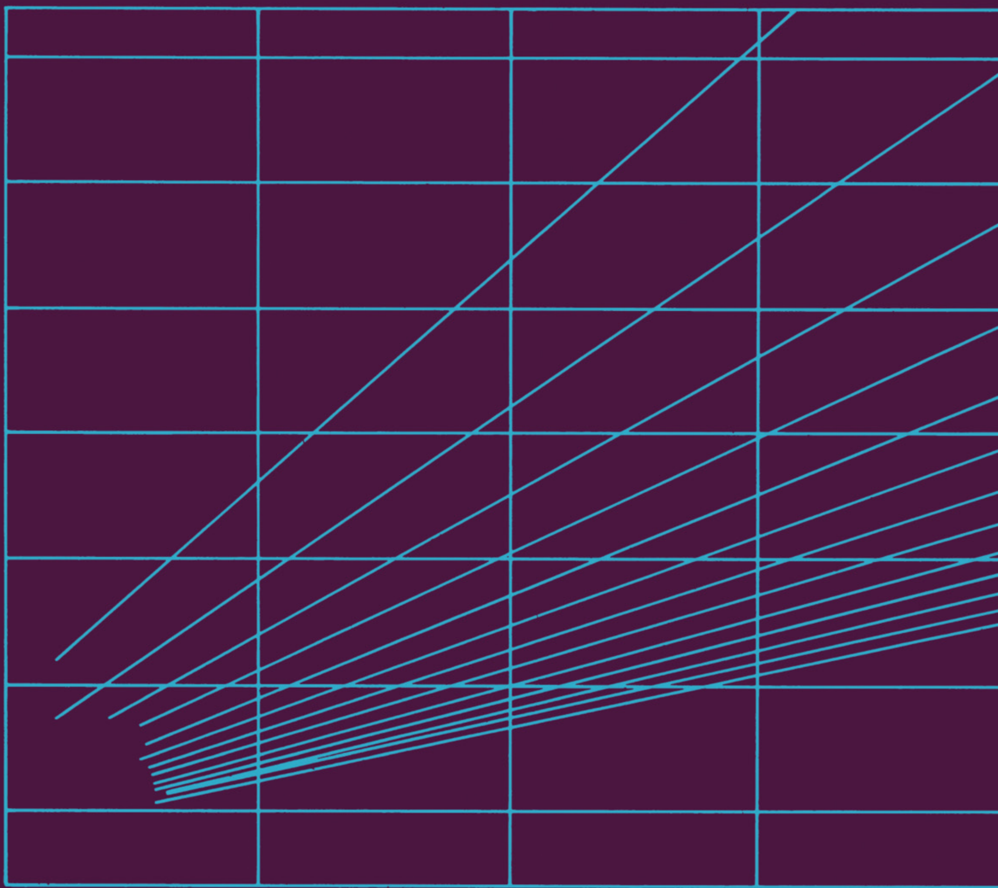
Boiler Efficiency and Safety



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Boiler Efficiency and Safety

Some potential savings from following advice in this book

- **First, enhanced safety saves life and health**

- **Savings of 5 to 10 per cent on fuel costs are often possible at little or no cost**

- **Savings of up to 30 per cent on fuel costs may be possible by using new steam-generating or steam-using equipment**

- **Target boiler efficiency with new package boilers can be up to 85 per cent at maximum continuous rating**

- **Off-line time can drop drastically, giving production continuity and reduced labour costs**

- **Repair costs can drop by thousands of pounds a year**

Only you can achieve savings of this kind at your plant, but the information in this book can help.

Boiler Efficiency and Safety

A Guide for Managers, Engineers and Operators responsible for Small Steam Boilers

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W. S. Robertson

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Preface

This book covers practical steps to achieve fuel – and money – savings in one specific area: for package steam boilers of up to about 10 MW output. The authors know its content achieves savings – they have achieved them in their own organisation.

The book is written principally for managers responsible for automatic steam boilers, and for supervisors and operators who run them. It gives managers the background data that they need to ensure their equipment is operated at maximum efficiency. It also gives operators the basic information they need to carry out efficient boiler operation. The book is not primarily intended for professional engineers: they are likely to know it all already, although some may appreciate a reminder of a few basic points.

The content of the book springs from a programme on boiler efficiency and safety introduced in Esso Petroleum Company marketing plants. That programme for plant managers and for operators saved £60 000 in fuel costs in its first year. The Boiler Efficiency and Safety Training programme was later made generally available to industry as an audio-visual presentation on filmstrip/tape and on video.

However, since audiovisual techniques are not always applicable, this book has been written, mainly by those involved in the original programme, to expand on the information in the programme and to make it more widely available.

The book begins with a discussion of vital safety factors. It then briefly covers the types and selection of oil fuels. Although the book as a whole uses oil-fired boilers as examples, only chapter 2 on types and selection is exclusively concerned with oil fuel – much of the remainder applies equally to gas firing and, to a lesser extent, to solid-fuel firing.

The book deals in some detail with the theory and practice of combustion and of water treatment. This is followed by a chapter on boiler operation and a comprehensive chapter on maintenance. The chapter on steam use stresses the important but sometimes overlooked point that savings here can be many times as great as savings in steam generation. Finally, there is a chapter on training courses and information for operators and managers.

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1 Safety

Oil or gas-fired package boilers are frequently described as 'fully automatic', giving the impression that once started they can be left to operate without supervision. This is possible, but dangerous. It could, in the extreme, cause a boiler explosion. It would certainly make the boiler operate well below its optimum efficiency. No boiler ought to be run without a qualified operator being on the site. He need not be in the boiler room all the time, but he should be where he can hear an alarm and act on it. It would be more accurate to describe package boilers as being automatic only to the extent that they are fitted with controls to maintain combustion efficiency under varying load conditions and to control water level, and that this enables the amount of attendance to be reduced.

Guidance Note PM5 from the Health and Safety Executive states 'Experience has shown that the incidence of damage or explosion caused by low water conditions has been higher *pro rata* with boilers having fully automatic level and firing controls than with those which are manually controlled'. It follows then that safe package boiler operation can only be achieved by working to a systematic, closely controlled operating plan.

Boiler safety cannot be separated from boiler efficiency; there are close ties between the two. There are also links with the maintenance and repair aspects. Figure 1.1 shows these links and their connection with operational practices. For example, the safety of a boiler will depend on the standard of maintenance and this in turn will be influenced by the way the unit is operated.

The complexity of a modern package boiler makes the statutory boiler inspection as covered by the Examination of Steam Boilers Regulations 1964 less than adequate. A more detailed three-part check is recommended, including such items as the control cubicle with its associated wiring, the motor starters, and so on.

Hazards from operating package boilers can arise on the water side from low water level, poor quality feed water or high steam pressure. On the fire side they may be caused by defects in the firing equipment and controls. Low water level is dangerous in any boiler. In particular, modern package boilers contain little water in relation to their steaming capacity, and failure of the water feed system

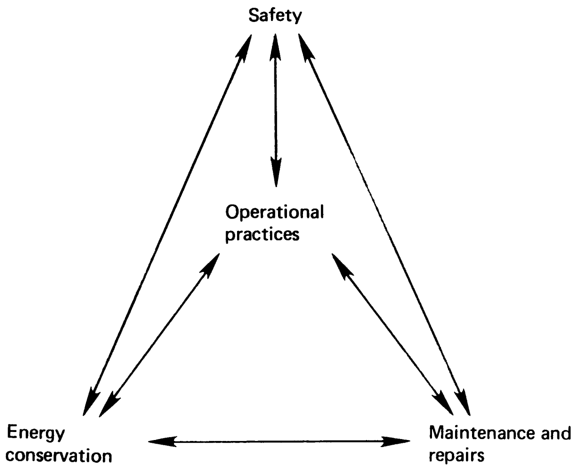


Figure 1.1

could quickly cause a serious accident from furnace tube collapse. To a lesser degree, perhaps, there is the danger of an explosion from tube over-heating where scale build-up has insulated heating surfaces from the water, so causing the tube material to soften and become deformed under the steam pressure. In a similar way, condensate contaminated with on can cause local over-heating.

Fire risk must also be considered; provision for testing and maintenance of fire valves and associated equipment is essential for continued safe operation.

The boiler specialist

Energy conservation is not, of course, confined to the boiler house. The greatest savings in fuel are likely to be made where heat is used, on the process plant. Here there can be conflicting interests between the production and service sides at a factory or installation. One solution is to set up an organisation where a single person (with deputy) is made responsible for the technical aspects of both the total steam-raising and steam-using operations within the boiler house and on the plant. He is described in this book as the 'boiler specialist'.

The boiler specialist is a suitably trained employee who is responsible for all aspects of boiler operation and safety. Each organisation will have its own ideas about the appointment, but certainly it could be covered by a senior plant operator, a plant fitter, a technician or a shift or maintenance supervisor. The advantages of undivided responsibility for this important area are clear, since a problem of shift operation is that the boiler plant may become no one's responsibility and be neglected. It would be the boiler specialist's responsibility to carry out the duties which can be summarised in table 1.1, so avoiding a possible random approach that might lead to unsafe as well as inefficient boiler operation.

This total operation would include setting up a system for routine checking

Table 1.1 Summary of specialist duties

- Monitor operation of boiler or heating plant
- Check legislation is compiled with and company practices followed
- Advise management about the maintenance and repair of the plant; when contractors are used, ensure their work meets requirements
- Participate in training plant staff
- Advise plant management on energy-conservation activities for boiler fuels, and regularly review results

of the actual boiler controls, a system for checking feed water quality, and a planned system of maintenance. It would also include a means for controlling combustion and steam usage. A recording system is required to give information which will ensure that defects are corrected as speedily as possible and fuel consumption minimised. Later chapters in this book cover these aspects, together with some suggestions for carrying out essential operator training.

The inspection system

The inspection system can be divided according to daily and weekly frequencies as shown in tables 1.2 and 1.3.

In addition to the daily and weekly inspections there is the statutory inspection, and an annual three-part inspection, dealt with in more detail in table 1.4, which summarises all these inspections and indicates the responsible bodies.

Table 1.2 Daily inspections

Safety	*Energy conservation*
4-hourly checks	*Daily or on receipt*
Boiler blowdown as instructed	Fuel oil receipts
Inspect for leaks	
Check water level in sight glass	
8-hourly checks	*Daily*
Blowdown sight glasses	Steam/water meter readings
Check feed water free from contamination	
24-hourly checks	
Check first level control	
Check second level control (specialist)	
Check flame failure device	
Observations made for possible fault reporting	

Table 1.3 Weekly inspections

Safety	*Energy conservation*	
Check level controls Check flame-failure device Check	Combustion testing	carbon dioxide, smoke number, flue gas temperature
Observations made for possible fault reporting		

Table 1.4 Overall inspection responsibilities

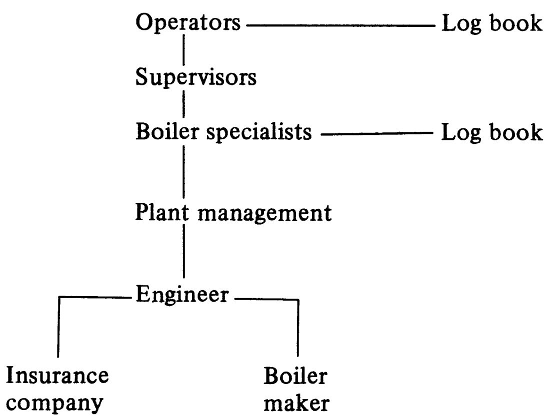
Trained boiler operator	4 and 8-hourly and daily
Boiler specialist	Daily and weekly
Insurance company	Statutory
Qualified engineer	Annual three-part

The three-part annual inspection has three principal objectives, to ensure that

- plant complies with legislation and company standards
- company safety and energy-conservation practices are followed
- proper standards of maintenance and repair are being applied.

It can be organised by the first part being done just before the statutory inspection, with the plant fully operational. The second part can be done during the statutory inspection, when the plant is stripped down. At this time all the items requiring internal inspection can be attended to. The third part of the inspection can be completed after the boiler has been put back on line. It is a check to see that all running adjustments have been correctly made.

Table 1.5 Action log procedures



Log books must be kept and used. They must have a section for fault reporting, and there must be an agreed set of procedures for dealing with faults logged in it. One such set of procedures is shown in table 1.5.

There are obviously many possible variations but every organisation should have a system which tells supervisors and management about a problem as soon as it arises. Regular inspection of logs, regardless of the fault reporting, is especially important if the necessary close control is to be achieved.

References

Guidance Note PM5: Automatically controlled steam and hot water boiler (Health and Safety Executive, HMSO, 1977)

Guidance Note GS5: Entry into confined spaces, hazards and precautions (Health and Safety Executive, HMSO, 1977)

2 Types and Selection of Fuel Oils

Types of fuel oil

The broadest classification of petroleum fuel is

- distillate fuels, including liquefied petroleum gas (LPG), composed of petroleum fractions which have been vaporised and condensed
- residual fuel oils, composed wholly or partly of petroleum fractions which do not vaporise during the distillation process.

LPG can be obtained substantially pure and accordingly is classified by its main chemical composition: butane or propane. The distillate and residual fuels are so complex that they are classified by their end use: petrol, paraffin, aviation fuel, diesel fuel, heating oil and a range of heavy fuels for marine and industrial use.

Standard specifications for fuels are issued in many countries, usually by some national body. In the United Kingdom it is the British Standards Institution. The standards ensure that all fuels meeting a given classification will give satisfactory performance in their designated end use.

Table 2.1 shows the standards issued by various countries and compares them with the fuel classes of BS 2869: 1970 Specification for petroleum fuels for oil engines and burners.

Distillate fuels

A distillate fuel is initially refined by primary distillation. It will usually be translucent and contain negligible amounts of water and ash-forming constituents. The sulphur content will depend on the crude oil from which it is distilled. The only distillate fuel to be considered here is heating oil, meeting BS 2869 Class D. A typical inspection is given in table 2.2. This is the main fuel used to fire domestic central heating units over 29 kW, and for central heating of shops, public buildings, and so on up, to at least a requirement of 150 kW. These installations usually employ fully automatic gun-type pressure jet burners adapted to ON–OFF operation, the fuel being ignited electrically.

Table 2.1 British Standard equivalents in other countries

Country	Standard					
United Kingdom	BS 2869	D	E	F	G	H
United States	ASTM D.396	No2	No5 Light	No5 Heavy	←No6→	
Sweden	SIS 155403	E01	E03	E04	←E05→	
Germany	DIN 51603	Heizol EL	Heizol M. (C.T.F.)	–	Heizol S	
Belgium	NBN 52501	A/B Gas oil/F.O. Leger	C F.O. Intermediare	D F.O. Lourd	E F.O. Extra Lourd	
Switzerland	SNV 81160	Heizol Extra leger	Heizol Moyenne	Heizol Lourd	–	
France	NF M15-	–008 F.O. Domestique	–009 F.O. Leger	–010 F.O. Lourd No1	–011 F.O. Lourd No2	
Italy	UNI 6579-69	Gas oil	Fuel Fluid & semi fluid		Fuel Denso	

Table 2.2 Typical inspections of oil fuels

BS 2869 Class	D Heating oil	E Fuel light	F Fuel medium	G Fuel heavy
Density at 15 °C (kg/l)	0.850	0.940	0.970	0.980
Flash point (PM) (°C)	+66	+66	+66	+66
Viscosity at 40 °C (cSt)	3.0	–	–	–
82.2 °C (cSt)	–	12	27	60
Water (% Volume)	negligible	0.1	0.1	0.1
Ash (% mass)	0.0002	0.02	0.03	0.03
Sulphur (% mass)	0.45	2.8	3.0	3.3
Cold filter plugging point (°C)	winter –9			
	summer 0	pour point °C –27	–6	3
Distillation 50% rec at °C	265	–	–	–
90% rec at °C	325			
Final boiling point °C	355			
Calculated specific energy				
gross MJ/kg	45.4	43.18	42.62	42.35
gross kWh/l	10.72	11.27	11.48	11.53
net MJ/kg	42.60	40.72	40.26	40.03
net kWh/l	10.06	10.63	10.85	10.90

The requirements for a distillate fuel are that it will ignite readily and burn completely even when the boiler is cold. It may be stored and handled at ambient temperatures. Filters and, wherever possible, the pipeline from the storage tank should be protected against extreme winter conditions. The fuel filter should always be indoors, and the pipe runs between tank and filter should be lagged or buried. Apart from the automatic controls, which are electrically operated, the only power consumption is to raise the fuel to atomising pressure. Electricity demand is therefore very low.

Because of their low sulphur content, distillate fuels are useful in installations where high chimneys are not permitted. The Chimney Height Memorandum waives any minimum on chimney height if the amount of sulphur dioxide emitted does not exceed 1.36 kg/h. Because distillate fuels are practically ash free and have low sulphur contents, maintenance costs (including boiler, burner and chimney cleaning) can be reduced considerably provided that the combustion conditions are optimised. These maintenance cost savings, coupled with ease of storage and handling and low electricity requirement, could be used to justify a distillate in place of a residual fuel. This is particularly important if the use of a residual fuel in a given installation is giving rise to a public nuisance – say smutting – which cannot be cured by the recommendations given in chapters 4 or 6. BS 2869 Class D distillate fuels are marked by a red dye and contain chemical markers so that they may be distinguished from road fuels, on which excise duty is payable.

Residual fuels

Typical inspections of light, medium and heavy grades of fuel oil are given in table 2.2. These fuels are based on the residues obtained from the distillation of crude oil blended as necessary with distillate fuel to give required viscosity ranges. The nature of the residues depends on the crude and type of distillation plant. Because no further refining takes place, residual fuels are cheaper to produce than distillates. To benefit from the reduced fuel cost, the user must take precautions to minimise potential problems such as low temperature corrosion, high temperature corrosion, poor combustion and so on. If he does not, the cost benefits of using residual fuels can easily be eroded. These problems and their solutions are discussed elsewhere in this book. The residues obtained from different crudes and distillation processes can vary in viscosity, sulphur and ash contents. Some of these qualities, and their impact on end use, are now discussed.

Viscosity grades

Residual fuels can be blended (cut-back) to a desired viscosity range. For economic, design and handling reasons, three grades are marketed generally in the United Kingdom. Some countries market different grades – see table 2.1. The choice of which fuel viscosity group to use depends on factors such as the ease of handling (pumpability), and burner and boiler design.

Pumpability

Residual fuel oil is a highly complex mixture. It can be regarded as a colloidal suspension of wax, asphaltenes and resins in a heavy oil. At higher temperatures, its temperature/viscosity relationship is sufficiently constant to allow the required atomising temperature to be calculated from the specified viscosity for that fuel grade. However, as the fuel cools and approaches its pour point, its temperature/viscosity relationship changes drastically. Low temperature behaviour of residual fuels cannot therefore be predicted from their specified viscosities. Pumpability tests are required to do that.

BS 2869 recommends minimum storage and handling temperatures for each of the grades (see table 2.3), covering the worst cases likely to be encountered, and burner manufacturers recommend the optimum atomising viscosity (or temperature) for a given grade of fuel oil for their burners.

Some economy may be available in storage and handling costs by applying the Institute of Petroleum IP 230/74 pumpability test to the fuel. This test assesses the temperatures at which the fuel has apparent viscosities of 25 poise and 6 poise, respectively the minimum storage and handling values. These are usually lower than those recommended by BS to cover the worst cases, so allowing less heat to be used.

Table 2.3 Recommended storage temperatures

Class of fuel	*Minimum temperature for storage* (°C)	*Minimum temperature for outflow from storage and for handling* (°C)
E	10	10
F	25	30
G	40	50

Sulphur content

All residual fuels contain some sulphur compounds. These compounds are unwanted impurities, but their total removal by refining would be uneconomic. Remedies to combat the adverse effect of the combustion products of sulphur on the cooler parts of the boiler/chimney installation are dealt with in chapter 4. These precautions should be respected. At best small boilers are likely to have 20 per cent excess air levels, and there will therefore always be some formation of sulphur trioxide in them, even with low sulphur content fuels.

Ash content

Petroleum crudes contain complex organic compounds containing vanadium, which concentrate in the residual fuels when the crude is distilled. The vanadium content of residual fuels will vary from a few parts to a few hundred parts per million depending on crude oil source.

On combustion, and in combination with sodium and sulphur, vanadium compounds can form low melting point compounds which can corrode iron at temperatures above 565 °C. Fortunately, high temperature corrosion is not a severe problem in the United Kingdom. The method used today for fixing fire-tubes in tube plates in packaged boilers optimises conduction of heat away to the water side. Older boilers may have fire-tube ends extending out of the plate and thus be vulnerable to high temperature corrosion. These boilers should preferably be modified. If this is not possible, the water side of the plate and tubes should be kept as clean as possible.

Selection of fuel oils

The various grades of residual fuel are obtained by blending residues with distillate fuel. The more residual fuel in the blend (the 'heavier' the fuel) the longer is the time for complete burn-out of all the components. For this reason, distillate fuels generally give short flames and residual fuels give progressively longer flames as they increase in viscosity.

Boilers are designed to be capable of generating a given amount of steam or hot water per hour. However, boiler designs differ, even for equivalent outputs, and two boilers with the same nominal ratings and operating under similar load conditions, but of different design, may not be able to burn the same fuel satisfactorily. There is a trend towards reduction in boiler size, with increases in heat release per unit volume.

As a first approximation, table 2.4 gives throughputs per burner for the different BS 2869 Class fuels discussed.

As a general guide, for boilers of a given rating destined for base load operation, the heaviest grade possible should be chosen. For those with intermittent duty or fluctuating load, the lightest grade should be chosen. For example, for

Table 2.4 Throughputs for various fuels

BS 2869 Class		Acceptable throughput per burner installed (kW)
D	Heating oil	23– 450
E	Fuel light	150– 900
F	Fuel medium	450–1500
G	Fuel heavy	900 upwards

a single-burner boiler designed to give 600 kW output on base load, choose Fuel Medium. If the same boiler is to modulate down to 60 per cent load, choose Fuel Light. If the dust burdens of the flue gases on the same boiler at base load are found to be intolerably high or if the boiler fouls quickly, giving increases in exit flue gas temperature, (remember that an increase of 15 °C reduces the boiler efficiency by 1 per cent) a lighter grade should be used.

In summary, choose the heaviest grade of fuel (this will be the cheapest) consistent with trouble-free operation of the installation as a whole.

Reference

BS 2869: 1970 Specification for petroleum fuels for oil engines and burners

3 Combustion Processes and Monitoring

Chapter 3 covers the theory of combustion, methods for monitoring combustion and the equipment required. It also discusses legal requirements for smoke and particulate emissions and ways to keep within these requirements.

The process of combustion in fire is the rapid oxidation of fuel by the oxygen in the air. The fuel elements – primarily carbon and hydrogen – are converted, respectively, into carbon dioxide (CO_2) and water (H_2O), accompanied by the release of heat and light. Chemically, this process can be represented by the following equations

$$C + O_2 \longrightarrow CO_2 + 7830 \text{ kcal/kg carbon burned}$$

$$2H_2 + O_2 \longrightarrow 2H_2O + 28\,890 \text{ kcal/kg hydrogen burned when, as in practice, water escapes as vapour}$$

Perfect combustion is obtained by reacting exactly the right proportion of fuel and oxygen to obtain carbon dioxide and water, with no unburnt fuel or unutilised oxygen left over. This is also referred to as combustion with zero excess air, or stoichiometric combustion.

When more oxygen is introduced into the system than is needed, the extra oxygen goes through unutilised. Since in practice air is used as the source of oxygen, the unutilised mass (including the nitrogen content of air) is approximately five times the excess oxygen. This unnecessary mass soaks up heat of combustion, lowers the peak flame temperature, and reduces heat transmission and the overall efficiency of the process.

Lack of oxygen in the system is even more undesirable. It leaves some of the fuel unburned or partially burned (a source of malodour), produces carbon monoxide (CO), hydrogen (H_2) and soot, and also releases less than optimum heat. So for perfect combustion, fuel and air must be supplied in the required amount, no more and no less.

Perfect combustion could be achieved if the burner and the combustion chamber were so well designed that the fuel and air, supplied in correct proportion, mixed well quickly and the flame chemical processes occurred unhindered, that is, without quenching due to any part of the flame coming in contact with colder surfaces. Commercial combustion systems, however, may have design deficiencies, and hence an operator's objective is to achieve the maximum possible efficiency from a given system. What follows describes how efficiency can be monitored, and what steps are necessary to ensure that it is the maximum achievable.

Monitoring combustion

The methods for monitoring combustion and heating efficiency are simple in principle. They involve ensuring the following.

(1) The carbon dioxide content of the flue gas is the maximum possible and, coincidentally, the oxygen content is a minimum.

(2) Soot emission is preferably negligible, and in no case more than that stipulated by the Clean Air Acts, 1956 and 1968 (not more than shade 1 on the Ringelmann scale). When the fuel used is not a distillate material but a fuel oil, containing mineral as well as sulphur and nitrogen impurities, the emission of particulate matter (composed of mineral residues and soot) must not exceed the stipulated value (SI 1971 No. 162).

(3) The flue gas temperature is the lowest practicable.

(1) indicates the efficiency of the combustion process, (2) helps fulfil the legally binding stipulation regarding visible smoke and discharge of solids and (3) indicates how well the heat generated is being utilised. These three measurements are absolutely essential and the way they are carried out will be discussed in the next section.

Besides these three measurements there are also others which may be desirable in certain circumstances. Among these are the measurements of carbon monoxide, hydrogen and unburned hydrocarbons. Their presence in the flue gas will be minimal, and hardly worth checking, if both (1) and (2) are entirely satisfactory. If this is not so, it is desirable to monitor them, usually only carbon monoxide, since all three rise and fall in a similar manner.

Another measurement required is that of sulphur trioxide (SO_3). During combustion the sulphur in the fuel is oxidised to sulphur dioxide (SO_2), and a small proportion of this, usually less than 5 per cent, is converted to sulphur trioxide. The formation of sulphur dioxide cannot be controlled, but that of sulphur trioxide can and may need to be. This is because sulphur trioxide can cause serious corrosion when and where the temperature of the flue gas drops below the 'acid dewpoint', the temperature at which sulphur trioxide combines with water vapour and condenses out as sulphuric acid.

Yet another measurement of possible interest is that of nitrogen oxides (NO_x), mixtures of nitric oxide and nitrogen dioxide. These are largely formed by the oxidation of the nitrogen impurities in the fuel. Some nitrogen oxides are also formed by direct reaction between nitrogen and oxygen of the air. They are known to catalyse formation of photochemical smog in sunny climates such as that in Southern California, and their emission must not be excessive. In the United Kingdom and most of Europe, however, photochemical smog is not experienced and here, therefore, it is usually unnecessary to monitor nitrogen oxides.

Equipment and analysis

A variety of equipment is available to measure the properties just described. Some, simple and inexpensive, is suitable for manual use in the field, whereas other, highly sophisticated, equipment is designed for automatic analysis. Both the simple and sophisticated types are described for the principal measurements: those of carbon dioxide, oxygen, smoke solids and temperatures.

CARBON DIOXIDE

For manual use a simple equipment is typified by the Fyrite analyser (figure 3.1). Here the flue gas sample, drawn into the upper part of the instrument, is brought into contact with a solution of sodium hydroxide, held in the lower part, by inverting the analyser. Carbon dioxide is absorbed by the solution and the resultant reduction in volume of the test gas represents the carbon dioxide content. A more sophisticated, and expensive, portable analyser is the thermal conductivity device, such as the one made by George Kent Electronic Products Ltd.

For automatic continuous analysis infrared analysers are highly suitable, although they are rather expensive. The flue gas, freed of moisture and solids, is continuously passed through the instrument and carbon dioxide is directly

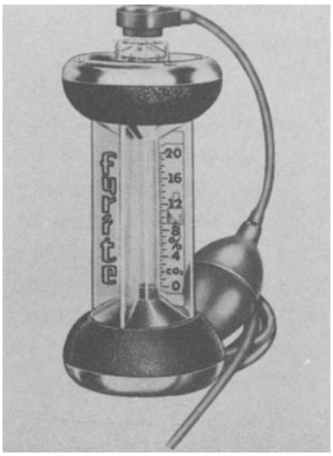


Figure 3.1 Fyrite carbon dioxide analyser

indicated on a dial or registered on a recorder. Such instruments provide a reliable measure of carbon dioxide and respond quickly to changes in its concentration, but they do require rather frequent calibration.

Figure 3.2 shows typical carbon dioxide and oxygen analyses of flue gas when combustion is carried out at different levels of excess air. The concentration of carbon dioxide falls, and that of oxygen rises, as more excess air is used for combustion. A low carbon dioxide reading and a high oxygen reading could also arise from air leakage into the system. If air leakage is suspected, its approximate location could be established by analysing the flue gas near the exit of the combustion chamber and at various points downstream of it.

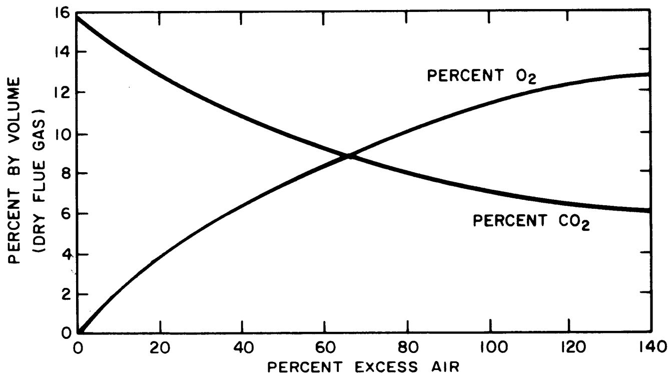


Figure 3.2 Influence of combustion excess air on carbon dioxide and oxygen in flue gas

OXYGEN

Fyrite-type equipment, with a different absorption medium to that used for carbon dioxide analysis, has in the past been used for oxygen analysis. However, nowadays smaller versions of the equipment developed for automatic analysis are increasingly used. These are very convenient to use and they provide an immediate indication of oxygen concentration. A commonly used instrument of this type is the Servomex Oxygen Analyser* (figure 3.3). Larger instruments with automatic sampling and recording arrangements are available for automatic analysis. Typical oxygen concentrations in flue gas and their significance have been discussed above along with carbon dioxide analysis.

* manufactured by Taylor Analytics, Crowborough, Sussex.

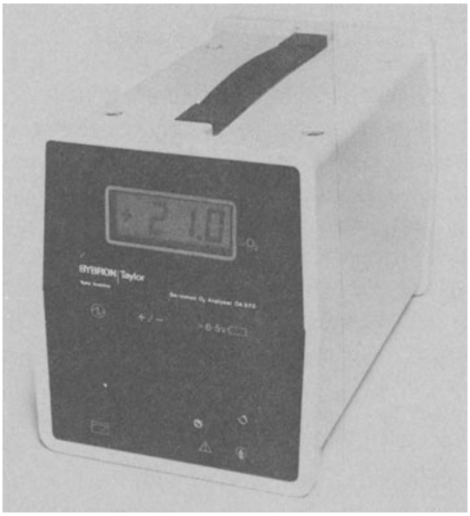


Figure 3.3 Servomex 570A oxygen analyser

SMOKE

The Ringelmann chart (BS 2742 C) is the prescribed method of smoke measurement, using shade cards with grilles or lattices of black lines of different intensity, numbered 0 to 4. The charts are held up against the smoke and the shade number which most closely matches the darkness of the chimney smoke when viewed in the prescribed manner is the Ringelmann smoke number measurement. A more convenient method is the miniature smoke chart (BS 2742 M) which, with an experienced observer, gives the same results as the Ringelmann chart.

Another convenient technique is the Bacharach smoke method. Here a fixed volume of flue gas is drawn through a filter paper. Smoke leaves a dark mark on the filter paper and the darkness of the mark, on comparison with a set of standards, provides a measure of smoke intensity.

For automatic analysis, optical smoke meters are available. These consist of two parts: a light projector mounted on one side of the flue duct and a light-sensitive receiver cell on the other. The amount of light obscuration provides a measure of smoke density.

Smoke emission represents inefficient combustion. Not only is the emission itself environmentally unacceptable, the build-up of carbon deposits within the system also impairs heat utilisation. Hence, optimum combustion performance requires achieving maximum carbon dioxide at the acceptable smoke level – not more than No. 1 Ringelmann scale or No. 4 Bacharach scale with fuel oil or No. 2 with heating oil.

