The Stoker's
Manual

50 Denny Avenue
Waltham Abbey
Essex
EN9. 1NT

The Curator,
Royal Gunpowder Mills,
Waltham Abbey.

Dear Sir,

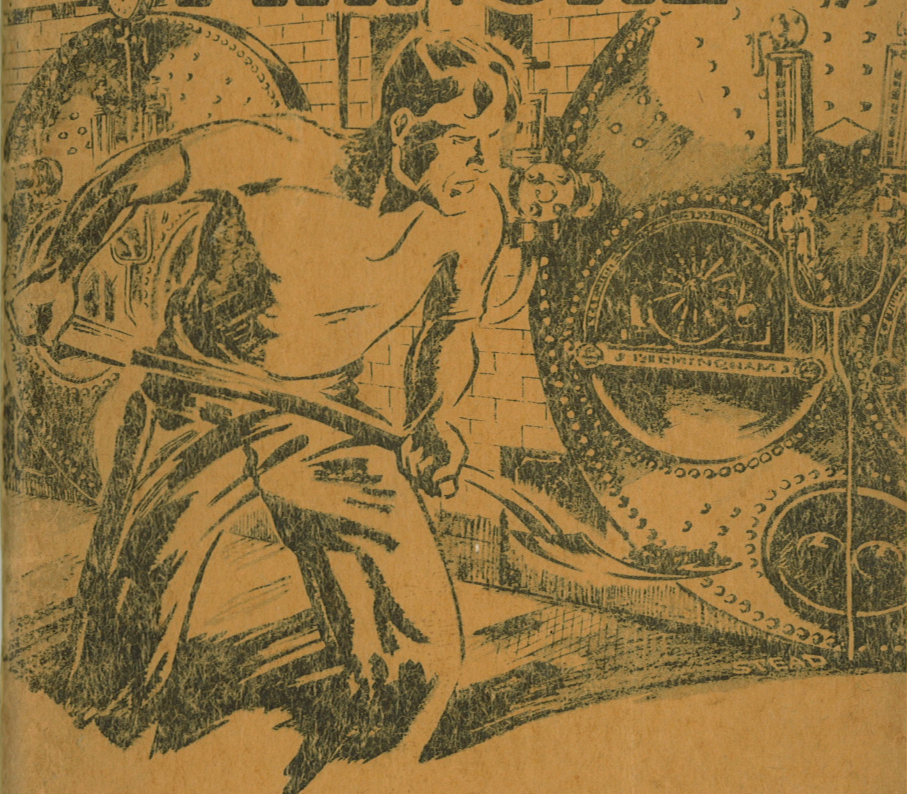
I would like to donate the enclosed artefact 'THE STOKER'S MANUAL' to be displayed or for reference.

One day, you may be able to re-build one of the missing Lancashire boilers, should one become available.

I feel this booklet may be of interest!

Sincerely
Graham J Bird
G. J. BIRD.

THE STOKER'S MANUAL



LONDON: HIS MAJESTY'S STATIONERY OFFICE

1945

SIXPENCE NET.

Continued on page 3 of cover.

MINISTRY OF FUEL AND POWER

THE STOKER'S MANUAL

LONDON: HIS MAJESTY'S STATIONERY OFFICE

1945

(Reprinted 1950)

THE STOKER'S MANUAL

To the Boiler Stoker :—

This book has been written specially for you.

It contains information that will help you to operate boiler plant in the best possible way. By so doing not only will the fuel be used to its best advantage but your work will be made easier, as the weight of fuel to be handled is reduced when better use is made of the coal. A lot of coal and work can be saved by knowing how. This book will give you the necessary information.

" Stoking " means a great deal more than just putting coal on the fire, as you will find when you have read this book. With first-rate stoking it is quite common to save between 10 and 20% of the fuel burnt without producing any less steam. If the boiler plant has been neglected it must also be put in order, as explained here, and this, in conjunction with good firing practice, may well enable savings amounting to 50% and over to be made. Saving fuel is work of the very highest value.

It is also hoped that this manual will increase your interest in your work and encourage you to take advantage of every opportunity of adding to your knowledge. For that reason this booklet tries to tell you not only " how " to do things, but " why " they should be done.

If you should find any section of this book difficult to understand, the Ministry's Regional Office will try to help you by introducing you to suitable classes or by other means.

The book is divided into five parts :—

 This Part may be called " theoretical " but do not let that prevent you from reading it. The modern boiler fireman likes to know " why " he does something as well as " how " to do it.

SUMMARY OF CONTENTS

PART 1.

STOKING APPLIED TO LANCASHIRE, CORNISH, ECONOMIC AND VERTICAL BOILERS.

HAND FIRING WITH COAL

METHODS OF FIRING. (1) Spreading or Sprinkling method. (2) Side Firing or Wing Firing method. (3) Coking method.

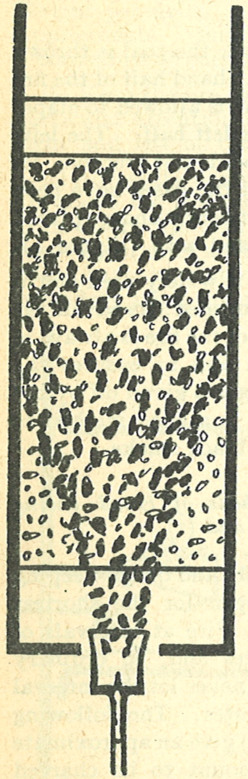


FIGURE 1. SPREADING OR SPRINKLING METHOD OF HAND FIRING.
Don't forget the corners!

(1) *Spreading or Sprinkling Method.*

This method consists in throwing an even layer of coal practically over the whole fire at each firing charge (Fig. 1). slightly less coal is placed on the back of the fire than on the front so as to prevent the production of smoke by cooling of the whole of the surface of the fire by the fresh coal. No portion of the grate should ever be bare and it is necessary to use the rake occasionally to level the fire because of the smaller amount of fuel at the rear of the grate.

With care this method is often found to produce more steam than any other and also tends to give a higher CO_2, but an unskilled fireman using it will produce more smoke. (See part 5 for explanation of "CO_2").

