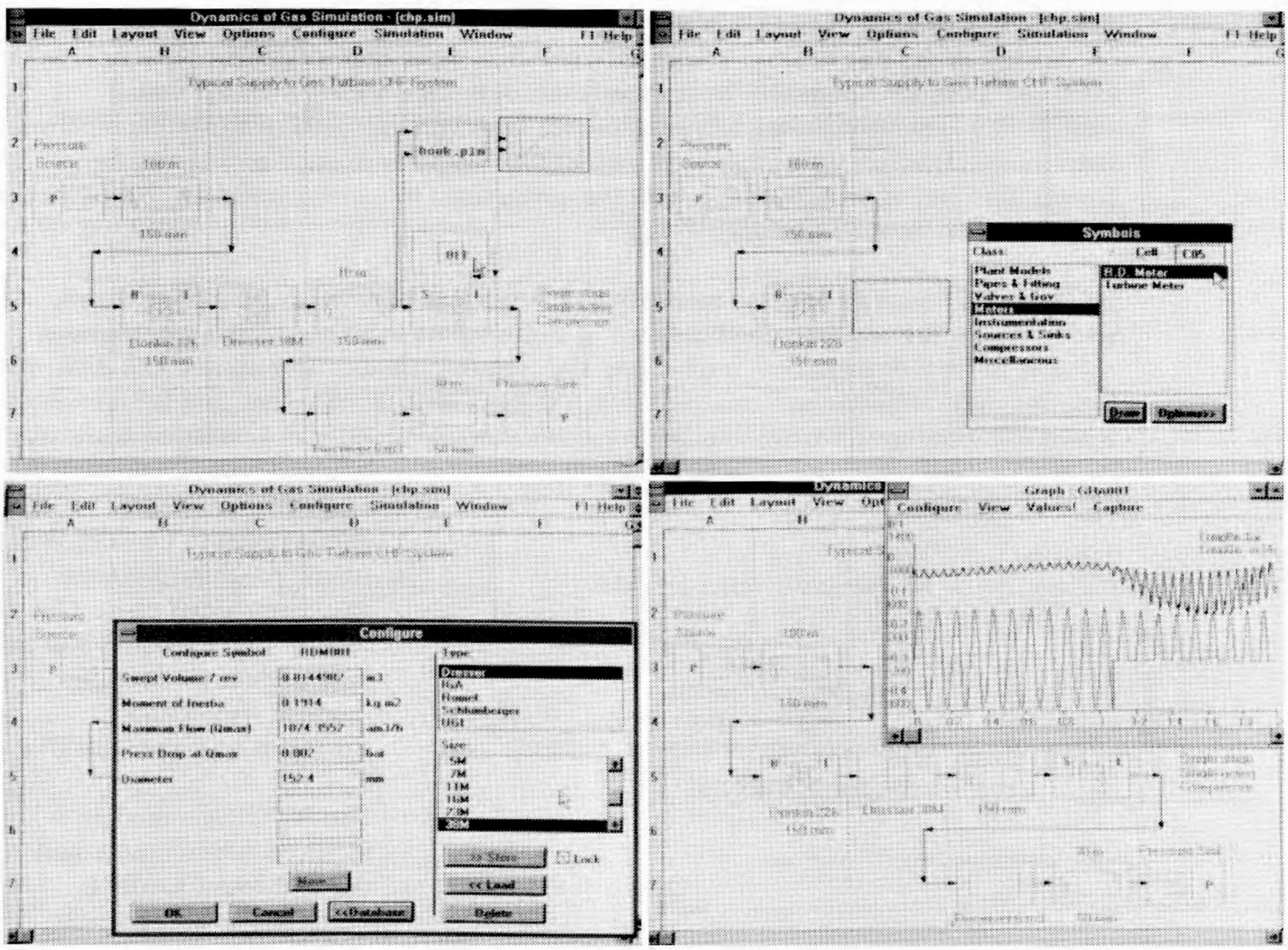

Fig. 12.7.2 Screen displays of PC version of DoGS.

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12.8 Plant Automation and Burner Management

T.P. Williams

MRS Pilot Plants

In the 1970s MRS operated numerous pilot-scale production plants for testing catalysts and gas clean-up processes as part of the SNG Programme. These plants were run continuously for up to 6 months at a time and were manned 24 hours a day. In order to reduce the required manning level and improve the safety and availability of the plants, work began on their automation. This started in 1975 with relatively simple sequenced shutdown systems linked into the existing plants' alarm monitoring systems to provide safe shutdown in the event of an alarm. The schemes proved to be very reliable and operated up to the early 1990s.

In order to gain more from plant automation, however, control engineers required more flexibility than could be provided by conventional relay logic. 1975 also saw the introduction of the first microprocessor-based equipment for general process control. This technology enabled more complex designs to be installed for further plant automation at a reasonable cost. Being 'computer-based' it was easier to reprogram these new systems than to rewire relay logic to accommodate a process change or additional alarm points. Some important lessons were learnt at this point about microcomputer technology. In particular there was the need to protect the hardware from electromagnetic radiation and mains-borne interference and the need to produce well-structured and well-documented software. The techniques developed at this point to ensure fail-safe and reliable operation of microcomputers were the corner-stone of several commercial products successfully licensed by MRS and described later in this chapter.

Burner Management

Until the arrival of the microprocessor, the automatic startup and supervision of industrial gas burners had been performed by motor-driven cam timers and relay logic. The benefits of microcomputers applied to burner control were seen as greater flexibility and improved communications between plant and operator. However, the failure modes of microprocessors were unknown and in order to gain experience in the design and testing of such equipment the world's first microprocessor-based burner controller was developed at MRS. The component and product cost of a single burner microcomputer controller was still too high to be commercially viable in the late 1970s, but it was recognised that a for a multiburner system it was a potentially more attractive product.

This led to the MRS development of a micro-based multiburner controller. The controller incorporated numerous patented fail-safe techniques and it had the flexibility to control various types of burner sequencing and on-line sequential fuel change-over for up to 32 burners, all to the relevant British Gas Codes of Practice and Standards. An important feature of the design was a 32 character message display which provided valuable information on burner sequence status and plant equipment or controller faults. The system was licensed to Delta Technical Services Ltd., Portsmouth, and it was manufactured and sold as the BC900.

The BC900 incorporated a number of important safety features (1). Every millisecond, the single burner microcomputers had to re-energise a fail-safe timer circuit. Circuitry was included to ensure safe-operation under abnormal power supply variations. Critical electrical loads, such as the ignition source and main fuel valves, were energised via three air-break relay contacts, rather than solid state relays. Burner lockout state was memorised even when power was removed from the controller. In order to ensure that an output could not fail in a permanently energised state a load relay was energised by a fail-safe circuit only when driven by an oscillating output signal within a specific frequency band. Continuous self-checks were additionally made on microcomputer memory, timing and output functions (Fig. 12.8.1).

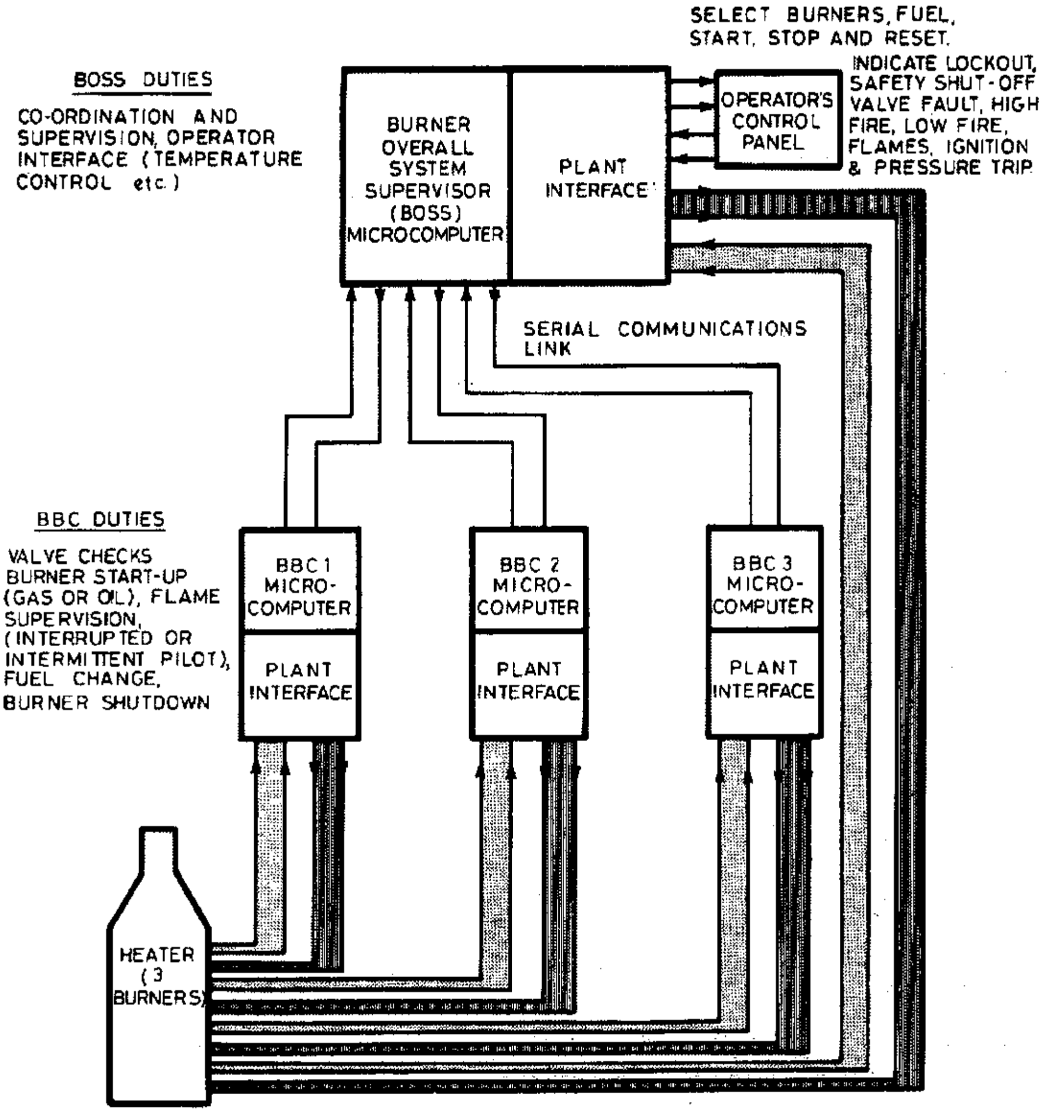

Fig. 12.8.1 Multiburner control scheme.

Following laboratory testing, initial prototypes of the multiburner controller were installed in May 1981 as a trial on a 3.5 MW process heater at Breakwater SNG Works, Plymouth. In 1983 the first commercial BC900 system was commissioned on a 13 burner process heater system at Granton SNG Works, Edinburgh. The burner controls were integrated into a plant-wide computer control system with remote control and monitoring of burner operation being possible for the first time from a central control room.

SNG Plant Automation

The successful automation of pilot-scale production plants at MRS led to investigations into the feasibility of providing a high level of automation on full-scale gas processing and production plants throughout British Gas. A demonstration programme was completed in 1979-1983 on the SNG production plant at Granton, Edinburgh (2). An important aspect of this work was to provide information to assist in the specifications of computer-based control systems for future British Gas plants.

The availability of powerful, low-cost microcomputers enabled the rapid development of distributed control systems. These consisted of several microcomputers linked within a communications network to provide total plant control. The benefits demonstrated at Granton included lower installation costs, reduced effect of individual component failures and ease of modification and expansion when compared with large centralised computer controls.

The base load SNG plant at Granton used the catalytic rich gas (CRG) process route to reform associated gas from the Forties Field into a medium CV gas which, with Forties Gas enrichment, was distributed as SNG. The plant could be divided into four process sections; feedstock purification, CRG stage, C02 removal, gas drying and enrichment, and finally site services. The control strategy demonstrated was that each of the individual process sections could be controlled by its own microcomputer installed locally on the plant (Fig. 12.8.2). Each of these 'front-end' microcomputers would

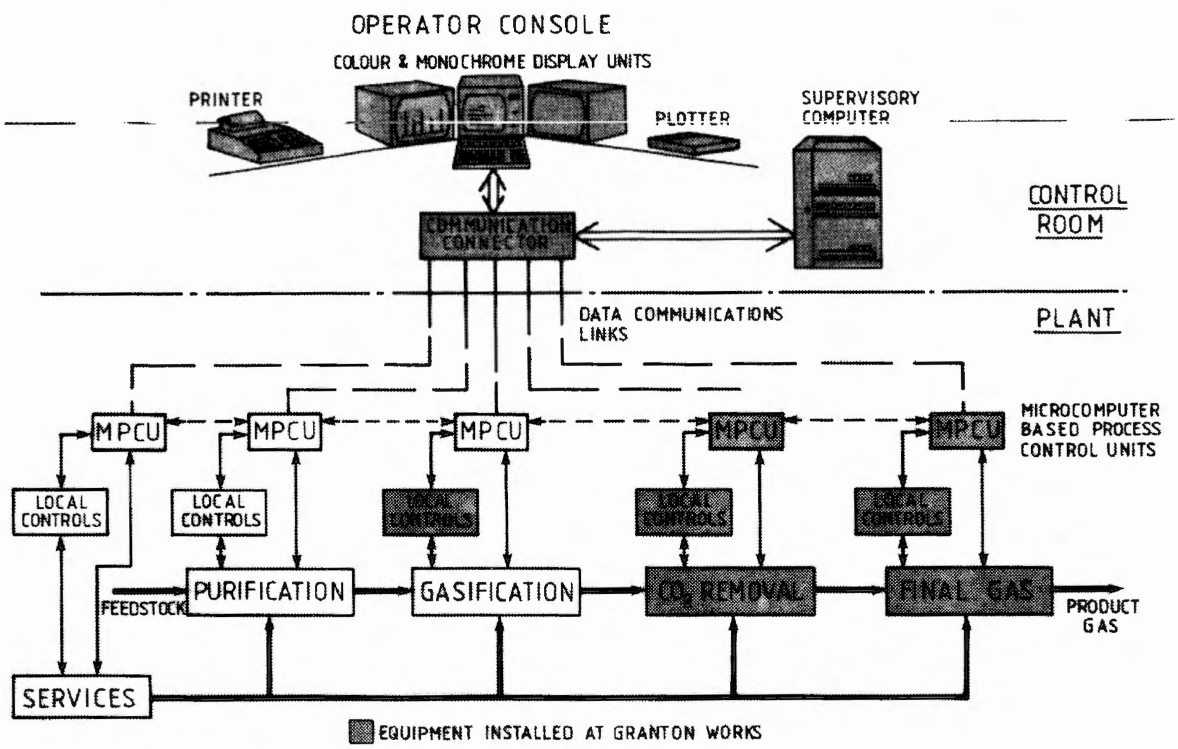

Fig. 12.8.2 Layout of distributed control system as applied at Granton SNG Plant.

perform the automatic startup or shutdown sequencing, continuous loop control of all flows, pressures, temperature etc., alarm monitoring and data acquisition for its process section. At plant level there were several local controllers which were needed to perform dedicated tasks such as burner management on fired heaters or pump condition monitoring and these were interfaced with the front-end controllers. A supervisory minicomputer was installed in the control room and this communicated with each front-end controller via a single cable. The supervisory computer co-ordinated the overall plant startup or shutdown sequencing and generated plant condition data for the operator console displays. In addition, remote plant monitoring and even remote plant operation from MRS at Solihull was demonstrated via modem links.

The development work successfully complete at Granton demonstrated the benefits of computer-based controls. Complex sequencing provided fully automatic startup or shutdown of the C02 removal and gas drying and enrichment sections. The C02 removal section could be started up within 90 minutes whereas previously with manual operation it had taken 8 hours or more. On-line process efficiency was improved by the implementation of feedforward control schemes. Mathematical models of the C02 absorber and the gas enrichment process enabled the control system to anticipate the effects of plant throughput changes and improve control accuracy (Fig. 12.8.3).

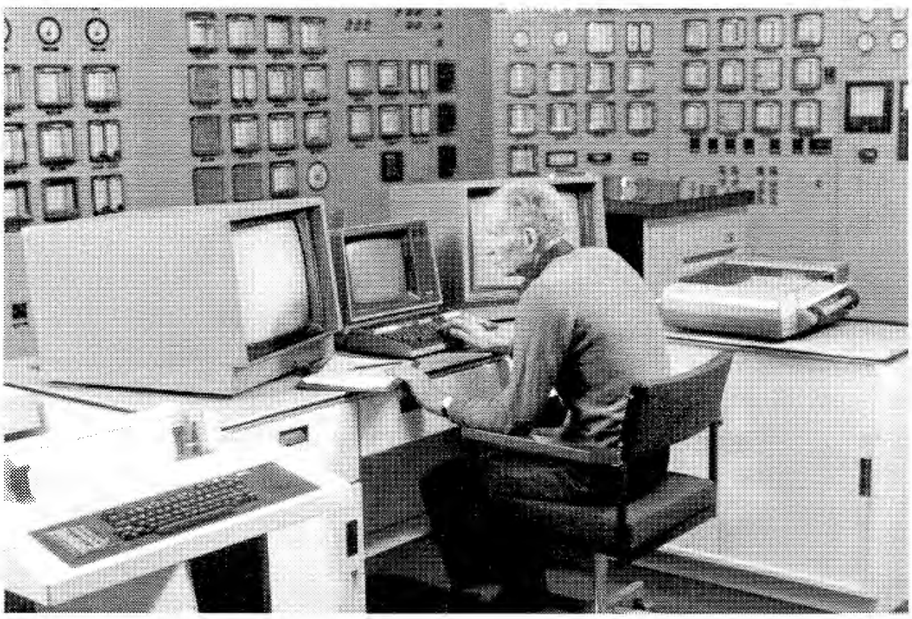

Fig. 12.8.3 Operators console (foreground) and conventional control panel (background) at Granton Works.

As well as demonstrating improved plant efficiency, this project also enabled trials on some important safety and reliability techniques which were to be incorporated in future British Gas plant specifications. A 'hot standby' technique was proven between front-end microcomputers to back up critical control functions immediately in the event of one microcomputer failure. An alarm handling system was developed to ensure that only alarms requiring operator action were displayed in the control room (3) (Fig. 12.8.4).

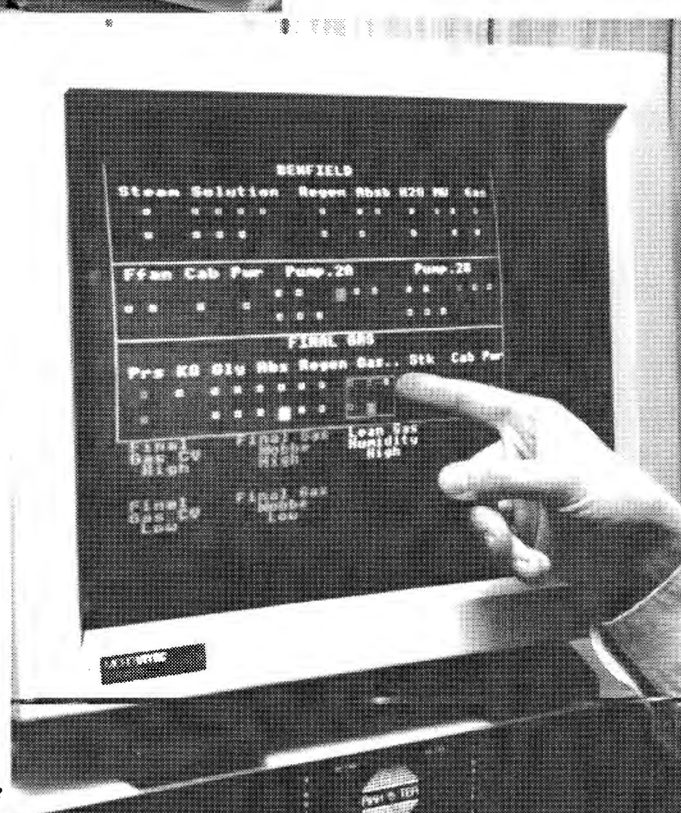

Fig. 12.8.4 Alarm page on a touch sensitive screen.

During the 1980s the cost of microelectronic components continued to fall although the processing power and memory capacity of microcomputers increased. Microcomputers were beginning to be used in safety critical applications and there was concern that too little was known of their failure mechanisms. This prompted the Health and Safety Executive to initiate discussion on the changes required to design methods when installing computer controls for plant and machinery. MRS staff made considerable contributions to the production of two important documents on the subject. First the H&SE issued guidance documents in 1987 on programmable electronic systems in safety related applications. This was followed in 1989 by the Institution of Gas Engineers safety recommendations IGR/SR/15 on the use of programmable electronic systems in safety related applications in the gas industry.

LNG Plant Automation

Against the background of the H&SE guidelines, work continued at MRS on the automation of British Gas plants. Liquefied natural gas (LNG) provides the final source of gas for the National Transmission System, particularly for peak load requirements during winter and therefore a very high order of reliability is required from these plants. Two critical process sections of the LNG plants have been automated; the LNG vaporisers and the pre-purification units (PPUs).

Direct fired vaporisers such as those installed at Dynevor Arms and Isle of Grain LNG facilities needed close and constant supervision to bring them on-line. Under microcomputer control these vaporisers are now automatically brought up to a set LNG flowrate with the correct outlet temperature. British Gas LNG sites have PPUs to remove C02 and water vapour from the feedgas prior to liquefaction. The PPU consists of two large towers, packed with adsorbent, operating alternately in adsorption and then regeneration operating mode. Optimisation of the process is obtained when the towers switch operating mode just as the on-line adsorption tower is saturated with C02. Original designs for PPU control were based on set operating times through assumed flowrates and C02 content of the feedgas. Since feedgas C02 content can vary between 0.1% to 1.0% the original timers were set cautiously to prevent C02 breakthrough into the liquefaction plant. However towers were changed over before saturation and this incurred unnecessary fuel gas costs on the regeneration heaters. Mathematical models for each tower were prepared by MRS to calculate a time to saturation from the C02 content for specific feedgas flows. Automatic monitoring of C02 content and feedgas flow was installed and the control algorithm was further refined by making it capable of responding to varying tower performance.

