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The Esso Energy Award Lecture, 1990 The Development and Exploitation of Gas-Fired Rapid-Heating Furnaces for Metal Heating

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The development and exploitation of gas-fired rapid-heating furnaces for metal heating

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Contents

Gas-fired rapid-heating furnaces are being applied in the metal reheating industry. They produce substantial energy savings, together with improvements in product quality, productivity and the working environment. These benefits are derived from the use of convection as the dominant mode of heat transfer, rather than radiation as in conventional furnaces.

Laboratory experiments and trials of prototype rapid heating furnaces have been undertaken in industrial situations. Together with physical and mathematical modelling techniques, they have enabled design procedures to be produced which allow rapid heaters to be individually specified to suit a wide variety of metal reheating processes.

The technology is sold through licensees and more than 300 units have already been installed. It is estimated that the cumulative energy savings from the date of the first commercial installation to the current time are in excess of 1.9 PJ with a current value of about £6 M.

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1. Introduction

Large amounts of energy are used in the manufacture of basic engineering materials and in the subsequent shaping and forming of these materials into finished products.

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In the U.K. the total energy consumption in 1989 was in excess of 6000 PJ purchased at a cost of £42 150 M. Almost one third of this was used for transport purposes and the remainder was supplied to industrial, commercial and domestic users.

The industrial market uses approximately 1700 PJ a^{-1} and high-temperature applications, that is processes operating at temperatures in excess of 500 °C, account for about one third of this amount. It is estimated that, in iron and steel, which is the largest user, and the engineering sectors, 74 PJ a^{-1} is specifically used for the reheating of metals and it is within these industries that rapid-heating furnaces are being applied.

The concept of rapid-heating furnaces for use in metal reheating processes is not new but the commercialization of viable gas-fired systems has only been achieved relatively recently. These furnaces are being applied to a wide range of processes and offer opportunities for greater energy savings than can be achieved by the addition of waste heat recovery devices to existing conventional plant. Rapid heating can also provide substantial benefits in improved product quality, productivity and in the working environment.

These advantages have been obtained in gas-fired rapid-heating furnaces which are designed to promote convective heat transfer from a stream of high-velocity combustion gases. This is in contrast with conventional fuel-fired furnaces which rely upon radiation from the furnace walls and the combustion gases to transfer heat to the material being processed and which of necessity tend to be large, slow to respond and have high heat losses.

Results from theoretical studies, laboratory experiments and industrial proving trials have been used to produce design procedures which allow rapid heaters to be individually designed to suit a variety of metal heating processes.

Licensees have been appointed to design, manufacture and market this development and a large number of furnaces have been supplied both in the U.K. and worldwide.

2. The concepts and benefits of rapid heating

When the work on gas-fired rapid-heating commenced at the Midlands Research Station, the basic design of fuel-fired furnaces used for metal heating had not changed for a great number of years. In conventional fuel-fired furnaces heat is transferred to the stock by a combination of radiation from the furnace walls, luminous flame radiation, non-luminous gas radiation and convection. Radiation from the furnace walls is normally dominant and the furnace chambers are large to improve non-luminous gas radiation. Because of the large size of the furnace chamber the combustion products velocity over the stock is low, consequently the contribution of convection to the overall heat transfer is small.

The rapid heaters that have been developed depend on achieving high rates of convective heat transfer and this requires that the combustion products flow at high velocity over the stock surface. The availability of clean high grade fuels such as natural gas and liquid petroleum gas (LPG) and the development of a range of gas burners which produce a high velocity stream of combustion products at high temperature allowed this approach to be taken.

To achieve the required velocities the furnace chamber, which constrains the combustion gases, is closely matched in shape and size to the stock being heated. This approach gives uniform heating over the whole of the exposed stock surfaces. Alternatively the combustion products discharging from a burner at very high

Figure 1

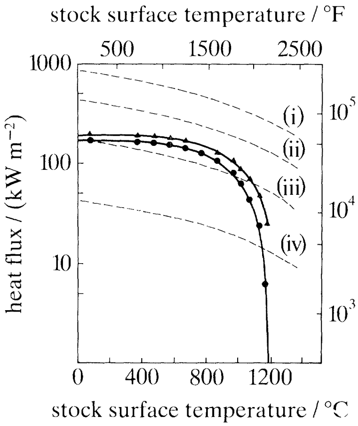

Figure 2

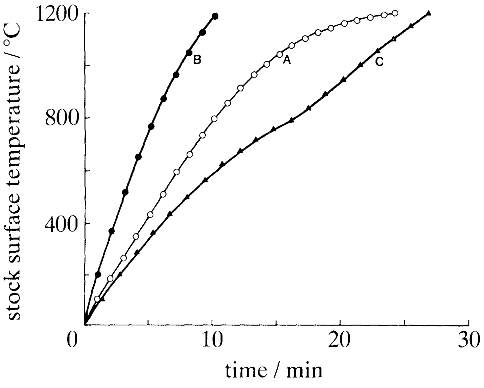

Figure 1. Steel reheating by convective and radiation. ---, Convection, $T_g = 1730$ °C; –▲–, $T_w = 1230$ °C; –●–, radiation, $T_w = 1180$ °C. (i) $h = 500$ W m^{-2} K^{-1}; (ii) $h = 250$ W m^{-2} K^{-1}; (iii) $h = 100$ W m^{-2} K^{-1}; (iv) $h = 25$ W m^{-2} K^{-1}.

Figure 2. Heating rates obtained by convection and radiation.

velocity can be arranged to impinge on to the surface of the stock. This produces very high rates local to the point of impingement. These techniques can be used to varying degrees to suit the particular application under consideration.

A combination of both of these effects can be observed in the heaters that have been developed by British Gas.

Before considering details of the heaters that have been developed, it is useful to consider the transfer of heat by radiation and convection in direct fuel-fired furnaces, and to examine how this affects their operation.

In figure 1 (Fricker *et al.* 1978) the net radiative heat flux between furnace walls and steel is shown as a function of stock surface temperature for two refractory wall temperatures. The emissivity of the furnace walls and the steel surface are assumed to be 0.8. The wall temperatures selected are typical of those found in steel reheating furnaces. It is clear from this figure that as the stock temperature increases and approaches that of the walls there is a rapid decrease in net heat flux to the steel. In practice this results in stock heating rates which are high at low stock temperatures and low at high stock temperatures. Figure 2 (curve A) shows the heating rate that would be obtained when 50 mm square steel bars are heated radiatively in a furnace chamber which has a constant wall temperature of 1230 °C.

It is usual in steel reheating furnaces to operate with a furnace wall temperature which is not much greater than the required final stock temperature and normally this difference would be about 50 °C. These conditions are set to ensure that reasonable control of stock temperature is achieved even if production rates vary. If higher temperature differentials are used then when production is reduced or stopped the stock would very quickly overheat. Figure 2 (curve A) shows that as a consequence of utilizing low-temperature differentials, the approach to the required temperature is slow and although this may be appropriate when heating very large steel stock, which may require long soaking times, there is no advantage in heating small steel stock or non-ferrous metals in this way. The long period of time spent at the higher temperatures results in unnecessary scale formation and decarburization

Table 1. *Typical convective heat transfer coefficients*

heating method	gas velocity		convective heat transfer coefficient (h)	
	m s^{-1}	ft s^{-1}	W m^{-2} K^{-1}	Btu ft^{-2} h^{-1} °F^{-1}
jet impingement	150	500	250–500	50–100
furnace/stock matching	50	150	100–250	20–50
conventional furnaces	< 5	< 15	< 25	< 5

when heating ferrous stock or excessive oxidation in the case of non-ferrous materials.