A good fireman is completely master of the art of using his shovel and can place the coal exactly where he wishes on the grate. Strength is not the only requisite. The shovel should be used with a peculiar motion that only comes with practice. When the shovel is almost at the end of its throw, the extreme end of the handle should be smartly tilted downward, so as to "spray" the coal over a wide area. If the shovel is simply jerked away from below then the coal falls in a heap and a fire of uneven thickness results which is bad. Firing unevenly makes it necessary to use the rake far too often to level the fires and whilst the rake is being used large volumes of air are entering, and cooling the furnaces.

The spi inkling method is also used for firing smokeless fuels such as coke and anthracite.

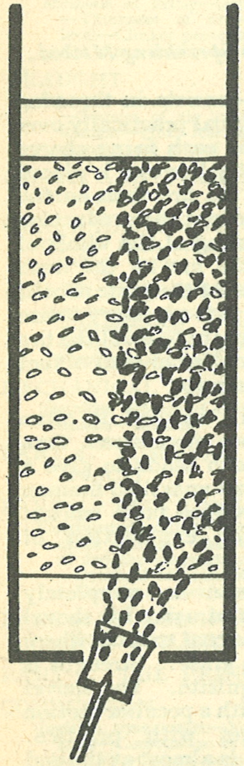


FIGURE 2. SIDE FIRING. OR WING FIRING METHOD.

(2) *Side Firing or Wing Firing Method.*

In this method, the coal is thrown first on the right-hand half of the fire and a short time is allowed to elapse before fii ing the left half. The left-hand side should not receive its charge until all the gases have been driven off from the first charge placed on the right-hand side (Figure 2).

This method is widely used and is strongly recommended. Its advantage is that one half of the fire is always in good condition and so ensures the burning of the gases given off by the other half. It is a good method to adopt to avoid black smoke.

Rules for Methods of Hand Firing described in (1) *and* (2).

(*a*) Fire lightly and often, keeping the fire-door open for the shortest time possible. Fire at intervals of about 5 minutes and, in ordinary circumstances, never let the interval exceed 10 minutes. The following figui es (Table 1) give an approximate idea of the amount to be charged according to the size of grate and load. The average weight of a shovelful of coal may be taken as about 11 pounds.

TABLE 1.

Grate 6 feet long × 3 feet wide = 18 square feet.

Burning rate per square foot per hour	35 lb.	25 lb.	15 lb.
Total coal required per hour	630 lb.	450 lb.	270 lb.
Number of firings per hour at 10 minute intervals ..	6	6	6
Weight per firing	105 lb.	75 lb.	45 lb.
Approximate number of shovelfuls at each firing ..	10	7	4

(*b*) Keep the fire bars completely covered with fuel, paying particular attention to the back of the grate and the corners right and left of the fire doors.

(*c*) Adjust the dampers according to the load and admit extra air above the fire (known as secondary air) through the air-grids in the fire doors as required. More of the extia air is needed just after a fresh charge of coal than when the volatile gases have burned off. (The explanation of primary and secondary air is given in part 5.)

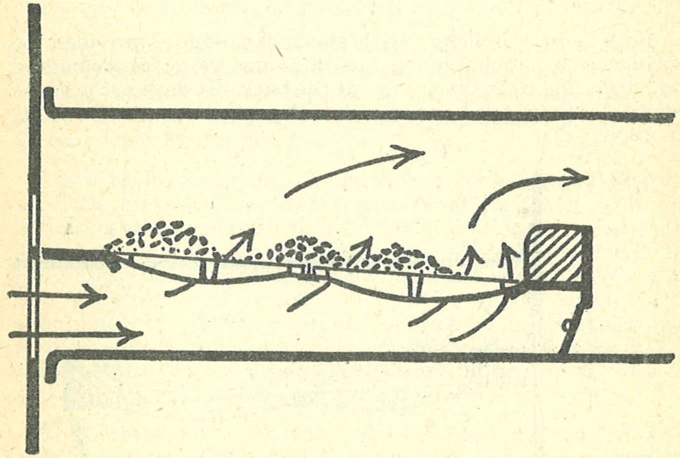
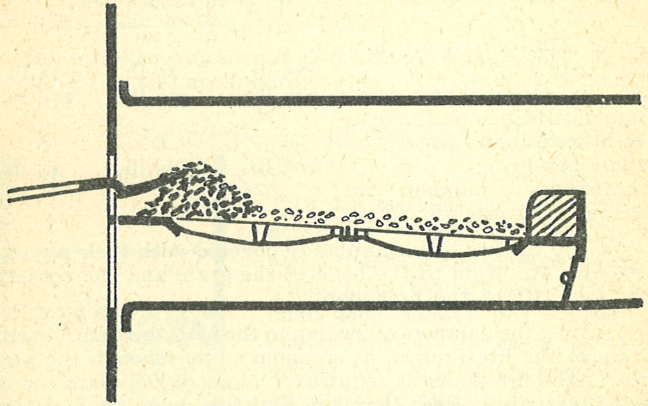


FIGURE 3. UNEVEN FIRES SUCH AS THE ABOVE WASTE FUEL.

(3) *Coking Method of Hand Firing.*

This method consists in placing the fresh coal on to the front part of the grate to a depth of about 10″ (see Figure 4), and after allowing time for the gases to be driven off, pushing it evenly over the rest of the grate with the rake (see Figure 4A).



COKING METHOD OF HAND FIRING.
FIGURE 4. COAL PILE AT FRONT OF GRATE.

With this method very little smoke is produced provided too much coal is not charged at one time since the gases are burned when passing over the hot fire at the back. It does not produce as much steam per hour as either the spreading or side-firing methods.

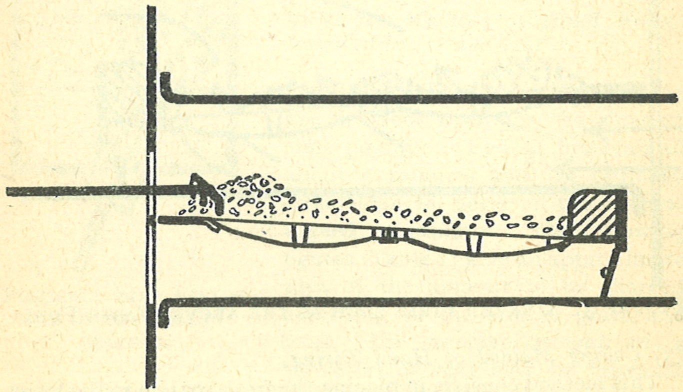


FIGURE 4A. SPREADING WITH RAKE AFTER COKING.