As a result of the automation, the PPUs can now liquefy feedgas at a maximum rate, tower regeneration costs have been reduced and consistent tower saturation is providing longer adsorbent life. The first microcomputer controlled PPU was commissioned at Avonmouth in 1988 (4). The process, and the accompanying control system, is now marketed by British Gas as ADAPT.

The Safety Monitor SaM

For the LNG plant applications, the H&SE design guidelines were met by a system configuration consisting of the microcomputer and an additional non-programmable system of electromechanical stepper switches and relays. An alternative configuration has also been developed at MRS and this consists of the critical microcomputer output signals, as well as critical process parameters, being routed through a safety monitor. The MRS safety monitor, SaM checks the validity of each microcomputer output action before allowing the output signal through to the plant. SaM is not microprocessor-based but it does contain programmable memory to hold sequence control operations data. SaM is now manufactured under licence from British Gas and sold for process plant applications (5).

Advanced Process Control

There was an increasing call for process modelling and dynamic simulation work in the late 1980s to investigate process problems and develop control solutions. The two approaches to obtaining mathematical models to represent plant dynamics are by thermodynamic and chemical theory based upon first principles or by practical frequency response analyses termed system identification. MRS developed a low-cost, easy to use system identification package which can be used on plant via a portable personal computer. This system was successfully licensed and marketed as PSI. This work led to the development of a new self-tuning controller which uses on-line estimations of the plant model. This project has been a collaboration between MRS, Dept. of Energy, Coventry Polytechnic and Eurotherm Ltd.

An MRS production plant was one of two test sites for a new artificial intelligence expert system, COGSYS (6). The development of COGSYS was funded by some 37 major international companies. COGSYS provides expert on-line advice to aid less-skilled staff to operate complex plant safely and efficiently. The success of the project is demonstrated by a new company COGSYS Ltd. being formed in 1990 by British Gas, Salford University and SD-Scicon specifically to sell this expert system. An MRS project engineer joined COGSYS Ltd. as technical manager.

Process control research at MRS has been aimed at improving the operability, reliability and efficiency of British Gas process plant both onshore and offshore and of industrial gas-fired plant on customers' premises. The successful projects described, with new products developed and licensed for general use, and the contributions made to new standards and British Gas plant specifications for computer-based controls demonstrate the achievements of the work.

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Chapter 13

Hazards and the Environment

13.1 Explosion Reliefs

D.J.Moppett

Background

The use of gas heated ovens for the drying of paint had led to many serious explosions in which people had been killed. The cause of death had been identified, by the Factory Inspectorate, in many cases, as due to blows received from parts of the oven, the doors and in some case the explosion relief. In addition to the risk of a gas explosion, there was the possibility of explosion from the ignition of paint vapour, regardless of the fuel used for heating the oven. There was an urgent need for the introduction of more effective reliefs which would not be themselves a hazard in the event of an explosion. The Factory Inspectorate asked the Gas Council, through the Industrial Gas Development Committee to carry out an investigation on the design of explosion reliefs. Prior to the commencement of the studies carried out by P.A. Cubbage, and his assistants there was little fundamental knowledge of the explosion process as applied to industrial plant. Experimental work started in early 1953 when P.A.Cubbage set up his first test box on the coke dump at Solihull Gas Works.

Technical Approach

The test area was in a gap between the coal heaps of the Solihull works stock yard. A small shed housed the instrumentation; towns gas and electricity supplies were laid on from the works. Gas was metered into the base of the test box and impacted on a disk to promote stirring, further mixing was achieved by the use of a fan. The gas air mixture was ignited by use of a small 'puffer', an electric match surrounded by small amount of medium grade explosive.

Pressures generated were measured by means of a variable capacitance gauge which was connected to a recording oscillograph made by Southern Instruments. The instrument had two cathode ray tubes; a three inch one displayed the vertical component of the pressure signal, a one inch tube displayed a time comb. The time component of the recorded signal was provided by the rotation of a drum carrying a strip of photosensitive paper about 24 in long by 4 in wide. The drum was run up to the required speed and the firing button pressed; this provided the ignition signal for the puffer, and also turned on the beams of the CRT's for one revolution of the drum. A reference ignition signal was obtained by the simple expedient of winding a few turns of the ignition lead around the signal lead. The behaviour of the the explosion relief was also filmed using a 16mm cine camera running at 64 frames a second.

The explosion relief was made from 1/4 in plywood and had 3 in deep sides which went into a sand tray around the top of the box to form a gas seal. The relief was made more gas tight with aluminium foil glued to the inner face. One hazard in the autumn was the resting place of the relief after a test. Damsonwood estate did not exist at that time and the opposite side of the canal was corn fields. John Bridgens, who did most of the tests kept his bike near him, ready for a fast ride down Alston Road, and Damson Lane and into the corn field to retrieve the relief and extinguish the fire. The rate of testing was controlled by the availability of reliefs; weather was used to advantage, on wet days a stock pile of reliefs were made and results analysed in detail; on fine days tests done.

This early work studied the effect of relief area, relief weight, relief location, oven volume, oven shape, mixture composition and position of the ignition source. An effective design for a low weight top relief was also developed. The work was published in 1955 at the IGE Autumn Research Meeting(1).

The application of the results obtained to ovens in use in industry necessitated the study of further parameters such as the effect of internal obstructions, such as shelves, the effect of proximity of walls and ceilings and the fitting of practical reliefs into vertical faces of commercial box ovens. In practical ovens the work being dried is placed on horizontal shelves. With a top relief in such an oven the flame will have to pass through the holes in the shelf and around the work. Clearly there will be an increased turbulence and higher pressures generated. A relief in the vertical face of the side or rear diminishes this effect. The effect of wall and ceiling proximity was studied with the aid of a corner of a cube suspended from a steel frame (Fig. 13.1.1). The top clearance was easily altered by raising and lowering the corner, the wall effect was obtained by moving the suspension pulleys. An undesirable side effect of the testing was the ground shock wave produced by the upward venting. This was overcome by the simple expedient of mounting the box on heavy springs to absorb the shock.

There are several apocryphal stories about the damage the shock waves did to the houses in Alston Road. The one about the china being dislodged from the welsh dresser is true, the one about the parrot being knocked off its perch is doubtful, but it may well have been agitated. Whether on not the housewife actually chased Pete Cubbage with a carving knife is questionable, but she was rightly angry.

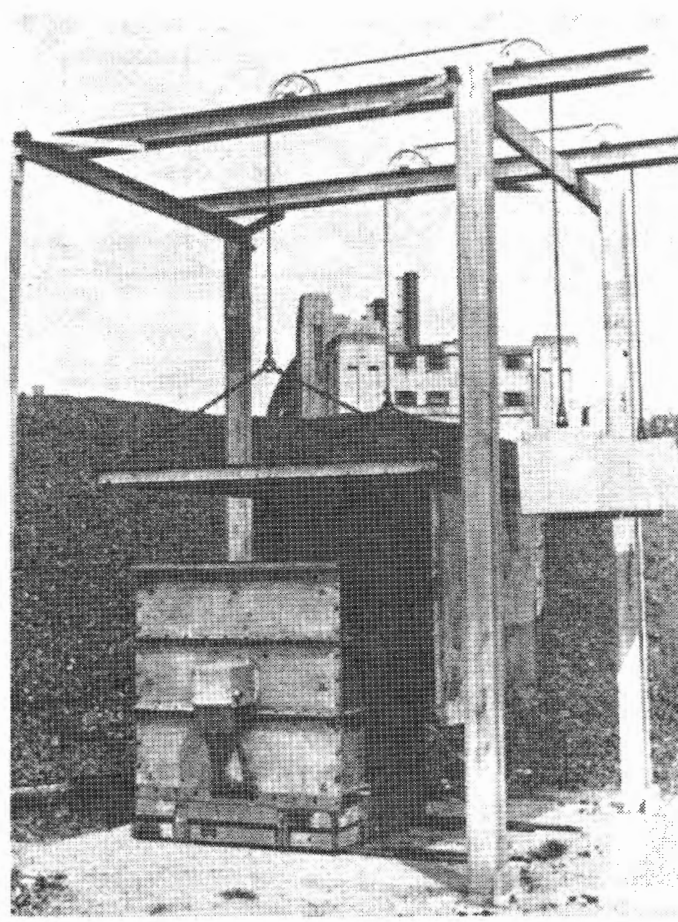


Fig. 13.1.1 Experimental oven on the coke dump with Solihull Gas Works in the background, showing the arrangement for simulating the effect of ceiling and walls.

Results of the Experimental Work

One of the most important findings was the existence of two pressure peaks in the pressure -time curve. The first occurred when the pressure had risen to a level sufficient to remove the relief from its mounting, thus providing a vent and allowing the pressure to fall. However, the area of the flame continued to increase, the vent becoming a restriction to the flow of gases out of the oven so causing pressure to rise again until most of the gas had been burned. Thus an effective practical relief had to be light enough and not unduly restrained to minimise the first peak pressure, and of as large an area as practicable to minimise the second peak.

Empirical relationships were derived for peak pressure in terms of vent weight and area, vent coefficient and burning velocity of the combustible gas or vapour which allowed design criteria for reliefs to be laid down (2).

An important aspect of the work was a consideration of the strength of ovens. It was concluded that it was prudent to limit pressure rises to less than about 2-2.5 psi. a figure subsequently used for deriving burner ignition criteria.

Commercial Implementation

The fitting of a usable relief in a commercial box oven was greatly helped by the involvement of R.J.Broomer of F.J. Ballard Ltd., one of the largest makers of box ovens. He produced a new oven design with improved door fastenings and fitted with a back relief consisting of a sandwich of lightweight insulating material between sheets of rubberised asbestos retained by a periferal metal strip (Fig. 13.1.2).

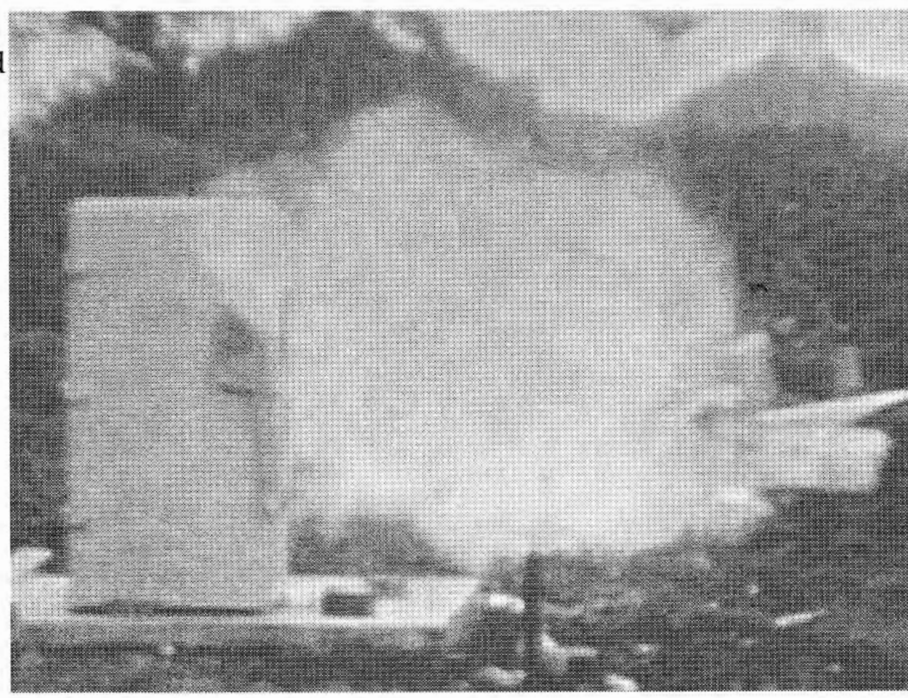
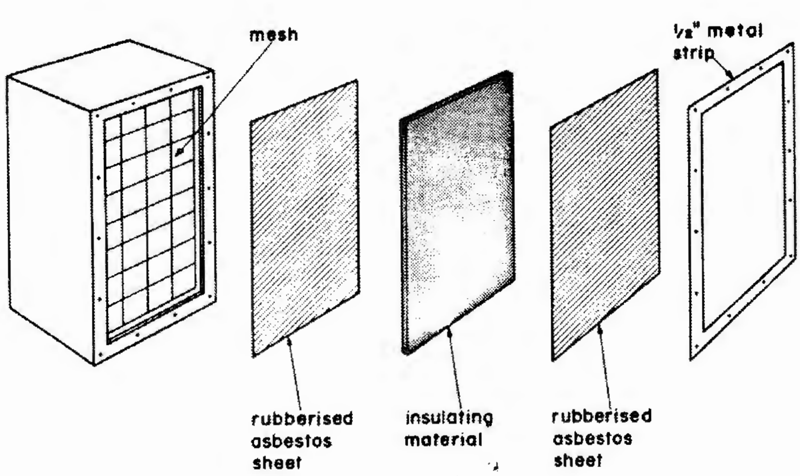


Fig. 13.1.2 Testing the strength of a Ballard box oven with a back relief.



This relief design (Fig.13.1.3) became the standard when incorporated into the Factory Inspectorate's Guidance Note 1856 (3) and its successors. The implementation thus became virtually mandatory on the oven manufacturers and the Industry generally and in a very few years virtually eliminated fatalities due to oven explosions, which had previously been running at about 10 or so a year.

Fig. 13.1.3 Explosion relief for box ovens.

References

(1) Cubbage P.A. & Simmonds W.A., "An Investigation of Explosion Reliefs for Industrial Drying Ovens, 1 - Top Reliefs in Box Ovens" Gas Council Research Communication GC23, November 1955.

(2) Cubbage P.A. & Simmonds W.A., "An Investigation of Explosion Reliefs for Industrial Drying Ovens, 2 - Back Reliefs in Box Ovens: Reliefs in Conveyor Ovens", Gas Council Research Communication GC43, November 1957.

(3) Ministry of Labour; Guidance Note 1856; Evaporating and other Ovens.

13.2 Flame Traps

D.J.Moppett

Background

It was common in the 50s for so called mixing machines to be used to supply a mixture of town gas and air to a number of plants in a factory. Typical applications were for machines employing a number of small burners such as in the making of light bulbs . Another was the production of glass or mineral fibres. The separation between the mixing machine and the burners means that there could be many hundreds of feet of pipe, sometimes as large as 9 in. diameter, filled with combustible air fuel mixture. The passage of a flame backwards from a burner, or even heat soak back, can provide a source of ignition so that a flame could propagate through the mixture, which might run up to detonation. There was thus a need for a flame trap capable of stopping a detonation in a towns gas/air mixture. There was a lack of knowledge of the effectiveness of existing commercially available flame traps, so MRS was asked to study their performance.

Technical Approach

Air and gas mixtures covering the range of flammability were fed into one end of pipe test sections from 1/2 to 4 in. diameter.The first safety device in the system was a length of cycle innertube connecting the rotameters to the test section. One end of the test section was closed with a plug cock, usually the inlet,but for some tests the outlet. The mixture was ignited using a spark generated by a car ignition coil. The passage of the flamefront along the test section was detected with more spark plugs acting as ionisation gaps and connected to a resistor capacitor circuit so that the flame discharged the capacitor giving a small voltage spike. The detectors were not 100% reliable, so detectors were alternately of positive and negative polarity and a sequence of "+" and "-" pulses set up. It was thus possible to detect the absence of an expected signal. The pulses were recorded using the same instrument that had been used to record the pressure signals in the box oven work. The drum mechanism was modified so that it turned on the CRT's for three revolutions, thus increasing the time resolution. An electronic modification was made by Peter Atkinson which added a small sawtooth signal to both the time comb and flame spikes so that each revolution of the drum could be distinguished.

The small scale tests, 3/4, 1, 1.5 in, were carried out in the"Giraffe room", later called Brunel lab 5; the large scale tests, 2, 3, 4 in, were carried out in Brunel yard, approximately where the boiler house now stands. Most of the tests were carried out in horizontal pipes, but the study of the effect of bends led to some pipes nearing the ceiling of the giraffe room.

Various types of wire gauze and crimped ribbon flame arresters were studied as well as the effect of bends and changes of pipe cross-section. The results of this work were published at the IGE Autumn Research Meeting in November 1959 (1). Information was given on detonation limits for town gas, run-up lengths for detonation and the temporary flame decelerating effects of bends,elbows, tees and sudden enlargements. Detonation velocities were around 5500 ft/sec.

Commercial Implementation

The crimped ribbon arrester (Fig. 13.2.1) was clearly superior to the many forms of wire gauze device, but in order to be certain of stopping a detonation the trap needed to be housed in an enlarged section of the pipe at least 3 to 5 times the pipe diameter in order to slow down the flame before it hit the arrester. With the cooperation of Maurice Roper of Amal Ltd. a conical housing was devised for a crimped ribbon trap which became more or less a "de facto" standard (Fig. 13.2.2).
As with the work on box ovens, the results of this work were incorporated by the Factory Inspectorate for use in their guidance booklets (2).

In 1961 when Joule lab was occupied the rig was rebuilt along the end wall of the building, the area later used as a dark room. The rig was used intermittently to test new traps which were said to be "as good as or better than" the industry standard Amal trap.

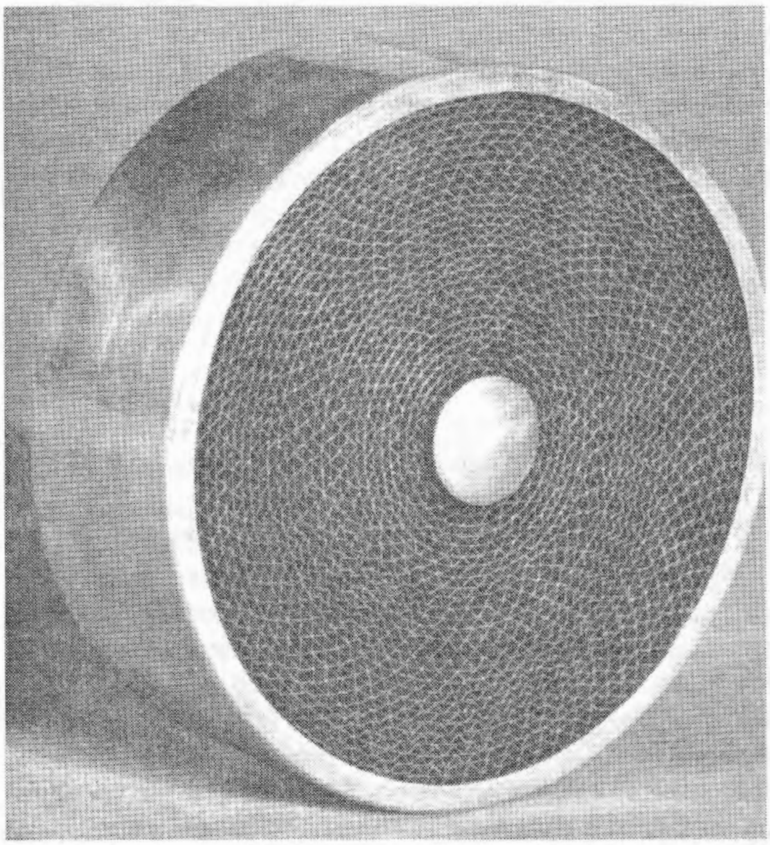


Fig. 13.2.1 A circular crimped ribbon flame arrester.

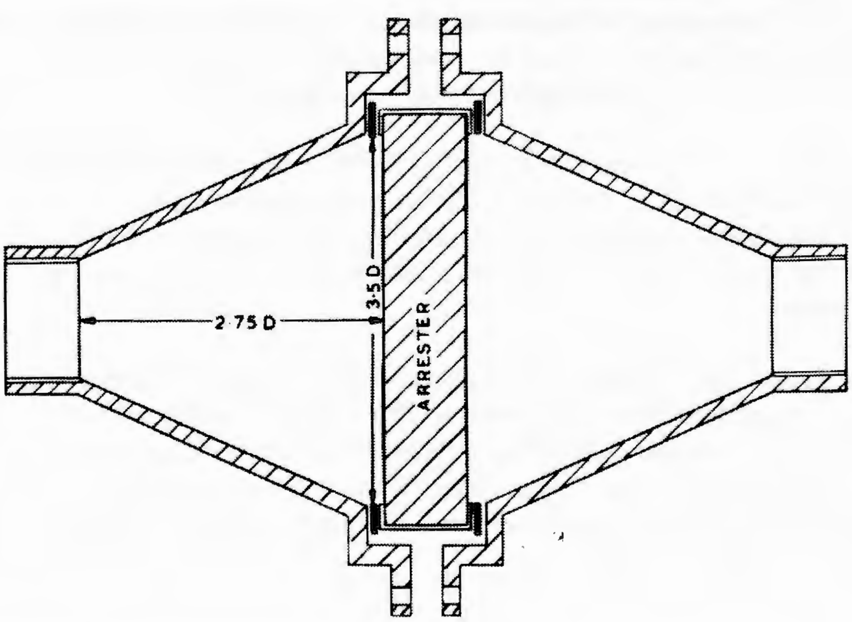


Fig. 13.2.2 Conical housing for nominal pipe diameter "D".

References

(1) Cubbage, P.A., "Flame Traps for Use With Town Gas/Air Mixtures" Gas Council Research Communication GC63, November 1959.

(2) Health and Safety Executive; Booklet HS(G) 11; "Flame Arrestors and Explosion Reliefs".

