THE DEVELOPMENT OF HEAT RECOVERY EQUIPMENT FROM CONCEPTION TO COMMERCIALISATION

By

NIGEL EDWARD KIRKWOOD

A thesis

submitted for the

Degree of

Doctor of Philosophy

The University of Aston in Birmingham

JANUARY 1983

THE DEVELOPMENT OF HEAT RECOVERY EQUIPMENT

FROM CONCEPTION TO COMMERCIALISATION

A thesis

submitted for the

Degree of

Doctor of Philosophy

By

NIGEL EDWARD KIRKWOOD

Summary

A comprehensive survey of industrial sites and heat recovery products revealed gaps between equipment that was required and that which was available. Two heat recovery products were developed to fill those gaps:

- a gas-to-gas modular heat recovery unit;
- a gas-to-liquid exhaust gas heat exchanger.

The former provided an entire heat recovery system in one unit. It was specifically designed to overcome the problems associated with existing component systems of large design commitment, extensive installation and incompatibility between parts. The unit was intended to recover heat from multiple waste gas sources and, in particular, from baking ovens. A survey of the baking industry defined typical waste gas temperatures and flow rates, around which the unit was designed.

The second unit was designed to recover heat from the exhaust gases of small diesel engines. The developed unit differed from existing designs by having a negligible effect on engine performance.

In marketing terms these products are conceptual opposites. The first, a 'product-push' product generated from site and product surveys, required marketing following design. The second, a 'market-pull' product, resulted from a specific user need; this had a captive market and did not require marketing. Here marketing was replaced by commercial aspects including the protection of ideas, contracting, tendering and insurance requirements. These two product development routes are compared and contrasted.

As a general conclusion this work suggests that it can be benefical for small companies (as was the sponsor of this project) to undertake projects of the market-pull type. Generally they have a higher probability of success and are less capital intensive than their product-push counterparts.

Development revealed shortcomings in three other fields: British Standards governing heat exchangers; financial assessment of energy saving schemes; degree day procedure of calculating energy savings. Methods are proposed to overcome these shortcomings.

Key Words
Waste heat recovery, new product development, industrial ovens, diesel engines.

ACKNOWLEDGEMENTS

The author wishes to thank D.C. Hickson and M.K. Addy, who have both helped and encouraged this work.

A final thank you must also go to my parents and special friends for their patience and understanding, encouragement and support, and unfailing help.

N.E. Kirkwood

January 1983

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Appendices

CHAPTER 1

ENERGY CONSERVATION - AN INCREASING AWARENESS

ENERGY CONSERVATION - AN INCREASING AWARENESS

1.0 Introduction

In recent years the world has seen a significant increase in the price of energy. This has created an acute awareness within industry of energy usage, and the need to reduce it. This increasing concern is reflected in an eagerness to 'save it' that has prompted critical appraisal of many processes.

For companies without the technical expertise necessary to achieve this, new organisations have been established to service this once dormant demand. This chapter describes the world energy situation, the establishment of a company within this new market and the development of two products that service these new industrial needs.

1.1 Rising Energy Costs

Following the Arab/Israeli conflict of 1973 [1,2] and the resulting oil embargo [3], the price of crude oil quadrupled [4]. OPEC sponsored price increases have continued this rise [5], figure 1.1 [6] showing this increase together with that of other fuels. (Two authoritative accounts of these events are detailed in [7,8]). More recently political events, exemplified by the Iranian Revolution of 1978 [9,10] and the Iran/Iraq conflict of 1980/1982 [11,12] has threatened the very supply of this oil.

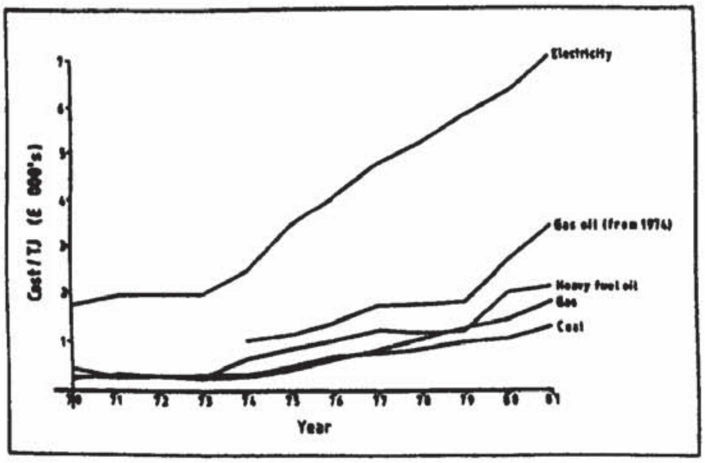


Figure 1.1 Industrial energy cost increases

This highlighted the need to reduce the dependence on the oil supplying countries and to increase the life of existing supplies.

To an extent this can be achieved by market forces. As energy prices become an increasing part of product cost, the incentive to 'save it' becomes greater. This, however, has a limited effect as energy constitutes only 3 to 4 per cent [13] of the total product cost in most industries, except cement, petrochemicals and steel [14]. It has been stated, both in the U.K. [15,16] and the U.S.A. [17], that very substantial increases in energy costs will achieve only marginal reductions in consumption; to obtain "a rapid drop in demand by 3 per cent would involve raising nominal energy prices by over 22 per cent" [18]. Strong political support may be required to augment effects to achieve conservation [19] and it has been suggested that "much stronger mandatory legislation" [20] is required to overcome the "widespread indifference to energy conservation which still exists in industry" [21].

Although economics appear to have only a marginal effect on consumption, the events since 1973 have created a greater awareness in the use of energy and prompted considerable interest in its conservation.

1.2 Energy Conservation Technologies

'Energy conservation' is a term covering a vast number of subjects from the draught-proofing of windows to reduce heat losses, to multi-million pound combined heat and power schemes (CHP) for more efficient utilisation of primary fuel. Most energy conservation measures can be grouped in three categories:

- general housekeeping;
- new production technology;
- retrofit technology.

1.2.1 General Housekeeping

General housekeeping is probably the least capital intensive of the conservation technologies and usually offers the shortest payback times. Much can be achieved by shutting doors and windows, turning off unnecessary heating, stopping steam leaks, etc. [22]. It has been suggested that up to 10 per cent of industrial fuel consumption may be saved in this way [23] and, in some cases, new processes may be superseded to economic advantage by general housekeeping techniques [24]. Usually, however, for major savings to be realised, other methods need to be considered.

1.2.2 New Production Technology

Re-designing processes or developing new ones to save energy may improve a company's competitive position [25]. New production technology is applicable throughout industry and involves a fundamental change in a production technique. Rising energy prices may enhance the development of new production techniques [26] and completely new processes have evolved (for example, the dry forming of paper [27]) that use considerably less energy than their predecessors. These new technologies often require heavy financial commitment over a long period of time, typically 10-20 years [28], and offer no guarantee of ultimate success. This is the type of investment that industry, at present, may be unable to afford. In the longer term, however, energy efficient processes must be considered seriously as the only alternative [23].

1.2.3 Retrofit Technology

Retrofit technology provides an addition to an existing process or production infrastructure; the original process remains largely unchanged, but its primary energy consumption is reduced. Retrofit technology encompasses many fields ranging from the use of low temperature detergents to sophisticated heat recovery schemes. Often requiring less capital investment than new technology, in the short term, retrofit offers an immediate answer to a pressing problem - how to reduce energy consumption.

In the present economic climate energy conservation is considered by many companies to be of low priority, as it is generally thought that "money saved is worth less than money made" [29]. This is unfortunate as such a short term decision could result in those companies being less competitive when the economy recovers.

The Energy Technology Support Unit (ETSU) of the Department of Energy is investigating 7 retrofit technologies, shown here in priority order [30]:

- waste heat recovery;
- waste as a fuel;
- improved instrumentation and control;
- heat pumps;
- process insulation;
- industrial CHP;
- improved machinery drive;

Waste heat is considered the most important and one of the first examples of such a scheme is described below.

1.3 A Pioneering Heat Recovery Installation

One of the first heat recovery schemes of major consequence is sited at Weetabix Limited, Kettering, and was completed in 1978. This scheme recovers heat from baking oven exhaust gases and provides all the space heating for the 9290m^2 factory [31].

The success of the installation is shown in figure 1.2 [32]. This shows how consumption of gas for space heating is virtually eliminated when the heat recovery scheme is operating.

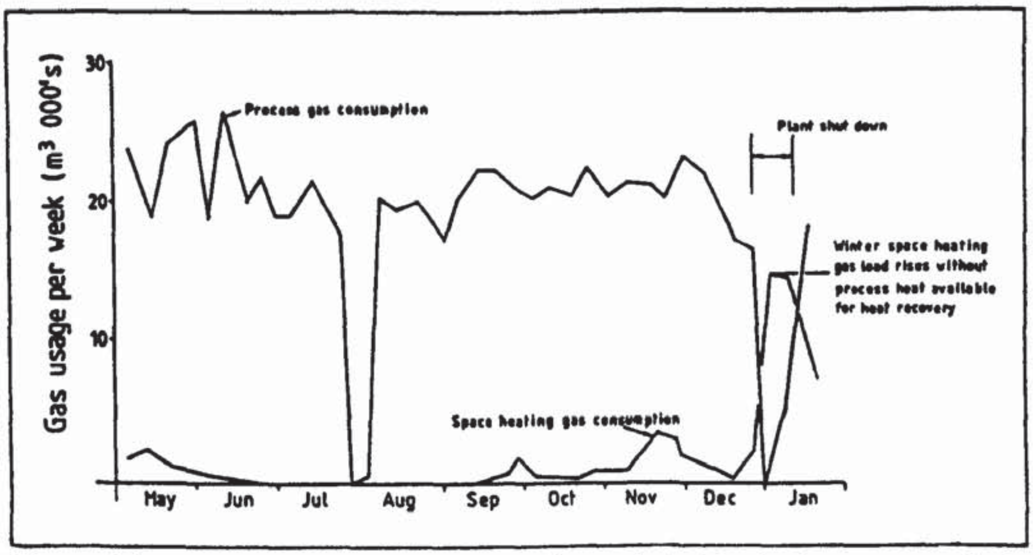


Figure 1.2 Space heating gas consumption related to heat recovery plant operation

The scheme's design, planning and installation brought together considerable expertise from several industrial areas, and loose ties between the different companies involved were formed as the project progressed.

The novelty of the Weetabix Installation [33] commanded considerable interest from the Department of Energy and resulted in much complimentary press coverage. One article in Energy Management [34] prompted over 150 enquiries. This level of response revealed British Industry's interest in this newly developing field - heat recovery. It also led to a proposal to set up an independent company whose brief was specifically to design and install heat recovery schemes.

1.4 The Formation of a New Company

Expertise for such a company was available from within the companies that installed the Weetabix heat recovery scheme [35]. The loose associations that had been formed were thought insufficient to allow any real penetration of the market, the potentially large benefits being realised only through a properly constructed business organisation. A survey at that time suggested the potential investment in capital equipment for heat recovery to be £192 million [36].

A new company, the Watt, Joule & Therm Company, was formed in 1979 from selected staff of the original companies. Its technical section was divided into two parts, design engineering and contracts engineering. It was felt, however, that there was a need to identify factors in the market place that were changing with the greater general awareness of energy. A position should exist to investigate these factors in depth. A developments engineering post was created and filled by a postgraduate research student through the Interdisciplinary Higher Degree (IHD) scheme at The University of Aston in Birmingham. This post provided a unique position: it afforded access to all levels of the company, yet was outside its hierarchy. External from this structure and responsible to the managing director, the position was freed from everyday routine to apply maximum effort to research. Figure 1.3 shows this structure.

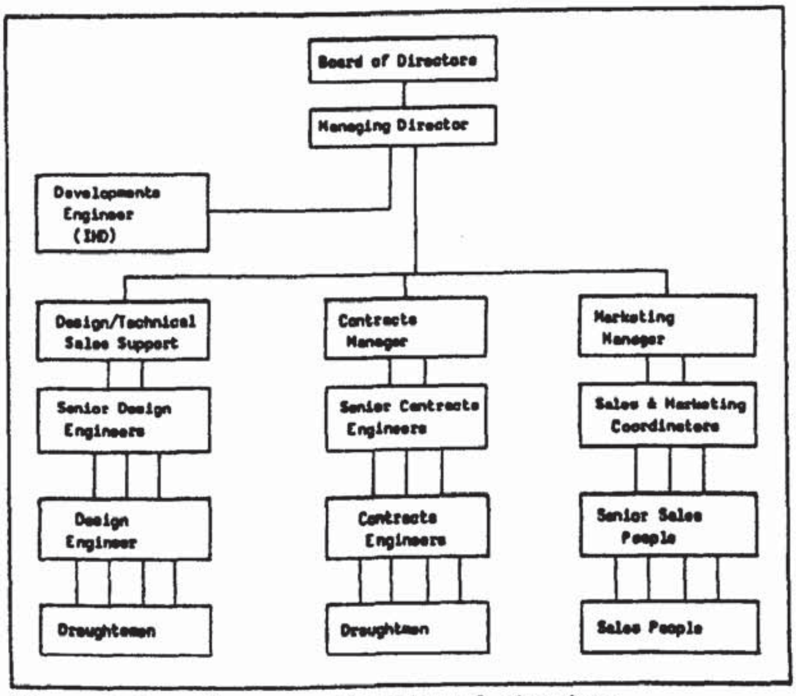


Figure 1.3 The sponsor's internal structure

1.5 Analysis of Market Needs

For preliminary familiarisation the developments engineer was included on many energy surveys. Much original data was collected, and this is described in section 2.3 (page 20).

In the preparation of heat recovery schemes following these site surveys, it was essential to have first hand and accurate information on the types of heat recovery equipment available. A central information system was set up detailing, as far as possible, all equipment currently available. This 'product' survey is detailed in appendix 1 (page 153).

Initial site energy surveys revealed several shortcomings in existing equipment and installation techniques:

- existing schemes were made from components that usually occupied physically large areas of site;
- no manufacturers produce all parts of a heat recovery system, this sometimes leading to incompatibility between various components;
- disruption of site and process was often extensive while installation was completed;
- very few items of equipment existed that could operate with high temperature exhaust gases (i.e. above 450K).

These shortcomings were taken as the framework for specifying a new type of product, the design brief of which was to overcome these problems.

1.5.1 An Internally Generated Product Idea

The design of this new product was a project generated entirely within the company (hereinafter referred to as the sponsor) as a result of general familiarisation and market research. It shall subsequently be referred to as the 'Internally Generated Product'.

The approach to the solution involved preliminary design work with a subsequent market survey using conceptual ideas developed. Suggestions obtained from this survey were fed into the development programme.

At the detailed design stage, a pre-launch market survey was conducted.

The response was favourable and prompted the building, installation and testing of a prototype unit. Following this, the final product was launched. Throughout the project, feedback from outside the company was used to guide the product's development.

This is an example of a 'product-push' product, ideas having been created within a company and tailored to market requirements by the use of extensive market analysis [37]. In some cases though, when a product required is not available, a client may approach a manufacturer. With this 'captive' market, no market analysis is required and the product is termed 'market-pull' [37]. This was the case for a second project - an externally generated product.

1.5.2 An Externally Generated Product Idea

One energy survey revealed a client considering heat recovery from diesel engine exhaust gases. These in-house engines were used in the testing of lubricants and were operated under very stringent conditions. A market survey revealed that no heat exchanger commercially available could operate in the sulphurous diesel gases at 800K and exhibit low enough back pressure to ensure minimal engine interference.

This identified a second deficiency in the market, the specification now coming from outside the sponsor. The design of a heat exchanger to meet this exacting specification was the genesis of a second or 'Externally Generated Product'.

This project did not involve market research, all design parameters having been supplied by the client. The first part of this product development was the design, approval and testing of a prototype heat exchanger, 001. With the knowledge obtained from this, a second design was produced, based on which, a total of 24 heat exchangers were finally manufactured.

1.5.3 A Comparison of Internally and Externally Generated Products

The internally generated product resulted from work carried out entirely within the sponsoring organisation. Market and product surveys were all undertaken on ideas generated internally. Aimed at a mass market, the risk in this type of development was high, but accepted, knowing the large financial rewards that could be obtained if a commercially successful product resulted.

The externally generated product, however, was defined by a source outside the sponsoring organisation, a single client supplying all design parameters. This development involved less risk, but less financial benefit if a commercial success. A comparison between the internal, high risk product to meet the demands of a mass market, and the external low risk product to meet the demands of a highly specialised market, is the basis of this thesis. How their development fits into this thesis framework is now described.

1.6 The Thesis

This thesis highlights the similarities and contrasts the differences in the development of product-push and market-pull products. The development of both is traced from conception, through design and development, to final commercialisation.

Chapter 2 details the sponsor's approach to heat recovery and describes site energy surveys. These, together with a review of existing technology, reveal two market gaps, one for a product-push product and one for a market-pull product. Chapter 3 describes the technical aspects of both giving specification and design details. Development and cost reduction exercises are also included. Market aspects, including test marketing, brochure design, exhibitions and market launch, are most applicable to product-push, and these will be described for this product in

Chapter 4. Market-pull, however, requires little marketing input. Commercial aspects feature more prominently here and include protection of industrial ideas, contracting and tendering, and insurance requirements. These are discussed in chapter 5. The installations in which the two products were tested are described in chapter 6. Payback of these systems is discussed together with a method for calculating the savings obtained when recovered heat is used for space heating. Chapter 7 assesses the success of both products, both from their technical and commercial viewpoints, and gives a cost/benefit analysis for each. Chapter 8 reviews the equipment available as a result of this project and discusses further work in this and related fields. The total potential for energy saving is also considered, should the products go into widespread use. To complete this thesis a review of the IHD scheme, through which this research was conducted, is given.

Chapter 2 now describes the early stages of the project - the conception of two products.

CHAPTER 2

THE CONCEPTION OF TWO NEW HEAT RECOVERY PRODUCTS

THE CONCEPTION OF TWO NEW HEAT RECOVERY PRODUCTS

2.0 The Early Project

The first four months of the project, from September to December 1979, were used as an introductory period to the sponsor and the technology of the industry. Site work was undertaken that gave first-hand information on waste heat sources and subsequent analysis revealed how this heat could best be recovered and utilised. Much information was gathered on these sources and the equipment produced to exploit them. As a result of this work two market gaps were discovered.

This chapter traces the development of the early project from initial introduction to the sponsor on 4th September, 1979, to the conception of two products, born out of numerous site surveys, before Christmas of that year. The sponsor's approach to heat recovery schemes and to site surveys is described, together with methods that were developed for their efficient execution. The chapter finishes by giving the specifications of the two products.

2.1 Stages of a Heat Recovery Project

Inundated with enquires from the installation at the Weetabix plant (see section 1.3, page 5), a fast and efficient method of answering them was required. An eight-stage plan was developed and this is shown below.

1) Initial meeting with the client to carry out site survey.
2) Assess potential for the application of heat recovery and the utilisation of the recovered heat.
3) Design a scheme that most suitably links recovery and utilisation of that energy.
4) Examine funding from external sources (e.g. energy demonstration grants), then prepare a financial report and tender.

At this stage the client assessed the value of continuing with heat recovery. Financial constraints, for example, may have made further work pointless. If, however, the proposals in 4 were accepted, stage 5 was started.

5) The proposal in 3) was augmented with a second more thorough survey from which, a detailed design was completed.
6) Install the heat recovery scheme.
7) Commission the system and train staff in its operation and use.
8) Monitor the system for correct operation.

Stages 1 to 4 were carried out at no cost to the client, stage 5 being undertaken using standard consultancy fees. Should the sponsor install the proposed scheme, this fee was subtracted from the overall contract value.

The site survey was an essential early stage as it collected information on which all subsequent analysis and decisions were based. This importance has been recognised and the site survey is now described in detail.

2.2 The Site Survey

Site surveys were the first stage in the design of a heat recovery system. They measured the potential for heat recovery and ways in which best to utilise it. Providing a platform from which to interview the potential client, they allowed a personal assessment of the client's enthusiasm for the application of heat recovery at that site. Surveys fall into two catagories, one-day surveys and extended surveys.

2.2.1 The One-Day Survey

The one-day survey had to gather sufficient information to make an assessment of the potential for heat recovery. Of equal importance was the identification of uses for the recovered heat. The purpose of the one-day survey can be summarised as follows:

- identify possible sources of waste heat and quantify them;
- identify uses for the recovered heat (it should be stressed that utilisation is of equal importance to recovery, as one without the other is worthless).

These two are now discussed.

2.2.2 Identification of Waste Heat Sources

There are three main sources of waste heat: hot gases; water and other liquids; the product itself.

Waste Heat Contained in Gases

Waste gas sources can be identified at two levels, site level and process level.

At site level, although general observations are made, they are supplemented by other techniques and considerations including:

- heat haze techniques - from a good vantage point can heat haze be seen rising from factory roofs, flues or ventilation ducts? This may identify areas worthy of further investigation;
- snow melt technique [38,39] - after a light snow fall can areas be seen from which the snow has melted?
- thermographic surveys [40,41];
- external consultants - could consultants employed under the One-Day Survey Scheme [42] detect sources of heat loss that, through familiarity, resident engineers have overlooked.

At process level the approach is more detailed:

- are flues exhausting directly to the atmosphere?
- is it so hot in any part of the plant that heat extraction is used? Can this heat be ducted to another part of the plant that requires heating?
- extract fans in walls and ceilings may no longer be required. Can they be turned off, or sealed off, permanently?
- can hoods be positioned closer to the process? If not they are extracting warmed factory air in addition to unwanted fumes;
- can steam plumes be eradicated at source?

This list is not exhaustive and is given only to show the general type of questions that can be asked on the survey exercise. Detailed lists are, however, given in references [43-57]. The above show a bias towards prevention as this is cheaper and saves more energy than retrofit cure.

Waste Heat Contained in Water and Other Liquids

There are several areas worthy of investigation:

- steam condensate - can condensate be returned to the boiler? If impractical, attempts should be made to use it in-situ.
- process cooling water - this is often hot and subsequently cooled using blast coolers. Could the heat be extracted by interprocess heat transfer?
- waste process water - often contaminated, this water (or other liquid) can be overlooked as a heat source. With the use of corrosion resistant heat exchangers this may be utilised to advantage.

Location of liquid sources may require detailed investigation on the shop floor. Discharge to drains or disposal by contractor can incur costs, and information from the finance department on effluent charges may be of value in pin-pointing possible sources of waste heat. Utilising these sources can provide heat and reduce disposal costs.

Waste Heat Contained in the Product Itself

Products may contain residual heat from the process. In one case crucibles were removed from a kiln at over 1470K and left to cool. Now, however, ambient gas (air) is drawn over them, to be preheated and fed to kiln burners, cooling the crucibles from 1470K to 500K. This gives an energy saving of 3 per cent for the overall process and a secondary advantage of reduced product cooling area due to shortened cooling time.

Having identified the sources of waste heat they must be quantified.

2.2.3 Quantification of Waste Heat Sources

Four parameters are required in calculating the quantity of heat available from waste sources: volume or mass flow rate; temperature; moisture content; specific heat capacity. Details of these, and the instruments used to measure them, are given in appendix 2 (page 174). In some cases moisture content and specific heat capacity were calculated or manufacturer's data consulted.

For liquids and solids the quantity of heat available for recovery can be calculated using standard formulae [58]. In 89 per cent of site surveys, however, the waste heat source was gaseous (see table 2.2, page 21), and quantification of this type of source is given below.

The potential for heat recovery from a gaseous source is given by the formula:

$$HR = m\,(h_1 - h_2) \qquad \ldots\ldots\; 2.1$$

where HR = heat recoverable ......(kW)

m = mass flow rate .....(kg/s)

h_1 = enthalpy at waste gas temperature, t_1 .... (kJ/kg)

h_2 = enthalpy after heat recovery at temperature, t_2 .... (kJ/kg)

In virtually all cases the waste gas consisted mainly of air. For waste gas (assuming it to be air and water vapour), taken from a datum of h_1 is zero for dry air at 273K (0^{o}C), h_1 is approximated using:

$$h_1 = (c_p)t_1 + (2501 + 1.805t_1)\,mc \qquad \ldots\; 2.2\ [59]$$

where h_1 = enthalpy at waste gas temperature, t_1 .... (kJ/kg)

c_p = specific heat of gas ....(kJ/kgK)

t_1 = waste gas temperature ......(^{o}C)

mc = moisture content of gas* .... (kg/kg)

h_2 is calculated using equation 2.2, but at t_2, the temperature to which the gas is reduced following heat recovery. The greater the difference between t_1 and t_2 (and hence h_1 and h_2) the greater the potential for heat recovery. t_2 is a particularly sensitive temperature and in some cases, especially where high sulphur content fuels are burnt, t_2 should not drop below the acid dew point of the gas. Condensation occurs below this temperature which may accelerate corrosion and reduce heat recovery plant life. In calculating the potential for heat recovery this factor should be considered to give a value for t_2 that is suitable for the application. Table 2.1 gives acid dew points for some common fuels. Optimising the heat's subsequent use is often the most difficult stage of the entire evaluation.

---

* moisture content is also known as humidity ratio and is defined as the mass of water vapour to the mass of dry air contained in the sample.

Fuel	Approximate Dew Point
General sulphur containing fuels	388K - 423K
Coal (good Midland)	300K - 340K
Coal (bad sulphurous)	up to 425K
Heavy fuel oil	415K
Light fuel oil	415K
Natural gas	343K

Table 2.1 Dew points of exhaust gases from the combustion of some common fuels [43, 60-62]

2.2.4 Utilisation of Recovered Heat

In the utilisation of recovered heat it is important, not only to find a use for the heat, but to find the most cost-effective use possible. There are two areas in which heat can be re-used, process or space heating. For a process operating 8 hours per day, 5 days per week, 50 weeks per year, the potential usage of recovered energy is 2000 hours per year. If used for space heating, for a 30 week heating season, this potential is reduced by 40 per cent to 1200 hours. Process applications invariably offer the best utilisation of heat and this was considered when site surveys were conducted.

Site surveys accumulated large quantities of information. In a few of the initial one-day surveys some figures were overlooked. To avoid this recurring, standard survey forms and analysis techniques were developed.

2.2.5 Site Survey Analysis Techniques

Although every site was different the information collected was similar. This enabled standard survey forms to be developed that could be completed on site during the actual survey. These are shown in appendix

3 (page 176). To complement the forms a suite of computer programs were developed to aid later analysis. Use of the computer improved accuracy, minimised the risk of error and reduced analysis time, on average, from 3 days to 1 hour.

The one-day survey was a preliminary assessment of the plant to ascertain the potential for heat recovery and utilisation. An initial scheme was designed around these findings and a report sent to the client. If the proposals were accepted, a second more detailed survey was instigated.

2.2.6 The Extended Survey

This second survey was used to verify and extend initial findings. Preliminary calculations allowed sizing of the heat recovery equipment required; its exact location, ability to be accommodated within existing buildings, loadings on existing structures, access to original plant and heat recovery equipment, location and size of electrical and water supplies, drainage connections and tie-in with process and/or space heating were all parameters finalised during the extended survey. These surveys usually lasted for up to a week.

From the onset of the project it was felt that little could be done to improve heat recovery technology without information on the types of waste heat available. These site surveys provided an ideal opportunity to collect this information, first hand, which was then pooled in a central survey index for future analysis.

2.3 Site Survey Data

Information gathered from site surveys on waste heat sources and utilisation is given in appendix 4 (page 178) and summarised in table 2.2. It shows the type of waste heat source, how it could be utilised and, in percentage terms, the type of heat recovery system specified. Gas-to-gas systems were the most common, being proposed in 62 per cent of cases.

Heat Source			Utilisation			Proposed Heat Recovery System			
Gas	Liquid	Other	Gas	Liquid	Other	Gas/Gas	Gas/Liquid	Liquid/Liquid	Other
89%	8%	3%	62%	33%	5%	62%	26%	7%	5%
Average payback of proposed systems (Years)						4.0	3.1	2.7	2.4
In some cases more than one type of heat recovery scheme was recommended, and ALL options considered are included in 'Proposed Heat Recovery System'. Each 'Heat Source' and 'Utilisation' has been included once only, so making comparison between the two groups invalid.									

Table 2.2 Summary of site survey results

By improving payback periods of gas-to-gas systems, either by cheaper equipment or cheaper installation, viability of this potentially largest market could be increased. This is considered further in section 4.2.2 (page 64). As a first step in achieving this, a product survey was undertaken to review latest developments in the field.

2.4 Product Survey

This review, in October 1979, showed that no index of heat recovery equipment manufacturers existed. The review was extended, with the resulting survey providing an extensive and up-to-date record of heat recovery equipment available, and, where it could be obtained.

The product survey was started in October 1979 and added to throughout the project. Survey details are given in appendix 1 (A1.2, page 156) together with a user index (A1.1, page 155). Since 1979 several professional registers of energy saving equipment have been published. These, together with other useful sources of information, are detailed in a bibliography in A1.3 (page 154) and A1.4 (page 173).

limited further analysis to gas-to-gas systems only (this decision is more strongly justified in section 3.1.1, constraint 2, page 30).

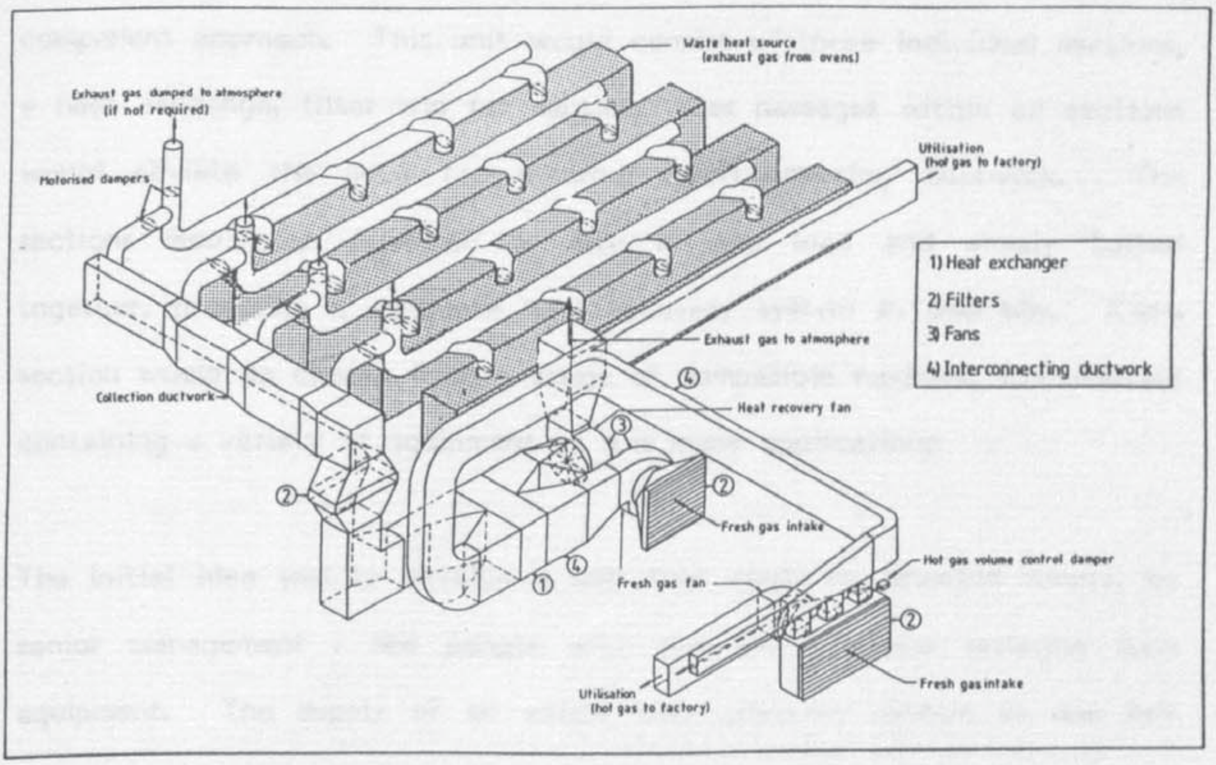


Figure 2.1 A typical gas-to-gas heat recovery scheme

A typical gas-to-gas recovery scheme is shown in figure 2.1. It has 4 main components.

1) The heat exchanger.

2) Filters - waste gas and fresh gas filters.

3) Fans - waste gas and fresh gas fans.

4) Interconnecting ductwork between 1, 2 and 3.

This 'component' system comes under criticism from several viewpoints:

- invariably several manufacturers' equipment is used in one system. This can incur incompatibility problems;
- the installation, with its associated plant disruption, can take extended periods of time;
- large floor area is often required;
- such systems incur large in-house or external design commitment.

In its favour the component system offers complete flexibility of design. There was, it was thought, however, a need for a new system with the flexibility of the component system, but which overcame the problems associated with that type of design.

A modular heat recovery unit was envisaged to supplement the existing component approach. This unit would consist of three individual sections, a heat exchange, filter and fan section. Gas passages within all sections would obviate the need for external interconnecting ductwork. The sections would be delivered to site in one load and simply bolted together, providing a complete heat recovery system in one box. Each section would be chosen from a range of compatible modules, the modules containing a variety of equipment to suit many applications.

The initial idea was to develop a unit that could be selected simply, by senior management - the people with the authority for ordering such equipment. The supply of an entire heat recovery system in one box would minimise the need for in-house design time, or consultants, and this would most likely be recognised by senior staff, one of their tasks being in-house cost reduction.

The 'modular' heat recovery unit or MHRU was conceived as a result of this market analysis. In the course of market research, however, an enquiry was received for a gas-to-liquid heat exchanger suitable for recovering heat from diesel engine exhaust gases. This could not be catered for by the gas-to-gas modular unit and, due to the enthusiasm of the client, it was decided to develop a heat exchanger specifically for this application.

2.7 Proposal for an Exhaust Gas-to-Liquid Heat Exchanger

The requirement for this purpose-built heat exchanger was a direct result of a survey undertaken at the client's site. At this site lubricants were assessed in diesel engines operating 240 hour continuous tests. All exhaust gases were expelled to atmosphere. The results of the survey can be summarised as follows:

1) 21 engines (those which exhibited the greatest operating period per year) were selected for heat recovery.

2) There was a constant demand on the medium pressure hot water (MPHW) system. This system could be supplemented by heat obtained from the exhaust gases.

3) By using a gas-to-liquid heat exchanger, water could be bled from the MPHW 'return' main, passed through the heat exchanger and heated to MPHW 'flow' temperature by the diesel engine exhaust gases. The energy saved would be derived from the existing boilers' reduced work load.

Table 2.3 gives a breakdown of output from a typical diesel engine per unit of input [64]. Approximately 32 per cent of the energy input is lost in exhaust gases. At this site 2.27×10^6 litres of fuel are burned per annum for lubricant testing, giving a potential for heat recovery equivalent to 7.26×10^5 litres of engine test fuel. An exhaust gas-to-liquid heat exchanger was required to achieve at least part of this potential saving.

Parameter	% of energy input
Shaft power	41
Loss to atmosphere through exhaust	32
Loss through radiation and conduction	3
Loss from cooling water	14
Loss from lubricating oil	4
Intercooling loss	6

Table 2.3 Output from a typical diesel engine

It was originally envisaged that an off-the-shelf heat exchanger could have been purchased. One such device had a specified static pressure drop of 2kPa. This magnitude of pressure drop was supported by American data which stated that typical values for this type of equipment would be in the order of 1.5kPa [49]. These pressure drops were rejected by the client as being too high. When pressed to give an acceptable figure, the client suggested that exhaust design (and as the heat exchanger would be connected to the exhaust, so falls into this catagory) was a "bit of a black art, and could not be specified. Static and dynamic pressure drop through the heat exchanger should, however, be minimal". This, together with other client-specified design parameters, are given in table 2.4

Heat exchanger should exhibit the following qualities:	
1) Ease of cleaning	
2) Minimal static and dynamic pressure drop	
3) Replacable high risk parts (due to corrosion)	
Heat transfer and other parameters:	
1) Exhaust gas temperature	811K
2) Minimum allowable gas temperature	383K
3) Exhaust gas flow rate	0.05kg/s
4) Water inlet temperature	366K
5) Water outlet temperature	variable
6) Water flow rate	variable
7) Diesel fuel sulphur content (maximum)	2%

Table 2.4 Specification for the exhaust gas-to-liquid heat exchanger

Following this unsuccessful attempt to find a commercially suitable device, and using the specification supplied by the client, it was decided to design a device for this particular application. This marked the start of the externally generated product.

The development of this and the MHRU continued in parallel, the former to meet specific requirements of a client, as stated in table 2.4, the latter to meet a perceived short-fall in the market, as defined by market research, in section 2.5.

This chapter has described the conception of the two products. Their development, from initial design to prototype, is the subject of chapter 3.

CHAPTER 3

TECHNICAL DEVELOPMENT OF TWO NEW HEAT RECOVERY PRODUCTS

3.0 Introduction

This chapter traces, in detail, the technical development of the project. It is divided into two parts:

- design and development of the internally generated Modular Heat Recovery Unit (MHRU);
- design and development of the externally generated exhaust gas-to-liquid heat exchanger.

3.1 Design and Development of a Modular Heat Recovery Unit

3.1.1 Design Approach for the MHRU

The general approach used in the design of the MHRU is shown in figure 3.1. The initial design brief was vague - to design a modular heat

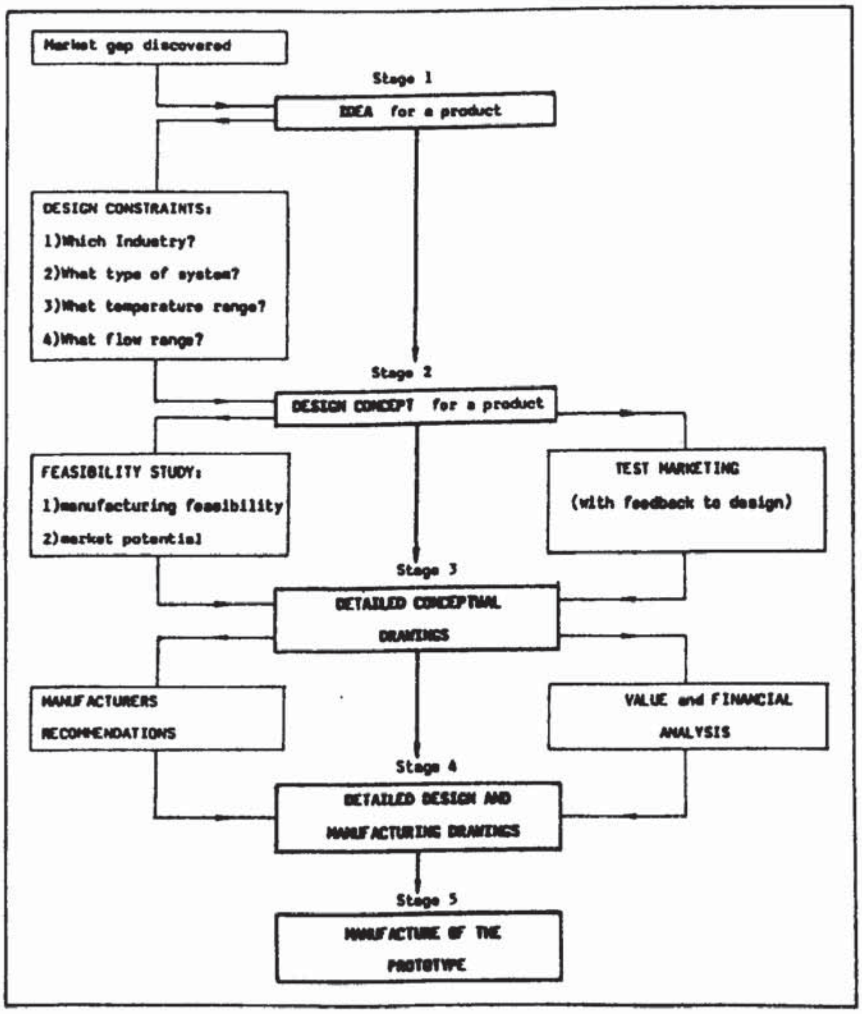


Figure 3.1 Five stages in the design of the MHRU

recovery unit. Contraints had to be applied to reduce the number of design options. They were categorised as global constraints, used in the conceptual stages of the project, and detailed design constraints used in the latter stages.

Answers to the following four questions provided the global constraints initially required:

- constraint 1: should the MHRU be designed for a particular industry?
- constraint 2: should it be gas-to-gas, gas-to-liquid or liquid-to-liquid?
- constraint 3: what should be the operational temperature range(s)?
- constraint 4: what should be the operational flow range(s)?

The order of the above four was important. A particular industry may have favoured one or other type of heat recovery system e.g. gas-to-gas. For this reason it was important to define the market first. Once defined, the type of system most popular in that market had to be ascertained. Physical constraints then had to be specified, temperature first, as this would ultimately effect the volume flow rate.

Constraint 1

The concept of the MHRU resulted from the site and product surveys. It was initially thought that its design should be as universal as possible to encompass applications in the largest number of industries. However, the sponsor, being 50 per cent owned by a cereal manufacturer, Weetabix Limited, had expertise biased towards the food industry and it was thought prudent to aim the MHRU at this sector. The sponsor's experiences, built up during the installation of the Weetabix system, also supported this decision.

Constraint 2

To achieve maximum application potential, the MHRU had to be of the same type as the most common heat recovery system in use, or proposed, in the food processing sector. Details of installed heat recovery systems proved difficult to obtain on a wide basis, so results of the previous site surveys were used to find the most proposed type of system. Of the 62 surveys detailed in appendix 4, 25 were in the food processing sector. Of these, 71 per cent proposed gas-to-gas systems, 26 per cent gas-to-liquid systems and 3 per cent liquid-to-liquid systems. At a majority of sites the heat source was oven exhaust gases and utilisation was pre-heating combustion air, for oven burners, or space heating. To achieve maximum market potential the MHRU would have to be a gas-to-gas device.

Constraint 3

With conceptual parameters defined, physical characteristics of the MHRU were considered. In the food processing sector the main source of waste heat is exhaust gases from baking ovens. The quantification of such sources was needed to define the physical specification required by the MHRU. The main parameters required were temperature of exhaust gases (quality) and their flow rates (quantity). A quality-quantity survey was undertaken to obtain measurements of flue gases at operational sites throughout the country. A total of 25 sites were surveyed having 83 ovens and 251 flues, details of which are given in appendix 5 (page 180).

Figure 3.2 shows the frequency of occurrence of measured exhaust gas temperatures. In 47 per cent of cases temperatures were in the range 424K-473K, the average, from appendix 5, being 437.5K (164.5^{o}C). Work in the biscuit industry broadly supports this finding.

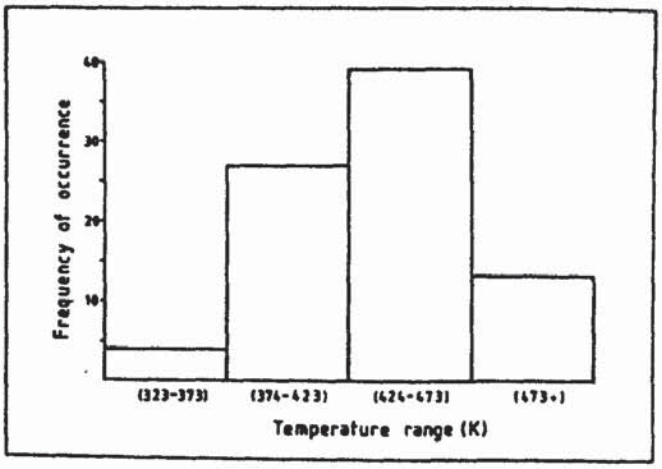


Figure 3.2 Temperature distribution of baking oven exhaust gases

In the biscuit industry, baking temperatures range from 466K for soft dough biscuits to 561K for cracker types [65]. However, baking temperatures are always hotter than exhaust gases, giving an actual exhaust gas temperature range of approximately 440K-520K [66]. The upper limit is slightly greater than the range specified previously (of 424K-473K). However, the high temperature cracker type biscuits account for only 14 per cent of the total biscuit market [67], leaving a majority of lower temperature baked biscuits to fall into the prescribed range.

Heat sources can be considered as the primary side of a heat recovery system and utilisation the secondary side. Table 3.1 shows the utilisation of the recovered heat on the 25 sites analysed. In 68 per cent of these cases utilisation required hot gas.

Utilisation	% of Total	
Space heating (hot gas)	36	
Pre-heating combustion gas (air) and other oven gas make-up	23	68
Pre-heating combustion gas and space heating	9	
Boiler feed-water pre-heating	14	
Domestic and process hot water heating	14	
Other (absorption cooling)	4	
	100%	

Table 3.1 Utilisation of recovered heat on 25 food processing sites surveyed

Again, to achieve the maximum potential market, these results show that the MHRU should be a gas-to-gas unit capable of using hot exhaust gases (in the temperature range 424K-473K) and providing hot gas for utilisation.

During the initial design stages this was the only temperature range considered. Later, however, the MHRU's flexibility was expanded, and in the final product 3 temperature ranges were available: 273K-323K; 323K-473K; 473K-773K (see section 3.1.6, page 47).

Constraint 4

Design flow rates for the unit were also defined by the quality-quantity survey. The MHRU should (ideally) meet the heat recovery needs of an entire process and for this reason analysis of flow is by total site output of exhaust gas (appendix 5), not individual ovens. Figure 3.3 shows the distribution of flow rates for the 25 sites surveyed.

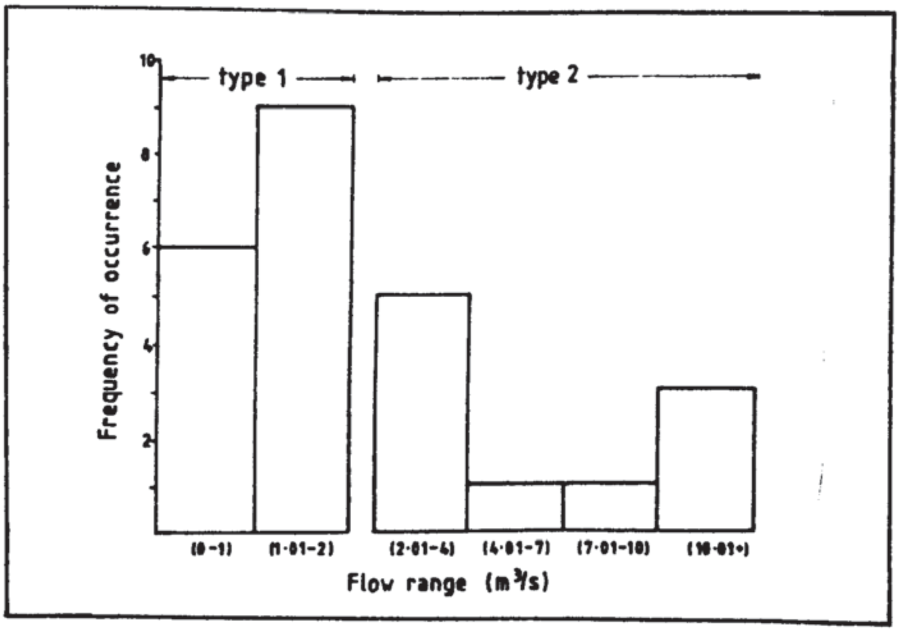


Figure 3.3 Site flow rate distribution of baking oven exhaust gases

Dominance of small flow rates was noted (60 per cent of flow rates occur in the range $0\text{-}2m^3/s$). The spread of flow rates was also great, the largest ($15.57m^3/s$) being nearly 60 times the smallest ($0.27m^3/s$). It was thought that two types of product were required:

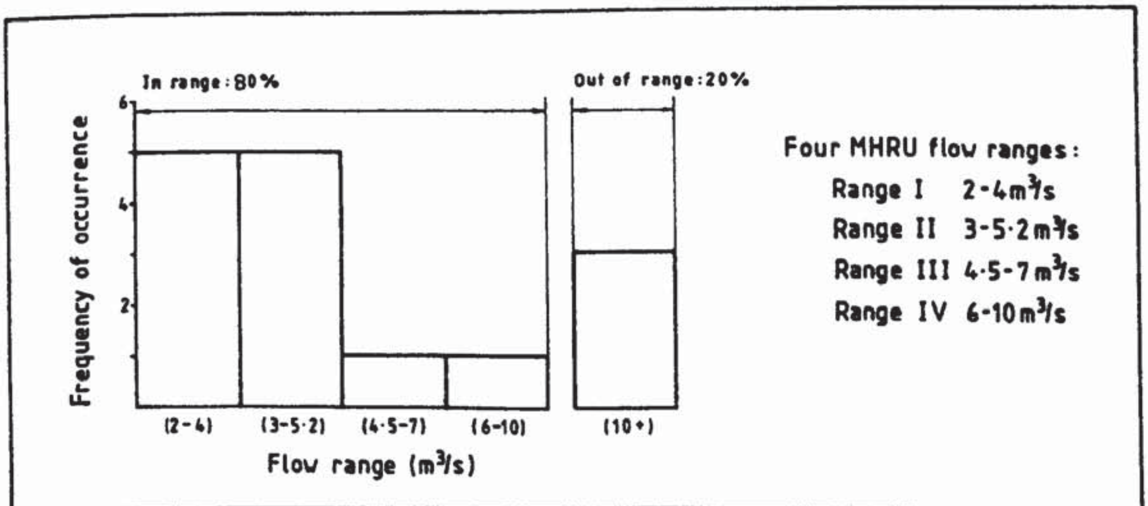
- type 1: a unit for small flow rates up to $2m^3/s$;
- type 2: a unit for flow rates between $2m^3/s$ and $10m^3/s$.

The type 1 unit became a project undertaken, for the most part, by other company staff. Its development is not detailed, but for completeness, however, the final design is shown in appendix 6 (page 192).

The type 2 unit, although required in much lower quantities than the type 1, would, due to its higher flow capacity, enable the saving of greater quantities of energy. This was the fundamental reason for pursuing this units design in preference to type 1.

The type 2 unit was for flow rates between $2m^3/s$ and $10m^3/s$. Some measured flow rates were, however, greater than this. A preliminary analysis suggested that units of more than $10m^3/s$ capacity would be physically large, structurally difficult to manufacture and of prohibitively high cost (when compared with an existing component system). In view of this, maximum throughput was limited to $10m^3/s$.

Between $2m^3/s$ and $10m^3/s$, four overlapping flow ranges were envisaged, these being shown in figure 3.4. (Above $2m^3/s$ these ranges encompass 80 per cent of all requirements). In applications where the flow rate falls into the overlap section, a choice could be made between two suitable units, the larger having greater efficiency but costing more.



1 Due to overlapping flow ranges, results may be included in more than one range

Figure 3.4 How four flow ranges selected for the type 2 MHRU fit market requirements

Product design, the first stage of which was equipment selection, was based on temperature and flow ranges to be accommodated.

3.1.2 Equipment Selection

The four basic parts of the gas-to-gas heat recovery system (heat exchangers, filters, fans and interconnecting ductwork) were, for initial design, considered separately.

The Heat Exchanger

The following qualities were defined that had to be exhibited by a heat exchanger selected for use in the MHRU:

- suitable for gas-to-gas heat exchange;
- capable of operation in temperatures up to 473K;
- ability to handle gas flows between $2m^3/s$ and $10m^3/s$.

Eight heat exchangers were found that could accommodate these requirements, four of which were selected for detailed analysis. Using 12 design parameters, a weighting and rating analysis was conducted to select the most appropriate design. Details of the four devices and the analysis of their suitability are given in appendix 7 (page 194).

Each type of heat exchanger analysed showed benefits in different applications. This, coupled with such a close result from the aforementioned analysis (169 and 182 being the lowest and highest scores respectively), suggested that an MHRU design which could accommodate any of the heat exchanger types may be advantageous. However, as a starting point for initial design work, the plate heat exchanger was selected as it received the best rating and was readily available.

Filters

All gases entering the MHRU had to be filtered for two primary reasons:

- particles not removed from gas flows could cause physical damage to heat exchanger surfaces by impingement; they could cause clogging, a change in pressure drop and a reduction in effectiveness as they collect on heat transfer surfaces;
- in nearly all cases utilisation would require a clean filtered gas supply.

Two classes of filters were required; high temperature filters for exhaust gas filtration and low temperature filters for supply gas filtration. (When the recovered heat is to be used for reheating recirculated gases, high temperature filters may also be required on the low temperature side.) The choice of filters is given in appendix 7 (page 194).

Fans

Adding heat exchangers and filters to an existing process causes an increase in system resistance. In most cases this extra resistance is not tolerable and fans - external to the process - must be added to enable heat recovery to be accomplished with no detrimental effect to the process. For this reason fans should also be part of the MHRU. The unit required two fans, one for the exhaust gas and one for the supply gas. Two fan types were found to be capable of the temperature and flow requirements, axial and centrifugal. Centrifugal fans were selected, as described in section 3.1.4 (page 42).

Interconnecting Ductwork

All interconnecting ductwork was to be incorporated into the heat exchange, filter and fan sections.

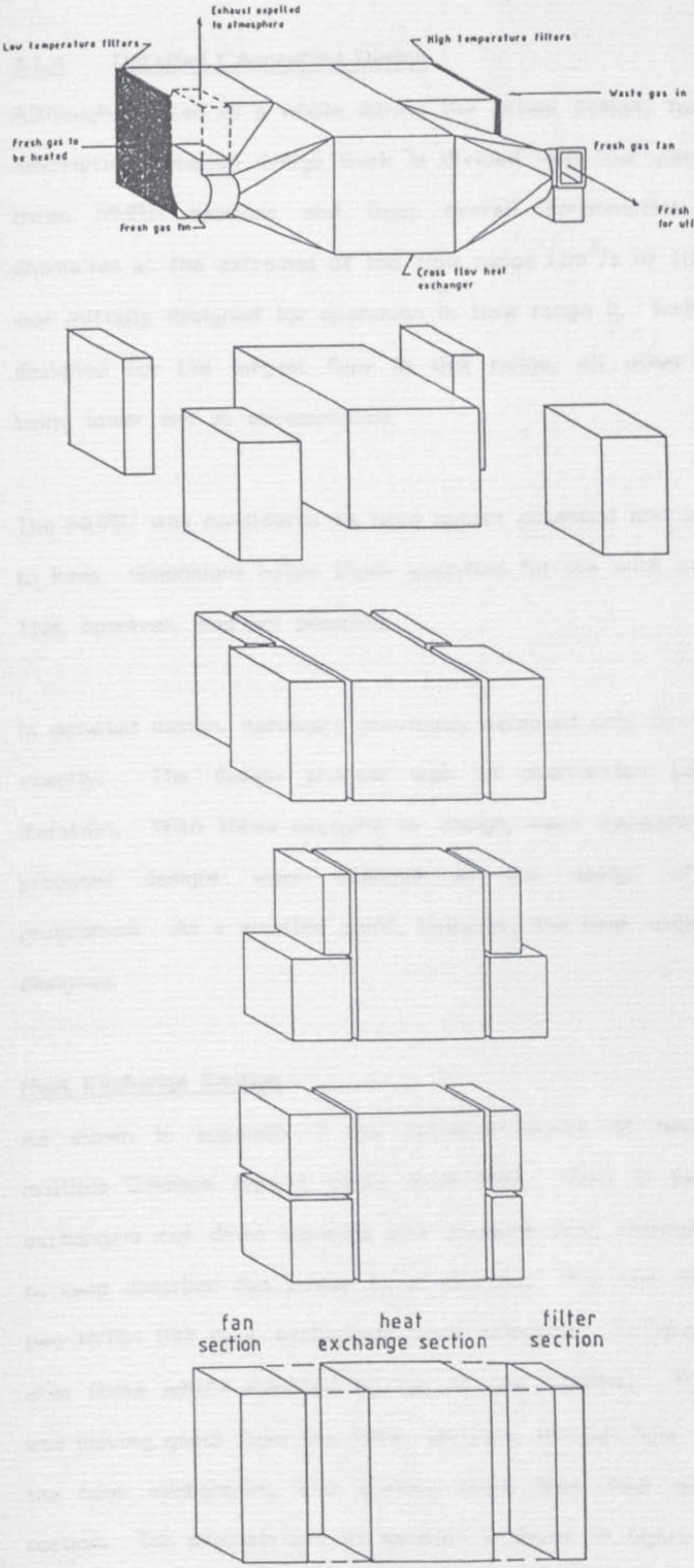
With basic selection of hardware complete conceptual design work was undertaken.

3.1.3 Conceptual Design

The design concept of the MHRU was that it should be delivered to site in one load, lifted into position and connected to source and utilisation ductwork - this to provide a fully operational heat recovery system in one box and in a fraction of the time of a component system.

Figure 3.5(A) shows a component system. The first stage of modularisation was putting the separate parts of the component system into individual boxes or modules, the interconnecting ductwork being housed within each module (figure 3.5(B)). This gave a squat system occupying a large floor area (figure 3.5(C)). Site surveys showed that floor area was more critical than height of equipment, and adopting this as a design precedent, the system was turned through 90°, reducing the floor area by two thirds (figure 3.5(D)). The next step moved the two filter sections to one end of the heat exchanger and the two fan sections to the other (figure 3.5(E)). A single location for the filters would facilitate maintenance and combining the fans would keep support steelwork and wiring to a minimum. The final stage amalgamated the separate filter modules into one section and the fan modules into another (figure 3.5(F)). Gases would pass through the filter section first, then the heat exchange and fan sections. Fans would be mounted down-stream to draw the gases through the unit enabling them to handle the now filtered (rather than unfiltered) gases.

This was the concept of the sectional modular heat recovery unit: sectional, since the unit would be supplied in three sections, the heat exchange section, the filter section (housing filters for both exhaust and fresh gas flows) and the fan section (housing fans for both flows); modular, since each section would be completely compatible with all other sections.



Stage 0
A typical gas-to-gas heat recovery system

(figure 3.5(A))

Stage 1
Each component is placed in a module

(figure 3.5(B))

Stage 2
A 'squat' heat recovery system is produced requiring a large floor area

(figure 3.5(C))

Stage 3
Reduction of floor area by lifting the modules through 90^{o} to stand perpendicular

(figure 3.5(D))

Stage 4
Reposition filters to one end of the heat exchanger, and fans to the other

(figure 3.5(E))

Stage 5
Amalgamate sperate filter sections into one, and fan sections into one

(figure 3.5(F))

Figure 3.5 Modularisation of a comoponent heat recovery system

3.1.4 Detailed Conceptual Design

Although treated as a whole during the actual design, for the purposes of description detailed design work is divided into four parts: design of the three MHRU sections and their overall construction. To avoid any anomalies at the extremes of the flow range ($2m^3/s$ or $10m^3/s$), the MHRU was initially designed for operation in flow range II. MHRU sections were designed for the largest flow in this range, all other flow rates then being lower and so accomodated.

The MHRU was considered to have export potential and efforts were made to keep dimensions below those specified for use with export containers. This, however, was not possible.