As the back of the grate cannot be seen after firing it is essential to make sure that there are no bare patches before firing a fresh charge.

This method is useful when the fireman has other duties besides that of stoking, since more coal can be put on at one time and the intervals between firings are longer.

GENERAL NOTE ON FIRING METHODS.

In selecting a method of firing, the nature of the fuel should be studied and that method selected which is best suited to the type of fuel to be used.

A good stoker should be versatile in his methods. He should study each boiler and variety of fuel like a doctor studies his patients, so that he can adapt his methods to circumstances.

FIRING TOOLS

It is most important that suitable tools should be provided. They should be made as light as possible consistent with strength. There are many different types and designs of firing tools but those shown on page 10 have proved satisfactory.

They comprise a shovel not larger than size 6, a poker or pointed bar, a rake for levelling the fire, a hoe for removing clinker, a slice bar for separating ash and clinker from the grate, and a pricker bar for cleaning the spaces between the firebars from underneath.

These tools (excepting, of course, the shovel) should be used as little as possible. Every care must be taken to avoid knocking the fire about and mixing ash with the burning coal. Frequent use of the rake tends to increase the danger of volatile gases escaping unburnt and producing black smoke. When its use is necessary it is passed lightly over the surface. It should never be driven down on the fire bars and pushed along as this tends to rub the soft clinker between the bars, causing them to burn; it also mixes the ashes with the coal, and makes cleaning longer, harder and more wasteful.

The extent to which the poker is used depends on the characteristics of the fuel. Anthracite, coke, free-burning coals and all non-caking coals, such as Welsh steam coal, are all the better for very little handling. A strongly-caking coal, on the other hand, requires fairly frequent handling to break up any masses of coke which may begin to form. Large masses of coke take a long time to burn.

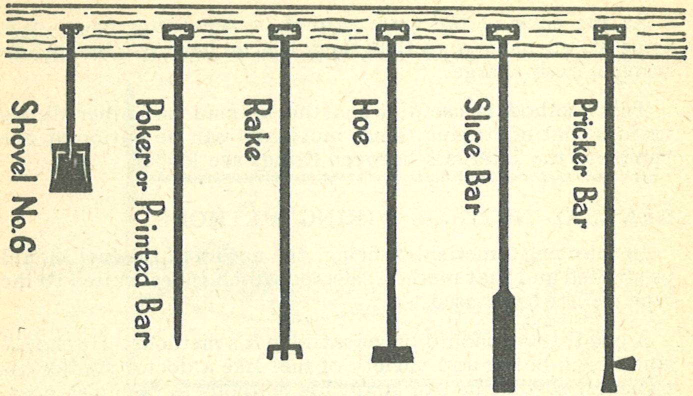


FIGURE 5A. APPROVED SET OF FIRING TOOLS.

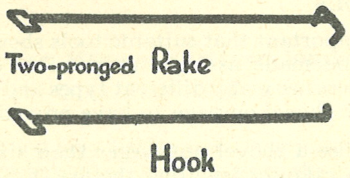


FIGURE 5B. OTHER TOOLS IN COMMON USE.

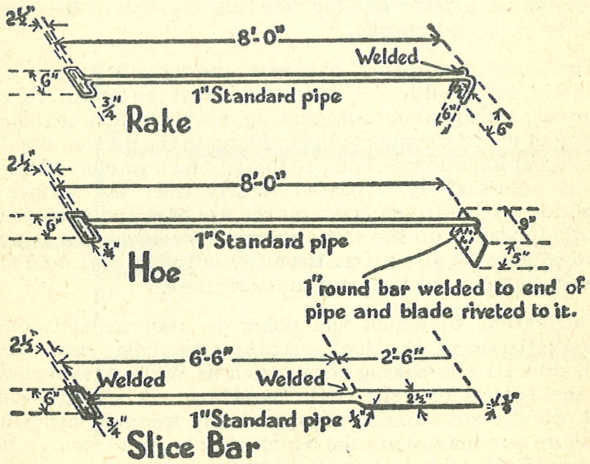


FIGURE 5C. FIRING TOOLS WITH SHAFTS OF PIPING TO DECREASE WEIGHT.

THICKNESS OF FIREBED.

The thickness of the fire necessary to produce good results will vary according to the rate of steaming and to the size and ash content, and possibly the caking properties, of the coal.

With hand firing the thickness of the firebed cannot be kept constant because the fire will be thickest immediately after firing and thinnest just before firing. It is, therefore, necessary to consider the average thickness.

For each coal there is probably a most suitable thickness of firebed, which must be determined by experience. When the load fluctuates considerably and there may be sudden demands for more steam, it is advisable to carry slightly thicker firebeds, in order to have a greater reserve of hot coal on the grate. The thickness of the firebed must be measured from time to time as shown in figure 6.

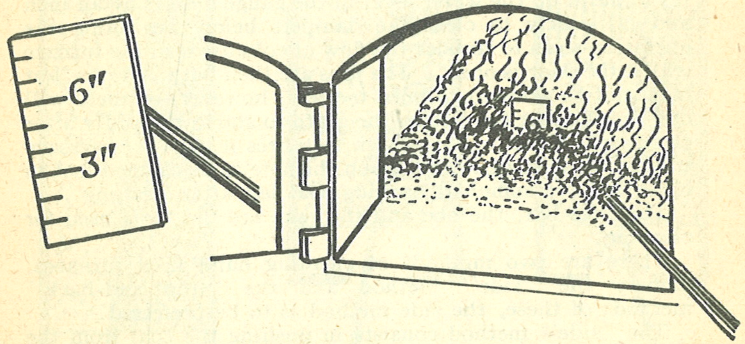


FIGURE 6. MEASURING THICKNESS OF FIRE BED. CHALK AN INCH SCALE ON THE HOE AND DIG IT INTO THE FIRE.

When hand firing it is difficult to get good results from a fire with an average thickness of 3″ or less owing to the ease with which air can pass through it, and the greater liability to form air holes. The greater the draught that is used, the more likely is too much air to pass through a thin fuel bed. Mean thicknesses of 4″ to 6″ have proved satisfactory.