SOLIDS (particulate matter)

Determination of solids in flue gases involves considerable effort. The method used is described in BS 3405: 1971 Simplified methods for measurement of grit and dust emission. The best known instrument* is that devised by the British Coal Utilisation Research Association (BCURA). Here a known quantity of flue gas is drawn through a nozzle attached directly to the inlet of a small cyclone. Particulate matter is centrifuged out and transferred into a detachable hopper. Gas-borne fine particles are further removed with an air filter of glass wool. The equipment is so designed that when operated at sampling rates above 8.5 m^3/h, the cyclone collects substantially all 'grit and dust' particles above 5–10 μm, and the filter collects primarily 'soot and fume' particles.

TEMPERATURE

Flue-gas temperature can be readily measured with thermocouples. Commercially available equipment, such as that by Comark,† is convenient to use. Alternatively, more elaborate suction pyrometers may be used. These help minimise radiation errors, notably when the flue-gas temperature is considerably different from that of the duct. In suction pyrometers the thermocouple junction is shielded from direct radiation and the flue gas is sucked past the junction. The velocity of the sucked gas is gradually increased until the thermocouple reading progressively reaches a steady value.

Temperature measurement of the flue gas, together with its carbon dioxide or oxygen content, helps assess the overall efficiency of the process (figure 3.4). A high net gas temperature (flue-gas temperature minus ambient temperature) indicates that the heat generated is not being used efficiently. Some is being wasted to the atmosphere. The gas temperature should be as low as possible without causing condensation of moisture and sulphur oxides, especially sulphur trioxide.

CARBON MONOXIDE, HYDROGEN, UNBURNT HYDROCARBONS, NITROGEN OXIDES AND SULPHUR TRIOXIDE

Equipment for analysing these products is usually highly sophisticated and expensive. Description and use of such equipment is outside the scope of this book.

Equipment care

All test equipment must be well maintained and its accuracy frequently checked

* Manufactured by Air Flow Development Ltd, High Wycombe, Bucks.
† Comark Electronics Ltd, Brookside, Avenue, Rustington, West Sussex BN16 3LF.

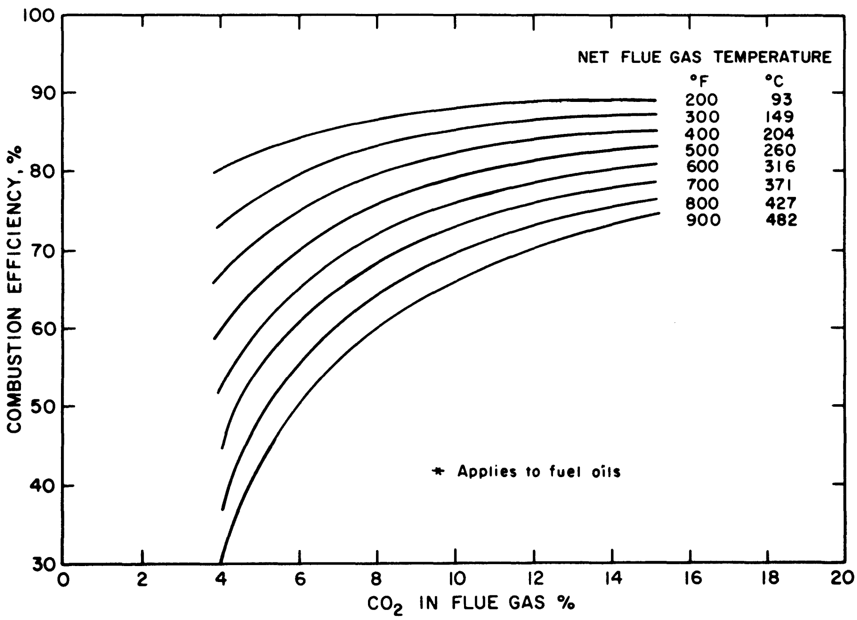


Figure 3.4 Influence of flue gas temperature and carbon dioxide concentration on combustion efficiency

so that the results are truly meaningful and useful in achieving optimum control of the system. If the test equipment is *not* properly maintained and checked it is worse than useless, and the boiler operator would probably be better off with no test equipment at all.

UK legal requirements for smoke and particulate emissions

The solids emitted from oil-fired boilers are

Smoke solid matter of less than 1 μm arising from the incomplete combustion of vapours

Solid matter (particulates) – grit and dust the skeletal remains of individual oil droplets which escaped complete combustion. They are composed of hard carbon plus ash. Particles below 76 μm are called 'dust'.

For the United Kingdom the permitted boiler emissions are contained in a number of Acts, principally

The Clean Air Acts, 1956, 1968
The Alkali, etc. Works Regulation Act, 1906
The Alkali, etc. Works Order, 1966
The Control of Pollution Act, 1974, and the Health and Safety at Work, etc. Act, 1974

The control of smoke

The Clean Air Act, 1956, prohibits the emission of dark smoke (Ringelmann No. 2 or greater) from a chimney, but certain exemptions are prescribed, principally in The Dark Smoke (Permitted Period) Regulations, 1958 (Statutory Instrument 1958 No. 498) (see table 3.1).

Table 3.1 Permitted emissions of dark smoke

Furnaces served by the chimney	In any 8 hour period	
	No soot blowing* (min)	Soot blowing (min)
1	10	14
2	18	25
3	24	34
4+	29	41

Dark smoke may be emitted continuously for four minutes and this allows for boilers starting up from cold. No emissions of black smoke (Ringelmann No. 4) exceeding 2 min aggregate in any period of 30 min is allowed. Defences are available to an occupier if he exceeds these levels. They are

- lighting a furnace from cold
- unavoidable mechanical breakdown
- unavoidable use of unsuitable fuel.

These are not absolute defences and the offender has to prove that every practicable effort was made to avoid the emission.

The control of grit and dust

The regulations are described principally in The Clean Air (Emission of Grit and Dust from Furnaces) Regulations SI 1971, No. 162. In simple terms the Regulations apply to all plant above 278 kW (825 lb steam/h) output or 366 kW (1.25 M Btu/h) input where the heated stock does not contribute to the emissions. Thus they do not apply to incinerators, cupolas, and so on, although legislation to cover these is in draft.

The occupier has the defence of 'best practicable means'.

If a notice to measure the emissions is served on an occupier he must provide sampling points, scaffolding, access and electrical connections and, if his plant is *above* 8.2 MW (28M Btu/h) heat input, carry out the tests himself. If his plant has a *lower* fuel input, he can ask the enforcing Authority to carry out the tests.

* Boilers of the type discussed in this book are most unlikely to have soot blowers

As a guide, the permitted grit and dust emissions are about 0.4 per cent wt of fuel burned for furnaces up to 14.65 MW (50 MBtu/h) input, reducing thereafter to a minimum of 0.18 per cent weight of fuel burned for the largest furnaces. Details are given in SI 1971, No. 162.

METHOD OF TEST

In the United Kingdom, any measurement of grit and dust made for the purpose of the Clean Air Act, 1968, must be made according to the Clean Air (Measurement of Grit and Dust from Furnaces) Regulations, SI 1971, No. 161. This requires the test to be made in accordance with the procedures laid down in BS 3405: 1971 Simplified method for the measurement of grit and dust emissions, and in pages 13–26 of *Measurement of Solids in Flue Gases* by P. G. W. Hawksley, S. Badzioch and J. H. Blackett (Institute of Energy, London, 1977). This does not permit the use of some of the automatic techniques described earlier. The equipment is costly and the test requires considerable expertise. Most works should engage a qualified contractor for such work.

Other regulations

Local Authorities now have wide powers to serve notice requiring information about emissions. These and the appeals procedures are contained in the following.

- The Control of Atmospheric Pollution (Research and Publicity) Regulations SI 1977, No. 19
- The Control of Atmospheric Pollution (Appeals) Regulations SI 1977, No. 17
- The Control of Atmospheric Pollution (Exempted Premises) Regulations SI 1977, No. 18

Appeals against research and publicity notices are permitted on three grounds

- disclosure would prejudice some private interest
- be contrary to public interest
- information not available and collection would incur undue expenditure.

Acid smutting

Earlier sections described how high levels of solids emission occur if atomisation is poor (coarse) or the flame is chilled. The large carbon particles so formed can agglomerate in the gas stream on cool surfaces and may subsequently lift off the surface and be discharged through the stack. They are known as smuts and are a special and severe case of emissions. In addition, if the cool *surfaces* are below the acid dewpoint temperature of the gases, then acid will condense on the surfaces and will saturate the smuts. When they are emitted (for example, during start-up), being heavier than air they will settle on and damage surrounding property. Apart from this the acid will undoubtedly corrode and damage the plant itself.

To avoid acid smutting the two fundamental points to follow are

- ensure combustion is good with low emissions
- ensure all *surfaces* within the boiler, flue and chimney are above the acid
- dewpoint temperature.

Control of combustion

Factors affecting the emission of smoke and solids are given in table 3.2.

Table 3.2 Factors affecting grit and dust emission

Quality of atomisation	
Fuel pressure	Higher oil pressures reduce emissions
Fuel viscosity / Fuel temperature	High viscosity/low fuel temperatures increase emissions Correct atomising temperatures minimise emissions
Burner maintenance	Inadequate maintenance increases emissions Damaged rims on rotary cups, badly scored nozzles on pressure jet and air atomising burners increase emissions
Residence time	
Mixing energy	Higher efficiency of fuel/combustion air mixing process reduces emissions (function of burner design and operating conditions)
Combustion intensity	Higher combustion intensity favours an increase in emissions
Flame temperature	
Excess air level	Too low an excess air level increases emissions: conversely too high an excess air level can cause increased emissions
Combustion air temperature	Higher air temperatures tend to decrease emissions
Boiler/furnace retention	
Geometry of heat exchange surfaces	
Efficiency of grit arresters (if fitted)	
Fuel quality	
Ash content / Asphaltenes content	High ash/asphaltene levels may directly increase emissions

Quality of atomisation, residence time and flame temperature factors have by far the greatest effect and are under the control of the designer and operator. Even with the best control there will be some emissions and retention of solids on the boiler and flue surfaces. Loose accumulations of such deposits must be removed periodically otherwise they will be disturbed and ejected at every start-up.

Control of surface temperatures

Flue gases must be well above the acid dewpoint and this must on occasions mean some loss of efficiency. However, the main points to watch for are to seal all air inleakages, to insulate flues and stacks and to design them to give good gas velocities and be resistant to acid attack.

In summary, *to avoid acid smuts*

- design stacks and flues to give good flue-gas exit velocity
- use acid-resistant stack lining
- blank off boiler tubes if necessary to increase flue-gas temperatures
- seal all air inleakages, explosion doors, dampers to other inoperative boilers on same flue
- insulate breeching, stack and other exposed hot surfaces
- ensure feedwater temperatures do not chill fire-tube surfaces
- improve combustion to reduce smoke
- operate at as low an excess air as possible without producing smoke
- maintain full load (match boilers to load demand), avoid frequent cold starts

References

Clean Air Act, 1956, 1968 (HMSO, 35p)
Clean Air (Measurement of Grit and Dust from Furnaces) Regulations SI, 1971, No. 162 (HMSO)
Clean Air (Emission of Grit and Dust from Furnaces) Regulations SI, 1971, No. 161 (HMSO)
Control of Pollution Act, 1974 (HMSO, £2.25)
Health and Safety at Work, etc., Act, 1974 (HMSO, £2)
Clean Air Act, 1956 Memorandum: Chimney Heights (HMSO)

4 Combustion in Practice

Chapter 4 is on the practice of combustion, covering the way combustion takes place in burners, types and principles of burners and calculation of combustion efficiency. The chapter also deals with the use to be made of results and provides tables for calculating costs.

Oil burner types and possible problems

An oil burner has to initiate, promote and sustain the process of combustion and direct the heat produced to the desired point. How does it achieve this?

Vaporisation

Combustion will only occur if the fuel and oxygen from the air are intimately mixed. Since this mixing must be molecular, liquid fuels must be vaporised before they can burn. To burn a fuel we therefore require

- conversion to vapour
- mixing of the vapour with sufficient air
- continuous source of ignition.

Kerosine, and sometimes gas oil, can be vaporised by exposing a large surface area to heat. This is usually accomplished by spreading the fuel on a wick and allowing the heat from the fuel to soak back on to the wick, for example in the wick or pot-type vaporising burner. These are mainly used for domestic space heating and hot water. The residual fuel grades (and very often gas oil) have to be broken down into a spray of small droplets, a process called atomisation. Most industrial burners are of the atomising type (the main types are described later).

How a droplet burns

A distillate fuel droplet evaporates by the action of heat, burns and is progressively reduced in size until total burn-out (see figure 4.1). The residual fuels

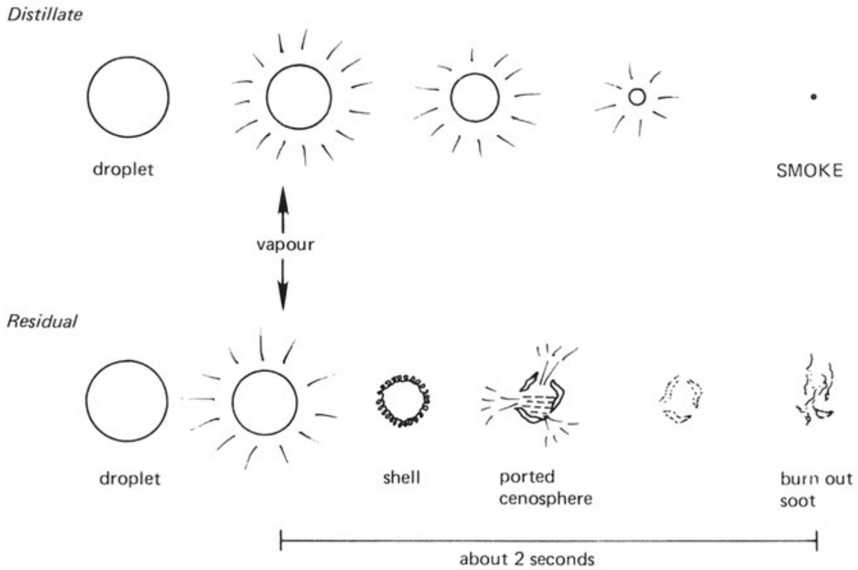


Figure 4.1 Vaporisation of liquid fuels

contain ash and very long chain hydrocarbon molecules. The low molecular weight compounds evaporate first, and burn. The heat produced causes further vaporisation but also cracks and polymerises the heavier compounds which, with the ash, form a carbonaceous shell. This empties under further heat and leaves the hollow sphere of ash, called a cenosphere, typically about half the diameter of the original droplet. Given sufficient time these cenospheres will burn out to ash only. It is therefore vital to good combustion that residual fuel oils are

- atomised to give small droplets; 10 to 200 μm preferred (average about 60 μm)
- given sufficient time to burn out before chilling (about 2 s is desirable).

Primary ignition is by a spark or a small gas pilot flame. The flame is sustained by heat from hot radiant refractories, and heat from hot gases is returned continuously to the vicinity of the atomiser.

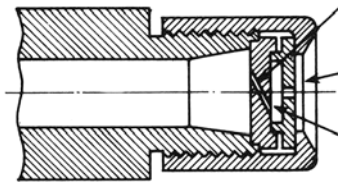
The air for combustion is provided by forced or natural draught, usually through air registers around the atomiser. It must be the right amount – not too much or efficiency will be impaired, not too little or smoke will be formed – and in the right direction to give the correct shape to the flame.

Atomiser principles and types

With all atomising burners it is essential to control the viscosity of the oil. If it is too high, the droplets will be too large and will not burn correctly, forming smoke and particulates. If the viscosity is too low the flame may lift from the burner and pulsate or be extinguished (see figure 4.6).

PRESSURE-JET BURNERS

Figure 4.2 shows a section through a typical pressure-jet burner nozzle. Oil at the correct viscosity is pumped at high pressure (3.5 to 35 bar) into a turbulence chamber via a swirl plate. This is a small plate with tangential slots which change the oil flow direction by almost 90° and give it a rotary motion. The oil is then forced out with a rotary motion through a small orifice into the combustion chamber. The oil-droplet spray pattern is in the form of a hollow cone, disintegrating at the edges and further broken up by the air stream around the nozzle.



The turn-down ratio of the pressure-jet burner is restricted to about 2:1. This is because the fuel throughput is controlled by the square root of the pressure. If the pressure range is 3.5 to 14 bar, giving a ratio of 4:1, the output will vary by 2:1. Oil droplet size also changes and may not be optimum at all loads. To increase turn-down, some burners use a range of nozzle sizes, and sometimes more than one nozzle is used. Another technique is to use a 'spill-back' design as in figure 4.3. In this a controllable amount of the oil from the turbulence chamber is fed back to the pump. This technique can increase turn-down to 5:1.

In summary, pressure-jet burners have the following features

- cheap to install and maintain
- ideal for base-load operation
- low turn-down, but vary load by multiple burners or spill-back
- oilways fine, must be cleaned frequently
- sensitive to variations in draught and to oil viscosity
- heat soak-back can coke up the fine oilways, especially if the shut-off valve is defective.

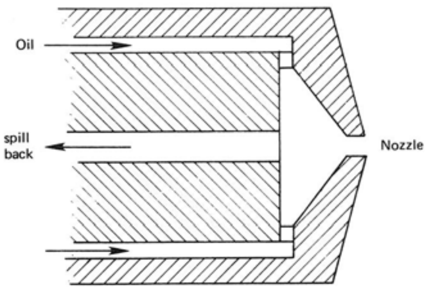


Figure 4.3 Spillback pressure jet burner

ROTARY CUP BURNERS

Figure 4.4 illustrates the operating principle. Oil is fed at low pressure into the rotating cup. The cup rotates (by air impeller or electric motor) at high speed, 4500 to 8000 rev/min. The oil falls on the cup at the point of lowest velocity, spreads on the surface and accelerates by centrifugal force along the tapered cup until the lip is reached, where it is thrown off at high velocity. The correct spray pattern is achieved by control of the primary air pressure and velocity around

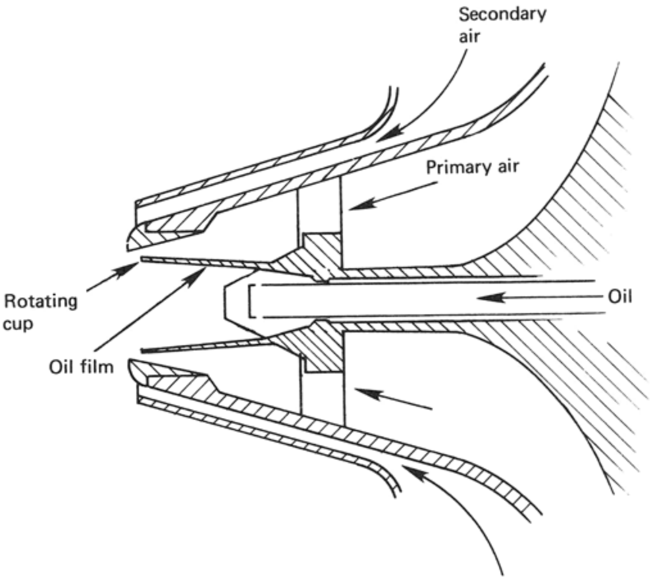


Figure 4.4 Rotary cup burner

the cup. The secondary air control is linked to the fuel delivery system to give good combustion control over a wide range, giving a turn-down of 5:1 or more.

In summary, *rotary cup burners* have the following features

- high turn-down – good for widely varying loads
- moderate cost
- not too sensitive to oil viscosity
- sensitive to cup condition (damaged lip)
- easy to clean – wipe cup each shift.

AIR BLAST ATOMISERS

The atomising effect is achieved by the shearing action of a stream of high velocity air striking a convergent stream of oil. Figure 4.5 illustrates the principles. The air enters the burner, usually through a swirl plate to give rotational velocity which assists in control of the flame shape.

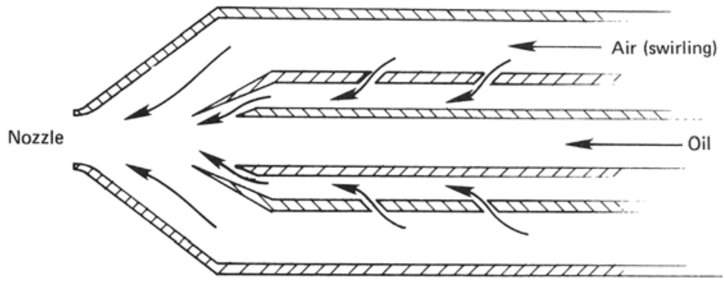


Figure 4.5 Air atomising burner head

With a low pressure air (LPA) burner, about 20 to 30 per cent of the air is supplied through the burner for atomising purposes, the remainder coming through the burner register from forced or natural draught. One fan can be used to supply the atomising air to several burners. If all the combustion air passes through the burner, the turn-down will be about 2:1, but this increases to 5:1 if only the atomising air passes through the burner.

Medium pressure air (MPA) burners use only about 3 to 5 per cent of the combustion air for atomising purposes, at a higher pressure. Turn-down ratios of 5:1 are easily achieved. High pressure air atomisers are not widely used on boilers – they are most suited to furnaces using preheated combustion air for increased flame temperatures.

High pressure steam can also be used in similar designs of burners and these are used on many larger boilers. They have the advantage of being virtually self-cleaning but do need a separate source of steam for start-up.

In summary, *air pressure burners* have the following features

- 5:1 turn-down: may be 2:1 on low pressure air
- easy to maintain

- one fan can serve several burners
- insensitive to poor draught conditions
- control of flame shape fairly easy.

A guide to typical burner conditions is given in table 4.1. The largest single cause of burner problems is usually incorrect preheat temperatures. It is essential to check the viscosity recommended by the manufacturer and determine the correct preheat temperature from the viscosity/temperature chart provided by the oil supplier.

A useful chart is given in figure 4.6. Using this, the temperature is readily determined.

Calculation of combustion efficiency

Heat input can be measured accurately from the rate of fuel usage and its calorific value. Heat output can be measured from the amount of heat in the steam or hot water. Efficiency can then be calculated as the ratio of heat output to heat input. This is not always convenient and it is more usual to use calculate the actual losses. A simplified technique is to use the Siegert formula to calculate the percentage heat loss as follows

$$\%\text{ heat loss} = \frac{K(T_G - T_A)}{\%\,CO_2} = Q_G$$

where T_G = exit gas temperature, T_A = boiler house temperature (ambient). If T_G and T_A are in °C, then K for fuel oil = 0.17. In addition to this heat loss, the losses Q_R due to radiation and other unaccounted losses must be calculated. Then

$$\text{boiler efficiency} = 100 - Q_G - Q_R$$

Q_R is about 1 to 2 per cent for medium sized water tube and larger shell boilers. With smaller boilers, this might increase to 4 per cent. These are full load figures – at half load the figures are doubled. For plants in a bad state of repair the figures might be two or three times higher. However, most operators will calculate combustion efficiency from charts which are based on the heat loss method and take into account the various differences due to fuels. Figure 4.7 shows such a chart for residual fuel oils (BS 2869 Classes E, F and G). This is based on a boiler house ambient air temperature of 20 °C.

In the example in figure 4.7, if the observed flue-gas temperature is 320 °C, read vertically upwards to the point of intersection with the relevant carbon dioxide line, in this case 11 per cent. Reading across horizontally gives the stack losses of 21 per cent. If the radiation loss is assumed to be 3 per cent, then

$$\text{Efficiency} = 100 - 21 - 3 = 76\%$$

Table 4.1 Air and oil pressures for burners

Type	Air pressure (bar)	Air pressure (iwg)	% combustion air used for atomisation	Fuel pressure (bar)	Turn-down ratio
Vaporising					
natural draught	–	0.02–0.12	–	Float level control	ON–OFF manual or automatic
forced draught	–	1.3	–		
Pressure-jet straight	–	0.5–6	–	3.5–24	2:1
spill-back			–	3.5–24	5:1 (10:1)
twin burner			–	3.5–24	5:1 (10:1)
Air blast					
low pressure (LPA)	0.2–1	10–25	25	0–1	5:1
medium pressure (MPA)		–	5	0.2–1	5+:1
high pressure (HPA)	1 upwards	–	2 max	1 upwards	5:1
high pressure steam	1 upwards	–	–	1 upwards	5:1
Rotary cup		4–10	15–20	1.4–1.7	5:1 (10:1)

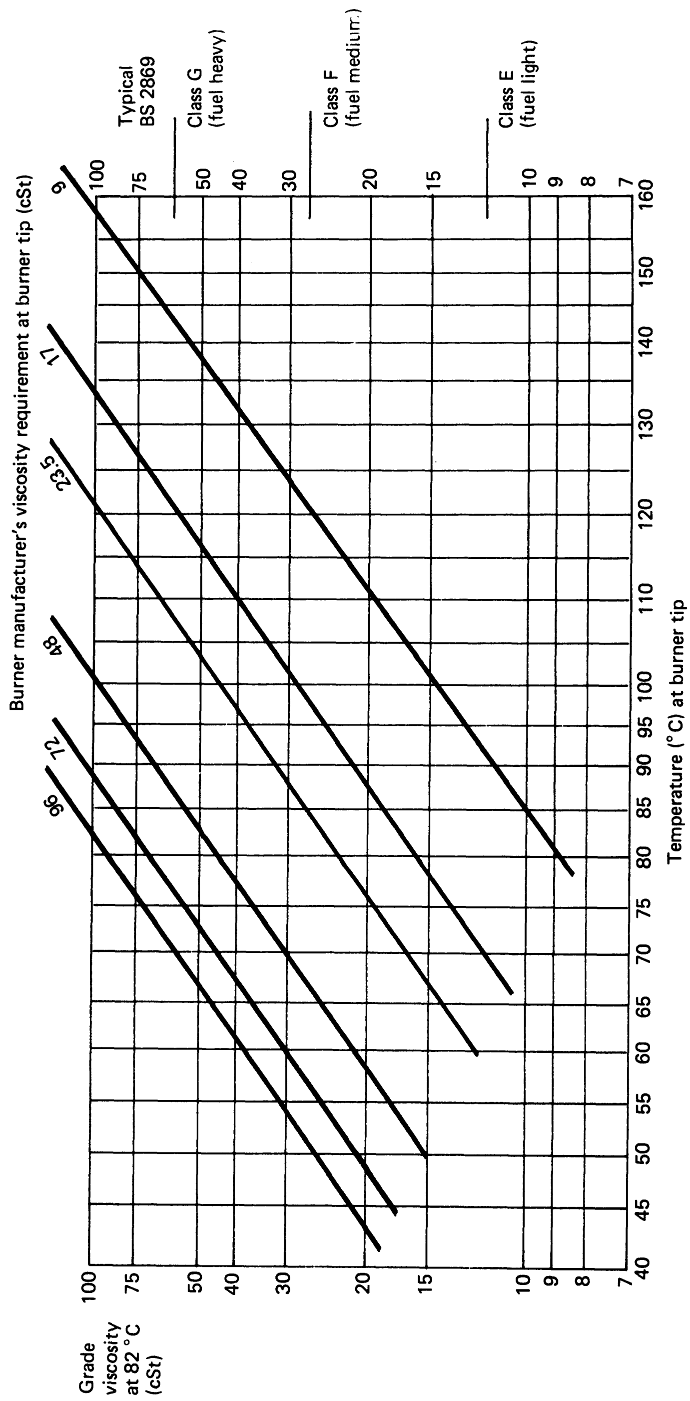


Figure 4.6 Viscosity/temperature chart for determining atomisation temperature

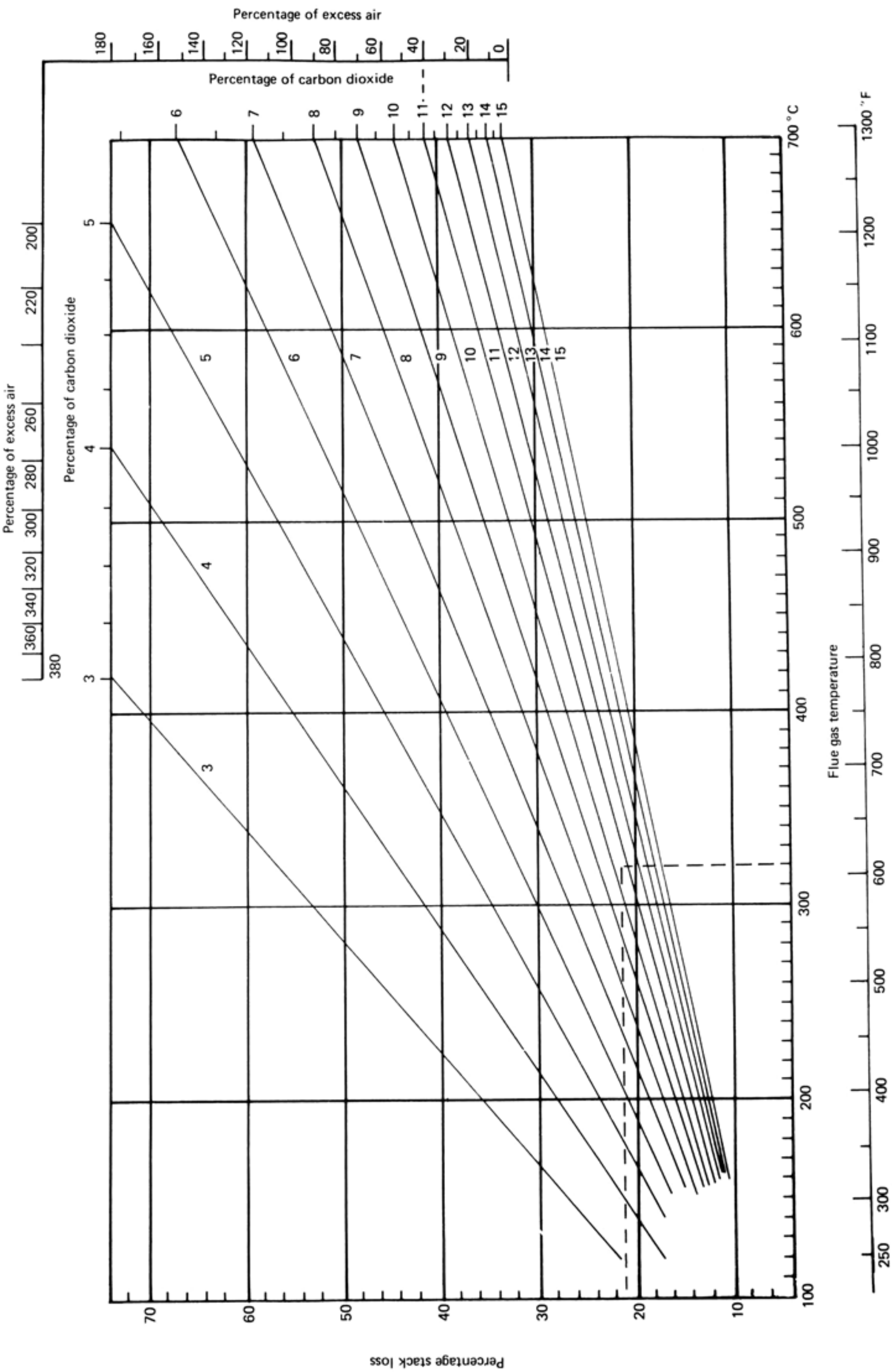


Figure 4.7 Combustion data chart for residual fuels

Table 4.2 Common burner problems and solutions

Problem	Cause	Cure
Sparky flame	Poor atomisation	Clean nozzles, raise preheat
Flame impingement (flame shape)	Incorrect air supply	Get expert to adjust
Flame pulsates	Too high fuel temperature	Lower preheat
	Too high air velocity	Adjust
High smoke emission	Too little air	Increase air, seal leaks
High particulate	Atomisation too coarse	Check nozzles, check preheat
	Combustion intensities too high	Design fault, lower loading

The right-hand scales of the chart also enable the operator to determine the percentage excess air from the percentage carbon dioxide measurement. (Larger copies of this Combustion Data Chart are available from the Esso Petroleum Co. Ltd, Esso House, London SW1E 5JW.)

Reporting and using results

A boiler plant supervisor must have records to enable him to assess the performance of his plant. Without these, he has no way of identifying problems, wastages and actions for improvement. Regular and comprehensive measurements are essential and the check list in table 4.3 is given for guidance. For some small plants, the instrumentation may be too costly but improvisation will at least provide some information. For example, tank dips may provide a fair indication of fuel consumption if the tank feeds only one boiler maintained at steady load.