Figure 1 also shows the heat fluxes to the surface of steel stock that would be obtained with a range of values of the convective heat transfer coefficient at the stock surface.

The values selected span the range likely to be encountered in various furnace types as indicated in table 1. In this case it is assumed that the combustion products are at a temperature of 1730 °C, an average combustion product temperature achieved by industrial gas burners. Although the net heat flux decreases as the stock temperature approaches set point this is not as severe as in the case of radiative heating and consequently higher heating rates are maintained at the higher stock temperatures. This is shown in figure 2 (curve B), and the much reduced time that the material spends at high temperature is evident. This reduces the amount of scale formation and surface decarburization that occurs when ferrous materials are heated.

Convective heat transfer coefficients are dependent on the velocity of the gas stream over the surface being heated and consequently if the burner throughput is changed this has an immediate effect on the heating rate. Coupled with the low thermal mass of the gases this results in a system which can readily control the stock temperature by adjusting the thermal input to the burners. This rapid response is fully exploited by using temperature control systems which measure the surface temperature of the stock rather than inferring this from a roof-mounted thermocouple which is frequently the case in radiant furnaces.

Figure 2 (curve C) shows a typical heating curve for material heated in a counterflow rapid heater as described in §3*d*. In this case the initial heating rate is low because the combustion products have been cooled during their passage through the furnace. However, the residence time above 800 °C is still considerably less than that achieved in the radiative case thereby ensuring good product quality and the benefits of improved control and rapid response are still available. It should be noted that on start-up from cold in the fully charged state the heating curve for the first piece of stock in the counterflow rapid heater would be similar to curve B.

To summarize, the implementation of rapid heating can result in a number of advantages. The low thermal inertia enables a rapid start-up from cold and this can lead to a reduction of fuel used during the initial heating or warm-up period. The relationship between convective heat transfer coefficient and burner throughput ensures that good stock temperature control can be achieved and this facilitates the application of automatic control. When heating ferrous materials the reduced residence time at temperatures above 800 °C results in lower scaling and decarburization. In some cases this reduction may result in realizable metal savings or in lower reject rates which will also offer further savings in costs, including energy, as a result of increasing the yield from a given supply of feedstock.

The introduction of rapid heaters will also lead to an improved working environment and where automation/mechanization is also included productivity can be increased. Finally the increased heating rates can lead to smaller heaters which will save space and in some cases may reduce capital cost.

3. The development of rapid heaters

During the initial development phase the approach adopted was to utilize the high-velocity, high-temperature combustion products produced from a newly developed range of gas burners (Francis 1958). In these burners the combustion is carried out at high intensity in a refractory lined chamber or tunnel and the resulting combustion products are discharged from this tunnel at high velocity. In some cases the exit from the combustion chamber is converged to accelerate the products to even higher velocities.

Attempts were made to improve the operation of a conventional slot-type forge furnace (Francis *et al.* 1962) by fitting it with high velocity burners. The results of this work indicated that it would be necessary to modify the furnace design to reap the benefits promised by these new burners.

(*a*) *Single-cell furnaces*

One of the first examples of a rapid heater (Francis *et al.* 1968) is the single-cell furnace shown schematically in figure 3. This is a batch type furnace used for heating a single large piece of material which is placed in the centre of a relatively small heating chamber. Furnaces of this type were examined in laboratory tests and figure 4 shows the improvement in efficiency achieved as higher convective heating rates are obtained with increasing billet to furnace diameter ratio. Physical modelling work was also undertaken to measure the recirculation ratio and convective heat transfer coefficients were determined for this system using the naphthalene sublimation technique.

A few prototype furnaces of this type were built and were successful in their particular applications but subsequently they have not found widespread use.

(*b*) *Continuous billet heaters*

The work with single-cell furnaces provided the basis for the development of continuous counterflow furnaces for use in the forging industry. These units, figure 5, described by Masters *et al.* (1971) have a burner zone coupled to a pre-heat section, the combustion products being drawn from the burner zone along the preheat zone using a hot gas fan or eductor. In this way the combustion products release more of their heat energy to the colder stock in the preheat region.

This development progressed through the laboratory stages and tests proved that at heating rates comparable with single-cell units the efficiency was about three times greater. During the development of this unit it was necessary to investigate the design of skid rail systems for supporting the billets in the centre of the heating chamber and this led to the development of an indirectly water cooled skid rail, as shown in figure 6. The rail consists of two concentric tubes and water flows through the inner tube. In use the outer tube, which is made from a heat resisting alloy and forms the skid surface, is cooled by radiation between its inner surface and the cooled

Figure 3

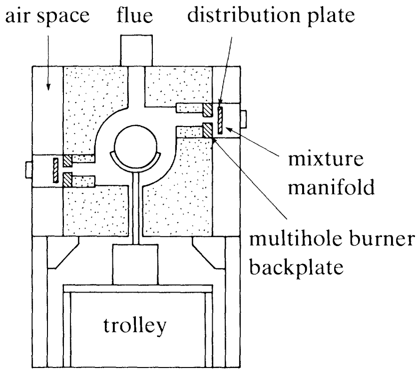

Figure 4

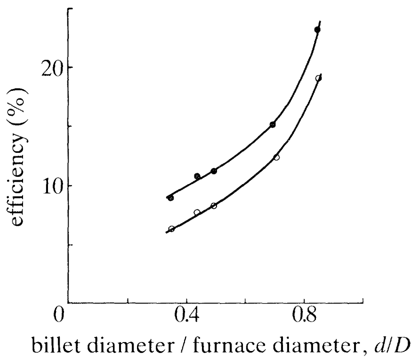

Figure 3. Single-cell furnace.

Figure 4. Single-cell furnace: variation of efficiency with (d/D) ratio. Aluminium heated to 550 °C; furnace chamber diameter = 10 inches (254 mm). ●, Heat input = 3.1 therm h^{-1} ft^{-1} run of furnace; ○, heat input = 5.0 therm h^{-1} ft^{-1} run of furnace†.

Figure 5

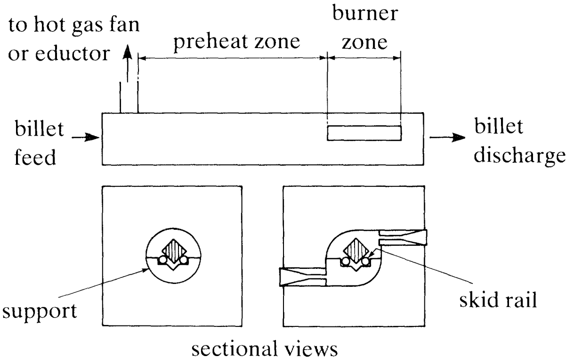

Figure 6

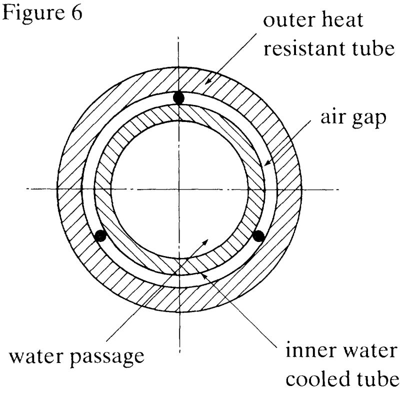

Figure 5. Continuous counterflow furnace.