The thinner bed should be used with small coals such as ½″ slack or pearls; the bed should be thicker with 1½″ slacks or singles or nuts. It will also be found necessary to carry somewhat thicker beds when the ash content is high, say about 15 per cent.

With a thin fire bed little difference in performance will be found between the free-burning coals and the caking coals. Thick beds will emphasize caking properties and cause formation of crusts.

For coke, the firebed thickness should be 8″ to 10″ for larger sizes and 6″ to 8″ for breeze.

HEIGHT OF FURNACE GRATE ABOVE FLOOR LEVEL.

This is important when furnaces are hand-fired. The grate should be of such a height from the floor that a man of average height can comfortably see the whole surface. It is generally impossible to alter the position of the grate, but it is sometimes possible to raise the firing floor and it is worth while doing so if it will give a better view of the furnaces.

CLEANING FIRES

Cleaning takes several minutes, therefore the first steps are (1) to build up the water level in the gauge glasses by an inch and (2) partly to close the dampers before beginning the operation so as to restrict the flow of cold air into the furnace whilst the door is open. The fires are then burned down, but must not be allowed to burn too low, however, or there will not be sufficient fire left on the grate to start up rapidly after cleaning. When working with thin fires it may be necessary to start by putting fresh coal on the side to be cleaned last in order to have sufficient burning coal left after cleaning.

The slice bar, the hoe and the rake are the tools used for cleaning.

There are two methods of cleaning hand fired furnaces, namely the "side" method and the "front-and-back" method; of these, the side method is to be preferred.

The "side" method consists in pushing the coal from the left-hand side of the furnace away from the ash and clinker lying underneath it onto the right-hand side. The ash and clinker are then scraped out with the hoe after loosening, if necessary, with the slice bar. The burning coal from the right-hand side is then pushed on to the clean portion of the grate and a few small shovelfuls of fresh coal may be added if thought necessary. The clinker and ash are then removed from the right-hand side of the grate. Finally, the fire is spread evenly over the whole grate and built up gradually with fresh coal (Figure 7).

In the "front-and-back" method the burning coal is pushed with the rake or hoe against the bridge wall. The clinker is loosened with the slice bar and pulled out of the furnace with the rake, and the burning coal spread evenly over the bare grate. This method is quicker than the "side" method but

not so thorough since some clinker and ash is always left at the back of the fire and may put an appreciable portion of the grate out of action as well as sticking tightly to the bridge wall and becoming difficult to remove.

The "front-and-back" method may have to be used, as being the quicker of the two, if it is necessary to clean a fire

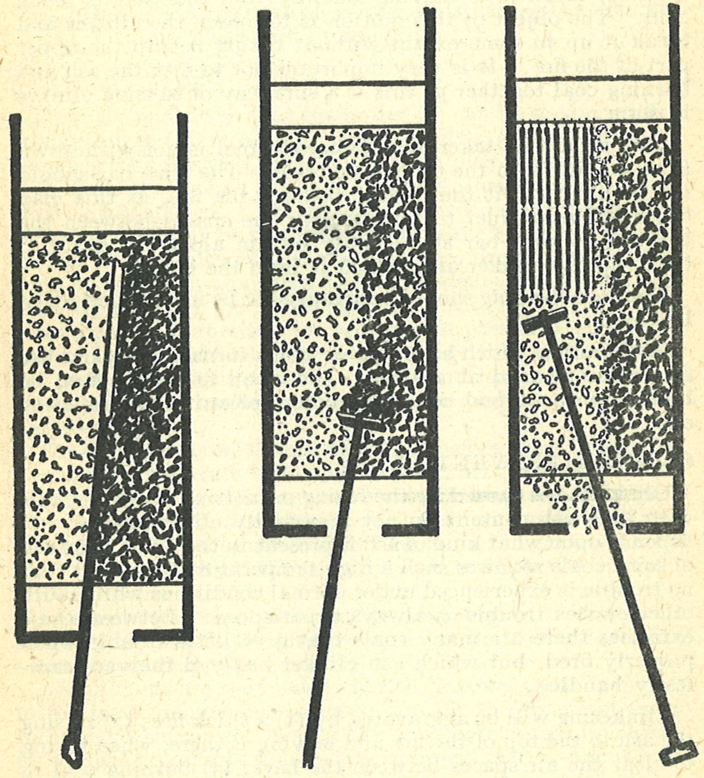


FIGURE 7. SIDE METHOD OF CLEANING OUT.

(A) AND (B) PUSHING LIVE COAL OVER FROM LEFT-HAND SIDE TO RIGHT.

(C) REMOVING CLINKER AND ASH AFTER LOOSENING, IF NECESSARY, WITH SLICE BAR.

during a period when a lot of steam is wanted. If so, the "side" method should be used after the day's run to remove the ash and clinker which has accumulated near the bridge.

If the fire becomes heavy with ash, when it is not a convenient time to clean out, and air is not passing freely through the fire, the slice bar should be run under the fuel and twisted slightly, meanwhile moving sideways the end that is being held. The object of this motion is to loosen the clinker and break it up to some extent without lifting it into the upper part of the fire. It is very important not to mix the ash and burning coal together as this is a sure way of causing clinker to form.

Care should be taken that unburned fuel is not withdrawn from the fire with the clinker and ash. The slice bar should not be used to lift the clinker through the fire, as this may cause unburned fuel to fall through the spaces between the bars. The slice bar should only be run along the grate to break up the clinker and detach it from the bars.

Times of cleaning should be arranged to fit in with periods of low load.

With boilers which have two or more furnaces only one fire should be cleaned at a time. The clean fire must then be brought into a good condition before cleaning out the dirty one.

CLINKER PREVENTION.

Clinkering is caused by the fusing or melting of ash. Coals with high ash content do not necessarily clinker badly. It depends upon what kind of ash is present in the fuel. The ash of some coals requires such a high temperature to melt it that no trouble is experienced under normal conditions whilst with other classes trouble is always experienced. Between these extremes there are many coals that give little trouble when properly fired, but which can clinker badly if they are carelessly handled.