LOG BOOKS

All the measurements should be carried out by the operators regularly as decided by the boiler specialist. They should be recorded in log books designed to make recording easy and at the same time to present the information to the specialist in a way that assists interpretation. A specimen is illustrated as appendixes I and II in chapter 6.

OPERATOR COMMITMENT

In order to encourage the operator to record the data needed, the reasons why the measurements are needed should be explained, and the results later discussed with him.

Table 4.3 Measurements and their significance

	What	Where	How	Why
Fuel	Maximum and minimum flow rate, temperature, pressure	Works total, and at each burner storage tank and lineheater, pump and lineheater	Meter and recorder Thermometer/gauge Gauge	To calculate heat input/ combustion process Check for correct burner loading and operating conditions
Feed water	Peak and offpeak feed water rate, temperature	At each boiler. Make-up feed and condensate return	Meter and recorder Thermometer and gauges	To estimate heat cost and heat recovered via condensate
Steam and hot water	Peak and offpeak production/consumption temperature, pressure	At each boiler and each major process. Boiler/process	Meter and recorder Thermocouple Thermometers and gauges	To calculate heat consumption/heating process Assess possible improvements Optimise load factors
Combustion products	Analysis carbon monoxide, carbon dioxide and oxygen Temperature, pressure/draught	Boiler or furnace flue before and after economiser or recuperator	Continuous electro-chemical or infrared, or manual chemical absorption kit (Fyrite) Thermocouple Thermometer/gauge Draught gauge	To calculate combustion efficiency of boiler/furnace (see Esso Combustion Data Charts)
Electricity	Electricity peak and offpeak consumption	All lighting, motors	Meters	Check for opportunities for reducing electricity consumption, e.g. is fuel pumping and heating set power consumption optimised? Can lighting be reduced without affecting safety? etc.
Compressed air	Storage pressure against required pressure and leakage	At receiver and ring main system	Pressure gauges	40% power saving by reducing pressure from, say, 7 bar to 3.5 bar

Standards to be expected

Older plant, particularly plant converted from coal firing, may have quite low thermal efficiencies. A converted Lancashire or Cornish boiler would be doing well to have an efficiency at maximum continuous rating (MCR) of more than 65 per cent. Radiation and unaccounted losses from older plant will probably be about 6 to 10 per cent, and at half-load operation the losses could be nearly double that.

For a modern package shell boiler the efficiency attainable should be at least 80 per cent at MCR and possibly as high as 85 per cent with radiation losses only 2 to 3 per cent. Package boilers are also far less susceptible than older designs to air inleakage, which can seriously affect boiler efficiency.

Savings to be made

There are many plants where more efficient operation can save on energy costs without any significant capital expenditure. A fuel efficiency saving of 5 to 10 per cent can often be achieved at little or no cost. There are also plants operating at or close to the most efficient level possible *with the equipment they now have*. But that equipment may not be capable of burning fuel or using the heat with the efficiency that today's costs demand. Savings of 30 per cent of fuel used can often be achieved by using newer, more suitably designed equipment.

How much investment is needed depends on

- possibility of savings with new equipment or modifications to existing plant
- tax position of the company
- cost of new plant and modification
- required rate of return on investment
- life of project and expected pay-back period
- fuel price changes.

There is also the possibility that grants may be available from various government schemes.

Tables 4.4, 4.5 and 4.6 allow a quick check to be made on the possible cash savings for a given fuel at certain prices. These savings may run into thousands of pounds. The tables have been derived using fuel consumption x heat content x price x thermal efficiency improvement.

Tables 4.4 and 4.5 will quickly indicate the very large savings to be made even from modest economies. For example, a 5 per cent gain in efficiency on a boiler burning 1250 tonnes/year of heavy fuel oil costing 20p/therm to make steam (15000 lb/h) will save *per annum* (from table 4.4)

$$4040 \times 1.25 = £5050$$

Table 4.4 Fuel cost savings: fuel oil heavy (£, before tax)
(Basis: fuel consumption 1000 tonne/yr; average heat content of fuel 11 840 kWh (404 therms)/tonne gross)

Fuel price			Percentage thermal efficiency improvement									
£/tonne	p/kWh	p/therm	5	10	15	20	25	30	35	40	45	50
81	0.68	20	4040	8 080	12 120	16 160	20 200	24 240	28 280	32 320	36 360	40 400
101	0.85	25	5050	10 100	15 150	20 200	25 250	30 300	35 350	40 400	45 450	50 500
121	1.02	30	6060	12 120	18 180	24 240	30 300	36 360	42 420	48 480	54 540	60 600
141	1.19	35	7070	14 140	21 210	28 280	35 350	42 420	49 490	56 560	63 630	70 700

Table 4.5 Fuel cost savings: distillate fuel (£, before tax)
(For distillate fuels such as gas oil having an average heat of 12600 kWh (430 therms)/tonne gross)

Fuel price			Percentage thermal efficiency improvement									
£/tonne	p/kWh	p/therm	5	10	15	20	25	30	35	40	45	50
129	1.02	30	6 450	12 900	19 350	25 800	32 250	38 700	45 150	51 600	58 050	64 500
151	1.19	35	7 525	15 050	22 575	30 100	37 625	45 150	52 675	60 200	67 725	75 250
181	1.43	42	9 030	18 060	27 090	36 120	45 150	54 180	63 210	72 240	81 270	90 300
215	1.71	50	10 750	21 500	32 230	43 000	53 750	64 500	72 250	86 000	96 750	107 500

Table 4.6 Justified investment: fuel oil heavy (£, based on table 4.4)

Fuel price			Percentage thermal efficiency improvement									
£/tonne	p/kWh	p/therm	5	10	15	20	25	30	35	40	45	50
81	0.68	20	24 825	49 650	74 480	99 300	124 130	148 955	173 780	198 605	223 430	248 260
101	0.85	25	31 030	62 065	93 095	124 130	155 160	186 195	217 225	248 260	279 290	310 320
121	1.02	30	37 240	74 480	111 715	148 955	186 195	223 430	260 670	297 910	335 150	372 390
141	1.19	35	43 445	86 890	130 335	173 780	217 225	260 670	304 115	347 560	391 005	434 450

Investment justified for improving thermal efficiencies of process heating systems for four different basic fuel prices and for each 1000 tonnes/year fuel oil originally consumed. Average heat content of fuel 11 840 kWh (404 therms)/tonne gross (fuel oil heavy): based on 10 per cent per annum depreciation (interest rate 10 per cent)

New investment

By replacing an old boiler with another 15 per cent more efficient the cost savings per year rise to

£12 120 x 1.25 = £15 150

The investment cost justified by these savings is considerable. One way of calculating it is the annual capital charge method, shown in table 4.6 and detailed as follows.

Justified investment

Table 4.6 is based on the simple annual capital charge (ACC) accountancy method which depends largely on the assumption that annual uniform cash flows (savings) will be made during the life of the project. The formula used is

$$I = \left(\frac{S}{(1+i)^n} \frac{(1+i)^n - 1}{i}\right)$$

where I = justifiable investment, S = annual fuel savings through improved efficiency, i = interest or cost of capital rates expressed as a fraction of 1 (for example for 10 per cent interest rate, $i = 0.1$), n = per cent depreciation or life of project. The formula does *not* take into consideration the tax-paying position of the company, investment allowances or other liabilities, nor have fuel cost rises been considered. Table 4.6 is based on an interest rate of 10 per cent (that is, $i = 0.1$) and depreciation of 10 per cent or life of project of 10 years (that is, $n = 10$). The fuel cost savings used in calculating table 4.6 are those given in table 4.4.

5 Water Treatment

This chapter looks at scaling, corrosion and carry-over problems in boilers, and at ways of avoiding these problems. It discusses simply water hardness and the actions that should be taken to deal with it. It also covers sources of information and equipment and methods for carrying out tests. The chapter concludes with notes on potential savings.

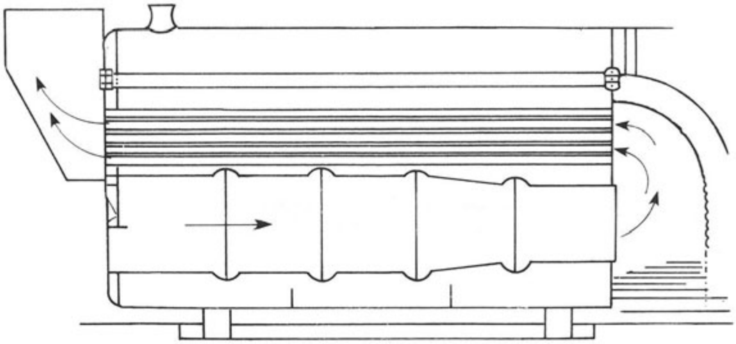
Modern package boilers require high quality water for their safe and efficient operation. Such water is never found in nature because impurities are accumulated as rain passes through the atmosphere. Then, as the water percolates through the Earth's surface, it becomes contaminated by the minerals in the soil and by acids in any organic matter which may be present.

The problems

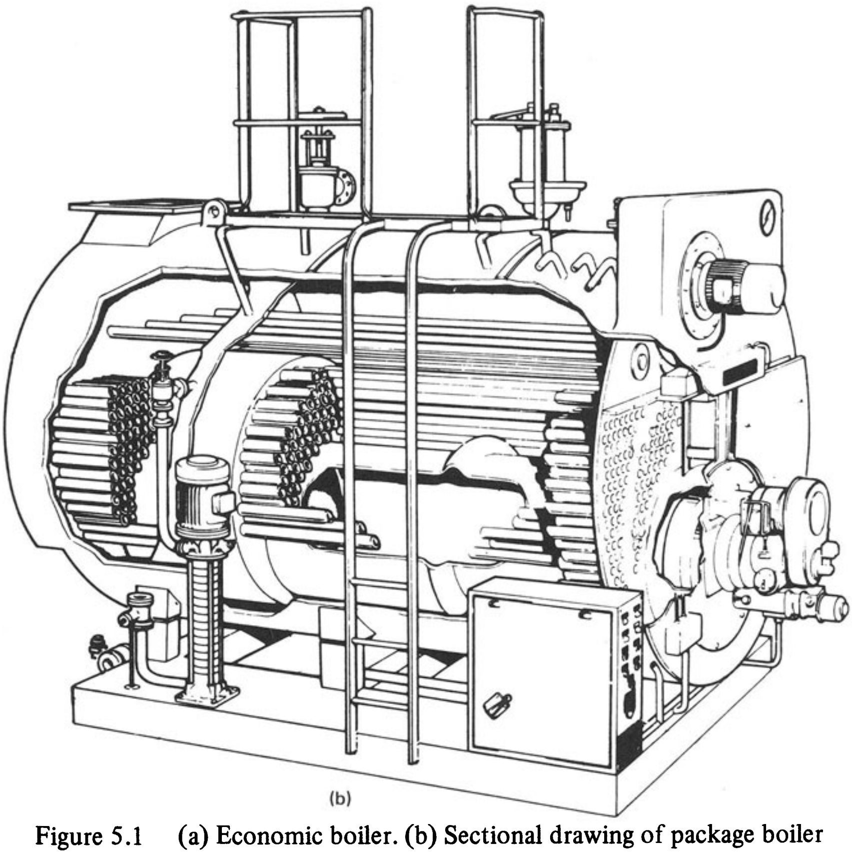
When water finally reaches the user it may contain (1) hardness salts, (2) non-hardness salts, (3) organic matter, (4) silica, (5) dissolved gases or (6) suspended matter. Any of these can make the water unsuitable for use in a modern boiler.

The modern package boiler is highly efficient in producing steam but is even more critically dependent on water quality than its predecessors. This is mainly because total boiler water content has been reduced dramatically over recent years for a comparable steam output, with a corresponding increase in heat transfer rate.

Figure 5.1 shows a drawing of a modern package boiler and compares it with an economic boiler, from which the basic design was developed. The main difference is immediately apparent. The modern boiler contains a mass of closely packed tubes in order to extract as much heat energy from the gases as possible. Cleaning deposits from around and between the tubes is extremely difficult other than by chemical means, which are less than ideal. It follows therefore that the only way to operate modern boiler plant is to remove the hardness by treating the water before it enters the boiler. This ensures that there is no dangerous build-up of solids – scaling – in the boiler itself, and also in the float chambers of the automatic controls. Solids could block the controls, so preventing their correct operation. Before proceeding further it is appropriate to consider two problems other than scaling: corrosion and carry-over.



(a)



(b)

Figure 5.1 (a) Economic boiler. (b) Sectional drawing of package boiler

Corrosion can occur in a boiler, and in the steam-using equipment and pipework, from acids in the boiler formed from dissolved oxygen and carbon dioxide in the water. Extensive damage can quickly occur if these acids are not dealt with in a strictly controlled manner.

Carry-over can also be a problem. Foaming occurs when bubbles form on the boiler water surface and build up to the point where the foam enters the steam main leading from the boiler, taking with it suspended or dissolved solids. Foaming is aided by a high level of total dissolved solids in the water (partly determined by water treatment), by suspended organic matter or by detergents. Boiler makers set the maximum level of total dissolved solids. This level is critical, since in many boilers foaming increases very rapidly once it is exceeded.

Priming is where steam is contaminated by surging of the water inside the boiler, so that water enters the steam main. Priming can be caused by running a boiler at below its design pressure, where the increased volume of the steam prevents proper disengagement of the steam from the water. This carry-over not only causes problems within the boiler, it can also cause rapid wear of steam-using equipment and pipelines, particularly at bends where erosion can take place. It is not uncommon for troubles to extend right through the steam-using system to the steam traps and control valves, so preventing their proper operation and increasing maintenance requirements.

Scaling, corrosion and carry-over must be eliminated or controlled. The six items contained in the boiler water listed earlier are now examined in more detail.

Hardness salts

Hardness in water is caused by dissolved salts of calcium and magnesium, such as the bicarbonates, sulphates and chlorides. If water containing hardness salts is used in a boiler, scale will be formed. The scale will insulate the heating surfaces from the cooling effect of the water and over-heating will occur. Over-heating can soften the metal so that, in the case of a furnace tube, it can collapse under the pressure of the steam with explosive force. This will endanger anyone in the vicinity and can cause extensive damage to plant and buildings. In a less dramatic way, scale build-up can cause tube-end leakage, where smoke tubes are expanded into the end plates of the boiler, requiring expensive replacements and possible loss of production.

Quite apart from the hazards arising from scaling, there is the energy-conservation aspect. As scale builds up on heat-transfer surfaces so the rate of heat transfer will steadily drop, with a corresponding increase in flue-gas temperature. The effect is similar to the build-up of soot on the fire side of the boiler. Scale build-up could account for an increase in fuel consumption of 3 or 4 per cent, which is considerable on a boiler which may be using, say, £1000 of fuel a week.

Non-hardness salts

Non-hardness salts in boiler feed water are usually sulphates and chlorides of sodium or other metals. They do not promote scale but they do contribute to carry-over problems.

Organic matter

Organic matter is often found in peaty areas and is derived from vegetable and animal material. It causes the water to become acidic and therefore corrosive.

Silica

If hard water contains silica in the form of silicates the scale formed will be extremely hard and thus very difficult to remove from surfaces where it is deposited.

Dissolved gases

All water contains oxygen, carbon dioxide and nitrogen in solution. These gases are absorbed when rain falls through the atmosphere. Chlorine gas may also be present, in very small amounts, since town mains water is often sterilised by the addition of chlorine.

Suspended matter

Sand and silt particles and organic matter are all found in suspension unless the strata through which the water percolates act as a filter bed. The particles all assist in foaming, as outlined earlier.

Solving the problems

The objectives of water treatment are

- prevention of scale on the water side of the boiler
- prevention of corrosion in the boiler and steam system
- prevention of carry-over of water into the steam system.

The chemistry of the reactions which take place when untreated water is boiled can be simplified as follows. Most scale is caused by the decomposition of bicarbonates into slightly soluble carbonates. Thus

calcium bicarbonate + heat ⟶ calcium carbonate + carbon dioxide + water or

magnesium bicarbonate + heat ⟶ magnesium carbonate or magnesium hydroxide + carbon dioxide + water

Rewriting these reactions using chemical symbols

$$Ca(HCO_3)_2 \longrightarrow CaCO_3 + CO_2 + H_2O$$

or

$$Mg(HCO_3)_2 \longrightarrow MgCO_3 + CO_2 + H_2O$$

The insoluble calcium and magnesium carbonates are precipitated. The liberated carbon dioxide will give an acid steam condensate since it forms carbonic acid, which is extremely corrosive. This can be shown as follows

$$CO_2 + H_2O \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

There are two types of hardness: temporary and permanent. Temporary hardness can be removed by boiling the water. It is caused by bicarbonates which decompose when heated into insoluble carbonates, as shown above. Permanent hardness is caused by salts such as calcium sulphate or calcium silicate, which are not affected by boiling. The differences between the two types of hardness are academic in water treatment and they are not distinguished in what follows. Hardness is measured by the equivalent amount of calcium carbonate, expressed as parts per million (ppm).

Prevention of scale

The technique used depends on the quality of the raw water to be treated. In fact, when water quality is good and with low pressure packaged boilers working at pressures of up to 16 bar, it is quite possible simply to add chemicals to the water in the boiler, using the boiler itself as the reaction vessel. However, really hard water will need a complicated treatment plant, with several different stages, to produce a water of the required quality.

The untreated water can be classified in three main groups.

soft water 0 to 50 ppm – calcium carbonate
intermediate water 50 to 200 ppm – calcium carbonate
hard water Over 200 ppm – calcium carbonate

SOFT WATER

When hardness is below 50 ppm, chemicals can be added directly to the water in the boiler itself. These chemicals react to form an easily removed sludge which can periodically be blown out of the bottom of the boiler through the blowdown valve. The chemicals most commonly used are based on sodium phosphate. Calcium bicarbonate to which sodium phosphate is added gives calcium sodium phosphate and sodium bicarbonate. The calcium phosphate is an easily removed sludge, the reaction being

$$Ca(HCO_3)_2 + Na_3PO_4 \longrightarrow \underset{\text{sludge}}{CaNaPO_4} + 2Na(HCO_3)$$

INTERMEDIATE WATER

This is the water with hardness between 50 and 200 ppm. The treatment previously described for soft water would generate large volumes of sludge with intermediate water hardness. This would mean repeatedly blowing down the boiler, which is wasteful in chemicals, water and, more important, fuel.

For intermediate water, hardness must be removed before the water enters the boiler. For this a simple water softener is required, operating by ion exchange. Any salt dissolved in water splits into ions. This splitting up occurs in an orderly fashion according to the electrical charges acquired by the component parts. As an example, calcium bicarbonate ($Ca(HCO_3)_2$) when dissolved in water is split up into

$$\underset{\text{(positive ions)}}{Ca^{2+}} \qquad \underset{\text{(negative ions)}}{\text{and } (HCO_3)^- \text{ and } (HCO_3)^-}$$

One atom of calcium carries two positive ions and this is balanced by two groups of bicarbonate, each of which carries one negative charge, so maintaining a balanced system.

By providing a solution with two compounds it is possible to exchange the ions from one pair to another pair so long as the electrical charges are kept in balance. This is the principle used in an ion-exchange water softening process.

For dealing with intermediate water, the calcium is removed by replacing calcium ions with sodium ions, using a resin ion-exchange bed. This bed is simply a container filled with insoluble resin beads. The resin beads are covered by sodium ions and as softening proceeds the sodium ions are exchanged for calcium ions until saturation, when regeneration becomes necessary. An equation illustrates the process.

$$\text{resin } Na_2 + Ca + 2(HCO_3)$$

becomes

$$\text{resin } Ca + 2Na(HCO_3)$$

From this it will be seen that the hardness salts will be converted into sodium bicarbonate (or sodium sulphate).

When saturation point is reached, the process must be stopped and the unit regenerated by passing a common salt (sodium chloride) solution through the bed. The process is reversed, thus

resin Ca + 2NaCl

becomes

resin Na_2 + $CaCl_2$

This process can be carried out indefinitely.

HARD WATER

The sodium bicarbonate from the above process is unstable and breaks down into carbon dioxide and sodium carbonate, which causes foaming. Both are highly undesirable and will be quite intolerable where hardness exceeds 200 ppm. The problem, however, can be solved by using an additional ion-exchange process known as hydrogen-ion exchange or dealkalisation. The process is similar to the previous one except that we have

resin H_2 + calcium bicarbonate becomes resin Ca + carbonic acid in solution

The carbonic acid is easily broken down by blowing air through it. It splits into carbon dioxide and water. The process can thus be expressed as

$$\text{resin } H_2 + Ca(HCO_3)_2 \longrightarrow \text{resin Ca} + 2H_2CO_3$$

The carbonic acid is then air blown and broken down

$$2H_2CO_3 \longrightarrow 2CO_2 + 2H_2O$$

The water at this stage has to be further treated with caustic soda to neutralise the acid. In addition calcium sulphate is left, and this is dealt with in a unit similar to that described for intermediate water. A full treatment scheme for hard water is shown in figure 5.2.

Corrosion

The second objective for water treatment is prevention of corrosion in the boiler and steam-using system. Corrosion can cost a great deal of money in maintenance and repairs. This is so both in the boiler house and on the plant, where pipework and steam-using equipment can quickly be destroyed by uncontrolled corrosion.

The basic requirement for corrosion is for oxygen to be present. As the concentration of oxygen increases or the temperature increases, so the rate of corrosion will increase. The presence of acid could increase the corrosion rate by several orders of magnitude, but the strength and type of acid will affect the rate.

The carbon dioxide in steam makes the condensate acidic and thus bicarbonates in the feed water must be minimised by use of the correct type of softening process. Calcium and magnesium bicarbonates decompose when heated to give calcium and magnesium carbonate plus carbon dioxide. Thus the softening

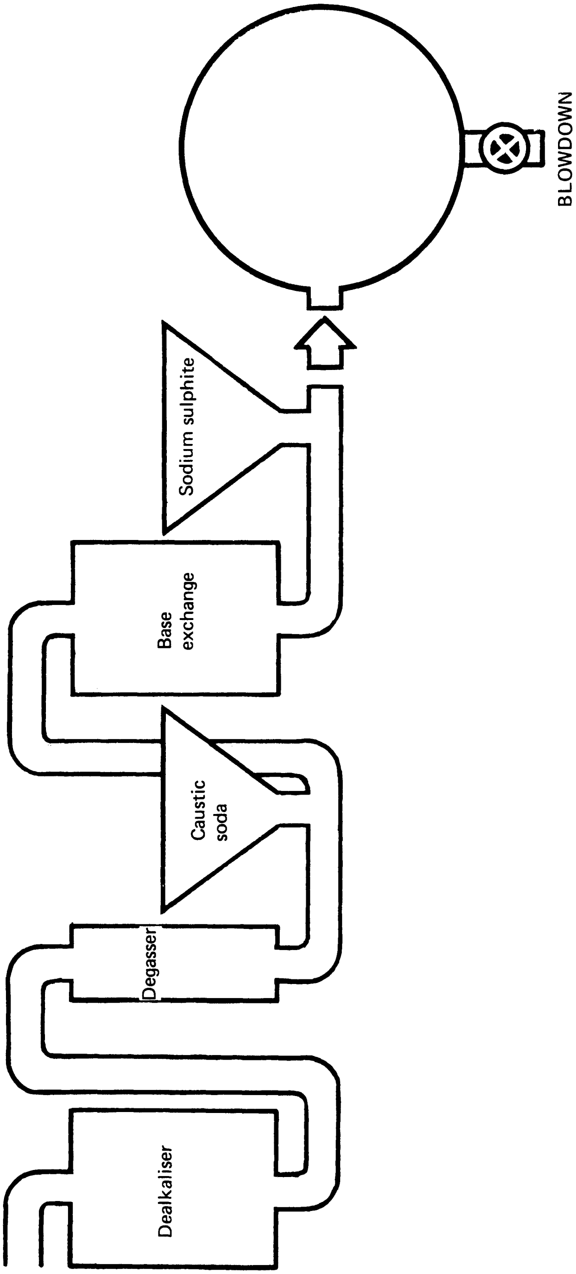


Figure 5.2 Treatment scheme for hard water

process itself needs careful control and the treatments described require a supplementary stage to act as a corrosion control. This additional stage is known as chemical dosing and must include caustic soda to absorb any carbon dioxide formed.

Dosing also implies the injection of oxygen-removal chemicals such as sodium sulphite into the treatment water before it enters the boiler. Reaction of these is speeded up by the use of a catalyst. Additional chemicals such as tannin or protective amines are quite often used to provide additional protection to pipe-work and steam-using equipment.

Carry-over

Excessive quantities of dissolved salts in boiler water will cause it to foam. Concentration of salts occurs whenever a boiler operates. It is aggravated by the use of base exchange softeners on their own and by the addition of dosing chemicals.

Modern package boilers have only a small space above the water level in which the steam can disengage from the water. In the old Lancashire boilers the space was comparatively large and carry-over was rarely a problem. For modern boilers, then, the manufacturers set rigid limits for level of total dissolved solids (TDS) to ensure that carry-over does not take place; this figure is usually between 2500 and 4500 ppm.

Control of TDS is by blowdown of the boiler, an operation which is wasteful of fuel. Clearly the original selection of the right treatment for a given feed condition is of paramount importance.

Carry-over can bring a whole host of problems with the steam-using equipment. The small particles of solid material carried by the steam can, as discussed earlier, dry out, forming an abrasive material which can erode away steam lines. This happens particularly at points of change in direction like bends or elbows. In addition, the particles can build up in steam traps, so preventing their correct operation.

Blowdown for the control of TDS, and hence the prevention of carry-over, can take several forms. It can be carried out periodically for a number of seconds (figure 5.3a), where TDS is constantly monitored by a conductivity meter which controls an electrically operated valve, or from a measure of the drop of water level in the boiler. By this means water with a high TDS is replaced by water with a lower TDS. Alternatively, continuous blowdown can be used (figure 5.3b), operated manually by setting a needle valve to a position related to interpretation of daily test results. Otherwise, an interval timer can be used to blow down for pre-set periods. The setting for these depends again on the interpretation of daily test results.

In continuous blowdown to reduce TDS, water is bled off just below the low water level mark, where the maximum concentration of solids occurs. It can be passed through a heat exchanger to recover as much heat as possible by pre-

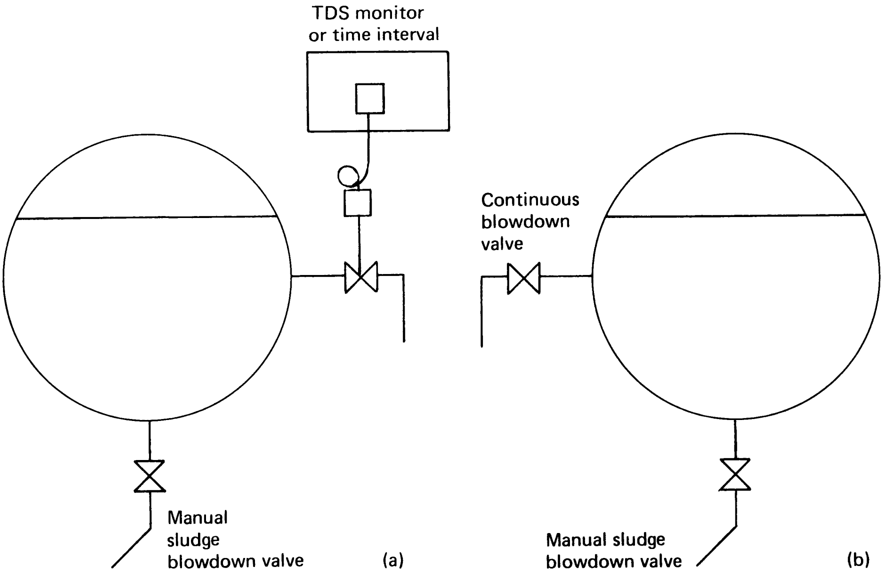


Figure 5.3 Continuous blowdown arrangements

heating the feed supply by a flash steam recovery system. There are variations to this system but they really relate to the way in which the blowdown is controlled. Whichever system is used, manual blowdown from the bottom of the boiler will still be necessary to remove accumulated sludge.

Additional treatment and condensate return

Ideally, boilers should be supplied with 100 per cent condensate, but this is very difficult to achieve in practice and treated water must be added to a feed system. This water is termed 'make-up water' because it makes up for the condensate which is lost in the system. The aim should be to return as much condensate as possible to the feed tank to save the cost of the water and of the treatment chemicals, and to make use of the valuable heat which the water contains.

However, reusing condensate returned from a process plant can be risky if it has become contaminated with oil, detergents or other substances. Appropriate precautions must be taken. In the case of oil entering a boiler there is the risk of severe local over-heating occurring, with possible collapse of the furnace tube. The use of an interceptor or separator with inspection facilities is essential, and electronic detection equipment can be provided to monitor condensate quality. Such systems need careful supervision and maintenance in the interests of safety.

Sources of information

BS 2486: 1978 Treatment of water for land boilers is of particular interest to operators of package boilers. This is a comprehensive basic reference work on water treatment. It includes sections on water quality, internal treatment of water in boilers, external water treatment, condensate purification, removal of gaseous impurities, conditioning of boiler water, corrosion and boiler cleaning.

BS 1170: 1968 Method of treatment of water for marine boilers will also be of interest, as will BS 1427: 1976 Routine control methods of testing water used in industry.

The tests described in BS 1427 are intended for laboratory use. The daily simple testing recommended here as part of boiler-operating routines is based on tests in BS 1170, as they are considered more suitable for use in the absence of laboratory facilities.

Routine testing

The increasing use of a 'water grid' means that in times of drought the quality of the town mains water could be changed without warning, from perhaps a relatively soft water to quite a hard water. Rapid build-up of scale could occur without the user's knowledge, perhaps requiring expensive repairs. Sometimes large users may be told about quality changes by the Water Authority but the best safeguard against such occurrences is for simple testing to be carried out daily.

Modern water-treatment plants are relatively complex and, even with good standards of maintenance, can develop faults. The water must be tested daily to ensure that the treatment plant is operating correctly or has been regenerated at the correct time.

Many users of package boilers will not have the facilities to carry out complicated tests, and a two-tier approach to water testing is suggested. This two-tier approach uses the comprehensive testing facilities provided by the water-treatment chemical suppliers. They can arrange to call monthly, or perhaps quarterly (depending on the nature of the water supply), to carry out on-the-spot tests followed up with any necessary changes to treatment and chemical dosing. Between these visits, the simple routine 'user tests' can confirm that there is no change in the raw water quality and that the plant is functioning correctly. If these tests indicate a fault, the chemical supplier can be asked to determine any changes which may be required. Alternatively, help may be sought from the manufacturers of the treatment plant itself.

The user tests are based on BS 1170. They require a simple test kit covering hardness, alkalinity and total dissolved solids tests, using the following equipment.

Hardness test

Apparatus	Auto-burrette, 10 ml, marked EDTA SOLUTION N/50; Drop bottle with 2 ml pipette marked AMMONIA BUFFER SOLUTION; Measuring cylinder, 100 ml; Casserole dish; Stirring rod with foot
Reagents (chemicals for testing)	EDTA solution N/50 (0.02N), 1 litre; Ammonia buffer solution, 500 ml (BS 1170: reagent D2); Total hardness tablets, 100

Alkalinity test

Apparatus	Auto-burrette, 10 ml, marked SULPHURIC ACID N/50; Drop bottle marked SCREENED METHYL ORANGE; Measuring cylinder, 100 ml; Stirring rod with flat foot, 15 cm; Casserole dish (these last two items are already available for hardness test)
Reagents	Sulphuric acid N/50 (0.02N), 1 litre; Screened methyl orange indicator, 250 ml

Total dissolved solids test

Apparatus	Hydrometers to BS 718 range 0.950–1.000 and range 1.000–1.050; Hydrometer jar, 300 x 50 mm; Thermometer, 10–105 °C; Washing-up liquid

Measurement of total hardness

This test is carried out on a sample of feed water. The results may determine whether the treatment plant is working correctly or whether there has been any change in raw water supply quality or perhaps the percentage of condensate which is being returned to the feed tank, so necessitating a change in treatment. The test may be carried out as follows.

(1) Measure out 100 ml of the boiler feed water sample into the measuring cylinder and pour this into the casserole dish.
(2) Squeeze the teat of the bottle containing the ammonia buffer and release until the liquid is up to the 2 ml mark. The tube now contains 2 ml

of the ammonia buffer, so transfer this into the casserole dish with the sample.

(3) Put one hardness tablet into the casserole dish and crush it with the flat end of the stirrer. This will give a reddish or mauve colour to the sample.