In detailed design, hardware previously selected only by type, was defined exactly. The design process was an open-ended problem solved by iteration. With three sections to design, each dependent on the others, proposed designs were changed as the design of other sections progressed. As a starting point, however, the heat exchange section was designed.

Heat Exchange Section

As shown in appendix 7 the optimum choice of heat exchanger was multiple Climate type I, plate units [68]. Used in parallel these heat exchangers cut down velocity and pressure drop through the MHRU, and so keep absorbed fan power to a minimum. For the flow range defined, two HVRH 095 heat exchangers were selected. To obtain minimum floor area these where mounted on top of one another. The design problem was moving gases from the filter sections, through four separate inlets on the heat exchangers, and ducting them from four outlets to the fan section. The problem and its solution is shown in figure 3.6.

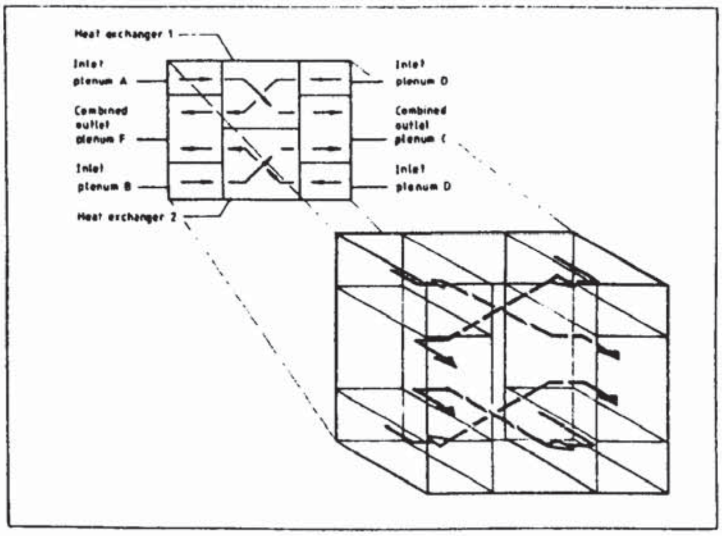


Figure 3.6 Ducting of gases through heat exchange section

Hot gases pass into the heat exchanger via inlet plenums A and B. Gases from inlet plenum A pass through heat exchanger 1 and fall into outlet plenum C. Gases from inlet plenum B pass through heat exchanger 2 and rise, also into outlet plenum C. Similarly, gases from inlet plenums D and E pass out from combined outlet plenum F.

To reduce the effect of pressure drop it was recommended that velocities in such plenums should not exceed 15m/s [69]. Velocity, for a given flow rate, is dependant on the cross sectional area of the plenum. Here the plenum's height was fixed and identical to that of the heat exchanger inlet (0.583m) so the width was chosen to ensure 15m/s was not exceeded. At the design maximum flow rate of 5.2m^3/s the total plenum area required was 0.35m^2 (5.2m^3/s / 15m/s), giving a required total plenum width of 0.6m (0.35m^2/0.583m). Only half the total flow would be handled by each heat exchanger, so making each plenum 0.3m wide. The overall dimensions of the range II MHRU heat exchange section are given

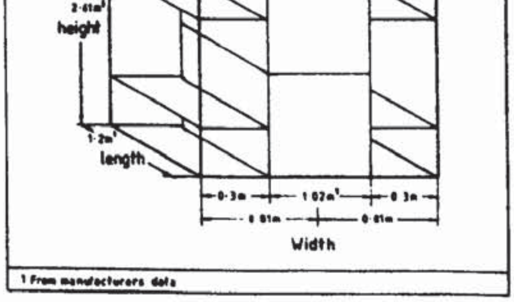


Figure 3.7 Preliminary dimensions of the heat exchange section for range II MHRU

in figure 3.7. These dimensions (and others quoted in section 3.1.4) were preliminary and did not include casing or structural steelwork.

With this type and make of heat exchanger, to accomodate various flow rates more economically, the number of heat transfer plates, and hence the length of the heat exchanger, can be varied. (The heat exchanger's height and width remain constant throughout the range.) This enables smaller (and cheaper) heat exchangers to be fitted into the standard framework (which could be simply shortened) to accommodate flows in the given range below $5.2m^3/s$ more economically.

With the dimensions and layout of the heat exchange section complete, this provided a base from which to start filter and fan section design.

Filter Section

The filter section had to be designed to accommodate those filters selected in appendix 7. Although filter type had been decided, as each application could be different, filter specifications (e.g. efficiency, quality) were left to the client's discretion.

Panel Filters

Panel filters may be used for both exhaust and fresh gas flows. A maximum working velocity of 2-3m/s was recommended over the face of panel filters [70] giving a required filter media area of $2m^2$ at a flow rate of $5.2m^3/s$. Using the most common size of filter (0.612m x 0.612m), the usable area of which is $0.34m^2$, the number of filters required was six. To be dimensionally consistent with the heat exchange section, filters were mounted one filter wide in a stacked zig-zag pattern, as shown in figure 3.8. A blanking plate was used to cover the extra width available. A similar flow rate may be expected on the other gas side and an identical arrangement of filters was used there.

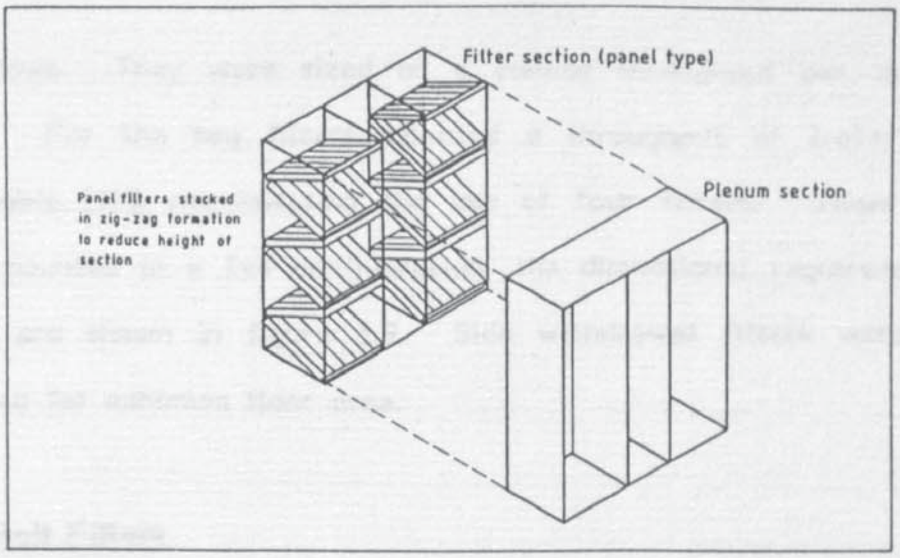


Figure 3.8 Filter section, incorporating panel type filters

To allow mixing of the gases and a more even distribution through the filters, a plenum chamber was added between filter and heat exchange sections (figure 3.8).

Panel filters had to be withdrawn, either from the side or the front for cleaning or disposal. Front withdrawal filters would have required a plenum in front of the filters (in addition to the one behind) to permit maintenance work. With the design precedent of minimum floor area, side withdrawal filters were selected. The dimensions of the filter section using panel filters is shown in figure 3.9

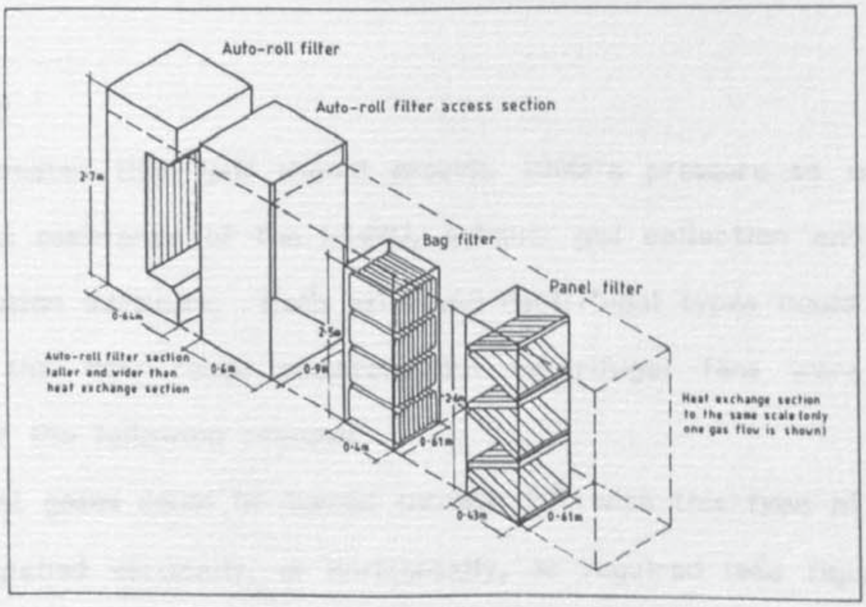


Figure 3.9 Dimensions required to house filters for one gas flow in the MHRU

Bag Filters

Bag filters, due to temperature limitations, were only suitable for fresh gas flows. They were sized on a volume throughput per individual filter. For the bag filters selected a throughput of $1.41m^3/s$ was obtainable [71], necessitating the use of four filters. These filters were mounted in a 1x4 configuration, the dimensional requirements of which are shown in figure 3.9. Side withdrawal filters were again selected for minimum floor area.

Auto-Roll Filters

The auto-roll filter is, fundamentally, a large panel filter that automatically changes itself when dirty (see appendix 7). For the flow range required the AAF 3-88 was selected [72]. Dimensions of the auto-roll filter section are shown in figure 3.9.

The auto-roll filter for range II flow rates would have cost £617 [73], compared with £33.54 [70] for the equivalent panel system. This considerable cost increase, coupled with the dimensional incompatibility of the auto-roll filter and heat exchange section, prompted a move to supply auto-roll modules to special order only. Later design work considered panel and bag filters only.

Fan Section

It was estimated that fans should provide 1000Pa pressure to overcome the internal resistance of the MHRU, exhaust gas collection and heated gas distribution ductwork. Both axial and centrifugal types could provide this over the flow range required, but centrifugal fans were finally selected for the following reasons:

- exhaust gases could be turned through 90^o with this type of fan, to be expelled vertically, or horizontally, as required (see figure 3.10, page 43);
- a separate access section was needed for cleaning axial fans, increasing the size of the fan section required. Access on

centrifugal fans was integral;

- the fan section, even without access would have been 0.5m longer using axial fans;
- centrifugal fans are of higher efficiency, giving reduced operating costs;
- processes are often changed or modified. Changes of flow can be more readily accommodated by the changing of pulleys and belts on centrifugal fans, than by the changing of blade angles on axials;
- the typical speed of a centrifugal fan (at the specified flow rate) would be 1000 rpm compared with 2850 rpm for an axial, making the former quieter in operation. This is important on the fresh gas side where noise may be transmitted along distribution ductwork to the utilisation environment. (External silencers may have been required should axial fans have been used;)
- centrifugal fans without silencers are of comparable cost to axial fans with silencers.

For minimum floor area, the two centrifugal fans were mounted on top of one another. The design of the fan section is shown in figure 3.10. Gases from combined plenum C (figure 3.6, page 39) were ducted up into

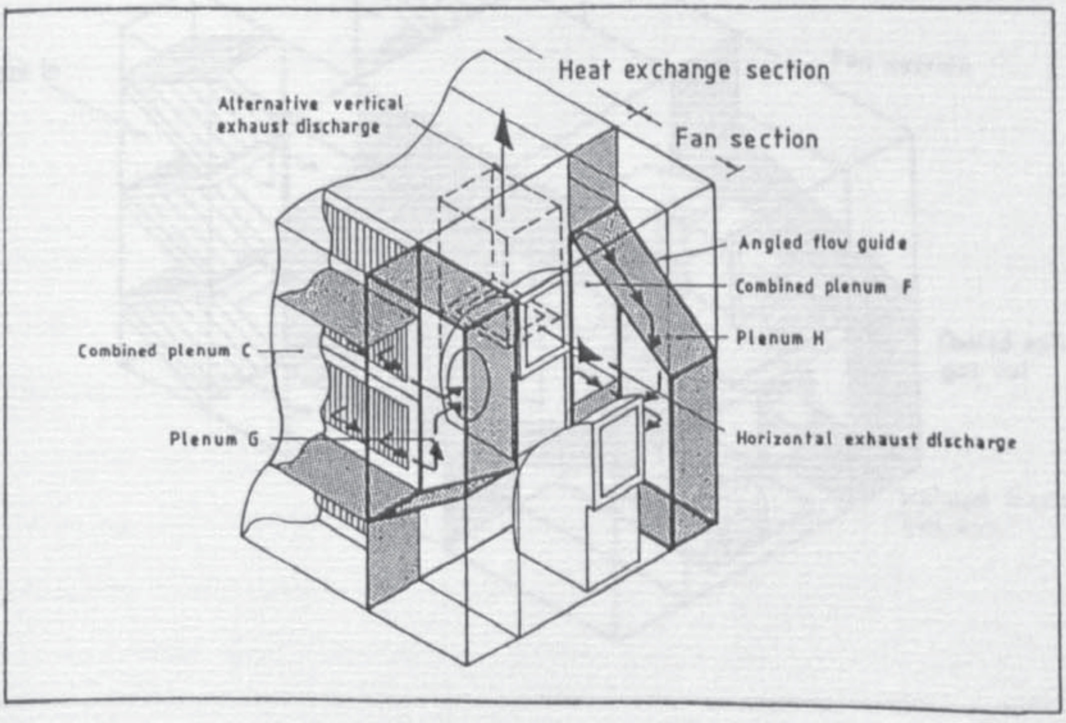


Figure 3.10 Fan section showing ducting of gases to upper and lower fans

a second plenum, G, in which the upper fan's inlet was mounted. Gases from combined plenum F were ducted down to plenum H, in which the lower fan's inlet was mounted.

The fan section height was approximately 0.1m greater than the heat exchanger section. Backward curved fans were originally specified for the MHRU. In the Engart range of fans forward curved fans are, however, slightly smaller [74] and in the final design this type were used to obtain the necessary height reduction.

To help prevent vibration being transmitted through the MHRU, and help reduce noise break-out along ductwork connections, both fans were isolated from the unit using anti-vibration mountings and flexible ductwork connections.

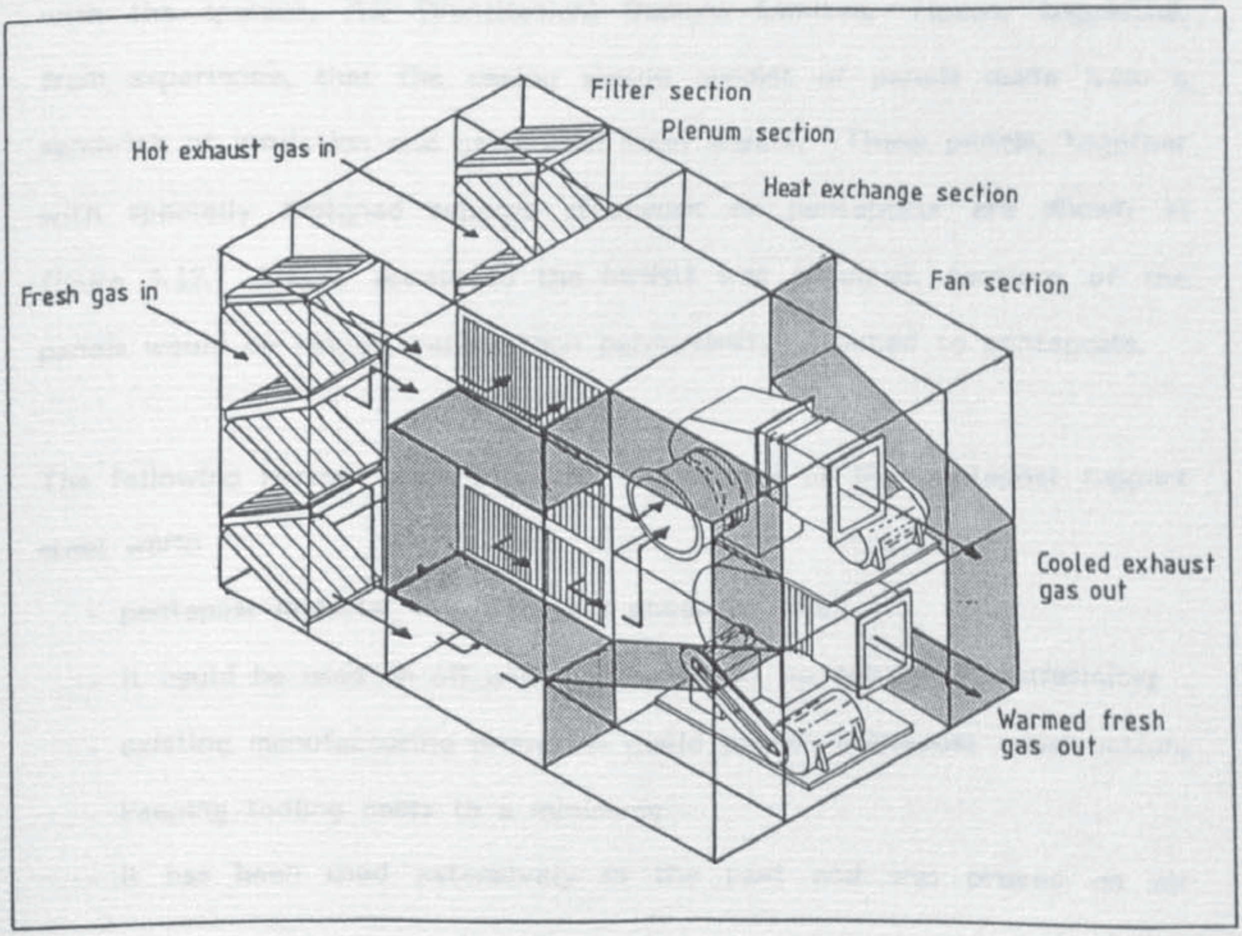


Figure 3.11 Detailed conceptual design of the MHRU

This concluded the detailed conceptual stage, the arrangement finally adopted being shown in figure 3.11. Slight dimensional discrepancies would be accomodated during detailed design and manufacture.

The casing of the MHRU was then considered in detail.

Case Construction

The casing of the MHRU served two functions: firstly it provided a housing for the hardware giving the MHRU its modular construction; secondly, it contained the gases to provide integral ducting. Since temperatures up to 473K had to be accommodated, case insulation was required to reduce heat losses and maintain safe external case temperatures.

The future manufacturer of the MHRU, a company financially associated with the sponsor, Air (Ventilation) Designs Limited, Tipton, suggested, from experience, that the casing should consist of panels made from a sandwich of insulation and galvanised steel sheets. These panels, together with specially designed support steelwork or pentaposts are shown in figure 3.12. Where access to the MHRU was required, sections of the panels would be hinged, rather than permanently attached to pentaposts.

The following reasons were cited for the choice of the pentapost support steel work:

- pentapost material was easy and cheap to use;
- it could be used on all units in the range, so enhancing uniformity;
- existing manufacturing processes could accept pentapost construction, keeping tooling costs to a minimum;
- it has been used extensively in the past and was proven on air

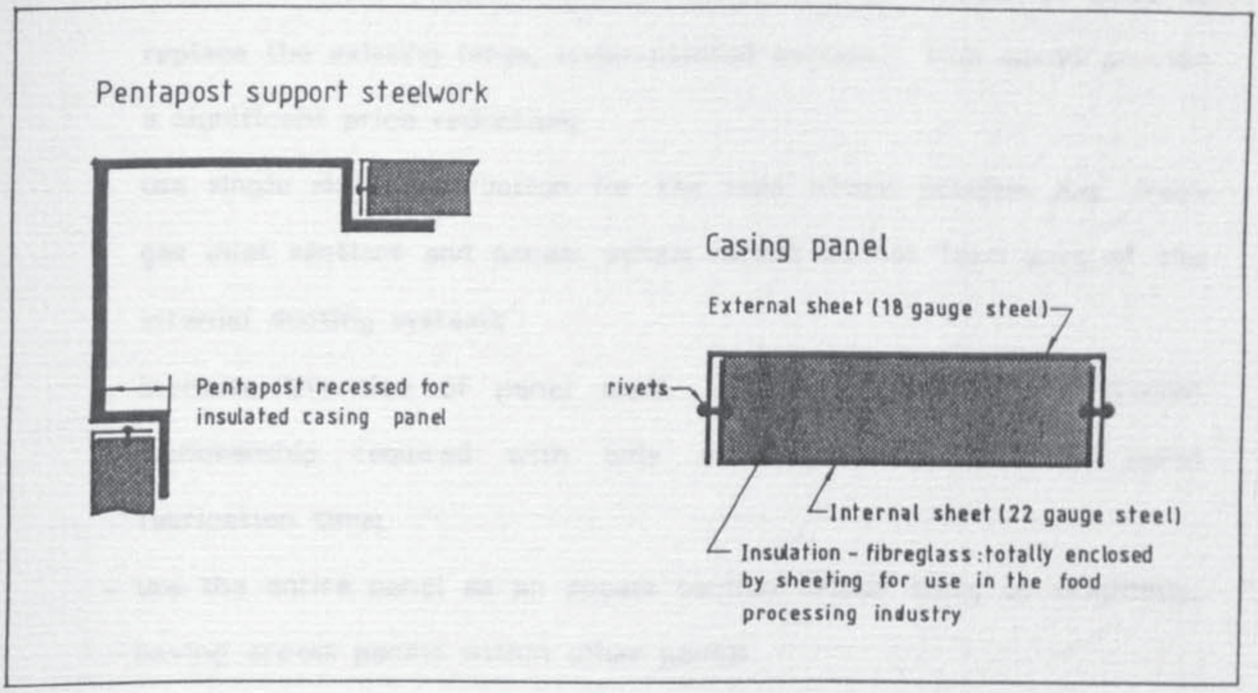


Figure 3.12 Pentapost support steelwork and double skinned insulating panel

handling units up to $24m^3/s$ [75] (maximum MHRU flow rate for combined exhaust and fresh gas flows would be $20m^3/s$);

- pentaposts were recessed to support insulating panels.

After completion of the casing design an estimate of construction cost was obtained. For the range II MHRU the construction cost was £9000 compared with £4000 for an equivalent component system. This difference was not justified by the inherent advantages of the MHRU, and a value analysis exercise was instigated to try to reduce this difference.

3.1.5 Value Analysis Exercise

The aim of this exercise was to reduce the construction cost of the MHRU to that comparable with a component system. The following were considered:

- divide the filter section into two compact, high utilisation units to replace the existing large, under-utilised section. This would provide a significant price reduction;
- use single skin construction for the case where possible e.g. fresh gas inlet sections and access panels (which do not form part of the internal ducting system);
- increase the size of panel used. This decreases the pentapost workmanship required with only a marginal increase in panel fabrication time;
- use the entire panel as an access section rather than, as originally, having access panels within other panels.

These produced only small aesthetic changes in the MHRU but, when costed, reduced construction to £4900. This figure was more comparable to the target of £4000 and the design, incorporating the above suggestions, was frozen and manufacturing drawings prepared. All final design details are contained in an MHRU reference manual produced for the sponsor [76].

The prototype was completed by 25th January 1981; its installation, commissioning and testing is described in chapter 6.

Previous sections describe the design of a 'base' MHRU using a plate heat exchanger for one temperature and flow range. In the final product three choices of heat exchanger were available with three temperature régimes and four flow ranges.

3.1.6 A Design for Versatility

The MHRU is primarily a high temperature device, the requirements of which made it more expensive than standard air conditioning equipment.

To increase versatility and potential market for the unit a low temperature version (273K-373K) was designed. Here specifications of the casing, filters and fans were reduced giving an overall saving, over the (medium temperature) base unit, of roughly £2000. By increasing the specification of the casing, fans and heat exchanger a high temperature unit was created. This, it was estimated, gave the MHRU a maximum operating temperature of 750K for an increase, over the base unit, of £1500.

In these temperature régimes, different types of heat exchanger may be required. Appendix 7 suggests four types that could be usefully incorporated in the MHRU, and figure 3.13 shows how heat wheel and heat pipe heat exchangers could be fitted into the existing plate heat exchanger section. The fourth, the shell and tube device, has been omitted from the options, its use being seen, in its gas-to-gas role, for more rigorous industrial applications - those inherently valuing from component system design.

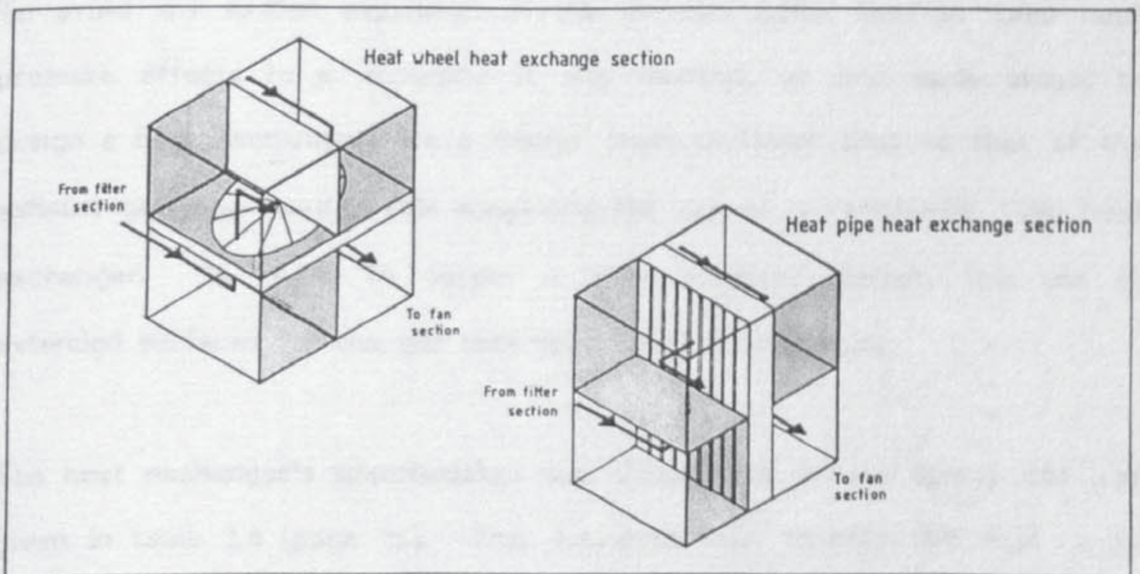


Figure 3.13 Heat exchange section incorporating heat wheel or heat pipe heat exchangers

Given the options in temperature, flow rate, heat exchangers and filters the MHRU offers a total of 108 combinations, the dimensions of which are given in an MHRU sizing manual [77].

This concludes the technical considerations used in the design of the

MHRU: those of the exhaust gas-to-liquid heat exchanger are now discussed.

3.2 Design of a High Temperature Exhaust Gas-to-Liquid Heat Exchanger

This unit was developed as a result of an externally generated product idea. The client, a multi-national company, was investigating the recovery of heat from in-house diesel test engines. The following sections describe how a heat exchanger was developed specifically for this purpose.

3.2.1 Design Considerations

Design considerations were divided into two parts: global considerations to determine the type of heat exchanger required; detailed considerations to provide a specification for the heat exchanger.

The exhaust gas pipe from the engine was small (approximately 100mm). To avoid any sudden expansion of the exhaust gases (and so keep back pressure effects to a minimum) it was decided, at any early stage, to design a heat exchanger with a similar cross-sectional area to that of the exhaust gas pipe itself. This suggested the use of a concentric tube heat exchanger. In order to obtain a more compact design, the use of extended surfaces for the gas side would also be required.

The heat exchanger's specification was determined by the client and was given in table 2.4 (page 26). This indicated four factors that had to be considered at an early stage in design: fouling, back pressure, corrosion and heat transfer.

Fouling

Particles contained in diesel exhaust gases can settle on heat exchange surfaces and reduce operating efficiencies. If unchecked these deposits may build up and can completely clog gas passages. To obtain compact heat exchangers, extended surface tubing is often used and conventional tubing of this type usually has fins helically wound around it. These fins, however, form traps for sooty deposits and are difficult to clean when fouled. Research has shown that tubes having a 5mm pitch, when used in a cross-flow arrangement, completely clog to the full height of the fin within 28 days of exposure to diesel engine exhaust gases [78]. The same report did conclude, however, that at a pitch of 8.5mm total plugging did not occur.

The use of helically wound finned tubing provides many cavities and bluff points that may foster the build up of sooty deposits, which as they gather, in-turn increase pressure drop. This problem would be greater should this tubing be used in longitudinal rather than cross-flow, as is the requirement in this case. It has been shown [79] that total particulate output from combustion is proportional to fuel sulphur content. This only served to compound the problem as the client's engines normally operated using medium (0.8 per cent) to high (2 per cent) sulphur content fuels. These reasons prompted a search for an alternative extended surface tube.

A longitudinally finned tube would provide a solution as exhaust gases flow along the fins providing a scraping action, so helping to prevent excessive soot deposition.

Back Pressure

Back pressure can be divided into two parts, static back pressure and dynamic pressure wave effects.

No definitive information could be found that gave design values for pressure drop. An experimental heat exchanger for a 6643kW DeLaval diesel engine had been designed in America producing a maximum pressure drop of 750Pa [80]. In the absence of other data, and in keeping with the client's previous statement that a pressure drop of 1.5kPa was unacceptable (section 2.7, page 25), this value was used for design.

Corrosion

Corrosion occurs when exhaust gases drop below their acid dew point and condense on heat exchange surfaces. The resulting sulphur compounds combine with water to form an acidic solution that can attack these surfaces. To minimise corrosion the exhaust gases should be kept above their acid dew point temperature.

Dew points for typical medium sulphur fuel (0.8 per cent) used by the client vary between 385K and 390K [49,81,82]. Much evidence, however, shows that maximum corrosion occurs below these temperatures [83,84,85], typically at 375K [81]. To ensure the bulk gas temperature remained above the acid dew point, a minimum design gas temperature of 450K was used.

Although, theoretically, little corrosion would take place in the heat exchanger, material selection was still an important factor. Of the commonly available materials the choice lay between low carbon steel or stainless steel, the combined purchase and manufacturing cost of the latter being twice that of the former. Research had shown that both exhibited good corrosion resistance when exposed to diesel exhaust gases [78]. It was suggested [78] that initially a thin layer of acid condenses on the cold, bare metal surfaces to which, after this wetting, soot particles adhere and form a fouling layer. As this layer thickens, the high thermal resistance of the soot causes the surface temperature exposed to the gas to increase above the acid dew point, and prevent additional condensation. With no advantage to be gained from the more expensive material, low carbon steel was selected as the working material.

Heat Transfer

The initial design idea was to use a single longitudinally finned tube mounted in a cylinder. Water would pass through the centre of the finned tube and exhaust gases in the annulus between the two (figure 3.14).

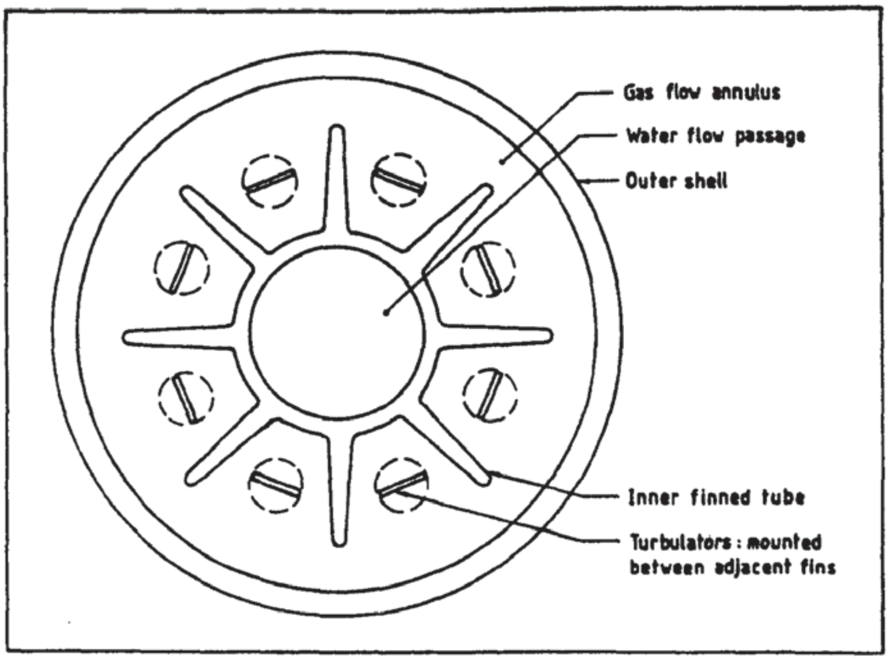


Figure 3.14 Cross-section through heat exchanger showing longitudinally finned tube, casing and turbulators

The cylinder diameter would be chosen to give the annulus approximately the same cross-sectional area as the existing exhaust pipe in an effort to minimise dynamic effects. The fins divide the annulus into, effectively, eight flow channels. To enhance heat transfer, turbulators would be included in each of these channels. Consisting of thin strips of steel (12mm x 3mm), twisted about their longitudinal axis and running for the entire length of the heat exchanger, they would induce swirl and turbulence into the flow and so help reduce boundary layers. When tested, the inclusion of turbulators increased heat transfer, as measured on the water side, by 20 per cent (see appendix 8.3.5, page 217).

3.2.2 Physical Design

The following design precedents were listed before design work started:

- the design should be easy to clean;
- static pressure drop should not exceed 750Pa;
- dynamic effects should be minimal;
- potential for corrosion should be minimised;
- standard materials and components should be used, where possible, to ease manufacture and shorten lead times, so promoting quick delivery;
- of the 21 engines selected for heat recovery, 18 (or 86 per cent) had outputs of 30kW. The heat exchanger should be designed for these engines and used in multiples on larger ones;
- provision should be made on a prototype for test points.

During the design phase references were made to several British Standards. These references, together with comments on the British Standards (B.S.) system are described in section 5.3 (page 92).

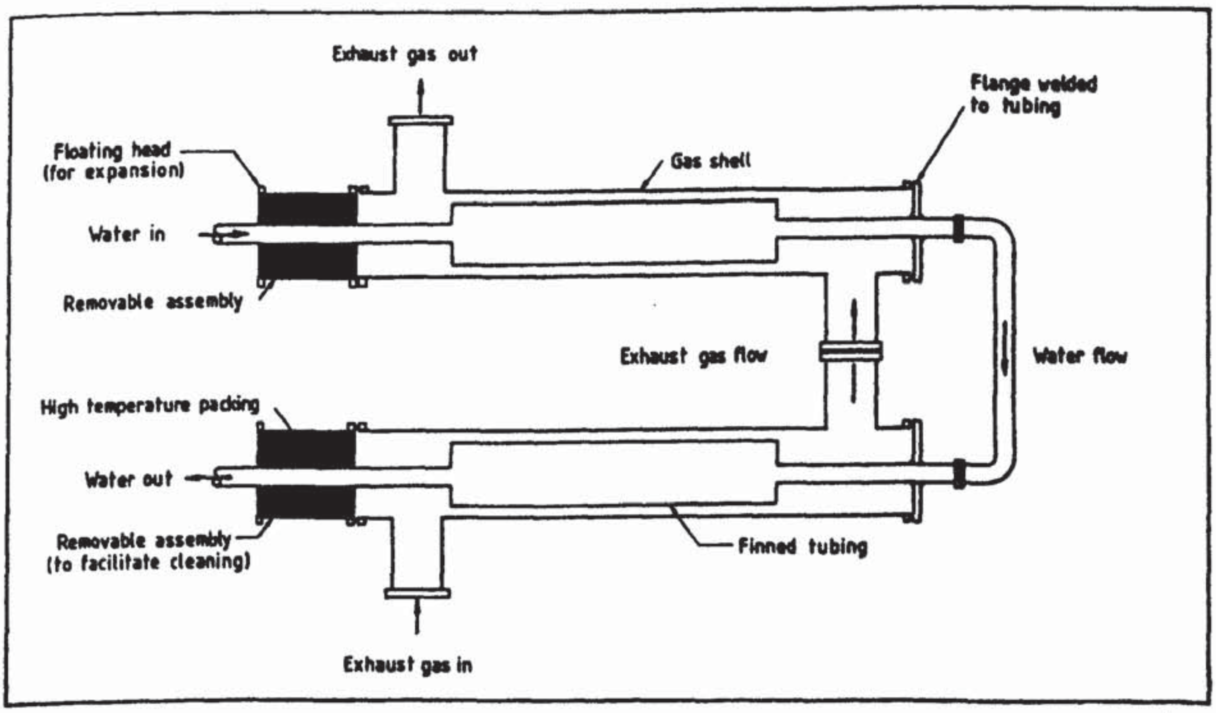


Figure 3.15 Diagrammatic arrangement of the exhaust gas-to-liquid heat exchanger (001)

The first prototype design is shown in figure 3.15. The shell of the heat exchanger is a length of standard B.S. 3601 tubing containing the finned tube. Two exchangers are joined in series to give the required heat transfer surface area. To allow for differential expansion between finned tube and gas jacket, a floating head was fitted at one end of the heat exchanger.

To clean the device the flanges at each end are unbolted, moved back and the turbulators removed. The finned tube is moved out of the heat exchanger at the welded flange end sufficiently for the heat exchanger to be rodded out (figure 3.16). Further design details are given in appendix 8 (page 209).

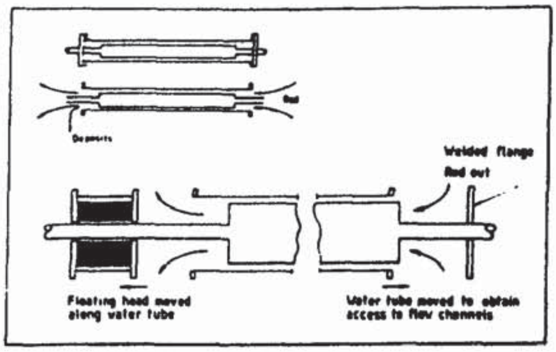


Figure 3.16 Cleaning the heat exchanger

This design (001) was approved by the client and a prototype manufactured. Testing was then required to prove the design.

3.2.3 Testing of the First Prototype, 001

A schematic diagram of the test installation is shown in figure 3.17. Due to the high operating temperatures involved (811K), a pressure relief valve was incorporated in the pipe work in case steam was produced during testing. Various water flows were required and these were obtained by altering valve IV.

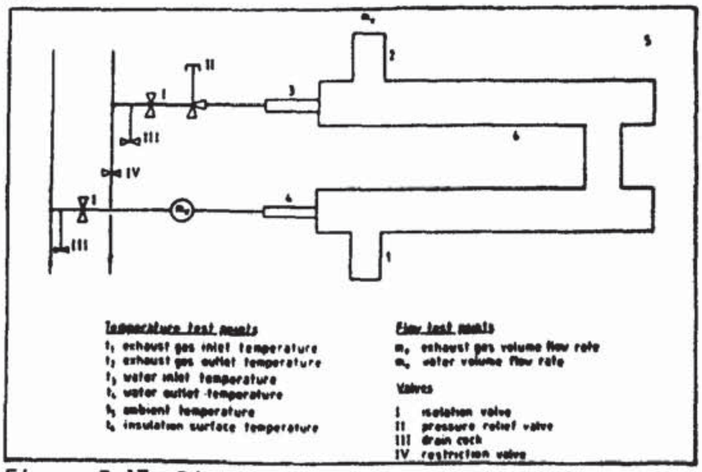


Figure 3.17 Diagrammatic arrangement of 001 test installation

Testing described in detail in appendix 8, conformed to standard test procedures as defined by the American Institute of Chemical Engineers [86], and was divided into two parts:

- tests carried out without turbulators in the heat exchanger;
- tests carried out with turbulators in the heat exchanger.

A total of 12 tests for each part were carried out at six water flow rates, each being repeated and the results averaged. Sixty minutes were left between tests to allow the system to equilibrate. Exhaust gas flow rate was the same for all tests.

Exhaust gas and water inlet and outlet temperatures were recorded for each test, together with ambient and insulation surface temperatures. Exhaust gas and water flow rates were also recorded.

A summary of the test results, without turbulators, is given in table A8.1 (page 213) and with turbulators in table A8.2 (page 214).

3.2.4 Conclusions from the Results

From theoretical calculations, using an exhaust gas temperature quoted by the client, a heat transfer rating of 17.7kW was expected from the heat exchanger. This temperature measured in practice was, however, considerably lower, giving a new predicted heat transfer rating, as discussed in appendix 8.3.4 (page 216), of 11.4kW. This compares favourably with a measured value of 11.6kW (1.7 per cent higher).

Test results, described in detail in appendix 8, show that the use of turbulators increased the rate of heat transfer by 20 per cent to 14kW. Applying this figure to the 21 engines under consideration, a total annual recovery of 2.7 x 10^6kW was possible, an equivalent saving of 3×10^5

litres of boiler fuel, giving a system payback of 2.7 years [87].

After testing, a visual inspection of the turbulators and heat exchanger, especially at the exhaust exit end (the point at which the bulk gas temperature was closest to its acid dew point) revealed no visible signs of corrosion. Fouling at this point was, however, greater than expected, possibly due to a stagnant region in the gas flow adjacent to the exit.

Some testing was also undertaken by the client. Standard reference tests on the engine were performed with turbulators in the heat exchanger, to assess the effect that the heat exchanger had had on the engine's operating characteristics. These tests showed there was an effect; they could not, however, quantify this effect or pinpoint what was causing it. Senior officials of the client suggested that static and dynamic back pressure were the most probable causes. Back pressure on the engine prevents exhaust gases being expelled from the cylinder as quickly as usual which, in-turn, increases cylinder operating temperature. This causes a decrease in the lubricating oil's viscosity and so accelerates engine wear. Further development was now required to eradicate detrimental effects on the engine itself.

Prestige coupled with sound financial prospects for the scheme, led to the development of a second prototype, 002.

3.2.5 A Second Prototype 002

It was suggested that pressure drop was a major factor in the perfomance drop of the engine when connected to the 001 design. For design improvement therefore, 002 should exhibit greatly reduced static and dynamic back pressure when compared with 001.

From the testing of 001 considerable knowledge had been built-up on the heat exchange performance of the finned tubing and its corrosion resistance. It was thought prudent not to change the tubing or fundamental design at this stage.

Reduction of Static Pressure Drop

Static pressure drop was reduced by streamlining gas flow and reducing the length of the heat exchanger itself.

A detailed pressure drop analysis is given in appendix 8.4.1 (page 218). It shows that for 001 without turbulators, 54 per cent of the pressure drop (364Pa) was attributed to heat transfer surfaces, the remaining 46 per cent (305Pa) being losses associated with the ducting of exhaust gases to and from those surfaces. No quantitative method was found to assess pressure drop including turbulators. Tentative work had been undertaken, however, [88,89,90] and this suggested a doubling of the pressure drop associated with the heat transfer surfaces if turbulators where fitted (see appendix 8.4.2 page 219). In 002 they were omitted, pressure drop outweighing their advantages of enhanced heat transfer.

Reduction of back pressure associated with heat transfer surfaces

This had to be obtained without change to heat transfer surfaces and was achieved by incorporating a water jacket around the previously unused hot gas shell of the original gas jacket (see figure 3.18 page 59). This increased the area for heat transfer per unit length and gave a reduction in heat exchanger length of 1.6m. This, in-turn, reduced the pressure drop associated with the heat transfer surfaces.

A peripheral advantage of the water jacket was a reduction of case temperature by approximately 140K. This would allow a corresponding reduction in insulation specification over the 001 design or, for the same insulation, give reduced heat losses.

Reduction of ducting losses

A more streamlined flow path was required to reduce ducting losses. The following changes were made:

- bends were fitted at gas inlet and outlet to replace square elbows;
- divergent pieces replaced abrupt enlargements at inlet and outlet, for more controlled expansion of gases;
- 002 was designed in one length, eliminating inter-pass ducting losses.

These modifications reduced ducting losses by 93 per cent to 20Pa.

Dynamic Back Pressure Reduction

The use of a greatly improved flow pattern for the exhaust gases would improve dynamic back pressure performance.

3.2.6 The 002 Design

Before the 002 design was fabricated a value analysis exercise was undertaken to help obtain the most cost effective design. Only two changes were made:

- due to low operating pressures table 'E' flanges were replaced by table 'D' flanges (table 'A' were preferred, but were no longer manufactured);
- gas outlet flanges were removed.

The revised design, shown in figure 3.18, was manufactured totally from standard pipework fittings (see table 5.1, page 95). It exhibits a pressure drop reduction of 54 per cent over 001 without turbulators and 69 per cent over 001 with turbulators. Heat transfer tests gave a performance of 15.8kW and back pressure testing, by the client, revealed no adverse effects on the engine. This design was accepted by the client and an order for a further 24 heat exchangers placed to implement the scheme proposed by the site survey described in section 2.7.

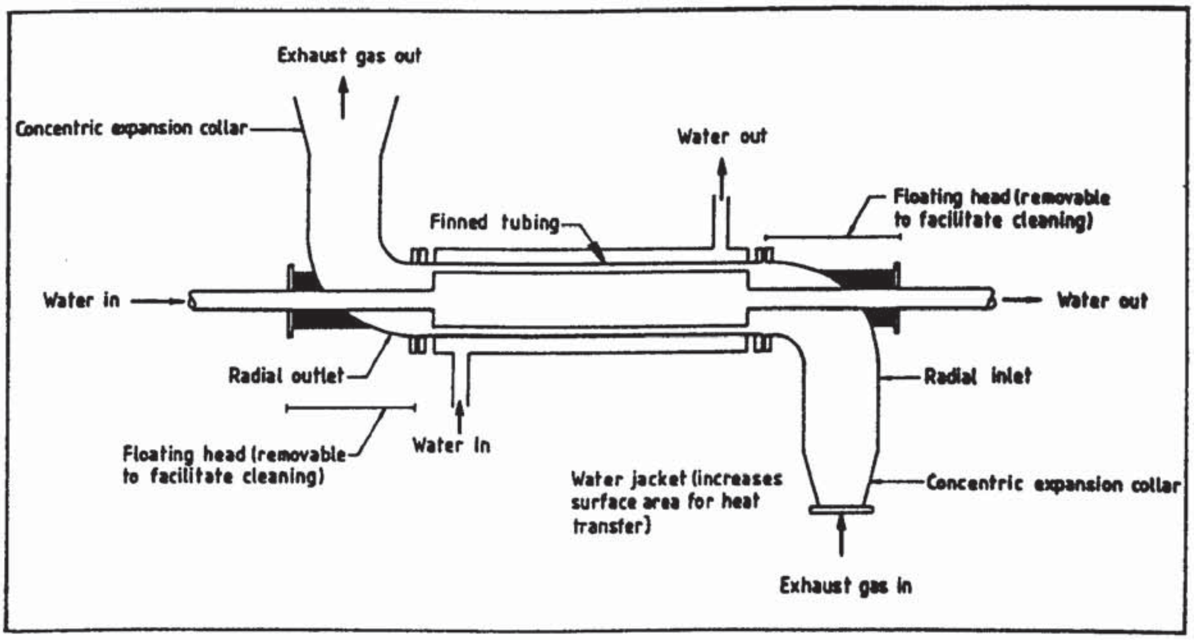


Figure 3.18 Diagrammatic arrangement of the exhaust gas-to-liquid heat exchanger, 002

3.2.7 Conclusions

The sale of 24, 002 heat exchangers demonstrates the client's confidence in the unit and suggests the technical success of the project. However, the production of what could be a commercially successful design created several new aspects to the project. These non-technical aspects, including commercial protection of the design, contracting and tendering, application for external project funding, insurance requirements and designs to British Standards, are directly applicable to the defensive approach adopted for market-pull products. Chapter 5 has been devoted to these and the rôle they have played in the overall development of this product.

There were also several non-technical aspects in the MHRU project. Differing from these above, they reveal the more aggressive nature of product-push products and include prediction of market potential, test marketing, advertising, media response analysis and product launch. These are described in the next chapter.

CHAPTER 4

NON-TECHNICAL ASPECTS OF THE MODULAR HEAT RECOVERY UNIT'S DEVELOPMENT

NON-TECHNICAL ASPECTS OF THE MODULAR HEAT RECOVERY UNIT'S DEVELOPMENT

4.0 Introduction

Chapter 3 was devoted solely to the technical design aspects of new product development. This, together with marketing, formed the initial links in the chain of conception to commercialisation. The next two chapters are devoted to the non-technical or commercial links.

The development of the MHRU was a high risk project as research money was invested with no guarantee of its payback. If commercially successful however, the financial benefits could be considerable. In contrast, the design of the heat exchanger was a relatively low risk project that would realise only modest financial returns (as the market is so specialised) should technical success prevail.

The commercial aspects of the two products are very different. This chapter describes those of the MHRU and includes initial feasibility studies, test marketing, media response analysis and product launch. Commercial aspects of the heat exchanger project are of a different nature and will be detailed in chapter 5.

One basic part of the commercialisation of the MHRU was marketing, the strategy for which is given below.

4.1 Marketing Strategy

There were several marketing stages for the MHRU, as shown in figure 4.1. The first stage was a feasibility study to assess technical and financial project viability.

Both were approved, design work continued and a test marketing phase was entered. Here proposed designs were sent out to prospective customers for their comments. Following this a prototype was built and tested. Product launch followed.

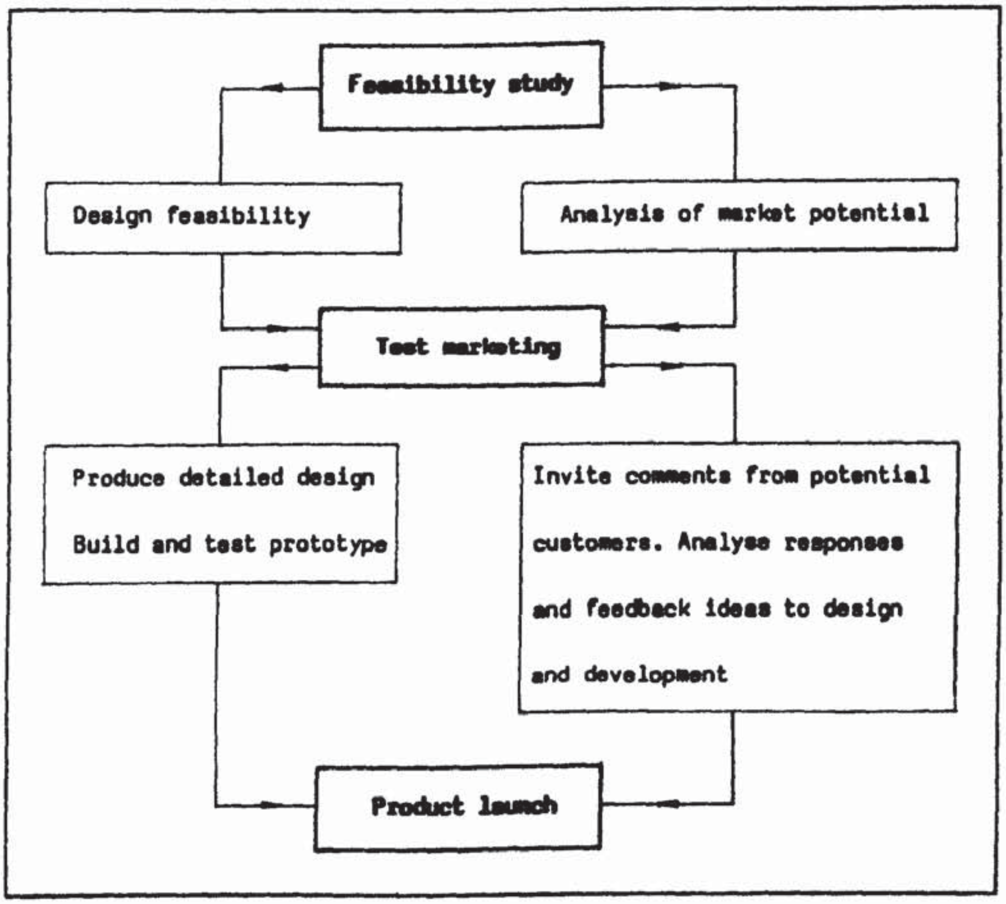


Figure 4.1 Overview of marketing strategy for the MHRU

4.2 Product Feasibility

Product development is capital intensive and it is important to ascertain, at an early stage, if initial product ideas are worth further consideration. Product feasibility was looked at from two areas, design feasibility and market potential.

4.2.1 Design Feasibility

Initial designs were assessed for practicability. The proposed manufacturer stated that there were no problems forseen and design feasibility was approved.

4.2.2 Market Potential

The MHRU was aimed at industry, although modified versions would be available for air conditioning and commercial applications. Based on studies, mainly by the Department of Industry and Department of Energy, and shown in table 4.1, the potential for heat recovery in 33 U.K. industries (excluding iron and steel) was, in 1980, approximately 63 600TJ per annum. With a payback of two years being generally considered the maximum for a heat recovery project to receive favourable consideration [91, 92] the market for heat recovery equipment could be approximated to twice the potential heat recovery savings (in cash terms). That value, based on an energy cost of £2370/TJ [93] (the cost of gas at January 1980 prices) was £301 million.

Industry	Annual			
	Total Sector Energy Use (TJ)	Estimated Savings through Heat Recovery (TJ)	Value of Heat Recovery Savings (£millions)	Potential Capital Investment (£million)
Aluminium	92 800	2 500	5.93	11.86
Baking	34 190	3 165	7.5	15
Brewing	29 000	4 800	11.38	22.76
Bricks	28 000	3 500	8.3	16.6
Bulk refractories	16 000	1 600	3.79	7.58
Cement	119 000	10 800	25.6	51.2
Chemical manuf.	9 200	155	0.37	0.74
Coke making	142 000	11 000	26.07	52.14
Compound fertilisers	25 000	720	1.71	3.42
Cotton spinning	8 860	241	0.57	1.14
Cotton weaving	5 700	171	0.41	0.82
Dairy industry	27 860	210	0.5	1
Dyestuffs	33 000	743	1.76	3.52
Elec. engineering	35 000	1 120	2.65	5.3
Food processing	38 000	1 824	4.32	8.64
Footwear/leather	9 250	62	0.15	0.3
Glass	49 000	2 200	5.21	10.42
Knitting	12 180	487	1.15	2.3
Malting	9 800	1 520	3.6	7.2
Mech. engineering	34 910	816	1.93	3.86
Non ferrous (base)	14 000	2 660	6.3	12.6
Non ferrous (copper)	12 900	2 064	4.89	9.78
Paper	125 000	1 280	3.03	6.06
Pharmaceuticals	17 830	195	0.46	0.92
Plastics	30 890	99	0.23	0.46
Potteries	15 320	2 107	4.99	9.98
Rubber, linoleum, plastic floor covering	33 700	1 250	2.96	5.92
Shipbuilding	23 000	2 070	4.91	9.82
Soap/detergents	6 480	972	2.3	4.6
Stationery	344	28	0.07	0.14
Textile finishing	25 900	1 673	3.97	7.94
Timber/furniture	42 400	636	1.51	3.02
Woolens	17 800	928	2.2	4.4
TOTAL	1124 314	63 596	150.72	301.44

1 Table excludes iron and steel industry
2 Capital investment based on a two-year payback
3 Value of savings based on a gas price of £2370/TJ (oil(35 sec) £3350/TJ, electricity £7220/TJ) January 1980.

Table 4.1 Analysis of market potential for the MHRU in some major industrial sectors [95, 96, 97]

For small heat recovery projects, up to £20 000, the MHRU would represent approximately 40 per cent of the total system value. This percentage decreases for larger projects and at £100 000 would be approximately 20 per cent [94]. For a mean of 35 per cent, the value of the MHRU market would be £105.5 million. However, site survey results have shown that 62 per cent of proposed heat recovery sytems were of the gas-to-gas type (table 2.2, page 21), giving a final potential market value for the MHRU of £65.4 million. Using a medium temperature, range II MHRU, the cost of which in 1980 was approximately £12 100, this represented a market of 5400 units. This was considered high enough to ensure the product's continued development.

Both aspects of the feasibility study revealed a positiveness to continue development and detailed design work progressed until a prototype design was completed. At this stage product ideas had to be tested in the market place. Before test marketing was considered, however, it was thought prudent to examine the stages of the innovation process and the adoption of new products from the potential customers' point of view.

4.3 The Innovation Process

Innovation is the use of knowledge to create and apply something that is new [98]. It can be portrayed as a four stage sequential model [99] and may be described as follows:

- knowledge - the innovation is brought to the attention of an individual who gains some understanding of it;
- persuasion - depending on the individual's perception of the innovation a favourable or unfavourable attitude towards it is formed;
- decision - the individual investigates the innovation and decides to adopt or reject it;
- confirmation - provided that the individual receives reinforcement

following the decision to adopt the innovation, its use will continue, otherwise this decision may be reversed.

The marketing aspects of the MHRU product development are discussed in relation to this model.

Testing of ideas in the market place was used as the 'knowledge' stage of the innovation process - creating an awareness of the new product. Work from several sources [100-102] suggested the usefulness of the written word at this stage and a brochure was produced giving design and conceptual details of the MHRU. Future promotion of the product would provide interest from potential customers, to whom a brochure would be sent. Subsequent follow-up would obtain comments and suggestions from these enquirers, which would be fed back to design and development.

4.4 Production of a Brochure

Several factors were considered in the design of the brochure:

- at whom should the brochure be aimed?
- should the brochure be a technical or merely promotional document?
- could the brochure be designed for use in test marketing and a future product launch?

4.4.1 The Target Reader

As previously stated (section 2.6) the MHRU was to be aimed at the people with the responsibility for making such a purchasing decision.

In a survey of British industry [103], it was found that the people most concerned with purchases of plant and equipment were the board, operating management and production engineers. This was broadly supported by a Financial Times Report [104] which found that the dominant influence for initiating and specifying plant and equipment purchases was production engineers. For the purchase of energy saving plant it was thought that the categories stated would also be supplemented by energy managers and project engineers.

It was also noted that it was normal for more than one person to be involved in the decision making process [105]; typically five or more in medium sized (400-1000 employees) British engineering firms, and six or more in larger (over 1000 employees) firms [106]; typically three or more in American firms generally [107]. From this it was concluded that the brochure should meet the needs of both management and engineers, and it was also recognised that these levels would require different types of information. A director or manager, whilst possibly being interested in the concept of the design, was not likely to be concerned with dimensional details, information more applicable to the project engineer. For the former, a single page at the front of the brochure would be included that detailed the virtues and benefits of the unit and that could be easily read. For the latter (and also including consultants) performance details and dimensional information was required. This would be incorporated in a technical follow-on section.

This last point has pre-empted the next consideration - should the brochure be technical or merely a promotional document?

4.4.2 A Technical or merely Promotional Document?

It has been stated that "the only motive for buying anything is that it will serve some real or fancied use" [105]. For this reason the brochure should promote the concept of the MHRU to provide the customer with an awareness of the product, and should give further information to allow the realisation of the unit's technical advantages. It is important to emphasise this prevalence as it has been shown that a lack of perceivable advantages can limit the potential customers' choice to products with which they are already familiar [109].