Clinkering will be aggravated by (1) a thick fire; (2) raising the ash to the top of the fire and leaving it there, when trying to clear the air spaces between the bars; (3) burning coal in the ashpit; and (4) excessive preheating of the air supply to the furnaces.

Sometimes a wisp of steam is used under the grates for this purpose. This practice is not recommended unless all other methods have been tried unsuccessfully. It is fatally easy to use quite a lot of the steam made in the boiler unnecessarily in this way. Water sprays are being used successfully instead of steam.

The precautions to take are:—

- Keep the fires as thin as is practicable.
- Use tools no more frequently than the type of coal demands.
- Do not mix the ash with the burning fuel.
- Keep the fire level by careful firing.
- Run as long as possible without disturbing the fires and then clean out thoroughly.

BANKING FIRES.

Fires are banked so that the boiler (1) can be re-started and brought up to full steaming quickly, and/or (2) to give a continuous, though small, supply of steam over a period.

In banking, the fuel left on the grate is allowed to burn away very slowly indeed. The amount burned during the banked period should only be just sufficient to make up for the natural cooling that would occur if the fires were drawn, and to produce, in addition, any small amount of steam that is required.

To do this, all the small amount of air, regulated by the main damper, that enters the boiler must pass through the hot part of the firebed. Any air which does not pass through the hot part of the firebed comes in cold and leaves hot and unburnt. Its heat has been stolen from the boiler and is a direct waste of coal.

The bulk of the fuel should be red hot before starting to bank. The back of the grate is then cleared and all the good, live fire is pushed on to the back against the brick bridge. This fire is then built up with fresh fuel, any clinker on the remainder of the grate being loosened, but left lying on the grate with the ash to help to prevent the passage of air through the front and middle of the grate.

In a self-cleaning stoker, the fire would be pushed near the back, on the least active portion of the grate, the self-cleaning action being stopped.

All dampers are then nearly closed, leaving them open only to the least amount necessary to prevent the escape of fumes into the boiler house. Secondary air openings are also closed. It is usually possible to close the dampers further about half-an-hour later

The water in the boiler should be left 3 in. or 4 in. higher than the working level. These figures are given as a guide only. The safe water level must be found by experience for each boiler. Care must be taken that the boiler feed valve, blow-down cock and water gauge drain cock are tightly closed, as otherwise the boiler may be empty and damage result. The main steam valve should be closed if no steam is required.

When re-starting after the fires have been banked or after the dampers have been closed for any length of time, great care should be taken before opening the firedoor or breaking the fire *to raise the chimney damper and open the regulators on the fire-doors*. This is very important as it allows the unburnt gases, which may have accumulated, to be swept out of the boiler and thus avoids the risk of explosion and back firing which at least are a danger to the fireman.

The clinker is then cleaned out and the live fuel drawn forward from the back. Finally, the fire is gradually built up to the required thickness by firing lightly and often.

When no steam is required during the "banked" period, some managements prefer to allow the fires to burn themselves out instead of banking. This practice, which is claimed to be more economical of fuel than banking, depends for its success upon the dampers being in such good order that when they are closed, no air is drawn through the boiler flues.

HAND FIRING WITH SLURRY AND OTHER SIMILAR FUELS.

These fuels include belt pickings, middlings, duff, fines and slurry and generally have a lower heating value than any of the fuels mentioned in Table 11 (page 83) Their behaviour varies very much in different types of grates and furnaces, but generally the best results will be obtained with furnaces of the forced draught type.

With duffs, fines and slurries the firebed must when necessary be lifted and not raked in order to keep the fuel bed open and to prevent the fires dying down. With inferior slurries the firebed should be of good depth say 10″-12″ to give the necessary "body" of heat to ignite the freshly-fired fuel.

OUTCROP OR OPEN-CAST COALS.

Considerable quantities of outcrop coals are now being used in all parts of the country. They vary considerably in type and quality, and consequently no hard and fast rules can be laid down for their treatment. Outcrop coals are frequently equal in quality to the coal obtained from the pits.

DRAUGHT.

If at some place in a volume of gas the pressure is higher than at another place, gas will flow from the place where its pressure is higher to the place where it is lower till the pressure becomes equalised; that, for example, is the cause of winds blowing

over the surface of the earth. The differences in pressure which cause air to flow through a firebed and the flue gases to flow through the flues and passages in a boiler setting are called "Draught".

To maintain this flow, differences of pressure must be set up and maintained. Three methods are used for doing this:—

(1) Natural draught created by a chimney. The hot gases in the chimney tend to rise and thus create a low pressure at the chimney base. This pressure is lower than that of the air, and air flows in to the place where the pressure is low. In a properly maintained boiler the only places through which air can enter are through the proper openings below and above the fire bed as explained elsewhere in this Manual.

(2) Induced draught created by a fan placed between the boiler and the chimney. The action of the fan sets up a low pressure at the inlet side, into which gases flow as just described.

(3) Forced draught, in which a higher pressure is created below the firebed by a fan or steam jet. A chimney or an induced draught fan is used to reduce the pressure in the remainder of the boiler flue system.

In any of these systems the amount of draught used must be sufficient to overcome the resistances to flow that are encountered in the various parts of the system. These resistances are:—

(1) The resistance of the firebed,

(2) The resistance of the flues, particularly wherever the gases change their direction by turning corners, etc., and

(3) The resistance of economisers, air-heaters or other plant through which the gases may flow.

The amount of natural draught depends upon the height of the chimney and the temperature of the gases flowing up it. For the same temperature of the gases it will be greater on a cold day than on a hot day.

A greater draught can be obtained by using an induced draught fan than with natural chimney draught. This fan draws the gases through the plant and discharges them through a short chimney (Fig. 8).

A fan which blows air into the grate is called a forced draught fan. The air should be taken from the hottest part of the boiler house in order to recover the heat. Forced draught gives better control especially when the air box under the grate is so divided that the air can be directed separately to different parts of the grate. (Fig 9).