13.3 Explosions in Buildings, Gas Mixing and Ventilation

M.R.Marshall

Background

Until the late 1960's, research into explosion hazards was concerned mainly with the industrial market. This stemmed from a request for help in the early 1950's by the Factory Inspectorate to improve the safety of operation of drying ovens and similar plant. The subsequent research carried out by Cubbage and Simmonds (see Section 13.1 above) laid the foundations of the expertise in explosion research which has formed an important part of the activities of MRS.

Following the collapse of the multi-storey block of flats at Ronan Point in 1968, as a result of a town gas explosion, there was a significant increase in the scope of the research on explosion hazards, to cover both the domestic and commercial sectors as well as the industrial market. As supplies to high rise buildings formed a significant portion of the domestic load it was recognised that to demonstrate the low risks involved in gas supply to such buildings an understanding of explosions was essential in order to defend this market.

Technical Approach

Whilst some of the expertise gained from the studies carried out previously to assess the hazard of explosions in industrial plant could be applied to explosions in buildings, basic information concerning the response of buildings and individual structural elements to explosion pressures was lacking. An opportunity to obtain this information arose in 1969 following an invitation from the British Ceramic Research Association to participate in a research programme, funded by the Brick Development Association, aimed at demonstrating that a properly constructed load-bearing brick building could withstand the type of gas explosion that had resulted in the collapse of the concrete panel, system-built structure at Ronan Point.

Interestingly, B. Cer. R.A. had originally invited the Atomic Weapons Research Establishment, Foulness to engineer the required gas explosions and measure the resulting overpressures. However, despite their expertise with both solid and nuclear explosives, AWRE did not consider themselves competent regarding gas explosions - hence the subsequent request for the involvement of MRS.

The preliminary phase of this research programme was concerned with determining the failure pressures of structural components such as brick walls, windows, light partition walls etc. This was carried out at a test site in Leicestershire referred to as Potters Marston where two concrete bunkers were located close to a purpose built 3-storey, load-bearing brick building in which the main test programme was conducted. Explosions were generated using a technique developed at MRS whereby the explosion pressure developed could be closely controlled by igniting known volumes of stoichiometric gas-air mixture contained in meteorological balloons. Using this method an individual structural element, such as a brick wall, could be subjected to successive increasing pressure loadings until failure occurred (Fig. 13.3.1).

Fig. 13.3.1 Failure of a brick wall during an explosion experiment in the concrete bunker at Potters Marston.

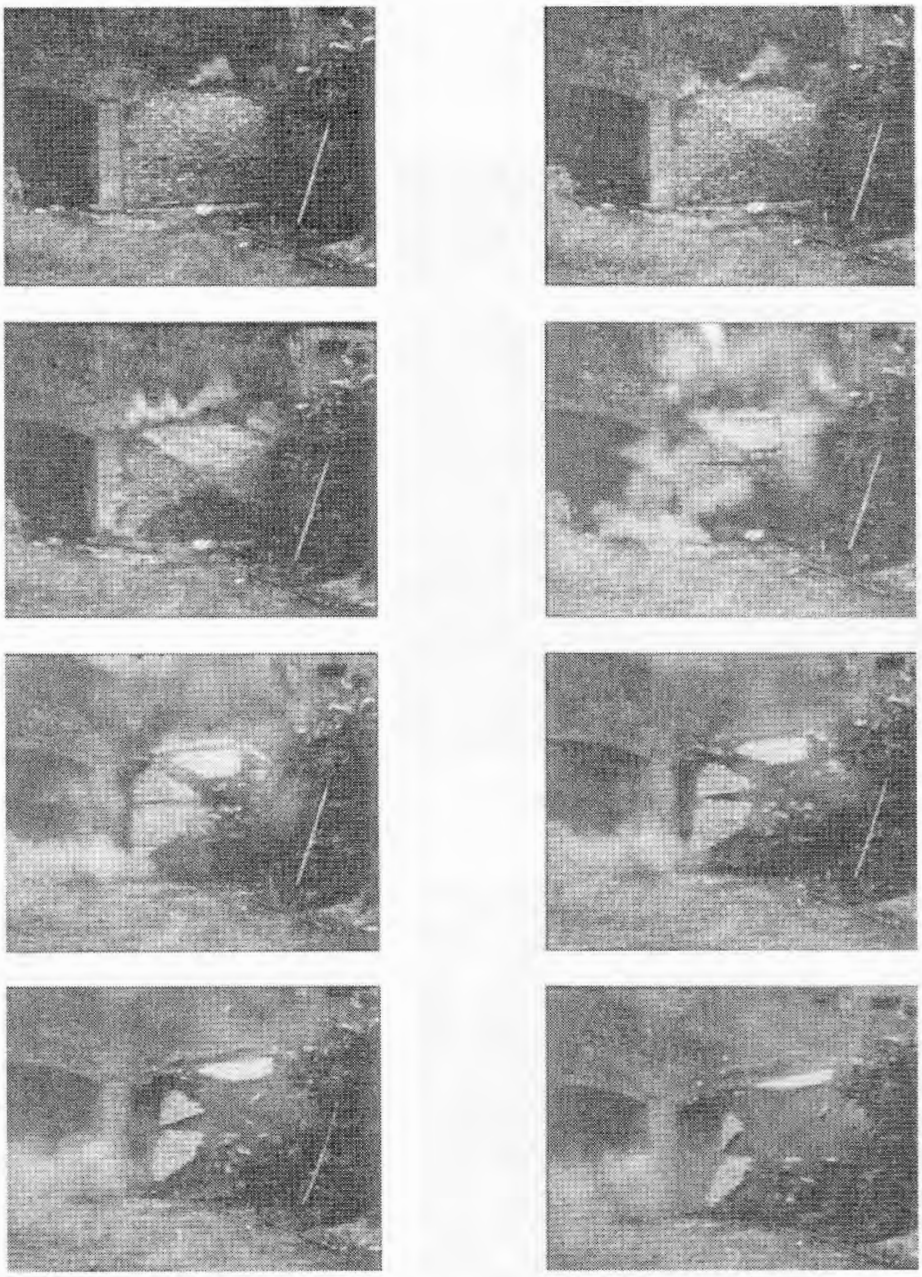
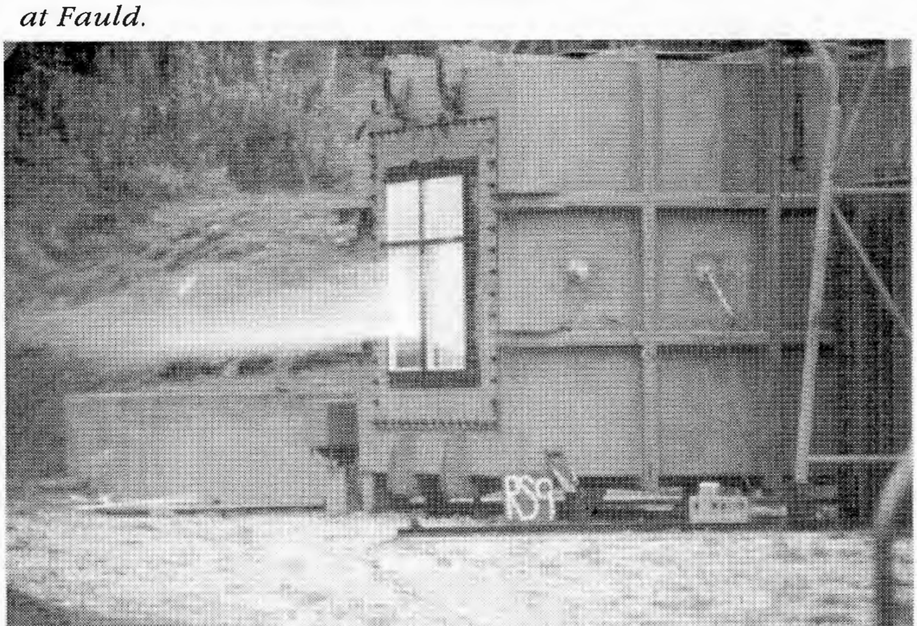


Fig. 13.3.2 Natural gas layer explosion in a vented enclosure at Fauld.



Subsequently, a series of explosion tests were performed in the 3-storey building. These culminated in a simulation of the Ronan Point explosion which, although causing minor damage did not result in the collapse of the building. This programme demonstrated the effectiveness of glass windows as explosion reliefs and provided confirmation of practical experience that, in most building explosions, severe structural damage would not occur. However, it was also apparent that an explosion 'cascading' from one room to another could result in an enhanced pressure rise due to turbulence effects.

Having achieved the initial objective of the experimental programme with the test facilities remaining intact, further studies were carried out in subsequent years (sometimes in collaboration with Fire Research Station) until construction of the M69 motorway prevented further use of these facilities. Part of this test programme concerned the use of shatter-resistant film on glass windows. It's effectiveness in minimising injuries to people involved in explosion incidents, by preventing the break-up of a window into a shower of high velocity glass fragments, had been demonstrated during the terrorist bombing campaign in Northern Ireland.

The studies carried out by MRS also demonstrated this ability when subjected to gas explosion pressures and, equally relevant, showed that proper application of the film did not impair the effectiveness of a window as an explosive relief.

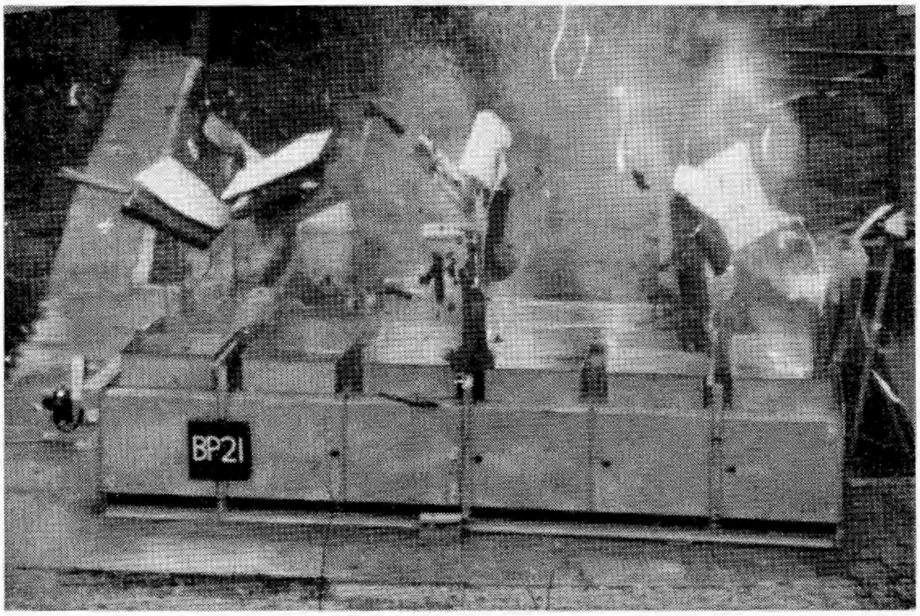
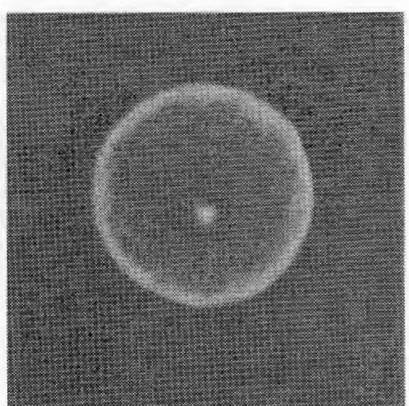
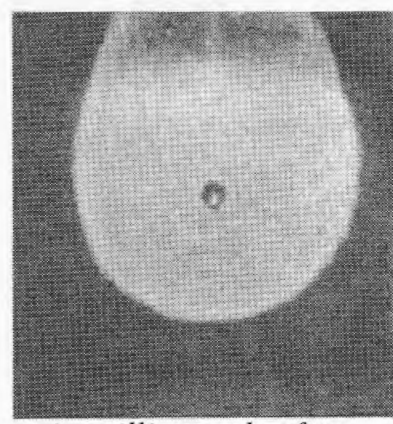


Fig. 13.3.3 Evaluation of explosion relief design for a long conveyer oven.

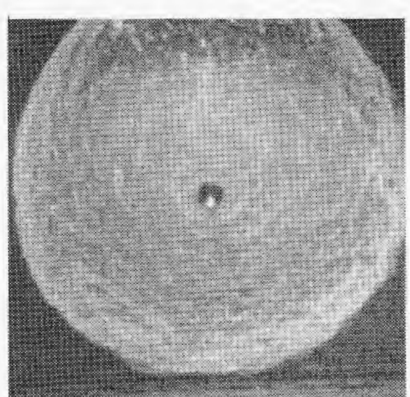
Work was continued at the Fauld site in purpose built explosion chambers (Fig. 13.3.2) to improve knowledge on the design of explosion reliefs (Fig.13.3.3) and on failure pressures of building components. To back up the development of mathematical models, the behaviour of the flame front in vented explosions was studied (Fig. 13.3.4).



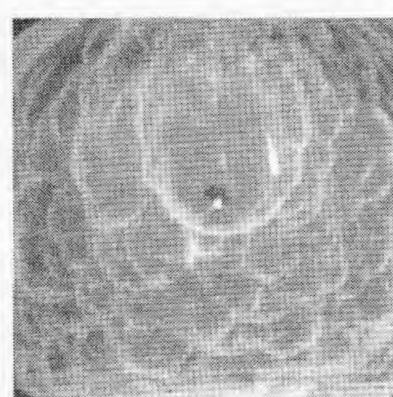
95 milliseconds after ignition.



130 milliseconds after ignition.



210 milliseconds after ignition.



320 milliseconds after ignition.

Fig. 13.3.4 Flame development during a vented explosion.

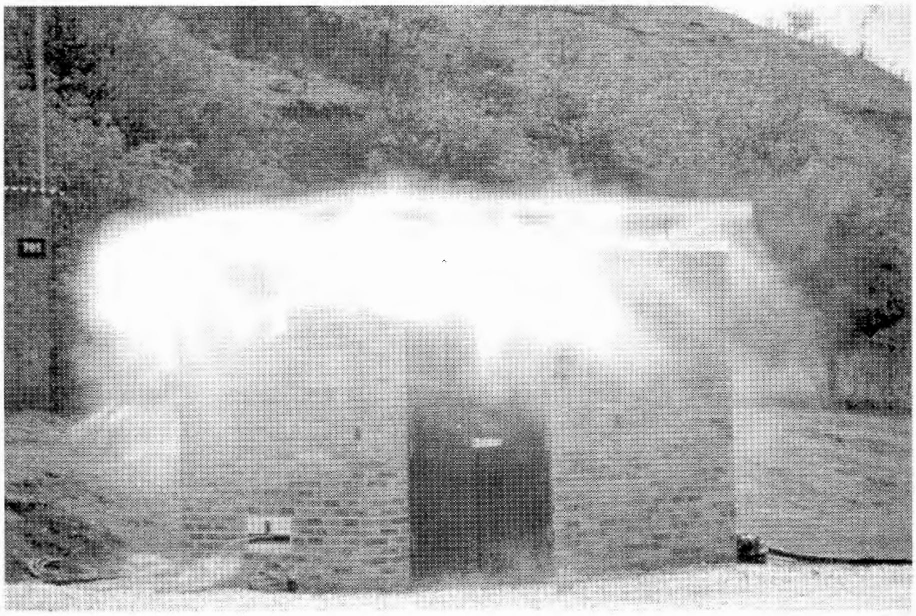


Fig. 13.3.5 Testing of a lifting roof explosion relief on a governor kiosk at Fauld.

A programme on the design of explosion relief for governor kiosks was undertaken and included tests on propietry "lifting roof" designs (Fig.13.3.5)

Gas Mixing and Ventilation

Whilst explosion relief can mitigate the effects of an explosion, obviously it is preferable to attempt to prevent such an incident occurring in the first place. The provision of adequate ventilation, to dilute and disperse any uncontrolled gas release to a safe level, is one way of achieving this. A considerable research effort was committed therefore to gaining an understanding of the process of gas mixing and accumulation within a confined volume and the influence of the ventilation air flowrate and flow pattern on this process.

In the case of ventilated rooms, it was shown that a well defined layer of gas air mixture of relatively uniform concentration was formed in the volume above the position of a gas leak, for a buoyant gas such as natural gas. For a dense gas such as propane, a similar layer formed from the leak down to the floor. These results had important implications for explosion incident investigations.

Implementation of the Results

The knowledge and expertise gained from the research enabled significant contributions to be made to government inquiries directly affecting British Gas operations, such as the King enquiry following a number of serious gas explosions in 1977 and the Inquiry into the continued operation of the Methane Importation Terminal at Canvey Island.

The research also provided essential background scientific support to the incident investigation service provided by MRS to British Gas Regions. The expertise provided has been used successfully on many occasions to determine the cause of explosions, often with considerable benefit to British Gas. Knowledge of the process of gas mixing has enabled minimum ventilation rates to be specified for particular installations (e.g. governor houses, etc) to avoid the formation of flammable mixtures and also guidance on the use of gas detectors to provide early warning of an uncontrolled release of gas. Finally, the data obtained on gas mixing and vented explosions has been used to develop mathematical models which have been incorporated into an overall risk assessment package to assess the consequences of gas releases in structures.

Reference

Much of the information and expertise gained from the research carried out by MRS was brought together and published for general use as the first in the series of British Gas applied science monographs "The Investigation and Control of Gas Explosions in Buildings and Heating Plant", published by E. and F.N. Spon in 1983.

13.4 LNG Spills, Fires and Suppression

J.Moorhouse

Background

The impetus for the interest in LNG safety in the early 1970's was British Gas's plans to construct additional storage facilities for peak shaving purposes and it needed information to support this programme.

Bund Integrity

The first study into the safety of spillages of liquid fuels was conducted in 1970/71. An enquiry from the Production and Supply Division of the Gas Council (as it was then) was received with regard to the design of the earthen bunding arrangements around a proposed new LNG storage facility at Hirwaun in S. Wales.

A series of specially designed square earthen bunds were constructed on land at the HSE Research Laboratories at Buxton.This site was chosen since MRS were already actively conducting studies of the thermal radiation characteristics of natural gas jet fires from pipelines. The test bunds were exposed to cryogenic conditions and LNG fire conditions and found to provide satisfactory containment of the cryogen. The results from the work were incorporated into subsequent designs for earthen bunds at British Gas storage sites. During these trials MRS made their first measurements of pool fire characteristics.

Fire Suppression Studies

The recognition that LNG pool fires had strongly radiating yellow flames without significant soot emission led to consideration of means for suppressing a spillage fire. Work on fire suppression was initiated in 1973 at the Fire Services Technical College at Moreton-in-Marsh, a large ex-airfield and ideally suited for the safe conduct of large fires.

Fig. 13.4.1 Foam spreading experiment.

The primary objective was to examine, with the assistance of foam manufacturers, the effectiveness of various types of aqueous foams as a means of suppressing, but not extinguishing, fires from spillages of LNG. These fires were recognised as being particularly difficult to control due to the highly volatile nature of the fuel, with a boiling point of -161 C which boils on contact with the ground or other objects (Fig. 13.4.1).

The work examined various aqueous foams in a programme which lasted for 4 years. One of the outcomes from the work was the selection of suitable foam systems for catchment pits and impoundment areas at LNG storage sites. A secondary outcome was that data was obtained on the free burning characteristics of LNG pool fires. This included the flame shape and the influence on it of the wind, the rate of thermal radiation emission from the flames, and the fuel burning rate. This information was used to produce a method for assessing the thermal radiation hazards posed by LNG pool fires, so that means of protection for facilities and escape for personnel could be considered.

A model was subsequently developed, named FIRE1, for calculating thermal flux loadings around a fire. This model found use within British Gas for all its storage sites, particularly since the legislation introduced in the UK in the 1980's required detailed safety assessments for all major fuel storage sites.

Work at Spadeadam

The work at Moreton-in-Marsh terminated in 1977. Subsequent studies of pool fires were conducted at Spadeadam, which was to become a world renowned site for all types of major safety work including pool fires.

The first study on pool fires at the site was for an external client, conducted on Pad C in 20m diameter pools, during May and June 1980. For this work a substantial investment in tanker discharge facilities was made and this provided a valuable resource for subsequent work by MRS.

The Canvey Inquiry

An additional motivation for the research into hazards such as fires during the early 1980's was the Planning Inquiry which was held into the British Gas Canvey Island LNG Import Terminal. This required detailed assessment of the consequences of a range of minor and major accident scenarios. These included fires resulting from spillages from land-based tanks or marine carriers and the MRS information on pool fires was an important input in assessing the risks to the public.

Other Liquid Fuel Pool Fires

British Gas was interested in assessing the potential hazards from other fuels which it stored such as propane, butane and naphtha. To meet this need large scale fire trials were carried out in rectangular pools of low and high aspect ratio to represent pool as well as narrow catchment pit fires. The pools were up to a maximum of 15 metres in the major dimension. A novel part of this work was that the opportunity was taken of using equipment from the Shell Thornton laboratories, to measure the flame infra red emission spectra. This was done to identify whether larger diameter pool fires would be more emissive than those studied in the experiments and showed that the emission from these fires was close to the limit for much larger fires.

The data on these fuels, as well as that from LNG fires, were used to extend the prediction program for pool fires, FIRE1. An important part of the FIRE1 model which was developed at MRS at this time was a new type of routine for calculating geometrical view factors between the flame surface and any location and orientation of a receiving surface, a routine which was, and still is, considerably more flexible than other available methods.

A second application of the data was in the development of design rules for the sizing and location of catchment pits adjacent to LPG vessels. The objective was to prevent flame impingement onto the vessel from a fire in the pit and these rules formed a part of a British Gas Engineering Standard.