The brochure was likely to be kept on file for future reference and a promotional orientation may aid future sales. However, the concept of the product was completely new and it was felt important to ensure that this was portrayed in an unambiguous manner. For this reason a technical brochure was essential and finally this type of brochure was integrated with a promotional overview.

4.4.3 A Brochure for Test Marketing and Full Market Launch?

To meet budgetary constraints, a comprehensive brochure was required that could be used for test marketing and product launch (this being the case if no major technical changes resulted from the test launch).

4.4.4 Brochure Design

Using the above considerations, the following points were listed as being essential in the final brochure:

- a promotional overview of the product. This would give the concept of the MHRU and its benefits i.e. ease of installation, compactness etc. To be written in a concise style, this would be aimed at directors and plant managers;
- a detailed technical section describing the various modules available within the heat exchanger, filter and fan sections. This to convey to the project engineer the versatility of the system and its advantages over existing products;
- flow rate selection chart, physical dimensions of the units, and graph of efficiency versus flow rate. From this, potential energy

(and hence cash) savings obtainable from the unit could be calculated;

- a list of industries in which the MHRU would be most applicable.

The above related directly to the MHRU. Some general considerations [110] were also noted as being useful during the writing of the brochure:

- brochures are scanned, not read. Important messages should be concise and stand out clearly;
- prospective customers want to know that the manufacturer has experience of their particular problems. Such experience should be the first thing noted in the brochure;
- include pictures - they are worth a thousand words.

The finished brochure is shown in appendix 9 (page 222).

A test marketing compaign was then instigated to obtain the potential customers' comments on the design.

4.5 Test Marketing

With the brochure completed, the customer had to be provoked into requesting one. Obtaining promotional coverage over a wide market area is labour intensive and expensive. Labour and finance were limited and an unusual approach to this problem was adopted. A campaign, relying heavily on 'free' editorial copy obtained in trade magazines, was used to acquaint industry with the broad concepts of the MHRU. Those interested further would request a brochure and comments on the unit's design and appeal would be subsequently obtained by telephone follow-up.

An exhibition was also used in the test marketing phase together with further site survey interviews.

4.5.1 The Promotional Campaign

A promotional campaign was planned that encouraged industry to request details of the new product. The level of response would be a measure of the interest in the MHRU. The advertising was in three parts:

- trade journals;
- an exhibition;
- contact through further site surveys.

4.5.2 Trade Journals

There are two distinct methods of obtaining publication of material (or copy) in trade journals, direct advertising and editorial.

Direct placing of an advertisment has the advantage of being under the control of the advertiser. The effect of advertising is cumulative but maximum response is obtained only after four or five insertions [111]. Costs for this type of advertising are high, typically £180 per quarter page.

Editorial, however, is completely free. A description of the new product, process, building etc., known as a press release is sent to the editor of the journal. Inclusion of some or all of the material is at the discretion of the editor. Editorial does not provide the continuity of direct advertising as it is a one-off event; for test marketing, however, this is not a problem.

Maximum response from the journals was required. It has been suggested that editorial copy and articles provoke a greater response for new industrial products than direct advertising [111]. This is supported by evidence in the marketing of new materials which showed that 41 per cent of responses obtained were from journals carrying articles, 42 per cent from journals carrying articles and advertisments and 17 per cent from journals carrying advertisments alone [102]. Editorial is not seen as 'advertising' but as unbiased information ostensibly from the editor. It may provide more impact than the often optimistic claims of an advertisment.

The use of editorial provided a large coverage of the market, copy being obtained in 11 trade journals [112-122] as shown in table 4.3, column 1 (page 75). This was obtained at very little cost to the sponsor.

A full analysis of the results obtained from this editorial is given in section 4.7.1 (page 73).

4.5.3 An Exhibition

Exhibitions provided an opportunity for company staff to meet potential customers and obtain their comments first-hand. The exhibition selected for the test market survey was the "Energy Saving and Industrial Efficiency Exhibition' in Tokyo, Japan, on 16-20 September 1980. This ambitious exercise was chosen for several reasons:

- Japan is one of the countries most keen to exploit new ideas;
- Japan has few indigenous energy supplies, so is inherently sympathetic to energy conservation. Should the Japanese interest prove high, the sponsor's executives could arrange distibutors and agencies to sell equipment, or to manufacture it under licence in Japan itself;
- the Department of Energy was keen to publicise British companies in the world market; those attending the exhibition were guaranteed large free coverage in the British press, an important benefit for the sponsor;

- the exhibition was supported financially by the London Chamber of Commerce and Industry.

For the exhibition stand, a model of the prototype MHRU was made. Shown in figure 4.2, it provided a centre piece for the stand and gave tangible support for conceptual and operational descriptions.

Figure 4.2 Scale model of the MHRU

4.5.4 Contact Through Site Surveys

All site surveys undertaken after the production of the technical brochure were also used for market research. Comments and suggestions from engineers on site were noted and fed into design and development.

There is invariably a time interval between market awareness of initial designs and test market results being obtained [123]. It was important to check that market trends had not changed during this period.

4.6 Market Trends

The product survey was being compiled concurrently with this stage of product development. It was noted that no detrimental change in the market had occurred and, in fact, there was a move towards gas-to-gas recovery systems, this being interpreted from an increase in the number of manufacturers of gas-to-gas heat exchangers over the corresponding period.

4.7 Analysis of Test Marketing Results

Analysis of the test marketing provided two separate but very important results:

- industrial reaction to the MHRU design;
- experience and information valuable in a subsequent product launch.

Each of the three promotional sources provided different results.

4.7.1 Trade Journals - Response Analysis

Response to the editorial in trade journals was good. Table 4.3 (page 75) shows in which trade journals editorial was included and the level of response obtained. The total response was 320 enquiries. Direct advertising, based on figures received from a publisher [124], would have had an expected yield of about 260 enquiries. This supports a previous statement that for new industrial products editorial usually produces a better response than direct advertising.

All enquirers were sent, by return of post, a copy of the MHRU brochure. After a period of one to two weeks the enquirers were telephoned and their comments on the design noted. Enthusiasm of the enquirer was found difficult to assess by telephone. Staff resource limitations allowed the follow-up of only 58 per cent of the enquiries.

A breakdown of the editorial response is given in table 4.2.

Type of Response	%
Enquirers interested in the newness of the product, not the product itself	34
Enquirers requesting information for central filing systems	17
Enquirers with applications for gas-to-gas heat recovery schemes	2
Enquirers unable to be contacted[1]	4
Competitors enquiries to which no response was given	1
Enquirers not contacted	42
	100%

1 These enquirers were telephoned several times but repeatedly unobtainable

Table 4.2 Analysis of response to editorial advertising

A vast majority of the enquiries came from pamphleteers, their interest being in the newness of the product not the product itself. The second largest group were enquirers requesting information for filing systems. Little valuable information was gained here. The third and most important group were enquirers having applications for gas-to-gas heat recovery systems and who were actively seeking products to meet their requirements. Here the MHRU was scrutinised and valuable comments obtained. Overall comments and impressions obtained were:

- the concept of a completely compatible heat recovery system (in one box) was liked;
- the modular concept was liked;
- a weatherproof unit for external use would be valuable;
- for some applications there must be zero cross contamination between gas streams;
- cleaning of the heat exchanger must be straightforward;
- moving parts (fan belts, pulleys) should be easily accessible;
- modular systems can cost more than component systems.

Column number 1	No 2	No 3	No 4	No 5
Journal	Total number of responses from each journal	Number of responses of the required type	Responses of the required type as a % of the total response from each journal	Responses of the required type as a % of the total response from all journals
	No	No	%	%
Building Services	34	3	9	2
Energy Manager	24	17	71	11
The Engineer	24	13	54	8
Heating & Air Conditioning Journal	77	37	48	23
Heating and Ventilating News	26	17	65	11
Heating and Ventilating Review	44	7	16	5
Plant Engineer	2	0	0	0
Process Engineering	13	10	77	6
Production & Industrial Equipment Digest	28	22	79	14
What's New In Industry?	21	10	48	6
Works Management	27	22	81	14
TOTAL / MEAN	320 / 29.1	158 / 14.4	- / 49.8%	100% / 9.1%

Table 4.3 Editorial response analysis by individual journal

This exercise showed that the initial response to the MHRU design was good. It also identified those journals which may prove most beneficial in future advertising. As stated in section 2.6 the MHRU was aimed at senior management - people with the responsibility for purchasing such products. They were identified in the editorial responses and their proportion of the total for each journal is shown in table 4.3. Heating & Air conditioning Journal provided the greatest response of this type. A full response analysis is given in appendix 10 (page 225).

Process Engineering was a journal that partiularly favoured the MHRU. Such was their opinion of the design it was granted the honour 'Product of the Month' [119]. This particular editorial is shown in figure 4.3.

The editorial provided much valuable information about industry's response to the MHRU and how future editorial may be exploited to the full.

Figure 4.3 Modular heat recovery unit
"Product of the Month"

4.7.2 Exhibition Analysis

Results from the exhibition can be summarised in three categories: the Japanese response to the sponsor's energy saving products; the Japanese market in general; experience obtained for the full market launch.

The Japanese were well disposed towards the MHRU, and no design changes were suggested.

Also on display was the prototype exhaust gas-to-liquid heat exchanger. One company was interested in pursuing licencing agreements for this device for use in marine applications (in 1980 35 per cent of the world's shipping was manufactured in Japan [125]). In 1980 this was not possible due to stringent Japanese import regulations on largely untried foreign equipment. With the subsequent proving of the design these negotiations have restarted.

The following points were noted about the Japanese market in general:

- Japan requires comprehensive documentation on all equipment imported or manufactured under licence (this was not available for the MHRU or the heat exchanger in 1980);
- Japan is orientated to dealing with very large companies. The sponsor was a small company;
- penetration of the Japanese market requires considerable effort. Analysis suggested that a trading organisation may be required in the initial stages to overcome barriers of language and documentation, the cost of which would be approximately £20 000 [126].

One point to emerge from the exhibition was the importance of face-to-face contact with potential customers. This contact allowed staff to formulate an opinion of the person and to assess their enthusiasm for heat recovery. The impression obtained was an aid in judging the sales time subsequently devoted to that enquiry. (Other pointers included size of company, size of the energy bill and the enquirer's position within that company.)

The exhibition was a prestigious event that obtained much press coverage both in Japan and the U.K.

4.7.3 Site Survey Results

Site surveys provided the most detailed responses from potential customers. In face-to-face situations, especially where there was genuine interest, the customer asked many detailed questions. Generally these were answered from within the brochure itself. No major design faults were revealed by this survey, all queries being minor (e.g. were fan grease nipples accessible?).

The concept of the MHRU was accepted by all as being good.

An important point to emerge from these surveys (and supported by a second source [127]) was the demand from industrialists to see an actual installation (using an MHRU), and to get first-hand operating experience from other purchasers. It has been suggested that trial use, or in this case, the viewing of an installation, can help convince a customer to buy the product if they are frozen at the decision stage [128]. As previously stated many questions were asked to which answers could be found in the brochure. This raised two points:

- face-to-face contact is better for selling products as people prefer to be told answers rather than finding them in a brochure. Face-to-face contact is also supported by arguments given in the exhibition analysis, section 4.7.2 (page 77);
- the brochure may have been too technical and insufficiently interesting to read.

4.7.4 Brochure Review

The brochure was designed as a technical document supplemented with a promotional overview. Based on comments received from its readers, the following criticisms and suggestions were made:

- the brochure was too technical and, if read by a non-technical person, may not be understood;
- a less formal style of writing was required;
- a cut-away diagram of the MHRU explaining its operation would have been of great value;
- the existing brochure did not include a successful heat recovery scheme using an MHRU;
- the brochure sold the concept of the unit, not the unit itself; a more sales orientated brochure was required.

It was originally thought that the brochure would have been used for test marketing and, if required, for product launch. In view of the above comments the following compromise was achieved. A second, easy-to-read sales brochure would be produced and include many diagrams and pictures. The concept of the MHRU would be explained, but few technical details given. Any enquirers interested in the unit would receive this brochure, to be followed, if required, by a sales visit at which the technical brochure would be presented and explained. This would give the sponsor's representative the face-to-face contact found essential from the results of the editorial and exhibition advertising, and allow the remaining technical brochures to be utilised.

This concludes the brochure analysis. A complete review of the test market launch is now given.

4.8 Conclusions from the Test Marketing

Test marketing provided many useful pointers that could help in achieving the success of any future product launch. These included:

- personal contact was essential for assessing potential customers and the amount of sales time to be expended on them. For this reason exhibitions were thought more useful than advertising;
- to achieve maximum benefit from exhibitions a sales force was required. (At this point the sponsor had no sales force, follow-ups being undertaken by technical staff);
- a second easy-to-read brochure was required;
- a working installation using an MHRU would be beneficial in the product launch and subsequent sales campaign;
- it would be advantageous to have a trade mark for the MHRU. The mark HE-RO was adopted (see section 5.1.3, page 86 and figure 5.1, page 87).

4.9 Manufacture, Installation and Testing of the Prototype MHRU

A prototype unit was completed by February 1981. From November of 1980, a site for the MHRU was being sought. By June (1981) a site had been identified, but it was not until October that final plans were passed and installation started. This delay, although pushing back the MHRU project six months, created a timely gap for development work on the exhaust gas-to-liquid heat exchanger. The MHRU was commissioned and tested by February 1982, and details of the installation are given in section 6.1.1 (page 104).

The final installation, shown in figure 4.4 (and schematically in figure 6.1, page 105) was ideally situated for marketing purposes. Occupying a site in front of a main factory, it provided excellent access for viewing by potential customers.

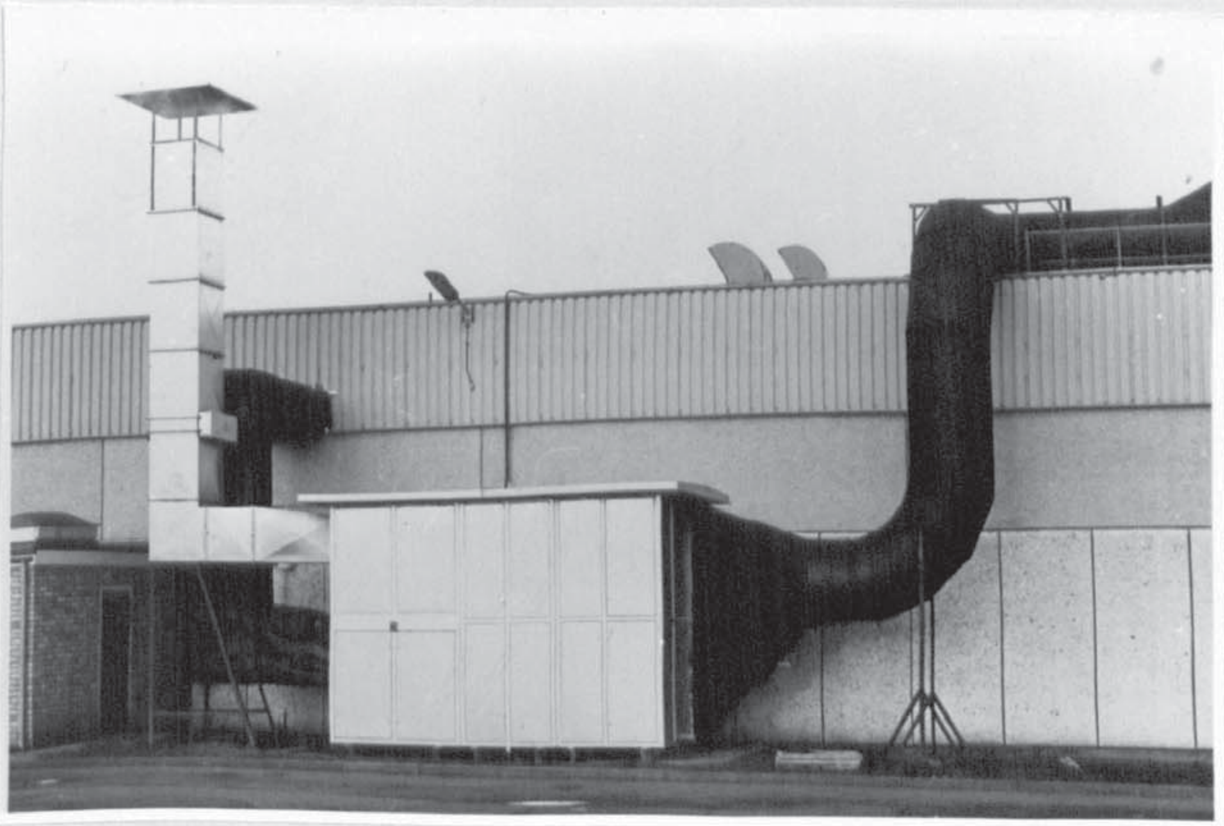


Figure 4.4 Modular heat recovery unit test site

The final phase of the project, product launch, could now follow.

4.10 Product Launch

The level of response and the experience gained from test marketing provided the confidence to move to full product launch. The important points noted as a result of the test marketing were all considered during the planning of the launch.

4.10.1 Face-to-Face Approach

As concluded from the editorial follow-ups, and supported by the exhibition analysis, it was thought beneficial to use face-to-face contact to create awareness and interst in the MHRU. This decision was also influenced by other work which suggested that companies searching for potential suppliers, would give preference to those known inside the purchasing organisation [129], and one of the best ways of achieving this was through personal contact at industrial gatherings.

To this end, an exhibition was chosen to launch the MHRU - the 'Processing Plant and Equipment Exhibition' in Manchester in February 1982. As a major proportion of waste heat results from processing plant, it was considered a good exhibition at which to launch a new heat recovery product. The exhibition was small and specialist, consisting of 30 manufacturers. The Manchester location was selected as it was one of the areas in which a number of previous MHRU enquiries had been concentrated. Manchester's industrial areas, eg. Trafford Park, Picadilly Trading Estate, Ringway and Gateway Industrial Estates, and the industrial areas of Merseyside and Preston were also relatively close.

A secondary advantage of the exhibition approach was that several products could be advertised simultaneously (direct advertising is usually limited to the promotion of one product per advertisement). This opportunity was used to exploit other developments including the exhaust gas-to-liquid heat exchanger.

Thirdly, the exhibition organisers promoted the exhibition and those exhibiting. This gave free background publicity for the companies involved.

4.10.2 The Sales Force

In the past all sales and marketing had been undertaken by engineering staff. This was less than satisfactory and, recognising this fact, a sales and marketing manager was appointed on 4th January 1982. Following this, sales leads were followed-up with more consistency and by a professional.

4.10.3 A Second Brochure

As stated in the brochure review it was thought necessary to produce a second brochure. However, lack of resources (both staff and financial) prevented this.

4.10.4 A Working Installation

The MHRU installation was completed and tested by February 1982 to coincide with the exhibition for the product launch. The customer had agreed that interested parties would be allowed to visit their site to view the installation. This, together with the appointment of a sales and marketing manager, completed the follow-up facilities, as stated in section 4.8, for the product launch.

4.10.5 Trade Mark

Particularly for young companies with new products it was thought advantageous to establish a trade mark as quickly as possible (see section 5.1.3, page 86). The trade mark HE-RO, a foreshortening of the words 'heat recovery', was granted in late 1981 and subsequently used on all of the sponsor's heat recovery products.

Before final product launch, pricing policy was considered.

4.11 Pricing Policy

Pricing for a new product can be determined either by market forces or internal on-cost pricing. For a range II, medium temperature MHRU the on-cost price was £12 100 whereas market competition (the component system) was 10 per cent below this figure. The sponsor was not prepared to sell at a loss and the MHRU's price was set at the net cost of manufacture (£12 100) This gave the MHRU a minor price disadvantage in the market.

4.12 The Launch

Over the two day period of the launch exhibition a total of 24 enquiries were received [130]. Of those, quotations for MHRU's were submitted to eight. At the time of writing no results of the quotations were available and experience (corroborated by a second source [131]) has shown that lead times of up to two years may be expected on the purchase of heat recovery equipment. Such time scales are beyond the scope of this work, and the product has since become the responsibility of the professional sales force.

Despite this lack of sales information, the technical design and marketing campaign has provided an insight into the development of the MHRU, from its conception to its commercialisation.

CHAPTER 5

NON-TECHNICAL ASPECTS OF THE EXHAUST GAS-TO-LIQUID HEAT EXCHANGER'S DEVELOPMENT

NON-TECHNICAL ASPECTS OF THE EXHAUST GAS-TO-LIQUID HEAT EXCHANGER'S DEVELOPMENT

5.0 Introduction

Chapter 3 detailed the technical development of a heat exchanger to recover heat from diesel engine exhaust gases. However, technical details alone did not constitute the entire project. This chapter describes the non-technical aspects which had to be researched and resolved before product development could be concluded. The following were considered:

- protection of industrial ideas and inventions;
- contracting and tendering;
- heat recovery scheme funding;
- insurance requirements and British Standards.

5.1 Protection of Industrial Ideas and Inventions

Commercially there are several ways of helping to ensure that any developments are exploited solely by the inventor or company. These include:

- patents;
- copyright and registered design;
- trade marks;
- technical papers.

Each is now described briefly in relation to the heat exchanger, further details being given in appendix 11 (page 230).

5.1.1 Patents

Patents can offer protection of an invention and, through their publication, can also help promote technical progress and stimulate research. The 001 design is protected by a full patent in the U.K.

(number 2 066 937 [132]) and provisional patents in Canada, Japan and the U.S.A. The 002 design, at present, has only a provisional patent in the U.K. [133]

5.1.2 Copyright and Registered Designs

Copyright protects the copying of physical material and not the reproduction of ideas [134]. For industrial designs, however, the ideas themselves must be protected. This can be achieved using registered designs.

Recovering heat from diesel engine exhaust gases was not a new idea and several manufacturers already produced equipment to do this. For this reason the protection of the idea through Registered Design would have been invalid. All design calculations, sketches and manufacturing drawings are, however, protected in standard copyright law.

5.1.3 Trade Marks

The commercial function of a trade mark is to distinguish the products of one manufacturer from those of another [135]. Trade marks can become synonymous with a consistency of quality, inducing potential clients to purchase products bearing a mark that is familiar to them.

The comments above, however, only apply to the well-established trade mark and it could, therefore, be considered important for a young company to establish a trade mark early in its development. The newness of the sponsor, the need to create an identity and be recognised in the market place, and the parallel development of several new products (MHRU and the exhaust gas-to-liquid heat exchanger) prompted the requirement for a trade mark.

The name HE-RO (a foreshortening of the words heat recovery) was registered in 1981 [136], and applies to the 'E'xhaust gas-to-liquid heat exchanger (HE-RO 'E') and the MHRU (HE-RO 'Modular') (see figure 5.1).

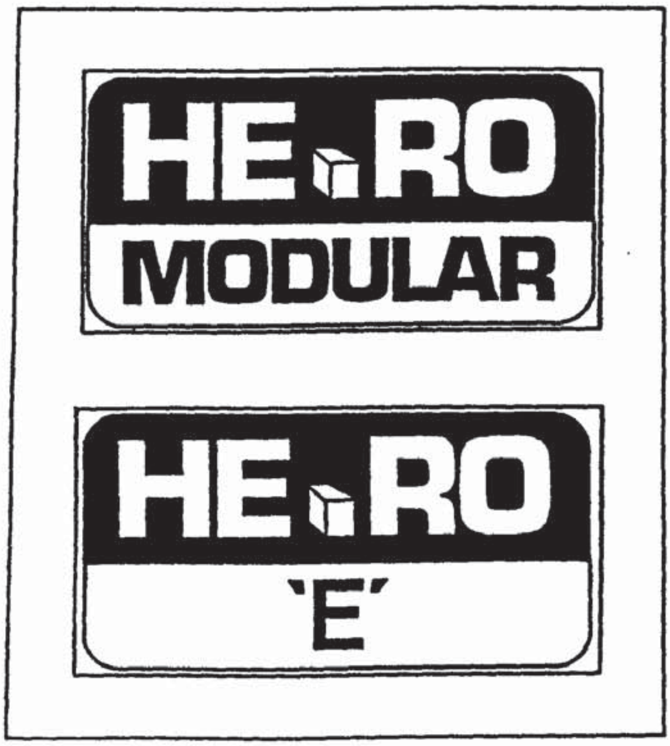


Figure 5.1 The registered trade mark HE-RO

5.1.4 Technical Papers

Technical papers in no way guarantee the rights of the ideas contained in them to the author, though they do register, morally at least, that a particular idea had been thought of by that date. A technical paper featuring the exhaust gas-to-liquid heat exchanger is to be written in early 1983.

This concluded the commercial protection of the design. The next aspect to be considered was contracting and tendering.

5.2 Contracting and Tendering

Following the client's approval of the 002 design, an order for a further 24 units was announced to implement the system suggested in the original site survey (section 2.7, page 24). The client requested several companies to submit quotations for the supply of the heat exchangers and how this order was won against other competition is shown below.

5.2.1 An Order for 24 Exhaust Gas-to-Liquid Heat Exchangers

Although now in direct competition, several factors contributed to the winning of this order:

- all test and development work had been undertaken at nominal cost to the client;
- a rapport and implied trust had been built up with the client over the three year development period;
- the client had been pleased with the quality of workmanship to date;
- much experience had been gained during the development of the design. This experience, most valuable during the installation and commissioning stages of the final system, may be lost by the client should this quotation be unsuccessful;
- previous manufacturing experience would help keep manufacturing costs to a minimum and the quotation competitive;
- the designer was known to the client (see section 4.10.1, page 81, face-to-face approach).

In this instance the contract was won, the client placing the order on the 3rd March 1982.

The sponsor had no manufacturing facilities and the order was subcontracted to a specialist manufacturer. The price difference between the sponsor's quotation to the client for supplying the heat exchangers, and the subcontractor's tender, in-turn, for their supply, is the profit margin. Maximising this profit, or as the modern term would have it, contribution, is the subject of the following discussion.

5.2.2 Price Reduction in Subcontractors' Tenders

To obtain a cost on which the quotation to the client could be based, four specialist manufacturers' tenders were obtained for the manufacture of the heat exchangers. The cheapest was then used in preparing the quotation to the client. To maximise the contribution from this supply contract, the subcontractors' prices had to be as low as possible.

Generally, initial prices quoted by subcontractors can be revised. This price reduction or 'squeezing' can be accomplished in many ways, some morally more acceptable than others. A résumé of some of these techniques is given below.

<u>Competition</u>

Competition forces all those applying for a contract to be more cost conscious. Companies who have a genuine desire to undertake work will examine their own costs more critically and cut profit margins in an effort to gain economic advantages over their competitors. The subcontractors' costs themselves can be cut by possible bulk purchase of equipment, selection of the correct labour, selective use of bonus payments, efficient organisation of plant and fabrication processes etc.

<u>Incentive</u>

At the tendering stage prices are very flexible and subcontractors can be 'induced' to submit a more competitive price. The promise of a larger order in future, for example, based on their performance on a particular contract, can result in a price reduction. A forward marketing plan presented to the subcontractor showing predicted sales of products is a positive incentive at this stage.

<u>Direct Approach</u>

Colloquially known as the Dutch Auction, the direct approach involves simply telling the subcontractor that their quoted price is too high.

There are two levels at which this method can be applied. The first involves a hint that they are, in contractor's jargon, 'over the top' on price. This can be used to advantage before the tender is finally received; a telephone call can surreptitiously state the figure that other subcontractors are quoting or what the buyer is willing to pay. If this is higher than their proposed price, the subcontractor may adjust the tender accordingly. The second method is straight forward; the subcontractor is told that their tender is too high and in some cases is told exactly what the price should be. If it cannot be met there may be little point in tendering.

The code of practice for tenders as laid down by the Association of Consulting Engineers frowns on tenderers being reapproached once their official price has been submitted. Fierce competition and the prevailing economic climate has, however, forced some companies to revise their 'professional' procedure.

Financial - Extending the Trading Cycle

If it is not possible to reduce the actual price of a tender then an effective reduction may be obtained by extending the trading cycle.

It is usual in business to have a 30 day trading cycle, the buyer being allowed this time from receipt of an invoice before payment has to be made. Interest can be obtained on the invoice value for this period or, as is more usual in business, less interest will be charged by the bank on the buyer's overdraft. The cost saved from the buyer's viewpoint on, for example a £100 000 contract, by delaying payment to the subcontractor for 30 days is £1644 (based on overdraft interest rate of 20 per cent). This figure increases to £3288 and £4932 for 60 day and 90 day trading cycles. This technique reduces the ultimate cost of the contract to the buyer and may be negotiated both before and after a contract has been signed.

Financial - Discount for Prompt Payment

The promise of prompt settlement of outstanding accounts (i.e. within 7 days) by the buyer can obtain a net reduction, from the subcontractor, of usually between 2-5 per cent of the contract value [137]. This direct reduction in cost must be balanced against the effective reduction obtainable by extending the trading cycle. The financial position of the buyer will influence the approach favoured.

Supplier Dependence

This approach is long term and adopted mainly by the vehicle manufacturers and large consumer orientated companies. Such companies will order ever increasing quantities of goods from a particular manufacturer, that manufacturer possibly neglecting smaller orders in favour of this major customer. Eventually the manufacturer becomes dependent on that one customer for an ever increasing proportion of its work, possibly losing those smaller orders in the process. When the supplier is in a position of dependence, the customer can start dominating proceedings and eventually command the price paid for goods delivered.

Buyer-Supplier Financial Tie-up

Trading between companies of the same group is often undertaken at preferential rates. On larger orders, where a company outside a group wishes to use that groups expertise, a financial tie-up between them and the group may be beneficial. Financially associated with that group, the buyer can then expect preferential rates to apply and a commerically more acceptable contract to result.

5.2.3 Subcontractor Selection

To obtain the most competitive tenders from the specialist manufacturers for the order, a price reduction exercise using 'competition' and 'incentive' was used: all subcontractors knew that at least three other companies were tendering for the order; a second application under consideration at the time would require a further 40, 002 heat exchangers, should it reach fruition.

The following tenders were received from those manufacturers:

Subcontractor 1 . . . .£13 296

Subcontractor 2 . . . . .unable to meet required schedule

Subcontractor 3 . . . .£13 393

Subcontractor 4 . . . .£18 194

Subcontractor 1 had manufactured both prototypes. With this previous knowledge of their workmanship and performance, and cheapest price, the subcontract order was placed with them on the 23rd February 1982. All heat exchangers were manufactured to schedule and delivered to the client's site on time.

There was a requirement that all plant installed on the client's site must be insured. This installation, using commercially untried equipment, provoked comments and reservations from the client's insurers. Insuring industrial plant, especially new plant, is a detailed exercise and its pursuit has revealed anomalies and omissions in the present system of British Standards. What these are and how they interact with insurance legalities is the next subject of discussion.

5.3 Insurance Requirements

To avoid invalidating the client's site insurance, the heat exchangers had to be inspected, by the insurers, to a specified standard. The insurance company, a nationally known industrial body, did not, however, specify the inspection code.

This, they stated, was the designer's responsibility. With the ball now firmly back in the design court, the British Standards governing heat exchangers were examined to find a suitable inspection code. To this point, in view of the low working pressure (345kPa maximum) and lack of critical dimensions on the 002, British Standards governing the design and construction of heat exchangers had received only a cursory inspection. They were now re-examined to find a standard applicable to the 002 design. Three were initially selected:

- B.S. 3274 Tubular Heat Exchangers for General Purposes, 1960;
- B.S. 1500 Fusion Welded Pressure Vessel for General Purposes- Part 1 Carbon and Low Alloy Steels, 1958;
- B.S. 5500 Unifired Fusion Welded Pressure Vessels, 1976.

5.3.1 British Standard 3274

B.S. 3274 detailed the design, construction, inspection and testing of cylindrical shell, plain tube heat exchangers. It encompassed design recommendations for heat exchangers with shell diameters of 0.15- 1.07 metres and lengths of 1.83 - 4.8 metres. Multiple-pass, multi-bundle heat exchangers are also detailed. Whilst examining the more complex heat exchangers it presented little information relating to the simpler designs. Procedures detailed consequently serviced the worst case or most complex designs and resulted in tight tolerances which, if applied to the 002 design, would have lead to gross over specification. For this reason B.S. 3274 was thought unsuitable as the inspection code.

Although B.S. 3274 as a whole was unsuitable, it did provide some parameters that applied almost universally to heat exchanger design. 002, as defined by the Standard, would be a Type 3, Class 75 device [138]. Material thicknesses specified for this type of design were used to guide materials selection, as were corrosion allowances and testing pressures.

In B.S. 3274 reference was made to B.S. 1500. This standard was subsequently reviewed for its suitability as the inspection code.

5.3.2 British Standard 1500

B.S. 1500 was used in the design and inspection of pressure vessels and heat exchangers. Whilst examining the more complex designs, once again little attention was given to the simpler designs. As a result tolerances detailed were far in excess of those required for the 002 design.

Of value in B.S. 1500 were stress calculations. These showed that the 002 design was well below all recommended maximum stress limits. These calculations, however, could only be used as check values as B.S. 1500 was withdrawn in 1978. This withdrawal was accompanied by a suggestion that it be superseded by B.S. 5500.

5.3.3 British Standard 5500

B.S. 5500 is an impressive document consisting of over 340 pages that replaced B.S. 1500 and B.S. 1515 ('Fusion Welded Pressure Vessels for use in the Chemical, Petroleum and Allied Industries'). The Standard was primarily intended for use in the design and inspection of high pressure devices that may or may not contain volatile fluids. Failure of this type of device could be of major consequence and the Standard's complex nature reflects its attempt to avoid this occurance. Failure of the 002 design, however, would be inconvenient rather than disasterous and B.S. 5500, if adopted, would lead to gross over-specification of the heat exchanger. It was rejected.

Following the preclusion of three British Standards it was concluded that a completely different approach to the problem was required. A close examination of the heat exchanger suggested a fabrication standard may be more applicable.

5.3.4 Heat Exchanger Review

The 002 design was manufactured from standard parts, and table 5.1 shows

Heat Exchanger Part	Covering British Standard
1 Water jacket	B.S. 3601
2 Gas jacket	B.S. 3601
3 Finned tube	B.S. 4360 50B
4 Radial inlet and outlet	B.S. 3601
5 Concentric expansion collars	B.S. 3601
6 Floating head	B.S. 3601
7 Flanges	B.S. 1962 table 'D'
8 Pipe threads	B.S. 21
9 Exhaust gas packing material	No B.S. number applicable[1]

1 information supplied by the manufacturer

Table 5.1 British Standards covering parts of the exhaust gas-to-liquid heat exchanger

how eight of its nine parts were covered by a British Standard. When constructed, the device was more akin to industrial pipework than a heat exchanger. It was finally agreed that its inspection should be to a pipework welding standard rather than a heat exchanger standard. B.S. 2971 was subsequently selected.

5.3.5 British Standard 2971

B.S. 2971 [139] is a specification for 'Class II metal-arc welding of steel pipelines and pipe assemblies for carrying fluids.' This was accepted by the insurers as being suitable for the inspection code of 002.

The 002 design was a simple single tube, single pass device with no critical overall dimensions, the manufacture of which to 'good engineering practice' would have been technically sufficient. The heat exchanger Standards examined were applicable to more complex designs for use in more exacting applications.

Imposing their rigours on the 002 design would have resulted, as stated, in gross over-specification of parts and manufacture, and an increase in production cost. No British heat exchanger Standard found was tolerant of the 002 design and this problem was ultimately side stepped by the use of a pipework construction standard. In similar circumstances, where simple heat exchangers are required in non-critical applications, this fact may be worthy of note to avoid further insurance anomalies. With the acceptance of the welding standard, technical and commercial aspects of this product development were concluded. Without additional finance, however, neither may have been of further value.

5.4 Heat Recovery Scheme Funding

From the onset of development, the client had been eager to achieve technical success in recovering heat from their test engines without affecting operational performance. On a small scale (one engine) the costs incurred had been acceptable. However, in a state of general recession (1981/82) and limited capital investment, the financial feasibility* of the entire heat recovery scheme, based on 20 engines, had never been certain.

The client, in order to fund the purchase of the heat exchangers, was keen to examine ways in which funding commitments could be reduced. Assistance was requested in maximising the financial returns on the heat recovery scheme by considering external sources of funding. External sources include group or corporate sources, leasing, refinancing, loan guarantees, EEC finance and energy grants.

---

* The word feasibility has been deliberately used here to replace the word viability. The viability of the project has never been doubted, the payback being 2.7 years (see section 3.2.4, page 56). The availability of capital to implement the scheme, however, had been under consideration. This affected the feasibilty of the overall installation.

5.4.1 Group or Corporate Sources

Many companies today are part of larger groups or corporations. If funds are not available from within the company itself, their group or parent organisation may provide an alternative source. Groups having a positive approach to energy conservation may regard favourably applications from within the group for energy project funding, especially those schemes applicable at other sites under the group umbrella.

5.4.2 Leasing

Leasing offers the lessee use of capital equipment without capital investment. Tax advantages enjoyed by leasing companies enables them, in-turn, to offer equipment at very competitive rates. In the past most things have been available for lease, but it has only been recently that this facility has extended to heat recovery schemes and equipment.

The cost of the lease (for energy saving equipment), per annum, is invariably less than the cost of the fuel savings that the heat recovery scheme liberates. This difference, a net gain to the lessee, increases year by year as fuel prices rise but lease costs remain stationary. The annual percentage rate of interest (APR) for this service varies between leasing companies from approximately 6 per cent to 24 per cent [140] depending on several factors including size of company, its credit rating, period of lease and the minimum lending rate. Although of relatively low profile in the U.K., leasing schemes are expanding rapidly in France and, to a lesser extent, in Germany.

5.4.3 Refinancing

Refinancing is the offering of interest rebates for medium to long term loans and/or the transfer of part of the risk of medium to long term lending from private to public bodies. In the U.K., a scheme of this type is operated by the National Enterprise Board [23] (now the British Technology Group).

In Germany finance is available at reduced rates to small and medium size enterprises given through the 'Sonderprogramm' (special programme) managed by the Kreditanstalt fur Wiederaufbau (credit and banking organisations) [23]. In France lower interest rate loans are available, though at present they are limited to investments in conversion to the use of coal [23].

5.4.4 Loan Guarantees

Although not a source of external funding, loan guarantees provided by Governments can help organisations obtain finance from private sources. Such loan guarantees are provided in the U.K. through regional offices of the Department of Industry and in the Federal Republic of Germany, through regional agencies set up in some of the Lander (local government areas).

5.4.5 EEC Finance

EEC finance can be obtained through the European Investment Bank and is available for all types of energy project. This finance is in the form of a loan made at preferential interest rates, typically 11-12 per cent (in April 1982) [141].

5.4.6 Grants

There are two principal schemes currently operating to support heat recovery projects in the United Kingdom:

- Energy Recovery Demonstration Projects Scheme (operated by the Department of Energy) [142, 143];
- European Community Scheme for Energy Saving Projects (operated by the EEC) [144].

The general differences between the two schemes are given in table 5.2, whilst details can be obtained from references [142, 144]. The Department of Energy (D.o.En) scheme can provide a grant of up to 25 per cent of the total cost of a proposed heat recovery scheme. A 100 per cent grant towards the cost of monitoring the installation can also be obtained. This grant is intended for viable schemes unable to proceed due to financial constraints. This grant is non-repayable. The EEC scheme provides risk capital for the more uncertain projects. Up to 40 per cent funding for the project can be obtained, repayable if the project is successful.

Criteria	Department of Energy Demonstration Projects	EEC Energy Saving Projects
Risk	Usually more applicable to EEC	Intended for high risk projects with a major development content
Capital Cost	For schemes up to approx. £250 000	Usually between £50 000 and £1 million
Economic Viability	Simple payback in (normally) less than 3 years	Simple payback can be greater than 3 years
Grant or aid	Non-repayable grant of up to 25% of project cost; plus 100% of monitoring costs	Up to 40% of project cost (repayable if the project is successful)
Replication (applicability to other installations)	The replication potential for the project throughout the U.K. must achieve 10 000 tons[1] of coal equivalent	The project must have replication potential throughout the EEC
Timescale	D.o.En. grants available (normally) within 6 months	EEC grants awarded on an annual cycle
Resources	D.o.En. grants can be prepared and negotiated by small engineering departments	Requires more comprehensive documentation; 50 copies of the proposal report (25 copies in each of two EEC languages)

1 This figure was not quoted by the D.o.En. but has been found to be the minimum replication potential acceptable for the awarding of a D.o.En. grant

Table 5.2 Comparison of Department of Energy and EEC energy grants (adapted from information given in [145])

During the heat exchanger project the client professed a keeness to apply for an energy grant of some kind. With a majority of the development work completed and the risk element considerably reduced, it was suggested that a non-repayable Department of Energy Demonstration Project grant be applied for.

5.5 Application Procedure for Department of Energy Demonstration Project Grants

Energy Demonstration Project grants are awarded on a quarterly basis. Each application is in the form of a report supplied by the client giving details of the proposed scheme, its novelty and replication potential. Each application is appointed a mentor, a civil servant responsible for representing the client at the grant committee meeting. Any questions or anomalies raised at this meeting about the scheme must be answered by the mentor, and it is therefore important that he or she be fully briefed on all aspects of the scheme, including its background. This briefing, together with a report submitted describing the scheme and an estimate of the scheme's replication potential, are three principal aspects in any grant application.

5.5.1 The Report

The report is the only evidence on which the grants committee can base its decision. The mentor, an 'impartial' advocate of the project, is unlikely to portray the same vigour and enthusiasm as those connected directly with it, so it is important to show this in the report.

A report [146] for this application was completed, in draft form, in October 1981 and included:

- project background;
- project objectives;
- technical summary of the scheme;
- breakdown of project costs;

- energy savings;
- economic viability;
- replication potential of the project;
- impact on the equipment supply industry;
- risk;
- request for Government funding;
- promotion of final installation.

Of particular interest to the grant committee is replication potential, the total savings that can be expected should the proposed scheme be adopted throughout the U.K.

5.5.2 Replication Potential

In this case replication can be divided into two areas; that directly associated with permanent test bed installations and that associated with general quality testing of commercial production engines.

To assess replication for the former, the number and type of permanent test beds throughout the U.K. had to be found. No central register was available that gave this information, but a list was compiled from the client's commercial knowledge, the Diesel Engineers and Users Association [147] and the sponsor's survey files. It was estimated that the equivalent of 570 of the type of engine for which the heat exchanger was designed existed in the U.K.

In the second category, the manufacture of commercial diesel engines, each engine undergoes quality testing, where operating performance is checked. Heat can be recovered from the test engines during this period. With a knowledge of annual engine production figures [147] and test durations [148], the potential for heat recovery could be estimated. The replication potential for this scheme was estimated as follows:

- heat recoverable from operation of engines for R and D purposes, 4724 tonnes of coal equivalent;

- heat recoverable from testing of standard production engines, 7502 tonnes of coal equivalent;
- (total heat recoverable 12 226 tonnes of coal equivalent).

The above figures show that this grant application met one of the unwritten criteria for success, that replication should exceed 10 000 tonnes of coal equivalent in primary energy savings (as stated in table 5.2, page 99).

By July 1982 no decision had been reached over the awarding of a grant although installation of the entire scheme had been completed.

The application for external funding marked the end of the non-technical aspects of the heat exchanger development. To this point only a single heat exchanger had been proved. In most commercial applications, however, many units are likely to be required. A scheme that would test the heat exchanger in this rôle (the scheme for which the grant application was made) is described in the next chapter.

CHAPTER 6

TEST INSTALLATIONS FOR THE DEVELOPED PRODUCTS

TEST INSTALLATIONS FOR THE DEVELOPED PRODUCTS

6.0 Introduction

The design and development of the two products has been examined together with their non-technical aspects. No matter how relevant these criteria are, however, the proof of any technological development depends on successful field trials. This chapter describes the outcome of such trials for both products.

The MHRU was designed to recover heat from an entire process and, as a result, only a single unit was tested. The heat exchanger, however, recovered heat from a single test engine. Such engines are usually grouped, in quantity, at specialised locations, and although proved individually, the test installation utilised 25 heat exchangers in order to assess their combined operational viability. These differences in the approach to testing are examined separately.

6.1 The MHRU

6.1.1 The MHRU Installation

The initial concept of the MHRU was to overcome deficiencies in existing component technology, and the prototype installation tested this objective.

The test scheme, shown in figure 6.1, recovered heat from two large baking ovens and used it for space heating purposes. Hot exhaust gases were collected from the ovens in two plenum ducts, a system of dampers controlling the quantity of heat recovered. These gases were passed through the MHRU and exhausted to atmosphere. Fresh gas (ambient air) entered the MHRU, was heated and ducted to the factory via induction mixing units. If factory conditions became too hot, gases from some of the flues were dumped to atmosphere (by opening damper 1 and closing damper 2, figure 6.1), so reducing the volume of hot gases recovered. To help maintain constant pressure in the plenum, damper 3 was opened allowing fresh air to be drawn into the system to replace the hot gas.

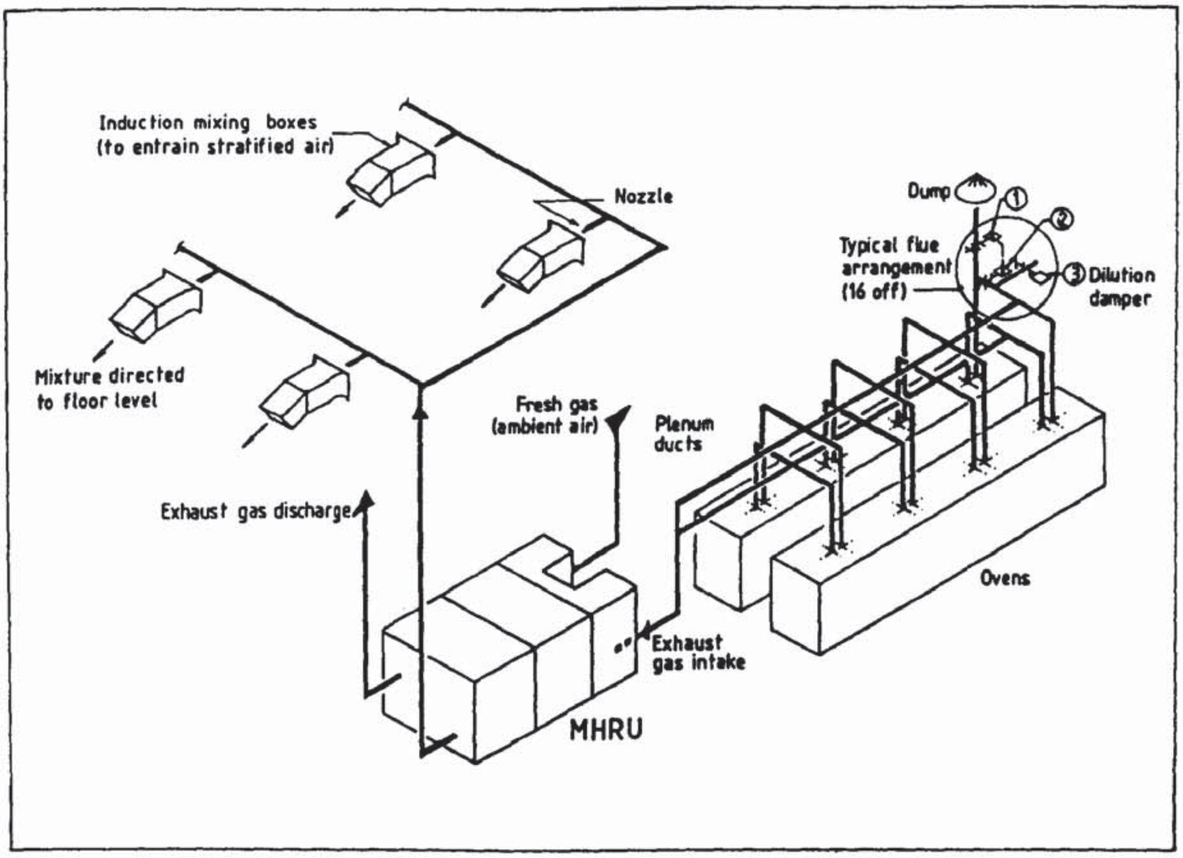


Figure 6.1 Schematic of the modular heat recovery unit test installation

Incidental heat gains from the ovens gave rise to a stratification of air in the baking hall. High velocity jets of heated gas from the MHRU were used in high level mixing boxes which, in-turn, entrained the stratified air and directed the mixture to floor level.

6.1.2 Testing of the MHRU

In the baking industry temperature and duration for which products are cooked is critical. Fears were expressed by Weetabix Limited (the recipient of the prototype MHRU) that fitting a new heat recovery product may effect these vital baking characteristics.

To help ensure that baking was not affected, the plenum collection ducts were maintained (by the MHRU exhaust gas fan) at a constant negative gauge pressure of 25Pa. This induced exhaust gases from the ovens and allowed the product to remain unaffected.

Weetabix's concern for continued product quality was reflected by insistence on their own initial testing of the device from a product quality, not heat recovery standpoint. (The effectiveness of the MHRU as a heating device can be in little doubt - on a Monday morning following a weekend period of errecting ductwork, heater boxes and the MHRU, packaging staff immediately noted 'more comfortable working conditions' - this, when the MHRU had not even been connected!). Product quality tests revealed that the MHRU had no effect on the baking characteristics of the original process.

By the time interference tests had been completed the heating season was over and no comprehensive heat recovery performance tests could be carried out. Preliminary testing, however, suggested that the heat exchange performance was to the heat exchanger manufacturer's specification.

A cost analysis of this system and its component equivalent was also undertaken. The analysis was limited to the MHRU and the component heat recovery system itself. Collection and distribution ductwork, being identical in both schemes, was not included in the comparison.

6.1.3 A Two System Cost Comparison

All costs and values given for the MHRU are actual, these costs having been taken from invoices received or from direct measurements taken during installation. All values for the equivalent component system were derived from discussions with the sponsor's contracts department by using price breakdowns from other heat recovery installations. Certain costs for the prototype MHRU, however, were regarded by its recipient as particularly sensitive, and this has resulted in a comparison (in parts) using percentages, not specific prices.

The supply cost of the MHRU was approximately 10 per cent greater than the supply cost of its component counterpart. This, however, was offset by the higher installation charges for preparatory work and insulation (something which is integral on the MHRU) associated with the component system. This resulted in an identical total cost for supply and installation of either system. There were, though, four advantages offered by the MHRU:

- the MHRU's installation time was approximately 100 man hours (4-5 days) shorter than that of a component system;
- there was only one delivery to site using the MHRU.

(These two factors resulted in less site disruption and a prompt return, for the customer, to a normal working routine.)

- the MHRU occupied approximately 60 per cent of the area required by its component equivalent.

(This would be an important factor to consider in applications where space was at a premium)

- no design charges were incurred by the client.

It was usual for a design fee to be levied by the contractor for designing a component system. Selection of the MHRU eliminated this cost saving a minimum of £1000. The above points are summarised in table 6.1.

Parameter	MHRU	Component System	Net Saving for MHRU		
			Hours	Other	£
Total installation time:					
-preparation of concrete bases	10 man hours	38 man hours	104		780[3]
-installation of actual units	6 man hours[1]	82 man hours[2]			
(total)	16	120			
Floor area occupied	$10.5m^2$	$18m^2$	-	$5.5m^2$	
Total deliveries to site	1	4	-	3	
Total unloading time	1.2 man hours	4 man hours	2.8	-	
Design and drafting time required for the system	0	100[4]	100		1000+

1 The actual installation time of the MHRU was 20 man hours. This, however, was the prototype design, and minor alterations had to be made on site. In subsequent units these refinements should not be necessary and installation should be achieved within 6 hours

2 This includes subsequent insulation of the components, something which is integral on the MHRU

3 Figure based on a cost per hour, per man pair, of £15 [149]

4 Includes selection of components, design of interconnecting ductwork, design of concrete bases, specification of insulation and engineering drawings of these aspects

Table 6.1 A physical comparison of the MHRU with its component equivalent system

These savings apply to the prototype installation and it is anticipated, as development work progresses, that the purchase price of the MHRU will be reduced. This will then liberate the savings offered by reduced installation time which are, at present, offset by the MHRU's greater purchase price.

This analysis shows the advantages and financial savings to be obtained by using the MHRU design. The analysis, although applicable in most cases, does not hold for all installations and to justify the MHRU design on a broader basis the following comparison has been included.

6.1.4 Modular Units Versus Component Systems

An item of equipment is not usually universal and specific plant offers advantages in certain circumstances. The MHRU is a compromise of design parameters that gives it advantages in a majority of applications.

The component system, however, has two major advantages over the modular or unit approach:

- it is custom designed for every application. Special design features can be incorporated that may prove difficult to include in the modular or unit design;
- in some applications space is particularly limited and it is possible to split component systems into several small locations and connect them with ductwork. The MHRU, although occupying significantly less floor area than its component counterpart, requires a physically large volume, in one place.

Having stated two advantages of the component system it is important, to obtain a true comparison between the systems, to remember the design aims of the MHRU. Designed for purchase by a customer that has identified a gaseous waste heat source, the MHRU provides an "off-the-shelf" heat recovery system that needs no design commitment from the purchaser. This is particularly advantageous for small companies with little or no in-house design facility and who cannot afford external consultants' designs, or for larger companies who simply wish to "do-it-themselves".

To sum-up, the MHRU could be used in a majority of the usual heat recovery applications to provide a heat recovery scheme more cheaply and

MHRU	Component System
favourable attributes	disadvantages
Minimum design time Reduced plant area Quicker and simpler installation Minimum plant disruption Ease of delivery No compatibility problems Internal or external use	Larger design committment Larger plant area Long and extensive installation Longer plant disruption Delivery up to 4 loads Compatibility problems Internal use preferred
disadvantages	favourable attributes
Physically large space needed Height can cause problems Concentrated weight per floor area	components can be spread Height not a problem Weight can be spread

Table 6.2 Attribute comparison of the MHRU and component systems

more quickly than the conventional component system, leaving the latter for more specialist markets. Each type of system has a rôle to play and a final comparison is given in table 6.2.

The cost and ease of installation of heat recovery schemes is effected by the selection of equipment and the prototype installation was approximately 2 per cent cheaper than a component equivalent. There is one calculated parameter, however, that effects not only the choice of individual equipment, but the viability of the entire heat recovery scheme - payback.

Payback can be defined as the time taken to repay the capital cost of a scheme out of the nett savings that scheme produces. Many companies place much emphasis on this figure and may not allow schemes to progress unless the payback period is below a specified value. There are several ways to calculate payback, each giving very different results. A method that gives a better result shows any scheme in a more favourable light and enhances that scheme's possibility of adoption. The profound effect that different methods of calculation can have on a scheme's perceived financial viability is examined below.

6.2 Calculation of Heat Recovery Scheme Payback

6.2.1 Present Methods

There are many methods of calculating payback, most of which are variations of one of the following three; simple payback, average rate-of-return and discounted cash flow internal rate-of-return. An analysis using these methods, and variations thereof, was conducted , all calculations being applied to an identical heat recovery system. A comparison of 8 methods of calculating scheme payback is given in appendix 12 (page 236), the results being summarised in table 6.3.

Method		Payback	
		Years	Rate-of-return %
1	Simple payback	2.32	-
2	Simple payback with inflation	2.04	-
3	Simple payback with inflation and residual value	2.24	-
4	Average rate-of-return	-	72
5	Average rate-of-return with inflation maintainence and reducing balance.	-	73
6	Average rate of return, as 5, but with straight line description	-	63
7	Discounted cash flow, for 5 years	-	33
8	Discounted cash flow, for 10 years	-	42

Table 6.3 A comparison of 8 methods of calculating scheme payback

The results lack of uniformity causes concern when schemes suggested by different sources (e.g. two separate consultants) are compared using different methods. To the uninitiated, scheme viability can be enhanced by simple arithmetic juggling. It is for this reason that a universally accepted method of payback calculation would be beneficial. It is outside the scope of this work to make any further suggestions in this area other than to register this need.

Whilst it is beneficial to have a universal method of calculating payback, it is essential to have a universal method of calculating energy savings. The energy saved by a scheme is a fundamental quantity and obtaining this figure accurately, is an essential base for the calculation of payback.

<u>6.2.2 Calculation of Energy Savings</u>

Energy savings can be divided into two parts; process energy savings and space heating energy savings.

Process energy consumption is normally controlled and therefore predictable. With a knowledge of throughput, energy consumption and, in-turn, energy savings can be calculated. With fluctuations in climatic conditions, lack of strict control and the general dynamic nature of heating systems, prediction of their energy savings is less certain and inherently more complicated. The following method, however, provides a widely recognised solution.

6.2.3 Savings for Space Heating Applications

(Note - all data obtained from external sources used in this section was given on the celsius temperature scale. For consistency its use has been continued).

The seasonal heat losses from a building, and hence the potential for space heating savings, can be estimated using the degree day concept [150]. The total seasonal heat losses, Q_T, from a building can be calculated using

$$Q_T = 24\ (Q_L.A.D)\ \text{kWh/year} \qquad \text{....6.1[151]}$$

where Q_L = total hourly heat loss per unit floor area per indoor/outdoor temperature difference ... kW/m^2K

A = floor area ....m^2

D = number of degree days per year ..... -

The degree day total is defined as the daily difference, in degrees celsius, between a given base temperature and the 24 hour mean outside temperature, when it falls below that base temperature.

The base temperature is the mean indoor temperature (which for the U.K. has been taken as 18.3^oC [152]), minus the incidental heat gains e.g. people, office equipment, lighting, etc. (which for commercial buildings in the U.K. has been given a value of 2.8^oK [152]). So the degree day total is the daily difference, in kelvins, between a base temperature of 15.5^oC (18.3-2.8) and the mean 24 hour outside temperature, totalled over an entire year. Used with equation 6.1 this would give an estimated total seasonal heating requirement (or saving if applied to a space heating heat recovery scheme) for a given building. The Chartered Institution of Building Services have a method of calculating these savings [153] and, though more elaborate, is the same in principle as the method described. Both use the fundamental quantity degree days.

Degree days are calculated over a 24-hour period and totalled for an entire year. This makes them suitable for calculating savings on continuously operated heating systems - but what of intermittently heated buildings? e.g. offices working 9am - 5pm, or 2 shift factories working, 7am-11pm. In such cases the 24 hour mean external temperature will invariably be lower than the mean external temperature over the period of occupation, so enhancing calculated savings from that system.