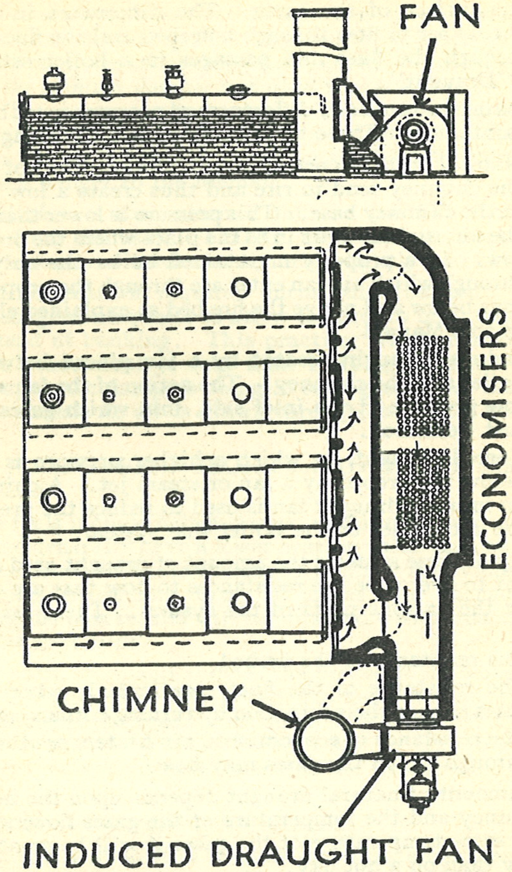


FIGURE 8. INDUCED DRAUGHT FAN APPLIED TO LANCASHIRE BOILER PLANT.

Many large boilers have both induced and forced draught, and work under what is known as "balanced" draught. This means that the dampers are so adjusted that there is a very slight suction over the fire, so that the door can be opened for inspection or firing without gases being blown out or air being drawn in.

Air heaters, economisers, and similar auxiliary plant through which the gases must pass cause resistance to the passage of the gases (often known as "setting up a back-

pressure"). The installation of such plant necessitates an increased amount of draught.

Watch must be kept for accumulations of grit and dirt in flues and fire-tubes. If the flues and tubes are blocked the gases cannot get through. It is not unknown for flues to be partly blocked by water having seeped in from some source.

It is also essential that the whole flue gas system be air-tight. Leakages spoil draught.

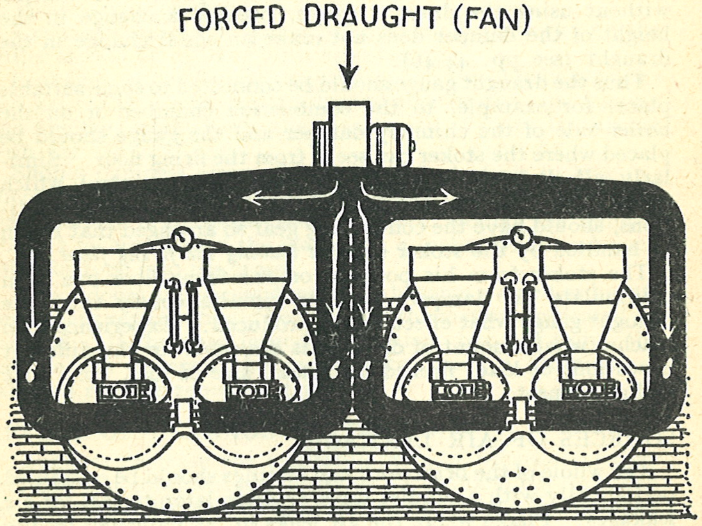


FIGURE 9. FORCED DRAUGHT FAN APPLIED TO LANCASHIRE BOILER PLANT.

DRAUGHT MEASUREMENTS.

The measurement of draught is described later under "Instruments" page 40.

The amount of draught used is very important and examples will be found in this Manual of the use to be made of draught readings. The differences in pressure between the inside of the furnace or flues and the outside air govern the flow of air and hence govern the rate of air admission and consequently the rate at which the coal can be burnt. In any particular plant a relationship can be found between the amount of steam made and the amount of draught required to make it. The draught used should always be the least that will provide sufficient air for burning the requisite quantity of coal.

POSITION OF DRAUGHT GAUGES AND DAMPERS.

The dampers should be regulated by the effect produced on the draught gauge when the fires are in good condition. If more steam is required the damper is raised until the required amount of draught is obtained. Likewise if less steam is needed, less draught is required to draw in the smaller amount of air now required, and the damper is lowered until the amount of draught as shown on the gauge is reduced to a suitable figure. It is not sufficient to operate the damper without using the draught gauge, because a change in the height of the damper does not make an equal change in the draught (see pp. 44-46).

Thus the draught gauge should be connected to some suitable place, for example, to the combustion chamber or on the boiler side of the chimney damper and the gauge should be placed where the stoker can see it from the firing floor. Similarly all dampers provided for combustion control which consequently have to be manipulated to meet varying conditions, should have the controlling gear so arranged that it can be handled by the stoker *without leaving the firing floor*.

The stoker from his position on the firing floor can then manipulate his dampers and see simultaneously from the draught gauge what effect he has produced. Experience soon teaches what amount of draught is desirable for the different conditions of load, firebed thickness, size of fuel, etc., that he has to meet.

SOURCES OF AIR LEAKAGE.

The whole of the brickwork and settings should be examined periodically with a candle, taper or duck-lamp to test for air leakages. Places where the air leaks in, as indicated by the flame being drawn in, should be marked with a piece of chalk for attention (see Fig. 10, pp. 22-23).

As a guide, here are some important points to look for on a Lancashire boiler:

Are the furnace fire-doors a good fit, or do they allow air to be drawn, uncontrolled, over the fire?

Is the ash pit wall in good condition?

Are the down-take and side flue covers air-tight?

Is there any leakage round the superheater manifolds or cover?

Is the brickwork round the blow-down recess tight?

Is the joint between the boiler shell and front cross wall tight? This is a frequent source of leakage.

Do the boiler dampers fit well?

Are the access doors and damper spindles of the economiser tight?

Is the whole of the brickwork free from cracks? Are the expansion joints still tight?

If the bricks are unglazed, is air filtering through them?

It is impossible to test by means of a flame the extent to which air may be passing through unglazed bricks. Unglazed brickwork should be treated with one or two coats of a mixture of hot tar and Portland cement, of suitable consistency, or by coats of tar only, or by two or three coats of whitewash. Whitewash enables cracks to be seen easily, but is not quite so good as tar for stopping leaks.