Figure 6. Indirectly water-cooled skid rail.

outer surface of the inner tube and typically operates at a temperature in excess of 1000 °C. The cold inner tube provides the mechanical strength necessary to support the stock.

Following on from the laboratory work a prototype unit was installed in a forge shop for trials heating 100–150 mm square steel billets to 1250 °C at a rate of 1 t h^{-1}. These trials showed that this type of furnace could be operated in a forge with good thermal efficiency and that the billets, supported on their passage through the furnace on the indirectly water-cooled skid rails, could be forged successfully.

Although further work was done and several prototype units were manufactured and installed in forge shops, problems were encountered with the transport of the cut billets through the relatively long furnaces and this type of rapid heater has not been successfully commercialized.

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† 1 therm = 105.506 MJ.

Figure 7

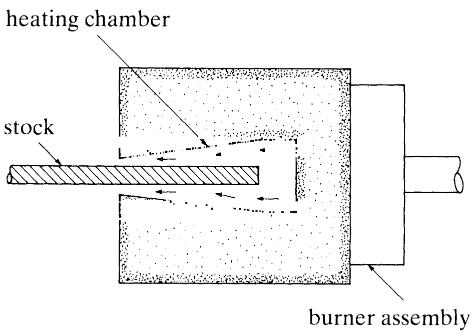

Figure 8

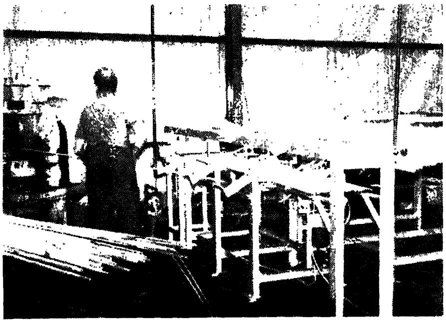

Figure 7. Bar-end heater.

Figure 8. Rod-end heater.

(c) *Local heating*

In the work described in the previous sections rapid heating was achieved by sizing the furnace chamber to closely match that of the material being heated and the whole of the piece was required to be brought up to temperature. There are many situations where it is only necessary to heat a small portion of a piece of material to enable a localized forging or other forming operation to take place.

During the development of high velocity tunnel burners it was realized that it should be possible to heat the ends of stock by placing them such that the surfaces form a part of the burner tunnel enclosure (Masters *et al*. 1971). With this original design, figure 7, air–gas mixture passes from a manifold along mixture ports and starts to burn on entry to the burner tunnel. The combustion products then transfer heat to the stock, mainly by convection, as they flow towards the tunnel exit.

To ensure uniform heating of the stock the burner tunnel converges to accelerate the combustion products as they pass along the stock, thus enhancing heat transfer. By using this method, good temperature uniformity can be achieved on heated lengths of up to 300 mm.

The main features of this type of heater are its simplicity, low floor space requirement and extremely low thermal inertia resulting in very fast start-up times (typically 5 min).

The manufacture of this type of unit has been taken up by licensees and many heaters based on this design are in commercial use.

One of the first companies to be granted a license for the manufacture of this type of heater was Jonas Woodhead Ltd. This company manufacture components for vehicle suspension systems and at the time wished to improve the heating processes in the manufacture of coil springs. In this application it was important that decarburization of the spring steel was minimized. The company participated in trials with a prototype heater, figure 8, and were so pleased with its performance that they asked to be granted a licence to manufacture these heaters. Initially the licence limited them to making heaters for their own use but later when other companies expressed interest the licence was extended to allow Jonas Woodhead to manufacture units for sale. The licence was eventually transferred to Fairbank Brearley, which at that time was a part of the Jonas Woodhead Group of companies, and this company has become the leading manufacturer of gas-fired rapid heaters.

Fairbank Brearley have also introduced some of their own developments into the

Figure 9

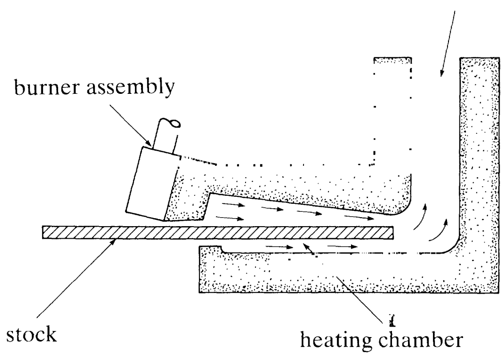

Figure 10

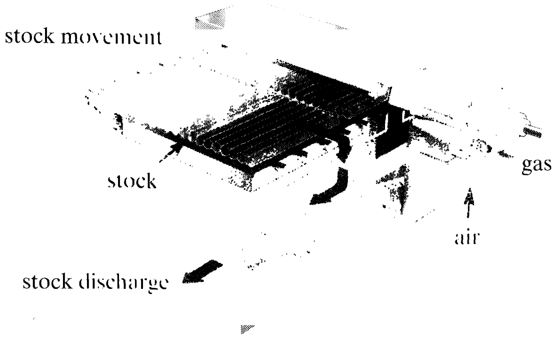

Figure 9. Front fired bar-end heater developed by Fairbank Brearley.

Figure 10. Schematic of a rapid heater with load recuperation.

Table 2. *Production data*

	July 1976–July 1977	August 1977–April 1978
no. of billets heated	30064	26718
mass of billets/t	2801	2502
gas consumed/therm	84760	70881
average production rate/(t h^{-1})	3.1	3.5
specific fuel consumption/(therm t^{-1})	30	28
thermal efficiency based (gross %) on 1100 °C billet temperature	24	26

design of the end heaters. They produced a front-fired version, figure 9 (Fricker *et al.* 1978). This operates on the same principle as the heater shown in figure 7 but the direction of firing is reversed. In this way the hot combustion gases are directed away from the furnace operator and can be flued conveniently, thus considerably improving the working environment.

(*d*) *Whole bar heating*

Designs for load recuperative furnaces, based on the counterflow heat exchange principle (Masters *et al.* 1971), to heat long billets or plates have also been developed. In these, figure 10, the stock is transported sideways through the heater with the combustion products travelling in the opposite direction above and below the stock. A breakthrough for this development came in the mid-1970s when a furnace for heating long bars at a rate of 4.5 t h^{-1} was designed, built and tested at the Midlands Research Station before being installed at the rolling-mill of Sanderson Kayser Ltd in Sheffield in 1976.