Degree day values are available for different parts of the country, different heating seasons [154], different base temperatures [154], different internal heat gains [155], making allowances for 5 day (not 7 day) continuous working [156], making allowances for heating to different and varying internal temperatures [157], but are not available for selected periods of the day. To overcome this anomaly the following correction factors (shown in table 6.4) are proposed to help predict final savings more accurately. Derivation of these correction factors is

Operating hours	Heating season			
	30 weeks (Oct -Apr)		35 Weeks (Oct-May)	
	MET (^{o}C)	DDC	MET (^{o}C)	DDC
Office Hours - 9am-5pm[1] Factory - single shift	7.39	0.92	8.19	0.90
Factory - two shifts[2] (7am-3pm, 3pm-11pm)	6.91	0.97	7.66	0.96
Factory - three shifts continuous operation	6.65	1	7.35	1

MET: Mean external temperature over the operating hours stated
DDC: Degree day correction factor for non-continuous heating

1 MET calculated over period 7am-4pm
2 MET calculated over period 5am-10pm } see section A13.1, page 243

Table 6.4 Degree day correction factors for the non-continuous heating of buildings given is appendix 13 (page 241). Using the same method described earlier, standard degree days can be used in the calculations but simply scaled down by the relevant correction factor to allow for various building heating times or occupancy.

The correction factors given here were obtained from Thames Valley area data only. Area correction factors to enable the results given in table 6.4 to be applied to the remaining 16 degree day regions in the U.K. (see figure A13.1, page 244) are given in table A13.2 (page 244).

By a more accurate prediction of savings and by using competitive quotations to obtain cost data, the assessment and comparison of heat recovery schemes could become more accurate. There is a possibility of developing a British Standard to contain what is considered by the most to be the 'best' method, although "it is axiomatic that national standard specifications are not prepared until there is a fairly widespread and steady demand for them" [158]. As heat recovery is a relatively small market this would suggest that this initiative must come from another larger and more established sector e.g. the Chartered Institution of Building Services.

This concludes the discussion of energy savings. The chapter now returns to its original theme of test installations and describes the scheme using multiple exhaust gas-to-liquid heat exchangers.

6.3 The Exhaust Gas-To-Liquid Heat Exchanger

6.3.1 Heat Exchanger Installation

The test installation (as briefly discussed in section 5.2) used 25, 002 heat exchangers to extract heat from diesel engine exhaust gases for pre-heating the boiler return water in the site's MPHW system. A schematic of the system is shown in figure 6.2.

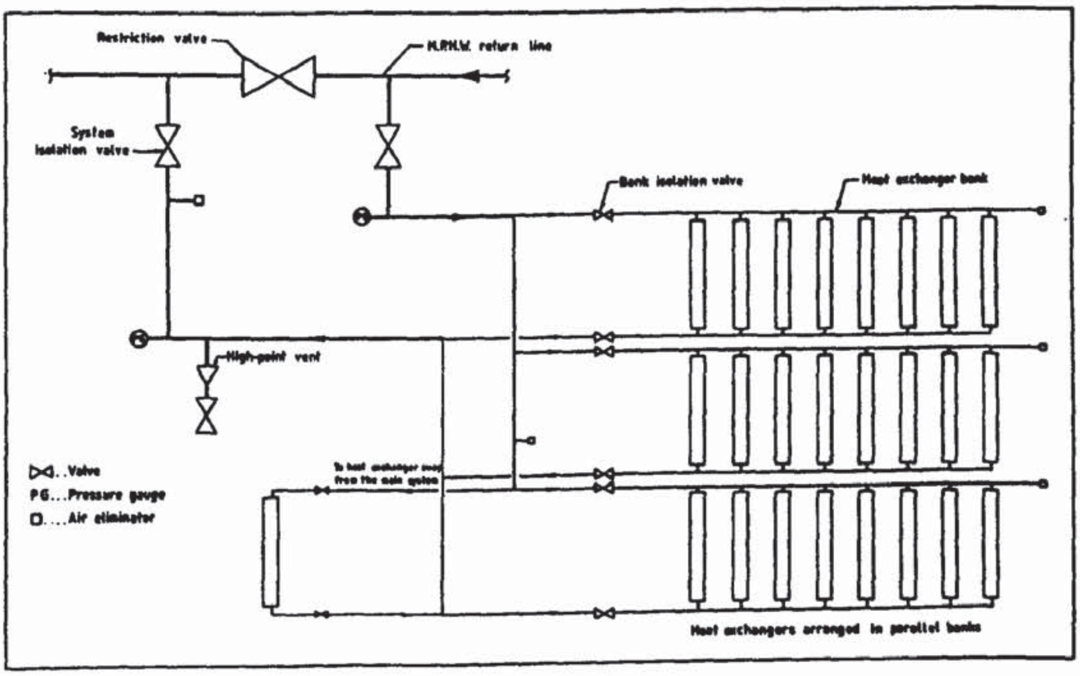


Figure 6.2 Schematic of the multiple exhaust gas-to-liquid heat exchanger installation

Previously the hot exhaust gases were ducted through the roof and exhausted to atmosphere. They are now passed through the heat exchangers then discharged. 25 heat exchangers, all of which were mounted at roof height, were used to recover heat from 21 test engines. (When an engine was larger than that for which the heat exchanger was designed, multiple units were used to cope with the extra exhaust gas volume.) The heat exchangers were arranged in parallel to heat a large volume of water through a modest temperature rise. Individual isolation valves (which doubled as flow measuring valves for commissioning purposes) were fitted to all heat exchangers.

The reduced temperature difference between water flow and return allowed the main boilers to operate at reduced load. MPHW was used for process & domestic hot water and test cell & general space heating. In summer one boiler was operated on low fire to supply these needs. Heat provided by the recovery scheme now obviates this requirement. The total installed cost of the scheme was £126 700 [159] and its economic viability is now considered.

6.3.2 System Viability

The total cost for the design, installation, commissioning and monitoring of the scheme was £126 700 (including £9600 for monitoring equipment). The savings were estimated at £34 126 per annum, giving a 'simple' payback of 3.7 years. This figure, however, was artifically pessimistic for the following reasons: the savings were based on space heating savings only (a process load did exist but was unquantified by the client and not included); the client's business enabled the purchase of boiler fuel at approximately 10 per cent below the typical market price. Due to the stringent criteria being applied to projects by the client's parent company, an Energy Demonstration Project Grant was applied for to enhance the case for capital funding. If obtained this would reduce the simple payback figure (from the client's view-point) to 2.9 years.

6.3.3 The Grant Application

The application procedure was summarised in section 5.5 (page 100). A basic demonstration grant would cover 25 per cent of the capital cost of the scheme and 100 per cent of its monitoring costs. The client applied for £29 275 (25 per cent of (£126 700 minus £9600)) and £18 590 (the cost of monitoring equipment and staff analysis time).

Grant application procedures were started in 1981 with a report [146] being submitted to a mentor by October of that year. In the absence of further comment, manufacture of the heat exchangers was started in February 1982. It was not until June 1982, when the entire installation was virtually completed, that action , provoked by the client, stirred the grants procedure into motion again, and a second, revised report was submitted to the mentor [159]. By July the scheme was operational and there had still been no official hearing for the grant application.

This delay appears to be of little consequence until the following fact is realised - no site work should have been allowed to start before the grant application had been officially considered. Should the client have obeyed this clause, the entire scheme would have been delayed at least six months, missing the 1982/83 heating session.

This instance was a single one in the many demonstration grants that have been applied for to date. It may not be typical. The competitiveness of the awards, coupled with a requirement to be seen to be dealing fairly with public money, could certainly have contributed to this delay. It is, however, unfortunate that one entire heating season's fuel savings may have been lost by the slow mechanism through which energy saving grants have to pass.

Although the grant application has not yet been offically considered, further testing and monitoring is to go-ahead as planned. An outline of this next phase follows; its completion, however, is outside the scope of the present work.

6.3.4 The Next Phase

The main objective of the installation is to prove that the developed unit could be successfully incorporated into a complete system, so demonstrating its operational viability. The next phase, monitoring, is scheduled for September 1982 until January 1983, with a report on the units' performance in multiple test engine installations being available in March 1983.

To conclude work on the heat exchanger's development, a review of the design has been given.

6.3.5 A Novel Design

There are several features that have made this heat exchanger particularly attractive to the client. These features are listed below.

Lower Static and Dynamic Back Pressure

The 002 design gave a calculated pressure drop of 306Pa. When compared with pressure drops of 1.5kPa [49] and 2kPa for other commercial designs, these figures can be seen relatively. It has since been stated [159] that acceptable back pressure effects on test engines can be achieved only if the static pressure drop is less than 750Pa, which this heat exchanger conforms to. As a conclusion, this work suggests that heat exchangers used with small (approximately 30KW), single cylinder diesel engines (the type used in this testing), should exhibit static presure drops of less than 20 per cent of the static gauge pressure of the exhaust gases available at the exhaust manifold, if major changes in the engine's operating characteristics cannot be tolerated.

The dynamic effect of the heat exchanger on the test engine was undetectable [159].

Minimum Clog Design

Helically finned tube has been used extensively in heat exchanger design. This tubing, with fins of pitch in the range 5-10mm, when exposed (in cross flow) to diesel engine exhaust gases, is prone to clogging, deposit build-up and pressure drop increases ([78] and section 3.2.1, page 50). The 002 design uses a longitudinally finned tube. This provides a 'cleaner' profile to the gas flow, the motion of which along the surface of the fins helps keep fouling to a miniumum.

When cleaning does become necessary, removable inlet and outlet flanges allow easy access for rodding the entire heat exchanger.

Long Life

The heat exchanger is of simple and robust construction. Corrosion tests were undertaken on the turbulator sections of the 001 unit after it had been in operation 4 months. A section of turbulator close to the gas outlet end (the point at which the exhaust gases were closest to their dew point) was examined. No pitting of its surface was found. The first prototype was on test for 15 months with no visible signs of corrosion.

Minimum Engine Wear

Back pressure effects cause an increase in cylinder operating temperature. This, in-turn, produces a thinning of the oil with a subsequent reduction of its lubricating properties. Accelerated engine wear often results. The 002 design presents minimal back pressure to the engine, helping to control engine wear and making it particularly suitable for the following applications:

- engines testing lubricants;
- engines operating on long duration testing;
- engines operating under stringent test conditions.

Minimum Retrofit Effect

Equipment retrofitted often affects the original system's operating characteristics. The 002 design minimises these effects, a major benefit when considering heat recovery from systems where it is necessary not to invalidate performance results obtained prior to the application of heat recovery.

Technically the product has been a success, the heat exchanger achieving the performance specified by the client. But what of its commercial success - has there been one and is there a future for the product? These points, together with similar ones relating to the MHRU, form the basis of the next chapter.

CHAPTER 7

BUSINESS ASPECTS OF THE TWO DEVELOPMENT PROJECTS

BUSINESS ASPECTS OF THE TWO DEVELOPMENT PROJECTS

7.0 Introduction

Chapter 6 has shown that the MHRU and the heat exchanger achieved technical success by performing to their defined specifications. But at what cost has this success been accomplished? This chapter assesses the financial implications of the projects from the customer's, client's and sponsor's viewpoints, and shows the benefits obtained by these investments. Both products are analysed and a final comparison between the product-push and market-pull techniques is given.

7.1 The MHRU

7.1.1 A Cost Analysis of the Product

The initial development of the MHRU has been completed; a product now exists that provides a modular heat recovery unit capable of handling high temperature gases. The cost of development and preliminary marketing of this product (shown in table 7.1, page 123) was £38 020. This figure, which is used in the following analysis, does not include the prototype cost as this was met by the customer (Weetabix). The costs have been divided into 5 categories.

Staff Time

This accounted for 58 per cent of the total cost, 86 per cent of which was for the development engineer's time. The sponsor's technical staff provided input amounting to 11 per cent of staff costs, the remaining 3 per cent being secretarial time.

Commercial Protection

During development of the MHRU a provisional patent was taken out. This patent covered the concept of the unit (all hardware used in it was

Item	Cost		
	£	% of total (excluding cost of the prototype)	% of total (including cost of the prototype)
Staff time Technical staff (sponsor) Development Engineer Secretarial	 2 420[1] 18 770[1] 750	57.7	42.4
Commercial protection Provisional U.K. patent	290	0.8	0.6
Test marketing Japanese exhibition Model of the MHRU Design and Production of technical brochure Editorial analysis	 1 320[2] 2 600 1 250 380	14.6	10.7
Prototype Manufacture Net production cost (including internal hardware)	13 750	-	26.6
Testing Carried out by the client under the supervision of the sponsor	minimal	-	-
Market launch Manchester exhibition	640	1.7	1.2
Direct advertising Advertising and public relations agents fees (for before, during and after launch)	9600	25.2	18.5
TOTAL (excluding prototype cost)	£38 020		
TOTAL (including prototype cost)	£51 770		

1 These figures include office overheads and travelling expenses

2 This exhibition was supported financially by the London Chamber of Commerce and Industry (see section 4.5.3)

Table 7.1 Development and marketing costs for the MHRU

supplied by other manufacturers and covered by their patents). Drafting and filing this application cost £290, 1 per cent of development costs.

Test Marketing

When design work had advanced sufficiently, a test marketing phase was entered to assess the market's reaction to the design. A model of the proposed MHRU was made and displayed at an exhibition. Interest created by this and a parallel editorial campaign was answered by sending brochures that described the MHRU in detail. The cost of this exercise was £5550, 15 per cent of development cost.

Prototype Manufacture

The prototype was manufactured, installed and commissioned by February 1982. It was purchased as part of an overall heat recovery scheme (described in section 6.1.1, page 104). The cost of the MHRU was £13 750.

Testing

After commissioning had been completed the customer took over and initiated a long term testing programme, the results of which are due in early 1983. Initial findings, however, suggest a favourable outcome to the tests. All testing was carried out by the customer at no charge to the sponsor.

Market Launch

The MHRU market launch consisted of an exhibition and associated advertising. The exhibition was small, but specifically aimed at energy conservation. Its total cost was £640. The advertising, which took place well before and during the exhibition was provided by the exhibition organisers.

Direct Advertising

Advertising throughout the project, together with PR agent's fees, totalled £9600, 25 per cent of development costs. These costs could not be separated.

7.1.2 The MHRU - A Commercial Success?

The total cost of this product's development to date has been £38 020. There have been no sales, and in pure financial terms this product has made no return on investment, so could be classed (to this point) as a commercial failure. There could be many reasons for this complete lack of sales but they are likely to fall into three catagories:

1) wrong product;

2) unfavourable economic climate for heat recovery purchase;

3) weak and mistimed marketing and sales.

The first reason seems unlikely to have effected sales as most feedback received from potential customers was favourable (see section 4.7.1, page 74). The second reason, however, could certainly have contributed to the lack of sales. The MHRU is an expensive product which may have fallen foul to a weak economic climate. The extent of this, is hard to access for two reasons:

1) heat recovery schemes have been installed in recent years [160-162];
2) the second reason is linked with marketing, and it is weak and mistimed marketing and sales which is thought to be the main reason for failure.

In a more optimistic economy the job of marketing and selling becomes more easy - money is available for purchases. In the present climate a larger effort is required - an effort which was missing from the MHRU campaign. The following gives some of the principal reasons why it is thought marketing has contributed to the lack of sales.

No Market Education

As stated in section 4.3 (page 65) there can be 4 stages to the innovation process, knowledge, persuasion, decision and confirmation. Information about a new technique or product is a pre-condition to adoption [123] and an educational content to this, in the early stages, is important [163].

With a new product the market should fully understand its advantages over those of other products. The MHRU, however, offers a completely different approach to the heat recovery problem and even before the advantages are understood, its concept should have been clearly presented. This was a fundamental education process omitted from its promotional campaign, all promotional material having assumed the potential customer's knowledge of the MHRU was equal to that of the design team.

Communication is essential for the success of an innovation [37,164,165] and it is thought unlikely that the promotional campaign provided this in sufficient quantity. In the education process the written word appears to be the most efficient means of creating awarness of a product [102] Papers and articles could have been written, in the early stages of the MHRU's development, presenting the differences between modular and component systems. This would have started the education process and may have provoked more customers into obtaining information about the MHRU system - (the knowledge stage).

Lack of Market Awareness

As stated, communication is essential for the success of an innovation. Due to financial constraints (starting in January 1982) there was no external promotion of the MHRU launch (other than that at the launch exhibition), which resulted in only limited communication. It has been stated that there are three steps to informed product selection: (1) the customer must know the product; (2) the customer must know how the product performs; (3) the customer must know how it performs compared with other products [166]. Limited promotion prevented people from 'knowing' the product and 'assumed awareness' advertising (i.e. advertisements that assumed the customer already had an indepth knowledge of the product) did not provide the information required for stage (2) 'how the product performs' and consequently stage (3) either.

Market Misconception of the Product

There is a growing feeling that the market has not understood the MHRU, or in fact has misconceived it. In advertising other products it has been suggested [167] that ball and roller bearings be thought of as anti-friction devices and diesel engines as energy producing units for use as auxiliary facilities in processing plants, ships etc. The MHRU has been advertised as "The last word in heat recovery - a unique range of modular heat recovery units" (see figure 7.1).

Aston University

Illustration removed for copyright restrictions

Figure 7.1 An advertisement for the modular heat recovery unit

It may have been of advantage to describe its function more fully i.e. a product that can recover heat from hot waste gas sources and can utilise that heat to provide space or process heating. Below are listed some of the initial reactions to the modular heat recovery unit that typify the possible misconception of the product:

"Modular heat recovery, yes, heat pumps - you can get separate compressors and condensers now can't you?".

"Modular - oh, if it breaks down I've got to replace the lot".

"Modular, I learned about that in maths at school".

"It's heat recovery from a boiler".

A different approach to the entire promotion may have been more beneficial. Emphasising the MHRU's attributes, i.e. 'it can save up to 10 per cent of your fuel bill', is a possible alternative. With this method it should still be remembered that what is important is not product attributes but the prospective customers' interpretation of them [168].

It has been stated (section 4.5.2, page 70) that editorial coverage of new products provokes a greater reponse from potential customers than direct advertising, as it is seen to be 'unbiased information ostensibly from the editor'. This greater response is supported by information in appendix 10 (page 225), but the above comments on misconception suggest this result may have been obtained for a different reason. Editorial (as it is free) often contains a more detailed description of the product and generally is longer than the cost-limited space available in an advert. This extra description could well help in educating the customer about a product, a product that could have been ignored in an advertisement that did not make the product's use immediately obvious.

But what makes someone look at a piece of editorial or an advertisement in the first place? If it is something directly related to their field or something of interest to them, they are more likely to read it. This suggests that even before market education through articles, editorial etc. there is an 'interest creation' phase. In this phase, thought provoking material can be presented to try to create an interest in a subject. In energy conservation the events following the oil crisis of 1973 have certainly contributed to this interest creation.

Interest creation and market education, however, both require staff resources to implement.

Lack of Sales Staff

The sponsoring organisation had no sales staff between 1979 and 1982. All products need to be sold, however, and this is probably most effectively achieved by professional sales staff. Personal selling still has the most important rôle in the industrial sector [169], and a sales manager was finally appointed approximately 6 weeks before the launch of the MHRU. His introductory company duties prevented any significant contribution to the launch campaign and it has been noted that marketing and sales are more likely to be successful if done by the existing chief executives of the company, and not by recruiting from outside, as there is insufficient time to become acquainted with the product [169].

Industrial goods are usually purchased by a group of people [129,170] and it is important to find out the different peoples' needs within that group and to change the 'sales pitch' accordingly [171]. A product usually has several benefits and the emphasis on particular ones should be tailored to customer requirements [170]. These techniques can best be accomplished by the experienced salespeople. The lack of such experience in the earlier part of the MHRU's development can be summed up in the following, somewhat cryptic fashion, which suggests that the product "is a tool in the selling process. The sharper the tool the better job it will do. But without someone to wield the tool it will do no work at all" [110].

Sales Promotion and Staff Resources Out of Phase

The appointment of the sales manager was too late to help the test marketing effort. Table 4.3 (page 75) showed that 320 reponses were received from the editorial promotion campaign and that only 53 per cent (table 4.2, page 74) of these were subsequently contacted. The follow-ups that did take place were undertaken by technical staff and were of a technical nature.

A more sales orientated approach of that stage may have converted some of those enquiries into possible test locations or even orders when the final product was available. This approach may have been too technical and section 4.7.4 (page 78, the brochure review) supports this argument by suggesting that a more easy-to-read, sales orientated brochure may have been beneficial. Enquirers were contacted once, though it is usual to be persistent in sales follow-ups.

A Fear For Commercial Secrecy

It was originally thought that the MHRU would be aimed at the food processing and baking sector. A report [172] was commissioned to examine the possible exhibitions that may have been suitable in that sector for test marketing and initial promotion of the MHRU. The British and International Baking Fayre was selected and used by the sponsor as a general promotional venture for their heat recovery consultancy expertise and as a test marketing exercise for the MHRU.

Originally the sponsor's financial association with Weetabix (the sponsor is 50 per cent owned by Weetabix) was emphasised. Commercially, the Weetabix company has a reputation second-to-none and it was thought this could only enhance the market's opinion of the sponsor. It became apparent, however, that by aiming products at what are, in effect, competitors of Weetabix, the promotion of this link prompted caution and possibily a reluctance to purchase. The impression obtained was that people feared for their commercial secrecy. In later promotional events the emphasis on this link was reduced.

No Established Installation

The MHRU's market launch was in February 1982 at a general energy conservation exhibition; the completion of the first prototype installation coincided with that date. Unfortunately no test information or operational performances were available at the launch. It has been noted in the past that results of innovations must be observable to others [173, 174] for them to establish the viability of alternative solutions [127] i.e. modular versus component systems. The lack of test results prevented this. One item in favour of the installation at that point, however, was that it did provide evidence to show that would-be purchasers would not be the first to install an MHRU, and it did provide a valuable lever to move customers from knowledge and persuasion (stages 1 and 2 of the innovation process) to decision (stage 3).

Premature Market Launch

Although the factors identified to help provide a successful market launch had nearly all been achieved (face-to-face approach, salesperson, a working installation, trade name), it is felt that a further phase of development would have benefited the MHRU considerably and provided a possibly superior, certainly cheaper poduct. Eagerness to get the product into the market place can sometimes, however, overshadow further development work. This coupled with lack of market education and possible over-optimistic advertising has, it is thought, been the present downfall of the MHRU as a commercial enterprise.

At market launch the MHRU was approximately 10 per cent more expensive than a corresponding component system. It is thought that the experience gained from installing, testing and operating the MHRU, together with a value analysis/cost reduction exercise, could have reduced this cost to that more in line with its direct competition. A preliminary cost reduction exercise was undertaken, the details of which, are given in appendix 14 (page 246).

Low Profile Market Launch

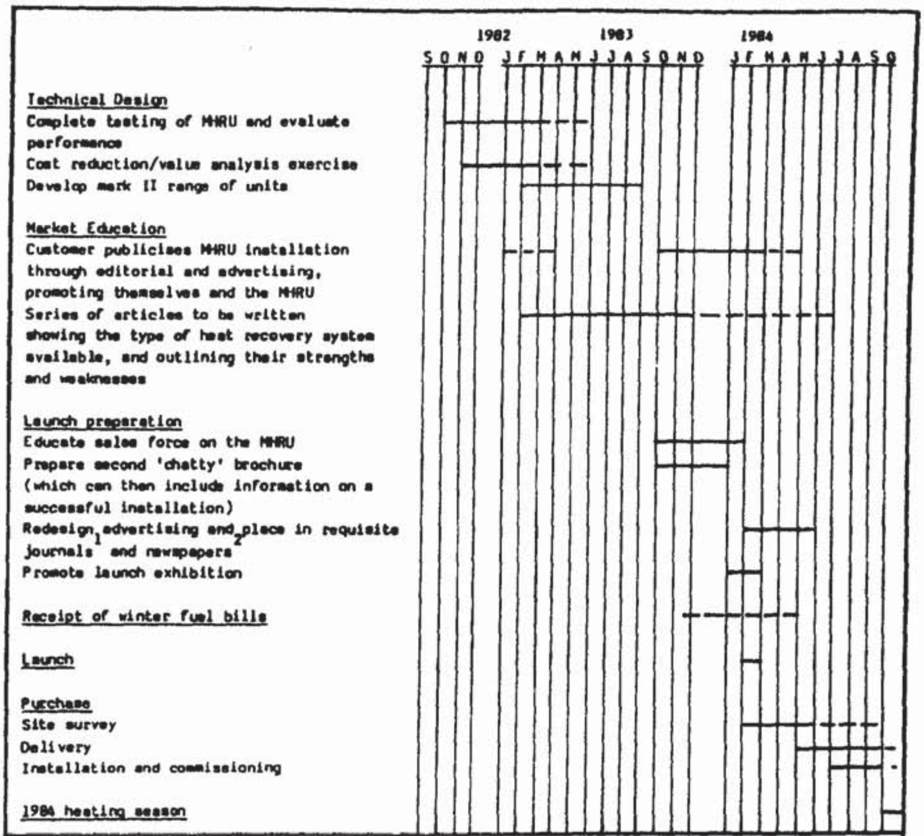
The market launch was a small event accounting for only 2 per cent of total project expenditure. Although the Manchester exhibition was assigned as the launch, due to financial limitations, no special treatment was given to the occasion and there was little press coverage. This consequently resulted in a disappointing level of interest in the MHRU. This low profile market launch may, however, be turned to advantage by relaunching the MHRU in the light of experience.

The Next Phase - Relaunch

By the end of 1982 the technical performance of the MHRU should have been assessed and operational experience gained. Comments from the client could then be used in conjunction with the value analysis/cost reduction exercise (appendix 14), to produce a mark II range of MHURs (although this would be the first really 'commercial' range). This range could then be launched in early 1984 to coincide with industry receiving its larger winter fuel bills, and when managers are most likely to be receptive to the purchase of heat recovery equipment. A proposed programme for relaunching the MHRU (figure 7.2) has been included for completeness.

Before a relaunch is considered, however, the sponsor must make a major decision - to remain in consultancy and contracting or to become dedicated to entering the manufacturing market. The latter will involve heavy financial commitment, and with present funding limitations, this is considered unlikely.

The project to date has cost over £37 000. This poses the question, what gains and advantages have been obtained by the sponsor for this investment?



1 Journals are important as they are a main source of information for technologists [175]. An evaluation of which journal to advertise in is given in appendix 10

2 A study carried out by the Financial Times showed it to be the most important source for keeping managing directors in touch with business trends and developments [176]

Figure 7.2 Relaunch programme for mark II modular heat recovery unit

7.1.3 Benefits of the MHRU Development

The benfits of the MHRU development to the sponsor can be divided into four areas:

- development;
- marketing;
- advertising;
- office systems.

Development

Work carried out on the MHRU culminated in the production of a prototype unit. This work has formed a well established base from which to develop a more commercial unit, if required.

The site surveys (detailed in appendices 4 and 5 pages 178 and 180) provided information on the physical specification of the MHRU.

These also generated an idea for second product, the single flue, exhaust gas heat recovery unit. This product was developed separately and is shown in appendix 6 (page 192).

The development of both these units has given the sponsor experience of product design, manufacturing and production techniques.

In the early stages with the sponsor an extensive survey of heat recovery equipment was conducted (appendix 1, page 153). This survey, which continued throughout the project, has provided an extensive product catalogue.

Marketing

The marketing campaign, in promoting the MHRU, also provided market information for the sponsor. The charge for this exercise, which provided valuable quantified information about media responses, sales techniques, market interest, advertising, sales experience, as estimated by the sponsor, would have been £8-£10 000 if carried out by marketing consultants.

Advertising

The advertising and promotional campaigns of the MHRU, although having not led to direct sales, helped establish the name of the sponsor in the market place. Promotions designed to have the same effect, again in the sponsor's assessment, would have amounted to £10 000.

Office Systems

Site survey systems and computer programs developed in conjunction with the MHRU saved considerable time when applied to analysis of site survey information. Following their introduction site surveys were taking four hours less, on average, and analysis of results, which previously took 3 days (3x8 hours), was reduced to 1 hour. The sponsor undertakes approximately 30 such surveys a year, and the net gain by introducing these systems has been:

4 hours x 2 persons x 30 = 240 hours saved/annum

(24-1) hours x 1 person x 30 = 690 hours saved/annum

The cost per man hour for this job in 1982 was £8.50/hour [177], giving a total saving of £7905/annum.

Cost-Benefit Analysis

From the above 4 sections the equivalent one-off expenditure saved by the MHRU project was approximately £20 000 and the recurring saving, per annum, was approximately £8000. The cost of the MHRU development has been £38 000 (table 7.1, page 123), and should development cease at this point, this cost, based on the above figures, would be recovered in two years. (This increases to 3-5 years if the entire development cost of £51 770 is considered.)

The MHRU project forms the ground work and first phase development for a new product - the modular heat recovery unit. With the lessons learned over the past 3 years and with a further modest input, this development could result in a commercially successful product.

7.2 The Exhaust Gas-To-Liquid Heat Exchanger

7.2.1 A Cost Analysis of the Product

The above exercise was repeated for the exhaust gas-to-liquid heat exchanger. The total cost of this development, shown in table 7.2, was £11 871. These costs can be divided into 4 categories.

Staff Time

These figures were taken from actual invoices despatched, hence their accuracy. Each person to work on the project was charged out at an

Item	Cost			
	£	%	Paid by sponsor	Paid by Client
<u>Staff Time</u>				
Technical staff (sponsor)	2 653	60	-	2 653
Developments Engineer	4 452		-	4 452
<u>Prototype manufacture</u>				
001	1 112	20	-	1 112
002	1 237		-	1 237
<u>Test equipment</u>				
001 and 002	203	2	203	-
<u>Commercial protection</u>				
Patents:				
UK 001 (full patent)	611			
UK 002 (provisional)	291			
Canada 001 (provisional)	394	18	2 241	-
USA 001 (provisional)	348			
Japan 001 (provisional)	570			
TOTAL	£11 871	100%	£2 417	£9 454

Table 7.2 Design and development costs for the exhaust gas-to-liquid heat exchanger

hourly rate, this rate incorporating an allowance for secretarial time.

Prototype Manufacture

Competitive tenders were obtained for the production of the prototypes. The cost for both units (which was met entirely by the client) was £2349, 20 per cent of the total the project cost.

Test Equipment

All test equipment bought specifically for this project is included here. The cost was £203, 2 per cent of the total.

Commercial Protection

All development was undertaken at the client's site. To protect commercial interests the sponsor took out a total of 5 patents as work progressed. Details of this exercise are given in appendix 11 (page 230). Their cost was £2214, 18 per cent of the total.

The total cost of this project was £11 871, of which the sponsor paid £2417. What has been the return on this investment and has this development been a commercial success?

7.2.2 The Heat Exchanger - A Commercial Success?

The commercial success of this exchanger can be considered from two viewpoints, the client's and the sponsor's.

For the client, the heat exchanger recovered heat from the exhaust gases of the diesel test engines with no detrimental effect. The installation using multiple units has reduced the client's fuel bill, so the development may be considered a commercial success.

For the sponsor too, the heat exchanger may be considered a commercial success. This is manifest by the client's order for a further 24 units. The resulting supply contract allowed the sponsor to recoup all expenditure on the development and, in fact, make a net financial gain. Other benefits to the sponsor as a result of this work are given below.

7.2.3 Benefits of the Heat Exchanger Development

The benefits to the sponsor of this development can be divided into 2 categories, a commercialy successful product and in-house expertise.

A Commercially Successful Product

The sponsor now has the design of an exhaust gas-to-liquid heat exchanger that can recover heat from the exhaust gases of diesel engines operated under stringent conditions. The markets for such a device are defined and the sponsor could embark on a sales campaign by visiting potential clients' sites individually. These markets could be found by desk research, so avoiding advertising, launch and staff problems that have been noted with the MHRU development. Before this, the sponsor is faced with a major policy decision - to remain in consultancy and contracting or to enter the manufacturing sector. If manufacturing is the option taken, entry into this market will be helped when PR (public relations) material featuring the multi-unit installation is released by the (prestigious multi-national) client. Should the scheme qualify for a Department of Energy Demonstration Project Grant, promotion of the product will be enhanced still further.

In-House Expertise Increased

The design and development of the heat exchanger has increased the sponsor's in-house expertise, not only in design, but also in the testing and evaluation of such devices. This expertise will be of value in the design and testing of similar equipment and in the assessment of the application of such devices at other industrial locations.

A Cost-Benefit Analysis

Table 7.2 (page 136) shows the financial input from the sponsor was £2417 and the total development cost was £11 871. The nett cost of heat exchanger manufacture (should mass production be started) would be in the region of £750-£1000 per unit. With 25 per cent mark-up, the profit would be approximately £200-£250. For the sponsor to completely offset their investment, 12 units needed to be sold (24 have already been sold); to recoup the total development cost, approximately 60 units must be purchased. As a general conclusion it can be said that this development has been commercially successful.

7.3 A Two Product Comparison

The two products are opposites in the marketing sense, the MHRU being a product-push product, the heat exchanger a market-pull product.

Product-push requires extensive market research to ascertain what is lacking in the market place. Its inherent nature is then for development behind closed doors to prevent competitors obtaining these ideas. The market too, is not largely aware of the product until its ultimate launch. This is where the MHRU failed. The market was not made sufficiently aware of the product, of its advantages or benefits over existing products. The MHRU achieved technically what was required of it, but lacked marketing and sales back-up.

7.3.1 Product-Push Development

To say categorically that the MHRU is a commercial failure is, however, a little premature and may still not yet be true. It has been shown that "the backward firm may not hear of an idea for several years after it has been launched" [165], that this may be as long as 10 years [123] (though it is usually 5 years), and it is often a "minimum of 3 years before the first hopeful signs become apparent" [169]. With the launch of the MHRU in February 1982, this process is still in its early stages. It has been suggested that for a product to succeed [99] it must:

- have a relative advantage (i.e. economic, social);
- be compatible (with existing values);
- have a low degree of complexity (i.e. easily understood by the customer),
- be open to trial;
- be observable to others.

The MHRU does have advantages over existing products (table 6.2, page 109); most industrialists know of gas-to-gas heat recovery, so it is consistent with existing values; it should (with revised advertising) be easy to understand; it is not open for trial (due to physical limitations) but is certainly open for inspection; it is observable to others. The MHRU, therefore, has the defined attributes of a successful product. With some further development work and a planned marketing and advertising campaign the product could be a success.

The MHRU has a potentially vast market offering large returns, entering which, however, involves high risk and large investments. It has been suggested, to complement development work, for every £1 spent on development, there should be 50p spent on advertising [94]. For the MHRU this ratio was £1 to 25p. This should be increased to the former, should further advertising be considered.

The market-pull product, however, has only a limited potential market. This would result in more modest returns, but at much lower risk, less staff commitment and at a smaller investment.

7.3.2 Market-Pull Development

Statistically the market-pull product has a greater chance of commercial success. 60-90 per cent of new ideas are market-pull [178], and a majority of successful innovations are initiated by user organisations with a need [178]. The development of the heat exchanger relied largely on technical expertise and its ultimate success was not dependent on subsequent marketing. This produced a product that fulfilled the requirements of the client.

7.3.3 Future Development Projects

In the light of these two product developments, the less ambitious market-pull product has been the more successful. As a generalisation it may be prudent for other young companies similar to the sponsor, whose main vocation is also technical expertise, to pursue product development of market-pull products. This would give those companies a higher probability of success with their developments and utilise their services in those areas in which they are most proficient i.e. technical not marketing aspects.

Generally, due to extra marketing and sales effort, product-push products cost more to develop than market-pull products, but have larger potential markets. Development of market-pull products does not require this input, however, and are therefore cheaper to develop to commercialisation and are statistically more likely to achieve success.

CHAPTER 8

CONCLUSIONS

CONCLUSIONS

8.0 Introduction

This final chapter gives an overview of the achievements of this project from its start in October 1979 to its completion in the summer of 1982. The conclusions have been divided into the following sections:

- initial research;
- development of a modular heat recovery unit;
- development of an exhaust gas-to-liquid heat exchanger;
- marketing heat recovery equipment;
- assessment of energy savings;
- areas for further work.

8.1 Conclusions

8.1.1 Initial Research

Initial research included an analysis of 62 industrial sites, a survey of energy conservation products and an assessment of the potential for waste heat recovery in some principal U.K. industries. The following points can be noted from this work:

1) 62 per cent of all heat recovery schemes proposed were of the gas-to-gas type, 26 per cent of the gas-to-liquid type, 7 per cent of the liquid-to-liquid type and 5 per cent other, e.g. burning wood waste for hot water production.
2) The average payback period for gas-to-gas heat recovery schemes was 4 years, for gas-to-liquid 3.1 years, liquid-to-liquid 2.7 years and for others 2.4 years.
3) An extensive survey of companies marketing energy conservation equipment was undertaken. This survey details over 1000 companies.
4) From a survey of 83 industrial ovens, the average exhaust gas

temperature (at outlet to atmosphere) was found to be 438K, with 46 per cent of temperatures occuring in the range 424K-473K.

5) From the survey carried out in the food processing industry, it was found that 68 per cent of applications required hot gas as the utilisation medium, i.e. for space heating or combustion gas pre-heating. Only 32 per cent required hot liquid for utilisation purposes.

6) 60 per cent of all ovens surveyed had total exhaust gas emissions in the range 0-2m^3/s, the average being 1m^3/s. 40 per cent of all sites surveyed had total exhaust gas emissions greater than 2m^3/s, the average being 3.6m^3/s .

7) An analysis in 1980 concluded that the total potential for waste heat recovery in 33 U.K. industries (excluding iron and steel) was 63 600TJ (18 TWh) per annum. With an average payback of two years, this gave a market for heat recovery schemes of £301 million.

8.1.2 Development of a Modular Heat Recovery Unit

The MHRU, the internally generated product idea, was a product-push product developed to fill a gap in the heat recovery field. A prototype was manufactured and an independent test report on the unit's performance is due to be available in early 1983. Preliminary evaluations, however, show the MHRU in a favourable light. The following conclusions can be made from the development of this unit:

1) The MHRU fulfilled the specifications as defined by market research by providing an easy to install, completely compatible heat recovery system in one box.

2) From preliminary marketing exercises it has been established that heat recovery systems in one box were liked, and the modular or unit concept for heat recovery equipment was liked.

3) In recent years, 8 other such modular heat recovery units have appeared in the market place. These competitors do not share the same temperature capability as the MHRU, the best having a ceiling of 413K. (The standard MHRU has a temperature maximum of 473K, with specials available up to 750K). The presence of these other units, however, does serve to reinforce point 2) immediately above.

4) This development has provided the sponsor with a prototype unit, from which a commercially acceptable device could result. The sponsor can now consider the following options seriously; to enter the manufacturing sector and develop the MHRU further, or to discontinue the project and remain in consultancy and contracting.

5) The potential for heat recovery from industrial ovens in the U.K., the market at which the MHRU was aimed, was estimated to be 3165TJ (0.88 TWh). Using the assumptions of energy and MHRU costs given in section 4.2.2 (page 64), and the gas-to-gas utilisation precentage given in section 3.1.1 (page 31), this represents a potential market of 295 units (£3.57 million). If applied to the 33 industrial sectors considered in table 4.1 (page 64), the potential U.K. sales increase to 5400 units (£65.4 million).

6) Preliminary market research for the MHRU revealed the possible requirement for a single flue heat recovery unit. This unit has since been developed in conjunction with a major industrial oven manufacturer, Baker Perkins. It is due to be marketed by them as an optional extra for their ovens in 1983.

7) The MHRU development, in addition to the design of a modular heat recovery unit, provided the sponsor with benefits in the following areas: development, marketing, advertising and office systems. These benefits alone, it has been estimated, should repay the cost of the MHRU's development within 2 years.

8.1.3 Development of an Exhaust Gas-to-Liquid Heat Exchanger

The exhaust gas-to-liquid heat exchanger, the externally generated product idea, was a market-pull product designed specifically for the needs of one client. Prototypes of the heat exchanger have been tested individually and an installation using 25 units, which it is estimated could save 2.35×10^5 litres of boiler fuel per annum, is at present (1982) proving their combined operational viability. The following conclusions can be made from the development of this unit:

1) A requirement of this development was the recovery of heat from the exhaust gases of diesel engines testing lubricants. This, to be achieved without affecting critical operating characteristics of the engine, and so not invalidating previously obtained engine test results.

2) Heat recovery equipment retrofitted often affects the original system's operating characteristics. The heat exchanger tested had no detectable effect on the engine from which it was recovering heat; this suggests the design may be particularly suitable for applications similar to the one tested where such an attribute may be advantageous, i.e. heat recovery from systems where there is a need not to invalidate performance results obtained prior to the application of heat recovery.

3) The static pressure drop through the heat exchanger was approximately 20 per cent of the static gauge pressure of the exhaust gases measured at the engine exhaust manifold. It is the allowable increase in pressure that can be tollerated whilst maintaining previous engine test criteria.

   This figure could be used as a preliminary criterion in the design of other heat exchangers for similar applications to the one tested i.e. where major changes in engine operating characteristics cannot be tolerated.

4) Increased back pressure on the exhaust of an engine can promote accelerated engine wear. The developed design presents minimal extra back pressure to the engine, so helping to limit the increase of engine wear. This makes it particularly suitable for the following applications; engines testing lubricants, engines operating long duration tests and engines operating under stringent test conditions.

5) Turbulators increased the heat transfer performance, as measured on the water side, by approximately 20 per cent over the design without them. This, however, increased pressure drop by approximately 35 per cent. Such an increase was not acceptable and the turbulators were subsequently removed.

6) Mild steel was used entirely for the construction of the heat exchanger. After 15 months use no trace of corrosion was found. Exhaust gases were above their due point for a majority of this period, and it is suggested that there is little advantage to be gained in attempting to extend the life of a heat exchanger through the use of more expensive stainless steels, certainly in applications with similar exhaust conditions to those tested.

7) The use of longitudinally finned extended surface tubing facilited cleaning of the heat exchanger.

8) The potential U.K. market for the heat exchanger in the recovery of heat from diesel test engines has been estimated at 570 units [146]. A further 960 [146] could be used in the testing of standard commercial diesel engines. This gives a total U.K. market of 1530 units or £1.3 million, based on a unit cost of £850. Again it is the sponsors decision to enter this market, if required.

9) The development of this heat exchanger has provided the sponsor with a commercially acceptable design and has increased the in-house design expertise. Although a majority of this development was funded by an external client, the sponsor's contribution was £2417. 12 heat exchangers were needed to completely off-set this investment - 24 have been sold to date.

8.1.4 Marketing of Heat Recovery Equipment

Several important points have emerged as a result of the MHRU's marketing campaign. Although below they are described in relation to heat recovery products, it is felt that they are applicable to new products in general:

1) In the marketing of new heat recovery products it should be ensured that customers understand what is being sold. The MHRU offers a new concept in the heat recovery field and an education process was required to teach the customer what this product was and did. This should be done before attempts are made to sell the product.
2) Before the education of potential customers is possible, they must be interested enough in a particular subject to want to be educated. It is proposed that this is an 'interest creation phase' and that it should precede the education process in the overall marketing strategy.
3) It is important to have simple advertising which does not presume prior knowledge on the part of the reader. What seems obvious to the designer of a product may be obscure and misinterpreted by the less aware customer.
4) The face-to-face approach was found most beneficial for marketing and selling the MHRU. To achieve greater success with this technique, however, the use of professional salespeople is likely to be of advantage.

5) To promote a new heat recovery product, particularly of such cost as the MHRU, an installation which potential customers can see for themselves was found to be virtually essential. This reassures the customer of the validity of the product and promotes their move from persuasion (stage 2 in the innovation process) to decision (stage 3).

6) Editorial copy is an important source of promotion. It has been found that editorial may provoke a greater response from potential customers than equivalent advertisements. Two reasons are put forward for this:

   - editorial is seen as unbiased information ostensibly from an editor and not as over-optimistic claims from a manufacturer;
   - new products are invariably described in more detail in editorial than in advertisements. This extra description may help in educating a customer about a product, a product that may have been ignored in an advertisement that did not make its use immediately obvious.

7) The editorial response analysis showed that two journals in particular provoked the best total response and the best response of the required type, from the editorial copy - Heating & Air Conditioning Journal and Works Management. These journals may be considered the most beneficial in which to place editorial or advertisements for future marketing campaigns.

8.1.5 Assessment of Energy Savings

In assessing energy savings it was found that the existing degree day method of calculation made no allowance for buildings heated on a non-continuous basis. Degree day correction factors have been derived (table 6.4, page 113) which, when multiplied by the quoted number of degree days, allow for the heating of buildings for selected periods i.e. between 9am and 5pm only.

8.1.6 Areas for Further Work

In the course of the described work both general and specific areas have been found that are worthy of further attention. These are listed below:

1) 62 per cent of heat recovery systems proposed were of the gas-to-gas type and their average payback period was 4 years. Further work in this sector is required to reduce this payback figure and enhance the probability of installing what is the most common type of heat recovery system demanded.

2) The British Standards examined for the design and manufacture of heat exchangers all considered designs more complicated than the heat exchanger developed in this project. There may be a requirement for a Code of Practice or Standard to produce heat exchangers for non-critical applications to merely "good engineering practice".

3) Enthalpy of a gas stream varies considerably with its moisture content. No apparatus was found that measured moisture content (or a second parameter which, when combined with a dry bulb temperature, would allow the calculation of moisture content) above a temperature of 413K. The development of a high temperature moisture content meter is, therefore, considered important. Such a device could make use of moisture sensitive crystals. By exposing such crystals to a given mass of 'wet' gas, the moisture they absorbed from the gas would change their colour. By quantifying this colour change, possibly with a photospectrometer, the gases moisture content could be derived.

4) Use of memory metals [179] as automatic dampers in heat recovery schemes; memory metals have the ability to achieve different pre-determined shapes at different predetermined temperatures.

This concept could be applied to produce an automatic exhaust gas dump damper. If gases were sufficiently hot to warrant their recovery, the memory metal's shape could be such that suitable dampers were opened to achieve this. Below a certain temperature the memory metal's shape would change and the gases dumped to atmosphere.

8.2 Summing Up

This thesis has described the development of two products from their conception to their commercialisation. The work has been undertaken in a joint industrial and academic venture through the auspices of the Interdisiplinary Higher Degrees Scheme, at the University of Aston in Birmingham. Details of this scheme are given in appendix 15 (page 248).

In the light of the two product developments, the less ambitious market-pull product has been more successful. This met the sponsor's resources most accurately by requiring a largely technical input. The product-push development, however, required a marketing input that was not available.

As a generalisation it may be prudent for other young companies in a similar position to the sponsor, and whose main vocation is also technical expertise, to pursue the development of market-pull products. This would give such companies a higher probability of success with developments and utilise their resources in those areas in which they are most proficient.

Appendices

APPENDIX 1

ENERGY RELATED PRODUCT AND COMPANY SURVEY

APPENDIX 1

ENERGY RELATED PRODUCT AND COMPANY SURVEY

A1.0 Product Survey

An extensive product survey was undertaken in the early stages of the project to ascertain the equipment available in the heat recovery field. The type of equipment surveyed is listed in section A1.1 (product survey index) and the manufacturers, agencies etc. that sell this equipment in section A1.2 (list of company names). The survey has continued throughout the project and whilst it may not be completely exhaustive, it does gives a representative selection of the heat recovery and associated equipment available, and where it is obtainable.

A1.1 Product Survey Index

This index (shown overleaf) lists the categories of equipment surveyed.

'Heat Exchangers' is a large section and different types are listed by design. The following indicates those designs that may be used for the given three fluid combinations:

Gas-to-Gas	Gas-to-Liquid	Liquid-to-Liquid
economisers	economisers	heat pipes
heat pipes	fluidised bed	plate type
heat wheels	heat pipes	recuperators
plate type	recuperators (spray)	run-around-coil
recuperators	run-around-coil	shell and tube
regenerators	shell and tube	
run-around-coil		
shell and tube		

A1.2 List of Company Names

Following the product survey index is a list of companies that sell equipment detailed in that index.

A1.3 Further Information

Since this compilation of products and companies, several professional registers of energy saving equipment have been published and these include:

- The British Gas Directory of Energy Saving Equipment [180];
- Energy Products and Services [181];
- The Energy-Saving Marketguide & Index Library [182];

Other publications that detail manufacturers of heat recovery equipment are given in references [43-57] and [183-186].

Product Survey Index

List of Company Names

AIR CURTAINS

Airstream Environmental,
Redcliffe, Bristol.

Aldridge Air Control,
Sutton Coldfield.

JB Auger (Midlands),
Bromgsgrove, Worcs.

BSS,
Leicester.

Bahco Ventilation,
Banbury, Oxon.

Beau Design Services,
Borehamwood, Herts.

FH Biddle,
Nuneaton, Warwicks.

Brake Shear
Barnet, Herts.

Claudgen,
Wembley, Middlesex.

Combat Eng.,
Bilston, West Midlands.

Constant Air Systems,
South Harrow, Middlesex.

Environco,
Windsor, Berks.

Eriks-Allied Polymer,
Manchester.

Gradwood,
Cheadle Heath, Stockport,

Harefield Rubber Co.,
Harefield, Uxbridge.

Isopad,
Borehamwood, Herts.

Kiloheat,
Sevenoaks, Kent.

Mather & Platt,
Manchester.

Myson Eng.,
Billericay, Essex.

Nationaire Eng.,
Washington.

Newman Ind. Sales,
Stonehouse.

PJ Air Curtains,
Hillingdon, Middlesex.

Premi-Aire,
Hereford.

Radiant Tube Systems,
London.

Ream & Co.,
Hornchurch, London.

Standard & Pochin,
Leicester.

Thermoscreen,
Eastleigh, Hants.

Wanson,
Borehamwood, Herts.

BOILERS

Fluidised Bed Combustion

Allied Boilers,
Oldham, Lancs.

Babcock Power,
Birmingnam.

Peter Brotherhood,
Peterborough.

Combustion Systems,
London.

Deborah Fluidised Combn.,
Peterlee, Co.Durham.

Dowson & Mason,
Manchester.

Energy Equipment Co.,
Leighton Buzzard, Beds.

Flameless Furnaces,
London.

E. Green & Son,
Wakefield.

ME Boilers,
Peterborough.

NEI Cochran,
Annan, Dumfrieshire.

NEI Int.Combustion,
Derby.

DJ Neil,
Macclesfield, Cheshire.

Parks of Netherton,
Devon.

Parkinson Cowan GWB,
Dudley, West Midlands.

Robey of Lincoln,
Lincoln.

Stone Boilers,
Crowley, West Sussex.

Stone Platt Fluidfire,
Brierley Hill, West Midlands.

Technical Design Int.,
Harrogate, West Midlands.

Thompson Cochran (NEI),
Annan, Dumfrieshire.

Urquhart Eng. Co.,
Greenford, Middlesex.

Gibson Wells,
Calverley, Leeds.

West Pyro,
Stockport, Cheshire.

Worsley Combustion Int.,
St. Helens.

General (including electrode)

Air Pollution Eng.,
S.Wigston, Leicester.

Allen Ygnis,
Tipton, Birmingham.

Allied Boilers,
Oldham, Lancs.

B & E Boilers,
Bracknell, Berks.

Babcock Power,
Birmingham.

C Bancroft,
Halifax, W.Yorkshire.

Beeston Boilers,
Beeston, Nottingham.

Bernard Lyons,
Birmingnam.

Bradlee Boilers,
Stratford, London.

Clyde Blowers(soot blowers)
Clydebank

Combserve Combn. Services,
Halifax, W.Yorkshire.

Controlled Flame Boilers,
Hitchin, Herts.

Crown Heat & Vent.,
Leicester.

Davair Heating,
Poole, Dorset.

DVS Boilers,
Uxbridge, Middlesex.

Energy Equipment Co.,
Leighton Buzzard, Beds.

Frema (Combustions),
London.

BOILERS - General, cont'd.

Fuelogic,
Malton, Yorkshire.

GR Garbutt & Sons,
Redcar, Cleveland.

Gibson Wells,
Calverley, Leeds.

E Green & Sons,
Wakefield, W.Yorks.

Hamworthy Eng.,
Poole, Dorset.

Hoval Farrar,
Newark, Notts.

HVE Thermoduct,
Wharfdale, W.Yorks.

Kayanson,
Chesham, Bucks.

TA Kidd,
Erdington, Birmingham.

ME Boilers,
Peterborough.

M Macdonald,
Glasgow.

Mellor Bromley,
Leicester.

NEI Cochran,
Annan, Dumfrieshire.

NEI Int.Combn.
Derby.

DJ Neil,
Macclesfield, Cheshire.

Nilfisk (boiler cleaning),
Bury St.Edmunds.

Perkins Boilers,
Wharfdale, W.Yorks.

Potterton Int.,
Warwick.

Robey of Lincoln,
Lincoln.

Rotatools UK (boiler clng.),
Liverpool.

Spur Eng.,
London.

Stelrad Group,
Kingston-upon-Hull.

Strax Distribution,
London.

Stone Boilers (UK),
Crawley, West Sussex.

Stone Platt Fluidfire,
Brierley Hill, W.Midlands.

Strebel,
Farnborough, Hants.

TI Hartley & Sugden,
Halifax, W.Yorks.

Thompson Cochran (NEI),
Annan, Dumfrieshire.

Twin Industries Agencies,
Camberley, Surrey.

UBH,
London.

Wanson,
Borehamwood, Herts.

TW Ward
Mitcham, Surrey.

Fred Watkins,
Nr.Coleford, Glos.

Modular

Acoustics & Envirometrics,
Walton-on-Thames.

Hamworthy Eng.,
Poole, Dorset.

Macdonald & Sons (Modular
Glasgow. boiler house),

Potterton Int.,
Warwick.

Stelrad Group,
Kingston-upon-Hull

TI Hartley & Sugden,
Halifax, W.Yorks.

Waste Heat Boilers

Absolute Energy Systems,
W. Wittering, Sussex.

AGA,
Ronneby, Sweden.

Allied Boilers,
Oldham, Lancs,

American Schack Co.,
Pittsburgh, USA.

APV Spiro-Gills,
Pulborough, W.Sussex.

B & B Boilers,
Bracknell, Berks.

Babcock Power,
London.

Beltran,
Macclesfield, Cheshire.

Bering Eng.,
Wokingham, Berks.

Peter Brotherhood,
Peterborough.

Int. Boiler Works Co.,
E.Strandsburg, PA, USA.

Burke Thermal Eng.,
Alton, Hants.

CE Power Boiler Combn. Inc.,
Windsor, CT, USA.

Cleerburn,
Andover, Hants.

Combat Eng.,
Bilston, W.Midlands.

Contrapol,
Chichester, W.Sussex.

Curwen & Newbury,
Westbury, Wilts.

Energy Equipment Co.,
Leighton Buzzard, Beds.

Fabdec,
Ellesmere, Shropshire.

Fairbank Brearley,
Bingley, Yorks.

GR Garbutt,
Redcar, Cleveland.

Gibson Wells,
Calverley, Leeds.

M & W Grazebrook,
Dudley, W.Midlands.

E Green & Son,
Wakefield, W.Yorks.

Hamworthy Eng.,
Poole, Dorset.

Hoval Farrar,
Newark, Notts.

Robert Jenkins,
Rotherham, S.Yorks.

Kayanson,
Chesham, Bucks.

Waste Heat Boilers, con'd.

Lyon & Pye,
Doncaster, S.Yorks.

ME Boilers,
Peterborough.

Metallurgical Eng.,
London.

Murray Div.of the Trane Co.,
Burlington, IA, USA.

NEI Cochran,
Annan, Dumfrieshire.

NEI Int. Combn.,
Derby.

NEI Projects,
Newcastle-Upon-Tyne.

DJ Neil,
Macclesfield, Cheshire.

Riley Stoker Corpn.,
Worcester, MA, USA.

Robey of Lincoln,
Lincoln.

Rossfor,
Harrow, Middlesex.

Scanfield Boilers,
Nr.Asford, Kent.

Sim Co.,
Erie, PA, USA.

Stone Boilers,
Crawley, W.Sussex.

Stone Platt Fluidfire,
Brierley Hill, W.Midlands.

Wanson,
Borehamwood, Herts.

Wilkins & Wilkins,
Poole, Dorset.

Zurn Industries, Inc.,
Erie, PA, USA.

Waste Heat Boilers (with provsn. for supplementary fuel injection)

Contrapol,
Chichester, W.Sussex.

Gibson Wells,
Calverley, Leeds.

M & W Grazebrook,
Dudley, W.Midlands.

E Green & Son,
Wakefield, W.Yorkshire.

NEI Projects,
Newcastle Upon Tyne.

Stone Platt Crawley,
Crawley, W.Sussex.

BURNERS

Dual Fuel & Multi Fuel Burners

Babcock Power,
London.

Bering Eng.,
Wokingham, Berks.

Clyde Combustions,
Chessington, Surrey,

Contrapol,
Chichester, W.Sussex.

Crown Heat & Vent.,
Leicester.

Davair Heating,
Poole, Dorset.

Dunlop,
Rugby, Warwicks.

Dunphy Oil & Gas Burners,
Rochdale, Lancs.

Energy Equipment Co.,
Leighton Buzzard, Beds.

David Etchells,
Wednesbury, W.Midlands.

GP Burners,
Swindon, Wilts.

GR Garbutt & Sons,
Redcar, Cleveland.

Hamworthy Eng.,
Poole, Dorset.

Hotwork International,
Dewsbury.

Ind Combn. Systems,
Sutton Coldfield, W.Midlands.

Laidlaw Drew,
Edinburgh.

NEI Cochran,
Annan, Dumfrieshire.

NEI Int. Combn.,
Derby.

Nu-Way,
Droitwich, Worcs.

Nu-Way Heating Plant,
Droitwich, Worcs.

Oetiker (UK)
Horsham, Sussex.

Parkinson Cowan GWB,
Dudley, W.Midlands.

Peabody Holmes,
Maidstone, Kent.

Perkins Boilers,
Derby.

Prowmatic,
Ilminster, Somerset.

Radiant Superjet,
Woodgate, Birmingham.

Rossfor,
Harrow, Middlesex.

H Saacke,
Portsmouth, Hants.

Stordy Combustion Eng.,
Wombourne, Wolverhampton.

Teknigas,
East Grinstead, W.Sussex.

Urquhart Eng.,
Greenford, Middlesex.

Weishaupt (UK),
Willenhall, Staffs.

General (Burners)

Aerogen Co.,
Alton, Hants.

Aeromatic Industrial,
Slough, Berks.

Babcock Product Eng.,
Crawley, Sussex.

Bering Eng.,
Crawley, Sussex.

British Gas & Oil Burners,
Burrell Way, Thetford.

Clyde Combustion,
Chessington, Surrey.

Cooperheat,
Southport, Merseyside.

Davair,
Poole, Dorset.

Dunphy Oil & Gas Burners,
Rochdale, Lancs.

Eurograde,
West Drayton, Birmingham.

Fuel Economy Systems,
Sparkhill, Birmingham.

Hamworthy Eng.Combm.
Poole, Dorset.

Hotwork Development,
Dewsbury, W.Yorks.

Hygrotherm Eng.,
Manchester.

Ind.Automated Systems
(Igniters Division),
Lichfield, Staffs.

General (Burners) cont'd.

John Thurley,
Harrogate, N.Yorks.

Laidlaw Drew Co.,
Edinburgh.

William May,
Ashton-under-Lyne.

Myson Marketing Services,
Ongar, Essex.

Nu-Way Eclipse,
Droitwich, Worcs.

Peabody Holmes,
Maidstone, Kent.