Fires in elevated high walled bunds (Fig. 13.4.2) were conducted at various scales to allow the differences in flame geometry to be observed and ensure that fires in tank tops or high-walled bunds could be satisfactorily predicted.

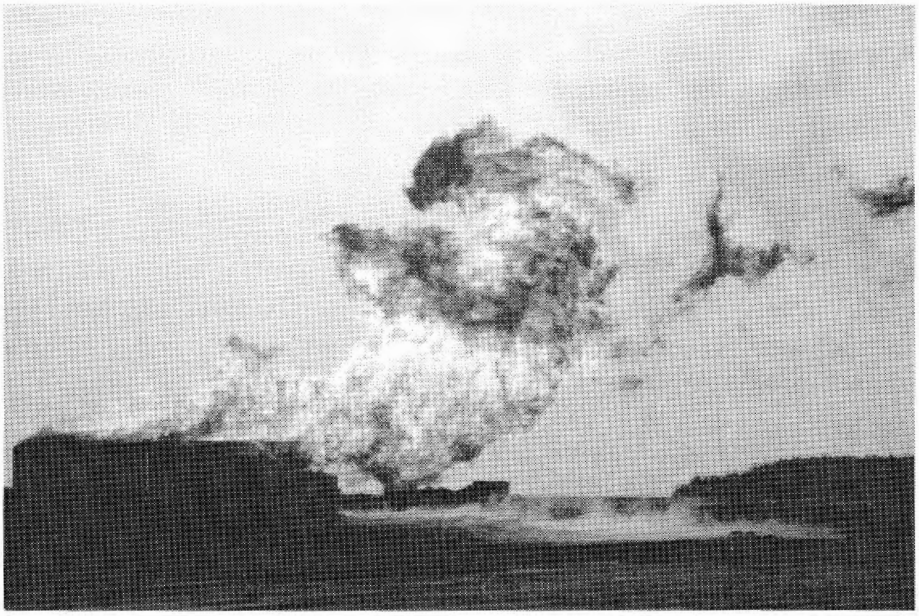


Fig. 13.4.2 LNG fire in a 10.7m dia. high walled bund.

An area of continuing interest was the means of suppressing pool fires. To this end large scale experiments were conducted to assess the value of a new means of suppression using an inert solid foam, a foamed glass, rather than an aqueous foam requiring continued application. Experiments showed it to be able to maintain prolonged effective suppression of LNG pool fires. A complementary trial was conducted to assess whether a permanently installed foamed glass system in an impoundment area could satisfactorily withstand prolonged outdoor exposure. This was done in an impoundment area at the Partington LNG facility and satisfactory performance was observed after 5 years exposure.

Collaborative Work

The expertise which had previously been gained in infra-red emission spectra was used again in an important piece of collaborative research with Shell Research and Elf Aquitaine in 1984. Two LNG pool fires in 6m and 10m diameter shallow bunds were conducted primarily to obtain measurements of the spectral emission characteristics at the flames' surface and the work had an unexpected outcome. It was found that even for these large fires there was scope for additional increases in the radiative power of the flames at larger pool diameters.

As a result it was decided that definitive experimental fires of much larger diameter were warranted. A consortium of 6 companies was therefore organised; three of the companies, British Gas, Gaz de France and Shell pooled their prior knowledge of LNG pool fires.Three 35m diameter LNG pool fires were successfully conducted in July and September 1987, the largest ever attempted. Considerable time was spent in assessing how sufficient LNG of a suitable representative composition could be accumulated in such large pools at an economic cost and this was achieved using various novel techniques to minimise boil-off of the LNG. These were conducted at Montoir in France and an MRS team was actively involved using its measuring equipment and expertise in making detailed measurements on the fire characteristics. This study set a definitive limit on the hazard from large LNG pool fires.The data was subsequently used by MRS to create FIRE2, which overcame some of the assumptions and major limitations in the FIRE1 code.

Collaborative work was also carried out on the conditions required to produce rapid phase transitions (RPTs) when LNG is spilled onto water (Fig. 13.4.3).

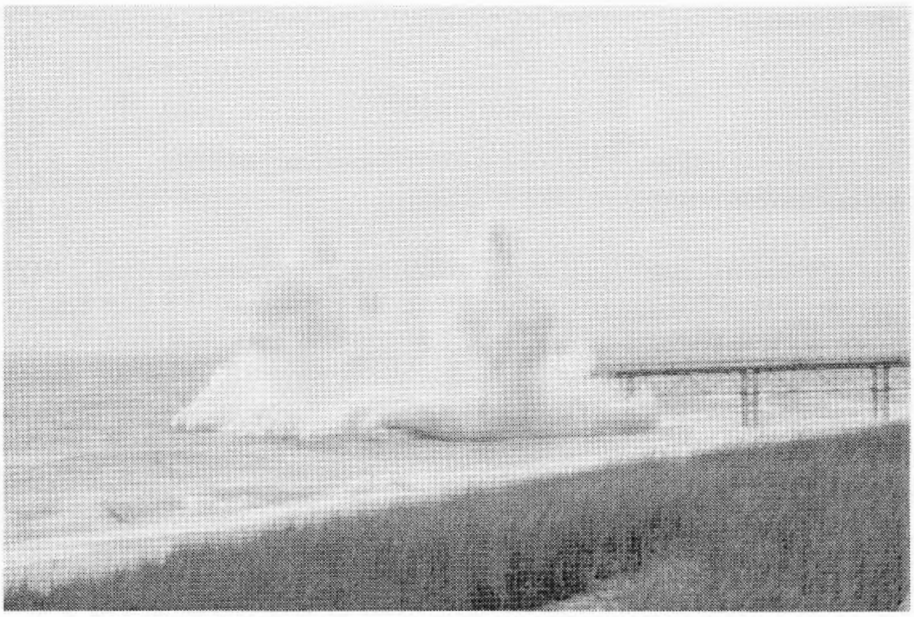


Fig. 13.4.3 An RPT experiment, Lorient, carried out in conjunction with Gaz de France.

Contract Research for GRI

Two major pieces of work were conducted under contract to the US Gas Research Institute (GRI). These both stemmed from the close links between British Gas and GRI through the 'LNG Safety Unit' of the Atlantic Gas Research Exchange.

The first piece of work was conducted in the period 1982 to 1984 and consisted of a large scale experimental study of the characteristics of fires of LNG in a range of shallow trenches, of various lengths (up to 52m), widths and aspect ratios (Fig. 13.4. 4). The data was required for the use in developing a model for such fires, i.e. in catchment pits etc. at storage facilities, and this was subsequently used for modifying the unduly onerous conditions in the US Federal Regulations for LNG facilities.

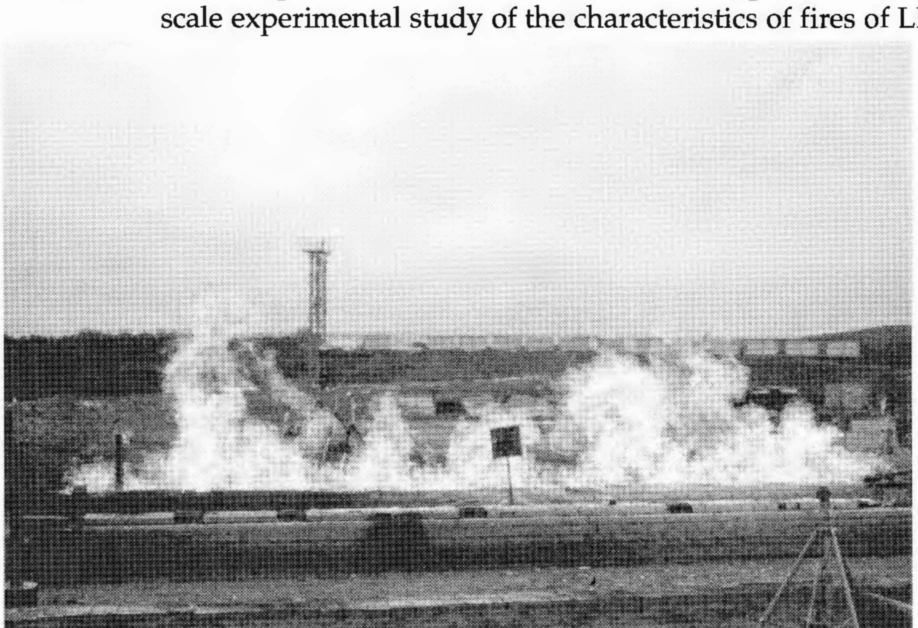


Fig. 13.4.4 LNG slot fire 23.5m x 2.35m.

The second piece of work was conducted during 1991/92 and was to examine the manner of spreading of LNG following a spillage onto a large water surface since this is the starting process for many accident scenarios. The objective was to provide data suitable for validating an existing model for this process. The main difficulties anticipated were the need to simulate large scale spillage rates over short periods and measure rapidly the progress and thickness of the layer of cryogen. This was accomplished by spilling into the apex of a long narrow test sector, with arrays of accurately located fast-response thermocouples. This work formed a part of a much wider programme of work supported by a number of LNG importing companies with an interest in the various types of incidents which can arise following spillages of LNG during unloading operations.

References

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13.5 Pipeline Fires and Flaring

G.Hankinson

Background

One of the considerations affecting the siting of high pressure gas pipelines is the possibility of escape of gas, due to failure or damage from external interference, and subsequent ignition of the gas. Radiation from the resulting fire extends the hazard distance well beyond the boundary outside of which the release is diluted to below its flammability limit i.e. well beyond the visible flame. Also an essential operational feature of high pressure gas plant is the need to release gas either by venting or flaring under routine or fault conditions.

Consequently, much attention has been focused on means of predicting the incident thermal radiation around a fire following either the deliberate or accidental ignition of escaping high pressure gas. Information on the potential consequences of an ignited release of high pressure gas is needed to carry out risk assessment studies and particularly to ensure the safe design and operation of the pipeline system.

Pipeline Fires

Experimental investigations were started in the late 60s to study fires following the ignition of accidental releases from damaged underground pipelines. The most common type of gas escape is due to external interference to the pipe from diggers or other machinery, resulting in the pipe being holed. The early work, carried out on the Safety in Mines Research Establishment site at Harpurs Hill near Buxton, therefore concentrated on jet fires from orifices of up to about 4 in. in diameter.

Fires resulting from ruptures in underground pipelines are generally associated with escapes of gas from a crater, formed either during the release or by excavating equipment immediately prior to the release. Consequently, the precise dimensions of the crater are difficult to predict and can have a significant influence on the size, shape and thermal radiation characteristics of the resulting fire.

A review was undertaken of the available literature describing pipeline failure incidents throughout the world in order to determine the range of crater geometries which had occurred. Subsequently, geometrically scaled experiments were undertaken in which gas at pressures of up to 70 bar was released from 50 to 150mm diameter pipes into a crater, representing that likely to occur following the rupture of a 900mm diameter pipeline. From about 1979 onwards the work was carried out at the Spadeadam Test Site.

Information obtained from this work enabled correlations to be obtained between the thermal radiation emitted by the fire, the flame dimensions and the total flow rate of gas, thereby reflecting the quantity of gas feeding the fire at its base. These relationships were used to develop an empirical model for predicting the level of incident thermal radiation at particular locations adjacent to a pipeline, for example at the proximity distance specified in I.G.E. code, TD/1. Results from this model provide a major input to risk assessments in connection with proposals for the diversion, reinforcement, or uprating of pipelines, or following applications to develop land in the vicinity of a pipeline.

At the time of writing work is in progress in collaboration with other major gas companies from throughout the world to adapt the theoretical model developed for flares to pipeline fires. In addition, experiments are being undertaken involving the simulated rupture of a 900mm diameter pipeline operating at a pressure of 60 bar to provide validation of the model at large scale.

Studies of Flaring

The methods incorporated within the I.G.E. code, TD/9 to determine the levels of incident thermal radiation following the ignition of a venting operation were originally recommended by the American Petroleum Institute in A.P.I. RP521. These methods, which assume that the thermal radiation emitted by a flame emanates from a point approximately at its centre, severely over estimate levels of incident thermal radiation, especially in the region close to the release point (within 1 flame lengths of the release point).

Work began in the late 60's to develop a more accurate and reliable method for predicting the incident thermal radiation field following an ignited venting operation or during a flaring operation. Laboratory scale experiments were followed by field scale studies. Information was obtained over a wide range of release and atmospheric conditions encompassing the full range under which operations would be carried out at British Gas installations including horizontal and inclined flare stacks as used on British Gas offshore platforms (Figs. 13.5.1 and 13.5.2)). Much of this work undertaken at Spadeadam in the mid 80's received substantial support from other major gas companies from throughout the world.

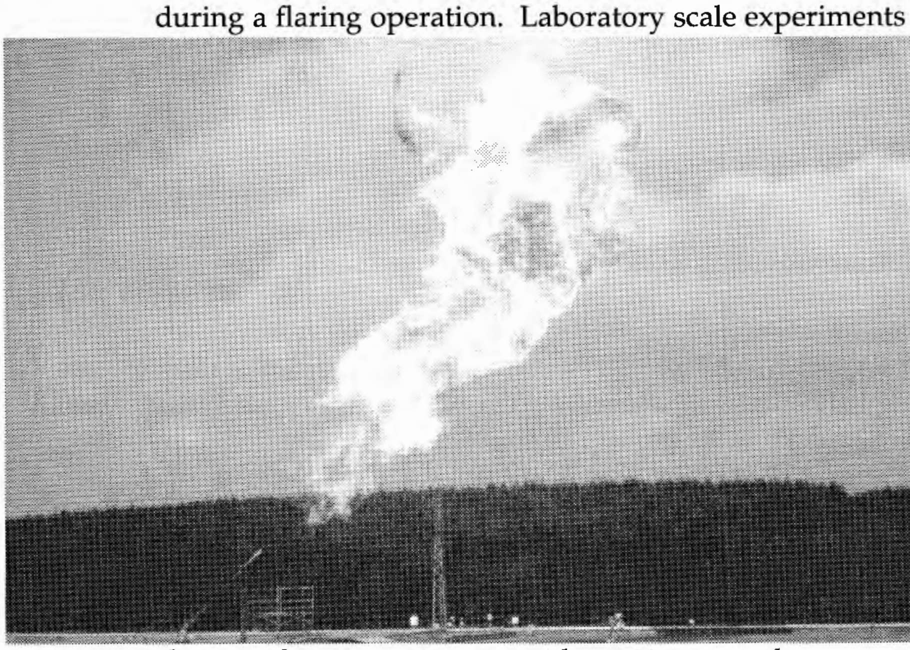
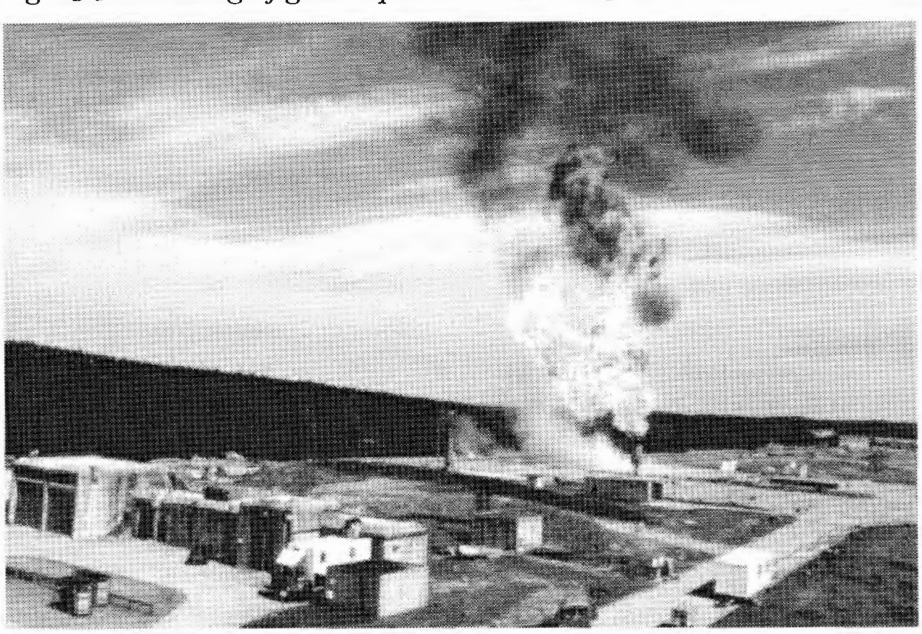


Fig. 13.5.1 Flaring of gas. Experiment with a 300mm stack.

Measurements of the thermal radiation emitted by a high pressure gas flare showed that although the maximum emission did emanate from its central region a substantial proportion was emitted from other parts of the flame.



13.5.2 Flaring of gas. Experiment with a 2 metre dia. silencer.

Therefore, it was recognised that in order to predict accurately the levels of incident thermal radiation around a fire, it was necessary to account for this variation in the emission of thermal radiation throughout the whole of the flame.

On the basis of the information obtained from this work an empirical model was developed which provided more accurate predictions than the A.P.I. code over a wide range of operating conditions. Subsequently, a physically based integral model was developed for jet-fires in which a solution is obtained to simplified forms of the conservation equations for mass, momentum and energy which describe the flow field. This integral model is designed to replace the empirical model and also provided an initial theoretical model of a high pressure gas fire suitable for extension to the more complex problem of the ignition of high pressure gas following an accidental release from a damaged pipeline (1)(2).

Fires in Above-ground Plant

Jet-fires resulting from accidental releases of either high pressure natural gas or LPG from punctures or rips in above-ground pipework which occur in congested areas can lead to impingement of the flame onto adjacent pipework, storage vessels or structural members. Failure of any one of these components, particularly those containing flammable or toxic materials, can lead to an escalation of the event.

Comprehensive experimental programmes of work have been undertaken in collaboration with Shell Research Ltd. as part of a Research Programme on Major Technological Hazards initiated by the Commission of the European Communities (C.E.C), and in collaboration with other major gas companies from throughout the world. The effect of interaction with the ground, adjacent pipelines and adjacent buildings on the size shape and thermal radiation characteristics of natural gas jet-fires has been examined (Fig. 13.5.3).

In addition natural gas and propane jet-fires involving flow rates in the range 1.5 to 20 kg/s were impinged horizontally onto an empty 900mm diameter, 16m long pipe and an empty 13 tonne LPG storage vessel in order to study the heat transfer to their surfaces. The results of this work demonstrated that the heat transfer to an object subject to jet-fire impingement varies considerably over its surface and that the application of uniform rates of heat transfer over the whole of the surface, as currently recommended in the literature, would lead to erroneous predictions. The data obtained from this work greatly extends the industry knowledge of heat transfer to components subjected to jet-fire impingement.

Fig. 13.5.3 Pipeline fire. Release from a 75mm hole at 20 bar.

Implementation of Results

The results of all this work have been used by British Gas engineers and others to aid in the formulation of Codes of Practice for the design of high pressure plant and pipeline systems. The availability of accurate data on radiation levels, flame sizes etc. has often avoided the need for over restrictive stipulations on proximity distances. The data has also been an essential input to the preparation of safety cases for major hazard sites for submission to the HSE.

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13.6 Vapour Cloud Explosions

M.Wickens

Background

In June 1974, a huge explosion at the Nypro chemical plant at Flixborough on Humberside destroyed the plant and caused extensive damage to properties within a radius of several miles. The explosion was produced by the ignition of a flammable vapour cloud,which had formed over part of the site following the accidental release of approximately 40 tonnes of cyclohexane.

Incidents such as occurred at Flixborough are known as vapour cloud explosions. They are extremely rare events, and have never occurred following the accidental release and ignition of either pipeline natural gas or liquefied natural gas (LNG). Nevertheless, the Flixborough incident stimulated the start of a new research project at MRS in 1975, designed in particular to establish whether or not a vapour cloud explosion could occur with either LNG or natural gas, and if so, under what conditions.

Technical Approach

When a vapour cloud burns, the overpressure produced is linked directly to the speed of the propagating flame, and to produce the damage sustained in actual incidents it was known that flame speeds of at least 200-300m/s were required, i.e. up to 100 times greater than are produced by laminar combustion in the laboratory. Initially, therefore, experiments were undertaken at sites at the old Coleshill gasworks and at Potters Marston in Leicestershire, to determine whether flame speeds were related to the size of the vapour cloud involved.

The tests were carried out using natural gas, propane, ethylene and cyclohexane, mixed together with air in meteorological balloons. The balloons were filled to a maximum volume of 120 cu.m and were ignited by a central spark. Flame speeds were only a few metres per second and the overpressures generated were negligible (Figs. 13.6.1 and 13.6.2). Similar experiments on a much larger scale, conducted by other organisations were known which led to the conclusion that vapour cloud explosions could not involve completely unobstructed clouds.

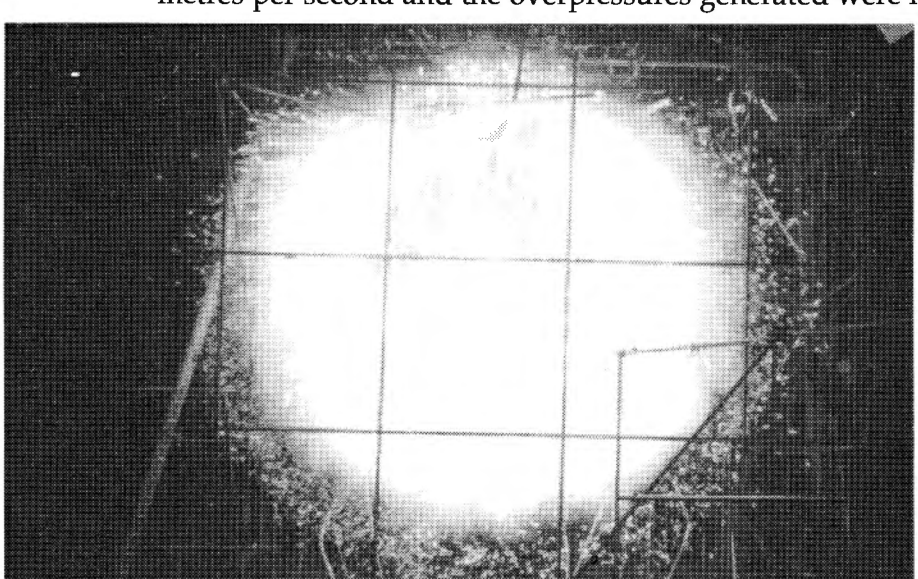

Fig. 13.6.1 Vapour Cloud Explosion (VCE). Early balloon experiment at Fauld.