(4) Now squeeze the bottle under the automatic burette to fill the burette with EDTA solution. Release the bottle and check that the liquid in the burette comes to 0 ml after the excess has drained back.

(5) Place the casserole dish under the delivery spout of the burette and squeeze the rubber tap so that the EDTA solution runs slowly into the casserole dish. Stir the sample in the dish and when it turns blue or greyish-blue release the tap to stop the flow of the EDTA solution.

(6) Note the burette reading, and multiply it by 10. This gives the total hardness in parts per million of the sample.

Measurement of total alkalinity

This test is also carried out on a sample of boiler feed water. It is used to determine whether or not the level of caustic dosing is correct. This is an important check because too high a level of caustic dosing can cause caustic embrittlement and cracking around the boiler tubes and end plates. Too little dosing can permit an acid water that may corrode the steam-using equipment and pipework as well as the boiler itself. The test is carried out as follows.

(1) Measure out 100 ml of the boiler feed water sample into the casserole dish.

(2) Add 2 to 3 drops of screened methyl orange from the dropper bottle.

(3) The automatic burette in this case is filled with weak sulphuric acid (0.02N). Run this slowly into the sample until all trace of the green colour disappears from the sample. Then stop and take the reading of the burette.

(4) Multiply the reading by 10. This gives the alkalinity to methyl orange in parts per million.

Measurement of total dissolved solids (TDS)

There are two main methods of test: using a conductivity meter and using a hydrometer. If you have the back-up for calibrating and checking a conductivity meter, it is an excellent method – if not, it is better to keep to the hydrometer method detailed here.

Unlike the previous two tests, this test is on a sample of water taken from the boiler shell. The test will highlight deviations in the performance of the continuous blowdown system if one is fitted, and whether the amount of condensate being used has changed or water quality has changed. A follow-up analysis is required to determine the actual problem. The procedure for measurement of TDS is as follows.

(1) First take a sample of water from the boiler. In an ideal case this would be taken from a sample cooler attached to the sample point on the boiler. You may, however, have to make do with a sample point directly off the boiler shell and in this case beware: it is hot, so use goggles and safety gloves. Also note that the result may be slightly high due to the steam flashed off from the sample which tends to concentrate the solids in the water. The sample will then have to be cooled until it is no more than warm to produce a valid result.
(2) Now put two or three drops of washing-up liquid into the tall glass jar and then fill it with the sample to near the top. Be sparing with the washing-up liquid or excessive foam will be created. Its purpose is to prevent possible traces of grease in the water being deposited on the hydrometer stem and giving a false reading.
(3) Float the hydrometer in the sample, without handling the hydrometer bulb or lower stem, which should be kept free of grease, and note the reading. This reading is the point on the stem of the hydrometer where the water surface appears to cut the stem when viewed from underneath. Be careful: each graduation is a reading of 0.001 and each reading is preceded by 1.0.
(4) The measurement has also to be corrected for temperature, so put the thermometer into the jar for about 1 minute and read off the temperature.
(5) From table 5.1 look up the TDS. This is done by taking the column headed by the temperature found and reading the number opposite the hydrometer reading. From the column headed 15, say, read off the line opposite the hydrometer reading of 02; this gives a TDS of 3080.

With practice these tests need take no longer than half an hour a day. The results should be logged, as historical records are invaluable should any investigation be required following a breakdown.

The results obtained from these three simple tests are by their very nature only indicators, not precise measurements. They do, however, provide early warning when something is wrong and can be relied upon for that purpose. There are proprietary instruments which can measure the three variables, but such devices should only be used with the utmost caution. Any instrument is only as accurate and reliable as the maintenance it receives and annual recalibration is the minimum requirement if reliance is to be placed on the readings obtained.

To summarise, it is probably better to accept the results obtained from the tests described rather than rely on sophisticated instruments, if these cannot be given the skilled attention necessary for their maintenance.

Table 5.1 TDS from density

Hydrometer reading	Temperature (°C) 15	16	17	18	19	20	21	22	23	24	25
0.998							0	220	440	660	880
98.5					110	330	550	770	990	1210	1430
99		0	220	440	660	880	1100	1320	1540	1760	1980
99.5	330	550	770	990	1210	1430	1650	1870	2090	2310	2530
1.000	880	1100	1320	1540	1760	1980	2200	2420	2640	2860	3080
00.5	1430	1650	1870	2090	2310	2530	2750	2970	3190	3410	3630
01	1980	2200	2420	2640	2860	3080	3300	3520	3740	3960	4180
01.5	2530	2750	2970	3190	3410	3630	3850	4070	4290	4510	4730
02	3080	3300	3520	3740	3960	4180	4400	4620	4840	5060	5280
02.5	3630	3850	4070	4290	4510	4730	4950	5170	5390	5610	5830
03	4180	4400	4620	4840	5060	5280	5500	5720	5940	6160	6380
03.5	4730	4950	5170	5390	5610	5830	6050	6270	6490	6710	6930
04	5280	5500	5720	5940	6160	6380	6600	6820	7040	7260	7480
05	6380	6600	6820	7040	7260	7480	7700	7920	8140	8360	8580
1.010						12980					
20						23980					
30						34980					
40						45980					
50						56980					

Penalties of using poor quality feed water

The dangers from scaling and the overheating it can produce have been discussed but not the hazards from scale and sludge blocking up vital water gauge and float control chamber connections.

All package steam boilers have two water gauge glasses, of which at least one must be connected direct to the boiler shell. (It is *not* now permissible to have both the gauge glasses connected in parallel to the bodies of the float control chambers.) The gauge glasses must be blown down once a shift. The purpose of this is of course to remove any sludge build-up around the connections to the boiler and to prove that the level shown in the site glasses actually reflects the level of water in the boiler itself.

It should never be assumed that because comprehensive water treatment and blowdown facilities are provided, regular blowing down of the sight glasses is unnecessary. This may seem to emphasise the obvious, but confusion can and does exist among package boiler users, and it is not unknown for regular blowdown of gauge glasses to be abandoned when automatic blowdown has been installed.

An even more dangerous condition can arise from scale and sludge build-up in the Mobrey float controls which control the feed pump and boiler firing. Failure of these units can cause a boiler explosion, so they must be regularly tested, like the gauge glasses, regardless of what water treatment plant is installed (see p. 58).

Potential savings

Water treatment is costly. The chemicals are expensive and the supply and installation of a water softener suitable for handling hard water can add considerably to the cost of a new installation. However, there are fuel savings to be made by ensuring that boilers remain scale free. As an example, a rise in flue-gas temperature brought about by the build-up of scale could cause a gas temperature increase of 55 °C and with a boiler burning fuel costing, say, £50 000 a year, a cost increase of £3000 could result.

It is always important to return the maximum amount of condensate to the feed tank for reuse, provided that it is unadulterated with oil or other substances. By using condensate the quantity of dosing chemicals required is reduced. The frequency of regeneration of the softener if one is fitted is also reduced, raw water is saved and, more important, fuel is saved because the condensate contains valuable heat.

Take a simple example. If 70 per cent of the condensate is normally returned for reuse at 86 °C but because of a leak the condensate quantity is reduced by 20 per cent there will be a drop in feed temperature. Whereas with 70 per cent condensate being returned to the feed tank the temperature was 63 °C, it will now only be 48 °C, a drop of 15 °C. It is generally accepted that a 5 °C drop increases fuel consumption by 1 per cent. Thus, when consuming fuel at the rate of £50 000 per year there will be an increase in cost of £1500.

As has been stated already, water treatment is costly. A boiler of 5 MW output could cost £4000 a year in chemicals for dosing and for operation of the water softener. If the percentage of raw water is increased from 30 per cent to 50 per cent, the cost could rise by as much as £2400.

The use of additional water treatment increases the quantity of blowdown, since the addition of chemicals increases the total dissolved solids. More fuel has to be used to make up for the heat which has been lost from the extra water blown down.

These figures become insignificant when repairs are necessary. Again with a boiler of 5 MW capacity, a replacement furnace tube might cost £6000 or more and a set of smoke tubes might cost a further £5000 or more. And, in addition to all these costs, there is the consequent loss of use and therefore loss of production.

It is also worth remembering that chemical cleaning of boilers after scaling has taken place is only a second best choice to preventing scaling happening at all, and that water treatment must be designed to safeguard the quality of the feed water if an economic operation is to ensue.

6 Boiler Operations

In chapter 1 on safety, some of the problems associated with automatic boiler operation were highlighted. The need for a systematic approach was stressed. One solution which has been found to be effective as well as economical in manpower is to use 'boiler specialists'.

The specialist is wholly responsible for the boiler, provides guidance for the shift operators and carries out check testing. He may be a senior plant operator, a fitter, a technician or a supervisor. The specialist could be used in a three-tier organisation, involving specialists, supervisors and operators, though some users would find a two-tier set-up with specialists and operators to be just as effective. This still allows a simple testing system to ensure that safety requirements are always maintained.

Tables 1.2 and 1.3 summarised the daily and weekly inspections required on boilers. A further summary was shown in table 1.4, which rearranged this information by showing the total responsibility of specialists, insurance companies and engineers. This may not totally reflect your administrative structure and, of course, it need not be done precisely in this way. What is important is that there should be a clear line of responsibility from the trained man who operates the boiler to a specialist or to a supervisor who can provide a regular, informed check on his test procedures. Only in this way can the procedures outlined in the next part of this chapter be reliably followed.

Safety precautions and action

All package steam boilers have safety devices. To appreciate fully the reasons for carrying out routine safety checks it is necessary to understand the purpose and method of operation of each device. Boiler explosions can occur for two reasons: excessively high steam pressure or lack of water.

Protection against excessive steam pressure

As the boiler steam pressure rises, the oil burner will be switched off at a pre-set pressure by a limit pressure switch. The switch is set by the manufacturers and should not be interfered with. Checking its operation is done by observation of the boiler pressure gauge and the cut-off on the burner when the pre-set pressure is reached. To maintain the pressure within working limits, the limit switches will cut in the burner as soon as the pressure falls by a given amount. When a modulating burner is used, a bellows switching device (figure 6.1) is also fitted to control the position of the burner modulating motor.

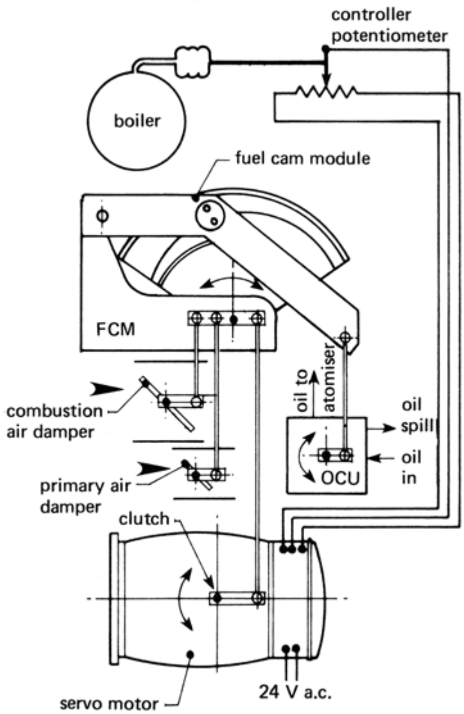


Figure 6.1 Bellows switching device

All boilers must have one safety valve. In practice, most makers fit two valves, usually spring-loaded. The valves are set when the statutory inspection takes place with the setting arranged slightly above the cut-out pressure for the oil burner.

The safety valves should be padlocked when they are set, and no adjustment should be made between inspections. Safety valves should not be tested by using the lifting handle with which they are sometimes provided – the escape of steam will, after a while, cut a groove in the valve seating which will leak, wasting valuable fuel, until the seating is reground.

Protection against low water level

Loss of water can create a serious hazard in any boiler. Over-heating of smoke tubes or furnace tube will rapidly occur if either becomes uncovered with water. The over-heating will make the steel quite soft and it will easily be deformed under the pressure of the steam. This can result in a violent explosion, capable of causing loss of life and extensive damage to plant and buildings.

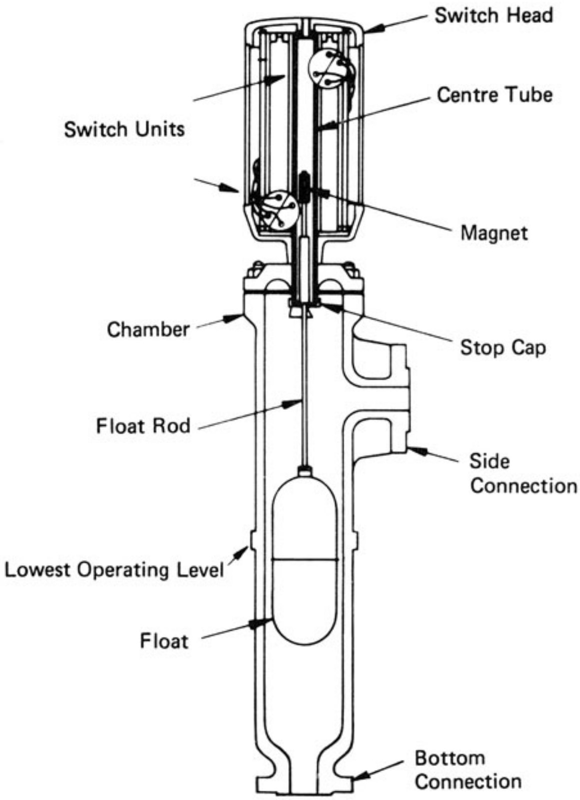


Figure 6.2 Water-level float control

Package boilers have two separate devices to protect them against low water. The first is a simple float chamber fitted to the side of the boiler, with connections to both the steam and water spaces in the boiler shell (figure 6.2). The float moves up and down with the level of water in the boiler. Attached to the float is a rod which moves and operates a series of magnetic switches, either of the tilting mercury tube or the air break contact type. These switches perform a series of operations.

FIRST LOW LEVEL FLOAT SWITCH

This turns the feed pump on and off in order to maintain the water level within close limits. As evaporation takes place so the float drops until the 'feed pump on' contacts are made. The pump then operates and the water level in the boiler rises until the float switch reaches the 'feed pump off' position. We thus have a simple and reliable means of maintaining water level in the boiler.

If for some reason the water level is not maintained and falls below the 'feed pump on' contacts, then a further pair of contacts will operate and turn the oil burner off. On this happening, a lamp on the control panel will be illuminated to show 'low water level' and an alarm bell will sound (see figure 6.3). Should the level be returned to normal, the unit may re-set. Some makers, however, arrange for the burner to go to lock-out. This requires manual re-setting of the controls before the burner can re-start.

There are numerous reasons for the water level not being maintained. There could be an electrical or mechanical failure of the feed pump, a filter could be blocked or a valve inadvertently left closed. Any of these will of course prevent the water from entering the boiler.

In some cases, particularly with larger boilers, there is a modulating feed control system. The feed pump runs continuously and, as the water evaporates, the control operates a modulating valve allowing water from the pump to enter the boiler at the required rate.

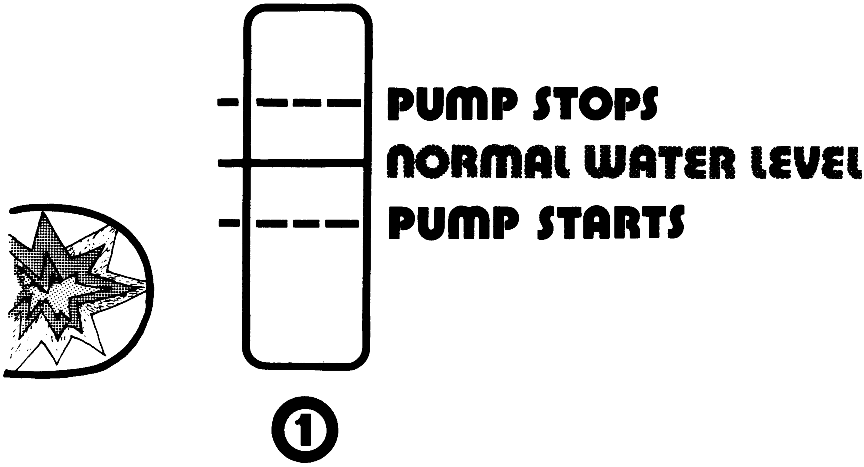
SECOND LOW LEVEL FLOAT SWITCH

Whichever feed control system is in use, all automatic boilers have a second extra-low level control system entirely independent of the first system. It is in fact mounted in a separate float chamber with independent connections to the boiler shell, as shown in figure 6.4.

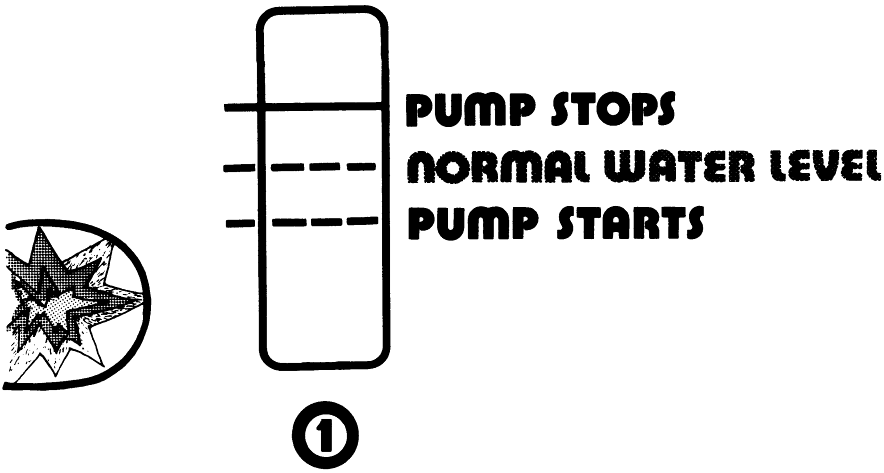
This extra-low level control operates in exactly the same way as the first low level control, except that there is just one set of switches. In this case the switches are set to shut the boiler down if the first low level switch should fail. Thus the level at which this happens is slightly below that of the first low level control. In all automatic boilers this second control actuates a lock-out control system and the burner will not re-start unless manually re-set. When this control operates, it illuminates a warning lamp and sounds an alarm bell. The operation of this unit is a serious matter as it implies the failure of the first low level control system.

Operation of the first and second low level alarms should always be recorded in the boiler house log and, in the recommended organisation, a boiler should never be re-started after operation of the second low level control without permission from the boiler specialist.

Some users prefer to connect a second low-level alarm to a klaxon or hooter rather than to the bell associated with the first low level control, but in any case



(a)

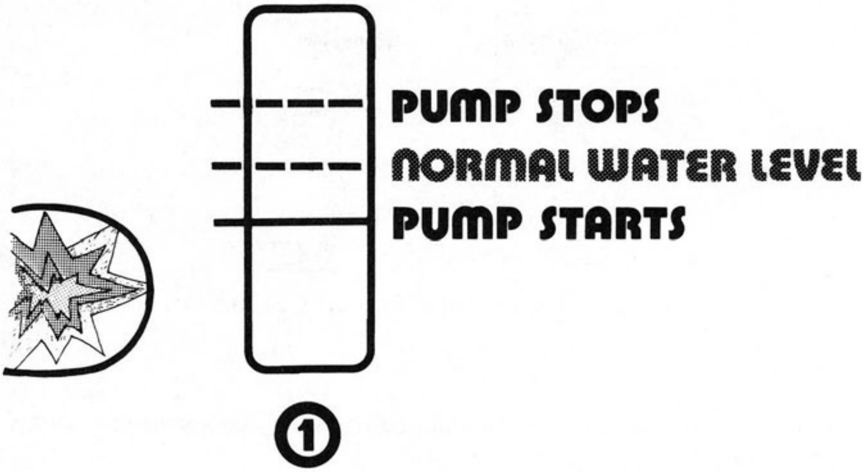


(c)

Figure 6.3 Sequence

the alarm must be where it can be heard by someone who has been trained to take the appropriate action. It is pointless to fit an alarm system which operates in a remote boiler house out of earshot of trained operators. It is equally pointless to provide warning in a gatekeeper's house where the person on duty has not been trained to take the appropriate action.

In fact, it should be a rule never to operate automatic package boilers without



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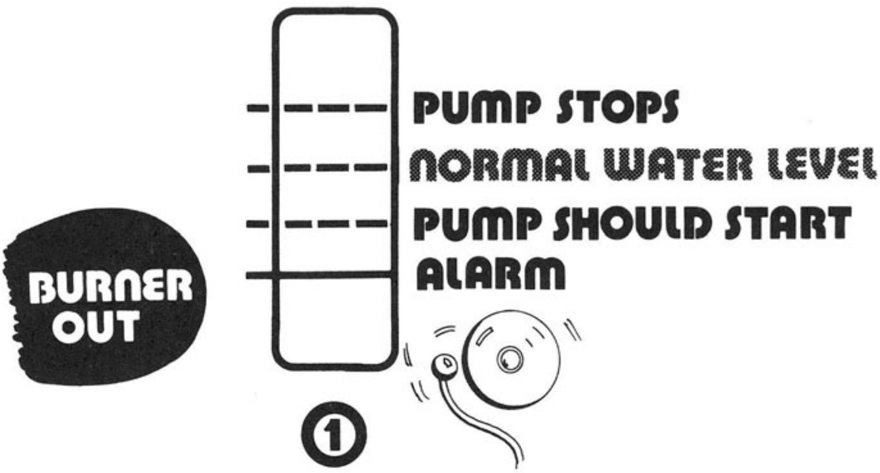

(d)

of float control action

a trained operator on site, although it is not of course necessary for him to remain within the boilerhouse.

Testing the float switches

To ensure that these float controls protect against low water level at all times,

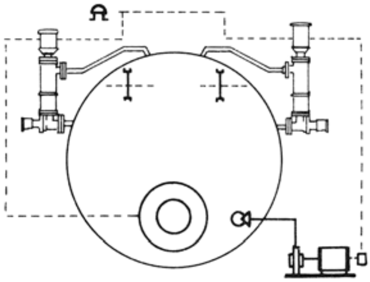

Figure 6.4 Connection of float controls to boiler

daily testing is necessary. It must be backed up by a more comprehensive weekly test procedure.

How may the controls fail? Sludge or scale may block one or both of the connections to the boiler shell. This could cause the water level in the float chamber to show as normal when the level in the boiler is, in fact, lower than it should be. Similarly, valves between the shell and the float chamber may have been left closed (how this can be prevented is covered below). Also, the float mechanism could be damaged by careless maintenance or there could be an electrical fault in the switches or wiring.

The following tests guard against harmful effects of these failures. The daily tests may be carried out as follows by the trained plant operator on the first low level and pump control.

Bring the water level up to the set level so that the feed pump is switched off. This can be seen by looking at the pump shaft and control cubicle indicator light. At the same time, make sure that the burner is operating. Next, blow down the control chamber. The feed pump should start up, the burner switch off, and the alarm bell sound. Then stop the blowdown. The water level in the chamber should be reinstated, the alarm should stop, and the boiler burner should relight after having gone through its purge cycle. Ensure that the float chamber is always left connected through to the boiler and that no isolating valves are left closed. This test will have proved that the controls operate and will have cleared any sludge or solids from the chamber and its connections.

With nearly all modern boilers isolation of the control chambers from the boiler shell is prevented by not having isolating valves on the steam connections and by fitting sequencing blowdown valves to the water connections. These valves provide foolproof operation; when they are in the isolating position the water is prevented from entering the chamber and so it is not possible for the boiler to operate. Figure 6.5 illustrates the three steps by which these valves operate. In the interests of safety, any boiler not equipped with valves of this type should be modified to take them – by so doing one of the most common forms of accident will be prevented.

Figure 6.5 Operation of sequencing valve

Where isolating valves are still fitted in the steam connections they should be chained and padlocked open.

The daily test on the second low level should be carried out by the specialist. Here the two-tier approach of having two different people do the tests is used because the second low level control is the final fallback control in the system. Its failure could cause a serious accident.

The second low level float control test is carried out by blowing down the chamber as just described. This time the combustion equipment should go to lockout and the appropriate alarm should sound. Check that, on reinstating the level in the float chamber, the burner does *not* relight without the re-set button being pressed.

The tests described so far should be carried out at least once every 24 hours. However, they do not accurately represent what may happen under operating conditions and therefore a further, much more searching, weekly test has to be made.

When a boiler is steaming steadily the water level drops relatively slowly and the level in the float chamber also drops slowly. If there is any tendency for controls or switches to stick or for the float to rub against the side of the chamber, there is always the chance that the unit might not operate.

The level controls should therefore both be tested under conditions as near as possible to those of normal operation. The blowing down operation for the daily test previously described is clearly quite violent: the force of the steam blowing through the chamber when it is quickly emptied is likely to dislodge all but the most obstinate controls.

The weekly tests are carried out by the specialist, who must remain by the boiler all the time the test is going on and must not leave it until normal operation has been re-established for at least 20 minutes. The weekly test requires great care as it involves deliberately lowering the water level in the boiler itself. It is carried out by one of the following two methods. (The first one is simple to control and more nearly simulates actual operating conditions, but the second may be more convenient on some boilers).

METHOD 1

With the burner operating and water level up to normal, switch the feed

pump to OFF and observe that as the level drops
the low level alarm rings and the burner cuts out, and as the level drops further
the extra low level alarm sounds and the burner locks out.
Switch the feed pump ON and check that the water level is restored and that the burner does *not* relight unless the re-set button is pushed.
Observe that the water level is reinstated and the feed pump stops when the level is restored.

METHOD 2

With the burner operating and the feed pump off, because water level is correct, switch the feed pump to OFF, open the main boiler blowdown valve and let the water level drop slowly.
Observe that the burner cuts out and the alarm sounds on first low level. As the level drops further: observe that the second low level alarm sounds, and the burner locks out.
On completion, check that the burner does *not* re-start after the water level has been restored until the manual re-set button has been pressed.

IMPORTANT: Whichever method is used, never let the water level in the sight glass disappear. A serious accident may result. Remember that all boilers must have at least one gauge or sight glass connected direct to the boiler shell.

Blowing down gauge and sight glasses

The procedure for blowing down gauge or sight glasses is straightforward. It must be carried out at least once a shift, or every 8 hours (figure 6.6).

- Open the drain tap by moving the lever to the horizontal position. Check that water and steam are going to drain.
- Close the bottom water connection by moving the bottom water tap to the horizontal position. Check that steam flows to drain.
- Open the bottom water tap by moving it to the vertical position.
- Close the top steam tap by moving it to the horizontal position. Check that only water is flowing to drain.
- Open the top steam tap by moving it to the vertical position.
- Slowly close the drain tap by turning it to the vertical position. Note that water level rises in the gauge glass.

Final check: leave all tap handles **vertical**.

Before completion of the water side, there are other regular operations to be carried out. If a condensate return system is in use, the condensate must be checked for contamination. This can be done in several ways. If an illuminated

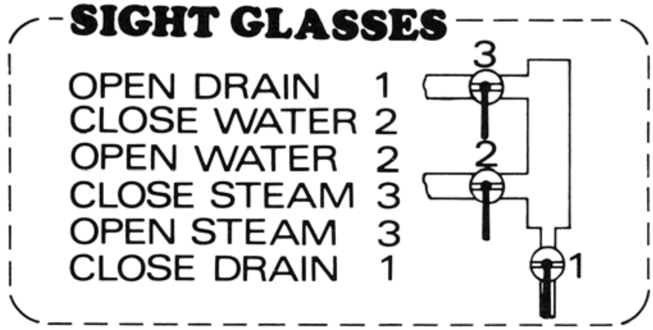

Figure 6.6 Procedure for blowing down sight glasses

sight glass is fitted, a visual check is all that is required. If an oil separator is installed, a detailed inspection of the compartments and filters is recommended.

The frequency of checking should be at least once in every 8 hours. If contamination is found the plant must be immediately shut down – it is too late when oil is observed in the boiler sight glasses.

Also on the water side is the blowdown of the boiler shell. This requirement will vary according to feed water quality, type and treatment. The operation is simple and consists of opening the main boiler blowdown valve either for a prescribed number of seconds every so many hours, or dropping the level of water in the boiler by an agreed amount through careful observation of the sight glasses. In some cases, the valve is in such a position that observation of the sight glasses is impossible and the time method must be used.

Flame-failure devices

The other test required daily is that of the flame-failure device. As described in chapter 3, every boiler has its burner flame monitored by either an infrared or ultraviolet sensor. If the flame went out even momentarily and oil was allowed to flow into the hot combustion space there would be a risk of explosion. The flame-failure device ensures that the fuel supply is cut off as soon as the flame goes out. Testing is a daily requirement that must be carried out by the plant operator using the following method.

- When the burner is alight, remove the photocell from its holder and cover it with your hand.
- Observe that flame-out is instantaneous.
- Check that the alarm bell rings.
- Replace the photocell, re-set the control and observe that burner re-starts after going through its correct firing sequence.

Other tasks

The checks and operations examined so far are all carried out 8-hourly or daily. In addition, a visual inspection should be made 4-hourly to see that there are no fuel or water leaks and that the sight glass levels are correct.

SCHEDULE OF ROUTINE TESTS

The operator's checks can now be summarised as follows.
Plant operators

Every 4 hours
- Visual check on boiler and boiler house
- Check for oil and water leaks
- Check water level in the sight glasses of the boiler

Every 8-hour shift, or as instructed
- Blow down the boiler

Every 8-hour shift
- Blow down sight glasses
- Check for oil contamination in water feed tank

Every day (24 hours)
- Blow down the float chamber controlling the boiler feed pump and low water level alarm
- Check the flame-failure device

Daily and weekly checks for the boiler specialists are as follows.

Boiler specialist

Every day
- Blow down the extra-low water level float switch chamber

Every week
- Check the flame-failure device
- Check the low level and extra-low water level float switch chambers by slowly lowering the water level in the boiler

Where a fire valve is fitted, it should also be tested once a week to ensure that it does not stick in the open position. This is particularly important where residual fuel is being burnt.

Because the tests just described are vital for safe operation the specialist should himself test all the above items.

Boiler operations and efficiency

The routines described have all been associated with the vital subject of safe boiler operation; now the efficiency of the boiler plant will be dealt with. Chapter 4, on combustion, covers measurement of flue-gas temperature, carbon dioxide content of the flue gas, smoke number and so on.

The simplest operational approach is to accept that the smoke emission from the boiler remains constant after having been checked by the weekly smoke test, so what else is likely to change? The most obvious change will occur with the consistent build-up of soot on the smoke tubes. The rate at which this occurs will depend on the grade of fuel being used, how well that fuel is being atomised and burnt and how the boiler is loaded. Even with nearly perfect combustion, there will be some build-up of ash and unburnt fuel particles. They will have to be removed manually, since package boilers do not usually have soot blowers.

A rise in exit flue-gas temperature indicates when boiler cleaning is required. Regular checking of this temperature will ensure that action is taken for the optimum heat transfer rates to be maintained and hence the flue-gas losses minimised, so providing valuable savings in fuel. Since a rise in flue-gas temperature indicates when the boiler needs cleaning, premature cleaning can be avoided, with an attendant reduction in labour costs. These can be considerable especially as this work may be carried out on overtime at weekends.

Chapter 3 described how combustion efficiency is measured. One example is given here of savings which can be made by taking account of these tests for cleaning the boiler at the appropriate time – probably after about each 1000 hours operation (though frequent starts and low loads will foul the boiler far more quickly than sustained use on, say, 70 to 80 per cent of full load).

As an example, according to the maker's combustion data recorded at the time of installation, a boiler exit flue-gas temperature was found to be 170 °C with a carbon dioxide content of 12 per cent at three-quarters full load which gave a combustion efficiency of 88 per cent. After a time this same boiler had an exit flue-gas temperature of 220 °C with a carbon dioxide content of 12 per cent at three quarters full load, giving a combustion efficiency of 86 per cent. With fuel costing £1000 per week, the increase in flue-gas temperature will cause the fuel bill to rise by 2 per cent per year, thus costing more than £1000 a year extra in fuel.

Build-up of scale on the fire side would have a similar effect but the daily water testing would control that situation and highlight the requirement to take remedial action.

Keeping boiler logs

Chapter 1 covered the requirement for the proper keeping of logs. (Guidance Note PM5, Automatically controlled steam and hot water boilers, issued by the Health and Safety Executive, illustrates a simple log for use with automatic package boilers.) Some users may prefer to design their own logs and to include a considerable amount of data, though the quantity of data to be included in the log may sometimes be difficult to determine. It can be argued that logs should only contain enough data to ensure that a safe and efficient operation is maintained. Log books are designed to record that the essential safety checks have been made and faults reported so that a historical record is always available to assist in fault diagnosis.