Priest Furnaces,
Middlesborough.

H Saacke,
Portsmouth, Hants.

Scanfield Boilers,
Nr. Ashford, Kent.

Speedaire Supply,
Nottingham.

Stordy Combustion Eng.,
Wombourne, Wolverhampton.

Submerged Combustion,
Shropshire.

TC Williams Burners,
Honley, Huddersfield.

Teknigas,
East Grinstead, W.Sussex.

Wellman Selas,
Manchester.

Infra-Red Burners

Cooperheat,
Southport, Lancs.

Stewart Gill & Co.,
Slough, Berks.

Radiant Tube Burners

Stein Atkinson Stordy,
Wolverhampton.

Stordy Combustion Eng.,
Wolverhampton.

Recuperative Burners

Consultant Gas Engineers,
Skelmersdale, Lancs.

Donald Shelley,
Stone, Staffs.

Laidlaw Drew, Co.,
Edinburgh.

Hotwork Developments,
Dewsbury, W.Yorkshire.

Nu-Way Eclipse,
Droitwich, Worcs.

Priest Furnaces,
Middlesborough.

Stordy Combustion Eng.,
Wolverhampton.

Wellman Selas,
Manchester.

Tank Heaters

Dunlop Energy Eng.Div.,
Rugby, Warwicks.

Stordy Combustion Eng.,
Wolverhampton.

Thermo Engineers,
Aylesbury, Bucks.

Wellman Selas,
Manchester.

COMBINED HEAT & POWER SYSTEMS (C.H.P.)

Applied Energy Systems,
Watford, Herts.

Peter Brotherhood,
Peterborough.

Centrax Gas Turbine Div.,
Newton Abbot, Devon.

Petbow,
Sandwich, Kent.

Rossfor Associates,
Harrow, Middlesex.

Ruston Gas Turbines,
Lincoln.

CONTROLS

Combustion Controls

Absolute Energy Systems,
West Wittering, Sussex.

Aerogen Co.,
Alton, Hants.

Alexander Controls,
Sutton Coldfield, W.Midlands.

Analysis Automation,
Eynsham, Oxford.

Auriema (Analytical and Environmental Instruments),
Slough, Berks.

Babcock Product Eng.,
Crawley, Sussex.

C Bancroft,
Halifax, W.Yorks.

Bell & Howell,
Basingstoke, Hants.

Bering Eng.,
Wokingham, Berks.

C E Invako Div.Comb.Eng.Inc.,
Tuls, OK, USA.

Coen Controls Co. Inc.,
Burlingame, USA.

Crown Heat & Vent.,
Leicester.

Drayton Kiln Co.,
Stoke-on-Trent.

Dunlop,
Rugby, Warwicks.

E Midlands Instrument Co.,
Morton, Gainsborough.

Econics UK,
Henley-on-Thames, Oxon.

Energy Equipment,
Leighton Buzzard, Beds.

Energy Tech. & Control,
Worthing, Sussex.

Fisher Controls,
Cowdenbeath, Fife.

Foxboro Yoxall,
Redhill, Surrey.

GR Garbutt & Sons,
Redcar, Cleveland.

Gulton Europe,
Brighton, Sussex.

Hamworthy Eng.,
Poole, Dorset.

Hoccon Developments,
Bridgnorth, Salop.

Honeywell Control Systems,
Bracknell, Berks.

Hotwork International,
Dewsbury.

Combustion Controls, cont'd.

Jeavons Engineering Co.,
Tipton, W. Midlands.

JEL Energy Conservation,
Stockport, Cheshire.

Johnson Control Systems,
Swindon, Wilts.

Kane-May,
Welwyn Garden City, Herts.

Kent Ind. Measurements,
Cambridge.

Laidlaw Drew,
Edinburgh.

Land Combustion,
Chesterfield.

Landis & Gyr,
North Acton, London.

Leeds & Northrup,
Birmingham.

Liberty Combustion Corpn.,
Syracuse, NY, USA.

March-May,
Huntingdon, Cambs.

Measurex Corporation,
Datchet, Slough.

Mechatherm,
Brierley Hill, W. Midlands.

NEI Cochran,
Annan, Dumfrieshire.

NEI Int. Combn.
Derby.

Neotronics,
Bishops Stortford, Herts.

Nu-Way Eclipse,
Droitwich, Worcs.

Nu-Way Heating Plants,
Droitwich, Worcs.

Pactrol Controls,
Skelmersdale, Lancs.

Peabody Holmes,
Maidstone, Kent.

Penn Controls,
Oak Brook, IL, USA.

Protection Controls Inc.,
Skokie, IL, USA.

Pye Unicam,
Cambridge.

Redland Automation,
Winchester, Hants.

Rosemount Engineering,
Bognor Regis, W. Sussex.

H Saacke,
Portsmouth, Hants.

Satchwell Sunvic,
Motherwell.

Sensors & Systems,
Melbourne, Derby.

Shandon Southern Inst.,
Camberley, Surrey.

Shawcity,
Farrington, Oxon.

Skil Controls,
Skelmersdale, Lancs.

Staveley Electronic,
Grosvenor St., Man'ter

Stordy Combustion Eng.,
Wolverhampton.

Taylor Instr. (Analytics Div),
Crowboro', Sussex.

Teddington Appliance Contls,
St. Austell, Cornwall.

Telegan,
Kenley, Surrey.

Western Automation,
Cardiff.

Westinghouse Electric,
Hitchin, Herts.

Westinghouse Elc. Corpn. Ind.
Systems Division,
Buffalo, NY, USA.

Ferranti Instrumentation,
Moston, Manchester.

Fuelsave,
Luton, Beds.

Gervase Instruments,
Cranleigh, Surrey.

Honeywell Control Systems,
Bracknell, Berks.

ISS Clorius,
Keynsham, Bristol.

Negretti Automation,
Aylesbury, Bucks.

Negretti & Zambra,
Aylesbury, Bucks.

Ranco Controls,
Southway, Plymouth.

Sangamo,
Port Glasgow, Renfrewshire.

Satchwell Control Systems,
Motherwell.

Simplex GE,
Stoke-on-Trent,

Spectrum Tech. Services,
Devizes, Wilts.

Systemation,
Shoreham-by-Sea, Suseex.

West Instruments,
Brighton.

Western Automation,
Cardiff.

Westinghouse Electric
Hitchin, Herts.

General

Arbon Instruments,
Gloustershire.

Bell & Howell,
Basingstoke, Hants.

TA Controls,
Harpenden, Herts.

Danfoss,
Greenford, Middlesex.

Delta Controls,
Haverhill, Suffolk.

Electrautom,
Maidstone, Kent.

ESC Energy Consv. Syms.,
Feltham, Middlesex.

Maximum Demand Controllers

Absolute Energy Systems,
West Wittering, Sussex.

BICC Bryce Capacitors,
Helsby, Cheshire.

Brit. Brown Boveri,
London.

Calex Instrumentation,
Leighton Buzzard, Beds.

C & C Div. Philips Bus. Systems,
Cambridge.

Chalmor,
Luton, Beds.

Channel Electronics,
Seaford, Sussex.

Maximum Demand Controllers, cont'd.

Crompton Parkinson,
Northampton.

Daita,
Northwich, Cheshire.

Demand Limited Control,
Rosemount, PA, USA.

Drayton Controls (Eng),
West Drayton, Middlx.

Energy Mangment. Group,
Rockford, IL, USA.

E S W,
Balmoral Tce., Aberdeen.

Ferranti Instrumentation,
Manchester.

Fuelsave,
Luton.

GR Garbutt & Sons,
Redcar, Cleveland.

Hanley Wilson Distrs.
Leeds.

Honeywell Control Sysms.
Bracknell, Berks.

Horstmann Eng.,
Bath, Avon.

JEL Energy Conservation,
Stockport, Cheshire.

Johnson Control Systems,
Swindon, Wilts.

Johnson & Phillips,
Haverhill, Suffolk.

Landis & Gyr,
North Acton, London.

Leeds & Northrup,
Birmingham.

Micro Eng.Mgmt.Systems,
Luton, Beds.

Morgan Smith Electronics,
Hatfield, Herts.

NEI Int. Combn.,
Derby.

Northern Design,
Bradford.

Pacific Technology, Inc.,
Renton, WA, USA.

Pactrol Controls,
Skelmersdale, Lancs.

Power Unit Electronics,
San Diego, CA, USA.

Pye Unicam,
Cambridge.

Rapaway,
Shirley, Solihull.

Rayleigh Instruments,
Rayleight, Essex.

Rectiphase Capacitors,
Bootle, Merseyside.

Robertshaw,
Richmond, VA, USA.

Sangamo Electric Co.,
Springfield, IL, USA.

Sauter Automation,
Slough, Bucks.

Sension,
Northwich, Cheshire.

Sensors & Systems,
Melbourne, Derby.

Skil Controls,
Skelmersdale, Lancs.

Square 'D' Co.,
Park Ridge, IL, USA.,

Systemation,
Shoreham-by-Sea, Sussex.

Transmitton,
Ashby-de-la-Zouche, Leics.

Turnright Controls,
Portsmouth.

United Automation,
Southport, Merseyside.

Western Automation,
Cardiff.

Woods,
Colchester, Essex.

Optimum Start Controllers

Absolute Energy Systems,
West Wittering, Sussex.

AMF Int.,
Eynsham, Oxford.

Andrews Weatherfoil,
Slough.

Ashton Alarms,
Hyde, Cheshire.

FH Biddle,
Nuneaton, Warwicks.

Brit. Brown Boveri,
London.

Chalmor,
Luton, Beds.

Colt Int.,
Havant, Hants.

Combserve Combn. Services,
Halifax, W. Yorkshire.

Comendec.,
Tamworth, Staffs.

Crown Heat & Ventilating,
Leicester.

Daita,
Northwich, Cheshire.

Drayton Controls (Eng),
West Drayton, Middlesex.

Dunlop,
Rugby, Warwicks.

E S W,
Balmoral Tce., Aberdeen.

Eurotherm,
Worthing, W. Sussex

Fecon,
Morden, Surrey.

Freeman Enercon.,
Cambridge.

Fuelsave,
Luton, Beds.

Honeywell Control Systems,
Bracknell, Berks.

Horstmann Eng.,
Bath, Avon.

Ind.Combn. Systems,
Sutton Coldfield, W. Midlands.

JEL Energy Conservation,
Stockport, Cheshire.

Johnson Controls,
Swindon, Wilts.

Landis & Gyr,
North Acton, London.

March-May,
Huntingdon, Cambs.

Measurex,
Maidstone, Kent.

Mellor Bromley,
Leicester.

Micro Eng. Management Systems,
Luton, Beds.

NEI Int. Combn.,
Derby.

Pactrol Controls,
Skelmersdale, Lancs.

PP Controls,
Hounslow, Middlesex.

Optimum Start Controllers cont'd

Rapaway,
Shirley, Solihull.

Rayleigh Instruments,
Rayleigh, Essex.

Satchwell Sunvic,
Motherwell.

Sauter Automation,
Slough, Berks.

Sensor & Systems,
Melbourne, Derby.

Simplex,
Stoke-on-Trent, Staffs.

Solar Technic.,
Wimbourne, Dorset.

Sopac Regulation (UK),
Farnborough, Hants.

Spectrum Tech. Services,
Devizes, Wilts.

Staefa (UK),
Staines, Middlesex.

Systemation,
Shoreham-by-Sea, Sussex.

TA Controls,
Harpenden, Herts.

Teddington Appl.Controls,
St. Austell, Cornwall.

Transmitton,
Ashby-de-la-Zouche, Leics.

United Automation,
Southport, Lancs.

Western Automation,
Cardiff.

DAMPERS (FLUE GAS TIGHT)

Actair Int.,
Cardiff.

Aerocowl Marketing,
Belfast, N.Ireland.

Air Pollution Eng.,
South Wigston, Leics.

Burgess Metroflex,
Bracknell, Berks.

Encomech Eng.,
Epsom, Surrey.

Energy Equipment Co.,
Leighton Buzzard, Beds.

Heat Lock Dampers,
Rickmansworth, Herts.

Hotwork International,
Dewsbury.

HVE Thermoduct,
Wharfdale, W.Yorkshire.

Mechatherm,
Brierley Hill, W.Midlands.

NEI Int. Combn.,
Derby.

Spectrum Tech. Services,
Devizes, Wilts.

Zest Equipment,
Sidcup, Kent.

ELECTROSTATIC FILTERS

AAF,
Birmingham.

Actair,
Cardiff.

Airstream Envmntl.Pdcts.,
Radcliffe, Bristol.

Aldridge Air Control,
Walsall, W.Midlands.

Andrews Ind.Equipment,
Wolverhampton.

Beltran,
Macclesfield, Cheshire.

Carlyle Air Conditioning,
London.

Combat Eng.,
Bilston, W.Midlands.

Crown Heat & Vent.,
Leicester.

Dalesman Scientific,
Pendlebury, Manchester.

DES,
Biggin Hill, Kent.

Environco,
Windsor, Berks.

Fecon,
Morden, Surrey.

Filtermist Co.,
Bridgenorth, Salop.

Flakt, Envmntl. Div.,
Staines, Surrey.

PJ Holloway,
London.

Horizon Mechanical Services,
Avonmouth, Bristol.

Lennox,
Basingstoke, Hants.

Mechanical Services Int.,
Avonmouth, Bristol.

Mellor Bromley,
Leicester.

Myson Marketing Services,
Ongar, Essex.

Pillinger-Air,
Croydon, Surrey.

John Plymoth,
Banbury, Oxon.

Steetley Eng.,
Brierley Hill, W.Midlands.

Stonair Filtration,
Burslem, Stoke-on-Trent.

Trion,
Andover, Hants.

United Air Specialists,
Leamington Spa, Warwicks.

Walker Air Conditioning,
Paisley, Glasgow.

Woods,
Colchester, Essex.

ENERGY MANAGEMENT SYSTEMS

Absolute Energy Systems,
West Wittering, Sussex.

Adbac,
Marlborough, Wilts.

Alpha Instrumentation,
Seaford, E.Sussex.

AMF Int.,
Bristol.

Ancom,
Cheltenham, Glos.

Applied Energy Systems,
Watford, Herts.

ASEA,
London.

Auriema,
Slough, Berks.

Base Ten Systems,
Farnborough, Hants.

BIS Margaux,
London.

ENERGY MANAGEMENT SYSTEMS (cont'd)

Brit. Brown Boveri,
London.

Broyce Marvid,
Wolverhampton.

Calex Instrumentation,
Leighton Buzzard, Beds.

Chalmor,
Luton, Beds.

Colt Int.,
Havant, Hants.

Combserve Combn.Service,
Halifax, W.Yorkshire.

Comendec,
Tamworth, Staffs.

C & C Phillips Bus.Systems,
Cambridge.

Control & Readout,
Worthing, W.Sussex.

Daita,
Northwich, Cheshire.

Drayton Kiln Co.,
Stoke-on-Trent, Staffs.

Dunlop,
Rugby, Warwicks.

E. Midlands Instrument,
Morton, Gainsborough.

Econics UK,
Henley-on-Thames, Oxon.

Energy Controls & Instrmnts.,
London.

Energy Equipment Co.,
Leighton Buzzard, Beds.

Energy Mangmnt.Systems,
Cambridge.

Environco,
Windsor, Berks.

Eurotherm,
Worthing, W. Sussex.

Ferranti Instrumentation,
Manchester.

Fisher Controls,
Cowdenbeath, Fife.

Foxboro Yoxall,
Redhill, Surrey.

Freeman Enercon,
Cambridge.

Fuelsave,
Luton, Beds.

Gervase Instruments,
Cranleigh, Surrey.

Gradwood,
Cheadle Heath, Stockport.

Holec,
Horsham, W.Sussex.

Home Automation,
Hoddesdon, Herts.

Honeywell Controls Systems,
Bracknell, Berks.

Ind. Combn. Systems,
Sutton Coldfield.

ISS Bldg. Mgmt. Systems,
Reading, Berks.

ITT Controls,
Glasgow.

JEL Energy Consvn.,
Stockport, Cheshire.

Johnson Control Systems,
Swindon, Wilts.

Laidlaw Drew,
Edinburgh.

Landis & Gyr,
North Acton, London.

Measurex,
Maidstone, Kent.

MEM,
Birmingham.

ML Enginerring,
Plymouth, Devon.

Micro Energy Mgmnt.Syms,
Luton, Beds.

Myson Mktg. Services,
Ongar, Essex.

NEI Int Combn.,
Derby.

Negretti Automation,
Aylesbury, Bucks.

Northern Design,
Bradford.

Oxford Automation,
Milton Keynes.

Pactrol Controls,
Skelmersdale, Lancs.

Pascall Engineering,
Crawley, W. Sussex.

Peabody Holmes
Maidstone, Kent.

Permex,
London.

Plasma Therm,
Penge.

Rapaway,
Shirley, Solihill.

Redland Automation,
Winchester, Hants.

Robert Electrics,
Cheltenham.

Salmon Electronics,
Croft, Darlington.

Sauter Automation,
Slough, Berks.

Savecar,
Cambridge.

Seaboard Energy Systems,
Petersfield, Hants.

Sension,
Northwich, Cheshire.

Sensors & Systems,
Melbourne, Derby.

Serck Controls,
Leamington Spa, Warwicks.

Simplex GE.,
Stoke-on-Trent, Staffs.

Skil Controls,
Skelmersdale, Lancs.

Spectrum Tech. Services,
Devizes, Wilts.

Staefa (UK),
Staines, Middlesex.

Stonefield Electronics,(Omicron),
Horsham, W.Sussex.

Systemation,
Shoreham-by-Sea, Sussex.

TA Controls,
Harpenden, Herts.

Taylor Instrument,
Crowborough, Sussex.

Telegan,
Croyden, Surrey.

Transmitton,
Ashby-de-la-Zouche, Leics.

Tronicair Int.,
Kilsyth, Glasgow.

Western Automation,
Cardiff.

Westinghouse Electric,
Hitchin, Herts.

H Williams,
West Wittering, Sussex.

FUEL ADDITIVES

Adfield-Harvey,
Wolverhampton.

Andex Chemical,
Leigh-on-Sea, Essex.

Arrow Chemicals
Swadlincote, B'ton-on-Tr'nt.

Chalbar,
Radlett, Herts.

Combustion Chemicals MHL,
Alton, Lancs.

DearbornChemicals,
Widnes, Lancs.

Feedwater Treatment Svcs,
Wallasey, Merseyside.

Industrial (Anti-Corrosion Services),
High St., Waltham Cross.

Nalfloc
Northwich, Cheshire.

T R Oil Services,
Cheadle Heath, Stockport.

Triple-E (UK),
Kearsley, Bolton.

United Lubricants,
Wembley.

Universal-Matthey Products,
Enfield, Middlesex.

FURNACES (THOSE INCORPORATING WASTE HEAT RECOVERY)

Boulton Ind Furnaces,
Stoke-on-Trent.

Morganite Thermal Designs,
Stourport-on-Severn, Worcs.

GAS ANALYSIS/GAS ANALYSERS

Analysis Automation,
Eynsham, Oxford.

Anglo Nordic Burner Pdcts.
Kingston-on-Thames, Surrey.

AEW Energy,
Andover, Hants.

Auriema (Anlycl & Envmtl Ind Div.)
Slough, Berks.

Drayton Kiln Co.,
Stoke-on-Trent, Staffs.

Econics (UK),
Henley-on-Thames, Oxon.

GKEP Anlytl Instmnts.
Cambridge.

Kent Ind Measurements,
Cambridge.

Laidlaw Drew & Co.,
Edinburgh.

Land Combustion,
Chesterfield.

Milton Roy,
Stone, Staffs.

Neotronics,
Bishop Storford, Herts.

H Saacke,
Farrlington, Hants.

Servomex,
Crowborough, Sussex.

Shawcity,
Faringdon, Oxfordshire.

Skil Controls,
Skelmersdale, Lancs.

Taylor Instrument
(Analytics Division)
Crowborough, Sussex.

Telegan,
Croydon, Surrey.

Westinghouse Electronics
and Control,
Stevenage, Herts.

HEAT EXCHANGERS

Corrosion Resistant Designs

Alfa-Laval Co.,
Brentford, Middlesex.

APV Co.,
Crawley, W. Sussex.

Beltran,
Macclesfield, Cheshire.

Climate Equipment,
Birmingham.

Corning Process Systems,
Stone, Staffs.

Dehl Co.,
Fermuf, Germany.

Deka, Bureau Technique
Jean Denis SA,
London.

Food & Beverage Dvlmnt(UK),
Lichfield, Staffs.

Plastic Constructions,
Sparkhill, Birmingham.

Serck Heat Transfer,
Energy Systems Division,
Birmingham.

United Air Spclsts. (UK),
Leamington Spa, Warwicks.

Wanson Co.,
Borehamwood, Herts.

Economisers

Absolute Energy Systems,
West Wittering, Sussex.

Acoustics & Environmetrics,
Walton-on-Thames.

Aeronca Inc.,
Torrance, Ca 90505, USA.

Airaqua Heat Recovery Systems,
Macclesfield, Cheshire.

APV Spiro-Gills,
Pulborough, E. Sussex.

Babcock,
Crawley, Sussex.

Bayliss Kenton Installations,
Blackburn.

Beltran,
Macclesfield, Cheshire.

Bering Engineering,
Wokingham, Berks.

Born Heaters,
Hove, Sussex.

Bradlee Boilers,
Stratford, London.

Bronswerk Heat Transfer, B.V.,
Nijkerk, Holland.

Burke Thermal Engineering,
Alton, Hants.

Corning Process Systems,
Stone, Staffs.

Curwen & Newbery,
Westbury, Wilts.

Deka,
London.

Gibson Wells Engineering,
Calverley, Leeds.

G.P. Burners,
Swindon, Wilts.

GR Garbutt & Sons,
Redcar, Cleveland.

E Green & Sons,
Wakefield, W. Yorkshire.

Hamworthy,
Poole, Dorset.

Heatsure Engineering,
Ashford, Kent.

Hoval Farrar,
Newark, Notts.

Economisers, cont'd.

Hunt Heat Exchangers,
Middleton, Manchester.

Hydrotherm Engineering,
Manchester.

Industrial Steam,
Oakland, CA 94623, USA.

R Jenkins Systems,
Rotherham.

M & W Grazebrook,
Dudley, W.Midlands.

M E Boilers,
Peterborough.

Metallurgical Engineers,
London.

Monometer Manfcting Co.,
Leigh-on-Sea, Essex.

NEI Projects,
Newcastle-on-Tyne.

Pinfin Inc.,
Mass 02154, USA.

Rheinstahl ECD GmbH,
Postfach 660, W.Germany.

Saacke Eurotherm,
Portsmouth, Hants.

Scanfield Boilers,
Ashford, Kent.

Senior Economisers,
Watford, Herts.

Senior Platecoil,
Watford, Herts.

Serck Heat Transfer,
Energy Systems Division,
Birmingham.

Spiral Tube (Heat Transfer)
Derby.

Spur Engineering,
London.

Stierle Hochdruch-Economiser kg.
Karl-Luwig Str 14,
West Germany.

Stone Boilers,
Crawley, W.Sussex.

Stone-Platt Fluidfire,
Brierley Hill, W.Midlands.

Stordy Combustion Eng.,
Wolverhampton.

Strax Distribution,
London.

Thermal Efficiency,
Watford, Herts.

Thermo Engineers,
Aylesbury, Bucks.

Twin Industries Agncs.
Camberley, Surrey.

Unit Superheater & Pipe Co.
Swansea.

H A Wainwright,
Godalming, Surrey.

Wanson Company,
Borehamwood, Herts.

Westwarm,
Hithergreen, Avon.

Willison Controls,
Bedford.

Fluidised Bed

E Green & Sons,
Wakefield, W.Yorkshire.

S P Fluidfire,
Brierley Hill, W.M'lds.

Stone-Platt Crawley,
Crawley, W.Sussex.

G P Worsley & Co.,
St.Helens, Merseyside.

Heat Pipes

AAF Co.,
Cramlington, Nthbland.

Aeronca Inc.,
Torrance, Ca 94062, USA.

Aeroplast,
Maixent L'Ecale, France.

APV Spiro-Gills,
Pulborough, W.Sussex.

F H Biddle,
Nuneaton, Warwicks.

Burke Thermal Eng.,
Alton, Hants.

Climate Equipment,
Shirley, Solihull

Commac (London),
Epsom Surrey.

Curwen & Newbury,
Westbury, Wilts.

DES,
Biggin Hill, Kent.

Environco,
Windsor, Berks.

Flakt,
Staines.

Heat Pipe Corporation,
Whippany, NJ 07981, USA.

Heat Rec Systems,
St.Albans, Herts.

Heatsure Enginerring,
Ashford, Kent.

International R & D Co.,
Newcastle-on-Tyne.

Isoterix,
Tonbridge, Kent.

A Johnson,
Aldwych, London.

Marubeni Corporation,
London.

Mellor Bromley Air Conditioning,
Leicester.

Filtration and Transfer,
Dawkins Rd., Poole.

Pyntech,
Waltham Abbey, Essex.

Rapaway,
Shirley, Solihull.

Redpoint Associates,
Swindon, Wilts.

Rossfor Associates,
Harrow, Middlesex.

Scurrah Hytech Products,
Ely, Cambs.

S & P Coil,
Leicester.

Solek,
Sevenoaks, Kent.

Walker Air Conditioning,
Paisley, Glasgow.

Wieland-Werke AG,
D 7900 Ulm, West Germany.

Wilkins & Wilkins,
Poole, Dorset.

Heat Wheels

AAF,
Cramlington, Northumberland.

Acoustics & Envirometrics,
Walton-on-Thames, Surrey.

Air Correction Dur, Univ.Oil Prod.
Darien, CT, USA.

Aldridge Air Control,
Walsall, W.Midlands.

Heat Wheels, cont'd.

American Schack Co. Inc.,
Pittsburgh PA 15237, USA.

Armca Specialties,
Ilford, Essex.

Babcock & Wilcox Inc.,
NY 10017, USA.

Bahco Ventilation,
Banbury, Oxon.

F H Biddle,
Nuneaton, Warwicks.

Cargoaire Eng Corpn.,
Amesbury, MA, USA.

Clipper Air Handling Units,
Amersham, Bucks.

Corning (UK) Ltd.,
London.

Curwen & Newbury,
Westbury, Wilts.

Denco Holdings,
Hereford.

Environco,
Windsor, Berks.

Flakt, Envrmntl.Div.,
Staines.

James H Heal & Co.
Halifax, W.Yorkshire.

James Howden,
Glasgow.

Heat Recovery Corpn.
Clifton, NJ, USA.

Heat Recovery Systems,
St. Albans, Herts.

Heatsure Eng,
Ashford, Kent.

Improvair,
Hayes, Middlesex.

Mechatherm,
Brierley Hill, W.Midlands.

Mellor Bromley,
Leicester.

S F Morgan (Filt-Air),
Felling, Tyne & Wear.

NEI Projects,
Newcastle-upon-Tyne.

Rapaway,
Shirley, Solihull.

Regenerative Heat Corpn.
Allendal, NJ, USA.

Uni-Tubes,
Slough, Berks.

Wing Corporation,
New Jersey, USA.

PM Walker (Halifax)
Sowerby Bridge, W.Yorks.

Woods of Colchester,
Tufnell Way,
Colchester.

Plate Heat Exchangers

AAF.,
Cramlington,Nthbland.

Absolute Energy Systems,
Macclesfield, Cheshire.

Acoustics & Envirometrics,
Walton-on-Thames Surrey.

AGA-CTC,
372 01 Ronneby, Sweden.

Alfa Laval,
Brentford, Middlesex.

APV Co.,
Crawley, W.Sussex.

Auchard Developments,
Southam, Leamington Spa.

Bahco Ventilation,
Banbury, Oxon.

Bayliss Kenton Instlns.
Blackburn.

Beltran,
Macclesfield, Cheshire.

Beverley Chem.Eng.,
Billingshurst, W.Sussex.

F H Biddle,
Nuneaton, Middlesex.

Carlyle Air Conditioning,
Knightsbridge, London.

Carrier-Ross,
Croyden, Surrey.

Climate Air Condning.
Shirley, Solihull.

Commac.
Epsom Surrey.

Conserve,
Yeovil, Somerset.

Corning,
Stone, Staffs.

Crown H & V Services,
Leicester.

Curwen & Newbury,
Westbury, Wilts.

Delta RA,
Haverhill, Suffolk.

Fabdec,
Ellesmere, Shropshire.

Flakt Environmental Div.,
Staines.

Food & Beverage Development (UK),
Lichfield, Staffs.

GEA Airexchangers,
London.

Hall-Thermotank,
Dartford, Kent.

J H Heal,
Halifax, W.Yorkshire.

Heat Rec Systems (London),
St.Albans, Herts.

H H Airpower Engineering,
Ashstead, Surrey.

Hotwork International
Earlsheaton,Dewsbury.

Hoval Farrar,
Newark, Notts.

ITT Reznor,
Folkestone, Kent.

R Jenkins,
Rotherham.

Kiloheat,
Sevenoaks, Kent.

Marine & Ind Heat,
Watford, Herts.

Mellor Bromley,
Leicester.

Mitsubishi Electric Service (UK),
Woolwich, London.

Moducel,
Stoke-on-Trent.

D J Neil,
Macclesfield, Cheshire.

Novenco,
Tyne & Wear.

Oakwood,
Macclesfield, Cheshire.

Owen Power Plant,
London.

Topcast Engineering,
Woking, Surrey.

Turbo Thermo Engineering,
Saltley, Birmingham.

United Air Specialists (UK),
Leamington Spa, Warwicks.

Recuperators - High Temperature Gas Heat Recovery

Acoustics & Envirometrics,
Walton-on-Thames.

Curwen & Newbury,
Westbury, Wilts.

Deka, Bureau Technique,
Jean Denis SA, London.

Donald Shelley,
Mount Ind. Estate, Stone.

E Greens & Sons,
Wakefield, W.Yorkshire.

Heat Transfer,
Cheltenham.

Serck Heat Transfer,
Birmingham.

Sismey & Linforth,
Birmingham.

Spur Engineering,
London.

Stein Atkinson Stordy,
Wolverhampton.

Teisen Furnaces,
Birmingham.

Thermal Efficiency,
Wattford, Herts.

Thermo Engineers,
Aylesbury, Bucks.

Recuperators - Spray Type

Spur Engineering,
London.

Regenerators - Static

James Howden & Co.,
Glasgow.

Mechatherm Eng.,
Brierley Hill, W.Midlands.

Run-Around-Coils

AAF,
Cramlington, Nthbland.

APV Spiro-Gills,
Pulboro' W.Sussex.

Bahco Ventilation,
Banbury.

F H Biddle,
Nuneaton, Warwicks.

Contrapol,
Chichester, Sussex.

Climate Equipment,
Solihull, W.Midlands.

Flakt,
Staines.

Gould Contardo,
Bishop Storford, Herts.

Myson Copperad,
Milton Keynes, Bucks.

Pyntech,
Waltham Abbey, Essex.

Searle Mfactng,
Fareham, Hants.

Serck Heat Transfer,
Energy Systems Div.
Birmingham.

SF Air Treatment,
Staines, Middlesex.

S & P Coil Products,
Leicester.

Trane,
Fleet, Hants.

Van Den Bergh & Ptns,
Windsor, Berks.

Shell & Tube Heat Exchangers

Alfa-Laval,
Brentford, Middlesex.

Bayliss Kenton Inslns.
Blackburn.

Bowman,
Birmingham.

Corning Process Sytms,
Stone, Staffs.

Covrad Heat Transfer,
Coventry.

Flakt,
Staines.

GEA Airexchangers,
London.

E Green & Sons,
Wakefield, W.Yorkshire.

Heat Transfer,
Cheltenham, Glos.

Marine & Industrial Heat,
Watford, Herts.

D J Neil,
Macclesfield, Cheshire.

Serck Heat Transfer,
Energy Systems Div.,
Birmingham.

Stordy Combustion Engineering,
Wolverhampton.

Thermo Engineers,
Aylesbury, Bucks.

United Air Specialists (UK),
Leamington Spa.

Unit Superheater & Pipe Co.
Swansea.

Wanson Co.
Borehamwood, Herts.

Special Heat Exchangers

ADBAC Co.
Marlborough, Wilts.

The APV Co.
Crawley, W.Sussex.

Turbulators

AEW Energy,
Andover, Hants.

Tubeguard Boilers,
Wirral, Merseyside.

HEAT PUMPS

AAF,
Cramlington, Northumberland.

Aerotechnica Air Condting Eqpment,
Shirley, Solihull.

AIM Air Conditioning,
London.

Aircon Regrigeration,
North Ormsby, Middlesborough.

Airaqua Heat Recovery Systems,
Macclesfield, Cheshire.

HEAT PUMPS, cont'd

Airwell Equipments,
London.

Andrews Ind. Equipment,
Wolverhampton.

Anex (UK),
Oakham, Leicester.

Appleco Europe,
Croyden, Surrey.

Applied Energy Systems,
Watford, Herts.

Applied Ind.Refrigeration,
Bristol.

Armstrong (Air Condtning),
Tyne & Wear.

Bahco Ventilation,
Enkoping, Sweden.

Bauknecht Gmbh,
Stuttgart 1,
7000 W.Germany.

Beekay Bauknecht,
London.

F H Biddle,
Nuneaton, Warwicks.

R Bosch Gmbh,
D7314 Werrnau,
Weat Germany.

Briton Air Condtning,
Staines, Middlesex.

Burgess,
Wokingham.

C A Burgin Bldg.Services,
Colchester, Essex.

Carlyle Air Condtning Co.
London.

Carrier A C (UK),
Warwick Row, London.

Churchill Instruments,
Greenford, Middlesex.

Climate Equipment,
Shirley, Solihull.

Conditionair (Scotland),
Edinburgh.

Creda Electric,
Stoke-on-Trent, Staffs.

Curwen & Newbury,
Westbury, Wilts.

Davair Heating,
Poole, Dorset.

Dawson & Gibbons
(Heat Pumps)
London.

Delchi (UK),
Maidenhead, Berks.

Denco Air,
Hereford.

Diamain,
Bingley, Yorkshire.

Ductwork Eng Systems,
Biggin Hill, Kent.

Dunham-Bush,
Farlington, Portsmouth.

Eastwood Heating Dvlmts,
Mansfield, Notts.

Electricity Board,
London.

Elemental Resource Genrtn,
Brinkworth, Wilts.

Elstree Air Condtning,
Borehamwood, Herts.

Environmental Supplies,
London.

Enviroquip,
Richmond, Surrey.

Eurotec Euipment,
Marlow, Bucks.

Frigidaire Div.
General Motors Corpn.
Dayton, OH, USA.

F & R Cooling,
Wellington, Somerset.

Gemini Cool,
Maidstone, Kent.

General Electric Co.
Louisville, KY. USA.

Girdwood Halton (Air Cdning),
Norwich.

G.Lloyd Associates,
Hitchin, Herts.

Hall Thermotank,
Dartford, Kent.

Heat Pump Products,
London.

HTI,
Dartford, Kent.

A Johnson,
London.

J Kenyon (Swansea),
Swansea.

Lennox Industries,
Basingstoke, Hants.

Marston Paxman,
Bridgehouse, Yorkshire.

McMillan Heat Pumps Inc.
Jacksonville, FL, USA.

MCP Electronics
Wembley, Middlesex.

Midlands Efficiency Services,
Stourbridge, W.Midlands.

N G Miller,
London.

M L Refrigeration & Air Cnding,
Slough, Bucks.

Monair Refrigeration Services,
Scotland.

Morris Warden,
Nitshill, Glasgow.

Myson Copperad,
Milton Keynes, Bucks.

NEI Projects,
Newcastle-upon-Tyne.

Norvent,
Newcastle-upon-Tyne.

Pathfinder (Environmental),
Havant, Hants.

Pillinger-Air,
Croyden, Surrey.

Prestcold,
Reading, Berks.

Qualitair (AC),
Sittingbourne, Kent.

Ranco (controls for heat pumps),
Plymouth.

Refrigeration & Air Condtning (NI),
Belfast.

Refrigeration & Elec.Maint.Suppl.
Hayes, Middlesex.

Rossfor Associates,
Harrow, Middlesex.

Rotary Electrical,
Sheffield.

Sarum Refrigeration Services,
Salisbury, Wilts.

Sealed Motor Construction,
Bridgewater, Somerset.

Servomatic,
London.

HEAT PUMPS, cont'd.

Siemens,
Congleton, Cheshire.

Sinclaire Air Condtning.
London.

S M Heating,
Kingston.

Southern Air Cndtioners,
London.

Spectrum Tech Services,
Deivizes, Wilts.

Stiebel Eltron
Northampton.

Sulzer Bros.
London.

T A Controls,
Harpenden, Herts.

Tech Climatisation,
01600 Trevoux, France.

Temperature Ltd.,
London.

Trace Heat Pumps,
Witham, Essex.

The Trane Co.
La Crosse,WI,USA.

D P Toomy,
Brighton, Sussex.

Universal Heat Pumps,
Bournemouth, Dorset.

Warrior Energy Appltions,
London.

Weathermaker,
Wembley, Middlesex.

Weltemp,
Kingston-on-Thames.

Westair Dynamics,
Molesey, Surrey.

Western Energy Systems,
Newton Abbot, Devon.

Westinghouse Electric, SA.
Windsor, Berks.

Westinghouse Electric Corpn.
Pennsylvania, USA.

W F Refrigeration,
London.

Willison Controls,
Bedford.

J Samuel White Air Cndns.
Cowes, Isle of Wight.

York Division
(Borg-Warner UK),
London.

York Division,
Pennsylvania, USA.

HEAT RECOVERY (from)
Compressed Air Systems

Hiross,
Rayleigh, Essex.

Effluent

Alfa Laval Co.
Brentford, Middlesex.

APV Co.
Crawley, W.Sussex.

Beltran,
Macclesfield,Cheshire.

BSS,
Leicester.

Heat Recovery Systems
(London)
St.Albans, Herts.

Marine & Ind. Heat,
Watford, Herts.

Serck Heat Transfer,
Energy Systems Div.
Birmingham.

Wanson Co.
Borehamwood, Herts.

The Product

James Howden & Co.
Glasgow.

Mechatherm Eng.
Brierley Hill, W.Midlands.

Newton Chambers Eng.
Sheffield.

Refrigeration

Andrews Engineering,
Chesterfield.

Borg Warner York Div.
London.

Conserve (Recycling),
Yeovil, Somerset.

Coolmation,
Ringwood, Hants.

Dunham-Bush,
Portsmouth.

Fabdec,
Shropshire.

Hubbard Commercial Products,
Perivale, Middlesex.

IMI Range,
Stalybridge, Cheshire.

Prescold,
Reading.

Willison Controls,
Bedford.

HEAT RECOVERY SYSTEMS

Applied Energy Systems,
Watford, Herts.

Associated Heat Services,
London.

Dravo Corpn.
Pittsburgh, USA.

Enercon Systems Inc.
Cleveland, Ohio, USA.

Energy Conservation Inc.
Cleveland, Ohio, USA.

GEA Airexchangers,
London.

GKN Birwelco,
Halesowen, W.Midlands.

Hall Thermotank International,
Dartford, Kent.

Heatsure Engineering,
Ashford, Kent.

Saphair,
Southam, Warwicks.

Stein Atkinson Stordy,
Wolverhampton.

WJT (Stratford),
Stratford-on-Avon.

INCINERATORS

Burners for Incinerator Purposes

Hygrotherm Engineering,
Manchester.

Luco Engineering Services,
Ascot, Berks.

Incinerators(those Incorporating Heat Recovery)

Gas Incinerators

As liquid and solid incinerators.

Liquid Incineration

Absolute Energy Systems
& Engineering Products,
West Wittering, Sussex.

Combat, Bilston,
West Midlands.

Davair,
Poole, Dorset.

Heat Transfer,
Cheltenham, Glos.

Hoval Farrar,
Newark, Notts.

RDM Ind Services,
Manchester.

John Thurley,
Harrogate.

Solid Incineration

Absolute Energy Systems
& Engineering Products,
West Wittering, Sussex.

Beverley Chemical Eng.
Billingshurst, W.Sussex.

Davair,
Poole, Dorset.

Farm 2000,
Studley, Warwicks.

The Incinerator Co.
Huntingdon, Cambs.

Lucas Furnaces,
Wednesbury, W.Midlands.

Robert Jenkins Systems,
Rotherham, S.Yorkshire.

Technical Design Int.
Harrogate, N.Yorkshire.

INSULATION

Accessible Products Co.
Tempe. AZ. USA.

Adhesive Specialities,
London.

Airlite Sectional Co.
London.

Armstrong Cork Co.
Uxbridge, Middlesex.

Atlas Products & Svcs.
Erith, Kent.

Badham Insulation Co.Inc.
Birmingham,AL, USA.

Baring Insulation,
St. Albans. Herts.

Baxenden Chemical Co.
Accrington, Lancs.

Belzona Molecular
Metalife,
Harrogate, Yorks.

Blue Circle Entprses.
Ind Minerals Division,
London.

BP Aquaseal,
Rochester, Kent.

Bradley Laminates,
Birmingham.

F Brown & Son,
Preston, Lancs.

Cape Incineration,
Stirling, Scotland.

Capricorn Ind. Services.
London.

Carborundum Co.
St.Helens, Merseyside.

CAS Urethanes,
North Humberside.

J R Coleman (Interwall),
Codnor, Derby.

Coolag,
Glossop. Derbyshire.

Dunlop Sentex,
Brynmawr, Gwent.

Euromatic (floating
ball blankets)
Brentford, Middlesex.

Evode,
Staffs.

Fibreglass,
St.Helens, Merseyside.

Foam Engineers,
High Wycombe, Bucks.

Freeman Insulation,
Cottenham.

Gulf Insulation,
Cheltenham.

Idenden Adhesives,
Aldershot, Hants.

Industrial Chem.Ind.
Billingham.

Injectawarm;
Aylesbury, Bucks.

E R Insulator,
Birmingham

Morganite Fibres,
Wirral, Merseyside.

Micropore Insultation,
Wirral, Merseyside.

Newalls Insulation Co.
Tyne & Wear.

North East Ins. (Newcastle),
Newcastle.

Rockwool,
Bridgend, Mid Glamorgan.

St.Regis Coatings & Laminating Div.
Stood, Rochester.

Saunders Development,
Cumbernauld, Glasgow.

Save-It Insulation,
Nuneaton.

Thermocomfort Ltd.
Newbury.

Thermobond,
Newcastle-upon-Tyne.

Whatlings Energy Conservation Svcs.
Glasgow.

MODULAR HEAT RECOVERY UNITS

Bahco Ventilation,
Banbury, Oxon.

Environmental Control,
Eynsford, Kent.

Lennox Industries,
Basingstoke, Hants.

Mechatherm Engineering,
Brierley Hill, W.Midlands.

S Newall,
Helensburgh, Dumbartonshire.

Novenco,
Tyne & Wear.

Saphair,
Southam, Warwicks.

Westwarm,
Clevedon, Avon.

W J T,
Stratford-upon-Avon.

ORGANIC RANKINE CYCLE SYSTEMS

A B Generator (UK),
Macclesfield, Cheshire.

OVENS (with Recirculation of Air)

AEW,
Andover, Hants.

POWER FACTOR CORRECTION

AEG-Telefunken (UK),
London.

ASEA,
London.

BICC Bryce Capacitors,
Helsby, Cheshire.

British Brown Boveri,
London.

Capacitors,
Bootle, Merseyside.

G Ellison,
Birmingham.

Gen Electric Co.
Schenectody, NY, USA.

Hawker Sidley Power Trnsfrms.
London.

A H Hunt (Capacitors),
Haverhill, Suffolk.

Johnson & Philips (Caps),
Haverhill, Suffolk.

Klockner-Moeller,
Aylesbury, Bucks.

Laurence Scott & Electromotors,
Chadwell Heath, Essex.

Rapaway,
Shirley, Solihull.

Rectiphase Capacitors,
Bootle, Merseyside.

Sprague Electric Co.
N.Adams, MA, USA.

Unity Power Systems,
Croyden, Surrey.

Westinghouse Elec. Corpn.
Pittsburgh, USA.

RADIANT HEATING

Ambi-Rad,
Warley, W.Midlands.

Beau Design Services,
Borehamwood, Herts.

F H Biddle,
Nuneaton, Warwicks.

British Furnaces,
Chesterfield, Derby.

Mellor Bromley,
Saffron Lane, Leicester.

BSS,
Leicester.

Colt Int.
Havant, Hants.

Combat Eng.
Bilston, W.Midlands.

Dunlop,
Rugby, Warwicks.

Econo-Rad,
Halesowen, W.Midlands.

Frenger Troughton,
Gerrards Cross, Bucks.

Gas-Fired Prod.
Ipswich, Suffolk.

S. Gill,
Slough, Berks.

Grayhill Wescott,
Poole, Dorset.

Hamworthy,
Poole, Dorset.

Joule Manufacturing,
Redditch, Worcs.

William May,
Ashton-under-Lyme.

Myson Mktg. Services,
Ongar, Essex.

Parkinson Cowan GWB,
West Dudley, W.Midlands.

Phoenix Burners,
London.

Powrmatic,
Ilminster, Somerset.

Radiant Tube Systems,
London.

Ritchie Bennie Products,
Yeovil, Somerset.

Schank,
London.

Steetley Eng.
Brierley Hill, W.Midlands.

J Tennant & Sons (Warrington),
Manchester.

Stein Atkinson Stordy,
Wolverhampton.

Wanson,
Borehamwood, Herts.

Wellman Selas,
Manchester.

SOLAR FILM (including insulation for other glass surfaces)

Banafix Solar Control,
Beaconsfield, Bucks.

Thomas Bennett,
Leeds.

Berkeley Invicta (London),
Nr.Tonbridge, Kent.

California Sunscreen Corpn.
San Leandro, CA, USA.

Camfine Thermsaver,
Burton-on-Trent.

Durable Solar Control,
Henley-on-Thames, Oxon.

Duratherm Insulation,
Henley-on-Thames, Oxon.

Heatseal Energy Conservation,
Hounslow, Middlesex.

Inco,
Birmingham.

Klingshield,
Plaidstow, London.

Koolshade Corpn.
Solana Beach, CA, USA.

3M UK,
Bracknell, Berks.

Northlite Insulation Services,
Wolverhampton.

Phoenix Rooflite Insulation Svs.
Couldsdon, Surrey.

Suncell,
Windsor, Berks.

Sunfoil,
Edenbridge, Kent.

Thermocell Ltd.,
York.

SOLVENT RECOVERY

Alfa Laval Co.
Brentford. Middlesex.

Chemical & Thermal Eng.
Wilmslow, Cheshire.

SOLVENT RECOVERY cont'd.

Crew Chemicals,
Sandbach, Cheshire.

Topcost Engineering,
Woking, Surrey.

STEAM

Boiler Blow-Down Recovery and Control and Flash

Auriema,
Slough, Berks.

Crane Pumps Division,
Stockport, Manchester.

Crown H & V Services,
Leicester.

Curwen & Newbury,
Westbury, Wilts.

Dearborn Chemicals,
Widnes, Cheshire.

Fisher Controls,
Cowdenbeath, Fife.

Gestra (UK),
Hitchin, Herts.

Girdlestone Pumps,
Woodbridge, Suffolk.

Honeywell Control Systems,
Bracknell, Berks.

IMI Rycroft (Calorifiers),
Bradford.

Johnson Control,
Leatherhead, Surrey.

NEI Int. Combn.
Derby.

Rosemount Engineering,
Bognor Regis, Sussex.

Thermotronic,
Hoylake, Merseyside.

Condensate Recovery

Bernard Lyons,
Birmingham.

Crane,
Stockport, Cheshire.

Gestra (UK),
Hitchin, Herts.

Girdlestone Pumps,
Woodbridge, Suffolk.

Jobson & Beckwith,
Bridge Rd., London.

Mather & Platt,
Manchester.

NEI Thompson Cochran,
Annan, Dumfrieshire.

Plant Energy Systems,
Warleys, W.Midlands.

Spirax Sarco,
Cheltenham, Glos.

Thermo Engineers,
Aylesbury, Bucks.

Steam Traps and Trap Failure Detectors

Bestobell Steam Products,
Livingston, W.Lothian.

British Steam Specialties,
Leicester.

BVMI,
Wolverhampton.

Dawe Instruments,
London.

Erics Allied Polymer,
Manchester.

Gestra,
Hitchin, Herts.

Plant Energy Surveys,
(steam trap failure detection)
Smethwick, W.Midlands.

Spirax-Sarco,
Cheltenham, Glos.

Yarway,
Salisbury, Wilts.

Thermographic Surveys

Aga Infra-red Systems,
Leighton Buzzard, Beds.

BL Thermographic Surveys,
Buckingham.

Clyde Surveys,
Maidenhead, Berks.

Hughes Aircraft Int. Service,
Weybridge, Surrey.

Lockwood Thermographic Surveys,
Shelley, Huddersfield.

A1.4 Other Sources of Information

There are many organisations, both Governmental and private, that are connected with energy and its efficient use. Some of these organisations are listed below. Other lists have been compliled [183, 187], though these emphasise research associations or government funded bodies.

Organisations Associated with Energy Conservation

Association for the Conservation of Energy, 39a Gloucester Place, London
British Combustion Equipment Manufacturers' Association, Market Place, Midhurst, W. Sussex
British Gas Technical Consultancy Service, 326 High Holborn, London
The National Council of Building Material Producers, 26 Store St., London WC1
Building Research Establishment, Bucknalls Lane, Garston, Watford, Herts.
Building Services Research and Information Association, Old Bracknell, Herts.
Chartered Institution of Building Services, 49 Cadogan Square, London
Construction Industry Research and Information Association, 6 Storeys Gate, London SW1
The Conservation Society, 12 London St., Chertsey, Surrey
Department of Energy, Thames House South, Millbank, London
Department of the Environment, 2 Marsham St., London
Department of Industry, 1 Victoria St., London
Electricity Council, 30 Millbank, London
Energy Quick Advice Service, 20 Kensington Palace Gardens, London
The Energy Research Group of the Open University, Walton Hall, Milton Keynes
The Energy Round Table of the Science Research Councils, Chilton, Didcot, Oxfordshire
Energy Users Research Association, address not available
Energy Technology Support Unit, Harwell, Oxfordshire
Heat Pump and Air Conditioning Bureau, 30 Millbank, London
The Association of British Manufacturers of Mineral Insulating Fibres, 7 Montague Mansion, London
The Institute of Energy, 18 Devonshire st., Portland Place, London
The International Energy Agency, 2 Rue Andre Pascall, 7555, Paris 16, France
International Solar Energy Society, 21 Albemarle St., London
Lighting Industry Federation, 25 Bedford Square, London
National Coal Board, Hobart House, Grosvenor Place, London
National Economic Development Office, 21 Millbank, London
National Industrial Fuel Efficiency Service Ltd., 14 Great Smith St., London
National Physical Laboratory, Teddington, Middx.
Organisation for Economic Co-operation and Development, 2 Rue Andre Pascall, 7555, Paris 16, France
Solid Fuel Advisory Service, Hobart House, Grosvenor Place, London
Regional Energy Conservation Offices, operated by Dept of Energy
Thermal Insulation Contractors' Association, 24 Orman Rd., Richmond, Surrey
Centre for Thermal Insulation Studies, Cranfield, Bedford
The Watt Committee on Energy, 1 Birdcage Walk, Westminster, London

APPENDIX 2

SITE SURVEY MEASURING INSTRUMENTS

APPENDIX 2

SITE SURVEY MEASURING INSTRUMENTS

A2.0 Site Measurements

The following instruments were used for taking measurements during site surveys.

For Measurement of Volume and Mass Flow Rate

Gases:

Vane anemometer by Air Flow Developments Ltd. (for use in temperatures up to 373K). Gas velocities from 0-25 m/s.

Pilot tube and inclined gauge manometer, type 4, by Air Flow Developments Ltd. (for use in temperature up to 900K). Pressures from 1-2500Pa.

Liquids and solids:

Information supplied by individual clients.

For Measurement of Temperature

Gases:

Mercury-in-glass whirling hygrometer by Casella for dry (and wet) bulb temperatures up to 373K.

Gases, liquids and Solids:

Thermocouple thermometer by Comark Electronics Ltd., for temperatures up to 1000K.

Thermocouple thermometer by Matronics Ltd., for temperatures up to 1700K.

Thermocouple thermometer by Leeds and Northrup Ltd. for temperatures up to 1300K.

For Measurement of Moisture Content

Gases:

These values were calculated for temperatures below 373K where dry and wet bulb temperatures were accurate. For temperatures above 373K mass balances were undertaken to calculate moisture content, or manufacturer's data consulted.

APPENDIX 3

STANDARD SITE SURVEY FORMS

APPENDIX 3

STANDARD SITE SURVEY FORMS

NAME OF COMPANY:

ADDRESS: TEL:

CONTACT: POSITION: EXT:

PRINCIPAL WASTE HEAT SOURCE (give brief description, duplicate and fill in separate sheets if more than one heat source)

TEMPERATURE OF WASTE OUTPUT

WASTE FLOW RATE:

MOISTURE CONTENT (if air)
(or added process moisture)

CONTAMINENTS:
i.e. dust, chemicals, solvents.

FUEL USED IN THIS PROCESS:

CURRENT COST OF FUEL USED (£/Unit)

PRINCIPLE OF HEAT INPUT TO PROCESS:
i.e. Direct, burner fired with
Indirect, burner fired with
M.P. H.W., burner fired with — Flow Temp. — Return Temp.
Steam, burner fired with — Gauge pressure
Electricity

CONSUMPTION OF FUEL USED ON THIS PROCESS:
(State litres/galls., ft^3/m^3, therms, etc). /Hour /Year

Operating Hours: /Day /Week /Year

WASTE HEAT UTILIZATION

Please state your own ideas for utilizing the waste energy at your plant.

a) IF TO BE USED FOR ANY PROCESS IN THE PLANT

Process medium: Temp. reqd. Flow:
Return:

Flow rate reqd:

Fuel currently used in this process: Usage:
Cost/Unit:

b) IF TO BE USED FOR SPACE HEATING/COOLING

Type of system.
Please give brief details of existing system, stating approximate duty of overall equipment.

Consumption of fuel used: /Hour /Year

Current cost of fuel (£/Unit)

Operating period:
Daily: Weekly: Yearly:

IMPORTANT:

Please duplicate form if there is more than one significant waste heat source or possible utilization.

FINANCIAL POLICIES

Payback period:

Maximum capital investment on heat recovery and utilization project:

Are you interested in the W.J.T. leasing scheme (brochure enclosed)?

FURTHER INFORMATION

If at all possible please enclose with your completed questionnaire a site plan marked with the key features of heat source and suggested or possible utilization.

Thank you for completing the form/s.

APPENDIX 4

A HEAT RECOVERY ANALYSIS OF 62 INDUSTRIAL SITES

APPENDIX 4

A HEAT RECOVERY ANALYSIS OF 62 INDUSTRIAL SITES

	HEAT SOURCES			PROPOSED SYSTEM				UTILISATION			PAYBACK FIGURES (YEARS) (I)									
											GAS / GAS			GAS / LIQUID			LIQUID / LIQUID			OTHER
Job No.	Gas	Liquid	Other	Gas/ Gas	Gas/ Liquid	Liquid/ liquid	Other	Space heating	Process heating	Space and Process heating	Space heating	Process heating	Space and Process heating	Space heating	Process heating	Space and Process heating	Space heating	Process heating	Space and Process heating	
1	•			•				•			N/A									
2	•			•				•			2,3									
3	•			•				•			4,4									
4	•			•				•			5,4									
5		•				•			•									2,9		
6	•	•			•1	•1		•						10;3			26,6			
7	•			•1	•1				•	•			7;3		5,3					
8	•			•				•			4,5									
9	•			•					•			4.0								
10	•			•						•			3,8							
11	•	•		•3	•3	•3			•			3.3			3.3			3.3		
12	•			•				•			1,8									
13		•				•			•									1,9		
14			•				(A)													16,7
15	•			•4				•			5,4									
16	•			•				•			N/A									
17	•			•				•			4,5									
18	•			•1	•1			•		•	6,2					3,7				
19	•			•				•			N/A									
20	•			•				•			8,7									
21	•			•					•			N/A								
22	•			•1	•1					•			N/A			N/A				
23	•			•1	•1			•	•		3,0				1,8					
24	•			•				•			N/A									
25			•				(B)			•										2,3
26	•						(C)	•												2,1
27	•			•				•			4,5									
28	•			•				•			N/A									
29	•			•					•			2,8								
30	•			•4				•			6,9									
31	•						(D)	•												2,8
32	•				•			•						6,9						
33	•			•1	•1			•		•	6,3					1,4				
34	•			•				•			N/A									
35	•			•					•			3,7								
36	•			•					•			1,9								
37	•				•1			•	•					4,2	3,1					
38	•				•					•						2,3				
39	•			•				•			N/A									
40		•				•		•									N/A			
41	•				•			•						1,8						
42	•			•				•			6,0									
43	•			•					•			4,7								
44	•			•2	•2				•			2,1			2,1					
45	•			•					•			2,8								
46	•			•4				•			2,5									
47	•			•					•			2,1								
48	•			•1	•1			•		•	6,8					4,1				
49	•			•						•			6,0							
50	•			•					•			2,0								
51	•				•				•						1,1					
52	•			•					•			1,9								
53	•			•1				•	•		10,8	3,5								
54	•				•				•						0,7					
55	•			•4				•			0,5									
56	•				•					•						1,1				
57	•			•				•			5,8									
58	•				•				•						3,0					
59	•				•				•						0,5					
60	•			•				•			1,5									
61	•			•					•			1,1								
62	•			•1	•1/5			•		•	2,5					3,4				
No.	64			73				69			73									
TOTAL	57	5	2	45	19	5	4	35	23	11	45			19			5			4
%	89	8	3	62	26 33	7	5	51	33	16	62			26			7			5
Average Payback Time (Years)											4.0			3.1			2.7 (II) 8.7 (III)			2.4(IV) 6.0(V)

Where alternative systems are proposed, the lowest figures have been used

(A) Insulation
(B) Burning wood waste
(C) Fans to reduce temperature gradient
(D) Reduction of stratification

(1) Two alternative systems proposed
(2) One system incorporating two types of heat recovery system
(3) One system incorporating three types of heat recovery system
(4) Gas / gas system using run around coil
(5) Gas / liquid system incorporating absorption cooling

(I) All payback figures calculated using simple payback without inflation (see section 6.2)
(II) Excluding survey 6
(III) Including survey 6
(IV) Excluding survey 14
(V) Including survey 14

N/A Not available

APPENDIX 5

QUALITY-QUANTITY SURVEY

APPENDIX 5
QUALITY-QUANTITY SURVEY

A5.0 Oven Exhaust Gas Analysis

This appendix details the quality-quantity survey for the food processing sector as described in section 3.1.1, constraint 3 (page 30). Of the industrial ovens measured, most had more than one flue and details of all flues were analysed using a computer.