This conclusion was consistent with evidence from recorded incidents, all of which appeared to have involved clouds which engulfed sections of process plant or areas of forest, i.e. conditions under which flame speeds could be increased by turbulence in

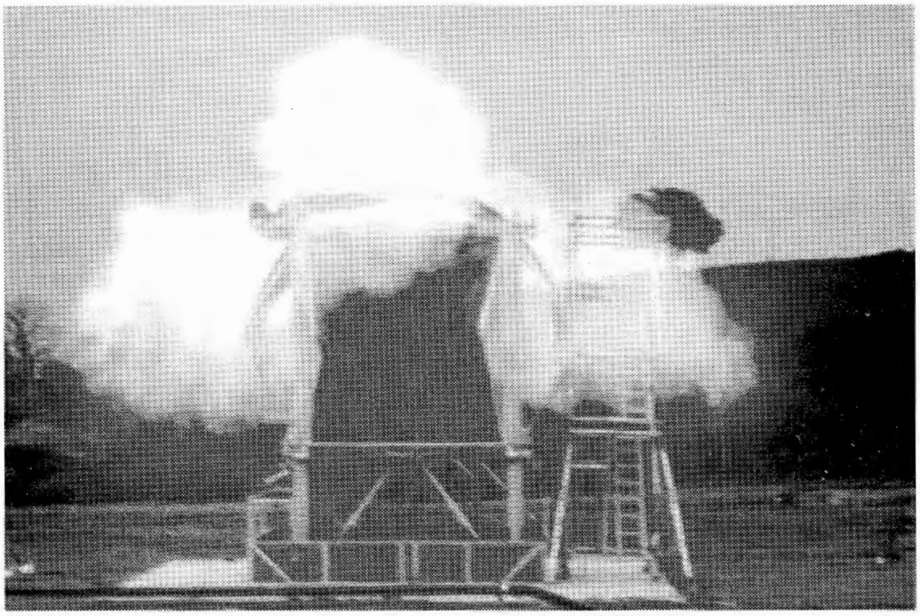

Fig. 13.6.2 Vapour cloud explosion which went sadly wrong. Experiment with a collapsible enclosure at Fauld to avoid all restriction to flame propagation. The collapsible shutters holding the air-gas mixture failed to move at the appropriate time with the unfortunate result shown here.

the gas-air mixture ahead of a flame. Therefore, in the late 1970's and early 1980's, experiments were carried out at the newly acquired Fauld test site, near to Burton-on-Trent in Staffordshire, to investigate whether high flame speeds might be developed if flames propagated through a cloud which engulfed repeated obstacles, simulating buildings, process plant, pipe runs or trees.

This work was conducted in a polythene covered test rig, 3m by 3m in cross-section and initially 18m in length, although this was soon increased to 45m. To ensure that it did not affect the flame propagation, an ingenious system of travelling knife blades was devised to cut the polythene free along all of the edges of the test rig just prior to ignition by a spark at one end of the rig. Pipework obstacle arrays were spaced at regular intervals over part or all of the length of the test rig.

These experiments provided a direct demonstration that obstacles readily accelerated flames propagating through gas-air mixtures involving ethylene, propane or cyclohexane, to speeds which generated damaging overpressures (Fig. 13.6.3). It was also shown that when high speed flames emerged from a region of repeated obstacles into an unobstructed region, the flame decelerated to speeds characteristic of completely unobstructed propagation, i.e. a few metres per second. Another important result obtained from this work was that flame acceleration was more difficult to achieve with natural gas, although very high flame speeds and overpressures were produced in a test using severe congestion and involving ignition within a confined region. In fact, the test rig was badly damaged in this experiment (see Fig. 6.29 in Chapter 6) and resulted in the work being transferred to the more remote test site at Spadeadam in Cumbria, and

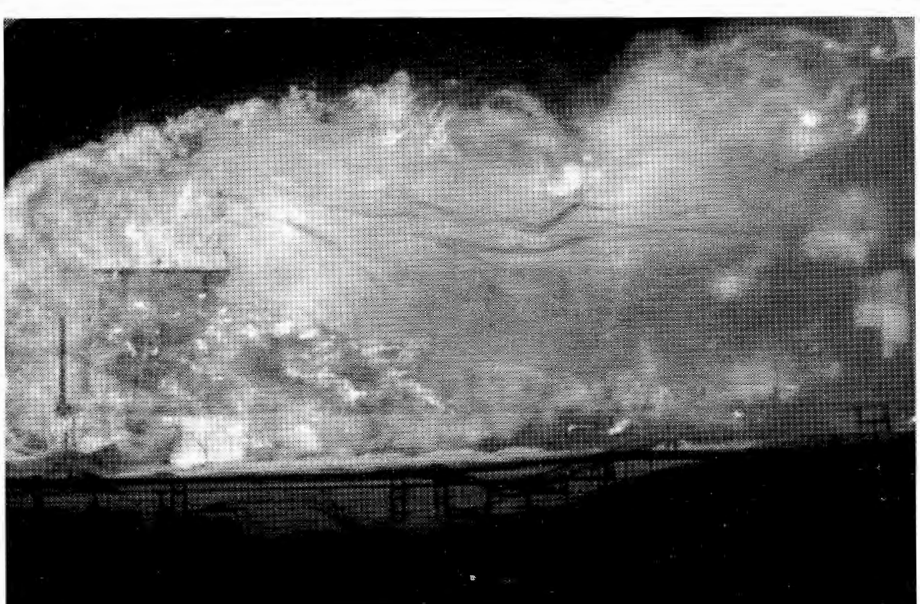

Fig. 13.6.3 Turbulent flame propagation in a congested vapour cloud.

the construction of a much more substantial test rig!

At Spadeadam, further tests showed that with natural gas, high flame speeds could only be produced and sustained when the degree of congestion was particularly severe (Fig. 13.6.4). Below a threshold level of congestion a high speed flame either did not develop, or if a flame entered a less severely congested region at high speed, it rapidly decelerated (1). Under much less severe conditions, detonations were produced with propane and cyclohexane, which despite the remote nature of the site, sometimes prompted complaints about noise levels from up to 15 miles away.

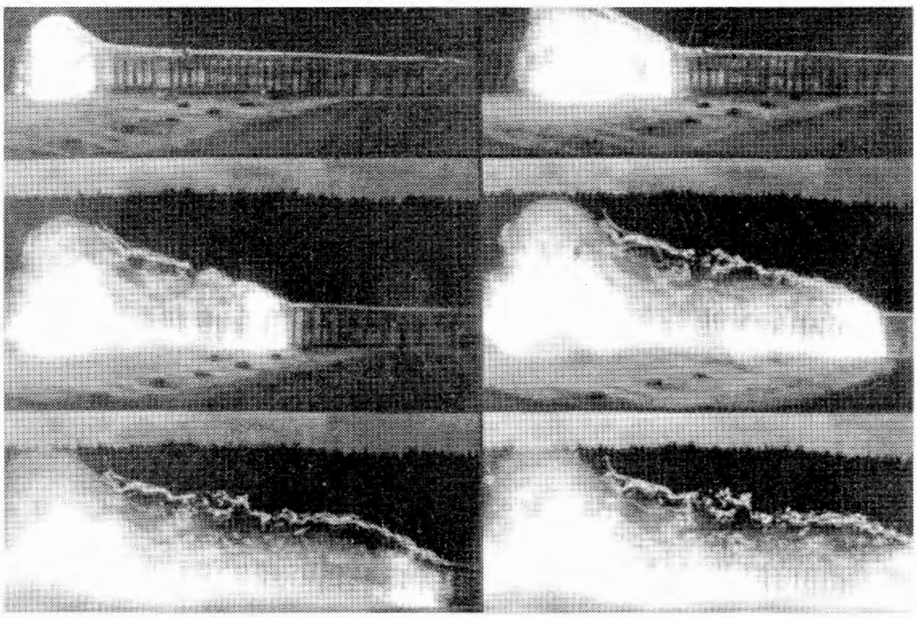

Fig. 13.6.4 Development of high speed flame propagation in a congested natural gas cloud.

To obtain detailed information on the range of obstacle conditions which could sustain high flame speeds in natural gas-air mixtures, a more practical approach than conducting a large number of expensive large scale experiments was adopted. This involved conducting experiments at small scale, in a way such that the results obtained could be applied to larger scales. To overcome scale dependent combustion processes, which would otherwise have meant that flame speeds and overpressures generated in small scale experiments would not have reproduced large scale combustion behaviour, a technique based on oxygen enrichment was devised (2). In the late 1980's, this technique was employed successfully in experiments using a 1/5th scale replica of a particular congested pipe-rack on a British Gas LNG storage site, to demonstrate for a Safety Report prepared under the Control of Industrial Major Accident Hazards (CIMAH) Regulations, that ignition of a natural gas vapour cloud in this region would not generate damaging overpressures.

Implementation of the Results

Results from the MRS research have enabled guidelines for new plant design to be specified to reduce the hazard if ignition of a vapour cloud were to occur following the accidental release of gas. In addition, they have been used to develop a new basis for predicting the overpressures generated in vapour cloud explosions which might occur at natural gas storage or processing sites, which in comparison with methods previously used, has a significant effect on reducing both the probability and consequences of such an event. In particular, where any cloud formed would not engulf regions of repeated obstacles, the methodology can be used to argue that vapour cloud explosions cannot occur.

The detailed understanding of the causes and consequences of vapour cloud explosions which has been obtained from the MRS research, was presented in a paper (1) given to the Autumn Research Meeting of the IGE in 1989, for which the authors were subsequently awarded the Institution's Gold Medal for that year.

Current Research

Having demonstrated the mechanisms which can lead to vapour cloud explosions, work is now continuing to develop an experimentally validated model for predicting flame speed and pressure generation during the combustion of a vapour cloud which envelops a congested region. Some of this work involves collaboration with other European research organisations and is also receiving funding from the Commission of the European Communities.

Offshore Explosion Hazards

Following the incident on the Piper Alpha platform, in the late 1980's increasing attention was paid to explosion hazards offshore. This work built on the understanding which had been developed from the work on vapour cloud explosions and particularly addressed the possible use of water sprays (3), already fitted as part of deluge systems for fire protection on offshore platforms, as a method of explosion suppression (Fig.13.6.5). Experiments were carried out in a number of different test rigs, including a geometry representative of an offshore module, and clearly demonstrated that water sprays produced by currently existing deluge systems are an effective technique for mitigating explosions in congested environments, with overpressures reduced by up to an order of magnitude. As a direct result of this work, the decision was taken that in process modules on British Gas offshore platforms, water deluge would be initiated on confirmed gas detection rather than flame detection.

Fig. 13.6.5 Water spray curtains to cause deceleration of a high speed flame.

Ultimately, the research should help to specify designs for nozzles specifically to produce water sprays which are even more effective at reducing the severity of an explosion.

Overall, as a result of the research which has been carried out, the Midlands Research Station became recognised world-wide as a centre of expertise on gas cloud explosions and helped British Gas to make a major contribution to gas safety.

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13.7 Gas Dispersion, LIDAR, Ignitability

D.R. Brown

Background

The development of the high pressure national transmission system and a new approach to safety in the UK, through the formation of the Health and Safety Executive, followed in rapid succession in the 1960's and 1970's. These changes introduced a variety of new safety related problems for British Gas, mainly related to the scale of possible releases, fires and explosions following any failure of the high pressure transmission system. The extent of the resulting hazards was of critical importance in determining the sterile areas necessary for safety around all installations and pipelines.

The problem was therefore, to determine how gas dispersed following a release, and how and where it could be ignited. The need to determine dispersion distances from high pressure pipelines was a new problem, it did however, conveniently follow on from an existing programme on gas/air mixing in large industrial burners and so in the mid 1970s, work commenced on studies of gas dispersion, initially from high pressure sources, although due to safety studies by the HSE at the Liquid Natural Gas (LNG) importation terminal at Canvey Island, the scope of the work was extended to studies of the dispersion of dense cold gas.

Technical Objectives

The technical objectives were relatively straight forward;

(1) to determine the distance required to disperse gas to its lower flammable limit(LFL) from both high pressure sources, such as those which would arise from pipeline failures and also to determine the dispersion distances from releases of dense cold gas, such as those possible from LNG spills.

(2) To establish the relationship between the gas/air mixture and the possible ignition of such releases.

Clearly, in the case of pipeline gas releases, the effects of pressure (up to 70 bar) would introduce a new problem compared with leakage from low pressure mains. The release would be sonic and compressibility effects would have to be considered.

As far as LNG was concerned the effects of temperature on density would affect any dispersion process as would the effects of heat transfer as the cloud acquired heat from its surroundings.

Whereas these physical phenomena could be considered from basic physics it was quickly realised that the need to consider the effects of the surrounding atmosphere, its wind speed and wind direction, the atmospheric stability (which encompasses the atmospheric temperature and density effects), would considerably complicate the dispersion processes and limit the use of more classical laboratory tests. This limitation of controlled laboratory tests was also increased by the sheer size of potential releases.

Technical Approach

The technical approach had four main aspects;-
(a) to build on previous laboratory experiments on gas/air mixing,
(b) to investigate and utilise wind and water tunnel modelling techniques, to quantify atmospheric effects and to examine scaling in conjunction with the laboratory work,
(c) to use laboratory and wind tunnel tests to help plan and optimise a limited series of large scale field trials and finally
(d) to develop a series of mathematical models to allow the prediction of gas dispersion in the atmosphere.

Laboratory Experiments

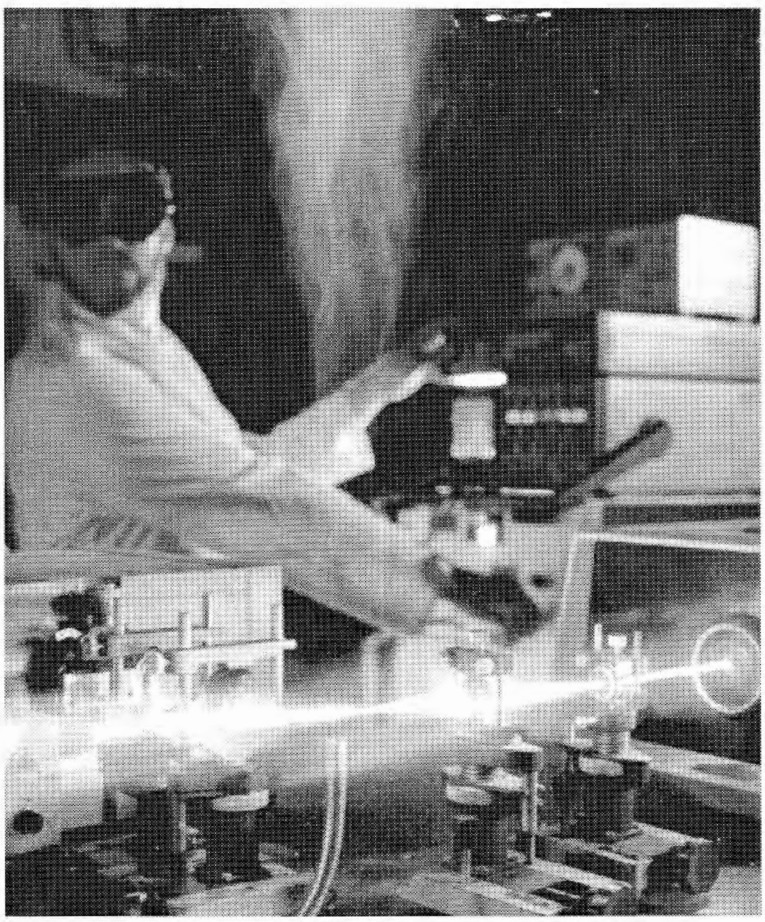

Fig. 13.7.1 Laser Anemometer velocity measurements on natural gas jets.

The mixing of gas from a high pressure source is controlled by the momentum of the release and the mixing takes place as a result of the shearing action of the release with its surroundings. Such releases are known as jets and are invariably turbulent in nature. This meant that techniques had to be developed which would measure both mean and fluctuating components of the velocity and gas concentration in the jet. In the mid 1970's work was progressing at MRS to develop laser techniques for measuring velocity (Fig.13.7.1) and these methods were expanded to measure concentration with the development of a technique known as Laser Raman Spectroscopy. The technique was not new but the use of photon correlation spectroscopy (a spin off from laser anemometry work) to process the Raman signal was developed at MRS. This method allowed the probability density distribution of concentration to be measured from which a full turbulence description of the concentration field could be obtained (1).

The next phase of the work was to examine the influence of the time dependent nature of the flow on the ignitability of the release (2). Through the development of a simple model of flammability, which related the chemical ignition time scales to the time scales of the presence of turbulent eddies of flammable mixture, and a large number of ignition trials, a full description of the ignition characteristics of the jet were measured.

Fig. 13.7.2 presents the data and indicates the importance of considering the turbulent nature of the flow as opposed to using the classical steady state flammability limits of 5 and 15% (2).

The influence of pressure on the dispersion process was studied in the laboratory through the use of Schlieren photography (Fig 13.7.3) and a simple mathematical model describing the effect of pressure on the apparent size of the jet orifice, due to further expansion of the gas downstream of the physical jet exit was developed(3).

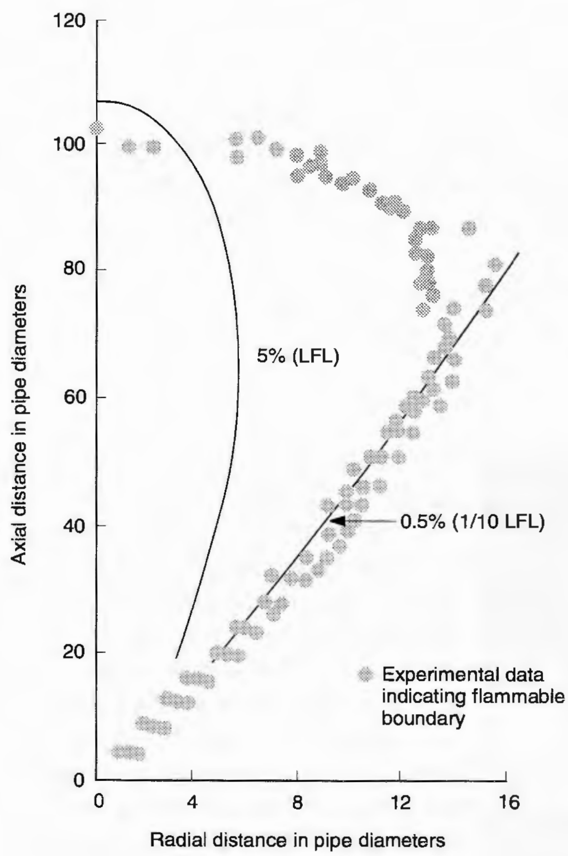

Fig.13.7.2 The flammable boundary for complete light up of a natural gas jet, showing also the 5% and 0.5% mean volume fraction concentration contours.

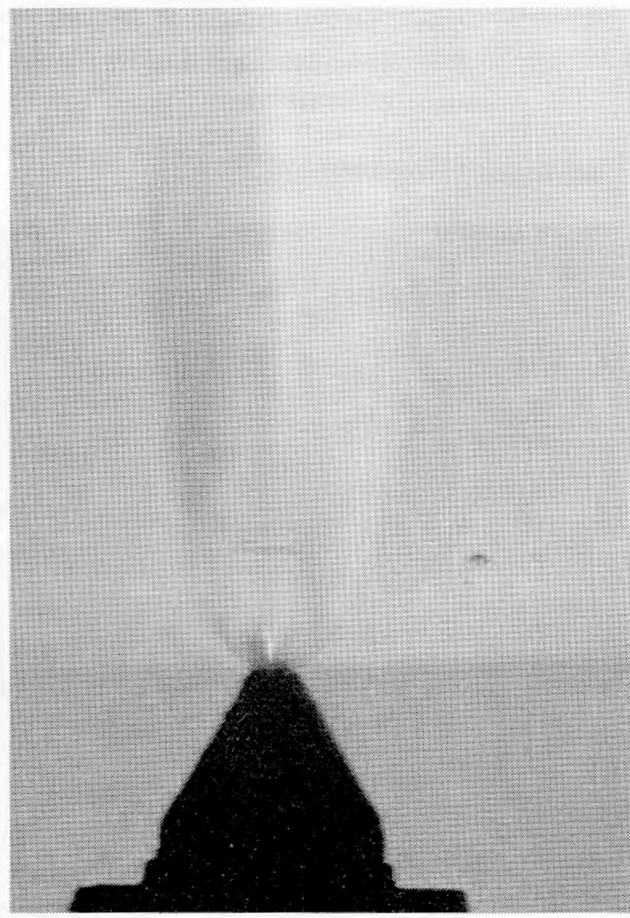

Fig. 13.7.3 Jet entrainment studies. Schlieren picture of an unignited supersonic natural gas jet, showing shock fronts.