A log book used by Esso Petroleum Company to give minimum data that is still comprehensive enough for the safe and efficient operation for its small package boilers is shown in appendix I and appendix II. The book is divided into two parts. The first part (appendix I) consists of 31 pairs of daily log sheets, one for each day of the month, and the second part (appendix II) of four pairs for weekly tests.

Distinctive colour sheets are used for each page and NCR paper is used instead of carbon paper. As each daily sheet is completed it is removed for filing, leaving a clean record copy for retention. The design of the sheets is arranged to cover all aspects of the two-tier control system.

REVIEW OF LOGS AND DATA

Logs must be regularly inspected by managers. Operators completing logs must be made aware of the importance of keeping a true record of events and that it is in everyone's interest, both for safety and energy conservation, for logs to be completed conscientiously.

One method of ensuring that true records are kept is for management to call regular meetings to review energy conservation performance and discuss any problems reported by operators. By this means all employees involved will be able to observe that their record-keeping is used and followed up, so increasing job satisfaction and maintaining interest. If there were an accident involving boiler plant, the boiler logs could be called for to provide evidence that proper operational procedures had been followed. Failure to produce such evidence could lead to prosecution under the Health and Safety at Work Act.

Esso Petroleum Company, Limited

Log of boiler daily inspections

Location ______________ Boiler number ______ ______ day 2 of ______________ month 19 ____

Four hourly inspections			Eight hourly check		Blow-down boiler		
Check water level sight glasses Boiler pressure Check for fuel, oil and water leaks			Blow-down water level sight glasses Check condensate for oil contamination		Frequency and quantity as instructed		
Time	Boiler pressure	Signature	Time	Signature	Time	Quantity	Signature

Daily tests:	
First low level alarm and Pump control Flame failure device	
Time	Signature

Daily test:	
Second low level alarm	
Time	Signature

Water testing daily			
TDS p.p.m.	Total alkalinity p.p.m.	Total hardness $CaCo^3$	Treatment added

Time of water test	Signature

Fuel oil receipts
Litres at 15°C

Steam meter readings (lb)	
Finish	
Start	
Generated	

Water meter reading (gallons)	
Finish	
Start	
Used	

Observations

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Esso Petroleum Company, Limited

Log of boiler weekly inspections

Location ____________ Boiler number: ________ Date: ____________

Note: These tests should be carried out within seven days of the previous tests

Safety controls – Checks by 'Boiler Specialist'

1 Flame failure device

2 First low level switch and pump control } By lowering boiler water level slowly

3 Second low level switch }

4 Fire valve

Date	Time	Signature

Combustion controls

Rate	Flue gas temperature	Carbon dioxide	Smoke number	Combustion efficiency %	Date	Signature
High fire						
Low fire						

Observations

7–R–126

7 Maintenance

Chapter 1 on safety discussed the importance of proper maintenance for safety and energy conservation and its link to operational practices.

Modern package boilers can only operate efficiently if they are well and regularly maintained and tuned. This chapter outlines some basic maintenance requirements and techniques as guidance for managers on what their operators are required to do, and as a reminder for operators of the work involved.

Some managers may think they do not need this amount of detail. It can be argued that they would be wrong. Of course they do not need the detail to do the jobs themselves. But they will find it very useful in assessing what needs to be done, who can do it, and when.

It is not possible here to give instructions for particular makes of equipment, so the information that follows is necessarily general. It covers maintenance of the water treatment plant as well as of the boiler itself, since water treatment is so vital for modern installations. *But it is not a substitute for the detailed instructions given in the boiler-maker's manual. That should always be used as the essential foundation of the maintenance system.*

The controls of modem package boilers and of some oil burners are complex. Although much routine maintenance can be done by trained operators or fitters, the boiler or equipment manufacturers should be contracted to carry out specialised maintenance.

In this section both operator/fitter and some manufacturer maintenance are referred to but there are only details for the in-plant work. The specialist manufacturer will know exactly what is required.

No two plants have identical arrangements for allocation of duties; a certain task may be carried out by operatives at one location and by a fitter or even by a specialist contractor at another. Jobs are therefore not divided here on a 'who does what' basis but into two groups: those which can be done by local staff, either operators or fitters, and those which should be covered by the specialist contractor.

The chapter is in four sections: an introductory section includes housekeeping and safety; the other sections cover fuel systems from the bunker tank to the burner, the feed system covering water treatment and condensate return units and a final section on the boiler itself with all its fittings, controls, alarm systems and instrumentation.

Figure 7.1 shows a simplified diagram of a typical boiler plant.

Safety

Boiler maintenance work can be hazardous. Boilers are pressure vessels with associated chemicals which may be toxic, fuels which are flammable and possibly gases which are explosive. There may be other substances which may present a hazard when being handled. Also associated with boilers is electrical equipment, operated both at mains voltage and at several thousand volts for ignition systems.

For all these reasons it is essential to work to a system using permits to work. This is particularly important when entry into confined spaces takes place.

The boiler specialist should decide the requirements for each job. Before issuing a permit to work (to anyone concerned, whether it is an employee or a contractor) he must assess each job to determine just what precautions have to be taken before the work is started. As an example, he will have to consider if the plant has to be taken out of service, if and how it has to be isolated from other plant and equipment, what protective clothing is required and if the work can be done without breathing apparatus. Sometimes a second man may be required to stand by during certain operations. He will consider what type of cleaning materials may safely be used.

The numerous points to be considered will vary according to local circumstances. It is not possible to give all the details here. However, whatever the details in a particular case, a permit to work system is essential and the instructions on the permit must be followed precisely.

Housekeeping

The boiler house is not the place to store chemicals, paint or cleaning materials. A separate store should be provided for these, and it should be kept clean and tidy.

To conclude, some basic facts of good plant maintenance are reviewed – basic though they are, it is still useful to remind ourselves of them.

Use the correct size of spanner for each job – do not try to make do with the wrong sizes or ill-fitting spanners – this is as dangerous as to use worn spanners.

Where possible, use the correct size of ring spanner – they cannot slip and cause damaged knuckles.

Where possible, avoid using adjustable spanners – they are poor substitutes for a spanner of the correct size.

Finally, do not use Stillsons for tightening or loosening nuts or bolts – the result can be damaged hexagons and broken studs or stripped threads.

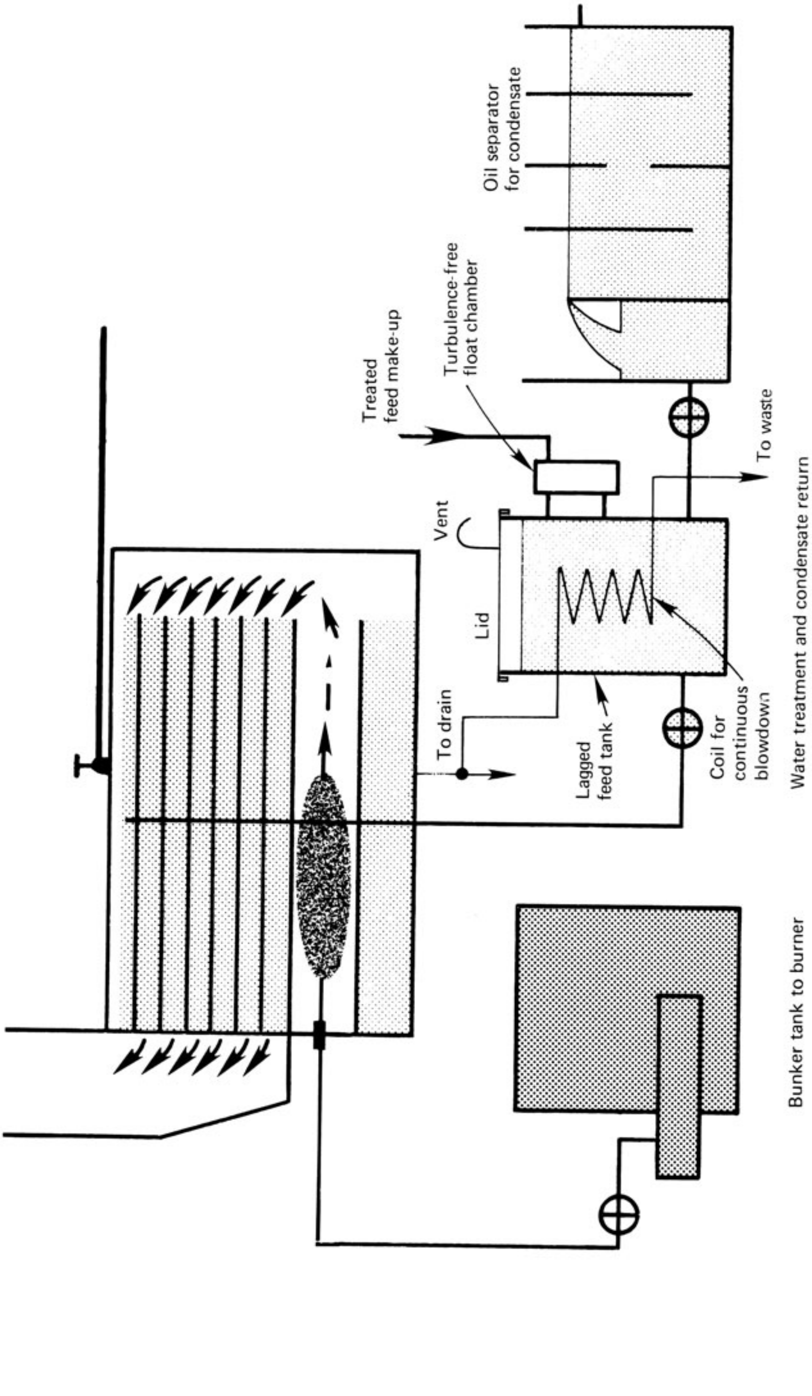

Figure 7.1 Diagram of typical boiler plant showing areas of maintenance covered in chapter 7

Lubrication

This is mostly straightforward lubrication of moving parts. Two kinds of grease are needed: a bentonite grease for valve spindles and screws subjected to great heat, and a lithium-based grease for lubrication of other valves and pump and motor bearings. The Esso grades recommended are Norva 275 bentonite grease and Beacon 3 lithium-based grease. For lubricating jobs requiring oil a medium-viscosity mineral oil should be used. The Esso grade recommended is Essolube 30.

Some simple lubrication rules are as follows.

- Keep all grease and oil containers clean and tightly closed when not in use.
- Never mix different types of lubricant. If two types of grease are used have two grease guns, each clearly marked with the grade it contains.
- Before lubricating any item, always wipe it clean.
- When using a grease gun, clean both grease nipple and gun adaptor before connecting the two together.
- When lubricating ball and roller bearings never over-grease – this will cause churning, over-heating and eventual failure of the bearing.
- After lubricating any item, carefully wipe clean any spilt or surplus lubricant.

Cleaning cloth and materials

Only use lint-free cloth for cleaning. Never use petrol or paraffin: use only approved cleaning solvents.

Valve and pump general maintenance

Valves in boiler plant may require renewal or adjustment of the gland packings. Pump seals may have either simple gland packings or mechanical seals, which cannot be adjusted and can only be serviced by replacement. This replacement is a specialised job, outside the scope of this book.

VALVE MAINTENANCE

(1) Check that valve is under pressure – both sides where applicable.

(2) Inspect for leaks at spindle gland. If the gland is found to be leaking, tighten the gland nuts evenly until the packing offers moderate resistance to spindle movement. If the gland continues to leak, renew the packing as detailed in the appendix to this chapter.

(3) Check for leaks at bonnet flange joints and pipe joints and body castings especially behind flanges. If the bonnet flange is leaking, partly open the valve and ensure that the bolts are tight. If it continues to leak, or if the body casting is found to be leaking, report to supervisor.

(4) Check that wheel retaining nut is tight. Tighten if necessary.

(5) Lubricate wheel mounting and gland (3-monthly). Apply grease gun to the appropriate grease nipple (where one is provided). If there is no grease nipple, oil the spindle using an oil can. If the valve is on a steam or hot condensate line, use a bentonite grease.
(6) Check general condition of valve: spindle clean and free from scoring, thread free from excessive wear and damage, corrosion absent, paintwork in reasonable condition. Faults found under this section should be reported to the supervisor, as the valve may have to be changed.
(7) Subject to operating conditions, ensure that valve is still freely operating by opening fully and closing fully. If excessive length of spindle is showing in the closed position, report to the supervisor.
(8) On completion of work, ensure that valve is left in the correct position.

A detailed procedure for renewing valve and pump packings is given in the appendix to this chapter, and illustrated in figure 7.11.

Maintenance planning

With just one boiler it is probably unnecessary to have an elaborate maintenance planning system. However, with several boilers installed in different parts of the plant a formalised system is worth while. The one shown in figure 7.2 has a planning board, with the tasks set out to cover a full year's operation, linked to job cards which can be issued to the staff and which give details of the work required.

This system is particularly useful for arranging planned maintenance by outside contractors; it is easy to see when the next visit is to take place and to make arrangements accordingly.

The planning board contains small coloured tags, the colours indicating the frequency of maintenance. The tags also carry serial numbers which correspond with the job cards. The board is divided into 52 weekly parts and it is a simple matter to look at each week in order to determine which job cards should be brought forward. On each of the job cards is a brief description of the work required and a box into which can be entered details of the particular plant involved. This makes maintenance of multi-boiler installations a simple matter. The job cards are housed in plastics wallets and fit a normal boilersuit breast pocket. At the back is a renewable record card showing the date when the service was carried out and signature of the person concerned. This system can be used for all items associated with the boiler house, right down to the humble but very important fire extinguisher. Esso uses this system for all its plant and equipment within its marketing organisation; this simple approach enables an efficient set-up to be maintained at low cost.

Remember that for the maintenance of safety, reliability and efficiency, regular checking and servicing are essential.

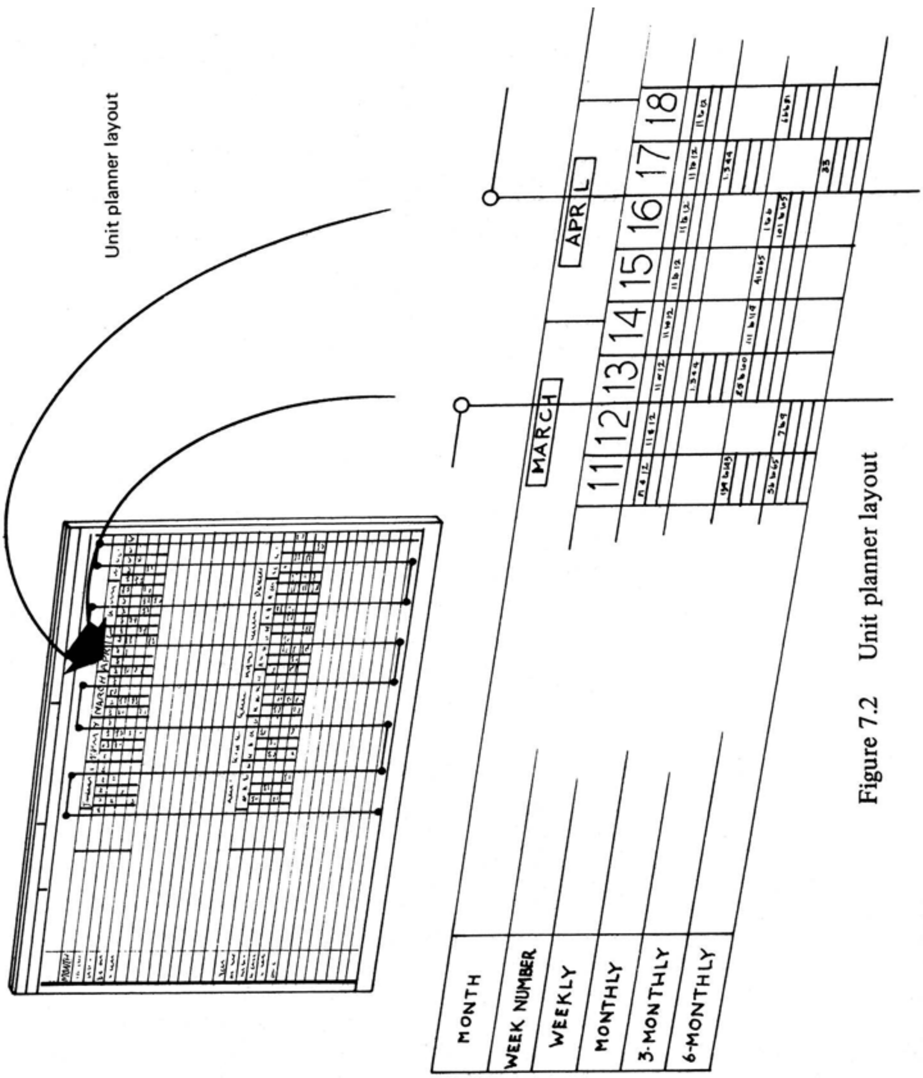

Figure 7.2 Unit planner layout

Fuel system: bunker tank to burner

This section reviews maintenance work on the fuel bunker tank and all between it and the burner (figure 7.3). A summary at the end of the section gives recommended periods of inspection or maintenance.

The bunker tank should be inspected monthly to ensure that there are no oil leaks, that the foundations are sound, and that any staircases, ladders, or catwalks are in good condition.

Water, inside and out

If the storage tank is lagged and clad – and it should be with residual fuel oil, which has to be heated – make sure that water is not getting in under the lagging. If water is getting in, two things will happen. First, the insulating properties of the lagging material will be greatly reduced and heat will be lost unnecessarily. Second, even more important, the tank shell plates will corrode. This will be very costly to repair.

One way of keeping the water out is to seal the lap joints of the cladding with tape. The most difficult parts to seal are around the fittings and handrail supports on the roof of the tank, and they require particular attention.

The next thing is to check that there is no water in the bottom of the tank. Use a dip tape with the brass weight at the end coated with water-finding paste. Note whether the paste changes colour, according to the maker's instructions on the tube. If there is water in the tank it must be reported; there may be a leak in the steam heating coils in the tank, or in the outflow heater.

If the tank has a contents gauge, check the reading against that from a weighted dip tape. This can be done when the tank is checked for water.

Temperature

A dial-type thermometer on the tank can be checked by comparing its reading with that of a mercury-in-glass thermometer hung from a string through the dip-hatch into the body of the fuel in the tank. It is worth occasionally checking dial-type thermometers, as they may, after a time, give false readings.

Valves

The tank inlet and outlet valves are usually gate valves. The only requirement is to check for leakage and to grease the screws with a lithium-based grease. If the valves have grease nipples each should be given one shot of grease, after any dirt has been cleared away. At the same time ensure that both valves operate freely. Ensure that screened vents (if they are fitted) are clear.

Finally, on the tank there is probably an outflow heater or steam coil, possibly both. An outflow heater may be operated by electricity or by steam, or may use

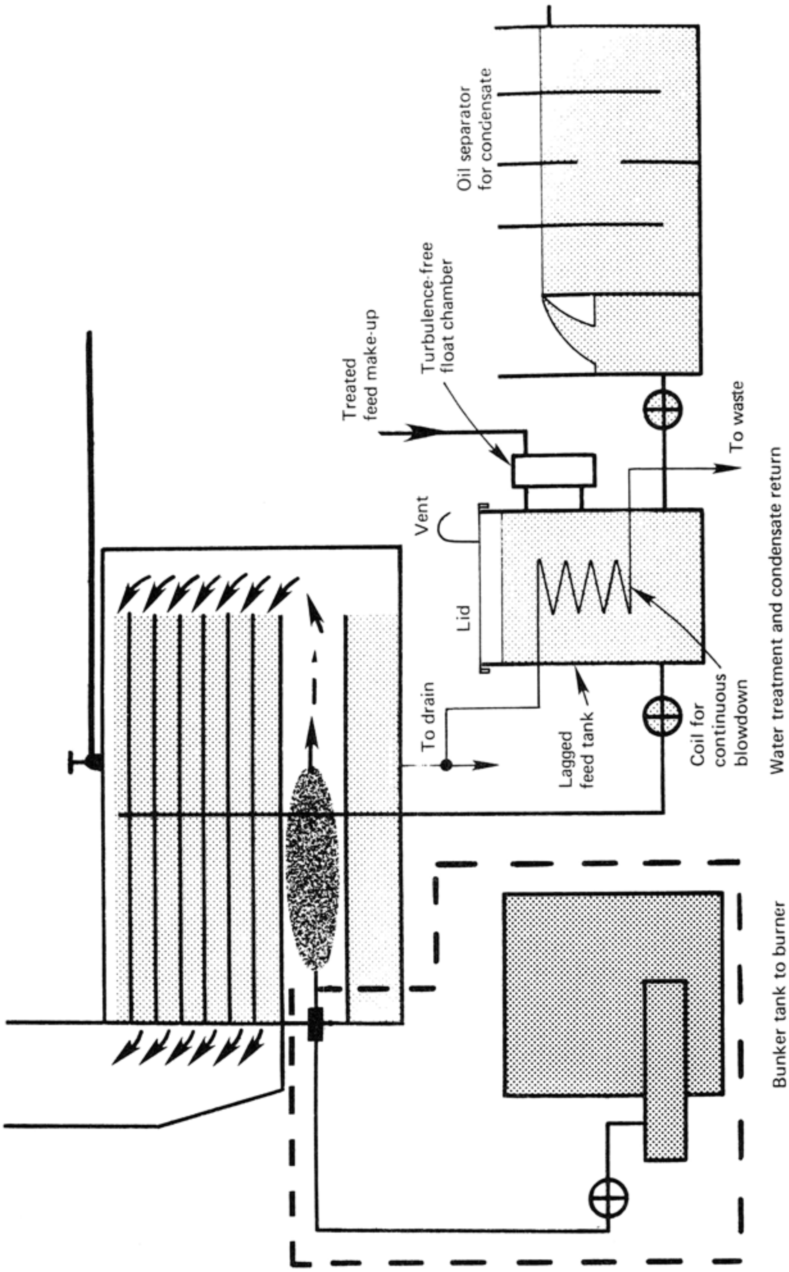

Figure 7.3 Bunker tank

both methods. Check that the thermostatic controls operate and that the oil coming from the tank is at the stipulated temperature. If the temperature is incorrect, report it; do not attempt to make adjustments.

Where steam traps are fitted to the tank heating system, ensure that they are working properly. Electronic indicators are now available for checking trap operation. There should be no continuous flow of steam, merely an intermittent burst of water with some steam flashing off from it. If a by-pass valve is fitted for quick warm-up, ensure it is kept closed during normal operations.

Check that the thermostatic valve controlling the tank heating coil is at the correct setting by seeing that the contents of the tank are at the correct recommended temperature.

Pipeline

In checking the pipeline between the oil bunker tank and the boiler, make sure that the insulation is protected from the weather and is undamaged, particularly at points where people step over the pipeline.

If the oil line is traced by a small-bore steam line, see that the steam traps operate correctly and that no by-pass valves have been left open. If the tracing is by electric cable, confirm the setting of the thermostats by checking the oil temperature in the line.

On long lines, there are probably two oil pumps for moving the oil from the tank to the boiler house; one pump in use and the other on standby. A ring main is frequently provided for multi-boiler installations or for boilers with more than one burner.

A system without pumps is only found in rare cases, where there is a gravity feed supply from overhead storage tanks. It is then possible to rely just on the oil pump fitted to the boiler burner assembly. The pumps are invariably small gear type. Maintenance is limited to checking for leaks around the gland packings or mechanical seals. Lubrication is provided by the fuel being pumped.

When the motors for these pumps have grease nipples for bearing lubrication, one shot of lithium-based grease per month will be quite sufficient. Avoid over-lubrication. As in all pumping systems, each pump should be fitted with a suction strainer. This should be removed and washed out in gas oil monthly (unless experience shows more frequent attention is necessary).

There will also be a preheater in the fuel system to bring the oil up to combustion temperature. In rotary cup or spinning cup burners this heater is built into the burner assembly.

For pressure-jet burners using residual fuel, the heater may be separate and operated by steam or electricity. Electricity is essential for start-up from cold when no steam is available. Maintenance is to check for leaks of oil and for the correct thermostat setting. When thermometers are used they should be checked by substituting the thermometers installed in the heater.

Finally, before the burner is considered, there is the fire valve. Testing is recommended weekly as part of the boiler specialist's duties. The main problem with fire valves is from leakage of oil around the seal which can cause the valve to stick if residual fuel is allowed to accumulate. The weekly tests confirm correct operation but a monthly visual inspection of the valve for leakage is an additional safeguard.

Summary of maintenance checks on the fuel system

These checks are monthly, except where indicated

Tank: Check for possible

- leakage of oil
- foundations, stairways, platforms, and handrails in good order
- lagging and cladding undamaged and watertight
- tank contents free from water
- tank valves operating freely and lubricated (3-monthly)
- vents not restricted
- contents gauge working accurately
- temperature gauge working accurately
- outflow heater operating at correct temperature
- any associated steam traps working correctly

Pipeline: Check for

- possible leakage of oil
- insulation and cladding undamaged and watertight
- steam or electric tracing working correctly
- valves lubricated and operating freely
- steam traps working correctly

Pump: Check for

- possible leakage of oil
- correct lubrication of drive motor
- pump strainer cleanliness (and product leakage particularly at joint faces)

Oil preheater: Check for

- possible leakage of oil
- correct operation of thermostats

Pressure-jet and fluid atomising burners

Burners have been discussed in chapter 4 and the descriptions here relate only to their maintenance. Burner maintenance has been divided into two groups: all burners which use oil pressure and air (or steam) pressure to achieve atomisation, and burners where atomisation is achieved by mechanical means, that is, by the rotary cup.

The medium pressure air burner is used as an example of the pressure-jet/fluid atomising category. There are other types of burners than those just mentioned but they are rarely found on package boilers and are not covered here.

Pressure-jet burners

Atomisation is brought about by delivering the oil to the burner nozzle at pressures of between 3.5 and 35 bar (figure 7.4). Combustion air is then introduced by natural draught or by a power-driven fan.

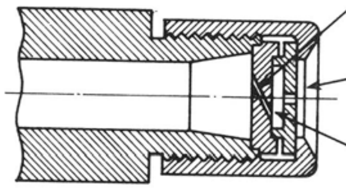

Figure 7.4 Pressure-jet burner

Fluid atomising burners

Here the oil is delivered at a much lower pressure with atomisation air supplied at between 0.15 and 1 bar from a compressor and with secondary air supplied by a fan or centrifugal blower (figure 7.5). Oil and air streams converge within the nozzle of the burner. The oil is atomised into fine droplets surrounded by air and the atomised mixture emerges from the burner as a fine spray and is initially ignited by a gas and electric pilot system.

Combustion air from the blower is controlled by a damper linked to the oil modulating valve, so providing a fully adjustable unit with a maximum turndown ratio of 5:1. (Turndown ratio is the ratio between the lowest and highest outputs of the burner.)

There are considerable differences in the ways pressure-jet and fluid atomising burners operate, but from the point of view of maintenance the differences are few, and both types can conveniently be covered together.

Whatever grade of oil is burned, proper atomisation will only be achieved if the viscosity is correct. For a distillate fuel, such as 35 seconds gas oil, the burner can be fed directly from the storage tank. Atomisation will be no problem at ambient temperature. A residual fuel, such as light, medium or heavy fuel oil, will have to be heated to reduce its viscosity to the right range for atomisation

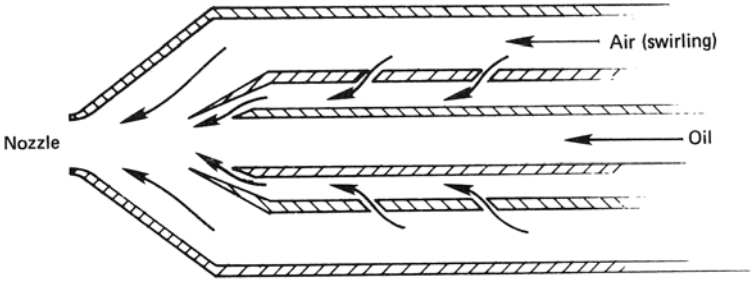

Figure 7.5 Fluid atomising burners

(see table 7.1). For each specific installation, however, the actual temperature used should be in accordance with the boiler makers' recommended settings.

Figure 7.6 shows the most common pipework system to be found in the boiler plant. The boiler is connected to the supply tank with flow and return lines, the latter being used to return unburnt excess oil from the burners according to the rate of firing. Where the boiler is running at maximum output, little if any oil will pass back to the tank, but as the firing rate decreases the 'spillback' also increases until all the oil being pumped is returned to the tank when the burner is in the 'off' state. In some cases the oil will not circulate back to the tank. In the arrangement shown in figure 7.6 there is a secondary circulation loop (shown dashed) for the unused oil which has been raised to combustion temperature.

When one or more boilers are connected in parallel from the twin pipe fuel system the 'spillback' will be proportional to the number of boilers in use and their relative rates of firing.

For simplicity, consider just one boiler with flow and return (figure 7.7) following through the flow of oil to the burner tip. The first item is the burner assembly oil filter. This filter must always be kept clean. It should be washed out weekly in gas oil. If pressure gauges on the inlet and outlet connections indicate a blockage it must, of course, be cleaned at once.

Table 7.1 Atomisation temperatures for fuel oil (pressure-jet burners)

		°F	°C
Fuel oil light	(Class E)	160–190	70–88
Fuel oil medium	(Class F)	200–230	93–110
Fuel oil heavy	(Class G)	260–280	127–138

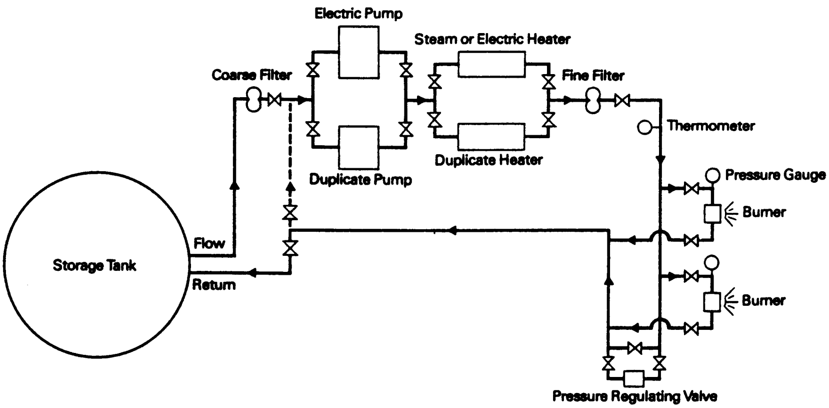

Figure 7.6 Ring main distribution system

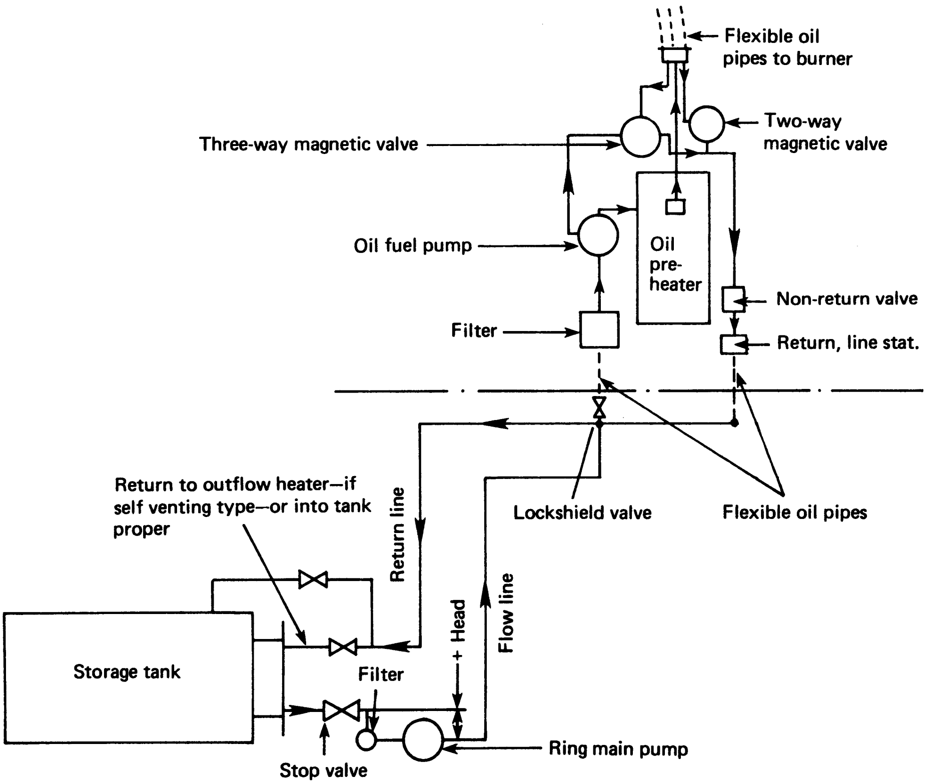

Figure 7.7 System for one boiler with flow and return

From the filter, the oil enters the pump, usually an electrically powered gear-driven unit. Maintenance is confined to checking seals for leakage and to lubrication of the motor bearings. The bearings should be lubricated at 6-monthly intervals with lithium-based grease. If sleeve bearings are fitted, a few drops of an SAE 30 oil every 6 months is the only requirement. Where a belt drive is used, checking for wear and damage is also necessary.