A5.1 The Computer Program

Details of all flue gases from a particular oven (temperature, volume flow rate and moisture content) were input to the program. A typical output (figure A5.1) displays these details, together with others (mass flow and moisture flow) calculated inside the program. Details of each flue (lines A,B,C, figure A5.1) are then added together and the mean and total output from the entire oven calculated. The mean temperature is obtained using a weighting from the mass flow rate, the remaining values being arithmetic means or totals. The company number corresponds to the job number in appendix 4 (page 178), the repetition of which indicates the presence of more than one oven on a site.

OVEN ANALYSIS

EACH LINE REPRESENTS 1 FLUE

MEAN AND TOTAL REPRESENT INDIVIDUAL OVENS

ERRORS MAY OCCUR DUE TO ROUNDING

'*'.......ESTIMATED READING

'N/F'.....NO FLOW FROM FLUE.

COMPANY	TEMPERATURE		VOLUME FLOW RATE		MASS FLOW RATE (DRY)		MASS FLOW RATE (WET)		MOISTURE FLOW RATE		TOTAL MOISTURE CONTENT
	C	F	CU.M/S	ACFM	KG/S	LB/HR	KG/S	LB/HR	KG/S	LB/HR	KG/KG-LB/LB
LINE 'A'	100	212	1	2118	.95	7503	1.04	8254	.09	751	.1
LINE 'B'	200	392	2	4237	1.49	11839	1.79	14207	.3	2368	.2
LINE 'C'	300	572	3	6356	1.85	14662	2.41	19061	.56	4399	.3
MEAN	226	438.8	2	4237	1.43	11335	1.75	13841	.32	2506	.2
TOTAL	-	-	6	12711	4.29	34004	5.24	41522	.95	7518	-

Figure A5.1 Typical quality-quantity computer analysis

A5.2 Oven Analysis

During site surveys 83 ovens having 251 flues were analysed, the details of which are given below (oven analysis A). Each line of information represents **one flue**, the mean and total being for all flues on that **one oven**.

Oven analysis B (page 188) summarises this information with each line representing **one oven**, the mean being the average of **all ovens** surveyed, and the total being that of the **entire survey**.

From the oven analysis the mean oven exhaust gas temperature was found to be 438K (165^{o}C) and the mean oven exhaust gas volume flow rate to be 1m^3/s.

Oven Analysis A

OVEN ANALYSIS
**** ********

EACH LINE REPRESENTS 1 FLUE

MEAN AND TOTAL REPRESENT INDIVIDUAL OVENS

ERRORS MAY OCCUR DUE TO ROUNDING

'*'.......ESTIMATED READING

'N/F'.....NO FLOW FROM FLUE.

COMPANY	TEMPERATURE		VOLUME FLOW RATE		MASS FLOW RATE (DRY)		MASS FLOW RATE (WET)		MOISTURE FLOW RATE		TOTAL MOISTURE CONTENT	
	C	F	CU.M/S	ACFM	KG/S	LB/HR	KG/S	LB/HR	KG/S	LB/HR	KG/KG-LB/LB	
7												
	280	536	.18	384	.12	918	.14	1085	.02	167	.1822	
	90	194	.15	314	.14	1143	.17	1351	.03	208	.1822	
	240	464	.2	419	.14	1080	.16	1276	.02	196	.1822	
	160	320	.14	288	.11	879	.13	1039	.02	160	.1822	
MEAN	189	372.2	.17	351.25	.13	1005	.15	1188	.02	183	.18	
TOTAL	-	-	.67	1405	.51	4020	.6	4751	.09	731	-	
8												
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	90	194	.26	545	.25	1984	.26	2037	.01	53	.027	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	142	288	.21	450	.18	1432	.19	1471	.01	39	.027	
	90	194	.23	491	.23	1787	.23	1836	0	49	.027	
	172	342	.31	655	.25	1944	.25	1997	0	53	.027	
	154	309	.19	403	.16	1248	.16	1281	0	33	.027	
	178	352	.3	627	.23	1838	.24	1888	.01	50	.027	
	142	288	.26	551	.22	1754	.23	1801	.01	47	.027	
MEAN	137.3	279.2	.2	413.56	.17	1332	.17	1368	0	36	.02	
TOTAL	-	-	1.76	3722	1.52	11987	1.56	12311	.04	324	-	
8												
	138	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.027	
MEAN	137.8	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.03	
TOTAL	-	-	1.73	3675	1.49	11823	1.53	12142	.04	319	-	
8												
	138	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.027	
MEAN	137.8	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.03	
TOTAL	-	-	1.73	3675	1.49	11823	1.53	12142	.04	319	-	
8												
	138	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.027	
MEAN	137.8	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.03	
TOTAL	-	-	1.73	3675	1.49	11823	1.53	12142	.04	319	-	
8												
	138	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.027	
MEAN	137.8	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.03	
TOTAL	-	-	1.73	3675	1.49	11823	1.53	12142	.04	319	-	
8												
	138	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.027	
MEAN	137.8	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.03	
TOTAL	-	-	1.73	3675	1.49	11823	1.53	12142	.04	319	-	
8												
	138	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.027	
MEAN	137.8	280	1.73	3675	1.49	11823	1.53	12142	.04	319	.03	
TOTAL	-	-	1.73	3675	1.49	11823	1.53	12142	.04	319	-	
11												
	260	500	.47	986	.31	2445	.32	2567	.01	122	.05	*
	150	302	.58	1232	.49	3849	.51	4041	.02	192	.05	*
	280	536	.44	940	.28	2247	.3	2359	.02	112	.05	*
MEAN	215.7	420.2	.5	1052.67	.36	2847	.38	2989	.02	142	.05	
TOTAL	-	-	1.49	3158	1.08	8541	1.13	8967	.05	426	-	
11												
	260	500	.47	986	.31	2445	.32	2567	.01	122	.05	*
	150	302	.58	1232	.49	3849	.51	4041	.02	192	.05	*
MEAN	192.7	378.9	.53	1109	.4	3147	.42	3304	.02	157	.05	
TOTAL	-	-	1.05	2218	.8	6294	.83	6608	.03	314	-	
11												
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
MEAN	148.9	300	.3	645	.26	2020	.27	2121	.01	101	.05	
TOTAL	-	-	.3	645	.26	2020	.27	2121	.01	101	-	
11												
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
MEAN	148.9	300	.3	645	.26	2020	.27	2121	.01	101	.05	
TOTAL	-	-	.3	645	.26	2020	.27	2121	.01	101	-	
11												
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
MEAN	148.9	300	.3	645	.26	2020	.27	2121	.01	101	.05	
TOTAL	-	-	.3	645	.26	2020	.27	2121	.01	101	-	
11												
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*

MEAN	148.9	300	.3	645	.26	2020	.27	2121	.01	101	.05	
TOTAL	-	-	.3	645	.26	2020	.27	2121	.01	101	-	
12												
	390	734	.64	1356	.34	2704	.38	3001	.04	297	.11	
	150	302	.57	1215	.48	3796	.53	4213	.05	417	.11	
MEAN	249.8	481.7	.61	1285.5	.41	3250	.46	3607	.05	357	.11	
TOTAL	-	-	1.21	2571	.82	6500	.91	7214	.09	714	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
16												
	200	392	.83	1757	.62	4909	.68	5356	.06	447	.091	•
MEAN	200	392	.83	1757	.62	4909	.68	5356	.06	447	.09	
TOTAL	-	-	.83	1757	.62	4909	.68	5356	.06	447	-	
20												
	90	194	.28	583	.27	2122	.29	2334	.02	212	.1	•
	336	637	.21	454	.12	985	.14	1084	.02	99	.1	•
	240	464	.24	518	.17	1335	.19	1468	.02	133	.1	•
MEAN	189.7	373.4	.24	518.33	.19	1481	.21	1629	.02	148	.1	
TOTAL	-	-	.73	1555	.56	4442	.62	4886	.06	444	-	
20												
	130	266	.36	771	.32	2528	.35	2781	.03	253	.1	•
	100	212	.16	335	.15	1187	.16	1305	.01	118	.1	•
	140	284	.19	406	.16	1299	.18	1429	.02	130	.1	•
	82	180	.07	139	.07	517	.07	569	0	52	.1	•
MEAN	121.4	250.6	.2	412.75	.18	1383	.19	1521	.02	138	.1	
TOTAL	-	-	.78	1651	.7	5531	.76	6084	.06	553	-	
21												
	192	378	.36	770	.28	2187	.3	2406	.02	219	.1	
	168	334	.28	600	.23	1799	.25	1979	.02	180	.1	
MEAN	181.2	358.1	.32	685	.26	1993	.28	2193	.02	200	.1	
TOTAL	-	-	.64	1370	.51	3986	.55	4385	.04	399	-	
23												
	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08	•
MEAN	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08	
TOTAL	-	-	.76	1609	.63	5027	.69	5429	.06	402	-	

23												
	138	280	.6	1263	.51	4063	.55	4388	.04	325	.08	*
MEAN	137.8	280	.6	1263	.51	4063	.55	4388	.04	325	.08	
TOTAL	-	-	.6	1263	.51	4063	.55	4388	.04	325	-	
23												
	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08	*
MEAN	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08	
TOTAL	-	-	.76	1609	.63	5027	.69	5429	.06	402	-	
23												
	176	349	.63	1328	.49	3908	.53	4221	.04	313	.08	*
MEAN	176.1	349	.63	1328	.49	3908	.53	4221	.04	313	.08	
TOTAL	-	-	.63	1328	.49	3908	.53	4221	.04	313	-	
23												
	152	306	1.01	2135	.84	6635	.9	7166	.06	531	.08	*
MEAN	152.2	306	1.01	2135	.84	6635	.9	7166	.06	531	.08	
TOTAL	-	-	1.01	2135	.84	6635	.9	7166	.06	531	-	
28												
	260	500	.09	200	.06	496	.07	570	.01	74	.15	
MEAN	260	500	.09	200	.06	496	.07	570	.01	74	.15	
TOTAL	-	-	.09	200	.06	496	.07	570	.01	74	-	
28												
	260	500	.09	200	.06	496	.07	570	.01	74	.15	
MEAN	260	500	.09	200	.06	496	.07	570	.01	74	.15	
TOTAL	-	-	.09	200	.06	496	.07	570	.01	74	-	
28												
	260	500	.08	170	.05	422	.06	485	.01	63	.15	
MEAN	260	500	.08	170	.05	422	.06	485	.01	63	.15	
TOTAL	-	-	.08	170	.05	422	.06	485	.01	63	-	
29												
	29	84	.2	426	.24	1864	.24	1905	0	41	.022	
	299	570	.61	1291	.38	2984	.46	3652	.08	668	.224	
	180	356	.7	1479	.54	4315	.62	4932	.08	617	.143	
MEAN	193.9	381.1	.5	1065.33	.39	3054	.44	3496	.05	442	.13	
TOTAL	-	-	1.51	3196	1.16	9163	1.32	10489	.16	1326	-	
34												
	96	205	.09	182	.08	652	.09	723	.01	71	.11	
	51	124	.15	309	.16	1260	.16	1267	0	7	6E-03	
	190	374	.26	553	.2	1579	.23	1815	.03	236	.15	
	191	375	.2	425	.15	1212	.18	1393	.03	181	.15	
MEAN	143.2	289.8	.18	367.25	.15	1176	.17	1300	.02	124	.1	
TOTAL	-	-	.7	1469	.59	4703	.66	5198	.07	495	-	
34												
	199	390	.08	160	.06	448	.06	511	0	63	.14	
	215	419	.1	216	.07	585	.09	679	.02	94	.16	
	162	324	.07	157	.06	477	.06	479	0	2	4E-03	
	161	322	.06	133	.05	405	.05	407	0	2	5E-03	
	94	201	.07	140	.06	504	.06	507	0	3	5E-03	
MEAN	169.8	337.6	.08	161.2	.06	484	.06	517	0	33	.06	
TOTAL	-	-	.38	806	.3	2419	.32	2583	.02	164	-	
34												
	208	406	.27	579	.2	1592	.21	1687	.01	95	.06	
	239	462	.62	1304	.43	3367	.43	3387	0	20	6E-03	
	259	498	.43	919	.29	2284	.29	2302	0	18	8E-03	
	266	511	.45	948	.29	2324	.34	2673	.05	349	.15	
	321	610	.66	1391	.39	3095	.42	3342	.03	247	.08	
MEAN	264.4	507.9	.49	1028.2	.32	2532	.34	2678	.02	146	.06	
TOTAL	-	-	2.43	5141	1.6	12662	1.69	13391	.09	729	-	
34												
	99	210	.38	795	.36	2825	.38	3023	.02	198	.07	
	88	190	.52	1101	.51	4032	.53	4234	.02	202	.05	
	154	309	.7	1492	.58	4619	.69	5450	.11	831	.18	
	88	190	.53	1133	.52	4150	.54	4274	.02	124	.03	
MEAN	111	231.8	.53	1130.25	.49	3907	.54	4245	.04	339	.08	
TOTAL	-	-	2.13	4521	1.97	15626	2.14	16981	.17	1355	-	
34												
	127	261	.36	762	.32	2516	.33	2617	.01	101	.04	
	244	471	.73	1549	.5	3961	.64	5030	.14	1069	.27	
	222	432	.72	1518	.51	4051	.53	4213	.02	162	.04	
MEAN	210.4	410.8	.6	1276.33	.44	3509	.5	3953	.06	444	.12	
TOTAL	-	-	1.81	3829	1.33	10528	1.5	11860	.17	1332	-	
34												
	113	235	.53	1133	.49	3881	.49	3916	0	35	9E-03	
	163	325	.53	1116	.43	3384	.43	3418	0	34	.01	
	200	392	.54	1147	.4	3205	.41	3269	.01	64	.02	
	238	460	.55	1166	.38	3017	.39	3078	.01	61	.02	
	184	363	.11	230	.08	665	.09	685	.01	20	.03	
	147	296	.23	479	.19	1508	.2	1569	.01	61	.04	
	79	174	.15	322	.15	1209	.15	1213	0	4	3E-03	
MEAN	165.4	329.6	.38	799	.3	2410	.31	2450	.01	40	.02	
TOTAL	-	-	2.64	5593	2.12	16869	2.16	17148	.04	279	-	
34												
	202	396	.81	1708	.6	4750	.6	4783	0	33	7E-03	
	197	387	.1	210	.07	590	.08	655	.01	65	.11	
	231	448	.99	2089	.69	5477	.77	6080	.08	603	.11	
	162	324	.08	180	.07	547	.07	563	0	16	.03	

MEAN	214.6	418.3	.5	1046.75	.36	2841	.38	3020	.02	179	.06	
TOTAL	-	-	1.98	4187	1.43	11364	1.52	12081	.09	717	-	
34												
	156	313	.81	1708	.66	5260	.67	5276	.01	16	3E-03	
	156	312	.27	580	.23	1789	.23	1824	0	35	.02	
	187	369	.31	647	.23	1858	.29	2304	.06	446	.24	
	141	286	.39	820	.33	2617	.34	2721	.01	104	.04	
MEAN	158.6	317.4	.45	938.75	.36	2881	.38	3031	.02	150	.08	
TOTAL	-	-	1.78	3755	1.45	11524	1.53	12125	.08	601	-	
34												
	59	138	.14	295	.15	1174	.15	1184	0	10	8E-03	
	43	109	.17	362	.19	1515	.19	1530	0	15	.01	
	71	160	.05	116	.06	445	.06	454	0	9	.02	
	46	115	.2	416	.22	1722	.22	1740	0	18	.01	
	114	237	.13	285	.12	973	.14	1090	.02	117	.12	
	77	171	.08	168	.08	634	.08	666	0	32	.05	
	139	282	.15	311	.13	998	.14	1108	.01	110	.11	
	121	250	.11	232	.1	778	.11	840	.01	62	.08	
	90	194	.11	230	.11	837	.11	871	0	34	.04	
	85	185	.14	289	.13	1067	.14	1131	.01	64	.06	
	77	171	.09	183	.09	690	.09	718	0	28	.04	
	82	180	.08	169	.08	629	.08	641	0	12	.02	
	83	181	.07	157	.07	583	.07	587	0	4	7E-03	
	107	225	.15	327	.14	1136	.15	1171	.01	35	.03	
	104	219	.07	139	.06	487	.06	497	0	10	.02	
MEAN	89.5	182.2	.12	245.27	.12	911	.12	949	0	37	.04	
TOTAL	-	-	1.74	3679	1.73	13668	1.79	14228	.06	560	-	
35												
	280	536	.62	1315	.4	3143	.45	3589	.05	446	.142	
	213	415	.72	1531	.53	4165	.61	4865	.08	700	.168	
MEAN	241.3	466.4	.67	1423	.47	3654	.53	4227	.07	573	.15	
TOTAL	-	-	1.34	2846	.93	7308	1.06	8454	.13	1146	-	
37												
	118	244	.22	466	.2	1576	.22	1733	.02	157	.1	•
	292	558	.36	769	.23	1798	.25	1978	.02	180	.1	•
	160	320	.33	698	.27	2130	.3	2343	.03	213	.1	•
	240	464	.23	485	.16	1250	.17	1375	.01	125	.1	•
MEAN	200.2	392.3	.29	604.5	.22	1689	.24	1857	.02	169	.1	
TOTAL	-	-	1.14	2418	.86	6754	.94	7429	.08	675	-	
37												
	184	363	.76	1620	.59	4686	.65	5155	.06	469	.1	•
	230	446	.36	765	.25	2010	.28	2211	.03	201	.1	•
	134	273	.2	422	.17	1371	.19	1508	.02	137	.1	•
	238	460	.28	584	.19	1511	.21	1662	.02	151	.1	•
MEAN	194.9	382.8	.4	847.75	.3	2395	.33	2634	.03	240	.1	
TOTAL	-	-	1.6	3391	1.2	9578	1.33	10536	.13	958	-	
37												
	182	360	.25	534	.2	1550	.22	1705	.02	155	.1	•
	148	298	.12	246	.1	773	.11	850	.01	77	.1	•
	160	320	.1	216	.08	659	.09	725	.01	66	.1	•
MEAN	168.4	335.1	.16	332	.13	994	.14	1093	.01	99	.1	
TOTAL	-	-	.47	996	.38	2982	.42	3280	.04	298	-	
42												
	107	225	.21	435	.19	1512	.2	1618	.01	106	.07	•
	148	298	.2	433	.17	1360	.18	1455	.01	95	.07	•
	148	298	.74	1573	.62	4940	.67	5286	.05	346	.07	•
MEAN	139.9	283.9	.38	813.67	.33	2604	.35	2786	.02	182	.07	
TOTAL	-	-	1.15	2441	.98	7812	1.05	8359	.07	547	-	
42												
	120	248	.49	1038	.44	3490	.47	3735	.03	245	.07	•
	14	57	.12	261	.15	1202	.16	1286	.01	84	.07	•
	148	298	.74	1573	.62	4940	.67	5286	.05	346	.07	•
MEAN	121	249.8	.45	957.33	.4	3211	.43	3436	.03	225	.07	
TOTAL	-	-	1.35	2872	1.21	9632	1.3	10307	.09	675	-	
42												
	80	176	.5	1064	.5	3983	.55	4381	.05	398	.1	•
	180	356	.37	778	.29	2270	.32	2497	.03	227	.1	•
	38	100	.48	1026	.55	4362	.61	4798	.06	436	.1	•
MEAN	84	183.3	.45	956	.45	3538	.49	3892	.05	354	.1	
TOTAL	-	-	1.35	2868	1.34	10615	1.48	11676	.14	1061	-	
48												
	237	459	.34	710	.23	1839	.24	1889	.01	50	.027	
	224	435	.24	516	.17	1373	.2	1551	.03	178	.13	
	201	394	.21	451	.16	1257	.19	1484	.03	227	.18	
	196	385	.41	862	.31	2429	.36	2817	.05	388	.16	
	200	392	.36	773	.27	2160	.3	2397	.03	237	.11	
MEAN	209.7	409.4	.31	662.4	.23	1812	.26	2028	.03	216	.12	
TOTAL	-	-	1.56	3312	1.14	9058	1.29	10138	.15	1080	-	
49												
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	240	464	.08	173	.06	446	.06	477	0	31	.07	
	191	376	.08	165	.06	470	.07	522	.01	52	.11	
	192	378	.08	175	.06	497	.07	547	.01	50	.1	
	274	525	.13	265	.08	640	.09	685	.01	45	.07	
	143	289	.06	125	.05	397	.06	449	.01	52	.13	
	59	138	.03	61.03		243	.03	248	0	5	.02	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	158	316	.03	66.03		202	.03	213	0	11	.05	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	182	360	.06	133	.05	386	.05	398	0	12	.03	
MEAN	195.5	383.9	.04	89.46	.03	252	.04	272	0	20	.04	
TOTAL	-	-	.55	1163	.42	3281	.46	3539	.04	258	-	

49												
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	256	493	.1	210	.07	525	.07	546	0	21	.04	
	151	304	.12	249	.1	776	.11	908	.01	132	.17	
	205	401	.07	148	.05	409	.06	467	.01	58	.14	
	168	334	.03	53.02		159	.02	160	0	1	.01	
	115	239	.04	81.03		276	.04	292	.01	16	.06	
	161	322	.05	114	.04	347	.05	361	.01	14	.04	
	145	293	.06	117	.05	370	.05	381	0	11	.03	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	150	302	.07	138	.05	431	.06	461	.01	30	.07	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	64	147	.05	104	.05	408	.06	441	.01	33	.08	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
MEAN	160.3	320.5	.05	93.38	.04	285	.04	309	0	24	.05	
TOTAL	-	-	.59	1214	.46	3701	.52	4017	.06	316	-	
49												
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	182	360	.07	145	.05	421	.06	459	.01	38	.09	
	190	374	.04	80.03		228	.03	244	0	16	.07	
	166	331	.12	245	.09	737	.11	841	.02	104	.14	
	218	424	.09	181	.06	487	.07	526	.01	39	.08	
	140	284	.06	125	.05	400	.06	452	.01	52	.13	
	178	352	.05	105	.04	308	.04	332	0	24	.08	
	127	261	.04	83.03		274	.04	290	.01	16	.06	
	93	199	.04	94.04		340	.05	401	.01	61	.18	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	198	388	.06	122	.04	342	.05	360	.01	18	.05	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	153	307	.04	84.03		261	.03	271	0	10	.04	
MEAN	166	330.8	.05	97.23	.04	292	.04	321	.01	29	.07	
TOTAL	-	-	.61	1264	.46	3798	.54	4176	.08	378	-	
50												
	148	298	1.91	4037	1.6	12679	1.84	14581	.24	1902	.15	•
MEAN	147.8	298	1.91	4037	1.6	12679	1.84	14581	.24	1902	.15	
TOTAL	-	-	1.91	4037	1.6	12679	1.84	14581	.24	1902	-	
51												
	284	543	.45	956	.29	2269	.31	2428	.02	159	.07	
	82	180	.47	987	.46	3671	.47	3745	.01	74	.02	
	152	306	.54	1149	.45	3571	.47	3714	.02	143	.04	
	259	498	.46	970	.3	2410	.34	2700	.04	290	.12	
MEAN	179.7	355.4	.48	1015.5	.38	2980	.4	3147	.02	167	.06	
TOTAL	-	-	1.92	4062	1.5	11921	1.59	12587	.09	666	-	
52												
	285	545	.42	889	.27	2106	.28	2253	.01	147	.07	
	314	597	.24	506	.14	1140	.16	1231	.02	91	.08	
	73	163	1.02	2161	1.04	8258	1.15	9084	.11	826	.1	
MEAN	134.4	274	.56	1185.33	.48	3835	.53	4189	.05	355	.08	
TOTAL	-	-	1.68	3556	1.45	11504	1.59	12568	.14	1064	-	
53												
	169	336	.37	777	.29	2324	.3	2394	.01	70	.03	
	100	212	.05	108	.05	383	.05	398	0	15	.04	
	100	212	.05	108	.05	383	.05	398	0	15	.04	
MEAN	151.7	305.1	.16	331	.13	1030	.13	1063	0	33	.04	
TOTAL	-	-	.47	993	.39	3090	.4	3190	.01	100	-	
54												
	260	500	.13	267	.08	662	.09	728	.01	66	.1	•
MEAN	260	500	.13	267	.08	662	.09	728	.01	66	.1	
TOTAL	-	-	.13	267	.08	662	.09	728	.01	66	-	
54												
	260	500	.13	267	.08	662	.09	728	.01	66	.1	•
MEAN	260	500	.13	267	.08	662	.09	728	.01	66	.1	
TOTAL	-	-	.13	267	.08	662	.09	728	.01	66	-	
57												
	140	284	.19	400	.16	1280	.17	1370	.01	90	.07	•
	170	338	.19	400	.15	1193	.16	1277	.01	84	.07	•
	120	248	.19	400	.17	1345	.18	1439	.01	94	.07	•
MEAN	142.3	288.2	.19	400	.16	1273	.17	1362	.01	89	.07	
TOTAL	-	-	.57	1200	.48	3818	.51	4086	.03	268	-	
57												
	170	338	.76	1600	.6	4773	.64	5107	.04	334	.07	•
MEAN	170	338	.76	1600	.6	4773	.64	5107	.04	334	.07	
TOTAL	-	-	.76	1600	.6	4773	.64	5107	.04	334	-	
57												
	150	302	.52	1100	.43	3437	.46	3677	.03	240	.07	•
MEAN	150	302	.52	1100	.43	3437	.46	3677	.03	240	.07	
TOTAL	-	-	.52	1100	.43	3437	.46	3677	.03	240	-	
57												
	90	194	.09	200	.09	728	.1	779	.01	51	.07	•
	250	482	.09	200	.06	505	.07	541	.01	36	.07	•
	120	248	.09	200	.08	672	.09	720	.01	48	.07	•
	215	419	.09	200	.07	542	.07	580	0	38	.07	•
	175	347	.09	200	.07	590	.08	631	.01	41	.07	•
	270	518	.09	200	.06	487	.07	521	.01	34	.07	•
	130	266	.09	200	.08	656	.09	702	.01	46	.07	•
	200	392	.09	200	.07	559	.08	598	.01	39	.07	•
MEAN	173.2	343.7	.09	200	.07	592	.08	634	.01	42	.07	
TOTAL	-	-	.72	1600	.58	4739	.65	5072	.07	333	-	
57												
	170	338	.33	700	.26	2088	.28	2234	.02	146	.07	•
	150	302	.33	700	.28	2187	.3	2340	.02	153	.07	•
	140	284	.33	700	.28	2240	.3	2397	.02	157	.07	•

MEAN	153	307.3	.33	700	.27	2172	.29	2324	.02	152	.07	
TOTAL	-	-	.99	2100	.82	6515	.88	6971	.06	456	-	
57												
	165	329	.76	1600	.61	4828	.65	5166	.04	338	.07	•
MEAN	165	329	.76	1600	.61	4828	.65	5166	.04	338	.07	
TOTAL	-	-	.76	1600	.61	4828	.65	5166	.04	338	-	
57												
	93	200	.76	1600	.73	5771	.78	6175	.05	404	.07	•
MEAN	93.3	200	.76	1600	.73	5771	.78	6175	.05	404	.07	
TOTAL	-	-	.76	1600	.73	5771	.78	6175	.05	404	-	
59												
	70	158	.94	2000	.97	7704	1.17	9245	.2	1541	.2	•
MEAN	70	158	.94	2000	.97	7704	1.17	9245	.2	1541	.2	
TOTAL	-	-	.94	2000	.97	7704	1.17	9245	.2	1541	-	
60												
	328	622	.88	1868	.52	4110	.64	5055	.12	945	.23	
	151	304	.49	1044	.41	3253	.42	3318	.01	65	.02	
	296	565	.69	1462	.43	3396	.47	3735	.04	339	.1	
	165	329	.11	238	.09	718	.1	761	.01	43	.06	
	110	230	.8	1698	.74	5858	.76	6034	.02	176	.03	
MEAN	214.4	418	.59	1262	.44	3467	.48	3781	.04	314	.09	
TOTAL	-	-	2.97	6310	2.19	17335	2.39	18903	.2	1568	-	
62												
	141	286	.08	168	.07	536	.07	568	0	32	.06	
	136	277	.08	167	.07	539	.07	572	0	33	.06	
	103	217	.3	625	.28	2198	.29	2286	.01	88	.04	
	161	322	.08	173	.07	527	.07	558	0	31	.06	
	148	298	.65	1373	.54	4312	.57	4485	.03	173	.04	
	182	360	.12	250	.09	726	.1	769	.01	43	.06	
	236	457	.12	262	.09	680	.09	714	0	34	.05	
MEAN	146.1	295	.2	431.14	.17	1360	.18	1422	.01	62	.05	
TOTAL	-	-	1.43	3018	1.21	9518	1.26	9952	.05	434	-	
62												
	196	385	.39	836	.3	2355	.32	2544	.02	189	.08	
	166	331	.14	298	.11	897	.15	1157	.04	260	.29	
	218	424	.27	568	.19	1530	.22	1713	.03	183	.12	
	242	468	.22	475	.15	1219	.18	1389	.03	170	.14	
MEAN	205.9	402.6	.26	544.25	.19	1500	.22	1701	.03	201	.16	
TOTAL	-	-	1.02	2177	.75	6001	.87	6803	.12	802	-	
62												
	102	216	.32	686	.31	2416	.33	2585	.02	169	.07	
	172	342	.45	963	.36	2859	.47	3688	.11	829	.29	
	172	342	.26	549	.21	1630	.27	2102	.06	472	.29	
	195	383	.48	1022	.36	2886	.4	3146	.04	260	.09	
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
MEAN	162.7	324.9	.3	644	.25	1958	.29	2304	.05	346	.15	
TOTAL	-	-	1.51	3220	1.24	9791	1.47	11521	.23	1730	-	
62												
	150	302	.72	1533	.6	4789	.63	5029	.03	240	.05	
	170	338	.24	507	.19	1513	.2	1558	.01	45	.03	
MEAN	154.7	310.5	.48	1020	.4	3151	.42	3294	.02	143	.04	
TOTAL	-	-	.96	2040	.79	6302	.83	6587	.04	285	-	
62												
	102	216	.35	742	.33	2613	.35	2796	.02	183	.07	
	172	342	.45	963	.36	2859	.47	3688	.11	829	.29	
	172	342	.26	549	.21	1630	.27	2102	.06	472	.29	
	195	383	.48	1022	.36	2886	.4	3146	.04	260	.09	
MEAN	161.6	323	.39	819	.31	2497	.37	2933	.06	436	.19	
TOTAL	-	-	1.54	3276	1.26	9988	1.49	11732	.23	1744	-	
62												
	105	221	.64	1359	.6	4751	.64	5036	.04	285	.06	
	209	408	.6	1275	.44	3497	.45	3567	.01	70	.02	
MEAN	148.1	298.5	.62	1317	.52	4124	.55	4302	.03	178	.04	
TOTAL	-	-	1.24	2634	1.04	8248	1.09	8603	.05	355	-	
62												
	162	324	.69	1469	.56	4461	.58	4594	.02	133	.03	
MEAN	162.2	324	.69	1469	.56	4461	.58	4594	.02	133	.03	
TOTAL	-	-	.69	1469	.56	4461	.58	4594	.02	133	-	
62												
	120	248	.27	581	.25	1954	.27	2110	.02	156	.08	
	146	295	.52	1103	.44	3478	.5	3965	.06	487	.14	
MEAN	137	278.7	.4	842	.35	2716	.39	3038	.04	322	.11	
TOTAL	-	-	.79	1684	.69	5432	.77	6075	.08	643	-	
62												
	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F	
	128	262	.16	329	.14	1085	.14	1117	0	32	.03	
	174	345	.11	226	.08	668	.09	688	.01	20	.03	
	180	356	.08	161	.06	470	.06	484	0	14	.03	
	172	342	.08	160	.06	475	.06	489	0	14	.03	
	207	405	.18	388	.13	1068	.14	1132	.01	64	.06	
	104	219	.49	1035	.46	3629	.47	3701	.01	72	.02	
	127	261	.55	1170	.49	3863	.58	4559	.09	696	.18	
	99	210	.44	925	.41	3287	.44	3517	.03	230	.07	
MEAN	126.3	259.3	.23	488.22	.2	1616	.22	1743	.02	127	.05	
TOTAL	-	-	2.09	4394	1.83	14545	1.98	15687	.15	1142	-	

Oven Analysis B

OVEN ANALYSIS

EACH LINE REPRESENTS 1 OVEN

MEAN AND TOTAL REPRESENT THE ENTIRE SURVEY

ERRORS MAY OCCUR DUE TO ROUNDING

'*'.......ESTIMATED READING

'N/F'.....NO FLOW FROM FLUE.

	TEMPERATURE		VOLUME FLOW RATE		MASS FLOW RATE (DRY)		MASS FLOW RATE (WET)		MOISTURE FLOW RATE		TOTAL MOISTURE CONTENT
	C	F	CU.M/S	ACFM	KG/S	LB/HR	KG/S	LB/HR	KG/S	LB/HR	KG/KG-LB/LB
	189	372.2	.66	1405	.51	4019	.6	4743	.09	724	.18
	137	279.2	1.76	3722	1.51	11987	1.56	12347	.05	360	.03
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03
	216	420.2	1.49	3158	1.08	8541	1.13	8968	.05	427	.05
	193	378.9	1.05	2218	.79	6294	.83	6609	.04	315	.05
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05
	250	481.7	1.21	2571	.82	6500	.91	7215	.09	715	.11
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09
	190	373.4	.73	1555	.56	4442	.62	4886	.06	444	.1
	121	250.6	.78	1651	.7	5531	.77	6084	.07	553	.1
	181	358.1	.65	1370	.5	3987	.55	4385	.05	398	.1
	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08
	138	280	.6	1263	.51	4063	.55	4388	.04	325	.08
	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08
	176	349	.63	1328	.49	3908	.53	4221	.04	313	.08
	152	306	1.01	2135	.84	6635	.9	7166	.06	531	.08
	260	500	.09	200	.06	496	.07	570	.01	74	.15
	260	500	.09	200	.06	496	.07	570	.01	74	.15
	260	500	.08	170	.05	422	.06	485	.01	63	.15
	194	381.1	1.51	3196	1.14	9046	1.29	10222	.15	1176	.13
	241	466.4	1.34	2846	.92	7314	1.06	8411	.14	1097	.15
	200	392.3	1.14	2418	.85	6754	.94	7429	.09	675	.1
	195	382.8	1.6	3391	1.21	9579	1.33	10536	.12	957	.1
	168	335.1	.47	996	.38	2982	.41	3280	.03	298	.1
	140	283.9	1.15	2441	.99	7812	1.06	8359	.07	547	.07
	121	249.8	1.36	2872	1.22	9633	1.3	10307	.08	674	.07
	84	183.3	1.35	2868	1.34	10614	1.47	11675	.13	1061	.1
	210	409.4	1.56	3312	1.15	9069	1.28	10157	.13	1088	.12
	196	383.9	.55	1163	.41	3281	.43	3412	.02	131	.04
	160	320.5	.57	1214	.47	3703	.49	3888	.02	185	.05
	166	330.8	.6	1264	.48	3805	.51	4072	.03	267	.07
	148	298	1.91	4037	1.6	12679	1.84	14581	.24	1902	.15
	180	355.4	1.92	4062	1.5	11859	1.59	12571	.09	712	.06
	134	274	1.68	3556	1.46	11533	1.57	12456	.11	923	.08
	152	305.1	.47	993	.39	3090	.41	3213	.02	123	.04
	260	500	.13	267	.08	662	.09	728	.01	66	.1
	260	500	.13	267	.08	662	.09	728	.01	66	.1
	142	288.2	.57	1200	.48	3818	.52	4085	.04	267	.07
	170	338	.76	1600	.6	4773	.64	5107	.04	334	.07
	150	302	.52	1100	.43	3437	.46	3677	.03	240	.07
	173	343.7	.76	1600	.6	4739	.64	5071	.04	332	.07
	153	307.3	.99	2100	.82	6516	.88	6972	.06	456	.07
	165	329	.76	1600	.61	4828	.65	5166	.04	338	.07
	93	200	.76	1600	.73	5771	.78	6175	.05	404	.07
	70	158	.94	2000	.97	7704	1.17	9245	.2	1541	.2
	214	418	2.98	6310	2.16	17109	2.35	18649	.19	1540	.09
	146	295	1.42	3018	1.2	9516	1.26	9992	.06	476	.05
	206	402.6	1.03	2177	.76	6008	.88	6970	.12	962	.16
	163	324.9	1.52	3220	1.23	9766	1.42	11231	.19	1465	.15
	155	310.5	.96	2040	.8	6303	.83	6555	.03	252	.04
	162	323	1.55	3276	1.26	9960	1.5	11853	.24	1893	.19
	148	298.5	1.24	2634	1.04	8267	1.09	8598	.05	331	.04
	162	324	.69	1469	.56	4461	.58	4594	.02	133	.03
	137	278.7	.79	1684	.69	5427	.76	6024	.07	597	.11
	126	259.3	2.07	4394	1.84	14543	1.93	15270	.09	727	.05
	143	289.8	.69	1469	.59	4664	.65	5131	.06	467	.1
	170	337.6	.38	806	.3	2406	.32	2550	.02	144	.06
	264	507.9	2.43	5141	1.6	12645	1.69	13403	.09	758	.06
	111	231.8	2.13	4521	1.96	15558	2.12	16802	.16	1244	.08
	210	410.8	1.81	3829	1.32	10468	1.48	11724	.16	1256	.12
	165	329.6	2.64	5593	2.13	16863	2.17	17200	.04	337	.02
	215	418.3	1.98	4187	1.43	11349	1.52	12030	.09	681	.06
	159	317.4	1.77	3755	1.45	11499	1.57	12419	.12	920	.08
	83	182.2	1.74	3679	1.72	13638	1.79	14184	.07	546	.04
MEAN	164.5	328.2	1.07	2277.63	.87	6885	.94	7421	.07	537	.08
TOTAL	-	-	89.21	189043	72.11	571414	77.82	615955	5.71	44541	-

A5.3 Site Analysis

The MHRU was to be designed to meet the needs of a complete site, not just one oven. Site analysis A, below, uses oven analysis A and combines all the ovens for one site. Each line now represents the total waste exhaust gas of **one oven,** the mean being the average for an **entire site** and the total being that for the **entire survey.**

Site analysis B (page 191) summarises this information, each line representing an **entire sites** output of waste gases, the mean being the average output of waste exhaust gases for the **sites surveyed,** and the total being the total output of waste gases for the **entire survey .**

From the site analysis it was found that the mean oven exhaust gas volume flow rate, for an entire site, was $3.6 m^3/s$.

Site Analysis A

OVEN ANALYSIS

EACH LINE REPRESENTS 1 OVEN

MEAN AND TOTAL REPRESENT THE ENTIRE SITE

ERRORS MAY OCCUR DUE TO ROUNDING

'*'.......ESTIMATED READING

'N/F'.....NO FLOW FROM FLUE.

COMPANY	TEMPERATURE		VOLUME FLOW RATE		MASS FLOW RATE (DRY)		MASS FLOW RATE (WET)		MOISTURE FLOW RATE		TOTAL MOISTURE CONTENT	
	C	F	CU.M/S	ACFM	KG/S	LB/HR	KG/S	LB/HR	KG/S	LB/HR	KG/KG-LB/LB	
7												
	189	372.2	.66	1405	.51	4019	.6	4743	.09	724	.18	
MEAN	189	372.2	.66	1405	.51	4019	.6	4743	.09	724	.18	
TOTAL	-	-	.66	1405	.51	4019	.6	4743	.09	724	-	
8												
	137	279.2	1.76	3722	1.51	11987	1.54	12227	.03	240	.02	
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03	
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03	
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03	
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03	
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03	
	138	280	1.73	3675	1.49	11823	1.54	12177	.05	354	.03	
MEAN	137.7	279.9	1.73	3681.71	1.49	11846	1.54	12184	.05	338	.03	
TOTAL	-	-	12.14	25772	10.45	82925	10.78	85289	.33	2364	-	
11												
	216	420.2	1.49	3158	1.08	8541	1.13	8968	.05	427	.05	*
	193	378.9	1.05	2218	.79	6294	.83	6609	.04	315	.05	*
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
	149	300	.3	645	.26	2020	.27	2121	.01	101	.05	*
MEAN	185.8	366.5	.62	1326	.48	3819	.51	4010	.02	191	.05	
TOTAL	-	-	3.74	7956	2.91	22915	3.04	24061	.13	1146	-	
12												
	250	481.7	1.21	2571	.82	6500	.91	7215	.09	715	.11	
MEAN	249.8	481.7	1.21	2571	.82	6500	.91	7215	.09	715	.11	
TOTAL	-	-	1.21	2571	.82	6500	.91	7215	.09	715	-	

16												
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	*
MEAN	200	392	.83	1757	.62	4909	.68	5351	.06	442	.09	
TOTAL	-	-	9.96	21084	7.4400000158908		8.16	64212	.72	5304	-	
20												
	190	373.4	.73	1555	.56	4442	.62	4886	.06	444	.1	*
	121	250.6	.78	1651	.7	5531	.77	6084	.07	553	.1	*
MEAN	151.8	305.3	.76	1603	.63	4987	.7	5485	.07	499	.1	
TOTAL	-	-	1.51	3206	1.26	9973	1.39	10970	.13	997	-	
21												
	181	358.1	.65	1370	.5	3987	.55	4385	.05	398	.1	
MEAN	181.2	358.1	.65	1370	.5	3987	.55	4385	.05	398	.1	
TOTAL	-	-	.65	1370	.5	3987	.55	4385	.05	398	-	
23												
	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08	*
	138	280	.6	1263	.51	4063	.55	4388	.04	325	.08	*
	150	302	.76	1609	.63	5027	.69	5429	.06	402	.08	*
	176	349	.63	1328	.49	3908	.53	4221	.04	313	.08	*
	152	306	1.01	2135	.84	6635	.9	7166	.06	531	.08	*
MEAN	152.7	306.9	.75	1588.8	.62	4932	.67	5327	.05	395	.08	
TOTAL	-	-	3.76	7944	3.1	24660	3.36	26633	.26	1973	-	
28												
	260	500	.09	200	.06	496	.07	570	.01	74	.15	
	260	500	.09	200	.06	496	.07	570	.01	74	.15	
	260	500	.08	170	.05	422	.06	485	.01	63	.15	
MEAN	260	500	.09	190	.06	471	.07	542	.01	70	.15	
TOTAL	-	-	.26	570	.17	1414	.2	1625	.03	211	-	
29												
	194	381.1	1.51	3196	1.14	9046	1.29	10222	.15	1176	.13	
MEAN	193.9	381.1	1.51	3196	1.14	9046	1.29	10222	.15	1176	.13	
TOTAL	-	-	1.51	3196	1.14	9046	1.29	10222	.15	1176	-	
34												
	143	289.8	.69	1469	.59	4664	.65	5131	.06	467	.1	
	170	337.6	.38	806	.3	2406	.32	2550	.02	144	.06	
	264	507.9	2.43	5141	1.6	12645	1.69	13403	.09	758	.06	
	111	231.8	2.13	4521	1.96	15558	2.12	16802	.16	1244	.08	
	210	410.8	1.81	3829	1.32	10468	1.48	11724	.16	1256	.12	
	165	329.6	2.64	5593	2.13	16863	2.17	17200	.04	337	.02	
	215	418.3	1.98	4187	1.43	11349	1.52	12030	.09	681	.06	
	159	317.4	1.77	3755	1.45	11499	1.57	12419	.12	920	.08	
	83	182.2	1.74	3679	1.72	13638	1.79	14184	.07	546	.04	
MEAN	167.1	332.8	1.73	3664.44	1.39	11010	1.48	11716	.09	706	.07	
TOTAL	-	-	15.57	32980	12.5	99090	13.31	105443	.81	6353	-	
35												
	241	466.4	1.34	2846	.92	7314	1.06	8411	.14	1097	.15	
MEAN	241.3	466.4	1.34	2846	.92	7314	1.06	8411	.14	1097	.15	
TOTAL	-	-	1.34	2846	.92	7314	1.06	8411	.14	1097	-	
37												
	200	392.3	1.14	2418	.85	6754	.94	7429	.09	675	.1	*
	195	382.8	1.6	3391	1.21	9579	1.33	10536	.12	957	.1	*
	168	335.1	.47	996	.38	2982	.41	3280	.03	298	.1	*
MEAN	192.6	378.8	1.07	2268.33	.81	6438	.89	7082	.08	643	.1	
TOTAL	-	-	3.21	6805	2.44	19315	2.68	21245	.24	1930	-	
42												
	140	283.9	1.15	2441	.99	7812	1.06	8359	.07	547	.07	*
	121	249.8	1.36	2872	1.22	9633	1.3	10307	.08	674	.07	*
	84	183.3	1.35	2868	1.34	10614	1.47	11675	.13	1061	.1	*
MEAN	112.3	234.1	1.29	2727	1.18	9353	1.28	10114	.09	761	.08	
TOTAL	-	-	3.86	8181	3.55	28059	3.83	30341	.28	2282	-	
48												
	210	409.4	1.56	3312	1.15	9069	1.28	10157	.13	1088	.12	
MEAN	209.7	409.4	1.56	3312	1.15	9069	1.28	10157	.13	1088	.12	
TOTAL	-	-	1.56	3312	1.15	9069	1.28	10157	.13	1088	-	
49												
	196	383.9	.55	1163	.41	3281	.43	3412	.02	131	.04	
	160	320.5	.57	1214	.47	3703	.49	3888	.02	185	.05	
	166	330.8	.6	1264	.48	3805	.51	4072	.03	267	.07	
MEAN	172.9	343.2	.57	1213.67	.45	3596	.48	3791	.02	194	.05	
TOTAL	-	-	1.72	3641	1.36	10789	1.43	11372	.07	583	-	
50												
	148	298	1.91	4037	1.6	12679	1.84	14581	.24	1902	.15	*
MEAN	147.8	298	1.91	4037	1.6	12679	1.84	14581	.24	1902	.15	
TOTAL	-	-	1.91	4037	1.6	12679	1.84	14581	.24	1902	-	
51												
	180	355.4	1.92	4062	1.5	11859	1.59	12571	.09	712	.06	

MEAN	179.7	355.4	1.92	4062	1.5	11859	1.59	12571	.09	712	.06	
TOTAL	-	-	1.92	4062	1.5	11859	1.59	12571	.09	712	-	
52												
	134	274	1.68	3556	1.46	11533	1.57	12456	.11	923	.08	
MEAN	134.4	274	1.68	3556	1.46	11533	1.57	12456	.11	923	.08	
TOTAL	-	-	1.68	3556	1.46	11533	1.57	12456	.11	923	-	
53												
	152	305.1	.47	993	.39	3090	.41	3213	.02	123	.04	
MEAN	151.7	305.1	.47	993	.39	3090	.41	3213	.02	123	.04	
TOTAL	-	-	.47	993	.39	3090	.41	3213	.02	123	-	
54												
	260	500	.13	267	.08	662	.09	728	.01	66	.1	*
	260	500	.13	267	.08	662	.09	728	.01	66	.1	*
MEAN	260	500	.13	267	.08	662	.09	728	.01	66	.1	
TOTAL	-	-	.26	534	.16	1324	.18	1456	.02	132	-	
57												
	142	288.2	.57	1200	.48	3818	.52	4085	.04	267	.07	*
	170	338	.76	1600	.6	4773	.64	5107	.04	334	.07	*
	150	302	.52	1100	.43	3437	.46	3677	.03	240	.07	*
	173	343.7	.76	1600	.6	4739	.64	5071	.04	332	.07	*
	153	307.3	.99	2100	.82	6516	.88	6972	.06	456	.07	*
	165	329	.76	1600	.61	4828	.65	5166	.04	338	.07	*
	93	200	.76	1600	.73	5771	.78	6175	.05	404	.07	*
MEAN	148.2	298.8	.73	1542.86	.61	4840	.65	5179	.04	339	.07	
TOTAL	-	-	5.12	10800	4.27	33882	4.57	36253	.3	2371	-	
59												
	70	158	.94	2000	.97	7704	1.17	9245	.2	1541	.2	*
MEAN	70	158	.94	2000	.97	7704	1.17	9245	.2	1541	.2	
TOTAL	-	-	.94	2000	.97	7704	1.17	9245	.2	1541	-	
60												
	214	418	2.98	6310	2.16	17109	2.35	18649	.19	1540	.09	
MEAN	214.4	418	2.98	6310	2.16	17109	2.35	18649	.19	1540	.09	
TOTAL	-	-	2.98	6310	2.16	17109	2.35	18649	.19	1540	-	
62												
	146	295	1.42	3018	1.2	9516	1.26	9992	.06	476	.05	
	206	402.6	1.03	2177	.76	6008	.88	6970	.12	962	.16	
	163	324.9	1.52	3220	1.23	9766	1.42	11231	.19	1465	.15	
	155	310.5	.96	2040	.8	6303	.83	6555	.03	252	.04	
	162	323	1.55	3276	1.26	9960	1.5	11853	.24	1893	.19	
	148	298.5	1.24	2634	1.04	8267	1.09	8598	.05	331	.04	
	162	324	.69	1469	.56	4461	.58	4594	.02	133	.03	
	137	278.7	.79	1684	.69	5427	.76	6024	.07	597	.11	
	126	259.3	2.07	4394	1.84	14543	1.93	15270	.09	727	.05	
MEAN	153.2	307.8	1.25	2656.89	1.04	8250	1.14	9010	.1	760	.09	
TOTAL	-	-	11.27	23912	9.38	74251	10.25	81087	.87	6836	-	

Site Analysis B

OVEN ANALYSIS

EACH LINE REPRESENTS 1 SITE

MEAN AND TOTAL REPRESENT THE ENTIRE SURVEY

ERRORS MAY OCCUR DUE TO ROUNDING

'*'.......ESTIMATED READING

'N/F'.....NO FLOW FROM FLUE.

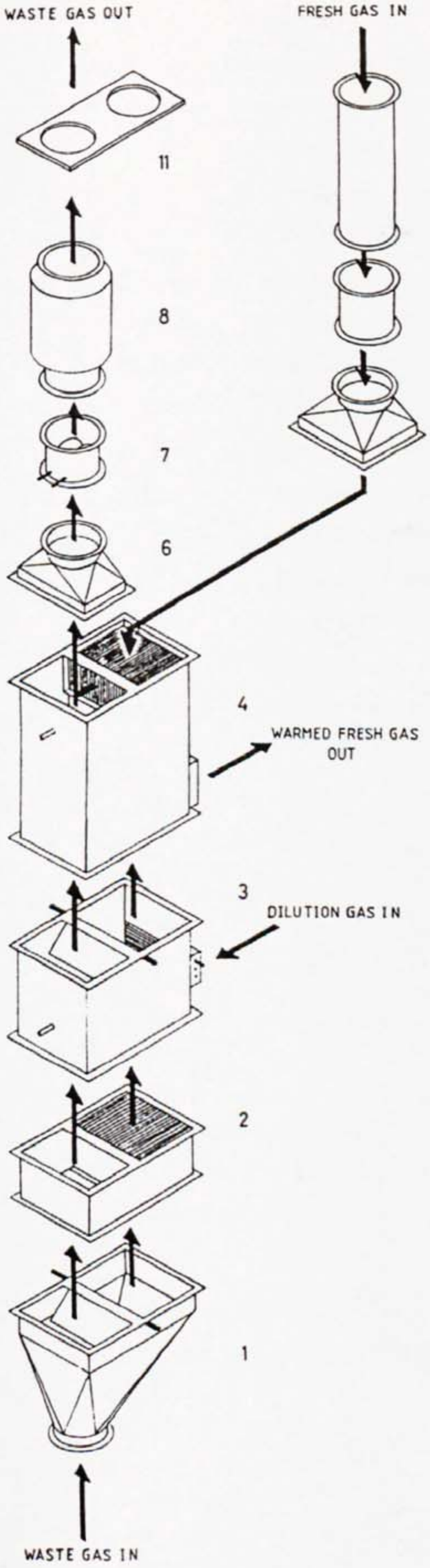
	TEMPERATURE		VOLUME FLOW RATE		MASS FLOW RATE (DRY)		MASS FLOW RATE (WET)		MOISTURE FLOW RATE		TOTAL MOISTURE CONTENT
	C	F	CU.M/S	ACFM	KG/S	LB/HR	KG/S	LB/HR	KG/S	LB/HR	KG/KG-LB/LB
	189	372.2	.66	1405	.51	4019	.6	4743	.09	724	.18
	138	279.9	12.16	25772	10.47	82922	10.78	85410	.31	2488	.03
	186	366.5	3.76	7956	2.89	22916	3.04	24062	.15	1146	.05
	250	481.7	1.21	2571	.82	6500	.91	7215	.09	715	.11
	200	392	9.95	21084	7.44	58913	8.11	64215	.67	5302	.09
	152	305.3	1.51	3206	1.26	9973	1.39	10970	.13	997	.1
	181	358.1	.65	1370	.5	3987	.55	4385	.05	398	.1
	153	306.9	3.75	7944	3.11	24660	3.36	26633	.25	1973	.08
	260	500	.27	570	.18	1414	.21	1626	.03	212	.15
	194	381.1	1.51	3196	1.14	9046	1.29	10222	.15	1176	.13
	167	332.8	15.57	32980	12.5	99033	13.38	105966	.88	6933	.07
	241	466.4	1.34	2846	.92	7314	1.06	8411	.14	1097	.15
	193	378.8	3.21	6805	2.44	19314	2.68	21245	.24	1931	.1
	112	234.1	3.86	8181	3.54	28059	3.83	30304	.29	2245	.08
	210	409.4	1.56	3312	1.15	9069	1.28	10157	.13	1088	.12
	173	343.2	1.72	3641	1.36	10792	1.43	11331	.07	539	.05
	148	298	1.91	4037	1.6	12679	1.84	14581	.24	1902	.15
	180	355.4	1.92	4062	1.5	11859	1.59	12571	.09	712	.06
	134	274	1.68	3556	1.46	11533	1.57	12456	.11	923	.08
	152	305.1	.47	993	.39	3090	.41	3213	.02	123	.04
	260	500	.25	534	.17	1324	.18	1457	.01	133	.1
	148	298.8	5.1	10800	4.28	33884	4.58	36256	.3	2372	.07
	70	158	.94	2000	.97	7704	1.17	9245	.2	1541	.2
	214	418	2.98	6310	2.16	17109	2.35	18649	.19	1540	.09
	153	307.8	11.29	23912	9.36	74142	10.2	80814	.84	6672	.09
MEAN	164.6	328.2	3.57	7561.72	2.88	22850	3.11	24645	.23	1795	.1
TOTAL	-	-	89.23	189043	72.12	571255	77.79	616137	5.67	44882	-

APPENDIX 6

SINGLE FLUE EXHAUST GAS HEAT RECOVERY UNIT (TYPE 1)

APPENDIX 6

SINGLE FLUE, EXHAUST GAS HEAT RECOVERY UNIT (TYPE 1)



KEY

1 MOTORISED DAMPER SECTION
2 GAS/LIQUID HEAT EXCHANGER WITH BYPASS
3 MOTORISED DAMPER WITH MOTORISED DILUTION DAMPER
4 GAS/GAS HEAT EXCHANGER
5 CHANGE SECTION
6 CHANGE SECTION
7 MOTORISED DAMPER SECTION
8 BIFURCATED HIGH TEMPERATURE FAN
9 NORMAL TEMPERATURE AXIAL FLOW FAN
10 CIRCULAR MAKE-UP SECTION
11 SUPPORT PLATE FOR FANS

APPENDIX 7

HARDWARE SELECTION FOR THE MODULAR HEAT RECOVERY UNIT

APPENDIX 7

HARDWARE SELECTION FOR THE MODULAR HEAT RECOVERY UNIT

A7.0 Introduction

This appendix describes the selection of the heat exchanger, filters and fans used in the MHRU.

A7.1 Heat Exchanger Selection

A7.1.1 Types of Gas-to-Gas Heat Exchanger

The following types of equipment are available for gas-to-gas waste heat recovery:

- plate heat exchangers;
- shell and tube heat exchangers;
- heat wheels (rotating regenerators);
- heat pipes;
- static regenerators;
- run-around-coils;
- convection recuperators;
- radiation recuperators.

Following a preliminary analysis of the above eight devices, the first four were selected for closer examination. Although these may offer heat transfer between several fluid combinations, the following descriptions are limited to that of gas-to-gas transfer.

Plate Heat Exchanger

The plate heat exchanger is particularly suitable when the temperature difference between two flows is small.

Operation and Construction

This type of heat exchanger consists of a framework containing an arrangement of thin parallel gas paths, separated by a series of plates. Heat is transfered across these plates, which may be corrugated to increase the heat transfer surface per unit volume. Construction of gas-to-gas units of this type varies considerably, but a typical arrangement is shown in figure A 7.1.

Plates are usually aluminium, though steel, stainless steel, glass, ceramic and paper plates are available. The plates are thin and should be protected from physical damage and blocking by using filters to ensure only 'cleaned' gases are passed through the device.

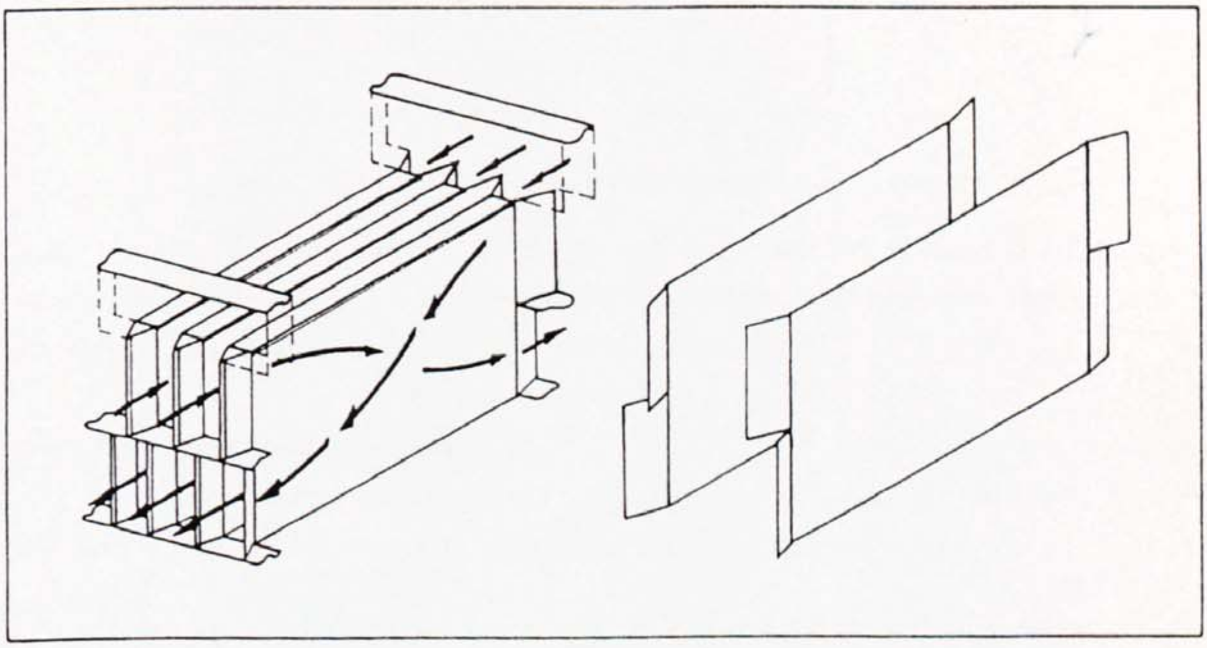


Figure A7.1 Construction of a gas-to-gas plate heat exchanger

The thinness of the plates limits the pressure difference acceptable between the two gas streams to approximately 1200Pa [188] and throughputs of $5.6m^3/s$ in a single unit are rarely exceeded. Several plate spacings are obtainable to accommodate various waste gas sources, these usually being 4mm or 8mm between plates.