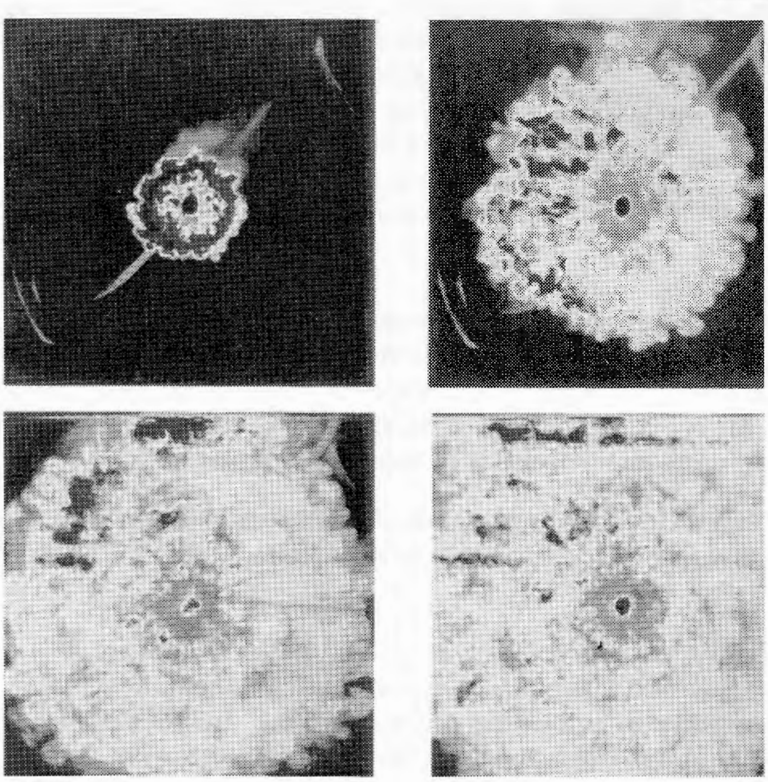

Fig. 13.7.4 Laser sheet image of an impacting jet.

This aspect of the work was completed by the mid 1980's and more recent work has concentrated on studies of jets impacting on adjacent surfaces and in developing two-dimensional laser imaging techniques to measure the concentration field in two dimensions simultaneously. Fig 13.7.4 shows the form of data which can be obtained on an impacting jet.

Wind Tunnel Studies

The need to determine the effects of the atmosphere on the mixing process and the extent of the hazard zone led to the use of wind and water tunnels in the late 1970's and 80's. At this time British Gas hired a number of wind and water facilities in the UK and in Europe to study the gas dispersion from pipeline failures, venting, gas holders (known as light or buoyant gas dispersion) and dispersion on LNG from failures at sea and on land (known as dense gas dispersion) (4).

The need to understand the necessary criteria for correct scale modelling was critical to the work and while it had its limitations, it helped to define a number of larger scale field tests at the newly acquired Spadeadam test site.

The use of wind tunnels continued throughout the 1980's with the work being extended to studies of ignitability and fires in cross winds (5). This reliance on wind tunnel techniques was such that in 1988 the decision was taken to build a wind tunnel at the Fauld Test Site specifically for the study of dispersion and fires. Fig. 6.31 in Chapter 6 shows the tunnel being used to study safety aspects related to an offshore platform, an area of work which has become increasingly important since the Piper Alpha disaster.

Later wind tunnel studies looked at the effects of cross winds on dispersion of flammable and toxic gases, fires, ventilation within structures and smoke movement within and around structures.

Field Trials

The need to understand the effects of scale on the physics of the dispersion process and the potential scale of releases possible from pipelines and LNG ships and storage tanks meant that some definitive large scale tests were required. Scaling was particularly important in the case of dense gas releases. The size of the tests needed was beyond the capabilities of a single company's efforts and so the HSE set up a European collaborative programme under the auspices of the EEC to undertake this work. British Gas was a major collaborator in this work which took place at Thorney Island (5).

However, in the case of dispersion from pipelines British Gas took responsibility for the work. This involved the development of a unique facility at the BG Spadeadam test site to release and control high pressure gas at pressures up to 70 bar, to develop methods of measuring the dispersion process and to confirm the ignition properties of the release under a range of wind speed conditions.

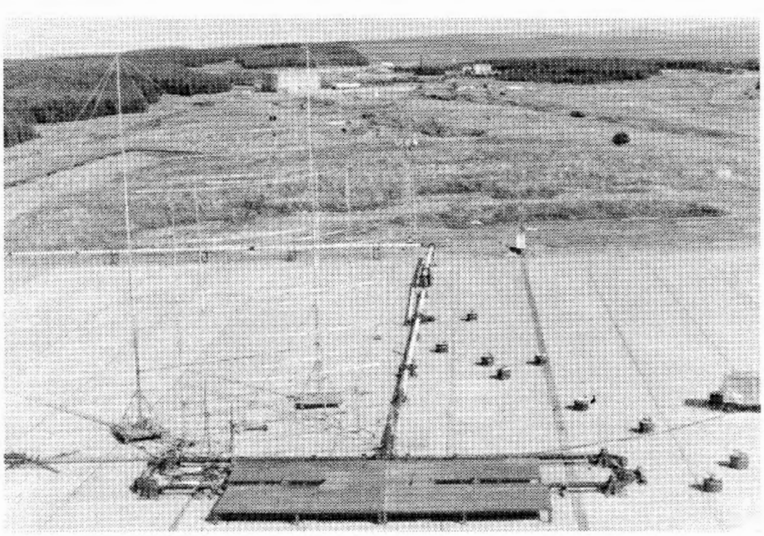

Fig. 13.7.5 Probes and masts being used at Spadeadam.

Work commenced in the late 1970's to use probe techniques (6) to measure gas dispersion from a wide range of releases. Fig. 13.7.5 shows the array of masts and probes required. It soon became obvious that because of the difficulties in forecasting wind direction days in advance of a test, in order to set up the probes downwind of the release, the development of some kind of remote sensing technique would be advantageous. The feasibility of using LIght Detection and Ranging (LIDAR) techniques was established and in 1981 a LIDAR system based on Raman Spectroscopy was constructed and delivered to British Gas (see Fig. 6.30 in Chapter 6 and Fig. 13.7.6). The unit has been used for a variety of gas dispersion problems where probes cannot be used (7). At the time of writing, the possibility is being examined of building a remote sensing Differential Absorption LIDAR (DIAL)system to extend the dispersion work to the measurement of parts per million (ppm) levels of concentrations of toxic gases as opposed to percent levels for flammable gases. In addition, CEC sponsorship has been obtained for a three year programme .

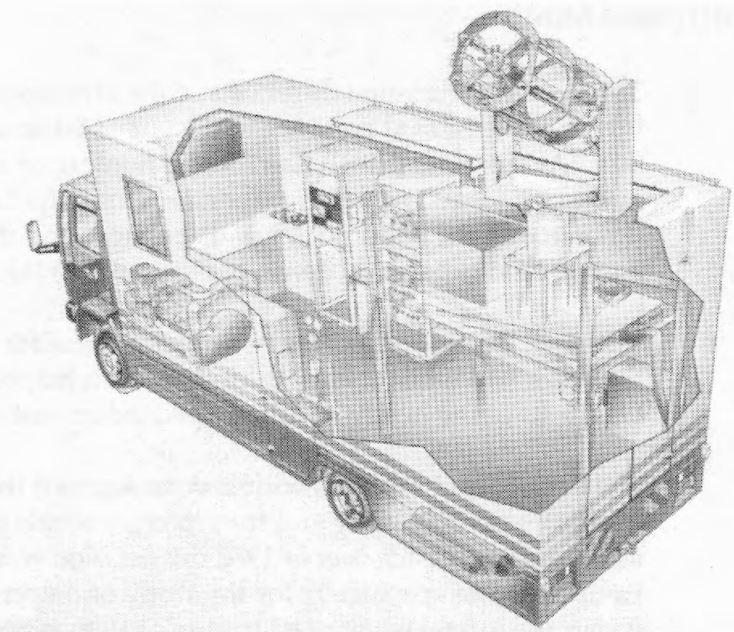
Fig. 13.7.6 Cut away diagram of the LIDAR system in the 10 tonne truck.

Implementation of the Results

The programme of work achieved its objectives and produced definitive data on gas dispersion distances and ignition characteristics of jet releases (8). In addition a number of British Gas and IGE standards and codes of practice have been made quantitative by the use of the data on jet dispersion.These include new British Gas and IGE standards on hazardous area classification (BG SHA1), Venting (IGE TD9 and BG SGV2) and proximity distances for Gas holders (SR4).

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13.8 Development of Predictive Techniques for Safety Applications

M. Fairweather

Background

The safe design and operation of industrial facilities which store or transport flammable materials necessitates an understanding of the consequences associated with operational and emergency releases of such materials. The consequences associated with accidental releases must also be assessed since, despite the care taken in the design and maintenance of installations handling these materials, there still remains a small probability that such a release might occur.

Consequence assessments allow appropriate safety procedures to be drawn up to cover any operational or emergency release, as well as providing information to assist in devising means of mitigating the effects of accidental releases. At the planning stages of any facility, they also allow safe distances to be determined which can be used in the design of intrinsically safe plant.

The specific consequences that need to be assessed include the heat transfer loads that plant and personnel might be subjected to in the event that a release results in a fire, and the overpressures that might result from explosions of premixed fuel gas-air mixtures in confined and congested environments. Coupled to these predictions are assessments of the response of structures and items of plant to the heat or overpressures to which they might be subjected. In addition, assessments of the way in which gas disperses in both open and congested environments form an integral part of any safety assessment.

Predictions from models are frequently used as the basis of safety cases and risk assessments on existing and proposed installations. In using mathematical models to predict the consequences of operational and accidental releases, it is necessary to demonstrate their ability to yield reliable results over a wide range of practical conditions through comparisons between model predictions and suitable experimental data.

Technical Approach

In providing mathematical tools for predicting the consequences described above, it is possible to adopt mathematical modelling techniques of varying levels of complexity. When safety related work began at the Midlands Research Station, limitations in the power of computers available at the time meant that the only viable way to provide reliable predictive tools for use within the industry was to develop what are known as empirical models. Gas dispersion, fire and explosion experiments at both a laboratory and field scale were therefore performed in order to generate reliable data over a wide range of conditions. Predictive models were then developed by fitting the experimental data in a form, generally based on dimensional analysis, that captured the essential physics of the hazard of interest, and thereby allowed the derived correlations to be applied with confidence over a range of scales.

As an example, experiments were conducted on fires in both wind tunnel flows and at a field scale in the atmospheric boundary layer in order to provide information for the derivation of a model of flaring operations. These data were in turn used to derive correlations that were capable of predicting the length, width and trajectory of a flare, for given gas flow rates and vent stack diameters, as well as its radiative characteristics. The information obtained from these correlation was then used to construct a mathematical model capable of predicting the radiative heat flux received at locations around a flare (1). Similar models for a variety of gas dispersion and explosion scenarios were also derived (2), (3).

Empirical models represent the simplest type of predictive method available, and are ideally suited for routine hazard assessment purposes because they are mathematically simple and easily embodied in computer programs with short run times. The main disadvantage with empirical models is that, because of their very nature, they have a strictly limited range of applicability dictated by the amount and extent of experimental data available for a given release scenario. Their extension to different release scenarios may also introduce unacceptable errors if relevant experimental data is not available to cross-check the predictions.

Phenomenological Models

Because of these limitations, the advent of more powerful computing resources provoked the development of more complex models. In deriving these models, known generically as phenomenological models, more details of the physics of a particular hazard phenomena were incorporated into the predictive methods in order to enable them to be more accurate and generally applicable than the simpler empirical models. These models strike a balance between achieving a fundamental description of the physics of a particular process and ensuring that the computational demands of the model are acceptable. This in turn requires a detailed understanding of the processes of interest in order that a simplified model, which only attempts to capture the most important underlying physics, can be derived.

Examples include models of explosions in which a thermodynamic description is used to represent the conservation of mass and energy during the combustion process, and as a result enable the prediction of explosion generated overpressures (4). Integral, or similarity, models have also been formulated for gas dispersion (5) and fire applications (6). These models invoke the assumption of self-similarity within a flow field in order to base predictions on solutions of simplified forms of the fluid dynamic equations. All these models contain some simplified description of the important physical processes involved in a given release scenario, and by adopting this approach have been developed as predictive tools that can be applied to a wide range of scenarios, but which have relatively short computer run times making them ideal for routine use.

Computational Fluid Dynamics

More recently, the advent of powerful computer workstations and supercomputer resources has allowed the development of a third class of predictive models. These are known as numerical models (7), and are based on computational fluid dynamic techniques which generally involve full three-dimensional, finite-difference solutions of the fluid dynamic equations which describe turbulent non-reacting or combusting flows. They represent the other extreme from empirical models in terms of complexity, being mathematically complex and embodied in sufficiently large computer programs to make their run times restrictively long for routine use. Provided sufficiently accurate sub-models of the most important physical processes occurring in the flows of interest are included, however, their fundamental nature means that they have a wide range of applicability and can be applied with only minor modification to a variety of release scenarios.

Implementation of Results

Empirical and phenomenological models are used routinely for performing consequence and risk assessments, and in other applications where turn round time is an important consideration. All the types of model described above, including numerical models, are used at the design stage of installations where run time constraints are not important. In addition, numerical models are also used to provide predictions of particularly complex flow phenomena which cannot be handled by the simpler approaches, as well as in the design and validation of the simpler approaches themselves.

A number of models have also been assembled in packages for use by safety engineers in computerised consequence assessments. As well as the predictive models themselves, these packages also contain geometry databases representative of particular industrial plant, and user-friendly pre- and post-processing facilities. Most notable amongst these is the CHAOS package, described in detail elsewhere in this document, which allows safety assessments of offshore structures. This package contains a suite of interactive theoretical models, grouped into areas of fire loading, fire response, blast loading and blast response. The use of such packages represents a further extension to the mathematical modelling work described above, and their increased use in the future will ensure that the detailed predictive techniques developed within R & T continue to be transferred for use in other parts of British Gas in as efficient a manner as is possible.

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13.9 CHAOS Enhances Offshore Safety

M W Vasey

Background

Following the disaster on the Occidental Piper Alpha platform in the North Sea in July 1988 British Gas was in the position, like all other offshore operators, of needing to review its offshore operations. Although little R&D work had been done by British Gas specifically on fire and explosion hazards offshore, the expertise that had been developed within R & D for onshore problems was available to consider this new problem area.

Technical Approach

Immediately following the incident on Piper Alpha, Research & Technology were requested by British Gas Exploration & Production to undertake a short-term study of the consequences of a major release of flammable gas on any of the British Gas offshore platforms, irrespective of the probability of that release. This study was largely concerned, therefore, with the development and consequences of gas explosions in an offshore environment.

The project was completed and reported by the end of 1988. The work, which was carried out jointly by MRS, on blast loading, and ERS, on blast response, showed that the consequences of an explosion offshore could be extremely severe. The work was able, however, to make some structural and operational recommendations, concerning vessel attachments and the use of water deluge, in addition to highlighting many areas of necessary future research.

Following this preliminary study into offshore explosion problems, specific work on offshore safety was introduced into the R&D programme from April 1989. This work involved the study at MRS of possible blast and fire loadings offshore, complemented by studies at ERS on the resultant blast and fire response of the structure and plant. The first target of this work was the provision of an initial set of user models on a computer workstation by the end of September 1990. These models were to be able to handle fire, dispersion and explosion predictions on any British Gas UK waters platform.

In order to develop these models, laboratory and wind tunnel experiments were carried out to provide basic data on fires and gas dispersion within an offshore module. Preliminary explosion experiments and blast and fire response tests were also carried out at Spadeadam. The outcome of one explosion experiment is shown in Fig. 13.9.1. These experiments all fed in to the production of the first generation package of predictive techniques. This package was mounted on a computer workstation and a user-friendly front-end was developed for the whole package. Fig. 13.9.2 shows an example of the advanced graphics which are available within the package to display the geometries being considered and the predictions which are made.

The prototype version of the package was delivered, on time, at the end of September 1990. The package was given the name of CHAOS (Consequence and Hazard Assessment of Offshore Structures). Thus, from October 1990 British Gas had a working package on which to assess safety issues on its offshore platforms. This package not only provided ease of use, but also the most up-to-date techniques available to any operator. The lead which British Gas had in this field was recognised by the Department of Energy and by many other operators. Indeed, British Gas wrote an expert review of the offshore explosion problem, under contract to the Department of Energy (1), and gave evidence on the possible mitigation of explosions by the use of water deluge to the Cullen Public Inquiry into the Piper Alpha disaster (2).

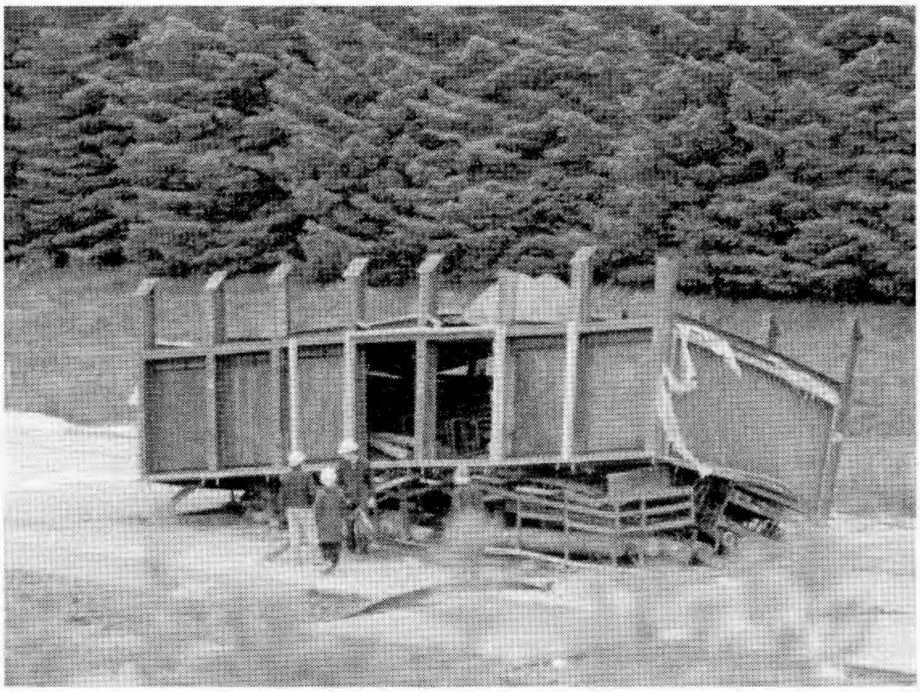

Fig. 13.9.1 Outcome of an offshore module explosion experiment.

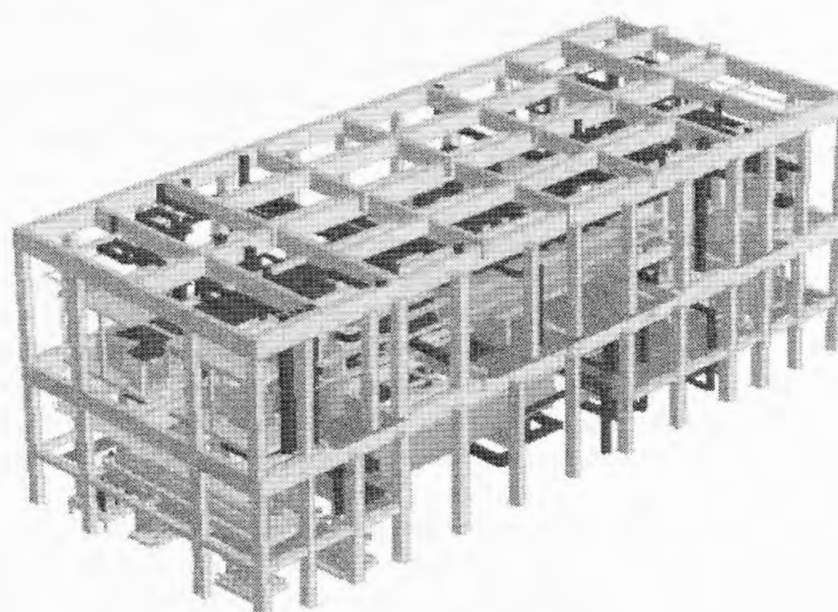

Fig. 13.9.2 Example of an offshore module contained within the CHAOS computer package.

Implementation of the Results

Some of the practical ideas suggested after the preliminary study of offshore explosions were used very quickly. In 1989 new legislation was introduced which called for the specific location of pipeline emergency shut-down valves on offshore platforms. This legislation resulted in most other operators being forced to relocate these valves at a very significant cost. The legislation also called for the protection of the valves from fires and explosions to ensure that they closed in such an incident. British Gas Exploration and Production (E&P) proposed a strategy which was an alternative to the relocation of the valves. This strategy embodied the enhancement of overall topside safety on the platforms. The strategy was crucially dependent upon novel blast and fire mitigation techniques developed by R&T.

E&P were able to convince the Department of Energy that, because of its long commitment to research in this area, British Gas R&T were the leading experts in the field of blast and fire engineering using state-of-the-art technology. Hence the alternative strategy, using the techniques developed and demonstrated by R&T, was accepted. The acceptance of this alternative strategy led to savings of around £20 million for E&P operations, in addition to enhancing the safety of British Gas offshore platforms.

Thus, two major benefits had already emerged from this work. Firstly, a unique consequence assessment package had been produced which could be applied to any current British Gas platform to supply the information required for any future legislation. Secondly, the expertise that had been developed had been applied in responding to existing legislation, with the result that safer solutions at lower cost had been found.

The publication of Lord Cullen's report on the Piper Alpha disaster in November 1990 had confirmed the forthcoming statutory requirement for Offshore Safety Cases, and provided clear evidence that all operators would require access to a suite of predictive codes, such as those contained within the CHAOS package. This requirement was emphasised by a strong response from other Companies to proposals to make the CHAOS package available commercially through a licensing agent. At the time of writing this licensing process is in the final stages of legal agreement.