This unit, shown in figure 11, incorporates many features which were the product of development work with earlier types of heater. The indirectly water cooled skid rails described earlier are used to support the stock in the centre of the heating chamber. Temperature control is based on the use of radiation pyrometers which are used to measure the surface temperature of the billet. Two pyrometers (Betts 1966)

Figure 11

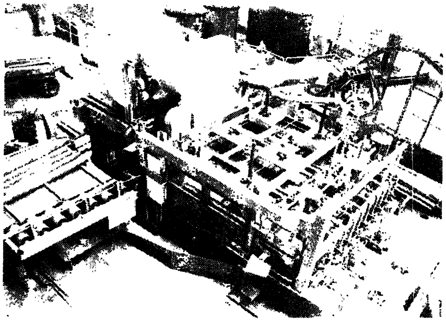

Figure 12

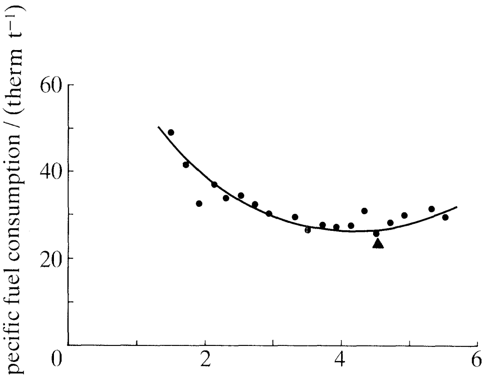

Figure 11. 4.5 t h^{-1} whole bar heater installed at Sanderson Kayser Ltd, Sheffield.

Figure 12. Furnace thermal performance. ▲, Predicted performance for steady-state operation at rated output.

Table 3. *Results obtained during steady-state furnace operation*

	period 1	period 2
time duration/min	52	58
gas consumed/therm	77.8	80
final billet temperature/°C	1110	1120
furnace output/t	3.5	3.9
output rate/(t h^{-1})	4.0	4.0
specific fuel consumption/(therm t^{-1})	22.2	20.5
thermal efficiency (gross %)	32	35

are used to obtain accurate metal temperatures, separate readings are taken of the radiation from the billet and the refractory wall and the proportion of wall radiation reflected by the billet is deducted from the billet radiation after correcting for billet surface emissivity. Systems using this principle are now available commercially from a number of temperature control system manufactures.

Table 2 gives a summary of the principle results obtained over two years of performance monitoring. Further detail in figure 12 shows the relationship between the overall specific fuel consumption and the operating rate.

The performance of the unit when operating under near steady-state conditions is shown in table 3. It is extremely difficult to find periods of steady operation in a production situation and the measurements for the two periods noted were taken during the final hour of a morning's production after about two hours of steady operation at the same rate following the 'breakfast' break. The specific fuel consumptions measured in these periods compare favourably with the steady-state design prediction of 24 therm t^{-1} (*ca.* 2.53 GJ t^{-1}).

The results obtained from this trial clearly demonstrate the advantages of rapid heating. The rapid warm-up from a cold start is illustrated in figure 13, which indicates the change in surface temperature of the first billet with time, from the instant the heater is switched on. Typically, following an increase or decrease in the required billet temperature of about 100 °C, steady operating conditions are re-established in about 5 min, allowing batches of material which require different final

Figure 13

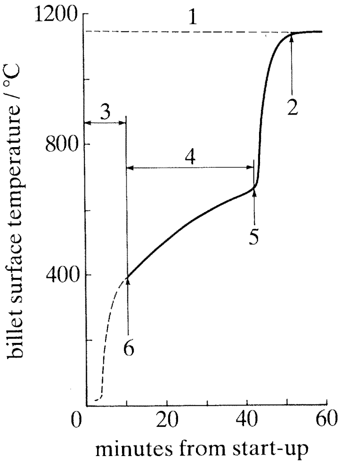

Figure 14

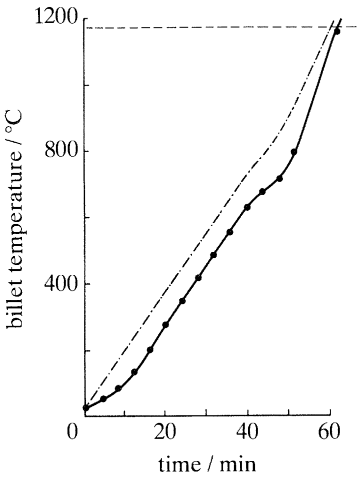

Figure 13. Response of heater from a cold start. 1, Set point temperature; 2, set point temperature reached; 3, pre-purge and automatic burner ignition period; 4, low fire warm-up period; 5, automatic temperature control selected; 6, all burners alight.

Figure 14. Comparison of measured and predicted billet temperature profiles along the heater. Production rate = 3.3 $\mathrm{t\,h^{-1}}$; —·—·—, predicted; ●–●–●, measured; – – –, set point temperature.

temperatures to be processed in succession. Before the installation of this heater it was necessary to schedule the work carefully with operating temperatures being changed progressively up and then down over a period of days as the conventional radiative furnace took a considerable time to stabilize when the operating temperature was changed.

During longer breaks in production the firing rate can be reduced to the low fire setting, under these conditions stock temperature falls quickly to below 900 °C, ensuring that excessive scaling and decarburization do not occur. At the end of the break, normal operation resumes and production conditions are regained within 5 min.

The temperature history of a billet passing through this heater is shown in figure 14. This result was obtained by attaching thermocouples to a billet which was heated during normal production. The measured results show good agreement with prediction. The heating profile is typical of rapid heating which ensures that the residence time of the material at temperatures in excess of 800 °C is kept to a minimum. In respect of decarburization, which was important to Sanderson Kayser, they reported that the decarburization levels were well below the Class I limits specified in British Standard 4659: 1971, Specification for Tool Steels. This heater is still in daily production use at Sanderson Kayser.

4. Furnace modelling

Throughout the development of rapid heating the practical laboratory work has been supported by mathematical and physical modelling work.

Flow visualization experiments (Francis *et al.* 1967) were carried out on small-scale water flow models of the single-cell units using polystyrene beads as tracers. These experiments were undertaken to examine the flow patterns, optimize burner and flue locations and to determine the recirculation ratio of the flow within the heating chamber.

In later studies mass transfer measurements in cold models were used to predict convective heat transfer in the full-scale furnaces by using the Chilton-Coburn analogy between heat and mass transfer. Mass transfer coefficients were determined by an electrolytic technique by measuring the limiting diffusion controlled current to an electrode in a water flow model used as an electrolytic cell. In air flow models, mass transfer coefficients were measured from the rate of sublimation of naphthalene. More recently heat transfer experiments have been carried out in air flow models, using infrared thermography (Gredley 1988) or the colour change in liquid crystal surfaces (Davies *et al.* 1984) to measure surface temperatures for known heat fluxes.

The heat transfer coefficients determined from the model experiments have been used in mathematical models which have been specifically developed for the load recuperative rapid heating furnaces and these are now used for the design of these heaters. These models are based on the Hottel (1967) 'long furnace' concept in which a furnace is represented by a series of well-mixed zones and for a specified geometry are able to predict the following:

(i) the gas consumption rates and furnace efficiencies for steady-state operation and periods of intermittent production;

(ii) the time–temperature history of the stock as it proceeds through the furnace;

(iii) heat transfer distribution within the furnace.

Given this information the equipment designer can use the model to optimize the performance of the furnace for a given set of conditions.

An important aspect of this work has been the validation (Lorton *et al.* 1984) of these models against reliable data; this is essential if they are to be used with confidence. The evidence accumulated over a large number of applications shows that these models provide an accurate representation of the actual performance obtained.