Unequal primary and secondary gas flows can be accommodated. The construction of these gas-to-gas devices makes cleaning relatively difficult. Spray coils can, however, be fitted to the exchanger to provide automatic washing of the plates' surfaces.

Discussion

Plate heat exchangers have no moving parts and this enhances reliability. Their compactness however does not match that of the heat pipe or heat wheel, and table A7.1 shows how this varies between the three devices [49]. Heat exchange plates can be coated with phenolics to allow recovery from corrosive atmospheres.

Heat Exchanger	Compactness (W/m^3K)
Heat pipes	7200
Heat wheels	5400
Plate type	4140

Table A7.1 Compactness of 3 gas-to-gas heat exchangers

Heat transfer efficiencies of up to 80 per cent can be obtained. Typical commercial units have a temperature limitation of between 420-470K, although specials are available for up to 1620K [189].

Shell and Tube Heat Exchanger

This type of heat exchanger is suitable for arduous duties and high pressure applications where temperature differences are large.

Operation and Construction

The simplest type of shell and tube construction, a single tube single pass device, is shown in figure A7.2. Although shown plain, the internal tube may have helical or longitudinal fins added to it, and its diameter can vary between 5-100mm.

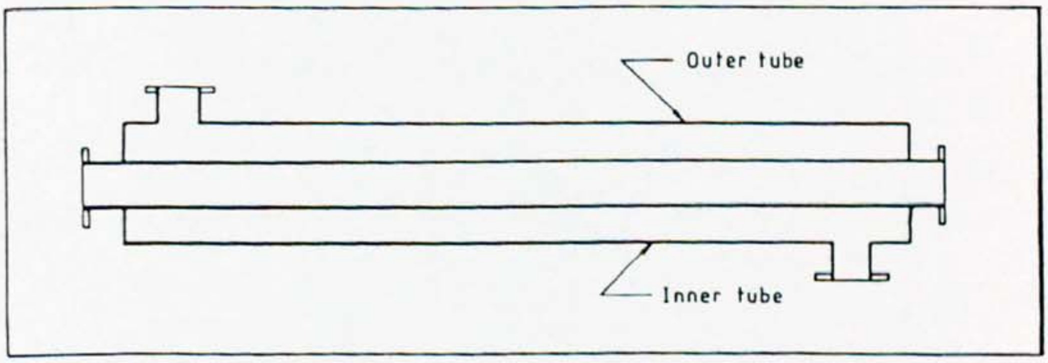


Figure A7.2 Basic shell and tube heat exchanger

In its present state, for large duties, this design could be clumbersome. By increasing the number of tubes, using multi-passing and baffles, the design becomes considerably more compact. Using smaller diameter tubes within a single shell improves compactness, but the design becomes more difficult to clean. Larger tubes occupy more space. Figure A7.3 shows a compact shell and tube design.

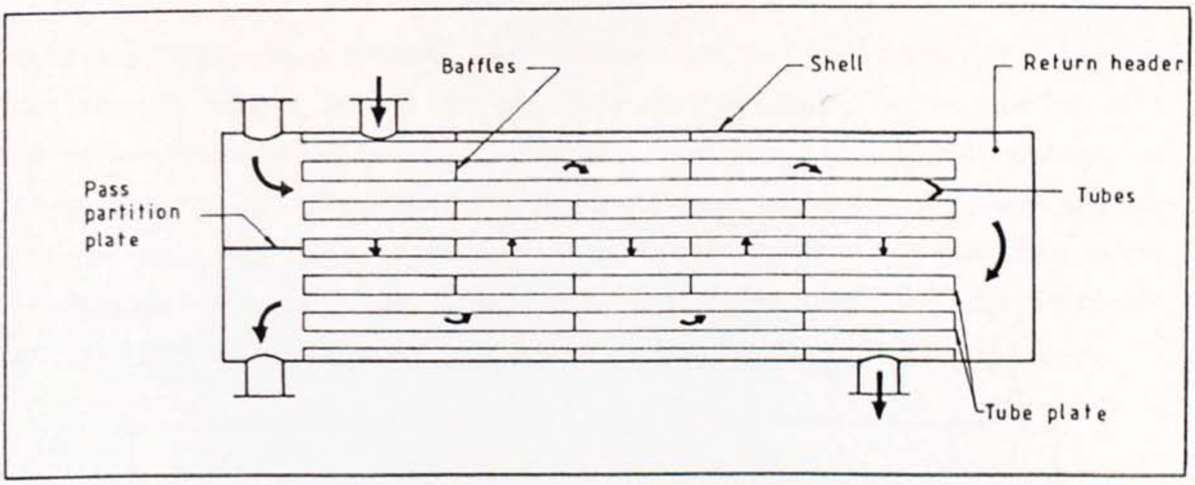


Figure A7.3 Compact shell and tube heat exchanger

Discussion

Heat exchangers of this type lend themselves to operation in arduous conditions and can withstand temperatures in excess of 1650K. They may also operate in hazardous or corrosive atmospheres and recovery can be accomplished from most gaseous waste heat sources. No moving parts promotes low maintainence, except for routine cleaning.

Thermal Wheel (Heat Wheel) Heat Exchanger

The thermal wheel or Ljungström heat exchanger, named after its Danish inventor [190], is a rotating regenerator. Its main area of application is in heat exchange between large masses of gas having a small temperature difference between them.

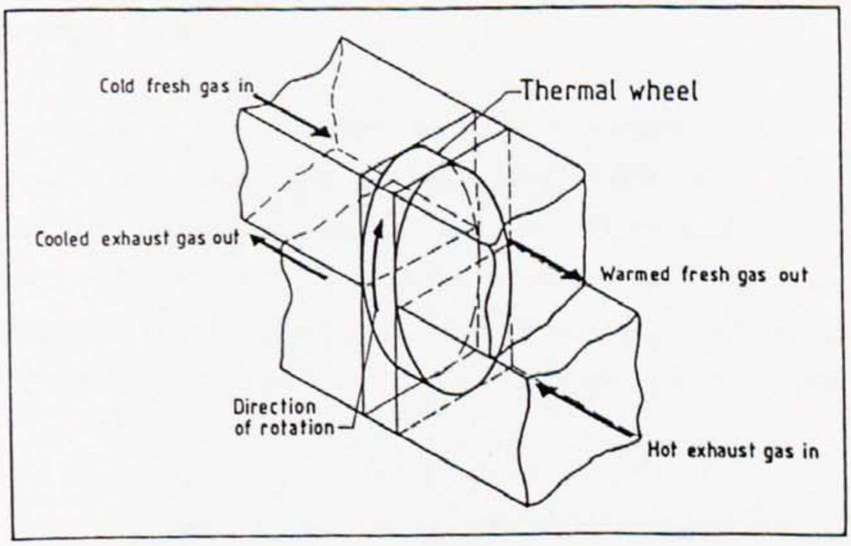


Figure A7.4 Operating principle of the thermal wheel

Operation and Construction

The device consists of a rotating wheel and drive mechanism mounted in a frame. The 'wheel' is made from a heat retaining matrix that rotates between separate hot (exhaust) and cold (fresh) gas streams. (In some designs (the Rothemuhle design) the matrix is stationary and the ducting rotates [191]. In operation, the exhaust gas passes through one half of the wheel's matrix and clean gas through the other, in a counter flow direction (figure A7.4). Heat is absorbed from the exhaust gas, and as the wheel rotates, is given up to the supply gas stream. A purge section ensures that each part of the wheel is flushed with clean gas once every revolution. This can keep cross contamination to less than 400 parts per million [192]. Operation of the purge section is shown figure A7.5.

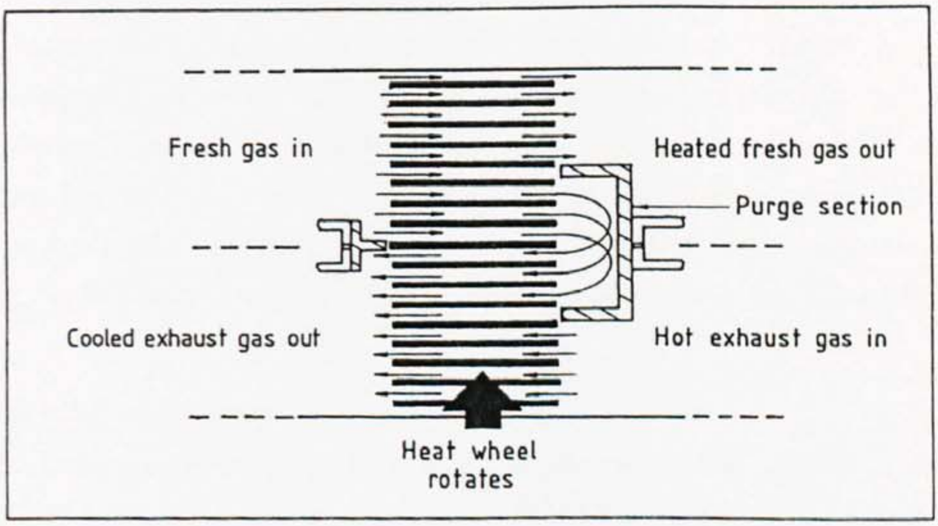


Figure A7.5 Heat wheel purge section

There are three common types of matrix available:

- metal matrix;
- glass-ceramic matrix;
- hygroscopic matrix.

The metal matrix is a honeycomb of flow channels allowing gas to pass through it with relatively low pressure drop (typically 35Pa [189]). The gas flow through these channels is laminar. This helps to prevent dust particles etc. from touching the wheel's matrix as they pass through it, and so helping to prevent clogging. The metal matrix is usually aluminium but for higher temperatures (up to 1000K) steel and stainless steels may be used.

The glass-ceramic matrix is of a cellular construction and has an operational ceiling temperature of approximately 1200K. Other features are as for the metal matrix.

The hygroscopic matrix is a non-metallic structure consisting of a fibre impregnated with lithium chloride. This can transfer latent heat as well as sensible heat. The cost of such wheels is roughly 35 per cent greater than the metal matrix counterpart [189]. The extra cost can be recouped by the increased heat transfer attributable to the latent part of heat recovery, especially where this is high (i.e. in swimming pools [193]). This type of matrix is, at present, limited to a maximum operating temperature of 370K.

Discussion

This type of heat exchanger can have operating efficiencies in the range 75-80 per cent if used correctly [194]. The wheel is driven by a small electric motor that may require periodic maintenance. Wheels are largely self cleaning by virtue of the effect obtained by continuous reversal of flow direction through the matrix of the wheel. Occasionally solvents, steam cleaning or 'vacuuming' may be used to thoroughly clean the wheel. Purging puts an extra load on the overall system and associated fans should be sized approximately 10 per cent larger than the given flow rate [195].

Heat pipe heat exchanger

The heat pipe, a recent derivative of a thermosyphon device, was first patented by R.S.Gaugler in America in 1942 [196]. It works on a boiling-condensing cycle and is a super conductor of heat.

Operation and construction

The basic heat pipe [197] (see figure A7.6) consists of a sealed tube (A) containing a capillary material or wick (B) which lines the inside wall. A small amount of working fluid (C), which is often water, enough to saturate the wick, is contained within the tube.

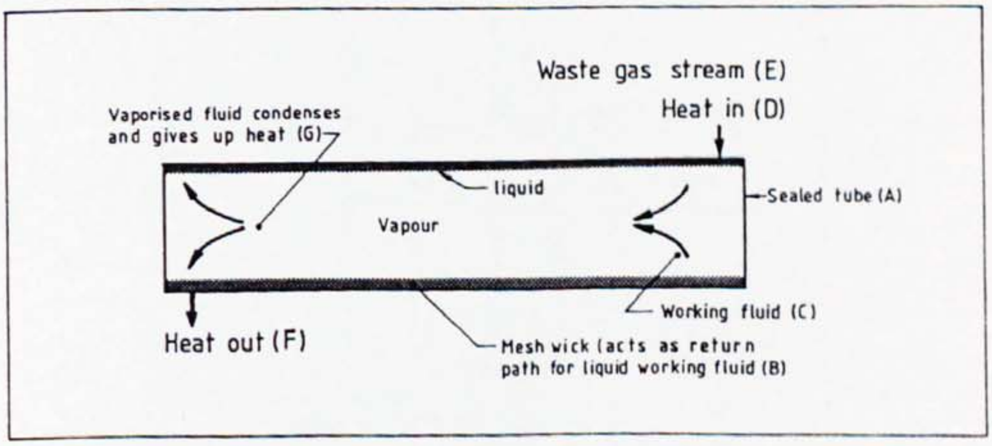


Figure A7.6 The heat pipe

The tube is evacuated so that the working fluid is largely vapour. As heat is applied to one end (D), the working fluid evaporates and absorbs its latent heat of vaporisation from the gas stream (E). The vapour, induced by pressure differences, travels to the cooler end of the tube (F) where it condenses and gives up this heat (G). The condensed fluid (H) returns to the hot end (D) by capillary action through the woven metal mesh (wick).

In heat pipe heat exchangers a number of these individual heat pipes are mounted in a battery. For gas-to-gas heat exchange, helical fins are usually added to the outside of the pipe, though where fouling may be excessive, bare pipes can be used, as this facilitates cleaning.

Discussion

With present technology, generally available heat pipes can accomodate temperatures up to 580K. Work sponsored by the Commission of the European Communities details common tube materials e.g. copper, mild steel etc. and compares their performance when used with various working fluids [198]. Beyond 580K, high vapour pressure necessitates the use of special tubes and exotic working fluids (liquid metals), adding considerably to the cost. Special coatings can be applied to heat pipes that are used in corrosive atmospheres.

Heat pipes have no moving parts and so require the minimum of maintenance. Primary and secondary flows can be separated by several metres, offering a fail safe configuration between the flows when cross contamination cannot be tolerated (figure A7.7). Recovery efficiencies in the order of 70 per cent are obtainable from this type of system.

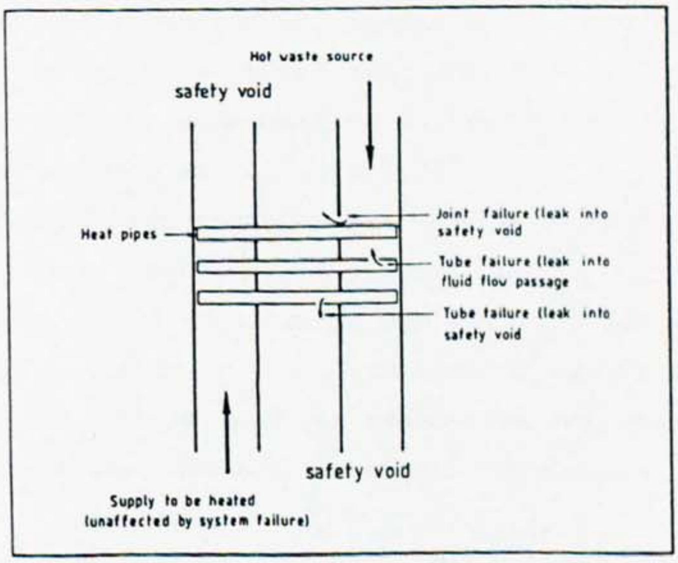


Figure A7.7 Fail safe operation of heat pipes for zero cross contamination

A7.1.2 Selection of a Heat Exchanger

The heat exchangers described all perform gas-to-gas heat exchange. The most suitable of these devices had to be selected for use in the MHRU and a weighting and rating analysis was used for this purpose.

This technique removes some of the subjectiveness involved in the selection of plant when several items meet the given requirements.

A7.1.3 Weighting and Rating Analysis for Heat Exchanger Selection

A rough specification for the desired exchanger was given in section 3.1.2 (page 34). This was added to by listing other desirable characteristics required. A total of 12 parameters were finally listed, the most desirable being given a high weighting number, 5, this gradually reducing to 1 as they became less important. Each heat exchanger was then rated with its ability to fulfil the given requirements (5 reducing to 1 for its ability). The products of the weighting and rating for each characteristic were then summed together. The statistically most suitable heat exchanger was that which received the highest overall score.

Desirable characteristics

Weightings for heat exchanger chatacteristics are given below:

Gas-to-gas suitability - weighting 5

- MHRU was to be designed as a gas-to-gas heat recovery system. A gas-to-gas heat exchanger was therefore essential.

Zero cross contamination between the gas streams - weighting 5

- this was important to prevent obnoxious odours being recirculated from exhaust to the working environment. This becomes acute in the food processing sector as ammonia is used in baking processes.

Ability to handle defined flow rates - weighting 5

- all heat exchangers were required to handle the flow rates defined by constraint 4, section 3.1.1 (page 32).

Heat exchanger temperature capability up to 473K - weighting 4

- the temperature range defined by constraint 3, section 3.1.1 (page 30) was 473K. If, in a particular application, a temperature greater than 473K was recorded these gases could be diluted with cooler gas (i.e. fresh ambient gas), to reduce the hot gases' temperature to that acceptable. This option reduced the weighing from 5 to 4.

Ease of cleaning - weighting 4

- exhaust gases from baking processes often contain a high proportion of moisture (see appendix 5, the quality-quantity survey, page 180). This condenses on heat transfer surfaces and is subsequently baked on by the hot waste gases passing over them. It was important to be able to remove these deposits to help maintain optimum performance of the MHRU.

Proven technology in gas-to-gas heat exchange - weighting 4

- the heat exchanger needed a proven track record in gas-to-gas heat recovery. The MHRU was to be designed to be commercially acceptable; potential customers are more confident purchasing equipment that has been proven in either the same or similar appliciations as their own. For this reason proven technology was given a high rating.

Price - weighting 4.

- it was important to keep the price of the MHRU as competitive as possible. To facilitate this the components within it also had to be competitively priced.

Efficiency - weighting 3

- efficiency of a heat exchanger is a compromise of size, weight, heat transfer, cost etc. A desired efficiency figure can usually be obtained by changing the size of the heat exchanger and the flow rate through it.

Ability to handle varying flow rates - weighting 3

- when recovering heat from multi-sources, there is a possibility that the waste gas flow rate may vary (i.e if one process stops for maintenance). Any variation in flow rate could result in pressure differences across the heat exchanger - the chosen type must be able to withstand these forces.

Corrosion resistance - weighting 3

- the MHRU would be designed to have long life expectancy. If a particular application had corrosive exhaust products, corrosion resistant derivatives of the given heat exchangers would be advantageous.

Compactness - weighting 2

- more compact heat exchangers give would a smaller overall unit in the final design, with cheaper production costs.

Weight - weighting 1

- this weighting was a result of two considerations: firstly, the MHRU would be designed to replace a component heat recovery system and would usually be mounted either in a plant room (which is designed for high floor loadings) or outside (where weight is not a problem); secondly, in the production of MHRUs, the manufacturer was equiped to handle heavy plant.

Results of the weighting and rating analysis are shown in table A7.2

Due to the closeness of the result (182 for the best 169 for the worst), it

Design Parameter	weighting	Plate (Rating)	weighting and rating	Wheel (Rating)	weighting and rating	Shell and tube (Rating)	weighting and rating	Heat Pipe (Rating)	weighting and rating
Gas-to-gas suitability	*****	5	25	5	25	4	20	5	25
Ability to handle defined flow rates	*****	5	25	5	25	5	25	5	25
Zero cross contamination between gas streams	*****	5	25	2	10	5	25	5	25
Temperature range - up to 473K (200°C)	****	5	20	5	20	5	20	5	20
Ease of cleaning	****	3	12	3	12	4	16	4	16
Proven technology in gas-to-gas heat exchange	****	4	16	4	16	5	20	3	12
Price	****	4	16	3	12	3	12	2	8
Efficiency	***	4	12	5	15	3	9	3	9
Ability to handle varying flow rates	***	4	12	5	15	5	15	5	15
Corrosion resistance (standard) (stainless steel)	** **	3 5	6 (10)	3 5	6 (10)	3 5	6 (10)	3 5	6 (10)
Compactness	**	4	8	4	8	3	6	5	10
Weight	*	5	5	5	5	1	1	3	3
Total for standard heat exchanger			182		169		175		174
Total (for stainless steel heat exchanger)			186		173		179		178
***** = very good * = poor									

Table A7.2 Weighting and rating analysis for the selection of a heat exchanger for use in the MHRU

was decided to attempt a design that could accommodate all the heat exchanger types considered. This, however, created a very open-ended design problem and for initial designs one type had to be selected. This was the plate heat exchanger as it received the best rating, and was readily available. Section A7.1.4 describes the selection of style and manufacturer of a device within this heat exchanger type.

A7.1.4 Selecting a Manufacturer of Heat Exchangers

Following a careful study of technical aspects (dimensions, efficiency, configuration etc.) and commercial aspects (availability, delivery, price) of plate gas-to-gas heat exchangers available (in late 1979) the Climate Company's range of (imported) heat exchangers was selected for the MHRU. Climate heat exchangers are of two types; type I, shown in figure A7.8 was suitable for flow ranges between 0.4-5m^3/s; type II, also shown in figure A7.8, was suitable for flow ranges betwen 2-10m^3/s. To obtain coverage of the required flow range for the MHRU (2-10m^3/s), three alternatives using these heat exchangers were found. The first involves the use of type I heat exchangers for lower flow rates, and type II for the larger flow rates. This idea was rejected as two separate designs for

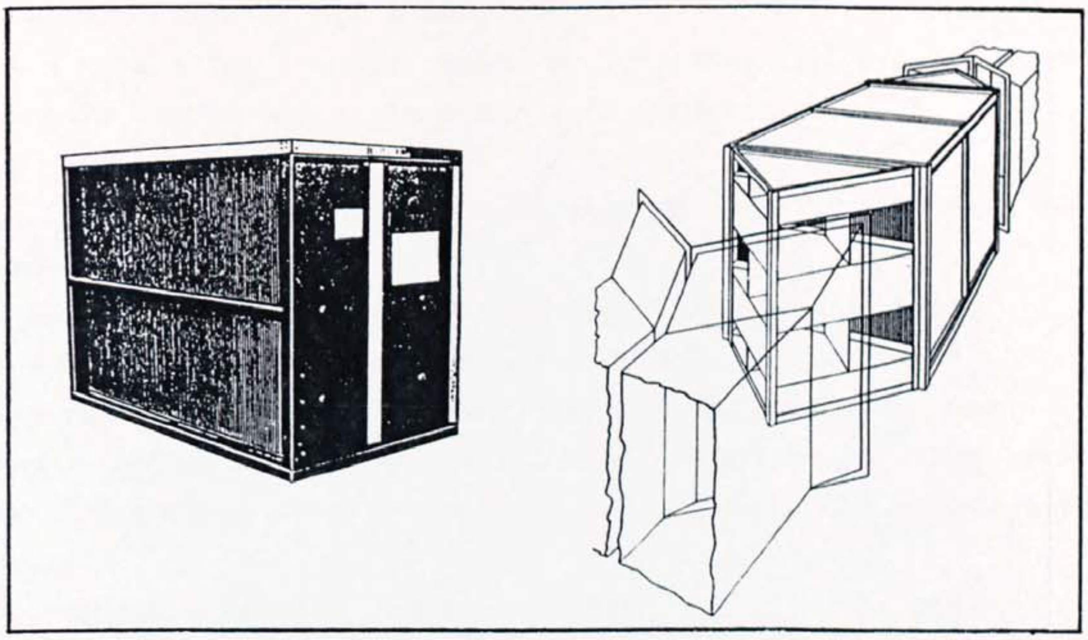


Figure A7.8 Climate Equipment Company heat exchangers

the MHRU would be required to accomodate the different heat exchangers. The second alternative would use single type I units for low flow ranges, and multiple type I units for flows above their individual range. The third method would use single type II units for the entire range. The following analysis shows that multiple type I units were preferred.

A7.1.5 Comparison of Type I and Type II Heat Exchangers

For the flow range, as stated in section 3.1.4 (page 38), of 3-5.2m^3/s, two type I heat exchangers (manufacturer's code HVRH 095) would be required, or a single type II unit (manufacturer's code HVRB 176). The following analysis uses various criteria to assess which of these combinations would best suit the MHRU.

Financial analysis

Both types of heat exchanger exhibit different efficiencies at different flow rates. On average over the given flow range, type I units exhibit a mean efficiency of 69 per cent, whilst type II, an efficiency of 66.3 per cent. Two type I units cost £235 more than one type II unit (in December 1979). For continuous operation at a mean throughput of 4.1m^3/s (mid-point of 3-5.2m^3/s) the type I units would repay their extra purchase price (through greater energy savings) in 0.7years. Although in the long term type I units would be more cost effective, this advantage is only marginal.

Physical Properties

Weight:

- total weight of two type I units 630kg

- total weight of type II unit 700kg

Type I units offer a weight saving of 70kg. From a materials handling view point smaller, lighter items are to be preferred.

Floor area:

Type I units would be mounted one on top of another. From manufacturer's data:

- total floor area required by two type I units . . $1.94m^2$
- total floor area required by a type II unit . . $3.20m^2$

These figures include the area of associated ductwork. The type I unit offers a saving in floor area of $1.26m^2$. In plant rooms, floor area is often at a premium and a unit offering such savings would be preferable.

Volume:

- volume occupied by two type I units . . $6.65m^3$
- volume occupied by a type II unit . . $6.40m^3$

The figures include the volume of associated ductwork. Hardware casing costs usually increase with the volume of components to be housed. This implies marginally higher manufacturing costs for the type I units.

A résumé of the above results is given in table A7.3 Multiple type I heat exchangers were selected for the MHRU as they occupy considerably less floor area than the type II heat exchanger.

Parameter	Heat Exchanger Choice	
	Type I units	Type II unit
Efficiency	*	
Financial		*
Weight	*	
Floor area	*	
Volume		*
* - preferred heat exchanger		

Table A7.3 Comparison of type I and type II heat exchangers

Filters and fans were also required in the MHRU.

A7.2 Filter Selection

Filters required for the MHRU fall into two categories, high temperature filters for waste gas filtration, and low temperature filters for fresh ambient gas filtration.

A7.2.1 High Temperature Filters

Only one type of filter was commonly available for waste gases up to a temperature of 473K, the metal mesh type. This filter consists of a series of flat metal meshes, analogous to those found in a domestic sieve, laid on top of one another. Each new mesh is slightly offset from the last to prevent any direct flow through the filter. Following competitive quotations from several companies, filters manufactured by the American Air Filter Company (AAF)(Birmingham) were selected.

A7.2.2 Low Temperature Filters

In normal applications fresh ambient gas (air) would be drawn through the MHRU to be heated by hot waste gases. Here, standard panel type air conditioning filters would be required and these consist of a polyurethane foam bonded to a metal frame. They may be washable or disposable depending on specification.

Should the MHRU be used in exceptionally dusty conditions a bag filter may be required. Holding greater quantities of dust than the panel filter, bag filters may also be fitted in normal circumstances where extended service intervals are required.

As panel and bag filters become dirty pressure drop through them increases. For some critically balanced systems this variation could be unacceptable and an automatic roll filter may be required to overcome this problem. Consisting of a roll of filter material, part of the filter is exposed to the gas flow. As this portion becomes dirty, so pressure drop through it increases. This is monitored by a differential pressure meter and when it exceeds a given value, a new portion of filter media is automatically wound from the supply roll to replace the dirty section, so maintaining pressure drop within given values.

To be as flexible as possible, the MHRU was to be designed to accomodate any of these three filter types. As a result of competitive quotations, panel filters were to be supplied by the Filter Supply Company (London), bag filters by Ozonair (Aylesford) and auto-roll filters by AAF (Birmingham).

A7.3 Fan Selection

Axial and centrifugal fans were available for use in the MHRU. The axial fan is primarily a high volume, low pressure device moving gas along its axis (and offering no change in the gas's path). The centrifugal type is a low volume, higher pressure device that changes the gas's direction through 90^{o}.

The choice of the type of fan was not made until later in the design, however, the reasons that lead to the final selection of centrifugal fans are given below:

- axial fans proved difficult to isolate from other plant in the MHRU whilst maintaining compact design;
- in the final design exhaust and fresh gas fans are mounted in the same part (or section) of the MHRU. The most suitable design for facilitating this employed centrifugal fans (the use of axial fans would have required an extra bend in the fan section which would have resulted in a larger overall unit).
- the centrifugal fan's ability to turn gases through 90^{0} increased the MHRU's installation flexibility.

Centrifugal fans exhibit two distinct and different characteristics dependent on the type of impeller used. Backward curved impeller fans have non-overloading profiles, intrinsically protecting their motor drive systems. This impeller design was adopted initially although, as supported by the following reasons, forward curved impellers were used in the final design:

- forward curved centrifugal fans operate at slower speeds, resulting in quieter, cheaper and lighter fans than their backward curved counterparts;
- forward curved fans are physically smaller in height than backward curved fans.

The final selection of fans was made from the Engart Company (Leicester) range of fans.

APPENDIX 8

DESIGN AND DEVELOPMENT OF THE EXHAUST GAS-TO-LIQUID EXCHANGER

APPENDIX 8

Design and Development of the Exhaust Gas-to-Liquid Heat Exchanger

A8.0 Exhaust Gas-to-Liquid Heat Exchanger Design

This appendix considers the design, manufacture and testing of a heat exchanger to recover heat from a diesel engine exhaust gas stream. Design calculations and predicted performances are described, and subsequently compared with actual figures recorded. This testing showed the single most important design constraint to be pressure drop.

Successful heat transfer performance of the first prototype, together with a sound financial outlook for a successful heat recovery scheme, prompted the client to commission the design of a second heat exchanger, with improved back pressure performance. A detailed analysis of pressure drop for both units is described. The appendix closes with a comparision of the two heat exchangers.

The first stage in the heat exchanger's development was that of design.

A8.1 Design - Stages of Calculation

The design of this heat exchanger can be divided into the following stages:

1) Calculation of heat obtainable from exhaust gases.
2) Calculation of surface heat transfer coefficients.
3) Calculation of the temperature at which (for the purposes of calculation) heat transfer takes place.
4) Calculation of the overall heat transfer coefficient.
5) Sizing of the heat exchanger.

General Assumptions

Three assumptions were made for design purposes:

1) Temperature and flow transients were negligible.
2) There was no change of phase.
3) The average overall heat transfer coefficient was uniform.

The first condition was substantiated by observation. Steady-state conditions were found to exist by the consistency of multiple measurements made simultaneously in both fluid streams. Condition 2) was also satisfied by observation and substantiated by a separate analysis of possible boiling within the heat exchanger. The weakest condition assumed was the uniformity of the overall heat transfer coefficient. The variation of this coefficient is dependent on the temperature distribution. In engineering design calculations, condition 3) approximates 'real' conditions.

The engines to which the heat exchanger would be connected were operated within stringent test conditions. Following the testing of the first prototype, back pressure, it was discovered, affected these conditions. At this point the client stated that back presssure must be reduced sufficiently to leave the engine unaffected by heat recovery. Heat transfer performance was of secondary importance. For this reason detailed design calculations have been omitted in favour of pressure drop calculations.

The first proposed design is shown in figure A8.1. This was accepted by the client and a prototype was manufactured. Testing started in late 1980.

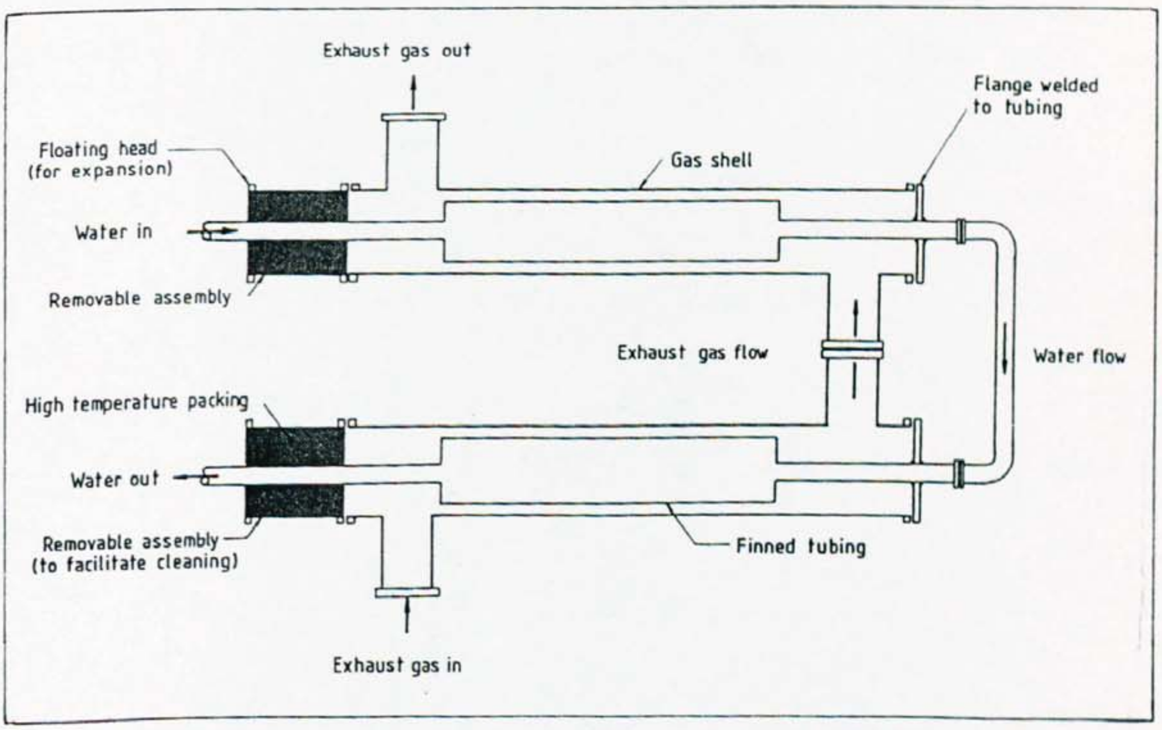


Figure A8.1 Diagrammatic arrangement of the exhaust gas-to-liquid heat exchanger, 001

A8.2 Testing

A8.2.1 Test Parameters Recorded

Testing conformed to procedures laid down by the American Institute of Chemical Engineers [86] and was divided into two distinct sections:

- tests carried out without turbulators in the heat exchanger;
- test carried out with turbulators in the heat exchanger.

Eight parameters were recorded on all tests as follows:

1) Exhaust gas temperature at inlet to the heat exchanger (t_1)
2) Exhaust gas temperature at outlet from the heat exchanger (t_2)
3) Water temperature - at inlet to the heat exchanger (t_3)
4) Water temperature - at outlet from the heat exchanger (t_4)
5) Ambient temperature (t_7)
6) Insulation surface temperature (t_8)
7) Exhaust gas flow rate (m_e)
8) Water flow rate (m_w)

Temperature measurements t_1 to t_4 were taken using four identical type K thermocouples (conforming to B.S. 4937 part 4 [199]). Sheathed, mineral insulated thermocouples were used to minimise effects of transient temperature response. Exhaust gas thermocouples were mounted directly in the flow streams. Heat conducting paste ensured intimate contact between pipe wall and thermocouples for water side measurements. The thermocouples were wired, using twin, solid core, electrically shielded, armoured, low loss cable, to a Leeds and Northrup chart recorder for continuous recording of the temperatures. Ambient temperature and surface temperatures (of the insulation) were taken using a hand held thermocouple thermometer.

Exhaust gas flows were measured using a pitot tube and inclined gauge manometer. Water flow readings were measured using a turbine type flow meter. An installation diagram showing these test points is given in figure A8.2.

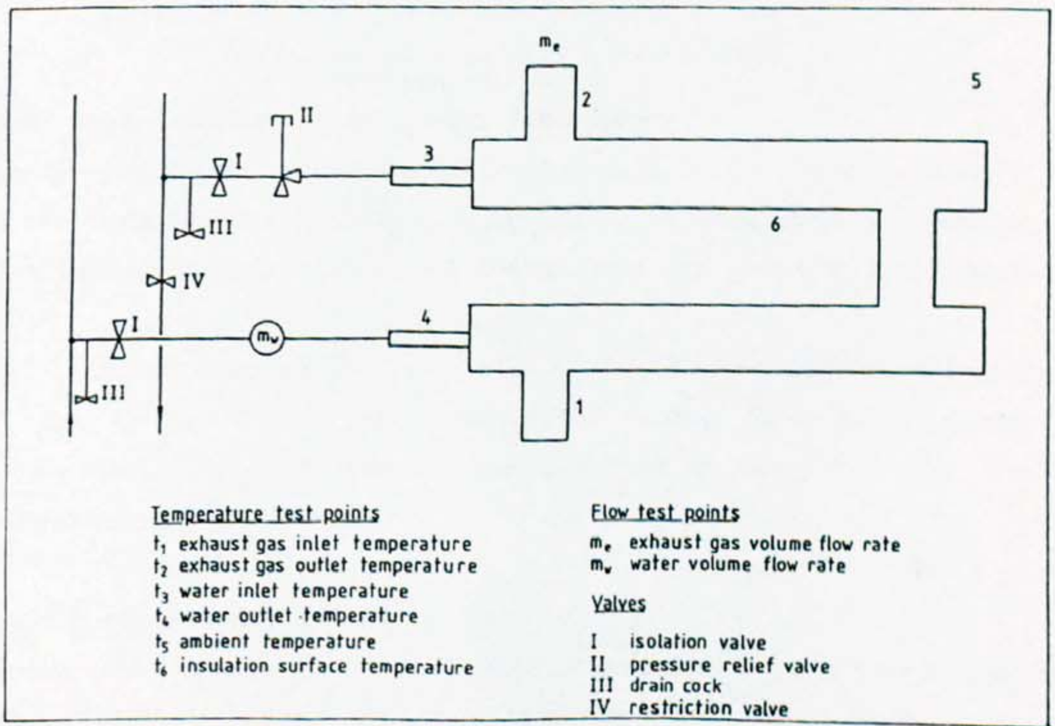


Figure A8.2 Installation diagram showing test points for the exhaust gas-to-liquid heat exchanger 001

A8.2.2 Setting-up

A preliminary back pressure test undertaken by the client suggested that the heat exchanger had no detrimental effect on the engine. Heat transfer testing was then allowed to begin. Initially water was passed through the heat exchanger at full bore for 2 hours, to flush the system and remove air.

A8.2.3 Heat Transfer Tests - Without Turbulators

The exhaust gas flow rate was constant for all tests. The water flow rate was adjusted, using valve IV (figure A8.2), to give varying water outlet temperatures. Sixty minutes were allowed for the system to equilibrate, at the end of which temperatures and flow rates were recorded. Water flow rate was constant throughout each test. The average flow rate was calculated using integrated meter readings from before and after the test. Results of the tests are given in table A8.1.

Test Number	Temperature difference (t_1-t_2) θ_e	Temperature difference (t_4-t_3) θ_w	Water flow rate	Heat transfer (calculated from water side)
	K	K	kg/s	kW
1	270	36	0.081	12.3
2	276	16	0.171	11.6
3	276	12	0.218	11.1
4	275	8.5	0.311	11.2
5	277	4.5	0.554	10.5
6	279	3.5	0.775	11.5
Mean	276	13.4	0.352	11.4
Exhaust gas inlet temperature (t_1) for all tests was 683K				

Table A8.1 Heat transfer test results for heat exchanger 001, without turbulators

A8.2.4 Heat Transfer Tests - With Turbulators

A similar sequence of tests were carried out on the heat exchanger, but with the turbulators in position. Again, sixty minutes were allowed for the system to equilibrate. Results of these tests are given in table A8.2.

It can be noted that all the results in table A8.1 are similar, and in table A8.2 are similar. This is because the water flow rate is not the dominant factor in heat transfer for this heat exchanger - it is the gas side coefficient.

A8.2.5 Back pressure Testing

Attempts were made to measure static pressure drop through the heat exchanger. The engine, a single cylinder low speed diesel, created pulsating effects in the exhaust and heat exchanger. This caused varying readings to be obtained when measured with an inclined gauge manometer. However, the pressure drop through the heat exchanger with turbulators was measured to be approximately 1050Pa.

Test Number	Temperature difference (t_1-t_2) θ_e	Temperature difference (t_4-t_3) θ_w	Water flow rate	Heat transfer (calculated from water side)
	K	K	kg/s	kW
1	298	25	0.114	12.1
2	296	23	0.133	12.9
3	297	19	0.162	13.0
4	298	19.5	0.170	14.0
5	298	8	0.440	14.9
6	298	2.5	1.420	15.0
Mean	298	16.2	0.407	13.7
Exhaust gas inlet temperature (t_1) for all tests was 683K				

Table A8.2 Heat transfer test results for heat exchanger 001, with turbulators

A8.3 Analysis of Test Results

Analysis of test results has been divided into two parts; assessment of the accuracy of the results obtained and a comparison of predicted and actual results.

A8.3.1 Accuracy of Results - Error Analysis

Error can be divided into 3 categories:

- random error;
- systematic personal error;
- systematic error of instrumentation.

Random Error

Random errors are usually caused by the observer. In the measurement of temperatures, t_1 to t_4 were recorded automatically on a chart recorder. When subsequently analysed, all readings taken from the print-out were checked several times. Temperatures t_7 and t_8 were recorded using a hand-held digital read-out thermocouple thermometer. The digital nature of the read-out and the consistency of multiple measurements suggested no error had occured in temperature readings.

Water flow measurements were taken from a flow meter with a digital read-out. This reading was noted at the begining and end of every test. Preceding test 'finish' readings were consistent with next test 'start' readings, and from this it was assumed that no error was made in these readings.

Systematic Personal Error

This occurs during the reading of instrumentation by an operator. Analogue displays are open to judgement by the operator, as was the case with the graphical output from the temperature recorder. It was estimated that the readings taken from the chart had an error no greater than 1K. All other instruments had digital read-outs and this problem did not arise.

Systematic Error of Instrumentation

Several techniques were used to locate and reduce systematic error of instrumentation. Consider t_1 to t_4:

1) A continuous plot of t_1 to t_4 was obtained for the duration of the test. A trend to steady state could be seen. (There were no observable effects of systematic error).
2) After several tests, thermocouple connections t_1 to t_4 were rearranged at the temperature recorder i.e. thermocouple t_1 was measured using the circuit previously used for t_4, t_2 for t_3 etc. Results obtained were indentical to those obtained previously.
3) Each thermocouple in turn was removed from its test location and allowed to cool to ambient temperature. Readings correlated, to within $\pm$2K, with those measured using a mercury-in-glass whirling hygrometer.

The hand-held thermocouple thermometer used to measure t_7 and t_8, was compared frequently with results obtained from the temperature recorder. At ambient conditions the temperatures agreed to within 1K, and at higher temperatures (gas inlet temperature) to within 1-2K.

For flow measurement systematic errors were not checked. The instrument was, however, overhauled prior to installation.

A8.3.2 Accuracy of Heat Transfer Results Obtained

Water side heat transfer was calculated from the equation $Q=mc\theta$ where Q is the quantity of heat imparted to the water, m its mass flow rate, c its specific heat capacity and θ its temperature rise. Error in a product is the sum of the individual errors [200] and the error of these three were calculated and subsequently summed to give the compound error.

Error in m, from the turbine meter manufacturer's data, was 1 per cent for the flow rates used in testing. From the temperature recorder manufacturer's data, instrument error in temperature readings between 373K and 773K would be $\pm$0.35K. This, coupled with the resolution error (stated above) of 1K, gives a total of $\pm$1.35K.

Thermocouples are also sources of inaccuracy. Conforming to BS 4937 part 4, their error should be less than $\pm 2.2K$ for temperatures up to 550K. Temperatures t_1 to t_4 were measured using thermocouples manufactured in the same batch. It is likely that these thermocouples will all produce identical errors, and in the measurement of temperature difference, rather than absolute values, this was thought acceptable. However, measurements of the same source by all thermocouples gave identical readings and this error was subsequently ignored. The total error for temperature measurement was taken as $\pm 1.4K$. At the mean value of θ_w, 13.4K (table A8.1, page 213), the worst possible error expected would increase or decrease θ_w by the greatest amount i.e. by decreasing t_3 by 1.4.K and increasing t_4 by 1.4K (or by increasing t_3 by 1.4K and decreasing t_4 by 1.4K). The worst case could change the mean temperature difference by ± 21 per cent. Error in c has been assumed negligible, as c is a function of temperature, which itself is not error free. In the worst case the total error could be 22 per cent (1% + 21% + 0%, error in m + c + θ). This, however, is unlikely to occur as positive and negative errors cancel each other out.

A8.3.3 Heat Transfer at Design Conditions

For the design of the heat exchanger the following conditions were supplied by the client (excluding those marked '1' which are calculated values):

- exhaust gas inlet temperature . . .(t_1) = 811K;
- exhaust gas outlet temperature . . .(t_2) = 450K;
- water inlet temperature . . .(t_3) = 366K;
- water outlet temperature[1] . . .(t_4) = 389K;
- exhaust gas flow rate . . .(m_e) = 0.05kg/s;
- water flow rate[1] . . .(m_w) = 0.17kg/s.

Using these figures a value for the log mean temperature difference, θ_m*, of 209K, was obtained, and for heat transfer, a rating of 17.7kW.

A8.3.4 Heat Transfer at Test Conditions

Under test conditions at the design flow rate without turbulators (test 2, table A8.1, page 213), the average temperatures recorded were:

---

* The log mean temperature difference (θ_m) is calculated from

$$\theta_m = \frac{T_2 - T_1}{\log_e \frac{T_2}{T_1}} \qquad \text{where} \quad T_1 = (t_1 - t_4) \quad \text{and} \quad T_2 = (t_2 - t_3)$$

t_1 = 686K t_2 = 410K t_3 = 382K t_4 =398K

Using these temperatures the log mean temperature difference (θ_m) became 112K, approximately 54 per cent of its design value. The change in θ_m was due largely to a difference between stated and measured values of t_1, the exhaust gas inlet temperature.

Using this revised figure for θ_m (but keeping all other design values the same), the expected heat transfer became 11.4kW. In practice the average heat transfer at design conditions (from table A8.1, test 2) was recorded at 11.6kW (1.7 per cent higher).

A8.3.5 Turbulence Promoters

Heat transfer without turbulators at the design flow rate (from table A8.1, test 2) was 11.6kW. With turbulators inserted, the heat transfer (from table A8.2, test 4) was 14kW, an increase of 20.7 per cent. Average over all tests this increase was 20.2 per cent.

Turbulators increased heat transfer in two ways: firstly, by improving turbulence in the exhaust gas stream, so promoting increased heat transfer; secondly, the turbulators were in contact with the finned tube, effectively increasing its surface area for heat transfer. The dominant effect is likely to be the former, as contact between turbulator and fin was poor.

This completed heat transfer tests on the first prototype. Different tests were then undertaken by the client to ascertain the affect the heat exchanger was having on the engine itself.

A8.3.6 Static and Dynamic Back Pressure Testing

This testing was undertaken solely by the client and was conducted with the turbulators in position. Due to time limitations no testing was undertaken without turbulators. A 10 day test was carried out and, although no details of the results were given, the final outcome was:

> "The heat exchanger did have an effect on the performance of the engine and, as such, must be modified to erradicate or significantly reduce these effects."

The client stated that back pressure, both static and dynamic*, was the cause of the adverse effect. Prestige, coupled with the sound financial viability for a successful heat exchanger, prompted the commissioning of a second design, 002, that should exhibit improved back pressure performance.

---

* Dynamic effects are those associated with pressure waves (and reflections of those waves) caused by exhaust gases.

A8.4.2 Ducting Losses and Heat Transfer Losses

The analysis can be divided into two parts: pressure drop associated with heat transfer surfaces (heat exchanger section number 3); and pressure drop associated with ducting of gases to and from these heat exchange surfaces (section 1, 2, 4-7). For 001 without turbulators :

- heat exchange pressure losses = 364 pa
- ducting pressure losses = 305 pa

Heat Exchange Pressure Losses

Pressure drop analysis has not yet considered the heat exchanger with turbulators. No documented analysis techniques were found that accurately calculated pressure drop as a result of turbulence promoting devices. However, a tentative analysis of the friction factor using similar turbulence promoters had been undertaken by Smithberg and Landis [88]. Their correlations suggest a doubling of the friction factor and a doubling of pressure drop for the heat exchange surfaces. Other work by Gambill and Bundy [89,90] supports an increase in friction factor. Of certainty is that turbulence promoters do increase pressure drop, and if included in 001, could increase it by (very roughly) 35 per cent to over 1000Pa. This ties in closely with the measured value of 1050Pa (section A8.2.5, page 213).

Ducting Losses

Ducting losses account for over 46 per cent of the total pressure drop through the heat exchanger without turbulators. In revising the heat exchanger design, both heat exchange and ducting pressure losses were carefully considered.

A8.5 Design of 002

Both static and dynamic back pressure effects had to be reduced if 002 was to be acceptable. The following design changes were made to help achieve these objectives:

- reduction of heat exchanger shell length whilst maintaining heat transfer surface area. (This was achieved by placing a water jacket around the previously unutilised gas shell);
- removal of the turbulators;
- bends were fitted at gas inlet and outlet to replace the square elbows;
- divergent pieces replaced abrupt enlargements at gas inlet and outlet.

The final modified design is shown in figure A8.4. and a detailed calculation of its pressure drop is given in table A8.4

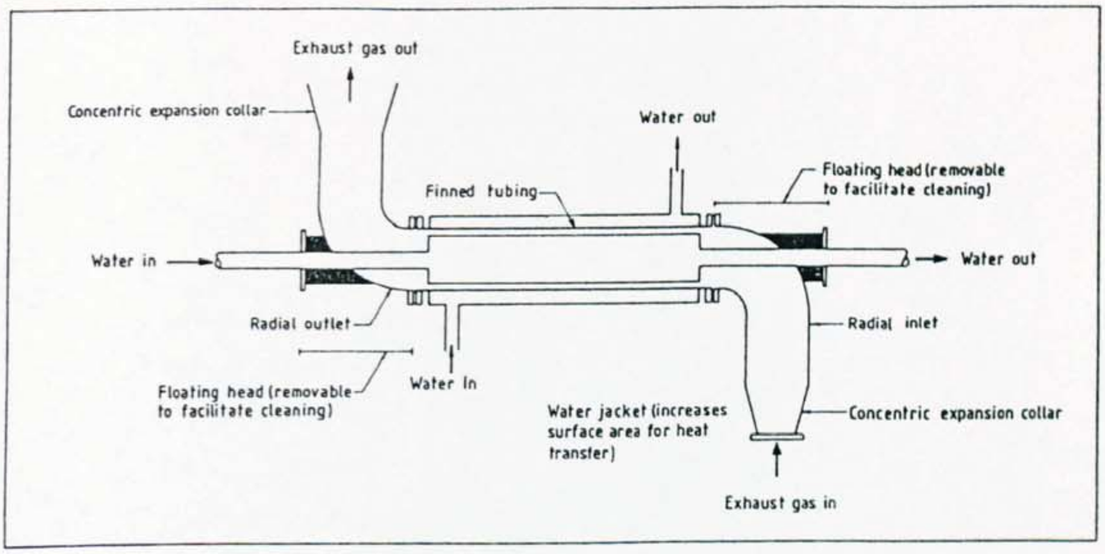


Figure A8.4 Diagrammatic arrangement of exhaust gas-to-liquid heat exchanger 002

This design gave a much smoother gas flow and this, it was anticipated, would reduce back pressure considerably.

Heat exchanger section number (see figure A8.5)	Density of gas[1] ρ	Velocity of gas v	Velocity pressure[2] ρv	'K' value[3]	pressure drop[4] p
	kg/m^3	m/s	Pa		Pa
1	0.519	12.7	42	0.1	4.2
2	0.536	11.8	37	0.2	7.5
3	0.643	10.7	-	-	286[7]
4	0.851	7.2	22	0.2	4.4
5	0.851	3.9	6	0.1	0.6
6	0.851	3.3	5	1.0	5.0
Total Pressure Drop 308Pa					
1,2,3,4,7 for notes see table A8.3					

Table A8.4 Pressure drop analysis for heat exchanger 002

A8.6 Comparison of Former and Revised Designs

This comparision of 001 and 002 has been considered under the following headings, pressure drop, manufacturing and design.

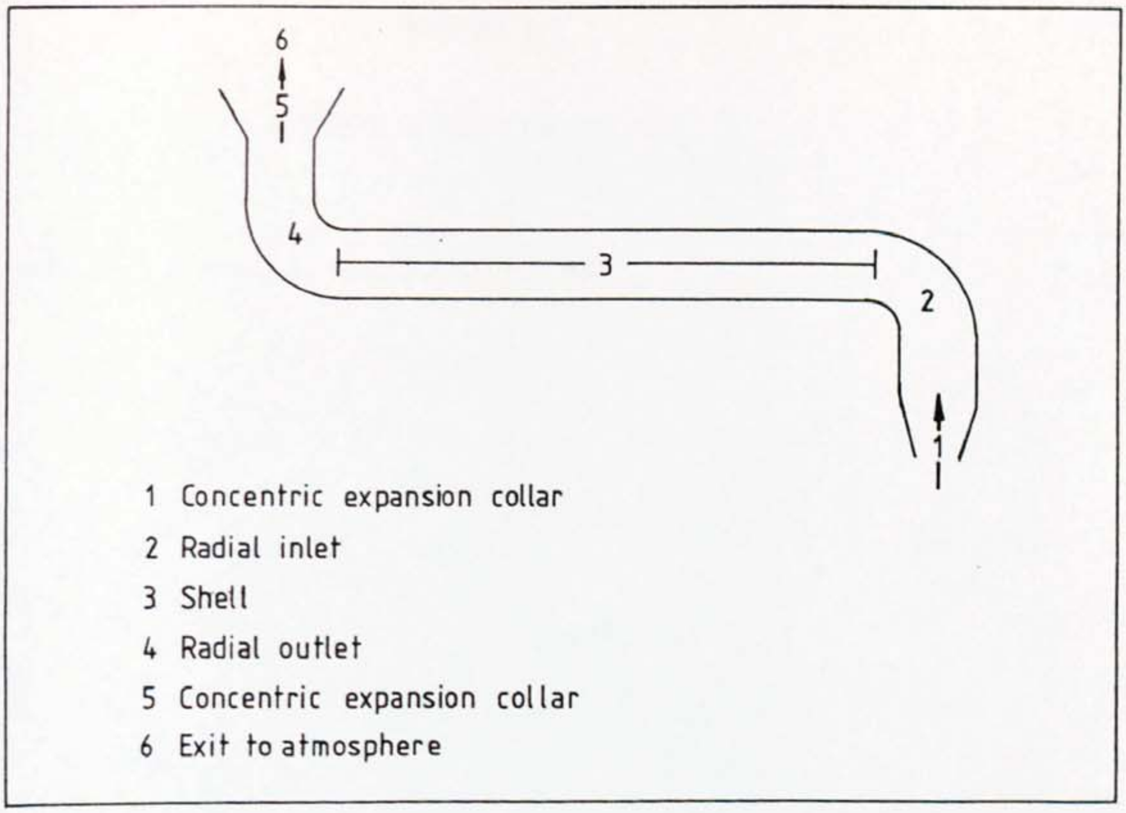


Figure A8.5 Divisions of exhaust gas-to-liquid heat exchanger 002 for pressure drop analysis

Pressure Drop

002 shows a reduction in pressure drop of 54 per cent and 69 per cent over 001 without turbulators and with turbulators. Testing by the client revealed no adverse effects on the engine as a result of fitting the 002 heat exchanger.

Manufacture

002 is also constructed totally from standard industrial pipework fittings, and requires only simple high quality welding for fabrication.

Design

002 is a single unit (not two, as was 001) which gives identical operating advantages to 001, i.e. minimal maintainence, but in a more compact device.

A8.7 Conclusions

The 002 design was accepted by the client and manufacture and installation of a second prototype took place in August, 1981. Heat recovery equipment retrofitted often affects the orignal system's operating characteristics. The 002 design had no detrimental effect on the engine from which it was recovering heat. This design was approved by the client.

APPENDIX 9

A TECHNICAL BROCHURE FOR THE MHRU

APPENDIX 10

EDITORIAL RESPONSE ANALYSIS

APPENDIX 10

EDITORIAL RESPONSE ANALYSIS

A10.0 Editorial Response Analysis

A 10.1 Overall Responses

Editorial coverage of the MHRU was obtained in 11 journals between October and December 1981. A total of 320 responses was obtained and their distribution between those journals is shown in figure A10.1 (page 228). All responses were placed into one of the following 9 groups, and their distribution between these is shown in figure A10.2 (page 228):

1) managing directors, chairpersons;
2) directors;
3) partners and associates, consultants, Chartered Engineers;
4) energy managers;
5) senior engineers, area engineers, managers, assistant managers;
6) project and other engineers;
7) other technical jobs (maintainence);
8) not known;
9) academics.

The responses in the 9 groups for each individual journal are given in figures A10.3 to A10.13 (page 229).

A10.2 Differentiating Between Required and Other Responses

As stated in section 2.6 (page 24), the MHRU was aimed specifically at senior management, those people who would have the responsibility for ordering such equipment. It was important, therefore, to ascertain, not only which journal gave the best total response, but which gave the best response of the required type. Groups 1 to 5 above encompass those people and table A10.1 shows their total as a percentage of the total response for each journal, and as a percentage of the total response for all journals.