From the pump, the oil enters the preheater. Here there may be a simple electric immersion heater or a steam and electric heater. Starting from cold, the oil will be brought to combustion temperature by this heater. Where there is an electric and steam heater, the unit will switch over automatically to steam as soon as sufficient pressure has been raised.

The only maintenance requirement for the preheater is to inspect it 3-monthly for leaks and to see that the outlet temperature is that recommended by the makers for the fuel being used. Control of the heating is by thermostats; if the thermometers indicate incorrect temperatures the thermostat settings should be checked and adjusted. If this action fails to correct the situation the boiler specialist should be advised.

Once a year, the preheater should be cleaned out and new gaskets used in reassembly. With boilers designed to operate on gas oil, of course, no heater will be provided. From the preheater the oil passes to the modulating control valve (in the case of the medium air pressure modulating burners being used as an example here). With fully modulating burners the valve permits a portion of the oil to reach the nozzle but the remainder returns to the tank. In some cases the oil will return to a simple pipe loop within the burner assembly itself. Where two-stage control is used with twin jets there can be an 'off' setting, a 'low fire' setting, and 'high fire' setting, as shown in figure 7.8 where magnetic valves control the flow of fuel.

Routine maintenance of these systems is limited to keeping the equipment clean and lightly lubricated. Detailed 6-monthly servicing should be done by the manufacturers.

The actual movement of the modulating control valve or magnetic valves is brought about by a steam-pressure actuated switch, coupled to a modulating motor for a valve system. The motor has cams and linkage for movement of the oil valve and the damper which controls the flow of air from the blower. It is the adjustment of the cams and the roller follower which determines the air/fuel ratio. The setting for this has to be made while carbon dioxide readings are taken with a Fyrite kit as described in chapter 3.

The air/fuel ratio setting should be checked every 6 months, unless the weekly combustion tests demonstrate the need for making more immediate adjustments.

Where magnetic valves are used for on/off setting or for a low fire/high fire system, the damper is moved by a small hydraulic piston and cylinder assembly where the fuel acts as the pressure medium. Again, air/fuel ratios are adjusted by setting the stops when the unit has been operating for at least 1 hour, for optimum carbon dioxide readings.

Pressure-jet burner nozzles

Now consider the burner head or nozzle itself. Pressure-jet nozzles should be replaced after 2000 hours of service. It is false economy to use worn nozzles. Maintenance during the 2000 hours service is simple but great care is needed; the monthly nozzle maintenance procedure is as follows.

- Switch off the boiler.
- Pull out the main electrical isolator.
- Undo the burner swing bolt and hinge the burner assembly into the open position. *Note* a microswitch is fitted to the door surround to prevent the burner from firing in the open position. Do not rely on this switch alone and always make sure the electrical isolator is pulled out.
- Use the special wrench to undo and remove the nozzle.
- Place the nozzle on a clean sheet of paper and with the wrench unscrew the centre cone (preferably away from the boiler house).
- Wash all nozzle parts in gas oil and use only a piece of paper or a sharpened sliver of clean wood to clean all the grooves on the swirler. This is a precision-made article and can easily be damaged. Never use a pin, a piece of wire or a scraper to clean the nozzle components.
- For single nozzle units, replacement of a nozzle is straightforward.
- For twin nozzle units, remove one assembly at a time to ensure correct replacement. This is important as sometimes the nozzles are of different capacities and they must be put back in their correct positions.
- While the unit is open, examine the igniter electrodes. See that the insulator is clean and dry and that the spark gap is correct. Refer to the makers' handbook to determine the correct method of making any adjustments.

Some burners are ignited directly by the igniter electrodes; others use a pilot system, where bottled gas is ignited by the electrodes after which the gas jet ignites the oil/air mixture. These systems are reliable and the only maintenance needed is to keep all components clean and dry and, in particular, to ensure that the high tension cable between the high tension transformer and the igniter is clean.

Fluid atomising burners/medium air pressure burner nozzles

Medium air pressure burners have only one nozzle per burner. The nozzle is, however, more complex than that of pressure-jet burners (figure 4.5). This type of burner can give excellent combustion provided that the burner is kept in immaculate condition. Cleaning a precision device like this requires the utmost care and it is vital that on reassembly the parts are fitted the correct way round. As they are dismantled, note how they are fitted.

Remove the nozzle at least monthly to clean and inspect the parts. Use paraffin or gas oil for cleaning to remove all sludge deposits. Do not touch any of the parts with any metal tools or pieces of wire; the slightest scratch or notch in the knife edges will upset the flame pattern. Note that the precautions earlier given about pulling out the electrical isolator apply equally here.

Air supply for combustion

So far the oil supply system has been followed. Now the air required for combustion is described. This air is supplied by fan or centrifugal blower for both pressure-jet and fluid atomising burners. For pressure-jet burners natural draught is sometimes used.

Arrangements for driving the fan vary. In general, the fan is driven by a flange-mounted motor coupled direct to it or, on larger installations, by a separate motor through a vee-belt drive system, sometimes using plummer blocks and overhung fan assembly.

Maintenance is confined to bearing lubrication and to 6-monthly lithium-based grease application for motor and fan (and plummer blocks if fitted). Use just one shot of grease for each point. Vee-belts, where fitted, should be adjusted. Do not forget to switch off the electrical isolator before removing the belt guards.

Air supply for atomisation

Pressure-jet burners rely on a high oil pressure for atomisation but fluid atomising burners – in our example, medium pressure air burners – require a supply of compressed air into the actual burner nozzle to assist atomisation. This air is supplied by a small compressor, at pressures of up to 1 bar. A compressor is usually driven either by its own motor or from the same motor that drives the oil pump.

Maintenance is confined to lubrication. Where oil lubricators are fitted, see that they are checked weekly and topped up with SAE 30 oil. For grease lubricators or nipples, use lithium-based grease. One shot of grease weekly is all that is necessary, but refer to the maker's handbook for details. Give vee-belt drives the same attention as recommended earlier. If an air filter is fitted service or change it in accordance with the maker's instructions.

Flame-failure protection

The operation and routine testing of the flame-failure device was described in chapter 6. Apart from cleaning the sensor and carrying out the daily tests, the only requirement for maintenance is for annual replacement of the photocell.

Minor items

This includes such items as flexible fuel hoses, which should be checked weekly for damage and leakage. Pressure gauges, thermometers, control switches such as thermostats, and air pressure switches should be checked by the manufacturer 6-monthly.

Most package boilers, in particular those burning residual fuel oil, use a gas pilot ignition system. The gas supply can either be town gas or bottled gas. The systems are virtually maintenance-free but should be checked annually for leaks. With bottled gas, a twin bottle assembly with changeover valve and regulator is usual. This equipment must always be housed outside the boiler house.

A reminder

Combustion equipment is precision equipment and its condition can determine the boiler's efficiency. One of the most important efficiency features is to keep the combustion equipment clean. Also, if the combustion equipment is clean, maintenance will be greatly simplified. When cleaning fire-tubes and smoke tubes the operator should cover all air inlet ports and combustion equipment.

Summary of pressure-jet/fluid atomising burner maintenance

Air compressor	Oil level check	Weekly
Fuel hoses	Check for leakage and damage	Weekly
Flame failure sensor	Clean	Weekly
Burner nozzle	Clean	Monthly
Fuel filter	Clean out	Monthly
Belt drives (fan)	Check for wear and tension	3-monthly
Oil preheater	Inspect for leaks and correct operating temperatures	3-monthly
Compressor drive	Check belts for wear and tension	3-monthly
Burner and drive motor	Lubrication of BRGs and check belt drive	6-monthly
Oil pump	Lubricate pump and motor	6-monthly
Modulation system	Check out system throughout combustion range	6-monthly
Thermostats	Check operation	6-monthly
Control switches and pressure gauges	Check operation and settings	6-monthly
Flame-failure sensor	Replace	Yearly
Pilot gas system	Clean and check	Yearly
Oil preheater	Clean out	Yearly

Rotary cup burners

This section discusses maintenance of rotary cup burners which can handle all grades of oil from 35 seconds gas oil up to heavy fuel oil. Before considering the maintenance requirements for these burners, the principles by which they operate are reviewed (see also chapter 4).

For efficient combustion, the oil has to be broken up into very small particles and mixed intimately with the air. With rotary cup burners atomisation is achieved by spinning oil off the lip of a very fast rotating cup driven by an electric motor. The oil is fed to the cup lip where it is spread out evenly by centrifugal force. The oil then meets an air stream delivered in the opposite direction to the rotation of the cup by the primary air fan. This fan may be fitted to the same drive shaft as the cup, or it may be separate. The stream of air further breaks down the oil droplets into a very fine mass of particles.

Figure 7.8a and b show how combustion air is ducted to the quarl from a

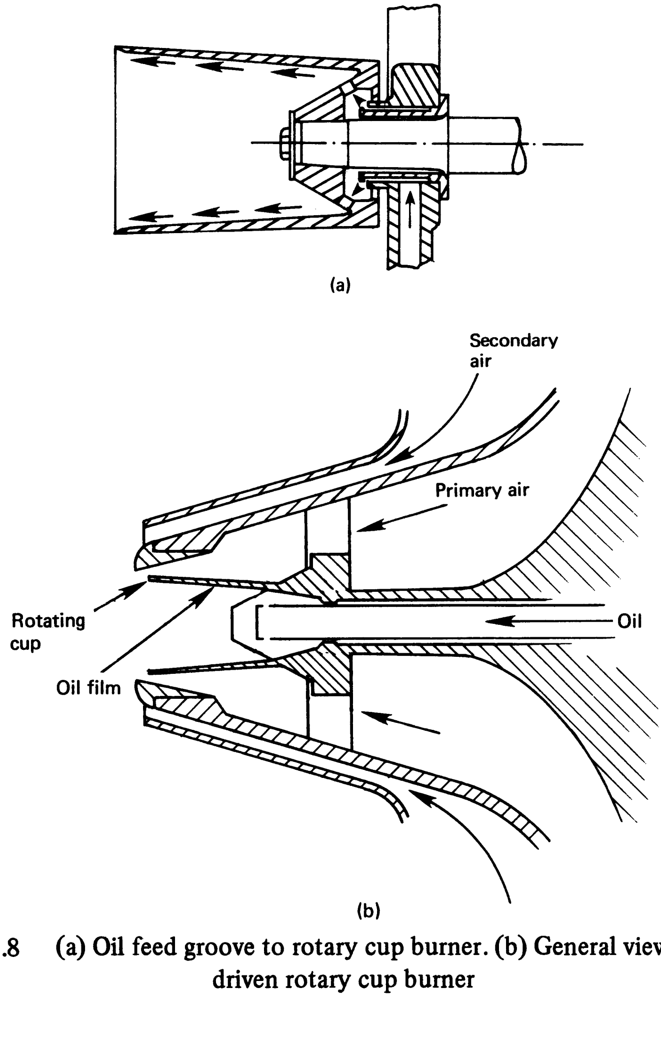

Figure 7.8 (a) Oil feed groove to rotary cup burner. (b) General view of motor driven rotary cup burner

motor-driven fan or blower, either in a separate casing or integrated into the boiler casing.

Rotary cup burners are fully modulating and can regulate the flame size in the ratio of 5:1. This is achieved in one make by a system of slide valves which proportion the oil passing to the cup by-passing the remainder back to the supply tank. In another make a motor-driven control unit performs the same functions. A secondary fan damper is linked to the modulating valve assembly, enabling the correct ratio to be maintained under varying load. The modulating valve is moved by a small motor linked to the boiler pressure 'slide wire controller' (Wheatstone bridge).

The burner assembly has two connections to the oil feed system, through flexible rubber hoses. One hose is the feed and the other the return for the portion of the oil which spills back either to the tank or to an internal circulation pipe loop. The difference passes to the cup for combustion.

Again, consider just one boiler with a single burner. Of course, the pipework systems described earlier for pressure-jet/fluid atomising burners could also be used. In one type of burner, oil enters the assembly through a strainer and the hollow hinge system on which the unit is supported. This hinge contains a spring-loaded relief valve which permits oil from the delivery side of the integral pump to circulate back to the suction side.

If a strainer is fitted before the hinge it should be cleaned out monthly by washing in gas oil. The oil level of any gearbox which transmits the drive to the pumps from the inner drive shaft should be checked and topped up weekly with an SAE 30 oil.

On top of the burner assembly is the drive motor, providing power through belts to the main drive shaft. Once a month, switch off the boiler and pull out the main isolator. Examine the belts for tension and damage and lubricate the drive motor with one shot only of lithium-based grease.

Some motor bearings are sealed for life and no lubrication points will be found.

Cleaning the rotary cup

The rotary cup is the key precision item of the whole burner assembly and it must be treated with the utmost care.

Once a day, and whenever the boiler is shut down for more than a few hours clean the cup as follows.

- Shut the boiler down
- Pull out the electrical isolator
- Undo the burner swing bolt
- Swing the burner through 90 degrees
- Wipe the cup rim with a clean rag moistened with gas oil; do not use a scraper or other tools
- Check that oil is not dribbling from the feed pipe into the cup

- If all is well, swing back the burner to the operating position and retighten the swing bolt.

A microswitch is fitted to the burner hinge, to prevent the burner from firing in the open position. Never rely on this. Always pull out the electrical isolator.

If the cup is not clean or if oil is leaking into the cup when the boiler is shut down, carbon will build up on the edge of the cup from back radiation from the brickwork. This carbonised oil is extremely difficult to remove. If the boiler is fired with carbon on the cup, it will result in defective atomisation and smoke generation.

As already described, there is a small motor which moves the modulating valve and the air damper. The pivots of the damper assembly should be kept clean and given a drop of an SAE 30 oil once a week. Once a month, give a light coating of lithium-based grease to the roller cam follower and cam profile strip.

The fan for providing combustion air will be either in a separate housing or built into the boiler casing. When lubrication points are provided, give each point one shot monthly of lithium-based grease.

Once a week clean the igniter. This can conveniently be done on shutdown when the cup is being cleaned, so that the same safety rules are observed. The igniter is merely a tube fed with air from the fan and gas, usually from a bottled supply which must be outside the boiler house. High tension current is fed to the igniter from a transformer actuated during the start-up sequence, and the gas supply is turned on and maintained at the igniter until the oil flame is fully established.

On the safety side the flame-failure device should be tested daily. It should be thoroughly cleaned weekly and changed every year, when the manufacturers should be called in to check all the other minor items as well as thoroughly to overhaul the burner assembly.

A pressure gauge on the burner indicates oil delivery pressure to the burner. There should also be two thermometers: one showing the temperature of the oil delivered to the cup; the other showing the temperature of oil in the reservoir. These all need checking yearly for correct operation by substitution or comparison with known units. At this time all other pressurestats and thermostats should be given a thorough checkover.

The actual oil temperatures required will depend on individual boiler makers' recommendations, but table 7.2 is a useful guide.

Table 7.2

Grade	*Combustion temperature* (°C)
Gas oil	ambient
Light fuel oil (E)	27
Medium fuel oil (F)	57
Heavy fuel oil (G)	78

Summary of rotary cup burner maintenance

Burner cup	Clean	Daily
Damper linkage	Lubricate pivots	Weekly
Gearbox	Check oil level and top up	Weekly
Igniter	Clean	Weekly
Flame-failure sensor	Clean	Weekly
Oil strainer	Clean	Monthly
Drive belts	Check for wear and tension	Monthly
Cam profile strip	Lubricate	Monthly
Gearbox	Change oil	6-monthly
Flame-failure sensor	Replace	Yearly

Feed water system

Figure 7.9 illustrates a typical feed system. Raw water from the town mains is treated before being mixed with condensate which has been returned from processes in the plant. There will be plants where no condensate is returned to the boilers, while at other plants as much as 80 per cent of the steam generated is returned to the boiler house for reuse.

The type of water treatment plant installed will depend very much on the quality of the raw water. (Details are given in chapter 5 on water treatment.) The situation is simplified by dealing with the water treatment plant on its own and then looking separately at the condensate return system. Finally the two systems are considered together, where they meet in the boiler feed tank. The main components in the water treatment plant are taken in turn.

Break pressure tank

Water from the town mains is stored in the break pressure tank prior to treatment in the softener. The tank's main function is to isolate the water treatment plant from the mains supply and prevent contamination of the mains if some valve or control system fails.

The tank will be made of metal or glass-reinforced plastics; the only check here will be for leakage and corrosion of metal tanks. The only moving part is the ball valve controlling the inlet of the mains water, which may require very occasional adjustment for level cut-off or equally occasional replacement of the valve sealing washer.

Raw water pumps

There will nearly always be two small raw water pumps at the tank outlet: one for service and one on standby. Each pump should be used alternately on a monthly basis. Maintenance is limited to the monthly application of one shot of

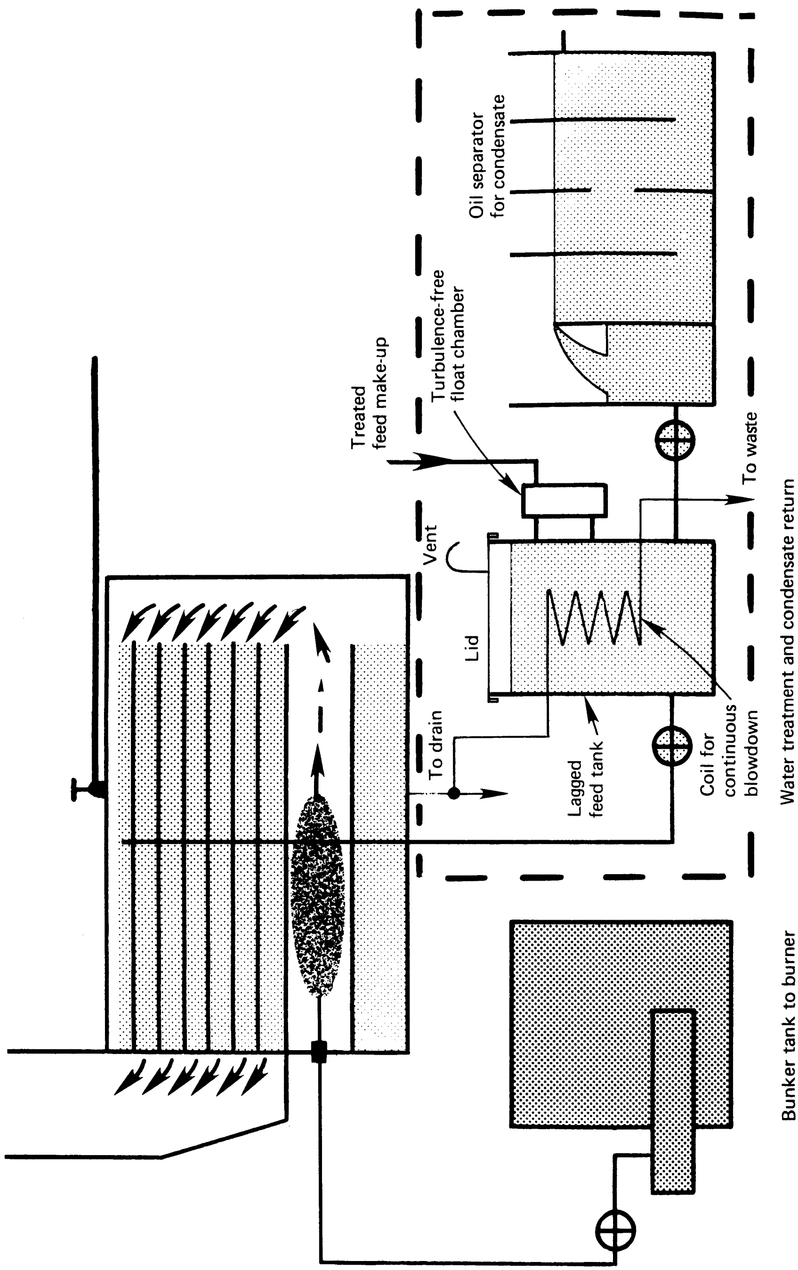

Figure 7.9 Feed water system

lithium-based grease to the bearings of the pump and motor, where grease nipples are provided.

Valves by the pumps should be checked for leakage, and the screws should be lubricated if applicable (some valves are made of plastics and require no lubrication). Suction strainers should be removed monthly for washing out when pump changeover occurs. From the two raw water pumps feed water enters the dealkaliser vessel, from which it is passed to the degassing tower.

Dealkaliser

Maintenance of the vessel is limited to checking all valves (whether they are automatically operated by air or manually operated) for free operation and for possible leakage. When valves have screwed spindles, one shot of grease for lubrication 6-monthly is all that is required.

Acid-regeneration unit

For regeneration of the dealkaliser, sulphuric or hydrochloric acid is used, so for all the following operations and checks safety glasses and protective gloves should be worn.

For the larger installations, acid will be delivered in bulk into a tank installed in a bitumen-lined bund or catchment pit. The tank should be checked for leakage and a check made that the bitumen lining is intact and in a good condition. The tank should be clearly marked with the contents and a first aid kit for eye irrigation must be permanently installed alongside it.

For the smaller installations, acid will be drawn from plastics containers by a portable drum pump. Avoidance of any spillage of acid is of the utmost importance. The acid should be kept in a locked store.

Any steelwork, bedplates, or supports in the plant must be properly protected from acid attack by an acid-proof paint. If any corrosion of steelwork is noted, it should be reported to the supervisor or boiler specialist.

The acid used for regeneration must be correctly diluted; this is usually done in one of two ways. For larger plants, a vacuum ejector powered by water is used; for smaller plants, the acid is added to water (*never* add water to acid) in a dilution tank made of glass-reinforced plastics. Modern systems have plastics piping. Provided the joints at elbows, tees, and so on, remain leak-free, there are no maintenance requirements. Valves in this type of system are also usually made of plastics.

Degassing tower

Here air is blown through the semi-treated water to remove as much of the entrained carbon dioxide as possible. More precisely, carbonic acid is broken down into carbon dioxide and water, and the carbon dioxide gas is disposed of into the atmosphere.

Larger installations have a tower, often concrete, filled with porcelain rings over which the semi-treated water flows from the top into the pond at the base. A blower forces air upwards against the flow of the water.

Smaller installations have a simple glass-fibre tower with a fan at the top. Either system has its maintenance confined to the fan and its drive motor, with a 6-monthly check for correct operation of the level controls.

The most complicated form of degasser is where a centrifugal blower is driven through vee-belts and pulleys from a small electric motor. There is little to go wrong in a set-up of this type but there are two areas in need of attention. First, the motor and fan bearings should be checked for noise when running. If the noise level is abnormal, bearing wear may be becoming a problem. If all is well give each lubrication point a shot of lithium-based grease, having taken the necessary precautions on lubrication laid down in the introductory section. The softening plant should be shut down before attempting this maintenance. It is unwise to lubricate or attempt to maintain any moving machinery.

Second, the vee-belts should be checked, so the guard will have to be removed with the power still isolated. Look at each of the belts in turn to see if they are worn, frayed, cracked or glazed. If any belts are worn the complete set should be changed; it is most unwise to change just one single belt as the load will not be equally shared.

If the belts are in good condition check them for correct tension. To do this, check the deflection of the belts. The amount of movement in inches can be calculated as being approximately equal to the distance between the pulley centres of motor and fan divided by 64 (figure 7.10).

If the belts are slack, tighten them by slightly slackening off the bolts holding down the motor and screwing up the adjustor screws on the slide rails until the required deflection is achieved. *Do not over-tension the belts*: this can cause premature failure of motor or fan bearings. Re-tighten the holding-down bolts.

If belt replacement is needed, remove the old belt by sliding the motor towards the fan. Take off the old belts, fit the new ones and tension correctly as described previously.

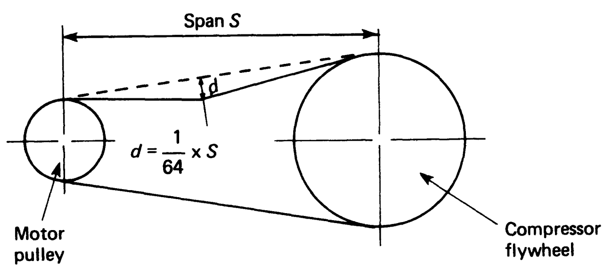

Figure 7.10 Belt drive adjustment

Note that new belts will stretch when first put into service so recheck the tension after a few days of operation. Finally, refit the guard and switch on the power supply to the unit.

There is a concrete or plastics sump at the base of the degasser tower. The level-switch controls for operation of the raw water pumps are in the sump. As water is passed through the system from the dealkaliser to the base exchange softener, the actual process will be controlled by these level switches. The only check here is to see that the pump on and off levels meet the maker's required level settings; if they do not, seek help from the plant supplier.

Caustic dosing unit

Caustic soda is dangerous if not handled with care, so wear safety spectacles and rubber gloves when working with it or with equipment containing it. The usual way of dealing with caustic injection into the system is to have a tank in which there is a maintained water level and into which weighed amounts of caustic flake are added. The tank may be of metal or, more likely, of glass-reinforced plastics. Some makers provide a paddle driven by a small motor to prevent settling of the caustic.

Maintenance of the tank is limited to corrosion checks on metal construction. From the caustic tank, the caustic solution has to be injected into the flow of semi-treated water as it passes from the degasser sump to the base exchange softener. This is done by a small chemical injection pump. The main difficulty here is to ensure that there is no blockage of the strainer fitted to the pump, which will prevent correct operation. This can only be checked by inspection and washing out of the strainer in water.

Lubrication is limited with these units to motor bearing lubrication points (where these are provided). A lithium-based grease should be used for lubrication of moving parts in ram pumps.

If leakage occurs with ram-type pumps, careful adjustment of the packings may cure the problem, but over-adjustment will cause over-heating and wear of the pump ram with increased leakage and a drop in efficiency. In cases of doubt about leakage refer to the pump manufacturer.

Base exchange softener and semi-treated water pumps

Maintenance is identical to that of the dealkaliser and of the raw water pumps.

Brine regeneration unit

Regeneration of the base exchange unit is by brine solution, made by dissolving common salt in water. The salt is delivered by road tanker lorry with air pressure discharge for large installations. On small installations it is delivered in sacks.

For the air discharge system the only check required is to see that the cover to the bulk storage tank (usually of concrete) is in place.

Salt in sacks will have to be measured out into the brine tank to maintain the required concentration. The brine tank itself will be either metal or glass-reinforced plastics. If it is metal, a check for corrosion is needed; both types will of course require a check for leakage.

Dosing unit

The final treatment element is the addition of dosing chemicals, usually based on sodium sulphite, to the feed water supply. The dosing chemicals are contained in a tank, and an injection pump controlled by the main boiler feed pumps operates whenever the boiler calls for water.

Maintenance checking comprises a visual inspection for leaks, a check on accurate operation of the injection pump, a visual inspection and washing out of the suction strainer in water and finally an operational check to confirm that the injection pump runs whenever the boiler feed pumps are running.

Control system

Water treatment plants can be operated entirely by hand, or they may be operated by a control system which functions on the number of gallons which have passed through the units. As a third alternative they may be operated by actual measurement of the water quality after dealkalisation or base exchange treatment.

In some of the automatic units no manual initiation is required; others sound an alarm when regeneration is necessary and initiation has to be by hand.

Whatever the system, there will be some instrumentation. There are usually pH controllers for control or indication of regeneration of the main dealkaliser and a hardness detector unit for initiation or warning of regeneration of the base exchange unit.

Where air is needed to operate valves, there is a small compressor. This should be checked to ensure that cut-in and cut-out pressures are correct, that the electric motor bearings are adequately lubricated – one shot of lithium-based grease is all that is necessary – and that the level of oil in the compressor sump is correct.

The instruments themselves require periodic checking. This should be done quarterly by a specialist contractor. Adherence to the daily water testing routines recommended in chapter 6 may well show up any malfunction of the instrumentation and controls, but even if all appears to be well the quarterly check is still vital.

Condensate return system

In dealing with the condensate return system only the collection system and oil separator are included. Pipework and pumps for return of condensate from the plant will be excluded.

The actual system used can be built up in a variety of ways. If there is a collection tank for condensate it may or may not contain an oil separator. Assuming it does have a separator, maintenance is limited to routine checking for oil or other contamination. This is covered in the once-per-shift or 8-hourly checks by plant operators in chapter 6 (p. 66).

The tank lagging and the cladding should be checked monthly for good condition and proper fit of the tank lid.

Transfer pumps

There will be transfer pumps for the condensate collection tank and separator, probably two of them: one in use and one on standby. Operation will be by float level controls. Maintenance is limited to checking correct levels to ensure that the tank is not overflowing for some reason, so losing this valuable condensate.

The pumps will require 6-monthly servicing of motor and pump bearings, and should be lubricated with lithium-based grease. Pump strainers should be washed out monthly with water. Any valves in the system should then be checked for leakage at packings and for adequate lubrication of their spindles.

Feed tank

Finally, the boiler feed tank (sometimes called the 'hot well') is a simple lagged and clad storage tank with a close-fitting insulated lid with a vent. The treated water from the softening plant is mixed with the hot condensate return in the feed tank. The main boiler feed pumps draw their supply from it.

Regulation of the feed tank level is usually by float switch or by a ball valve. There is often a considerable turbulence in this tank and it is a good idea to fit the level controls in a separate chamber, as shown in figure 7.9.

Maintenance is limited to a 6-monthly visual inspection of the tank for condition of the insulation and cladding. Where a heat recovery coil is fitted from a continuous blowdown system, it should be checked for leakage if there is an abnormally high TDS level in the boiler water on which the blowdown is otherwise working correctly.

Summary of water treatment plant maintenance

Break pressure tank	Check for leakage and corrosion; check for operation and setting of float control valve	Monthly

Raw and semi-treated water pumps	Lubricate bearings of pumps and motors; check packing for leakage	Monthly
Pump strainers	Wash out elements	Monthly
Acid tank	Check for leakage; check bund lining for good condition	Monthly
Acid injector	Check that this is a clean and in good working order	Monthly
Piping systems	Check for freedom from leaks	Monthly
First aid equipment	Check that this is complete and that the equipment for eye irrigation is on hand	Monthly
Caustic dosing unit	Check tank for corrosion; check injector pump for leakage at seals; lubricate where necessary; check suction strainer	Monthly
Salt storage tank	Check cover is in place	Monthly
Brine tank	Check for corrosion and leakage	Monthly
Chemical dosing tank	Check for corrosion and leaks	Monthly
Air compressor	Check compressor sump lubrication and motor bearings lubrication; check pressure switch setting	Monthly
Instrumentation and controls	Check for correct calibration; check for correct 'set point' adjustment	3-monthly
Valves	Check for leakage, adjust packings, lubricate where necessary	6-monthly
Dealkaliser vessel	Check valve operation and lubrication where applicable	6-monthly
Steel work	Check all steel work for freedom from corrosion and protect with acid-resistant paint where necessary	6-monthly
Degasser	Lubricate fan and motor bearings; check vee-belts for correct adjustment and condition as appropriate; check sump level control system	6-monthly
Base exchange softener	Check valve operation, lubricate as necessary	6-monthly
Chemical dosing pump	Check for correct adjustment and that suction strainer is clean; check packing for leakage; lubricate pump and motor bearings as applicable	6-monthly

Summary of condensate return system and feed tank maintenance

Separator	Check condition of lagging and cladding; check for leakage from tank and overflow line; check for operation of transfer pump control switches	Monthly
Condensate pumps	Check gland packings for leakage and adjust as necessary; wash out strainers	Monthly
Feed tank	Check lagging and cladding for condition and for maintenance of correct operating level	Monthly
Condensate pumps	Check pumps and motor bearings for wear and lubricate as necessary	6-monthly
Valves	Check packings, and spindle for wear and lubrication	6-monthly

Boiler shell and fittings

The fuel system, the burner assemblies and the feed water system have been discussed. This last section is on maintenance of the boiler itself, and covers all the items delivered by the boiler-maker as part of his boiler 'package'. It also covers the chimney stack and some additional instruments not normally supplied by the boiler-maker but essential for efficient operation.