Expansion cracks or spaces between the brickwork and the boiler should be caulked with asbestos rope.

Leakages in brickwork can be stopped by plugging cracks and gaps with a mixture of asbestos fibre or dry pipe lagging and fireclay, worked into the consistency of putty by mixing with tar.

Sliding dampers often allow a good deal of air to leak in; there are air excluders on the market which reduce this defect. One method is to recess the brickwork around the damper about 2 inches clear of the blade and 3 inches deep, and pack asbestos rope into the recess.

If soot doors and access doors have become warped or burnt, permanent repairs should be made by the method indicated on page 68. If they are in good condition, but not tight, the trouble can generally be rectified by using a grummet of asbestos rope or asbestos string.

EFFECT OF LEAKAGE ON DRAUGHT.

Leakages decrease the available draught because (1) they increase the total volume of gases to be handled, (2) they reduce the temperature of the gases and so reduce the chimney draught.

USE OF DRAUGHT.

When all the avoidable sources of draught loss have been reduced to the minimum, it is still necessary to consider what may be called the effective draught available for forcing the air through the grate, and to remember that air and gases will take the path of least resistance. It may be difficult or impossible to raise steam at the desired rate, not because the draught is insufficient but because it is not correctly applied.

For example if the grate is not covered by fuel at the back—which can be observed by looking under the bars—the air will flow through this part instead of taking the path of greater resistance through the fuel bed, and the steaming rate will be reduced. Before complaining of draught shortage, it is essential to see that what is available is correctly applied. Here is an example:—

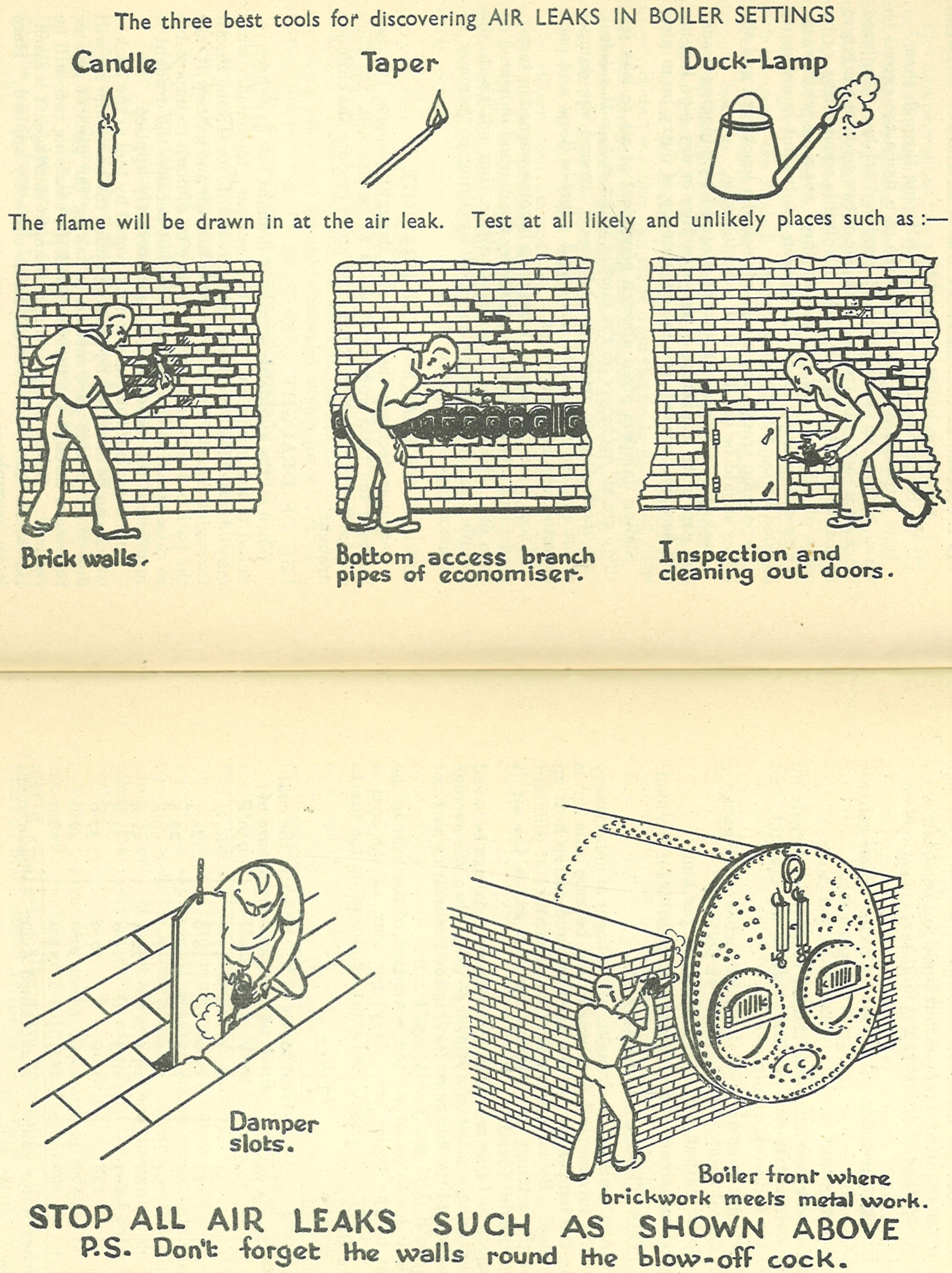


FIGURE 10. TESTING FOR AIR LEAKS.

In a plant recently investigated, when the complaint was made that the required steam output could not be obtained on account of shortage of draught, the following conditions were observed:—

Draught over fire	0·64 inches water gauge*
CO_2	8 per cent.
Boiler output	12,220 lb. per hour.

A visiting engineer corrected the fire conditions, largely by getting a well-distributed fuel bed, *reduced* the draught, and obtained the following results:—

Draught over fire	0·32 inches water gauge
CO_2	12 per cent.
Boiler output	13,000 lb. per hour.

It is a good rule to use *as little draught as possible* for the load.

HEAT LOSS THROUGH LEAKAGE.