A10.3 Results

The editorial promotion provided valuable information about the 11 journals and their readers. The following points can be made from the information derived from their analysis:

- Heating & Air Conditioning Journal showed the greatest response (77), the largest response of the required type (37), the greatest percentage of the total responses (23 per cent), and the biggest ratio of responses to circulation number (2×10^{-3});
- Works Management had the second largest response of the required type but the largest percentage of response (81 per cent) in the required groups;

Journal	Total number of responses for each journal	Number of responses of the required type	Responses of the required type as a percentage of the total response from each journal	Responses of the required type as a percentage of the total response from all journals	Circulation figures	Responses for each journal divided by its circulation figure
	No	No	%	%	No	No $\times 10^{-3}$
Building Services	34	3	9	2	17 000	0.2
Energy Manager	24	17	71	11	17 500	1.0
The Engineer	24	13	54	8	41 000	0.3
Heating & Air Conditioning Journal	77	37	48	23	19 000	2.0
Heating and Ventilating News	26	17	65	11	22 150	0.8
Heating and Ventilating Review	44	7	16	5	N/A	N/A
The Plant Engineer	2	0	0	0	9 300	0
Process Engineering	13	10	77	6	18 450	0.5
Production and Industrial Equipment Digest	28	22	79	14	N/A	N/A
What's New In Industry	21	10	48	6	45 770	0.2
Works Management	27	22	81	14	24 500	0.9
(N/A - not available)						
TOTAL	320	158	-	100	-	-
MEAN	29.1	14.4	49.8	9.1	26 940	0.66

Table A10.1 Editorial response analysis by individual journal

- Energy Manager, Heating and Ventilating News, Process Engineering and Production and Industrial Equipment Digest all had high percentages of their total responses in the required groups (71, 65, 77 and 79 per cent respectively);
- Building Services had the third highest overall response but only 9 per cent of these were of the required type;
- The Plant Engineer had the lowest response of all (2) and none of the required type;
- From this exercise the journals' suitability for future use can be arranged approximately as follows: (1) Heating & Air Conditioning Journal; (2) Works Management; (3) Production and Industrial Equipment Digest; (4) Energy Manager; (5) Heating and Ventilating News; (6) The Engineer; (7) Process Engineering; (8) What's New in Industry?; (9) Heating and Ventilating Review; (10) Building Services; (11) The Plant Engineer.

Editorial is usually a once-off occurence which, for MHRU test marketing purposes, has now been used. It provided valuable information about the journals themselves and the type of people that read them. In early 1981 it was thought that direct advertising would be used to provide coverage of the MHRU's market launch. Such information would be useful for selecting the best journal in which to advertise. Heating & Air Conditioning Journal and Works Management would be recommended for this rôle. (In the final launch limited funds prevented the use of direct advertising).

This analysis also revealed that editiorial provoked a greater response than that expected from direct advertising. Equivalent direct advertising would have been expected to yield approximately 260 responses [124] - editorial resulted in 320 responses, 23 per cent higher.

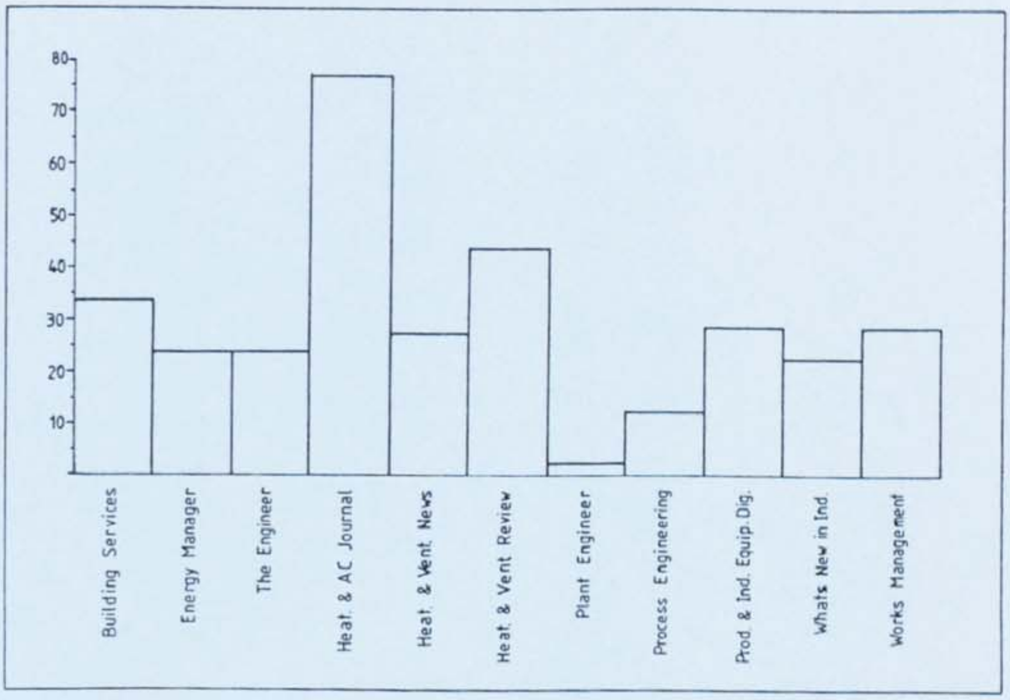


Figure A10.1 Total response from editorial in 11 journals

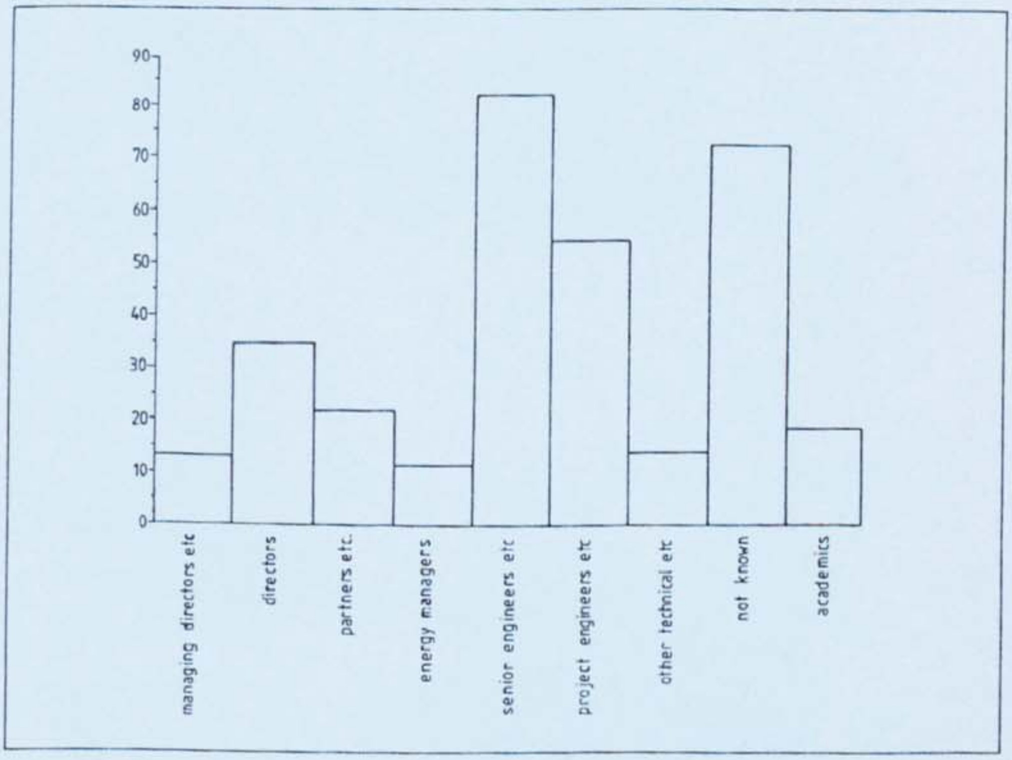
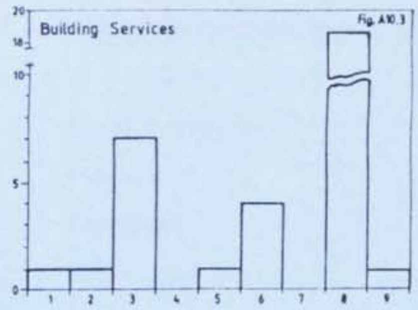
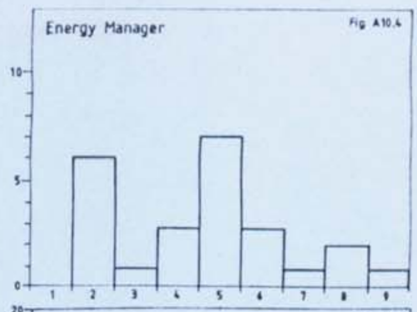
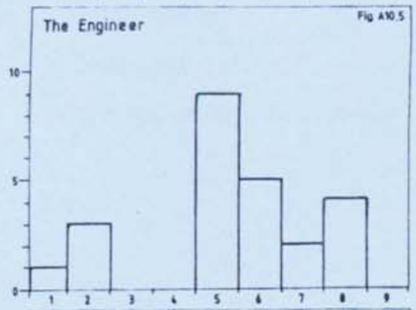
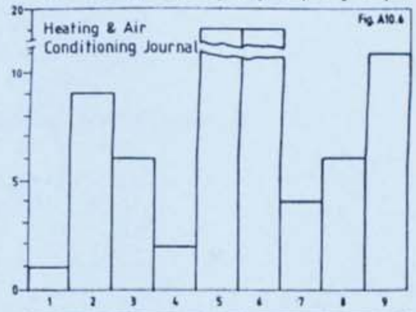


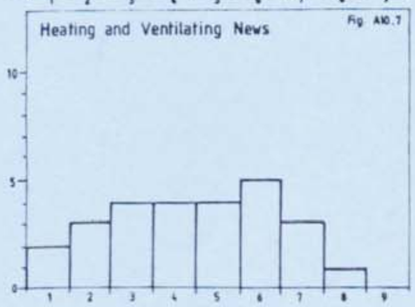
Figure A10.2 Editorial response analysis for nine catagories of people (for all journals)

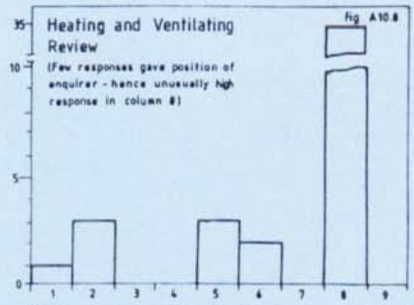


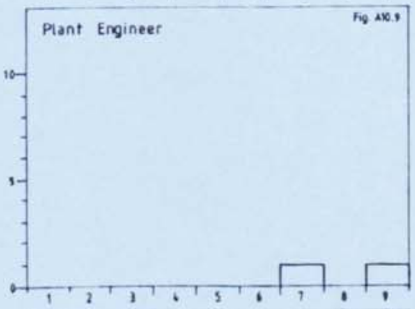


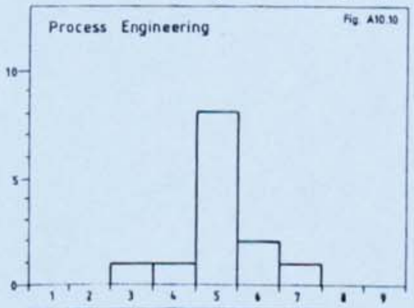


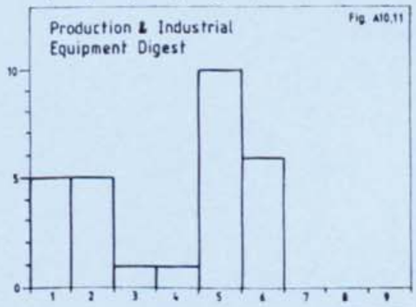


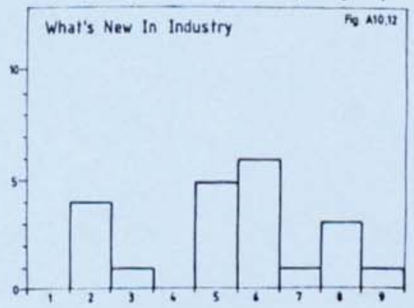


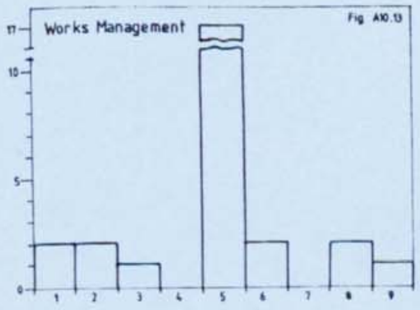




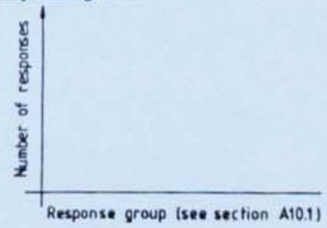








Key to figures



APPENDIX 11

PROTECTION OF INDUSTRIAL IDEAS AND INVENTIONS

APPENDIX 11
PROTECTION OF INDUSTRIAL IDEAS AND INVENTIONS

A11.0 Legal Framework

Four aspects of legal protection of industrial ideas are described in this appendix:

- patents;
- copyright;
- registered design;
- trade marks;

The role of technical papers for this purpose is also discussed.

A11.1 Patents

Patents are probably the most well known of the protection methods. Patents offer a limited monopoly, granted by a government, to an inventor (or an inventor's employer) in return for making an invention public by the publication of its specification at the patents office. Although seemingly contradictory, patents offer protection of an invention whilst helping to promote technical progress and stimulate research. In applying for a patent the invention must be published (see table A11.1). This publication alerts others to the invention, so stimulating research, and at the same time, legally granting the inventor a monopoly to exploit the invention. Ownership of a patent in the U.K. prevents others from copying that invention for a period of 20 years.

1) File the description of the invention with the patent office (provisional application). 12 months are then allowed for development, commercial testing etc. of the initial invention. 2) Before a 12 month period has elapsed, the patent should be changed to a complete application. Any changes from the provisional application can be included in the complete application. 3) A search is then undertaken to check that the patent claims are not anticipated by earlier patents or provisional applications. This search is approximately 15 months from the provisonal application. 4) Approximately 18 months from the provisional application, the first publication is released. 5) Within 6 months from the first publication, substantive examination is requested. Thereafter the examiner checks the wording of the patent and any prior articles cited, and makes a desision as to whether or not a patent will be granted. Granting and second publication may then follow. 6) The above procedure must be completed within four and a half years from the filing of the provisional application.
Note a detailed application procedure can be found in reference [203]

Table A11.1 Six stages to patent application

With increasing competition some companies now feel that such protection is inadequate and certainly difficult to enforce; some feel the only way of protecting their ideas is to keep them secret, and do not patent them to avoid the obligatory publication.

Patents do, however, have a secondary advantage which may influence that decision. They make good public relations (PR) material and, used in this role, can foster good will and enhance a company's image. Whilst it may be facile to presume that a company may undertake patent protection from a purely PR stand point, this extra facet may certainly influence that decision.

The two reasons outlined , protection and PR, promoted the sponser to take out the following patents on the exhaust gas-to-liquid heat exchanger 001:

United Kingdom	provisional patent	8000582
	full patent	2066937
Canada	provisional patent	368279
U.S.A.	provisional patent	222097
Japan	provisional patent	5600081

Following the development of the 002 design a second U.K. patent, number 8130561, was applied for.

Patents are taken out in the countries in which protection is required and each patent must be filed in that particular country. This is usually achieved through a patent agent based in the U.K.

Costs incurred in pursuing the above patents are listed in table A11.2

A11.2 Copyright

Copyright is a protection granted automatically, without the need for any registration, to prevent the deliberate copying of original work. It applies to the following groups only: literary works, dramatic works; musical works; artistic works; sound recordings; cinematograph films; television broadcasts; published editions of work. All copyright law is contained in the Copyright Act of 1956 and the Copyright (Ammendment) Act, 1971.

Copyright lasts for 50 years from the death of the author, and protects the author from the unlawful reproduction of original work. It is concerned with the copyright of physical material, not with the

Patent number	Services	Cost (£)
8000582 (UK)	Drafting and filing patent application (including informal drawings)	251.85
	Drafting and regularising patent application, filing a request for preliminary examination and search, preparation and filing of claims, abstract, formal drawings and statement of inventorship	201.25
	Novelty report	36.80
	Substantive examination	120.75
8130561 (UK)	Drafting and filing patent application (including informal drawings)	290.95
368279 (Canada)	Filing patent application corresponding to U.K. patent 8000582	394.00
222097 (USA)	Filing patent application corresponding to U.K. patent 8000582	348.00
5600081 (Japan)	Filing patent application corresponding to U.K. patent 8000582	570.00
	Total	£2113.06

Table A11.2 Patent application costing

reproduction of ideas [134]. Engineering drawings are protected in copyright law. For the actual design, however, the ideas themselves must be protected. This can be achieved through the registration of the design.

A11.3 Registered Design

Protection of industrial designs is a separate subject and is contained in the Registration Designs Act 1949 and the Design Copyright Act 1968. Protection of industrial design is given in section 7 of the 1949 Act: It provides that:

> "the registration of a design gives to the registered proprietor the copyright in the registered design, that is to say, the exclusive right in the United Kingdom and the Isle of Man to make or import for sale, or for use for the purposes of any trade or business, or to sell, hire or offer for sale or hire, any article in respect of which the design is registered, being an article to which the registered design (or a design not substantially different from the registered design) has been applied" [134].

In copyright, to stop the infringment of an idea, there must be proof that the idea was deliberately or recklessly copied, since it is always possible that two 'artists' may have independently created the same thing.

Registered design, however, can protect against even unintentional or innocent imitation or reproduction of ideas or designs. Protection of an industrial design lasts for 15 years from the first industrial application.

Recovery of heat from diesel engine exhaust gases is not a new idea. For this reason the exhaust gas-to-liquid heat exchanger could not be protected under registered design.

A11.4 Trade Marks

Trade marks can be words, symbols or devices and are used to distinguish one manufacturer's products from another. 'Ford', 'Apple' and 'Tipp-Ex' are trade marks; they should not be confused with generic words, which simply describe things - motor car, computers and correction fluid.

Good trade marks can be of great value, and it is important not to use them in a way that simply turns them into generic words (aspirin, linoleum, petrol and kerosene all used to be trade marks [204]).

Trade marks may or may not be registered. If a trade mark is registered, it allows the original holder to stop others from using it. If the trade mark is not registered others can only be stopped from using it by proving that the originator or original company has a public reputation in that trade mark and that a competitor was 'passing-off' their goods as the original company's.

HE-RO, a foreshortening of the words 'heat recovery', was the trade mark used by the sponsor to describe its range of heat recovery products. HE-RO was also the trade mark for a series of hand tools. When registered, the sponsor's application was also granted, as the difference in the areas of use was so great.

A11.5 Technical Papers

Technical papers can describe a product or an idea and register, in copyright, that idea to the author. They are an aid or reinforcement to the other forms of protection described, as on their own their usefulness is moral rather than legal. In a legal argument over the ownership of an idea or invention, however, any published material supporting the date of invention is of advantage. A technical paper is to be written about the exhaust gas-to-liquid heat exchanger in early 1983.

A11.6 Protection of the Exhaust Gas-to-Liquid Heat Exchanger

Summing up, the exhaust gas-to-liquid heat exchanger design has been protected by the following:

- patents: a total of 6 pending or full patents in 4 countries;
- Copyright: exists on all design calculations and drawings;
- registered design: not applicable;
- trade mark: HE-RO is the registered trade mark of the sponsor's heat recovery products;
- technical paper: to be written in early 1983.

APPENDIX 12

ANALYSIS OF SEVERAL METHODS OF CALCULATING SCHEME PAYBACK

APPENDIX 12

ANALYSIS OF SEVERAL METHODS OF CALCULATING SCHEME PAYBACK

A12.0 Calculation of Scheme Payback

There are three common methods of calculating scheme payback, simple payback, average rate-of-return on investment and discounted cash flow internal rate-of-return. There are many variations of these methods depending on whether various factors, some of which are listed below, are included in the calculation:

- cost of energy - constant or escalating;
- cost of borrowing capital;
- maintenance and labour cost;
- operational personnel;
- cost of floor area occupied;
- whether the effect of capital allowances are considered;
- depreciation rates;
- time span of financial evaluation.

An evaluation of the three basic methods considering the effects of some of these factors was undertaken. The figures used in the calculations were taken from an actual heat recovery scheme proposed by the sponsor and were:

- capital cost of system . . . .£100 000 pa;
- value of fuel saved . . . .£50 000 pa;
- running cost (electricity) . . . .£3 000 pa;
- maintenance cost . . . .£2 600 pa;
- personnel cost . . . . . .£1 300 pa;
- other costs . . . . small.

(pa - per annum)

A12.1 Simple Payback

A12.1.1 Simple Payback with no External Considerations

Simple payback is the quotient of capital cost and nett savings. The capital cost, in this case, was £100 000. Net savings are the value of fuel saved less the cost of achieving those savings i.e. less running, maintenance and personnel cost.

With simple payback, the given scheme has a payback of:

$$\frac{100\ 000}{50\ 000 - (3000 + 2600 + 1300)} = 2.32 \text{ years}$$

A12.1.2 Simple Payback Considering Inflation

In recent years the cost of energy has increased by 25 per cent per annum and general inflation by 13 per cent. (These figures change from year to year and should be regarded as approximate rather than actual.) Incorporating these factors, changes the payback in section 12.1.1 from 2.32 years to 2.04 years (see table A12.1).

No	Item	Year 1	Year 2	Year 3	Year 4	Year 5
1	Value of fuel savings [A]	50 000	62 500	78 125	97 656	122 070
2	Running cost [A]	3 000	3 750	4 688	5 860	7 325
3	Maintenance [B]	2 600	2 938	3 320	3 752	4 240
4	Personnel [B]	1 300	1 469	1 660	1 876	2 120
5	Net Saving (1 - (2+3+4)	43 100	54 343	68 457	86 168	108 385
6	Capital remaining (100 000 - accumulated saving)	56 900	2 557	-65 900	-152 068	-260 453
7	Payback (years)	1	1	0.04	-	-
	Total payback period 2.04 years		Total 5 year gain £260 453			
	A Energy inflation at 25 per cent per annum					
	B General inflation at 13 per cent per annum					

Table A12.1 Calculation of payback considering escalating fuel and other prices

A12.1.3 Simple Payback Considering Inflation, Residual Value and Tax Allowances

A heat recovery scheme is capital equipment and will always have some value. For accounting purposes this 'residual value' is usually taken as 42 per cent of the initial capital cost of the scheme. Considering this, the tax allowance on capital (received in year 2), and the other factors considered so far, the payback from, table A12.2, becomes 2.24 years.

No	Cash	Item	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
		Capital Cost	100 000					
1	Income	Energy savings [A]	-	50 000	62 500	78 125	97 656	122 070
		Investment allowance [B]	-	-	17 654	-	-	-
		Residual value [C]	-	-	-	-	-	42 000
2	Outgoings	Operating cost [D]	-	3 000	3 750	4 688	5 860	7 325
3		Maintainence [D]	-	2 600	2 938	3 320	3 752	4 240
4		Personnel [D]	-	1 300	1 469	1 660	1 876	2 120
5		Loan interest [E]	-	14 000	14 000	14 000	14 000	14 000
6		Net Saving (1 - (2+3+4+5))	-	29 100	57 997	54 457	72 168	136 385
7		Capital remaining (100 000 - 6)	100 000	70 900	12 903	-41 554	-113 722	-250 107
8		Payback (years)	-	1	1	0.24	-	-
		Total payback period 2.24 years			Total 5 year gain £250 170			
		A Energy inflation at 25 per cent per annum			D General inflation 13 per cent			
		B Investment allowance 52 per cent			E Loan interest at 14 per cent			
		C Residual value 42 per cent						

Table A12.2 simple payback considering inflation, residual value and tax allowance

A12.2 Average Rate-of-Return on Investment

A12.2.1 Average Rate-of-Return on Investment Considering Inflation

This method of payback calculation has evolved from accountancy and is more applicable to financial calculations involving capital (and the cost of this). The average rate-of-return (r-o-r) requires the calculation of r-o-r every year for a given period (i.e. five years). Using figures quoted in section A12.0 (page 237) and from table A12.3, the average r-o-r (considering inflation) is 72 per cent. This method is widely used because of its compatibility with existing accounting systems.

Item	Year 1	Year 2	Year 3	Year 4	Year 5
Net savings (£) [1]	43 100	54 343	68 457	86 168	108 385
Annual rate-of-return (%)	43	54	68	86	108
Average rate-or-return over 5 years: $\frac{\text{total savings over 5 years}}{5 \times \text{capital cost}} = \frac{£360\ 453}{£500\ 000} \times 100\% = 72\%$					
1 Taken from table A12.1					

Table A12.3 Average rate-or-return method for assessing energy savings

A12.2.2 Average Rate-of-Return on Investment Considering Inflation, Cost of Finance and Depreciation

An extension of the method in section A12.2.1 considers the cost of finance and depreciation as well as inflation. The result, calculated in table A12.4, gives a r-o-r of 73 per cent. (A common alternative to this method uses straight-line depreciation, rather than a reducing balance). For the case above, but with straight-line depreciation over five years (i.e. depreciation is £20 000 per year), the average r-o-r becomes 63 per cent.

	Item	Year 1	Year 2	Year 3	Year 4	Year 5
1	Capital [A]	100 000	80 000	64 000	51 200	40 960
2	Net saving [B]	43 100	54 343	68 457	86 168	108 385
3	Depreciation [C]	20 000	16 000	12 800	10 240	8 192
4	Funding cost [D]	14 000	11 200	8 960	7 168	5 734
5	Nett balance (2 - (3+4))	9 100	27 143	46 697	68 760	94 459
6	Rate-of-return (%) (5/1)	9	34	73	134	231
	Average rate-of-return = $\frac{\text{total nett balance}}{\text{total capital}} = \frac{£246\ 159}{£336\ 160} \times 100\% = 73\%$					
	A Capital reducing at 20% per annum; B Net saving from table A12.1; C Depreciation at 20% per annum; D Funding cost at 14% per annum					

Table A12.4 Average rate-of-return considering inflation, cost of finance and depreciation

A12.3 Discounted Cash Flow Internal Rate-of-Return

Discounted cash flow (DCF) internal rate-of-return (ir-o-r) is one of the most complex methods of payback calculation. Essentially, it is that interest rate which, when applied to the nett savings, results in them being equal to the initial investment. This is the most universal method of comparing the financial rating of projects. In practice, however, it is rarely used in the U.K. for evaluating energy projects, perhaps due to its complexity .

In practice this calculation is usually carried out using a small computer. For brevity the calculation will not be detailed here, only the results. The DCF ir-o-r for the given scheme, evaluated over a 5 year period, is 54 per cent.

A summary of the calculations described is given in table A12.5. All results are different, and the question arises as to which method should be used. In most cases an evalution method consistent with existing company accounting techniques is used. In others, it may be prudent to select the method showing the heat recovery scheme in its most favourable light.

Method		Payback	
		Years	Rate-of-return(%)
1	Simple payback	2.32	-
2	Simple payback, with inflation	2.04	-
3	Simple payback, with inflation residual value and tax allowance	2.24	
4	Average rate-of-return, with inflation	-	72
5	Average rate-of-return, with inflation,cost of finance and depreciation	-	73
6	As 5, but with straight line depreciation	-	63
7	Discounted cash flow, for 5 years	-	33
8	Discounted cash flow, for 10 years	-	42

Table A12.5 A comparison of 8 methods of calculating scheme payback

As yet there is no standard method of rating energy projects against other industrial projects. It is not within the scope of this work to make any suggestions in this area other than to register the fact that there is a need for such a standard method. More collaboration between purchasers and manufacturers, however, would certainly help in this area.

APPENDIX 13

DEGREE DAY CORRECTION FACTORS FOR THE NON-CONTINUOUS HEATING OF BUILDINGS

APPENDIX 13

DEGREE DAY CORRECTION FACTORS FOR THE NON-CONTINUOUS HEATING OF BUILDINGS

A13.0 Definition of Degree Days

Note - all data obtained from external sources used in this appendix were given on the celsius temperature scale. For consistency, its use has been continued.

The generally accepted definition of a degree day is the daily difference, in Kelvin, between a base temperature of $15.5^{0}C$ and the 24-hour mean outside temperature (when it falls below this base temperature) [152]. The base temperature is derived from an average internal temperature of $18.3^{0}C$, from which are subtracted the fortuitous heat gains (which are assumed to provide 2.8 K [152]).

A13.1 Verification of External Data used in Calculation

For the Thames Valley, on which the described degree day correction factors have been based, the total number of degree days for a 30 week (210 day) heating season from October to April were 1850 [205]. The average increase in building temperature supplied by a heating system in this period would have been approximately 8.8 K (1850/210) i.e. heating was required for 8.8 K above the mean external temperature for the building to achieve the base temperature of $15.5^{0}C$. This gives a mean external temperature of $6.7^{0}C$ (15.5-8.8).

To verify this derived result, the mean external temperature for the same period was calculated from other original data [206]. (This data was supplied by the meteorological office and may have been used by them in their own degree day calculations. This, however, could not be ascertained.) The mean external temperature was calculated by obtaining the temperature readings every three hours over the given period i.e. October to April, and finding the mean. This analysis showed the mean external temperature to be $6.65^{0}C$, which compares favourably with the $6.7^{0}C$ stated earlier. This closeness of result shows that both sources of data are compatible.

The same data source was then used to calculate the mean outside temperature, not continously throughout the heating season, but for selected times within that period i.e. for office hours between 9am-5pm etc. These selective period mean temperatures are listed in table A13.1.

Operating hours	Heating season			
	30 weeks (Oct -Apr)		35 Weeks (Oct-May)	
	MET (^{o}C)	DDC	MET (^{o}C)	DDC
Office Hours - 9am-5pm[1] Factory - single shift	7.39	0.92	8.19	0.90
Factory - two shifts[2] (7am-3pm, 3pm-11pm)	6.91	0.97	7.66	0.96
Factory - three shifts continuous operation	6.65	1	7.35	1

MET: Mean external temperature over the operating hours stated
DDC: Degree day correction factor for non-continuous heating

1 MET calculated over period 7am-4pm } see section
2 MET calculated over period 5am-10pm } A13.1, page 243

Table A13.1 Degree day correction factors for the non-continuous heating of buildings

For office hours (9am-5pm) the mean external temperature was calculated over a period from 7am to 4pm. This allows time for the building to achieve temperature prior to opening, and for the switching off of heating before building closure. For a factory two shift system, the mean temperature is over a period from 5am to 10pm.

A13.2 Calculation of Degree Day Correction Factors

By using the calculated selective period mean external temperatures and comparing them with the mean continuous external temperature, a degree day correction factor can be obtained that scales down the original number of degree days to allow for this shorter heating time.

From table A13.1, the mean external temperature during office hours from 9am-5pm (allowing time before 9am for the building to reach operating temperature) is, for a 30 week heating season, 7.39^{0}C. This gives a required temperature increase, for the building to reach base temperature, of 8.11 K (15.5 - 7.39). By using degree days, the continuous heating supplied over the same period would have given an increase of 8.81 K. Taking 8.81 as unity, 8.11 becomes 0.92. Similarly for a two shift system the average outside temperature was calculated to be 6.91^{0}C. This gives a temperature requirement of 8.59 K (15.5-6.91) compared with 8.81 K, and a corresponding correction factor of 0.97.

These factors of 0.92 and 0.97, when multiplied by the 24-hour degree day total, give a corrected degree day value for non-continuously heated buildings. Further degree day correction factors are given in table A13.1.

Figure A13.1   Degree day regions for the British Isles

The mean external temperatures in table A13.1 were calculated for the Thames Valley area. Figures for other regions, as identified by figure A13.1, can be obtained by subtracting the figures given in table A13.2 (area correction factors) from those in table A13.1.

	Area	Factor		Area	Factor
1	Thames Valley	-	10	North Eastern	-1.5
2	South Eastern	0	11	East Pennines	-1
3	Southern	-0.5	12	East Anglia	-1
4	South Western	0	13	West Scotland	-1
5	Severn Valley	0	14	East Scotland	-1.5
6	Midland	-1	15	North East Scotland	-2
7	West Pennines	-1	16	Wales	-0.5
8	North Western	-1	17	Northern Ireland	-1
9	Boarders	-2			

Areas are given in figure A13.1

Table A13.2 Area correction factors

For example, a factory operating a 2 shift system on a 35 week heating season in East Scotland would have an average external winter temperature of 6.16^{o}C (7.66-1.5). By using this figure with the continuous mean external temperature (calculated from degree days) the degree day correction factor can be obtained.

APPENDIX 14

A COST REDUCTION EXERCISE

APPENDIX 14
A COST REDUCTION EXERCISE

A14.0 A Price Advantage

At market launch the MHRU was approximately 10 per cent more expensive than its component counterpart. A preliminary cost reduction (including value analysis) exercise was undertaken to reduce this percentage.

A14.1 Cost Reduction Ideas

The following ideas were suggested to reduce the production cost of the MHRU:

- fans represent over 30 per cent of the total hardware cost of the MHRU. Those used in the prototype were of the highest quality and it was thought that similar fans could be obtained considerably cheaper with only marginal reduction in quality;
- in the prototype, the entire fan section was insulated using double skin insulating panels. By insulating the fans and ductwork inside this section separately, single skin construction (which is considerably cheaper than double skin construction) could be used for the casing;
- the filter section could be supplied without filters. Most clients purchasing the MHRU would have fresh gas filters on site. Clients, by supplying filters themselves, can take advantage of their own purchasing systems discounts. Waste gas filters, if difficult to obtain, could be purchased, as an extra, from the sponsor.

From discussions with equipment suppliers and the manufacturers of the MHRU it was estimated that, by incorporating the aforementioned changes, the MHRU's cost could be reduced by 6 per cent for a size II unit, slightly less for a size I and slightly more for sizes III and IV. This reduces the price advantage of the component system to between 3 and 5 per cent and, in-turn, with its installation advantages, should give the MHRU a market advantage.

APPENDIX 15

THE INTERDISCIPLINARY HIGHER DEGREE (IHD) SCHEME

APPENDIX 15

THE INTERDISCIPLINARY HIGHER DEGREE (IHD) SCHEME

A15.0 An Academically based Industrial Solution

The IHD scheme was initiated at the University of Aston in Birmingham in 1968, in response to the Swann report on higher education [207]. This report suggested there was a requirement for students who, once their research was complete, could take up positions in industry without further training.

Research work at IHD is undertaken on 'real' projects supplied by external sponsoring organisations, the scheme thereby achieving a blend of practical research and academic respectability. The availability of this sponsorship reveals a genuine desire for work to be undertaken. Often employed directly by a sponsor, students spend approximately two thirds of their time in industry, the remaining one third at the University of Aston. This position gives the student special privileges both at university and within the sponsoring organisation, and provides freedom and scope for initiative.

Although there is a place for purely academic research, the IHD approach must represent a balance between the commercial pressures of problem solving and the academic rigour of university based research. For the work described in this thesis all parties found the scheme beneficial.

LIST OF REFERENCES

1 The Sunday Times; "The Secret Arab Deal that Launched the War"; 14 October, 1973; p5-9

2 The Times; "Israel and Arabs: Old Wounds Reopened"; 8 October, 1973; p16

3. The Times; "Arabs will Cut Oil by 5 per cent a Month"; 18 October, 1973; p1

4 Anon; "The OPEC Decade"; The Economist; 29 December, 1979, p39-60

5 Kelly, D.R.(ed); "The Energy Crisis and the Environment"; Praeger, New York; 1977

6 Dept of Energy; Energy Trends

7 Bailey, R.; "Energy - the Rude Awakening"; McGraw-Hill; 1977

8 de Montbrial, T.; "Energy - the Countdown"; Pergamon Press; 1979

9 Nicholas, H.; "Oil Troubles could Pose a Threat to Oil Supplies"; The Times; 12 September, 1978; p19

10 The Times; "Iran Oil Strikers Defy General's Ultimatum"; The Times; 13 November, 1978; p1

11 The Sunday Times; "The Gulf War - Iraq get Ready for Round Two"; 5 Ocotober 1980; p9

12 The Sunday Times; "War Flare Up - Battle of Destiny"; 24 May 1980; p1, 10

13 Energy Manager; "Government replies to ACEC report"; Energy Manager; Vol 5, (8), 1982

14 Department of Energy; "Advisory Council on Energy Conservation, Paper 4 - Industrial Group session 1975-1976"; Energy Paper 32; HMSO; 1978

15 Armatage Norton Consultants; "A study of Investment in Energy Conservation in Industry"; Dept of Energy; to be published

16 Maddala, G.S., Chern, S.S. and Gill, R.T.; "Econometric Studies of Energy Demand and Supply"; Praeger, 1978.

17 Willson, C.L.; "Energy - Global Prospects 1985-2000"; Report of the Workshop on Alternative Strategies, McGraw Hill; 1977

18 Economists Advisory Group; "Domestic Energy Conservation and the U.K. Economy"; Association for the Conservation of Energy; 1981

19 Commission of the European Communities; "Review of Member States' Energy Policy Programmes and Progress Towards 1990 Objectives"; Report COM (82) 326 Final, Brussels; June 1982

20 Palmer, A. (M.P.); quotation from the press conference preceding the Launch of the Select Committee Report "Conservation in buildings"; July 1982

21 Leach, G. et al; "A Low Energy Strategy for the U.K.", 2nd edition; Science Reviews; 1979

22 Dept of Energy; Fuel Efficiency Booklets

23 Commission of the European communities; "Investment in the Rational Use of Energy"; Report COM (82) 24 Final, Brussels; February 1982

24 Allen, J.A.; "Studies in Innovation in the Steel and Chemical Industries"; Manchester University Press; 1967

25 Wolf, C.A.; "Canada's Voluntary Industrial Energy Conservation Programme"; The Pollution, Energy & Process Engineering Conference & Exhibition, Toronto, Canada; 21 June, 1979

26 Anon; "Rising oil Prices spur growth of New Technology"; European Chemical News, Chemiscope; 23 July 1979; p18-30

27 Attwood, B.; "Dry Forming - a Survey of the State of the Art with an Emphasis on the Implications for the U.K."; Report for the Dept of Industry; August 1982

28 Dept of Energy; "Energy Research and Development in the U.K."; Energy Paper 11, 2nd edition; HMSO; 1978

29 Newey, D.C.; "Some Technical & Commercial Aspects of Fluidised Bed Gas-to-Gas Heat Exchangers"; PhD thesis; University of Aston in Birmingham; 1981

30 Currie, K.; "New Conservation Technologies - what are they, and what can they do?"; National Energy Management Conference; 8-9 October, 1981

31 Energy Management; "Food Factory Feeds on Oven Heat"; Energy Management; December 1979

32 Weetabix Company; "Space Heating Gas Consumption Related to Heat Recovery Plant Operation"; Weetabix Company; 1981 (unpublished)

33 British Patent Office; "Improvements in or Relating to Air Conditioning Installations; British Patent 1 591 142; April 1981

34 Beare, S.D.J.; "Free Heat"; Energy Management; January 1978

35 Anon; "Free Heat - the Trading Consortium"; Weetabix Company; 1979

36 Client Construction Company; "An Analysis of the Potential for Heat Recovery Equipment in the U.K."; Client Construction Company 1978; (unpublished)

37 Langrish, J., Gibbons, M. Evans, W. G. and Jevons, F R.; "Wealth from Knowledge"; Macmillan; 1972

38 Gray, M.F.; "A Study of Energy in a Complex Industrial Environment"; PhD thesis; University of Aston in Birmingham; 1980; p310-334

39 Rodrigues, C.M.B.; "Energy Conservation Measures on an Industrial Site"; PhD thesis; University of Aston in Birmingham; 1982; p132-137

40 Lockwood Thermographic Surveys; "Potential Problem Identification through Thermographic Surveying"; Lockwood Thermograph Surveys; not dated

41 Cocking, S. J.; "Aerial Infra-Red Survey for Heat Loss Determination"; AERE Harwell, HL 78/2939; September, 1978

42 Dept of Energy; "Energy Survey Scheme"; Dept of Energy Publication ESS/5; November, 1979

43 Payne, G.A.; "The Energy Managers Handbook", 2nd edition; IPC Business Press; 1980

44 Thuman, A.; "Plant Engineers & Managers Guide to Energy Conservation"; Van Nostrand Reinhold; 1977

45 Smith, T.E.; "Industrial Energy Management for Cost Reduction"; Ann Arbor Science; 1979

46 Chiogioji, M.H.; "Industrial Energy Conservation"; Marcel Dekker; 1979

47 Dept of Energy; Fuel Efficiency Booklets 2, 5, 10, 11, 15, 17; 1976-1981

48 National Industrial Fuel Efficiency Services; "Fuel Economy Handbook", 2nd edition; Graham and Trotman; 1979

49 Boyen, J.L.; "Thermal Energy Recovery", 2nd edition; Wiley Interscience; 1980

50 Bataille, G.S.; "Stop Wasting Energy - Here are Some Practical Ideas"; Plant Engineering; 13 June, 1974, p137-139

51 Gwyther, N.; "Energy Economy in Industry - 150 Fuel Saving Ideas"; TGW Industrial & Research Promotion Ltd, Leicester

52 Dept of Energy; "Energy Conservation - Research, Development and Demonstration - An Initial Strategy for Industry"; Energy paper 15; HMSO; 1976

53 Chartered Institution of Building Services; "Guidance towards Energy Conserving Operation of Buildings and Services", Parts 1, 2, 3; Collins & Wilson; 1977, 1979

54 Shell Ltd; "Cutting Industrial Energy Costs"; Shell publication no. TP/006/77; 1977

55 Institution of Heating and Ventilating Engineers; "Energy Notes for Factories"; not dated

56 Public Technology Incorporated; "Energy Conservation, a Technical Guide"; National Science Federation, U.S.A.; 1975

57 The Electricity Council; "Energy Management in Commercial Buildings"; Electricity Council publication no EC 3325; not dated

58 Dept of Energy; "The Recovery of Waste Heat from Industrial Processes"; Fuel Efficiency Booklet 13; 1979

59 American Society of Heating, Refrigeration & Air Conditioning Engineers; "Fundamentals Handbook"; 1981; p5.3

60 National Coal Board; private communication

61 Shell Oil Co.; private communication

62 Energy Manager; "Infernal Combustion"; Energy Manager; Vol 4, (8), 1981; p31-34

63 Kirkwood, N.E.; "The First Month"; in-house report for the sponsor; October 1979

64 McNeil, C.; "Total Energy"; paper presented in Bradford by NEGAS; Institution of Gas Engineers Manchester & District Section; 21 January, 1977

65 Saint, J.C.; "Gas in the Biscuit Industry"; paper presented at the Manchester District Junior Association of Gas Engineers at Symbol Biscuit Works, Blackpool; March, 1965

66 Crown House Engineering; private communication

67 Anon; "Marketing Pocket Book"; The Advertising Association Creative Press (Reading); December 1981

68 Kirkwood, N.E.; "Selection of a Gas-to-Gas Heat Exchanger for the MHRU"; in-house report for the sponsor; December 1979

69 Sponsoring organisation (technical director); private communication

70 Filter Supply Company; private communication

71 Ozonair Engineering Company; "Hi-Cap Air Filters"; publication SfB57 UDC 697.9; 1980

72 American Air Filter Company; "Roll-o-MATIC"; publication Af-2-248A-Aug-03

73 Convery, E.F.; American Air Filter Company quotation B11.1.0056/EFC/SAH; 1981

74 Engart Fan Company; "HV Series Centrifugal Fans"; Engart Fan Company; not dated

75 Building Trades Journal; "Crosby Opens New Distribution Centre"; Building Trades Journal; 14 November 1980; p50

76 Kirkwood, N.E.; "HE-RO Reference Manual"; internal document for the sponsor;1981

77 Kirkwood, N.E.; "HE-RO Sizing Manual"; internal document for the sponsor; 1981

78 Silvestrini, R.; "Fouling and Corrosion Evaluation of Heat Exchangers in Diesel Exhausts"; AiResearch Manufacturing Company of California, Torrance , California 1978, U.S.A.; 1978

79 Breslin, J.A. et al; "Size Distribution and Mass Output of Particles from Diesel Exhausts"; U.S. Bureau of Mines, investigation report 8141r; 1976

80 U.S. Department of Energy; "Acid Corrosion and Fouling of Extended Surfaces in Diesel Engine Exhaust Streams"; 1980

81 Engel, P.K.; Silvestrini, R. and Thompson, R.E., "Corrosion and Fouling Potential in Diesel Exhausts"; ASME paper 78-WA/Fu-5; 1978

82 Thielbahr, W.H.; "Heat Exchanger Fouling in Diesel Exhaust Streams"; U.S Dept of Energy; Idaho 83401, U.S.A.; 1980

83 Hunter, S.C. et al; "Control of Oxides of Sulphur from Stationary Sources in the South Coast Air Basin of California"; ARB contact ARB4-421, 1976

84 Gibson, G. and Kufta, R.; "Cold End Corrosion Monitoring Methods", Power Engineering (U.S.A.); Vol 81, (4), 1977; p70-73

85 Clark, N. D., et al; "Boiler Flue Gas Measurement Using a Dew Point Meter"; ASME paper 63-WA108; 1963

86 American Institute of Chemical Engineers; "Equipment Testing Procedure - Heat Exchangers", 2nd edition; American Institute of Chemical Engineers; 1968

87 Kirkwood, N.E.; "Assessment of a Prototype Gas-to-Liquid Heat Exchanger for use in Diesel Engine Exhausts", intercompany report between sponsor and client; 1981

88 Smithberg, E. and Landis, F.; Journal of Heat Transfer; Trans., ASME, 86:39; 1964; quoted in Rohsenow, W.M. and Hartnett, J.P.; "Handbook of Heat Transfer"; McGraw Hill; 1971

89 Gambill, W.R., and Bundy, R.D.;ASME paper 62-HT-42; 1962; quoted in Rohsenow, W.M. and Hartnett, J.P.; "Handbook of Heat Transfer"; McGraw Hill; 1971

90 Gambill, W.R., and Bundy, R.D.; AICHE Journal; Vol 9, (55), 1963; quoted in Rohsenow, W.M. and Hartnett, J.P.; "Handbook of Heat Transfer"; McGraw Hill; 1971

91 Dept of Industry; "A Preliminary Analysis of the Potential for Energy Conservation in Industry"; Industrial Energy Thrift Scheme; 1977

92 Klaschka, J.T.; "Development of Heat Exchangers for Waste Heat Recovery", in O'Callaghan, P.; Energy for Industry; Pergamon press; 1979; p277-295

93 National Industrial Fuel Efficiency Service; "NIFES Comparison of Energy Costs"; Energy Management; February 1980

94 Sponsoring organisation (managing director); private communication

95 Dept of Industry; Industrial Energy Thrift Scheme reports 1, 2, 4-24, 27; 1978-1981

96 Dept of Energy and Dept of Industry; Audit series reports 2, 3, 4, 6, 8, 9, 11, 13, 15; 1981-1982

97 Energy Manager; "Lyons Bakery takes the Biscuit"; Energy Manager Vol 5, (1), 1982

98 Holt, K.; "Product Innovation"; Newness-Butterworth; 1977

99 Rogers, E. M. and Shoemaker, F.F.; "Communication of Innovations"; The Free Press; 1971

100 Briggs, E. and Rees, A.M.; "How Word Gets Round"; New Society; 29 June, 1978

101 Menzel, quoted in Holmes, P.L.; "The Role of Information in Science and Technology"; OSTI report 5180; 1974

102 Commander, W.M.; "A Study of New Product Market Search and User Adoption"; PhD thesis; University of Aston in Birmingham; 1978

103 Buckner, H.; "How British Industry Buys"; Hutchinson; 1967

104 Financial Times; "How British Industry Buys"; Joint Financial Times/Industrial Market Research Ltd survey; 1974

105 Hill, R.W. and Hillier, T.J.; "Organisational Buying Behaviour"; Macmillan; 1977

106 Anon; "A Special Report on the Buying and Selling Techniques in the British Engineering Industry"; McGraw-Hill; 1963

107 Alexander, R.S., Cross, J.S. and Hill, R.M.; "Industrial Marketing"; Irwin, Illinois, U.S.A; 1961

108 Henderson, H.D.; "Supply and Demand"; Cambridge University Press; 1922

109 Cunningham, M.T. and White, J.G.; "The Behaviour of Industrial Buyers in their Search for Suppliers of Machine Tools"; Journal of Management Studies; Vol 11, (2), 1974

110 Coxe, W.; "Marketing Architectural and Engineering Services"; Van Nostrand Reinhold; 1971

111 Harris & Hunter Ltd; private communication

112 Building Services; "Modular Heat Recovery"; Building Services; November 1980

113 Energy Manager; "A Bolt is all it takes"; Energy Manager; October 1980

114 The Engineer; "Heat Recovery"; The Engineer; October 1980

115 Heating & Air Conditioning Journal; "Heat Recovery Unit"; Heating & Air Conditioning Journal; December 1980

116 Heating and Ventilating News; "Hook-up and Waste Not"; Heating and Ventilating News; November 1980

117 Heating and Ventilating Review; "Modular Heat Recovery Unit"; Heating and Ventilating Review; October 1980

118 Plant Engineering; "Modular Heat Recovery"; Plant Engineering; November 1980

119 Process Engineering; "Product of the Month"; Process Engineering; November 1980

120 Production & Industrial Equipment Digest; "Modular Heat Recovery Unit"; Production and Industry Equipment Digest; November 1980

121 What's New in Industry; "Heat Recovery Units are Modular in Design"; What's New in Industry; December 1980

122 Works Management; "Recovering Waste Process Heat"; Works Management"; November 1980

123 Nabseth, L. and Ray, G.F.; "The Diffusion of New Industrial Processes"; Cambridge University Press; 1974

124 Energy Manager; private communication

125 The Economist; "Shipping Dips, Shipbuilding Sinks"; The Economist; 29 December 1979; p50

126 Dodwell & Associates; private communication

127 Mumford, E. and Pettigrew, A.; "Implementing Strategic Decisions"; Longman; 1975

128 Kotler, P.; "Behavioural Models for Analysing Buyers"; Journal of Marketing; Vol 29, (4), 1965

129 Brand, G.T.; "The Industrial Buying Decision"; Cassell; 1962

130 Kirkwood, N.E. and Witticker, J.E.; "Response to Manchester Exhibition"; report for sponsors; 1982

131 Evans, B.; "Heat Recovery - HAC Special Report"; The Heating & Air Conditioning Journal; June 1981

132 British Patent Office; "Improvements in or Relating to Heat Exchangers"; British Patent 2 066 937; July 1981

133 British Patent Office; "Improvements in or Relating to Heat Exchangers"; British Patent Pending

134 Flint, F.M.; "A Users Guide to Copyright"; Butterworth; 1979

135 Meinhardt, P.; "Inventions, Patents & Trade Marks"; Gower Press; 1971

136 Marks & Clerk; Patent Agents; private communication

137 Sponsoring organisation (contracts dept); private communication

138 British Standard 3274; "Tubular Heat Exchangers for General Puposes"; British Standards Institution; 1960

139 British Standards 2971; "Specification for Class II Metal-Arc Welding of Steel Pipelines and Pipe Assemblies for Carrying Fluids"; British Standards Institution; 1961

140 Holmguard Finance Company; private communication

141 Marshall, M. and Watt, J.; "The Coal Question"; Energy Manager; Vol 5, (4), 1982

142 Dept of Energy; "Energy Management - British Businesses Guide to Government Assistance"; not dated

143 Beirne, T.; "Your Key to the Productive Use of Energy"; Energy Technology Support Unit; not dated

144 Dept of Energy; "European Community Scheme for Energy Saving Projects"; 1981

145 Kirkwood, N.E. with Addy, M.K.; "Industrial and Commercial Heat Recovery"; due for publication by Cambridge Energy Publications in Spring 1983

146 Kirkwood, N.E.; "Demonstration of Effective Heat Recovery from Multiple Test Engine Exhaust Gas Systems"; Dept of Energy Demonstration Project Grant report; 1981

147 Diesel Engineers & Users Association; private communication

148 Leyland Vehicles; "Potential Energy Saving of Engine Testing"; internal company report; 1980

149 Sponsoring organisation (contracts dept); private communication

150 Fisk, D.J.; "Thermal Control of Buildings"; Applied Science Publishers; 1981; p61-65

151 Dixon, A.E. and Leslie, J.D.; "Solar Energy Conversion"; Pergamon Press; 1979; p643-647

152 Dept of Energy; "Degree Days"; Fuel Efficiency Booklet 7; 1978

153 Chartered Institution of Building Services; "Estimation of Fuel Consumption for Space Heating"; Guidebook B18; Curwen Press; 1977

154 Director General; Meteorological Office, Bracknell, Berks

155 Dept of the Environment; "Relationship between Construction and Heating Costs"; Housing Development Notes; HMSO; December 1973

156 Billington, N.S.; Colthorpe, K.J. and Shorter, D.N.; "Intermittent Heating"; Heating and Ventilation Research Association Laboratory report 26; date not available

157 Billington, N.S.; "Estimation of Annual Fuel Consumption"; Journal of the Institution of Heating and Ventilating Engineers; Vol 34; 1966; p253

158 Starr, C.H.; "The Specification and Management of Materials in Indusry"; Thames & Hudson; 1957

159 Kirkwood, N.E. and Reeves, B.; "Demonstration of Effective Heat Recovery from Multiple Test Engine Exhaust Gas Systems"; Dept of Energy Demonstration Project Grant report; July 1982

160 Dept of Energy; "Heat Recovery Saves Distiller's Headache"; Energy Management; March 1980; p4

161 Dept of Energy; "Maltsters have to Minimise Energy Costs"; Energy Management; November 1980; p6

162 Dept of Energy; "Helicopter used in Energy Saving Operation"; Energy Management; January 1981; p1

163 Corey, E.R.; "The Development of Markets for New Materials"; The Riverside Press, Cambridge, Massachusetts, U.S.A.; 1956

164 Meyers, J.M. and Marquis, D.G.; "Successful Industrial Innovations"; NSF 69-71; National Science Foundation, Washington, U.S.A.; 1969

165 Carter, C.F. and Williams B.R.; "Industry and Technical Progress: Factors Governing the Speed of Application of Science"; Oxford University Press; 1957

166 Turner, D.F. quoted in Enis, B.M. and Cox, K.K.; "Marketing Classics", 3rd edition; Allyn & Bacon Inc.; 1969

167 Majaro, S.; "Product Planning - a New Perspective", in Rines, M. (ed); Marketing Handbook, 2nd edition; Gower; 1981; p101-112

168 Baker, M.J.; "Developing and Launching a New Industrial Product", in Rines, M. (ed); Marketing Handbook, 2nd edition; Gower 1981; p143-155

169 Stapleton, J.; "Making a Marketing Plan", in Rines, M. (ed); Marketing Handbook, 2nd edition; Gower; 1981; p113-129

170 Brand, G; "How Industrial Purchasing Decisions are Made", in Rines M. (ed); Marketing Handbook, 2nd edition; Gower; 1981; p21-30

171 Bauer, R.A.; "Consumer Behaviour as Risk Taking", in Hancock, R.S. (ed); Dynamic Marketing for a Changing World; American Marketing Association, Chicago; 1960; p389-398

172 Kirkwood, N.E.; "Exhibition Analysis"; internal report for the sponsor; 1981

173 Webster, F.E.; "New Product Adoption in Industrial Markets - A Framework for Analysis"; Journal of Marketing; Vol 33, 1969; p35-39

174 McNiven, M.A.; "Plan for More Productive Advertising"; Harvard Business Review; Vol 58, March-April 1980; p130-136

175 Rothwell, R.; "Patterns of Information Flow During the Innovation Process"; Aslib proceedings; Vol 27, (5), 1975; p217-226

176 The Financial Times; "MOD buying decisions"; 11 April, 1967; p4

177 Sponsoring organisation; "Schedule of Consultancy Fees"; 1982

178 Utterback, J.M.; "The Process of Innovation, a Study of the Origination and Development of Ideas from New Scientific Instruments"; IEEE Transactions on Engineering Management, EM-18; 1971; p124

179 McDonald Schetky, L.; "Shape Memory Metals"; Scientific American; Vol 241, (5), 1979; p74-82

180 Cambridge Information and Research Services; "The British Gas Directory of Energy Saving Equipment"; Cambridge Information and Research Services (now Energy Publications, Cambridge); published annually

181 Energy Manager; "Energy Products and Services"; Energy Manger; Vol 4, (10), 1981

182 Aydee Marketing; "The Energy-Saving Marketguide & Index Library"; Aydee Marketing; - published annually.

183 Reay, D.A.; "Industrial Energy Conservation", 2nd edition; Pergamon Press; 1979

184 Lloyd, S. and Starling, C.; "Heat Recovery From Buildings"; Building Services Research and Information Association, Bracknell, Berks.; 1976

185 Heating & Ventilating Publications; "The HVCA Red Book"; Heating & Ventilating Publications (Developments); published annually; p288-291

186 American Society of Heating, Refrigeration and Air Conditioning Engineers; "ASHRAE Product Specification File"; American Society of Heating, Refrigeration and Air Conditioning Engineers, Georgia U.S.A; published annually

187 Jones, J.R.; "What's What in Energy Conservation"; RIBA Publications; 1978

188 Climate Equipment Company; private communication

189 Reay, D.A.; "A Review of Gas-Gas Heat Recovery Systems"; Journal of Heat Recovery Systems; Vol 1, (1); 1981; p3-41

190 Lapedes, D.H.; "Dictionary of Scientific and Technical Terms (2nd Edition); McGraw Hill; 1978; p931

191 Chojnowski, B. and Chew, P.E.; "Getting the Best Out of Rotary Air Heaters"; CEGB research report 7, 1978; p14-21

192 Acoustics and Environmentrics; "Econovent Energy Recovery Wheel"; Acoustics and Environmetrics publication; 1980; p4

193 Mortimer, J.; "Exchanging Heat to Save Fuel"; The Engineer; 2-9 August; 1973; p34-37

194 Campbell, A.; "The Ins and Outs of Heat Recovery"; Industrial Energy; September, 1981; p17-18

195 Applegate, G.; "Heat Recovery"; Maintenance Engineering"; April 1975

196 Gaugler, R.S.; "Heat Transfer Device"; U.S. Patent 2 350 348; Applied for 21 December, 1942; Published 6 June, 1944

197 Grover, G.M., Cotter, T.P. and Erikson, G.F.; "Structures of Very High Thermal Conductance"; Journal of Applied Physics; Vol 35, (6), 1964; 1990-1991

198 Groll, M. Nguyen-Chi, H. and Krahling, H.; "Research on Heat Pipes and Thermosyphons for Heat Exchangers"; Commission of the European Communities report EUR 7006; 1981

199 British Standard 4937 Part 4; "International Thermocouple Tables for Nickel/Chromium & Nickel/Aluminium Thermocouples, type K; British Standards Institution; 1967

200 Topping, J.; "Errors of Observation and their Treatment", 4th edition; Chapman and Hall; 1972; p9-16

201 Institution of Heating and Ventilating Engineers; "Flow of Fluids in Pipes and Ducts"; Guide Book C4; W.P. Griffiths & Sons; 1970

202 Butterworth, D.; "Introduction to Heat Transfer"; Oxford University Press; 1977

203 Massey, A.; "Information on British Patents"; Marks and Clerk; 1982

204 Carlisle, M.; "The Legal Framework", in Rines, M. (ed); Marketing Handbook, 2nd edition; Gower; 1981; p170-181

205 Department of Energy; "Degree Days for 1955-1975"; Energy Management; September 1977; p4

206 Meteorological Office Records; "Mean Air Temperature and Dew-Point, London (Heathrow)", in Institution of Heating and Ventilating Engineers; Guide Book A2; 1980

207 Swann Report; "The Flow into Employment of Scientists, Engineers and Technologists"; HMSO Cmnd 3760; 1968