Benefits

Although quite costly, offshore safety research certainly has an attractive cost/benefit potential. A figure of a benefit to the Company of £7 million per year has been estimated. This comprises savings in actually carrying out calculations for Offshore Safety Cases and also savings in operational costs from the cost-effective safety solutions identified.

Further Work

The programme from October 1990 represented the logical continuation of the development of the CHAOS computer package. Model validation and enhanced user interaction were the first two key areas which were to be addressed.

In addition to internal funding every effort has been made to attract external funding for the more general parts of the work. Funding has been obtained from the European Community for some of the explosion, fire and toxic gas dispersion work. In addition, British Gas has been involved in a Joint Industry Project, along with Shell, reviewing the whole area of blast and fire engineering offshore. This project, which was supported by 29 sponsors, including every North Sea operator, also made recommendations for necessary future research. Much of this overlapped with the internal British Gas programme and hence should attract more funding to parts of that work, or else jointly fund its execution by another organisation.

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13.10 Risk Assessment and Fault Tree Analysis

H.F.Hopkins

Background

Safety studies carried out by MRS and described elsewhere in this history have typically been concentrated in two main areas: the study of the consequences of releases of gas from pipes and vessels, and the identification and control of the mechanisms by which explosions could occur in gas-fired plant.

While the causes and consequences of releases which have been identified and studied can be eliminated, there inevitably remain hazards from any process involving the transport, storage or utilisation of a form of energy such as natural gas. What then becomes important is the likelihood of the hazard being realised, in other words the risk, where risk is defined as the probability of the occurrence of a particular consequence such as a casualty or property loss resulting from an accident or failure. Risks can be either individual or societal where individual risk is the risk per year of a person in a particular location, or carrying out a specified activity, becoming a casualty. Societal risk relates the frequency of an event per year with the number of casualties which might be caused.

For traditional gas industry activities, such as the distribution and use of gas, an important means of identifying the causes and consequences of incidents and the frequency with which they occur is from the investigation and study of failures and accidents, both when they occur and as trends determined from the historical record. Changes in technology however, affecting the materials and processes employed, and the scale of industrial operations, result in activities for which there is no historical record on which to base judgements. This is the case with the high pressure gas transmission system and associated storage installations which have been developed since the discovery of natural gas in the 1960's and for offshore platforms which have been operated by British Gas since the mid 1980's. For these cases a predictive approach must be followed where the frequencies assessed for particular failure modes are combined with predictions of the consequences of failure to determine the risks associated with these installations.

Safety Guidelines

The use of quantified risk levels to assist with decision making on safety matters was developed in the mid 1960's in the nuclear industry, and in the chemical industry (notably by ICI). British Gas began to study the techniques and the benefits of risk assessment in the early 1970s in Operating Divisions and in the Research Stations. To co-ordinate the growing awareness of the subject within R&D Division a liaison panel, the Safety Guidelines Panel, was set up under the chairmanship of Mr.W.E. Francis. The Panel reviewed the subject and produced a report indicating the advantages of the use of quantitative risk assessment to aid decisions within British Gas on safety matters. This report was considered by the top level committees in British Gas at around the time of the occurrence of a number of serious explosions over the Christmas/New Year period of 1976/77 which brought the safety of gas, and the risk of the occurrence of gas explosions, to the attention of the general public and to politicians, and led to the setting up of the King Inquiry.

The significance of the recommendations in the Safety Guidelines Report was recognised and, to ensure a Companywide consideration of this approach, the Working Party on Safety Guidelines was set up. The Working Party produced a report in 1978 which recommended the use of risk assessment as part of the decision making process on safety matters, and proposed criteria to be used. The criteria were based on an upper, or unacceptable, risk level above which risks must be reduced; and a lower, or trivial, risk level below which no further reduction in risk was considered necessary. Between these two levels the reduction in risk should be considered on a cost benefit basis. This type of approach is generally known as the 'three band' approach and both the approach, and the values chosen for the limits, are still appropriate today provided that the cost benefit approach used to determine the requirement to reduce the risk can be shown to comply with the 'reasonably practicable' requirement of health and safety legislation.

The Working Party recognised the need to consider societal risks, and this has been a major concern of the further development of risk assessment, for major hazard plant and transmission pipelines, and more recently for offshore platforms. The first significant MRS involvement with major hazard risk assessment was the Public Inquiry into the Canvey Island Methane Terminal which was held in 1982.

Canvey

Arising out of a series of planning applications for chemical refinery and oil storage developments in the Canvey Island and adjacent areas on the Thames Estuary the then Safety and Reliability Directorate of the UK Atomic Energy Authority produced, on behalf of the HSE, the first comprehensive quantitative risk assessment of major hazard plant. The assessment published in 1978 included, in the facilities studied, the British Gas Canvey Methane Terminal, which had been used for the import of liquefied natural gas (LNG) since the mid 1960's. A reassessment of the risks was carried out in 1981 and the consideration of all the facilities in the area led to the setting up of a Public Inquiry into the continued use of the Methane Terminal.

The major parties who gave evidence to the Inquiry were the protest groups, the HSE, and British Gas. The British Gas evidence was concerned with the safe operation of the import of LNG by tanker and of the operation of the site for LNG and LPG storage. MRS were requested to provide evidence on the consequences of gas and liquid releases and to carry out a quantitative risk assessment using up to date information from British Gas research, adopting a cautious best estimate approach to the calculations. The MRS contribution was co-ordinated by Dr. David Lucas who used a team of MRS experts to cover LNG dispersion, LNG fires, vapour cloud explosions, risk assessment, and a number of other related topics.

The MRS evidence was founded on research into release consequences and supported by many complementary studies carried out specifically for the Inquiry. The incorporation of this information into the risk assessment, supported by a large number of sensitivity studies, made it very difficult for the evidence to be challenged with any real prospect of success. The outcome of the Inquiry was successful in that the risk from the Terminal was considered acceptable and it was allowed to continue in operation.

A number of useful lessons for MRS were gained from the experience of the Canvey Inquiry: the importance of risk assessment in decisions affecting major hazard plant: the need for, and benefit of, presenting the supporting results at a level which will stand up to legal scrutiny; the quantity and variety of data, information and knowledge required for a full quantitative risk assessment; and the value of risk assessment in determining gaps in the knowledge required and hence the need for further research to obtain the necessary data.

Transmission Pipelines

MRS had carried out experimental work in the 1970s on the hazards from transmission pipeline releases to support the development of design codes such as IGE TD/1. In the early 1980's it was believed that transmission pipelines would require safety assessments to be carried out as a requirement of impending major hazard legislation. A risk assessment procedure was developed, in conjunction with the Safety and Reliability Department of the then Production and Supply Division, to determine the critical issues and any additional R and D requirements, and an assessment was carried out of the risks from the design basis failure modes (ruptures in rural areas, punctures in suburban areas). In order to make such an assessment possible, predictive models were developed from the experimental work previously carried out, to allow the prediction of the thermal radiation from pipeline rupture and puncture fires. A model (DESC) was also developed to allow the assessment of the effects of thermal radiation on people and property by summing the dose received and comparing with predetermined criteria derived from literature data, later supplemented by experimental data from large scale fire tests. The ability to escape to safe shelter or a safe radiation level is taken into account in the calculations.

An additional complication with a pipeline, as compared with a fixed hazard such as a storage vessel, is that a failure could be predicted to occur at any point along its length, and the risk at a specified location will result from integrating the consequences along the length of pipeline which can produce a hazard at that point, the interaction length. Fig. 13.10.1 illustrates the elements involved in a pipeline risk assessment. A program (WINSR) has been written to carry out the integration of the effects along the interaction length and hence the calculation of the individual risk at specified distances from the pipeline. The frequencies of different wind directions, affecting the thermal radiation received, is also taken into account. The program also allows the calculation of the predicted number of casualties, to give the societal risk, for areas of uniform population density. A further program SLRISK has been written to calculate the the societal risk from non-residential developments and activities where the population exposed can vary substantially. This program produces output in the form of frequency-consequence or FN curves.

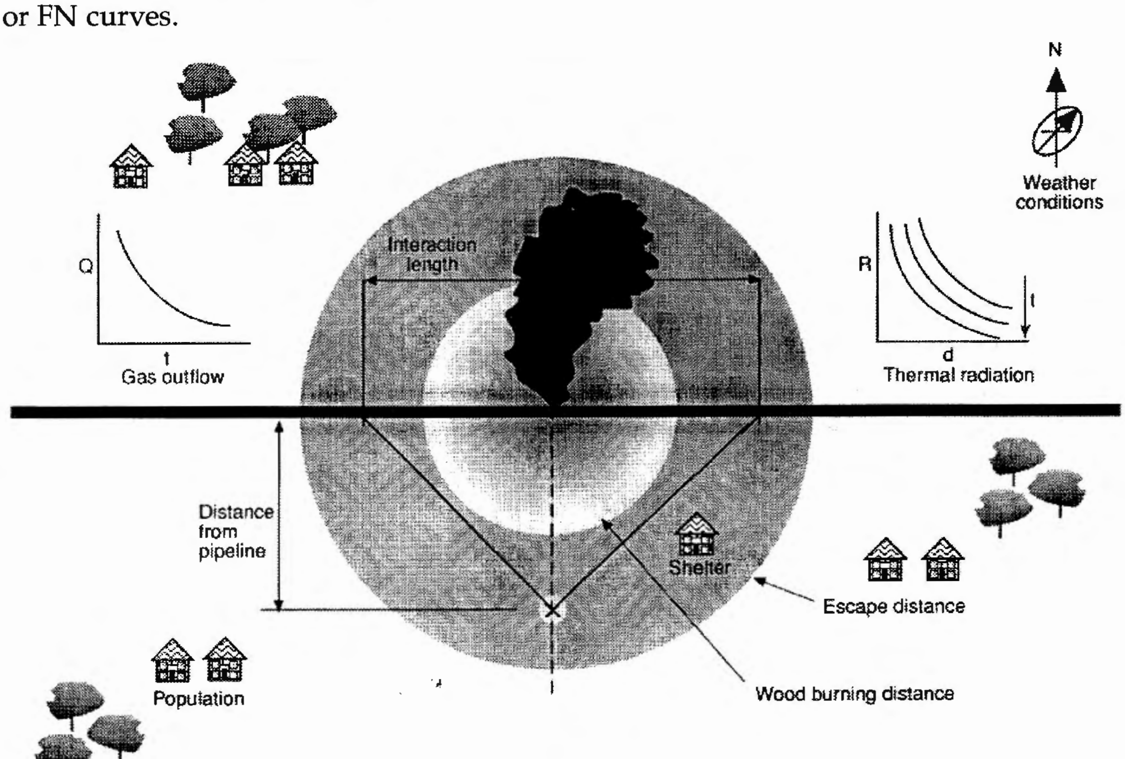

Fig. 13.10.1 Elements involved in a pipeline risk assessment.

Since the development of the methodology for pipeline risks, assessments have been carried out for many operational situations involving design code infringements and land development issues. The number of pipeline risk assessments required is likely to continue to increase. In anticipation of this and the quantity, scope and complexity of assessments of all types required, a collaborative industry approach has been adopted for the development of assessment packages. An assessment procedure is developed and agreed with operating departments; this includes the development of a logic diagram (in essence a form of event tree, a simplified version of that for pipelines is shown in Fig. 13.10.2) for the assessment, the collation of the data, rules and procedures, necessary to access the calculation models used and to produce the results of the assessment, in the form of a knowledge base. This information is then coded into expert system shell software to provide a user friendly flexible and maintainable system. The first package, called TRANSPIRE was for transmission pipelines, and enabled the type of assessments which had been carried out over previous years to be produced in a more efficient and consistent manner.

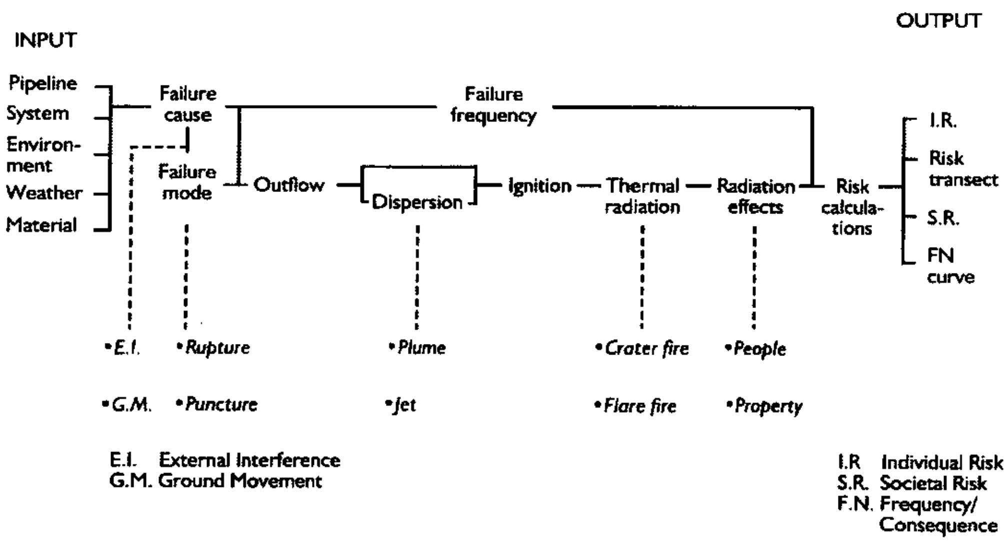

Fig. 13.10.2 Simplified logic chart of TRANSPIRE.

Fault Tree Analysis and Similar Techniques

Fault tree analysis involves a top down approach where the undesired event is called the top event, and the factors or sub system failures necessary to cause the top event to occur are combined in a tree structure using logic gates, normally AND and OR gates. From a knowledge of the failure probabilities of the sub components the tree can be evaluated to give the probability that the top event occurs. Many computer programs have been produced to enable fault trees to be evaluated and R & T, initially LRS and later MRS, have supported and extended the FTAP and IMPORTANCE codes for standard British Gas use.

A more difficult problem than evaluating a fault tree is its initial development from the plant pipework and installation (P&I) diagram. A number of approaches have been investigated or supported including the directed graph (or digraph) approach and the fault tree synthesis programs RIKKE, from the Danish RISO Laboratories, and FAULTFINDER , from Loughborough University. The fault tree synthesis programs use component library models which are then combined to develop the fault trees.

The traditional way of dealing with the events which flow from a specified failure or top event is to use an event tree. Where the sequence involves failures of different systems or components of a plant then a form of event tree called a cause consequence diagram can be used where the options are derived from mini fault trees representing the specific failure condition at each point in the sequence. Cause consequence diagrams are another technique which was further developed at MRS.

13.11 Explosion Incident Investigations

D.J.Moppett and M.J.Wickens

Background

As described in a previous section, research into the effects of gas explosions on building structures and components commenced at MRS in 1968, shortly after the collapse of part of the Ronan Point tower block in London. Since then MRS continued to undertake tests on the effects of gas explosion loadings on structural components, such as brick walls, lighter partition walls and glass windows, and also on accumulation and ventilation of gas in buildings.

As a result of this work, MRS acquired considerable knowledge on the effects produced on buildings by internal gas explosions, and this expertise was offered to the Regions of British Gas, to help with investigations to determine the causes of explosion incidents which occurred in buildings. Initially, these early investigations took place on an informal basis, and were usually requested by Regional personnel who had close contact with MRS. At that time, when a request was received at MRS, on-site investigation assistance was provided by sending a senior member of one of the "explosion" or "gas build-up/ventilation" field trials teams in Special Projects Division who was available (e.g. Peter Cubbage, Dave Moppett, Mike Marshall or Bob Harris), together with a younger team member, who would help to carry the equipment (mainly cameras), take photographs, measure room/window sizes, etc., and generally learn how to conduct investigations!

However, partly as a result of the series of explosions which occurred over the Christmas holiday period in 1976 at Bristol, Bradford and Beckenham and the subsequent King Inquiry, it was recognised that the ability of British Gas to mount an in-depth investigation with the backing of the considerable technical resources of R&D, could have significant benefits to the Company. Hence, more formal procedures for Regions to obtain MRS assistance were agreed in 1977 by the Marketing Policy Committee, and in order to ensure that MRS could always provide a response to any request for technical investigation assistance, a weekly standby rota was instigated at the start of 1978. This ensured that there was always a team of two fire/explosion investigation experts ready to attend an incident, 24 hours a day, 365 days a year. This standby system has formed the basis of the MRS fire/explosion incident investigation service which has been provided to the Regions since that date.

Objectives of MRS Incident Investigations

Fortunately, major gas explosions resulting in loss of life and/or extensive structural collapse or damage, are very rare events. However, it is important to conduct adequate technical investigations in order to help improve safety standards, to ensure effective liaison with any Inspectors from the Health and Safety Executive who may be involved, and to protect the Company against unfounded civil or criminal proceedings. This latter point is also particularly relevant for the less dramatic, although more frequent, explosion incidents which occur within properties, where, irrespective of the actual fuel involved, it is almost always natural gas that is cited by the press, etc. as being the cause. Hence, in fire and explosion incidents it is important to determine the sequence of events which preceded the event, and the three main aims of the investigations which were carried out by MRS were therefore to establish:-

(i) the nature of the flammable material involved (solid explosive, vapourised liquid or gas),

(ii) the type of gas (this is often a matter for legal dispute when determining liability), and

(iii) the source of gas and the reasons for its accumulation within the building or plant.

When conducting investigations, in order to achieve these aims, it is usually necessary to identify the concentration and distribution of fuel within the property, the pressures generated by the explosion and the source of ignition. This requires detailed examination of the forensic evidence at the scene (in particular, the location of any evidence of flame contact with internal surfaces, details of the structural damage to the property, window glass breakage, spread of debris, etc.) as well as any damage to pipework, meters, appliances, etc. This evidence is used to enable calculations of gas build up to be undertaken, the results from which are then assessed to identify the most probable sequence of events leading up to the explosion, which are consistent with the evidence.

Operation of the MRS Incident Investigation Service

To obtain the maximum benefit from any investigation, it was always stressed to the Regions that it is important to call in MRS to visit the site as soon as possible after an incident has occurred, before too much of the evidence is removed or modified by cleaning up of the site. Hence the provision of a two-person MRS investigation team permanently on standby, ready to attend any call for assistance. Being located fairly centrally within the country, MRS was usually able to ensure that an investigation team was on-site at the scene of any incident within a few hours of a request being received. Even then, success could not always be guaranteed. For example, in 1985, Scottish Gas asked for assistance with an explosion which caused substantial damage to a house close to Edinburgh Airport. Within a few hours an investigation team had flown to Edinburgh, but were greeted by the sight of an excavator perched, quite literally, on the top of a pile of rubble - the entire house had already been completely demolished!

Typically, following an on-site investigation, the MRS team sent a simple factual memo setting out their observations and providing minimal interpretation of the evidence. Very often, this was the end of any MRS involvement in the incident. However, in some cases, litigation or prosecution of British Gas then followed, and this involved providing more detailed, interpretative, reports, briefing counsel on the case and giving evidence in Court. Sometimes, in criminal cases the presentation of evidence in Court also had to be given at the direct request of the Police (or Procurator Fiscal in Scotland), and it has not been uncommon for subpoenae to be received by staff at MRS, instructing them when/where to appear in Court! Often, the period between an incident actually occurring and the case coming to Court has been several years. In one case, Malcolm Wickens investigated an explosion at a fish and chip shop in Greenock, Scotland in April 1981 which was caused by petrol, and gave evidence to defend a claim for damages against British Gas Scotland, which was not brought until January 1993!

Since the formal service has been set up, in excess of 250 incidents have been investigated by MRS staff. The members of the investigation teams continue to be drawn from staff who are, or who have been, involved in research into explosions and gas build-up/ventilation, and each comprise of one experienced investigator (at the time of writing Mike Acton, Harry Hopkins, Mike Johnson, Mike Marshall, Brian Parker, John Tite and Malcolm Wickens) and a younger, less experienced person.

Results

The frequency with which incident investigation requests have been received over the years, has obviously been a function of the frequency with which major incidents have occurred, but has also been dependent on the sensitivity of gas explosions as far as the press and media are concerned (several incidents close together become very newsworthy as also does any explosion which follows within a short period of a particularly serious incident). Over the first 10 years of the formal MRS "service" (1976-1985), the number of incidents which were investigated averaged about 17 per year, and peaked in 1984, when 22 investigations were carried out.

During the 1980's MRS was particularly pro-active in passing on the expertise which it had to Regional Technical Service Departments and, partly as a result of the improved understanding of the effects of explosions by Regional staff and also a reduction in the number of incidents occurring, since the mid-1980's, the number of incidents which have been investigated has been gradually reducing, averaging 14 per year over the 5 years 1986-1990 and reaching a "low" of only 4 in 1992.

The breakdown of investigations by Region, reveals that over the period 1976 - 1992, the largest number of investigations have been carried out for British Gas West Midlands and British Gas Scotland (17% of the total number each). As the British Gas West Midlands Regional HQ was on the same site as MRS, the former is not surprising as it was always very easy for them to call in MRS. Scotland, being the most remote Region from MRS is perhaps more surprising, but is explained by the fact that differences between English and Scottish law make it desirable for British Gas Scotland to use non-Regional experts in any litigation, and MRS staff were always considered to be in this category.

Particular Incidents

Over the years, there have been several very large and well known explosion incidents, often involving fatalities, which have occurred and been the subject of extensive MRS investigations and, very often, subsequent Court appearances for the investigating team. These have included, for example Clarkston Toll, Glasgow in 1971, Park Street, Bristol in 1976, The Royal Darroch Hotel in Aberdeen in 1983, Newnham House, Putney, London in 1985 and Guthrie Street, Edinburgh in 1989. Although these were major incidents, usually, the causes of such explosions have been relatively straightforward to identify.