5. Commercialization

The commercialization of this development has been undertaken over a period of years in association with appropriate companies who have requested licences. Rapid heaters are individually designed to suit each customer's specification and the 'know-how' and expertise accumulated during the life of this project has been collated and supplied to the licensees. This has involved the preparation of design manuals for the various types of heater. In the case of the part bar heaters the manuals provide simple arithmetic procedures to be undertaken whereas the mathematical models described previously for load recuperative heaters have been used to prepare a manual thermal design procedure derived from the computer models to cover a range of common applications. This procedure is incorporated into the design manual for this type of heater. Currently versions of the mathematical models which can be operated utilizing personal computers, rather than the larger mini-computer on which they were developed, are being prepared to facilitate their uptake by the licensees.

When licensees are appointed technical assistance is made available by British Gas to assist them with the first few designs and installations and this input is reduced as experience is gained until the licensees become self sufficient.

The first licences for this development were granted during the early 1970s to two companies, Fairbank Brearley and R. H. Furnaces Ltd. Initially both companies produced heaters which were used for the localized heating of materials and many of these have been successfully applied in the spring making industry. As noted previously as experience has been gained by the licensees they have introduced improvements to the designs to facilitate manufacture and maintenance and to improve acceptability to their customers.

Following on from the successful application of the prototype whole bar heater at Sanderson Kayser Ltd the first commercial unit of this type was ordered from Fairbank Brearley in 1979 and installed at the Aycliffe plant of Jonas Woodhead. This unit is used for the high volume production of vehicle stabilizer bars which are safety critical components requiring good temperature uniformity and accurate temperature control. The success of this unit in meeting the stringent quality control standards of the automobile industry, together with the low fuel consumption and high productivity of highly automated plant, enabled Jonas Woodhead to attract and maintain business in this highly competitive market.

Subsequently heaters of this type have been used for applications in forging and rolling and have been supplied in considerable numbers worldwide.

One of the limitations of the bar-end heaters described previously was that they are only suitable for a heated length of about 300 mm and there are many applications which require a longer heated length. For example a recent development in the spring industry is the minimum leaf spring. In a conventional leaf spring the required characteristics are obtained by bolting together a number of leaves of different lengths; however, the minimum leaf spring is made from a single piece of material which varies in thickness from the end towards the centre of the spring. In the manufacturing process half the length of a piece of material with constant cross section is heated to 1000 °C and this is rolled to give the required thickness profile. These pieces can be up to 2 m in total length, consequently they cannot be heated in the type of heater described previously.

A satisfactory solution to provide a rapid heater for this application was achieved by designing a heater with load recuperation with a slot down one side which would allow the unheated portion of the stock to remain outside the furnace. Not only does this design allow the heating of lengths in excess of 300 mm but because of the counterflow principle the units are more efficient in use than the original end heaters. A design procedure has been established for this type of heater and the licensees have completed many examples.

The success of the licensees in bringing this development into industrial use can be seen from figure 15 which shows the cumulative sales of heaters since the introduction of the licence agreements.

More than 300 heaters with an installed thermal capacity in excess of 100 MW have now been sold. Results obtained from many of these installations indicate that significant fuel savings are being made in comparison with the previous installation, generally this is in excess of 40%. A survey carried out in 1985, covering sales of rapid heaters to the end of 1983, indicated that more than 90% of the units sold were still in production use and the average daily shift time was 10 h. Using this information, and making assumptions concerning the average thermal input and plant utilization, it is estimated that rapid heaters have saved a total of 1.9 PJ with a current value of about £6 M.

The value of the sales completed to date is in excess of £3 M and these have been obtained during a period when there has been limited investment in the relevant

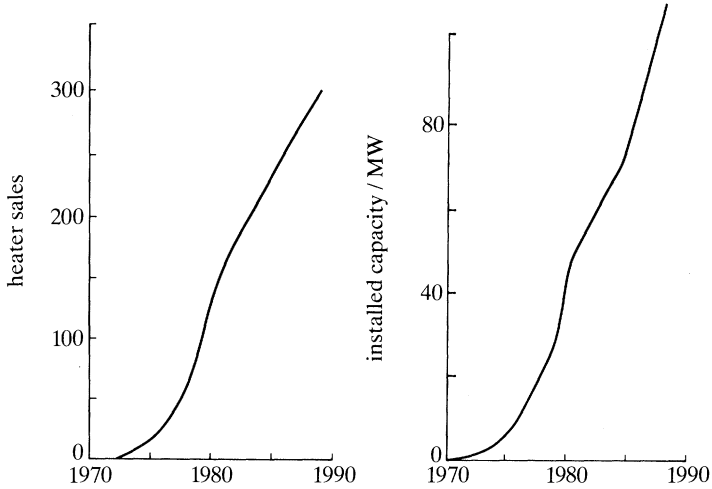

Figure 15. Cumulative heater sales and installed thermal capacity.

industries. The success of existing rapid-heater installations has prompted many users to place repeat orders and increasing numbers of companies considering investment in new furnaces now regard this technology to be the most cost-effective route to energy savings combined with improvements in product quality and productivity. The interest being shown by customers in this technology was recognized by Camlaw Ltd, an existing British furnace manufacturer and they made an approach to British Gas in 1989 with a request that they could become a licensee for rapid heating. They were granted a licence during 1989 and have recently completed their first order for a customer in Germany.

Rapid-heating technology has been recognized outside the U.K. and in the past few years exports have accounted for more than 30% of the business. Heaters have been sold to many countries throughout the world but currently there is considerable interest from companies in the United States and Canada and a number of heaters have already been supplied to these countries. This interest has resulted recently in the granting of a licence to an American company Rapid Technologies Inc., a company formed within the Marmon Group and follows the successful application of rapid heaters within other Group companies.

Clearly these new licences are the result of demand for the product which has been recognized by these companies and augurs well for continuing growth in the application of rapid heating in the future leading to increased fuel savings on a global basis.

This paper is published by permission of British Gas. The authors acknowledge the contributions made to the work by many people. This includes both present and former colleagues at the Midlands Research Station and within British Gas, who have supported and encouraged this work over many years. The results that have been achieved would not have been possible without the contributions from the licensees and we thank them for their support and wish them continuing success for the future.