Boiler drum

A monthly check should be made to ensure that the insulation and cladding are in good condition and that all mud holes and manholes are free from leakage. Any leakage is unsightly and can affect the insulating properties of the lagging. If there is a leak which cannot be stopped by pulling up the nuts on the strong-back, it should be reported so that arrangements can be made to replace the joint ring.

Whenever mud hole doors or manhole doors are removed they should always be fitted with new gaskets. A little powdered graphite will assist with the removal on the next occasion. Before replacement, always ensure that the seatings on both cover and shell are absolutely clean. Retighten the nuts fully when the boiler is being returned to service and during the warming up stage, when a further visual check is also required.

Make sure that all access ladders, platforms and handrails are secure and that they are free from grease or oil. Check this monthly.

Safety valves and crown valve

On the top of the boiler the two safety valves and the crown valve must be checked.

The safety valves should be padlocked when they are 'floated' after the annual inspection. They should not be tested by lifting – this encourages the seatings to become worn, with consequential leakage of steam.

If leaks are found at normal working pressure the boiler will have to be taken out of service to have the valve seats recut. This is a job for the boiler-maker or another specialist contractor.

The crown valve must always be able to be operated without difficulty. If for some reason the boiler became short of water it would be necessary to shut the valve quickly to avoid further loss of water. Hence, its operation should be possible without having to use wheel spanners or other tools.

Maintenance of the crown valve comprises 3-monthly lubrication, with a bentonite grease, of the screw and the grease nipple. At the same time, the packing should be checked for leakage. If there is any, careful adjustment of the gland nuts may provide a cure. Great care will be necessary because the valve is almost at steam temperature. Safety gloves and eye shields must be worn. Always ensure that, after adjustment, the valve can operate freely.

If the leak can only be stopped by clamping the gland tightly, it is almost certain either that repacking is necessary or that the spindle needs to be replaced. In this case, the boiler will have to come out of commission for the work to be carried out. In any case always seek expert advice before adjusting packings of valves.

Where more than one boiler is connected to a common steam main, special precautions will be necessary. If it is necessary to steam one boiler on the same main when another boiler is down for crown valve or any other repair on the pressure side, a blank flange of the correct pressure rating must be fitted to isolate that boiler from the live steam supply. An acceptable alternative to this is for an additional stop and non-return valve to be fitted between the crown valve and steam main.

Gauge glasses

At least one gauge glass must be connected direct to the boiler shell. It is not permissible to have both gauge glasses connected in parallel with Mobrey float chambers.

The maintenance of gauge glasses is limited to ensuring that there are no leaks and that the actual glass tubes and seals are replaced annually. Always look at replacement tubes and reject any that have chipped ends. Each tube should have smooth ends if early failure is to be avoided. Never reuse old seals for gauge glasses and if the cocks are dismantled they should always be reassembled with new packings. Dirty glasses indicate that the water treatment may be defective, or that the boiler is priming.

Mobrey controls

While at the side of the boiler, check the Mobrey sequencing valves for gland leakage. If there is any sign of leakage at this point, ensure that the valves are fully serviced. Scalding could be possible during the daily testing of the controls, when the chambers are blown down. Minor leaks can of course be cured by gland adjustment as already covered.

Servicing of the sequencing valves can be combined with 6-monthly servicing of the actual Mobrey controls. This should be done by the control manufacturers.

Pressure gauge

At the front of the boiler there is the pressure gauge. This is maintenance-free and calibration will be checked during the statutory 14-month inspection. The gauge should return to zero whenever the boiler is at atmospheric pressure and should give a steady reading when the boiler is steaming. If there are faults here, replacement is the only solution, with gauge repair by a specialist repairer.

Blowdown valve

Beneath the boiler is the blowdown valve. It will be used regularly, probably once a shift, according to the water quality and other factors. Most blowdown valves are of the rack and pinion type and only gland packing will require attention. Glands should be just tight enough to contain the boiler pressure and yet allow ease of operation with the removable handle provided.

Where poor feed water is encountered and a full three-stage softening process is necessary, it is often beneficial to use continuous blowdown from the boiler, with flash steam recovery. The continuous blowdown valve is in effect maintenance-free again, apart from gland adjustment. To comply with section 34 of the Factories Act, where more than one boiler is connected to a blowdown system, only one valve key should be provided and this must be of the removable type.

Feed check valve

Between the feed pump and the boiler there is a non-return valve or feed check valve. The only checks are for packing and lubrication. To ensure that the valve does hold pressure, where condensate is not being returned to the feed water tank, feel the delivery line from the pump. If it is hot then the valve is in need of reseating. If condensate is being returned, this check is not practical, because the water will in any case be hot.

Pressure controls

There are two pressure switches fitted to the boiler. One cuts off the burner should the normal modulating control already have reduced the burner output to its lowest setting while the load continues to fall. It is set just below the blow-off pressure for the safety valves. A second pressure switch controls the modulation of the burner, where such a type of burner is fitted. Adjustment of either switch is best left to the specialist contractor during a 6-monthly check-up.

Combustion chamber, smoke tubes and chimney

The burner assembly has been covered earlier and this section deals with the fire side of the boiler. Once a month the burner quarl should be visually inspected. If repairs are necessary because of cracking or spalling this may be a job for the specialist contractor.

The question is often asked, 'when should we clean smoke tubes'? As discussed in chapter 6, use the flue-gas temperature indicator, or the thermometer in the Fyrite tester to indicate when to clean the fire side of a boiler. With good combustion, one would normally expect 1000 hours of operation before cleaning is necessary, but this time will vary considerably with the way in which the plant is being used. For instance, repeated firing on light loads will increase the frequency of cleaning over that required with a continuously steady load of, say, 80 per cent of full boiler output.

For cleaning, a vacuum soot-removing kit, spanners, face masks and protective gloves are needed. The boiler should be shut down, the fuel valve closed and the electrical isolator turned to 'off' with an appropriate notice hung on the box to say 'Danger Men Working – Do Not Touch'. It is not enough to switch off the boiler and rely on the control box switches for making the boiler safe. Where boilers are connected to a common flue, appropriate isolation will be necessary before starting work.

When the boiler has cooled sufficiently, remove the nuts by slackening them slowly one at a time to gain access to the various doors which can then be removed or swung away for cleaning. Clean each tube in turn and check to see that there are no signs of water leakage, particularly where the tubes emerge from the tube plates. With dry back boilers, take the opportunity to examine the refractory. If it has any minor cracks or defects they can be repaired with refractory cement.

Then examine the rope seals on all doors. Replace any which show signs of damage or deterioration. If any of the rope seals leak and allow air to enter the combustion system the fuel/air mixture will be affected.

On the doors or cover plates which separate the various passes for the gases there will also be seals. These must also be in good condition. If there are leaks here there can be short circuiting of the gases so that they reach the chimney without having given up their full amount of energy and so wasting fuel. If in doubt, always replace these joints. It is cheaper to replace joints on inspection than to find that they leak after the boiler has been re-started.

Finally, here are some safety points to remember.

Always wear eye shields and protective gloves.

Always use a face mask when working with tube-cleaning equipment.

Always ventilate the boiler house thoroughly during this operation.

When using a hand lamp for inspection of the work make quite sure that it is either battery powered or a low-voltage type. Mains voltage could give a lethal shock in a metal boiler.

It is permissible to wear normal industrial clothing for cleaning of boiler tubes.

It is appropriate at this point to say that any tube leakage found during cleaning must be rectified before the boiler is returned to service. If there is repeated leakage, further investigation is clearly necessary. It may be that build-up of scale on the water side through faulty water treatment has caused tube over-heating, so clearly this is something to be considered.

Minor leaks can often be repaired by expanding the tube ends. If cracking has occurred or further expansion is not possible then tube replacement is the only remedy – this of course is a specialist contractor's job.

While tube cleaning and carrying out this inspection work, examine the furnace tube itself. Any distortion, bulges or other problems should be drawn to the attention of the boiler insurance inspector. On no account should a boiler be returned to service where any furnace tube defects have been noted or suspected.

Having considered the fire side of the boiler it is now convenient to look at the chimney stack. The stack is nowadays more likely to be steel, lagged and clad with aluminium sheeting, than to be made of brick of concrete. Small boilers often have the chimney flanged directly on to the boiler shell. Larger units are connected to the chimney with ducting.

Maintenance work on chimneys is a job for a specialist contractor but visual inspection is a simple matter from ground level and should be done at least every 6 months. All that is needed is to see that any cladding is intact, that inspection plates are tight and that there are no signs of leakage causing stains to appear at the joint faces.

If there are any signs of fumes in the boilerhouse there may be a blockage in the trunking or in the chimney itself, possibly brought about by the collection of combustion solids. If this is the case, expert advice is required – there are probably faults in the combustion equipment which have to be cured before any further investigation is carried out.

Feed pump

Some package boilers have dual feed pumps, so that one can be in service and one on standby. It is a good idea to use them alternately on a monthly basis. Never service feed pumps without switching the boiler off and without pulling out the main electrical isolator. Maintenance is limited to lubrication of pump and motor bearings, where lubricators are provided. One shot only of lithium-based grease each 6 months is all that is required. There should also be a check for leaks of water at glands or mechanical seals.

Gland packings should be adjusted, as in the instructions at the beginning of this section. If mechanical seals are faulty, replacement is the only solution. This is probably a job for the pump manufacturer.

Flexible couplings between pump and motor should be checked for wear, indicated by relative rotational movement between the pump and motor shafts. Worn couplings should be replaced or rebushed as appropriate; again, this may be a job for a specialist manufacturer. Feed pump strainers should be washed out weekly. If joints on the casing leak they should be replaced to prevent air infiltration, which can cause pump cavitation and damage to bearings and seals. Forced draught fans are included in the appropriate burner section.

Control cubicle

Work on the control cubicle is a job for the specialist contractor and 6-monthly checks are necessary. The check includes a complete test of all wiring and connections, with an insulation check to show that there is a minimum resistance of not less than 1 MΩ to earth. In addition, an earth continuity check should also be made and the resistance should not exceed 1 Ω. A further check on the sequence timer and control unit is necessary, with complete cleaning of all contacts on the timer motor and starters.

Instrumentation

Steam flow integrators, flue-gas temperature indicators and oil and water meters should all be serviced 6-monthly by specialist contractors or the manufacturers. Inaccurate or unreliable instruments can waste time in investigating fault conditions and can, indeed, be actively dangerous.

Summary of boiler shell and fittings maintenance

Feed pump strainer	Wash out	Weekly
Shell manholes	Check for leaks	Monthly
Ladders, platforms and handrails	Check security and freedom from oil	Monthly
Crown valve and feed check valve	Check for free operation lubricate as required	3-monthly
Mobrey controls and sequencing valves	Specialist check clean contacts	6-monthly

Pressure controls	Check and adjust	6-monthly
Chimney stack	Visual check	6-monthly
Feed pump and drive motor	Lubricate bearings	6-monthly
Instrumentation	Check for accuracy	6-monthly
Gauge glasses	Replace glasses and seals	Yearly

Appendix

Procedure for renewing valve gland packing (figure 7.11)

- Drain the system as necessary. Put a tray under the valve. Close the valve.
- Withdraw the gland flange and follower. Fasten it with string to the top of the spindle.
- Remove all the packing rings by an extractor. Note the number withdrawn.
- Remove the lantern ring (if fitted) and fasten it in the same way as the gland flange. Continue removing packings, taking note of the number of rings below the lantern ring.
- Wipe the shaft and stuffing box with a clean cloth.
- Place new packing material round the shaft (or round a former of the same diameter as the shaft) in sufficient length to make the required number of rings. To assist in cutting rings, two guide lines, parallel to the shaft or former may be drawn on the packing material, separated by a distance equal to the packing section. First cut the ring at an angle of 45° diagonally across the guide lines. Check to ensure a correct fit before cutting further rings in the same way.
- Apply a thin film of grease round the inside and outside of the packing rings.
- Fit the same number of rings as were removed, ensuring that the lantern ring, if one is fitted, is replaced in the same position.
- Bring the gland follower up squarely against the last packing ring, replace the gland flange and tighten the gland nuts until the packing offers moderate resistance to spindle movement.

Subject to operating conditions, ensure that valve is still freely operating by opening fully and closing it fully. On completion of work, ensure that the valve is left in the correct position.

Procedure for renewing pump gland packing (not mechanical seals)

Slight leakages normally occur on pumps with gland packings instead of mechanical seals. This leakage can normally be controlled by careful adjustment of the nuts fitted to the gland follower. After such adjustment the pump should be run for a short time to make sure the gland has not been overtightened and therefore caused over-heating.

If considerable leakage continues after the adjustment, the gland packing must be renewed as described below. The procedure is basically the same as that illustrated in figure 7.11.

Over-tightening of gland packings in any pump can cause rapid wear of the shaft. Where oil products are being pumped, incorrect adjustment can also present a serious fire hazard. The following instructions must therefore be carefully carried out. These checks must be made after isolation from normal power control/service.

OLD PACKING REMOVAL

- Ensure that pressure is off the stuffing box and that liquid is drained from it.
- Remove the gland follower nuts and pull the gland follower clear of the stuffing box.
- Withdraw old packing with extractor tools and wipe the stuffing box clean.
- Examine the shaft for scoring or eccentricity. If it is satisfactory, proceed to fit a new gland. If not, send for the boiler specialist.

NEW PACKING PREPARATION

- Measure the depth of the stuffing box to ascertain how many rings are required, making allowance for entry of the gland follower.
- Cut the rings. Gland packings are supplied as a spiral or on a spool or coil.
- Place the packing round the shaft.
- To assist in cutting, draw two parallel lines to the shaft axis on the packing material at a distance equal to packing section.
- Cut the rings from the coil at an angle of 45° diagonally across the guide lines.
- Leave no gap between the ends.
- Check the first ring to ensure correct fit in the stuffing box before cutting further rings.
- Wipe a thin film of grease inside and outside the packing rings.

FITTING THE PACKING

- Check the shaft turns freely.
- With a split sleeve and using the gland follower, push each ring hard home.
- Stagger the joints at 120°. Check the shaft for free movement after fitting each packing ring.

Warning

When using gland packings from graphite or PTFE multi-filament yarn, slide the rings into the box. They must not be tamped or driven home.

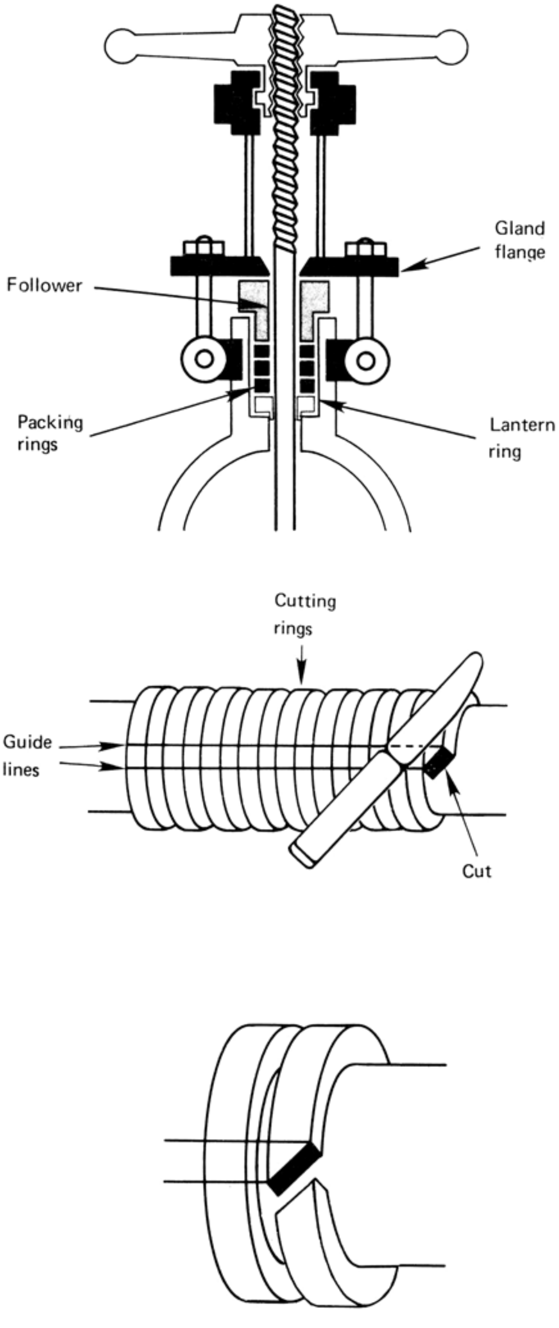

Figure 7.11 Procedure for renewing valve gland packing

Bring the gland follower up squarely. Tighten the nuts evenly to finger pressure.
Turn the shaft to ensure that there is no binding.

RUNNING PUMP IN – ADJUSTMENTS

A packed gland must leak slightly and adjustment must take place until this leakage is at an acceptable level. Run the pump for 10 minutes, then tighten the gland nuts by one-sixth of a full turn. Repeat this every 10 minutes, until the leakage is contained.
Subsequent adjustments should be made in the same way when the equipment is operating at normal working temperature and pressure.

8 Efficient Use of Steam

Steam use is the area where major fuel savings are possible. For every 1 per cent saving on the boiler, there is certainly at the very least 2 per cent saving possible in most plants.

This chapter covers the heating qualities of steam and its distribution and heat transfer. It deals with ways of reducing demand by preventing the escape of heat and by reducing process heat requirements.

Why is steam used for heating process applications? Because in most cases it is not practicable to extract heat from fuel at each point of heat usage; this process is usually carried out in a centrally located boiler, and the heat transferred to a suitable heat-carrying medium. Saturated steam is by far the most widely used conveyor of heat, other media being hot water and heat transfer oils. The main advantages of steam over the other carriers are that it has a very high heat content allowing small pipes to be used, and a high heat transfer coefficient. In this chapter, the basic principles of efficient steam utilisation are described, together with how energy savings can be effected in practice.

To begin, a brief revision of the basic physical properties of steam will help explain how steam may be used in the most efficient and economical way.

Latent heat and sensible heat

When water in a boiler (shown simply in figure 8.1) is heated its temperature is raised. The heat thus added is called sensible heat. When the water temperature reaches the boiling point, further addition of heat ceases to raise the temperature and begins to convert the water from the liquid state to vapour, that is, steam. The heat added to convert boiling water to steam at the same temperature is called latent heat.

Therefore to turn 1 kg of water into 1 kg of steam, both sensible and latent heat must be added. The higher the pressure, the higher the boiling point temperature required, as indicated in the familiar steam tables (table 8.1 shows part) which give the precise relationship between the pressure and temperature of saturated steam. This emphasises one of the major advantages of steam for use

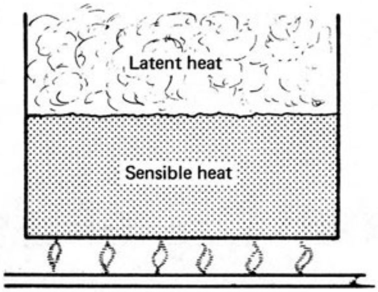

Figure 8.1 Sensible heat and latent heat in water

in process heating: that the temperature required for the process, which in some cases can be critical, can be ensured by the choice of steam pressure.

The latent heat is considerably greater than the amount of heat required to raise the water temperature from cold to boiling point. This is clearly illustrated in figure 8.2, showing the latent heat of steam to be 70 to 80 per cent of the total heat. When steam gives up heat, it loses its latent heat until it condenses, the condensate being at the temperature of the steam. It will be seen from figure 8.2 that the higher the steam pressure, the lower the latent heat per kg of steam. As will become evident, this physical fact has an important bearing on fuel economy.

Table 8.1 Steam table (abbreviated)

Pressure bar gauge	Temperature (°C)	Specific enthalpy (kJ/kg)		
		Sensible heat	Latent heat	Total
0	100.0	419.0	2257.0	2676.0
1	120.4	505.6	2201.1	2706.7
2	133.7	562.2	2163.3	2725.5
3	143.8	605.3	2133.4	2738.7
4	152.0	640.7	2108.1	2748.8
5	158.9	670.9	2086.0	2756.9
6	165.0	697.5	2066.0	2763.5
7	170.5	721.4	2047.7	2769.1
8	175.4	743.1	2030.9	2774.0
9	180.0	763.0	2015.1	2778.1
10	184.1	781.6	2000.1	2781.7
11	188.0	798.8	1986.0	2784.8
12	191.7	815.1	1972.5	2787.6
13	195.1	830.4	1959.6	2790.0
14	198.4	845.1	1947.1	2792.2

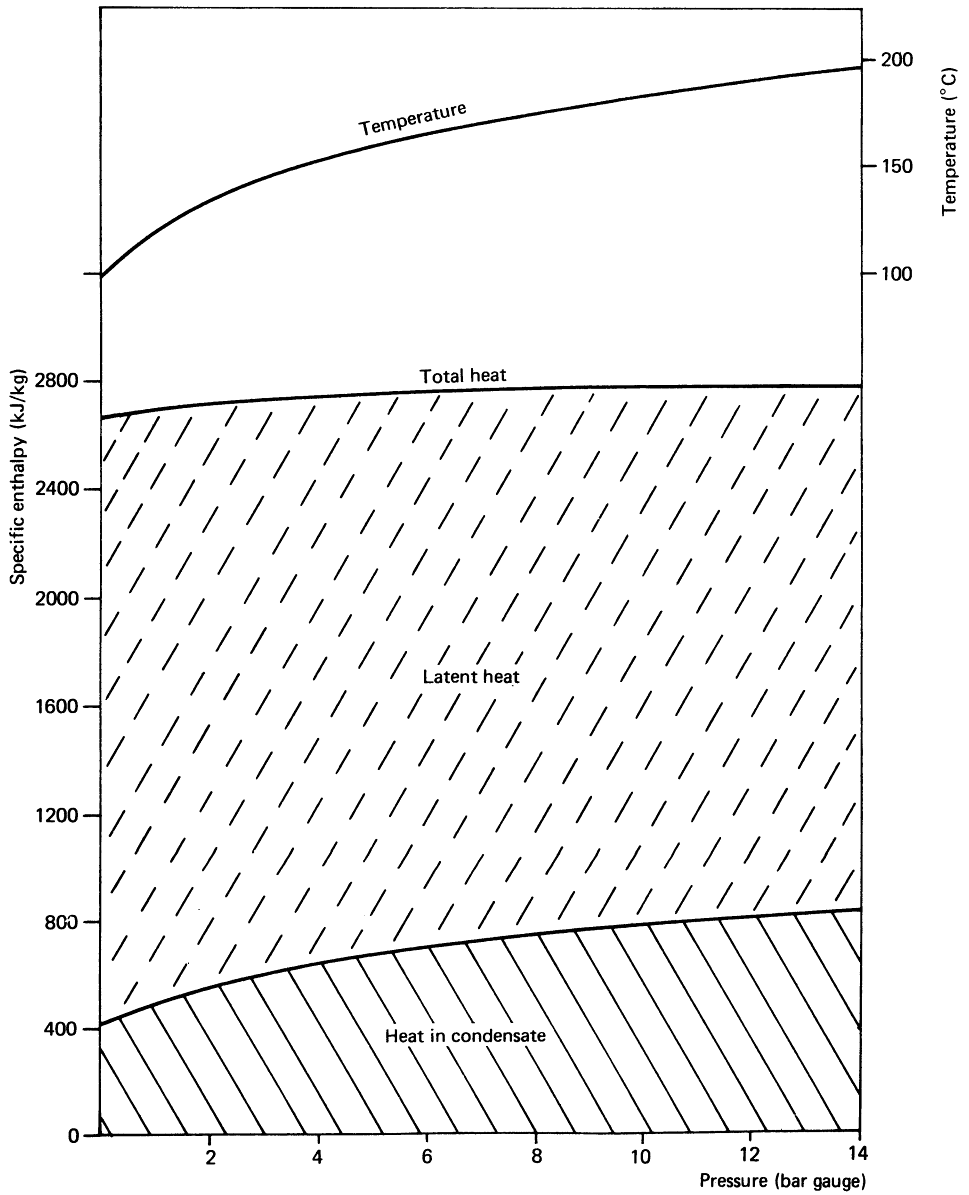

Figure 8.2 Heat in steam against pressure

Steam quality

All data in the steam tables are for 'dry saturated' steam, which is practically impossible to obtain under typical operating conditions. On most boilers, a certain amount of water is carried over with the steam in the form of fine droplets. Furthermore, this moisture content is likely to be increased by condensation in the steam piping system. Any moisture fraction in steam is undesirable because it carries no latent heat, and it increases the resistant film of water deposited on the heat transfer surface in a heating application.

The amount of moisture carry-over from a boiler is very much influenced by the solids content of the boiler water, emphasising the need for correct water treatment procedures (chapter 5). The provision of adequate drainage and condensate trapping in a steam distribution system is therefore essential.

The presence of air in steam is even more detrimental because it also forms an insulating layer on heat transfer surfaces, but its thermal conductivity is 25 times less than that of water. Removal of air by suitably positioned air vents must therefore be given close attention.

Steam distribution system

The steam distribution main is the vital link between the boiler and the points of steam use, and correct design of the system is therefore important. For maximum economy, steam should be distributed at high pressure because this will allow smaller distribution piping to be used. This piping is less costly to install and has less heat-losing surface than larger diameter pipe. If the pipe diameter is too small, however, the pressure drop along its length will be high, leading to steam starvation at the using end. The optimum pipe size is usually calculated from a formula relating pipe size to pressure drop, for which numerous nomograms and graphs are available.

For process or space-heating purposes, steam should be used at the lowest possible pressure, remembering that low pressure steam offers the maximum amount of latent heat per kg (figure 8.2). But there are practical factors which limit how far pressure can be reduced. The fact that steam temperature drops with reduced pressure means that heat flow from a given area of heat surface drops correspondingly. The available heating surface in the plant is thus a determining factor for minimum steam pressure. Another factor is that certain products must be processed at a particular temperature, for example, to initiate a chemical reaction, and this in turn decides the pressure.

To keep the steam main distribution pressure high and match the lower pressure requirements of the heating processes in the plant, a reducing valve can be installed before each major usage area. This will maintain the desired downstream pressure, and also have an advantageous drying effect on the steam by flashing off some of the entrained water with the extra latent heat made available by the pressure reduction.

Steam traps

As heat is transferred from steam to the walls of the vessel confining it, the steam will give up its latent heat and condense to water. This will occur in the equipment being heated and also to some extent in the distribution pipework. For continued operation the condensate must of course be removed without allowing dry steam to escape. The most effective way of controlling this is by the automatic steam trap. This is esssentially a valve which opens when condensate is sensed and closes when steam is present. There are many types of steam trap to suit particular duties but the more popular ones are the thermodynamic trap, the float trap, the thermostatic trap and the inverted bucket trap.

THERMODYNAMIC TRAP

This has many advantages over other types of trap. It is compact, simple, robust and has only one moving part (figure 8.3). The valve opens when the inlet pressure is greater than that at the outlet. When the discharging condensate is hot enough, some of it will flash to steam as it passes through the trap. The increased velocity of the flashed steam creates a low pressure zone below the valve disc and a back pressure in the discharge pipe. This combination results in the valve closing. The flow of condensate and flash steam ceases and the back pressure in the discharge pipe reduces and the cycle starts again. Usually the condensate discharge temperature is close to that of the steam, but design variations can allow the condensate to be discharged at somewhat lower temperatures.

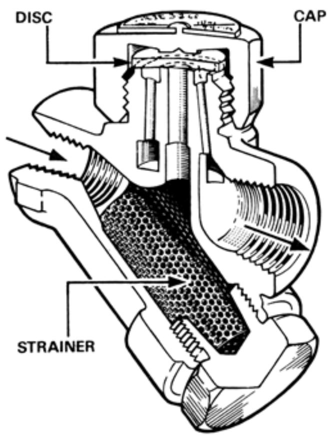

Figure 8.3 Thermodynamic trap

FLOAT TRAP

This consists of a valve operated by a lever connected to a ball-float (figure 8.4). The float chamber connects with the inlet to the trap and when sufficient condensate has collected in the ball chamber, the ball begins to float and opens

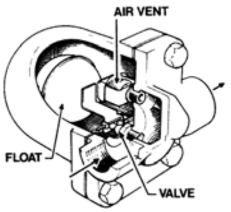

Figure 8.4 Float trap

the valve which is located below the condensate level. The condensate is thus discharged, the ball drops and the valve closes. This type of trap works well on both heavy and light condensate loads and is not disturbed by wide and sudden pressure changes.

THERMOSTATIC TRAP

This consists of a valve operated by an element which moves in response to temperature changes (figure 8.5). The element can be a gas-filled bellows, a bi-metal strip or a liquid-filled expanding plunger. The condensate must be below steam temperature so this type of trap will not discharge condensate as it forms. Usually it must be fitted to a cooling leg if the heater is not to become water-logged. It does, however, allow use to be made of some of the sensible heat in the condensate.

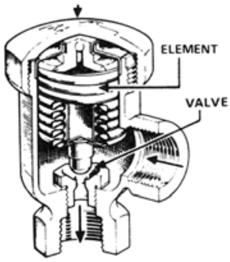

Figure 8.5 Thermostatic trap

INVERTED BUCKET TRAP

This type of trap is similar to the float trap but operates in the opposite sense. The 'float' is the inverted bucket, the valve is opened when the bucket falls and closes when it floats (figure 8.6). When the trap contains condensate the bucket does not float, hence the valve is open and condensate is allowed to discharge. When the condensate is hot enough, flash steam is formed in the trap. This fills the inverted bucket and causes it to float, thus closing the valve.

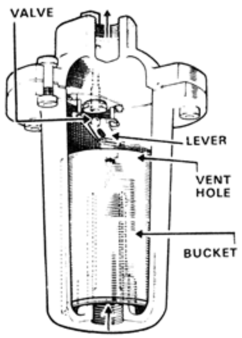

Figure 8.6 Inverted bucket trap

Condensate return

Provided that there is no contamination of the condensate, provision should be made to return as much as possible of the condensate to the boiler feed system. The condensate is virtually pure distilled water which is ideal for boiler feed. Maximising condensate return will reduce the need for make-up water and hence the considerable cost of feed water treatment. It will also contribute to energy savings. Because the solids content of the condensate is practically nil, boiler blowdown can be reduced in proportion to the condensate used. Although some of the sensible heat in the blowdown water can be recovered, reducing the amount of blowdown will usually result in a small but real increase in steam availability.

The largest energy savings, however, come from the direct use of the sensible heat in the condensate. For every 5 °C rise in temperature of the boiler feed water approximately 1 per cent less fuel will be used.

Most boilers are equipped with feed water tanks vented to the atmosphere. This will of course limit the temperature of the boiler feed to 100 °C. In some cases, condensate is available in large quantities at temperatures well above 100 °C. For such cases, equipment is available which allows the condensate to be returned directly to the boiler without entering the feed water tank.

Where there is a real risk of the condensate becoming contaminated, particularly with oil, the sensible heat should be extracted in a heat exchanger and the condensate rejected.

Heat transfer from steam

The utilisation of steam in a factory involves many different applications and a variety of processes, with steam acting either as a prime mover for turbines, pumps and compressors, or as a heating medium. The latter is by far the most common application, with steam usually being employed for indirect heating, that is, the steam does not come into direct contact with the material to be processed. For this reason it is important to understand the mechanism of heat transmission through the wall separating the steam from the material being heated.

Consider the cross-section through a typical metal heating surface as shown in figure 8.7. On the steam side of the wall, a water film is naturally formed as the steam gives out latent heat and condenses back to water. This water film is continually draining down towards a low point where a steam trap is fitted. But, for equal thickness, the water film is 60 to 70 times more resistant to heat transfer than the steel wall, and 500 to 600 times more resistant than copper. It is obviously critical to keep the thickness of this film to a minimum, by providing adequate drainage and by keeping the wetness of the steam coming from the boiler as low as possible.