There have also, of course, been many more, less well known incidents which have been considerably more difficult to explain fully! There have also been a number of incidents which have passed into investigation folklore, e.g. :-

(i) The explosion which caused a house to collapse around a gentleman as he sat on the toilet (whilst, amongst other things, he was busy sniffing LPG - hence the source of fuel for the explosion!)

(ii) The case of the rhododendron bushes which "exploded" in the garden of a house as a match was applied shortly after a number of branches had been lopped off, piled up into a bonfire and dowsed with petrol.

(iii) The explosion which was caused by propane gas (used as the propellant) which escaped from an ordinary can of fly-spray.

(iv) The explosion which occurred when the "head in the gas oven" suicide attempt failed because the would-be victim was unaware that natural gas is non-poisonous and decided to have a cigarette whilst he waited !

(v) The "what came first" incident in an unoccupied bungalow -the gas leak or the explosion. The evidence found at the site and from subsequent metallurgical and other tests showed that the source of gas was natural gas from a broken carcass pipe in the roof space and that the fracture in the pipe was caused by the roof lifting up in the explosion !!

Needless to say, the last example above serves to demonstrate that although MRS had an excellent record of "solving" a very large number of incidents which have been investigated, it is never possible to dot all the i's and cross all of the t's all of the time and, very occasionally, even MRS reached a dead-end !

Finally, it should also be noted, that the ability of MRS to conduct investigations of fire and explosion incidents in domestic and commercial properties, meant that MRS was also able to help with the investigation of "in-house" incidents which have occurred over the years, and the Court proceedings which eventually followed, e.g. the massive explosion which occurred in the underground storage tank belonging to British Gas East Midlands at Effingham Street in Sheffield in 1973, the explosion which occurred in the downstream process train of the experimental slagging gasifier at the Westfield Development Centre in 1985 and the fire/explosion which occurred following the accidental venting of a small quantity of LNG at the Partington site in 1990.

13.12 Environmental Issues & Pollutant Emission

R.M.Davies

Background

The Midlands Research Station has been concerned with pollutant emissions from combustion plant for the past two decades. During the majority of this period the UK has had very little legislation addressing, quantitatively, the control of atmospheric pollution from industrial plant. However the Environmental Protection Act (EPA), which became law in 1990, is having a radical effect on the way in which pollutant emissions are dealt with in Britain. Consequently much of the research and development undertaken by MRS in the fifteen years from 1972 to 1987 can be seen as preparation for the enactment of the present legislation as it affects both industrial gas utilisation and British Gas's own operation of the National Transmission System (NTS).

Origins

It appeared in the early 1970's that it was only a matter of time before the UK had limits on the concentrations of pollutants issuing from combustion plant, as was already the case in USA, Federal Germany and Japan. Characteristically however it was a very long time before anything happened in the UK, but British Gas was well prepared for eventualities which for a decade were always "just over the horizon".

The objectives were, and remain, to be well informed about emissions and emission control technology so as to be able to identify potential problems and opportunities, to provide consultancy and assistance to Marketing Division, National Transmission System, Regions, customers and manufacturers and to be able to negotiate and discuss environmental issues or regulations with government departments and enforcement agencies.

Technical Approach

The first task was to obtain information on pollutant emissions from a range of gas fired plant so as to build an inventory or what would subsequently be termed a database. Thus during the period roughly from 1972-82 numerous visits were made to customers premises to measure emissions from shell and water-tube boilers, kilns, reheating furnaces etc. - the traditional types of industrial plant. The pollutants of primary concern were, and still are, oxides of nitrogen (NOx) although carbon monoxide was also measured. Visits to friendly customers premises were arranged by Regions, usually presented as a check up on how well the plant was performing - pollutants were rarely mentioned in those less environmentally aware days. Quite often Regions had the ulterior motive of extra gas load in mind and visits were by way of a deal between MRS and local industrial departments. A series of emission measurements was also made on the gas turbines used on the compressor stations of the British Gas transmission system.

After a decade of this type of activity a significant database had been created. With no imminent legislation, effort was eventually reduced to a holding operation to preserve expertise.

With the promulgation of the European Community's Directive on Emissions from Large Combustion Plant (>50MW input) and the creation in UK of the EP Act it has been necessary in the past few years to revive emission surveys. These latest activities are now directed towards plant types which are subject to the EP Act or which might have restrictions imposed as a consequence of future European Standards or Directives (3). Notable in this respect are industrial gas turbines, commercial boilers, spark ignition engines and LNG vaporisers.

Low NOx burner development

In parallel with the original emission surveys it was desirable to gain practical experience of NOx reduction techniques and also to develop, where necessary, low NOx versions of MRS's own licensed equipment and developments. The obvious candidate for these twin aims was the recuperative burner. The air preheats - up to 600°C - achieveable on recuperative burners were sufficient to triple flue gas NOx concentrations.

Two 'classic' techniques of NOx reduction were evaluated on a 150kW recuperative burner. The first approach was to recirculate cooled flue gases through the air supply of the burner, the second was to "stage" the combustion process by diverting up to 40% of the combustion air to the mouth of the burner tunnel. Both methods lower the peak flame temperature and were effective in reducing NOx emissions by 50% or more.

In total contrast MRS was also involved in limiting NOx in a process where the objective was to produce hot drying air at only 75°C by dilution of combustion products. This technique was extremely effective in drying malt for whisky and beer production but research in Germany (where else?) had shown that small quantities of potentially carcinogenic nitrous-amines could be found in the product. The cause of nitrosamine formation in malt was NO2 in the diluted combustion products. The solution to the problem was to develop a burner which absolutely minimised NOx formation. This was achieved by premixed combustion operating as close to the lean flammability limit as possible in order to produce the lowest possible flame temperatures. MRS was an active collaborator with the UK malt drying industry and burner manufacturers in testing and developing ultra low NOx burners for use in maltings. The lean premix combustion concept is also the basis for the latest designs of low NOx gas turbine combustor.

In recent years interest has reverted to high temperature processes (5). The basis of NOx reduction from the highly preheated air flames used in glass melting furnaces has been investigated at the International Flame Research Foundation (IFRF) via a consortium of European and Japanese gas companies. In design and collaboration with BG's licensee (Hotwork), and with support from ETSU, a low NOx version of the regenerative burner has been developed.

Spark Ignition Engines

Although emission of NOx and other pollutants can be limited by combustor operation it is not always possible to achieve satisfactorily low emissions. Small scale CHP using spark ignition engines is a case in point. In this instance it is desirable to achieve greater than 90% reduction in emissions of NOx, CO and hydrocarbons - to do so requires the use of automotive type exhaust catalyst with very fine control over air-fuel ratio. MRS has undertaken the development of an economical and robust air-fuel ratio control system for use with small CHP systems which has been subject to extended field trials (6).

Emissions Modelling

Process and burner development at MRS has usually been supported by theoretical modelling. Prediction of NOx formation has been no exception but is extremely difficult and much development remains to be done before generally applicable methods are available. Limited success was obtained using simple chemistry and traditional reactor modelling methods when making predictions for NOx control by flue gas recirculation on recuperative burners. In recent years it has also been a goal of computational fluid dynamic modelling (CFD) to be able to predict NOx formation in some detail. Modest success has been achieved to date on high temperature processes such as glass melting where, as with recuperative burners, relatively simple chemical mechanisms have their greatest validity.

In parallel with the development of NOx prediction via CFD there has been a series of experiments at the Coleshill test site. The facilities have in recent years been used to investigate the effect of the quality of fuel-air mixing on NOx formation and latterly to produce very detailed sets of experimental data against which to test CFD models now and in the future.

Implementation of Results

Major objectives of MRS's involvement with emissions and their control have been the provision of detailed advice to the industry and its customers and the ability to speak with authority when arguing the case for the company in dealings with government departments. The expertise and knowledge developed over the years has realised these objectives and MRS has had a significant input to regulations concerning industrial boilers, gas turbines and reheating furnaces. Since environmental regulations and issues are continuously changing and evolving there is a need to maintain this expertise which has to be based on an underlying programme of environmental research and development.

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13.13 Combustion Noise Reduction

B.Mugridge

Background

The application of gas burning technology in industry can occasionally create problems of excessive noise either as an annoyance or exceptionally as a hazard to health. Annoyance to the general public may result if a large boiler generates low frequency resonant noise which propagates over large distances without significant attenuation. The use of large high combustion intensity burners for rapid heating or in batch furnaces can sometimes generate noise levels in excess of 95dBA at the operator's location. In the Commercial sector problems are generally limited to the transmission of sound from gas plant to adjacent offices or living space. A typical example would be the pulsing sound from a gas engine driven CHP or chiller unit.

Technical Approach

MRS maintained a small team of noise experts to assist British Gas in tackling noise problems that occurred within the Regions. This often involved the application of standard noise reduction technology such as vibration isolation, acoustic enclosures, absorptive silencers and barriers (1). The MRS team co-operated fully with local Environmental Officers to establish good working relationships and credibility with the enforcing authorities. During the 1980's MRS carried out over 150 technical service jobs to reduce noise levels from gas fired equipment, often using techniques developed in the MRS laboratories.

However, in many cases the application of this technology was not sufficient either on the grounds of cost or because of operational restrictions. In these instances the MRS team developed a range of noise reduction measures which were specifically aimed at combustion generated noise phenomena. The simplest example was the design and exploitation of a top hat flue terminal tuned to reduce the single tone resonant noise from boilers. Affectionately known as the 'dustbin', this was a most cost effective solution to this difficult problem.

Combustion Noise Studies

More pertinent to ensuring lower noise levels from plant was a greater understanding of the noise generating mechanisms within natural gas plant, particularly the burner system. The MRS team therefore carried out more basic research into combustion noise. An initial target was the measurement of sound power levels from a range of proprietary burner systems and the effect on noise levels of the furnace or boiler environment. The MRS reverberation chamber was built specifically for this type of analysis. These studies led to the development of several low noise burner designs which were successfully exploited commercially (2)(3).

Boiler resonant noise was a particularly difficult problem to overcome. It arose from an interaction of the flame with sound waves propagating within the boiler firetube passages and flue system. It often proved most difficult to eliminate since no one solution was generally applicable to the various combinations of burners and boilers used commercially. At the lowest level of noise reduction was the fitting of flue silencers.

Where this was not practicable or sufficient, modifications to the burner design were necessary. This latter approach produced some amazing results with intense tonal noises being completely eliminated. Unfortunately this approach was somewhat "hit or miss" and often its application was both unsuccessful and bad on the nerves. It was often the case that the MRS noise consultant was only called in after all other attempts by burner experts had failed and the magic wand approach was expected. A more scientific understanding of combustion driven oscillations was needed to provide consistent reduction options.

It was at this stage that the MRS Noise Group became the Acoustics Group because the solution of combustion oscillation problems required a much greater understanding of general acoustics theory. The interaction of sound waves with gas flames was a relatively new topic involving aero-chemical-acoustic interactions and the propagation of waves through flows with severe temperature gradients. During the 1980s the MRS team developed experimental data and theoretical guidelines that were at the forefront of knowledge and which, even today, represent a fund of advanced expertise.

The greatest advance of these fundamental studies was the development of the transfer function approach to oscillation theory where both the gas flame and combustion chamber environment were considered as elements of a feedback network (4)(5). In this context several different experimental systems were devised for establishing flame transfer functions. These included an acoustic impedance approach and a CH band spectral emission technique which could also be used as a source for an anti-noise feedback control method. Whilst the latter was not viable at the time due to problems with suitable transducers, it is interesting that the anti-noise technique is now used very successfully in numerous other applications.

The transfer function approach needed an extension to the current wave propagation theory because of the flow and temperature effects experienced in real industrial furnaces and boilers. In this respect the MRS team were fortunate in securing the services of a highly talented Cambridge graduate who not only broke the record for filling more laboratory log books per year than anyone else at MRS, but who also generated original theories to suit these difficult wave propagation conditions. He also extended this work to the propagation of turbulent flames in unconfined explosions, a related problem being examined by another MRS group. This latter work produced some remarkably elegant analytical solutions to some of the limiting conditions of expanding flame front phenomena.

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Chapter 14

Retrospect

Chapter 14

W. E. Francis and M. L. Hoggarth

Retrospect

Looking back over the forty or so years of MRS existence, one is struck by the frequency with which quite major changes in emphasis and direction have been necessary in response to changes in the Gas Industry or in the wider energy scene. At the start, work on the gasification of coal was paramount, and coal based gasmaking remained as a longer term objective right to the end. However even in 1954, the use of oil feedstocks was being contemplated for the hydrogenation plant at Poole and by the early 60s development of distillate based processes dominated, resulting in the Gas Recycle Hydrogenator and the Catalytic Rich Gas processes.

The dominance of gasification work was brought to a rather abrupt end around 1967, with the recognition that the Industry's future was with North Sea natural gas. A relatively rapid run down of Production effort and transfer of staff to Utilisation ensued. The Utilisation side was fortunately ready for rapid expansion, having been familiarising with natural gas combustion since 1965 and gradually increasing the scale of its operations. The chemical engineering skills of the ex-production people proved ideal for the large scale boiler firing and other applications on which work was now required and staff responded well to the new challenges.

However by the early 70s it was clear that, in relation to the much greater demand, the supplies of natural gas were not unlimited, and the need for a Substitute Natural Gas fallback was recognised. The possible routes to SNG via CRG or GRH processes had been explored as early as 1968, but the production effort had sunk to an almost non viable level and had to be rapidly geared up again, albeit with an almost entirely new team.

Also in the late 60s and early 70s, to some extent reacting to major incidents such as Ronan Point, the "hazards" work increased in importance so that the Station by the end of that decade had three major fields of activity, a situation that persisted almost to the end of the Station, although by the late 80s some of the process expertise was increasingly used in support of the natural gas processing activity both on and offshore. The need to back up development work with good scientific background research and modelling meant that the Station's expertise became increasingly polymathic, employing almost the whole range of scientific and engineering disciplines.

Despite the several severe changes in emphasis and objectives, an evolutionary approach in technological improvements building on past achievements is clearly discernible. For example a continuous line of research can be traced in the development of nickel/alumina catalysts from the early work of Dr. Dent's team at Leeds University in the 30s through methane synthesis at Poole in the 40s, CRG catalysts in the 60s/70s to HICOM methanation in the 80s. Similar examples may be found in the many applications of recirculation and the gradual improvement in theoretical and physical modelling techniques.

This evolutionary approach may explain why there were very few failures to achieve a significant result in projects to which a serious effort was applied.

Perhaps there should have been a more adventurous choice of speculative projects, which would almost certainly have led to a higher proportion of failures but could also have provided more spectacular changes in technology. Two projects possibly come into this category; Moseley's work on very high pressure hydrogenation of coal, which suffered from the run down in production research, and the ultra low temperature catalytic distillate gasification based on ruthenium catalyst, which foundered on doubts about the economics of ruthenium availability. It has to be said that there never seemed to be any spare effort for this kind of activity, and the "end-users" tended to urge more concentration on the projects which they regarded as most important at the time.

There were certainly some failures. The fluidised gasifier could be counted a failure of timing, since it was never operated as a result of the run down in production effort. Pulsating combustion was a failure to recognise that its potential lay in relatively small scale units. The tower melter seemed to be within a whisker of success, suffering from problems which always seemed to be of a relatively trivial nature; perhaps this was a failure of determination to see it through.

The majority of projects resulted in some degree of technical success. Converting this into wider commercial implementation often proved difficult. The early coal gasification work at Nechells could be said to have been accepted quickly by the decision to build a plant at Coleshill, but planning problems delayed its construction for several years, by which time oil gasification was more economic. The GRH was adopted very quickly by the Area Boards for enrichment of lean gas from ICI reformers, as was the CRG process, until the adoption of the "Series A" plants. CRG came into its own when applied to SNG production. The exploitation of these processes was aided by the Gas Council's organising of a "Contractors Club" of Licensees, and by the fact that initially the plants were under the Industry's own control. Trials could be undertaken on premises, such as Portsmouth and Killingholme. The commercial success was recognised by the winning of the Queens Award and the MacRobert Award.

On the utilisation side, commercial exploitation was often harder to achieve since MRS was forced to work through heating plant manufacturers, or in the early days through the network of Area Board Industrial Engineers. The early work on explosion relief's and flame traps was taken up quickly through the involvement of the H.M. Factory Inspectorate, who incorporated the designs as a mandatory requirement in its Guidance Notes for industrial plant. Similarly the work on controls and safety was implemented through the Standards for Automatic Burners and the Codes of Practice for Large Gas and Dual Fuel Burners.

The early developments, such as tunnel burners, were taken up through opportunist contacts with a few manufacturers and with some of the Area Board Development Engineers. However from the mid 70s onwards most of the Regions wound down their Development Labs., and their capability was much reduced. The only direct involvement of Marketing HQ was the highly successful but all too brief "Radex" initiative to kick start the commercialisation of the recuperative burner. Eventually a more structured approach to licensing, publicity and exploitation was put in place and led to widespread application of all the main MRS energy saving developments. By the mid 80s, there were so many field trials on customers premises and joint development projects with manufacturers that there seemed to be no one left in the Solihull Labs. These trials involved direct interference with customers' production plant and processes and although UK industry has often been criticised for failure to innovate, there were Companies who were prepared to put their production at risk by installing equipment on trial; Sanderson Kayser and Craelius are two good examples.

The success of an Industrial Research Laboratory can be judged by the benefit to the Company of using the results of the research in its business activities. MRS can fairly claim to have made some significant contributions during its lifetime to help British Gas achieve its strong position in UK energy supply.

All of these technical achievements and the progressively strengthening business contacts had been established in an organisation operated predominantly with a functional line management structure where responsibility for formulating and undertaking the programme and liaising with the customer was carried by the responsible department. While some cross disciplinary activities had been undertaken, these were confined to the provision of specialist engineering science, controls and materials services and general administrative and engineering support. Strong control was exercised by the main functional units related to Gas Processing and Production, Industrial and Commercial Utilisation and Major Hazards.

While this management structure had served the Company and R&T well during nationalisation and early privatisation, the very rapid changes recently encountered linked with the amalgamation of the three southern stations (and latterly the Engineering Research Station) called for a re-examination of the R & T organisation to respond to the new challenges and changing circumstances. As a result, it was decided that a matrix management system incorporating the most desirable features of the old stations' operations but with the ability to work more flexibly and to respond more rapidly to the industry's changing needs was the most appropriate solution. The matrix combined three interacting components, namely a programme axis, a technical axis, and a general services arm.

The programme axis' main function is to interact with the business users within British Gas plc and with associated industrial organisations. In so doing it has the prime responsibility for formulating the research programme in consultation with the users to meet their technological and business needs and for ensuring that it is delivered to the specified quality, time and cost. A Programme Controller, supported by Business Area Managers who specialise in the customer's needs, is responsible for delivering the research and development programme to the four main business sectors, i.e. Exploration and Production, Transmission and Storage, Industrial and Commercial Utilisation and Domestic Utilisation. Each Programme Controller is responsible for formulating a longer term research programme for each of these areas funded by the Corporate Centre.

A Technical Controller supported by a team of Divisional Managers and Skill Groups is responsible for the conduct of the research programme allocated to each of four principle scientific/engineering disciplines, i.e. Physical Sciences, Chemical Sciences, Engineering Design and Electronics and Computing. Each Technical Controller and his management team have particular responsibility for the technical excellence of the research, the provision of suitably qualified trained staff and for the examination of emerging technologies and very long term scientific research that could benefit the Company.

Administration and Engineering Services are provided by the third arm of the matrix which supports both the programme and technical axes.

The long established traditions of high technical quality, dedication to the customer, and the commercialisation of R&T products, developed at the Midlands Research Station have been absorbed in the new culture of R&T. Many of the Midlands Research Station senior managers were appointed to key roles in the top management of the reformulated R&T Division.

Under the leadership of Gerry Clerehugh (Director of Research and Technology) David Lucas, having headed the GRC project team, became Head of Research Resources responsible for the technical axis of the matrix, while Lawrence Conway became Head of Research Services. Gerry Clerehugh took personal responsibility for the programme axis in which Jeff Masters became Programme Controller for Industrial and Commercial Utilisation. Malcolm Hoggarth was appointed Technical Controller responsible for Physical Sciences. Many other MRS managers became Business Area Managers, amongst them were:-

Bob Harris (Programme Manager - Domestic Utilisation), Neil Fricker (Natural Gas Vehicles), John Chapman (Air Conditioning), Geoff Parkinson (Industrial Processes), Bob Carpenter (Power Generation and CHP), Haydn Davies (Gasification and Hydrogenation), Geoff Hankinson and Colin Bradley (Offshore and Onshore Safety), Keith Wild (Gas Treatment and Environment), Phil Borrill (Process Technology and Environment), Martin Atkinson (Kitchen Products and Catering), David Thatcher (Strategic Research) and Terry Williams (Customer Service) as Business Area Managers and Bob Ensell, Martin Vasey, Roger Webb and Malcolm Wickens as Divisional Managers with Barbara Lowesmith, Rachel Palmer, Roger Brown, Mike Fairweather, Greg Jones, Keith Tart and Tony Cross as Skill Group Leaders.

In the service area, Keith Adams as General Services Manager and David Moppet as Safety and Environment Manager, play key roles, together with Bill Barnes (Engineering Services Manager) , Bill Keddie (Computing Services Manager) and Brian Wake (Engineering Design and Manufacturing Services Manager).

Clearly, MRS personnel have, and will continue to play a central role in a broad range of top and senior management posts in R&T.

Inevitably, many valued members of the Midland Research Station took the opportunity in July, 1993 to conclude their careers in British Gas R&T and retired. Notable amongst them were John Lacey, Mike Davies, Roger Hancock, Peter Spittle, Roland Phillips, John Templeman, Brian Mugridge, John Anderson, John Barrett and Jeff Jackson. Their successors and serving colleagues maintain the continuity in the tradition of the MRS in R&T.