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igure 7

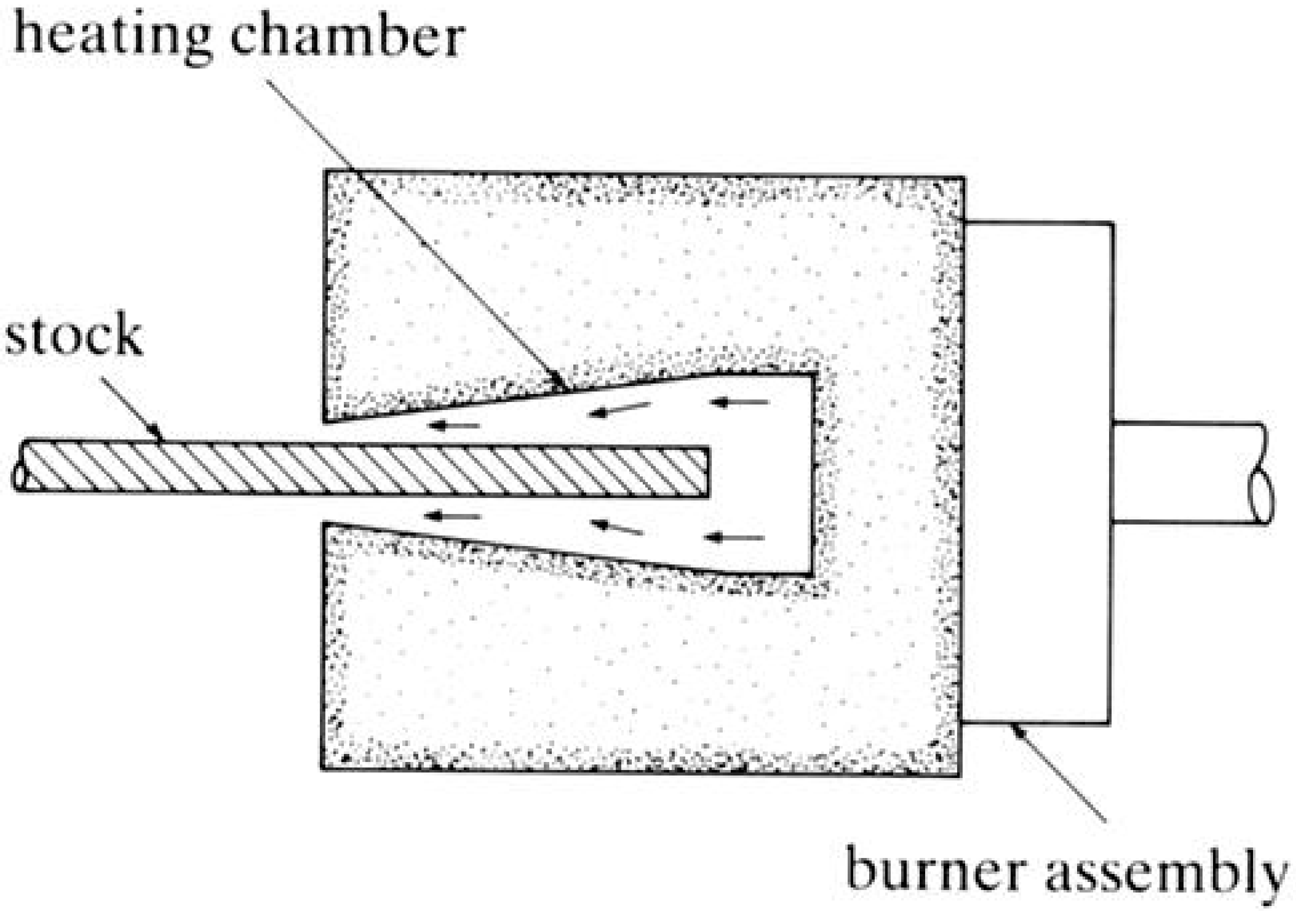

Figure 8

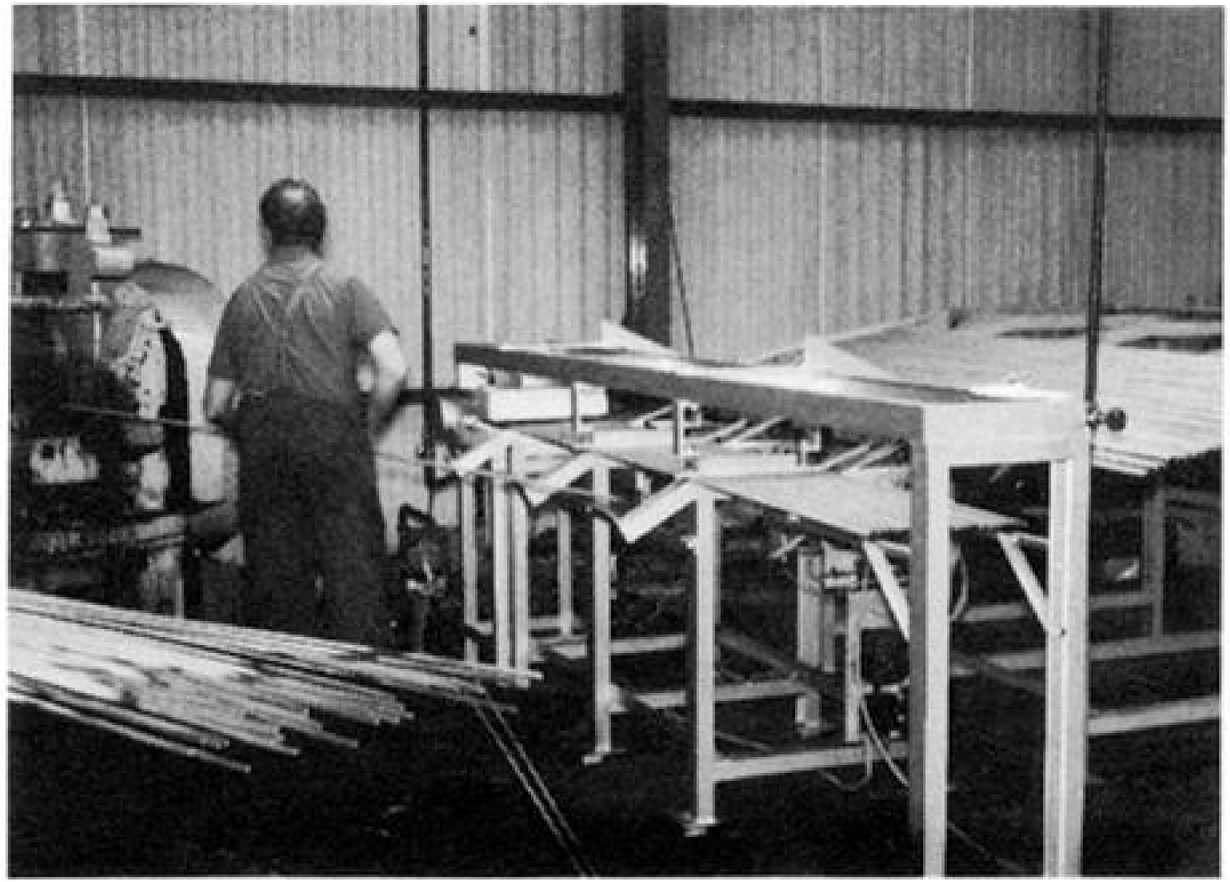

Figure 7. Bar-end heater.