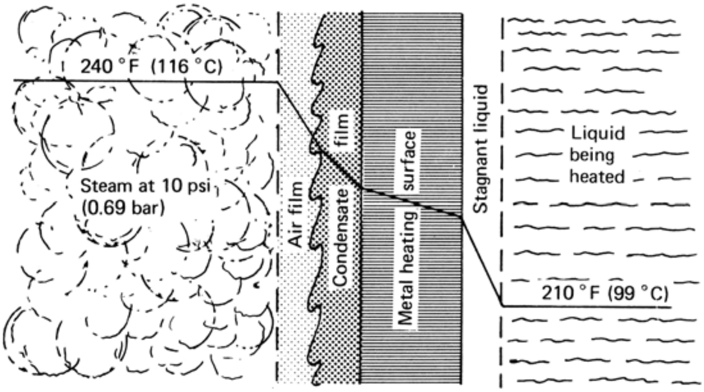

Figure 8.7 Heat transmission through metal wall

The insulating effect of the air film is even more drastic, since air is 1500 times more resistant to heat transfer than the steel wall. Air must therefore be removed as rapidly and completely as possible by providing air vents in the steam spaces of heating plant, paying particular attention to the position of the air vent in relation to the steam inlet and shape of the steam space.

Reducing demand

Steam users should always be on the look out for ways of saving steam. Process steam, because it is available 'on tap' is often used carelessly, in contrast to the considerable care that has been taken to generate it efficiently in the boiler house. There are two principal ways to cut down the demand for steam

- by preventing the escape of heat
- by reducing the work to be done by steam in each process application.

Some typical examples on how to avoid steam wastage will be given under both these categories.

Preventing the escape of heat

INSULATING PIPEWORK AND EXPOSED SURFACES

Thermal insulation is the most obvious deterrent for excessive heat losses and its installation on steam piping and process vessels is seldom neglected in today's energy-conscious climate. Nevertheless, there is usually scope to improve the effectiveness of insulation by examining whether the optimum thickness of insulating material has been applied, and whether all possible heat-losing surfaces have been insulated. For example, pipe flanges and awkwardly shaped bends are often left uninsulated for convenience, but represent significant heat loss surfaces.

For calculating the most economic thickness of insulation for an individual application, a number of factors need to be taken into account. Insulation cost must be balanced against cost of lost heat in arriving at the optimum insulation thickness which will give the most cost-effective operation. Technical data on heat losses and the properties of various commercially available insulating materials are available in many publications: for instance, reference 2 for pipe insulation and reference 3 for insulation of heated storage tanks.

ATTENDING TO STEAM LEAKS

Steam is produced in the boiler to perform a useful function. If it is allowed to leak to atmosphere, not only is the steam availability reduced but, more important, much energy can be wasted and the steam loss must be replaced by fresh feed water.

The most likely places for such leaks to occur is at valves and flanged pipe joints. A badly packed seal around a 20 mm diameter valve spindle could have a leakage area equivalent to a 2 mm hole. The 'oil equivalent' of the energy wasted can be estimated from figure 8.8. This shows that if the steam pressure at the valve is 5 bar, up to 6 tonnes of oil could be wastefully burned in a year.

Flanged pipe joints are the other common source of steam leaks particularly if the pipe is subject to temperature cycling. This sets up additional stress in the pipe, some of which is relaxed at the flange joint and causes the joint face to become worn. This can be minimised by ensuring that all pipe joints are properly insulated.

Sometimes the leaking steam may be contained within the pipework at, for example, a nominally closed stop valve. Although there may not be any water loss, the energy wastage can be the same as that for a leak to atmosphere. All valves should be therefore checked periodically for correct functioning and any that are found to be leaking repaired or replaced.

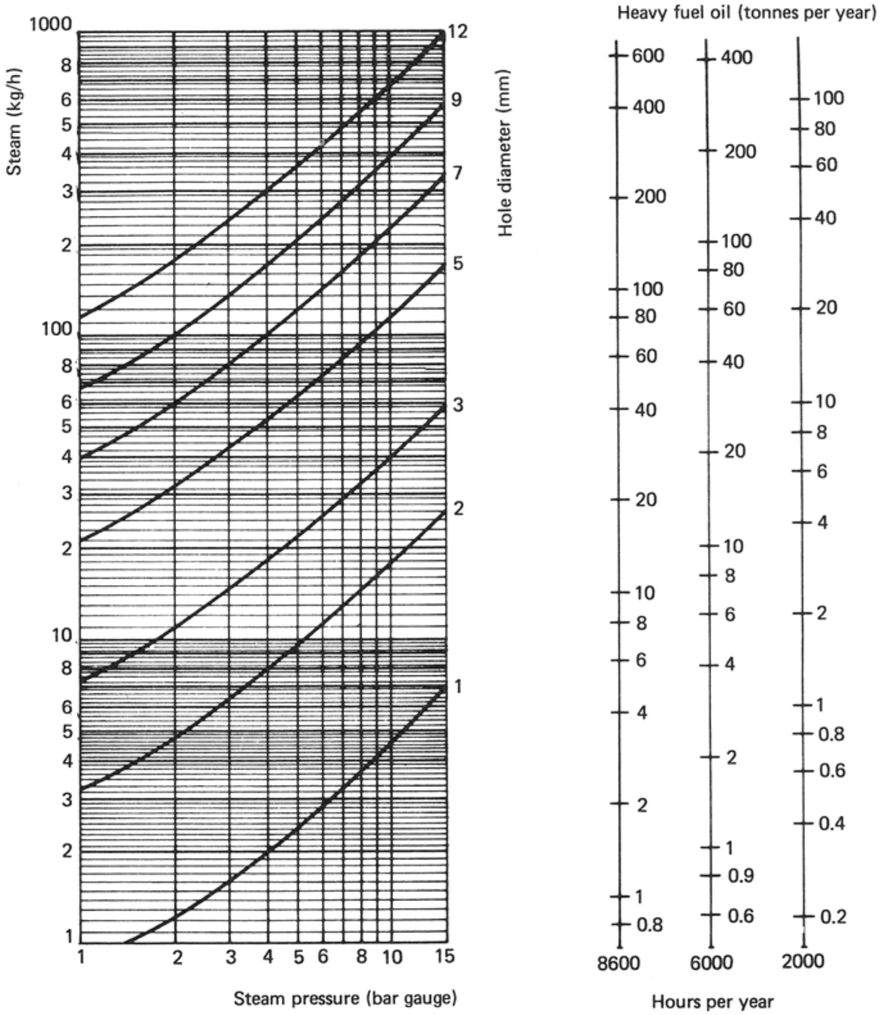

Figure 8.8 Oil wasted through steam leakage

ENSURING EFFICIENT OPERATION OF STEAM TRAPS

For efficient operation of the steam-heated equipment, a number of factors concerning steam traps must be considered. First, the correct type of steam trap must be chosen. There are several kinds of steam trap and although they perform the same basic function they operate in different ways. Expert advice should be taken in selecting the appropriate type and size of trap for a particular duty. If an incorrect choice is made there will be a good chance that the heater will either become waterlogged and lose performance, or will continuously blow steam and thus have a low thermal efficiency.

Second, the trap must be correctly installed. It must of course be the right way round (most types have an arrow on the body). It must also be in the proper location in relation to the equipment it controls. A thermostatic trap, for example, discharges condensate below steam temperature so a cooling leg is usually needed to prevent the steam space becoming waterlogged. It is nearly always bad practice to drain several pieces of equipment by a single trap. Individual trapping of each heat exchanger is needed for efficient operation.

Third, the trap must be properly maintained. In time the valve and valve seat will be eroded by abrasive particles carried in the condensate. Unless the trap is already fitted with a screen, it should be protected from pipe scale and rust by a strainer. The traps should be regularly checked for proper operation and faulty ones repaired or replaced.

Reducing process heat requirements

ELIMINATING UNNECESSARY STEAM WASTAGE

An energy audit, that is, an in-depth study of exactly where and how heat is used in a factory will usually pay handsome dividends. Instrument back-up is required to measure steam flow and system temperatures so that energy consumption can be evaluated against the actual energy requirements of each process. It may be possible to modify the processing sequence to ensure full loading, giving more efficient heat utilisation, and to rearrange the distribution system so that sections with intermittent steam requirements can be isolated. Redundant piping in a distribution system that has grown in an unplanned manner over the years should be removed.

MAINTAINING EFFECTIVE STEAM MANAGEMENT

An essential requirement for effective management of steam utilisation in a plant is to monitor steam flow by installing flow meters in the steam mains leading to each major user area. By keeping a record of steam supplied against time, periods of excessive consumption can be revealed; increased consumption due to fouled heat transfer surfaces can be plotted, and the influence of different operating practices between operators on different shifts shown. Correct interpretation of consumption data is of course essential. Once an increased consumption trend has been identified, measures to rectify it can usually be brought into effect.

LOWERING PROCESS TEMPERATURES

Overheating of liquids in tanks can be prevented by installing thermostatic temperature control equipment. Automatic temperature controls on space heaters and optimum start controllers on sufficiently large installations are also vital. Building heating is an area often suffering from excessive energy wastage due to over-ventilation from cold air blowing through open doors and windows. Bad heat or air distribution in a building is another common problem.

MAXIMISING HEAT TRANSFER EFFICIENCY

In the description of heat transfer through a metal surface it was shown how much the heat transmission is impaired by the presence of insulating air and water films. Both films must be removed as completely as possible for optimum heating efficiency, and good steam quality is imperative to achieve this.

Wet steam will deposit water on the metal wall, increasing the thickness of the insulating water film formed by condensing steam. A steam separator fitted in the supply pipe will cause any entrained water particles in the steam to be separated out and drained to a point where the condensate can be handled through a conventional steam trap.

Removal of air can be carried out by either manual or automatic air venting. Air vents with balanced pressure elements have the advantage of closing in the presence of steam, but allowing an unwanted air/steam mixture to be discharged.

References

1 *Practical Steam Trapping*, Spirax Sarco Ltd (1977)
2 Department of Energy, The economic thickness of insulation for hot pipes, *Fuel Efficiency Booklet No. 8* (1977)
3 *Fuel oil delivery, storage and handling*, Esso Petroleum Co. Ltd, London (1977)

9 Training Courses and Material

Books such as this can be useful background to action that will achieve fuel and cost savings. Practical guidance and experience in the techniques discussed are two essentials for success. Another essential is contact with suitably experienced people from whom one can obtain further information. This book would therefore be incomplete if it did not refer to training courses for managers, engineers and operators, and to supplementary training material.

There is now no shortage of training courses and material in energy conservation generally. The difficulty is to find what is relevant to one's own requirements, and what is acceptable and useful to those being trained.

This chapter does not pretend to be a complete list of courses and material available: no one has yet compiled such a list. What it does is to bring together information on a number of different types of course which are probably reasonably representative of others that are on offer. It is hoped that the list will be found useful as a starting point, as an indication of where further information may be found, and as a pointer to the types of organisation in the locality or concerned with the type of equipment where more help may be available to the reader.

In fact, though there is no problem in finding graduate and post-graduate courses for specialists and little problem in finding courses and material for energy managers, it is not so easy to find material suitable for boiler and process operators – and without their informed commitment energy saving will never fully succeed.

Operator training usually has to be on site, and the list that follows mentions the help that boiler and burner manufacturers can give in arranging *ad hoc* courses in the plant. Fuel suppliers can help with this too. But a good deal of operator training has necessarily to be arranged by the organisation itself, using such publications and audio-visual material as are available and relevant to the organisation's own requirements.

One excellent way to start with that is by getting in touch with the Department of Energy's Regional Energy Conservation Officers. They are familiar with local requirements and the availability of material from all over the country that meets the requirements. A list of some Department of Energy publications and Department of Energy and other audio-visual material follows, but it will rapidly become out of date, as also will all the sources quoted here. Application should be made to the Department's Regional Energy Conservation Officer for up-to-date information.

Although all the details on courses and costs given here will date rapidly, it is thought well worth giving them as a means of comparing the courses and material available now. The sequence of courses listed after the Department of Energy source materials section in this chapter is

Universities, polytechnics and colleges (Northern Energy Group list, Institute of Energy list, and some additions)
Burner and boiler-maker's courses
Other operator's courses
Other manager's courses

Department of Energy Publications

Fuel Efficiency Booklets (available without charge)

1 Energy audits
2 The sensible use of latent heat
3 Utilisation of steam for processing and heating
4 Compressed air and energy use
5 Steam costs and fuel savings
6 Flash steam and vapour recovery
7 Degree days
8 Economic thickness of insulation for hot pipes
9 How to make the best use of condensate
10 Controls and energy saving
11 Energy audits
12 Energy management and good lighting practices
13 The recovery of waste heat from industrial processes

The Department of Energy monthly periodical *Energy management* is distributed without charge to all with a professional interest in the subject. It can be obtained from

The Editor
Energy Management
Room 1395
Thames House South
Millbank
London SW1P 4QJ

A wide range of other publications on many aspects of energy conservation and of energy policy generally is available from or through the Department of Energy.

Department of Energy Films

Managing Energy (Three films: on oil and gas-fired burners, on burners for boilers and on heating and ventilating in factories.) Provided with speaker's notes and technical booklets. The first two are designed mainly for operators and foremen, and the third for project and works managers.
The SAVER Approach illustrates how a company can set about energy saving.
Audit! on how to understand more about the way energy and fuel are being used in your organisation.
Save It – Energy in Industry Case histories of how nine companies saved energy.

Other energy-saving films are now being produced or considered by the Department. All are available from Central Film Library, Government Building, Bromyard Avenue, Acton, London W3 7JB (01–743–5555).

Other audio-visual material

The Esso Boiler Efficiency and Safety Training (BEST) programme is designed for on-site use, for managers and for boiler and process operators. It consists of four modules: on the arithmetic of energy conservation; on efficiency and automatic boilers; on water treatment; and on maintenance. Each module contains a number of filmstrip/audio-tape programmes. The modules also contain back-up publications including notes for managers, operators' guides, course leaders' guides and wall charts. A booklet giving more detail of the programme is available without charge from Esso Petroleum Company Limited, Room W 8 22, Esso House, Victoria Street, London SW1E 5JW.

Universities, Polytechnics and Colleges

The range of energy-related courses at universities, polytechnics and other colleges is wide and growing. These notes do not attempt to cover fully the range of courses available: they only show a very few typical short courses at this level and at this time; the situation changes rapidly. You can obtain further information from your local university or college.

Generally, energy-related short courses at universities and polytechnics are restricted to or suitable only for people of graduate level. Some courses at polytechnics and colleges do not require graduate-level entry standards.

The Education Working Party of the Northern Energy Group prepared a most useful report on graduate and post-graduate courses (and some non-graduate courses) available, and this is reprinted with permission, on pp. 124–126. It was compiled in late 1978 and information on particular courses should therefore be checked with the institution concerned to ensure it remains valid.

Current training courses – Northern Energy Group List

NEWCASTLE UPON TYNE COLLEGE OF ARTS AND TECHNOLOGY

The college offers a course leading to the Institute of Fuel Diploma of Fuel Technology or to Tech Eng (CEI). The course is part time, requiring one afternoon and one evening per week and includes industrial visits. A course on fuel technology for chemical technicians started in September 1979. It formed part of the new unit type programmes and represents two units at Level III.

NEWCASTLE UPON TYNE POLYTECHNIC

A post-graduate Diploma Course in Fuel Technology, offered by the Department of Mechanical Engineering and Naval Architecture is normally available as an afternoon and evening course of one year duration. The course is an alternative to the CEI (Council of Engineering Institutions) Part II examinations. It is a specific qualification and gives exemption from the examination requirements for Corporate Membership of the Institute of Fuel.

TEESIDE POLYTECHNIC

A Diploma Course in Fuel Technology is offered by the Department of Metallurgy and Materials and normally runs for two evenings each week through the year. The Polytechnic Diploma is assessed by the Institute of Fuel and gives exemption from the examination requirement of the technician grade of the Institute of Tech Eng (CEI).

Candidates are accepted with HNC, HND in science or engineering, a Diploma in Environmental Engineering, or City and Guilds of London Institute qualifications in: Mechanical Engineering Technicians Certificate Part II; or Chemical Technicians Advanced Certificate; or Metallurgical Technicians Certificate (Final); or Heating, Ventilating and Air Conditioning Technicians Certificate Part II.

Examination papers comprise: Fuels and elementary stoichiometry, Fuel utilisation.

The Polytechnic also prepares candidates for the following CEI examinations: Fuel and Energy, Combustion and Propulsion.

SUNDERLAND POLYTECHNIC

BSc Energy Studies

OTHER POLYTECHNICS

Brighton	BSc Combined Studies, Chemistry with Fuel Technology
Middlesex	BSc Engineering (Fuel Technology Option)
Portsmouth	BSc Applied Chemistry (Fuel Technology Option) BSc Mechanical Engineering (Fuel Option) MSc Fuel Technology
Paisley College of Technology	BSc Applied Chemistry (Fuel Option)

see also p. 127

UNIVERSITY OF NEWCASTLE UPON TYNE

A post-graduate MSc Course in Energy Engineering offered by the Department of Chemical Engineering covers the principles and economics of new techniques, assessment of energy needs for particular processes and the factors governing the choice of the most appropriate methods of meeting these needs. A BSc Chemical Engineering (Fuel Option) course is also available.

OTHER UNIVERSITIES

First degree courses:

Aston	BSc Chemical Engineering (Fuel Option)
	BSc Energy Technology
Bath	BSc Power and Propulsion Engineering
Cambridge	BA Mineralogy and Petrology
Heriot-Watt	BSc Chemistry (Fuel Option)
	BSc Civil Engineering for Gas Engineers
Leeds	BSc Fuel and Combustion Science
	BSc Chemistry/Fuel and Combustion Science
	BSc Fuel and Energy Engineering
	BSc Fuel and Energy Management Studies
London	BSc Mechanical Engineering (Power)
London, King's College	BSc Chemical Engineering (Fuel Option)
London, Imperial College	BSc Mechanical Engineering (Fuel Option)
London, Queen Mary College	BSc Energy Engineering
Salford	BSc Natural Gas Engineering
	BSc Mechanical Engineering (Fluid and Thermal Option)
Sheffield	BSc Technical Fuel Technology
	BSc Technical Energy Studies
Strathclyde	BSc Chemical Engineering (Fuel Option)
	BSc Environmental Engineering (Fuel Option)
	BSc Applied Chemistry (Fuel Option)

Swansea	BSc Energy Studies
UMIST	BSc Chemistry (Fuel Technology and Furnace Design)

Higher degree courses:

Heriot-Watt	MEng Petroleum Engineering
Leeds	MSc Combustion and Energy
	Post-graduate Diploma Fuel and Combustion Science
	MSc Environmental Pollution Control
	Post-graduate Diploma Fuel and Energy Engineering
	MPhil, PhD Fuel Research
London	DIC/Thermal Power Engineering MSc
London, Imperial College	DIC/Advanced Chemical Engineering MSc
Loughborough	MSc Electroheat Industrial Process Heating
Queen's University, Belfast	MSc Fuel Technology and Power Engineering
Sheffield	MSc MEng Chemical Engineering and MS Tech PhD Fuel Technology
Cranfield Institute of Technology	MSc Energy Conservation and Environment

CONSULTANTS

Many consultants are prepared to offer specially tailored courses for energy conservation related to their normal consultancy expertise. No specific or regular courses have been identified, but it should be noted that some of the consultants on the Department of Energy list come from the Northern Region and several of these would be willing to give courses in energy related matters.

Institute of Energy List – Degree-level Courses in Fuel and Energy

Some courses on the original Institute of Energy list appeared in the Northern Energy Group list above; they have therefore not been repeated here.

A number of universities and polytechnics in the United Kingdom offer undergraduate or advanced courses in fuel and energy or contain a substantial fuel or energy content. The list is not necessarily complete and in some cases the provision of an optional course will depend on the student demand. It should also be noted that some meet with full approval from the Institute of Energy, others partial approval.

UNIVERSITIES

Bath	BSc Engineering, Thermal Power
Birmingham	MSc Reactor Physics and Technology
Heriot-Watt	BSc Offshore Engineering
	BSc Chemical Engineering (Fuel Option)
Leeds	BSc Chemical Engineering
	BSc Mechanical Engineering (Combustion Engineering Option)
London, Imperial College	BSc(Eng) Chemical Engineering (Energy, Combustion and Pollution, or Nuclear Technology Options)
	BSc(Eng) Mechanical Engineering (Energy Option)
	DIC/MSc Nuclear Reactor Science and Engineering
	BSc(Eng) Petroleum Engineering
	MSc(Eng) Petroleum Engineering
London, Queen Mary College	DIC/MSc Nuclear Reactor Science and Engineering (see Imperial College)
Newcastle upon Tyne	BSc Chemical Engineering
	MSc Advanced Chemical Engineering (Energy Engineering Option)
Sheffield	MSc(Tech) Combustion Science and Pollution Control
Surrey	MSc Energy Technology
Cranfield Institute of Technology	MSc Thermal Power
	MSc Applied Energy

POLYTECHNICS AND COLLEGES

Brighton	BSc Combined Studies in Applied Science (Fuel Technology Option)
Leicester	BSc Technology (Energy Utilisation Option)
Middlesex	BSc Mechanical Engineering (Fuel Engineering Option)
	Postgraduate Diploma in Fuel Technology
Newcastle upon Tyne	BSc Building Services Engineering
	Postgraduate Diploma in Fuel Technology
Portsmouth	BSc Applied Chemistry (Fuel Option)
	BSc Mechanical Engineering (Fuel Option)
	MSc Fuel Technology
Sunderland	BSc Energy Studies
Paisley College of Technology	BSc Industrial Chemistry (Fuel Option)

DIPLOMA IN ENERGY MANAGEMENT

Syllabus: technical features The Institute of Energy is introducing a diploma course for Energy Managers and it is hoped that colleges offering the existing Institute diploma course will be able to run the new diploma course in addition, alongside the existing diploma in fuel technology. The syllabus for the diploma in energy management includes a wide coverage of the basic technical material of which Energy Managers should ideally be aware. Properties of fuels, features of fuel-using plant and the basic principles of combustion and heat transfer are included. Essential instrumentation and fuel and flue gas analysis are vital ingredients for success in energy management.

Energy costs and methods of saving In addition to the requisite technical features, energy managers will be directly concerned with energy costs and methods of achieving savings in consumption or in total fuel costs by use of alternatives. The availability of government grants, etc., using case history studies are recommended inclusions in this section. Energy audit of plant, and the assessment of individual items of fuel usage in a works, are featured.

The energy manager's role and responsibility Finally, the energy manager's role and responsibility in energy policy decisions in the company will be covered. Other general matters such as long term energy prospects and alternative energy sources of which energy managers should be aware, will also be featured.

Course of study It is envisaged that the course of study for the diploma in energy management would entail in total 180 to 200 hours of study (a period corresponding to day release of, for example, one day per week or equivalent part-time evenings).

Firms wishing to sponsor their energy managers or other employees on these diploma courses, and other interested parties, should write to

The Education Officer
Institute of Energy
18 Devonshire Street
London W1N 2AU

Other University and College Courses

Name	**Cranfield Institute of Technology**
	Applied Energy Group, School of Mechanical Engineering
Address	Cranfield, Bedford, MK43 0AL
Telephone	0234 75011
Course	MSc course on Energy Conservation and the Environment
Purpose	To produce engineers with a full understanding of energy conservation and energy use, and of the energy implications of management decisions
Designed for	Graduates with honours degree in science or engineering

Duration	1 year (from October).
Location	As above
Fees	£837 at time of writing (31.5.79)
Digest of Syllabus	Overview of energy, heat transfer, energy release, combustion, furnaces and boilers, total energy systems
Further Information	Cranfield also hold short courses on energy subjects (see p. 130).

Name	**Portsmouth Polytechnic**		
Address	Anglesea Road, Portsmouth, PO1 3DJ		
Telephone	0705 27681		
Course	Courses additional to those listed in the Northern Energy Group list		
Purpose	*Energy Supervisors' Course*	*Principles of Fuel Utilisation*	*Current Practice in Fuel Efficiency*
	Comprehensive, practically orientated course designed for energy managers; includes 4 weeks industrial training	A conversion course for engineers who have no formal academic training in industrial fuel technology	One-day annual symposium examining specific aspects of boiler plant operation
Designed for	Minimum standard, HNC or equivalent	Practical engineers and newcomers to the subject	Managers interested in boiler plant
Length	20 weeks	1 evening/week for 9 weeks, plus 4 laboratory sessions	1 day
Contact	Dr M. R. I. Purvis, Senior Lecturer		
Location	As above		
Fees	Not available at time of writing	£30 in 1979	£30 in 1979
Digest of Syllabus	Not available at time of writing	Fuel properties, combustion, instrumentation, efficiency calculations, boiler design and maintenance, steam generation, energy audits	Different aspects of the subject each year

Name	**Cranfield Institute of Technology**, Applied Energy Group, School of Mechanical Engineering

Address	Cranfield, Bedford, MK43 0AL
Telephone	0234 75011
Course	Energy Conservation and the Environment
Purpose	Inform those having overall responsibility for energy management in an organisation on the background and current technology
Standard of Entry	Generally, science or engineering degree or equivalent level
Length	1 week
Contact	Dr A. M. Jones, Course Director
Location	As above
Fees	£120/£192 (includes residence) (1979)
Digest of Syllabus	Energy market uses, policies, fuel technology, combustions, thermal loss reduction, environmental effect, advanced energy technology (nuclear, etc.)

Name	**Cranfield Institute of Technology**, Applied Energy Group, School of Mechanical Engineering
Address	Cranfield, Bedford, MK43 0AL
Telephone	0234 75011
Course	Energy Management
Purpose	Enable energy managers better to monitor, control and redirect energy flows in a system so that they reach maximum efficiency
Standard of Entry	Practising engineers or energy managers
Length	3 days
Contact	Dr P. W. O'Callaghan, Course Director
Location	As above
Fees	£149 (1979)
Digest of Syllabus	Scope of energy management, location of priority conservation areas, simulation modelling, energy audits, thermal structures, processes, furnace design, materials, specialised techniques

Boiler and burner-makers

Instruction at clients' plants

The following boiler and burner manufacturers provide on-site instruction for the use of their equipment.

Allen Ygnis (Tipton) Ltd
P.O. Box 4
Princes End
Tipton
West Midlands, DY4 9EX
Telephone: 021 557 3977

George Clark & NEM Ltd
Ferry Road,
Hartlepool TS24 0RX.
Telephone: 0429 66678

Boiler-makers

Name	**Parkinson Cowan GWB Ltd**
Address	P.O. Box 4, Burton Works, Dudley, West Midlands DY3 2AD
Telephone	0384 55455
Course	Boiler Operation and Maintenance
Purpose	Familiarisation
Designed for	Boiler operators of Parkinson Cowan GWB customers
Length	Normally 3 days but longer courses can be arranged
Contact	G.B. Spittle, Quality Control Manager
Location	As above
Fees	Nominal fee of £10/day
Digest of Syllabus	Courses arranged, usually four times a year, for package boilers using oil, gas, coal and other fuels
Further Information	The company manufactures a range of industrial package boilers and offers all new customers familiarisation courses applicable to the particular boilers being used. Courses are arranged for existing customers, particularly when changes of boiler operator are made

Name	**NEI Thompson Cochran Ltd**
Address	Newbie Works, Annan, Dumfriesshire, DG12 5QU
Telephone	046 12 2111
Course	Boiler Maintenance
Purpose	Instruct electricians, fitters and boiler operators in the safe operation, monitoring and correct maintenance of Thompson Cochran boilers. Separate courses biased to rotary cup, pressure-jet or fluid atomising burners
Designed for	Operators, fitters, electricians
Length	3 days
Contact	W. J. Graham, Product Training Instructor, The Training Centre
Location	As above
Fees	Details given on course brochure, available on application
Digest of Syllabus	Boiler and burner design, operation and maintenance. Electrical circuits, controls and fault-finding
Further Information	On-site training can be provided if required, subject to quotation

Boiler operator courses

Name	City & Guilds of London Institute
Address	76 Portland Place, London W1N 4AA
Telephone	01 580 3050

Course	Boiler Operator's Certificate
Purpose	Provide and prove through examination an understanding of the safe and efficient operation of boilers. The course is designed to complement training and experience obtained in employment
Designed for	Boiler operators
Length	90 study hours
Contact	City & Guilds of London Institute, as above
Location	Local technical college
Fees	Arranged locally
Digest of Syllabus	Section 1: Large water tube boilers Section 2: Industrial boilers Section 3: 'Automatic' boilers Section 4: Small heating boilers

Name	**Department of the Environment and Department of Transport**
Address	Training and Conference Centre, RAF Station, Cardington, Bedford, MK42 0TF
Telephone	0234 58651
Course	*Boiler House and Heating (4 Weeks)*

For craftsmen or technical boiler operators who work on automatic and semi-automatic boilers and associated heating systems.

Course Content

Basic combustion theory. Basic electrical theory. Type of boilers, oil and gas burners; sequence of operation, methods of control and fault diagnosis. Operation and use of instruments in the boiler house. Basic knowledge of water treatment, its application to boilers and systems. Basic knowledge of heating systems and controls applied to these systems. Practical operation of boilers, burners, system controls and fault-finding exercises on same. Practical use of instruments and interpretation of results. Practical water treatment tests and interpretation of results.

Heating Systems and Controls (2 Weeks)

This course is intended for the technician/craftsman up to senior engineer involved in the efficient and economical operation and maintenance of heating installations.

Course Content

Basic theory of controls. Types of heating system and controls used with these systems. Water and air balancing. Practical operation and maintenance of controls and fault-finding exercises. Practical exercises on balancing water and air systems.

Water Treatment (1 Week)
For those involved in water treatment from the operator who actually carries out sample testing and dosing tasks to senior maintenance engineers with the responsibility for ensuring effective water treatment over a wide range of equipment.
Course Content
Water contamination and its effects. Methods of treatment, external and internal. The practical application of sampling, testing diagnosis and treatment of boilers, heating and cooling systems.
Boiler House Practice (2 Weeks)
For foremen to senior engineers responsible for the operation and maintenance of boiler house and heating installations.
Course Content
Combustion, heat transmission, types of boiler, instrumentation, fuel, oil burners and controls, gas burners and controls, boiler performance, feed water treatment, practical demonstrations and exercises.

Contact	V. Cameiro, Senior Mechanical Engineering Lecturer
Location	As above
Further Information	These courses are designed primarily for PSA staff. However, other Government departments as well as outside industry do make use of the facilities.

Consultants

Name	**National Industrial Fuel Efficiency Service Ltd (NIFES)**
Address	26 Calthorpe Road, Edgbaston, Birmingham, B15 1RP
Telephone	021 454 4471
Course (1)	Courses for Boiler Operators
Purpose	Broad instruction on boiler operation, with accent on safety and economy. Mainly for boilers of 1.5 to 14 MW (5000 to 45 000 lb steam/h) but also suitable for some larger water tube and some smaller boilers
Designed for	Boiler operators
Duration	3 days
Contact	Mr J. Mason
Location	All areas: apply to NIFES for details
Fees	£100 approximately depending on numbers (1979)
Digest of Syllabus	Fuel and steam properties, combustion, economy, water treatment, firing, boilers, safety, instruments and controls, records

Further Information	Practical instruction individually designed and arranged at user's premises. NIFES also run other courses
Course (2)	Energy Management and Control
Purpose	To show how efficient energy control can be managed
Designed for	Middle levels of works, plant and energy managers
Duration	3 days
Contact	Mr J. Mason

Managers' courses

Name	**British Gas School of Fuel Management**		
Address	Wharf Lane, Solihull, West Midlands, B91 2JW		
Telephone	021 705 7581		
Course	A wide range of 4½-day courses, including		
	Basic heating plant controls	and	*Combustion engineering (industrial)*
Designed for	Engineers who control heating plant installation and use		Fuel engineers and managers
Length	4½ days		4½ days
Location	As above		
Fees	Not stated		
Digest of Syllabus	Fuel and air controls, safeguards, plant controls including design requirements		
Further Information	Although the courses are primarily concerned with gas technology, other fuels, particularly oil, are included		

Name	**Department of Energy**
Address	Room 1685, Thames House South, Millbank, London SW1 4QJ
Telephone	01 211 3000
Course	Energy Managers' Course
Purpose	To train energy managers in the concepts needed to implement an effective cost-related energy management programme within their own organisation
Designed for	Practising energy managers
Length	5 days
Course director	Mr Don Gotch, MBE

Location (1979/80)	St John's Hotel, Solihull, West Midlands
Fees (1979/80)	£250 + VAT
Digest of Syllabus	Government support, finance, energy audits, technical advisory services, insulation, factory services, transportation, motivation

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