Figure 8. Rod-end heater.

igure 9

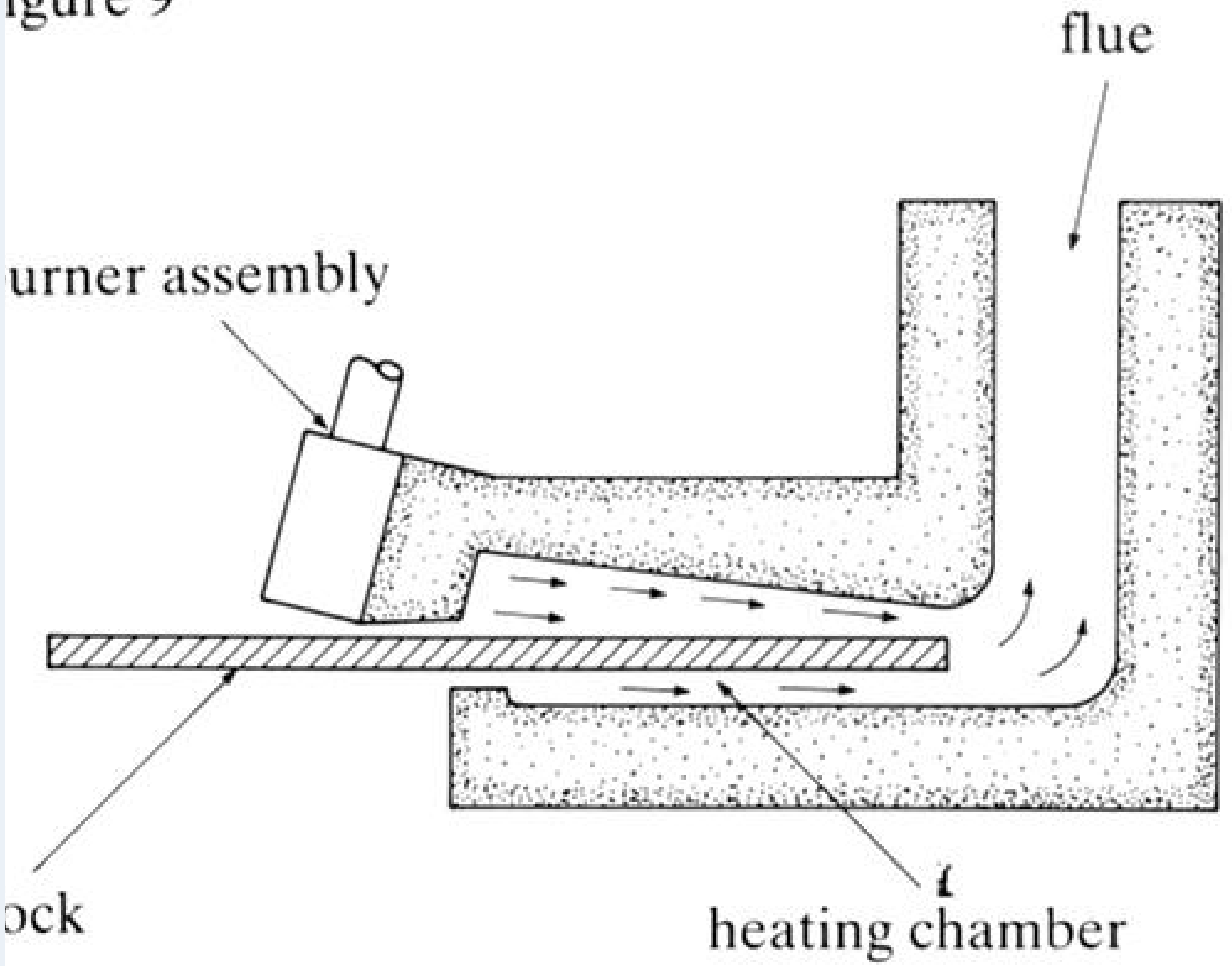

Figure 10

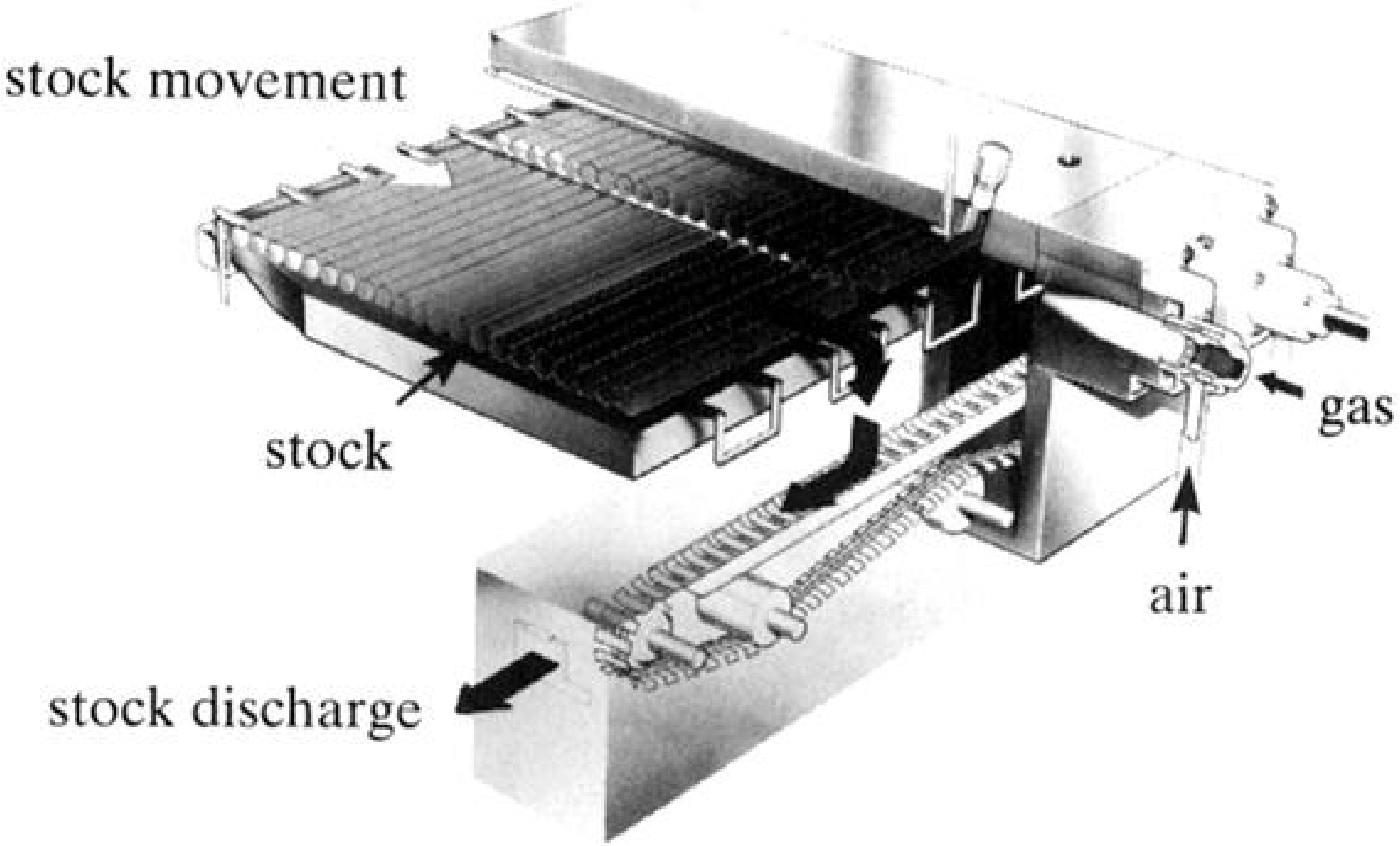

Figure 9. Front fired bar-end heater developed by Fairbank Brearley.

Figure 10. Schematic of a rapid heater with load recuperation.

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Figure 11

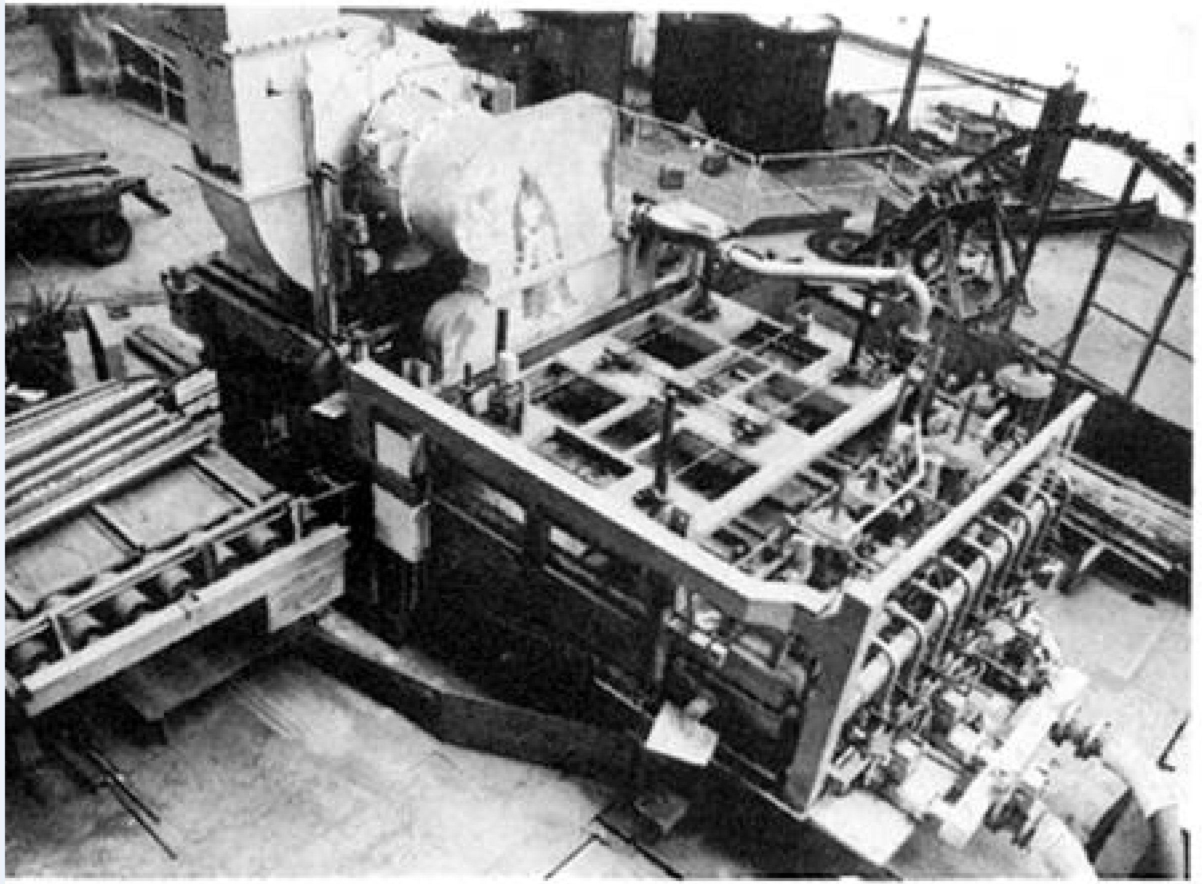
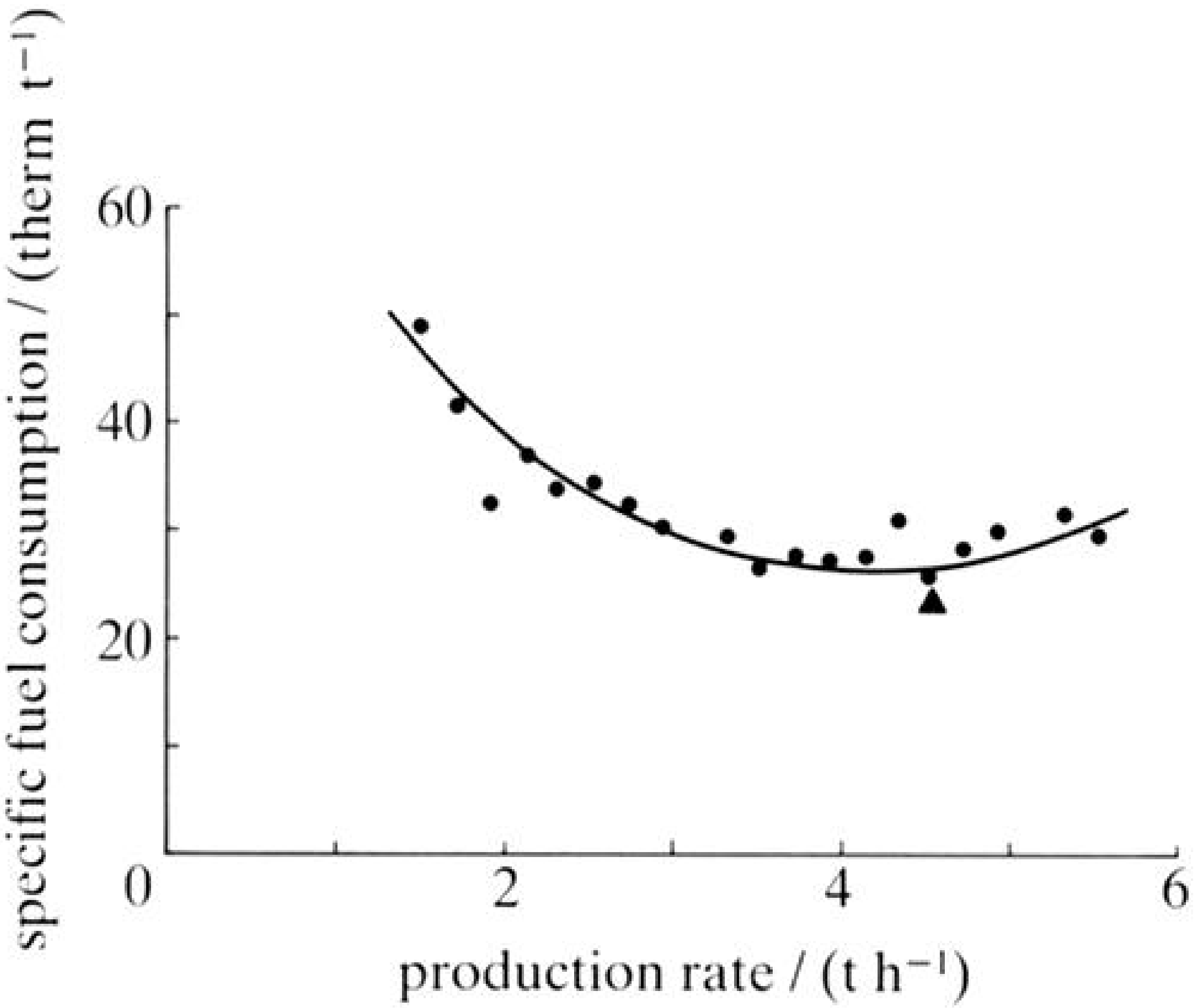


Figure 12



igure 11. 4.5 t h^{-1} whole bar heater installed at Sanderson Kayser Ltd, Sheffield.

igure 12. Furnace thermal performance. ▲, Predicted performance for steady-state operation at ated output.