Apart from spoiling the draught, all leakages of unnecessary air into the furnace and fires waste fuel because this air is raised to the temperature of the flue gases and carries heat up the chimney. By measuring the CO_2 percentage at different parts of the settings the sections through which the air is entering can be found.

Reference to Table 2, will show how much coal can be saved by maintaining a satisfactory level of CO_2, when the average temperatures of the flue gases leaving the last heating surfaces are (1) 300°F., (2) 500°F., (3) 750°F.

The heat losses given are the percentage of the heat in the coal put on the boiler fire. If 30 per cent, of the coal is wasted, 30 per cent. more coal must be stoked on the fire to make for the waste.

TABLE 2.

% CO_2 in flue gas	% excess air used	Heat losses as % of heat in the coal fired, at flue gas temperature of		
		300°F.	500°F.	750°F.
14	33	12·5	17·5	24·0
13	43	13·0	18·0	25·5
12	55	13·8	19·5	27·5
11	63	14·5	21·0	29·0
10	88	15·3	22·5	31·5
9	103	16·5	25·0	34·5
8	128	18·0	27·0	37·0
7	160	20·0	30·0	42·0
6	206	22·5	34·0	49·0

*"Inches water gauge" is explained under "Measurement of draught" (page 41).

THE RELATIONSHIP BETWEEN DRAUGHT AND RATE OF BURNING.

If it is assumed that a certain effective draught is available for drawing in air, the resultant amount drawn through the fuel bed will depend on the resistance of the fuel. This, in its turn, will depend on (1) the caking properties of the coal, (2) the size of the coal, and (3) the fuel bed thickness. With every class of coal there is some thickness of fire that will fit in best with existing conditions. It may be desirable sometimes to alter the grate area.

The following figures give some idea as to the draught required for burning slack at different rates by hand firing.

Burning Rate per sq. ft. per hour.	Approx. Natural or Induced Draught over the fires, in inches water gauge.
Up to 15 lb.	0·15
,, ,, 20 lb.	0·20
,, ,, 25 lb.	0·30

USE OF STEAM JETS IN BOILER FURNACES.

The steam jets used for forced draught in some boiler furnaces may be wasteful. This may be due to the jets being too large. Wear in use, particularly with wet steam, will cause great waste—often unsuspected. It is also wasteful to have the jets out of centre.

The correct size of jet should be ascertained by practical trial with holes of different sizes, it being obvious that the smallest size found to be satisfactory is the best. A metal gauge should be provided to test the wear of the jets and they should be replaced when any appreciable wear is found to have ocurred.

A valve should be provided to regulate the steam supply to the jets, and a pressure gauge fitted between the valves and the jets to indicate the pressure on the jets. The provision of a run of piping in the flue side of the boiler is helpful in obtaining dry or superheated steam. Steam jets should always be operated with the lowest pressure consistent with satisfactory combustion. It is not always realised that unless due care is taken steam jets can easily use 15% of the total output of the boiler.

Table 3 gives the steam consumption for jets of varying diameters operating under different pressures. It also shows that if a $\frac{1}{32}$" jet is allowed to wear to $\frac{1}{16}$", it will pass four times as much steam at the same pressure.

TABLE 3.

Gauge Pressure lb. per sq. inch	Lb. of Saturated Steam per hour for each jet having diameter			
	$\frac{1}{32}''$	$\frac{1}{16}''$	$\frac{1}{8}''$	$\frac{1}{4}''$
10	1	4	16	63
35	2	8	32	126
60	3	12	47	189
85	4	16	63	252

GRATES AND FIREBARS

The furnace grate is a highly important part of the equipment used by a fireman.

No grate has yet been devised that will deal equally well with every class of coal that it may be called upon to burn.

The purpose of the grate is to support the fuel bed and at the same time allow the passage of air ("primary air") for combustion purposes. For natural draught grates, the air spaces should therefore be as wide as possible but not so wide as to allow the fuel to fall through them.

Different opinions are held as to the advisable sizes of the air spaces in furnace grates but it is generally agreed that, when burning bituminous coal, they should not be less than $\frac{1}{4}''$ wide nor more than $\frac{3}{4}''$. A straight grate with $\frac{5}{8}''$ openings and $\frac{3}{4}''$ bars would have a little less than 45% free air space. With bituminous coal greater air space than this is desirable if it can be secured while meeting other conditions. The spacing will depend on the size of the fuel used.

The grates should dip slightly towards the rear.

With forced draught grates the spaces are much smaller (usually about $\frac{1}{8}''$) and there is very little loss of fine fuels.

Firebars should be made of the best material to resist the effects of heat. They should be so designed that the heat is dissipated as quickly as possible. This means that as little metal as possible should be exposed to the heat of the fire, and as much metal as possible should be exposed to the cooling effect of the incoming air. Narrow firebars provided with deep fins meet this condition and increase the total area of the air spaces and help to distribute the air more uniformly through the whole grate.

Straight grate bars should have a groove running down the centre, as ash accumulates in these grooves and helps to prevent clinker sticking to the iron (Fig. 11). When cleaning the fire the groove acts as a guide to the end of the poker or pointed bar and makes it easier to plough out the ash and cut the clinker loose.

With a straight grate it is also an advantage to have the bars cast in sets of three and provide suitable side bars to make up. The advantages are that a more level fire-grate is obtained and the bars are less likely to warp sideways and leave a space through which fuel can drop. Also, as the weight of the triple bar units is so much greater than that of a single bar they are much less likely to be displaced and fall into the ashpit when the fire is being sliced or cleaned out.

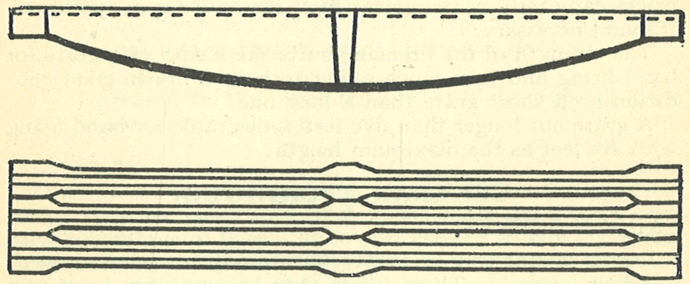
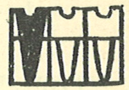


FIGURE 11. SUITABLE FIREBARS FOR BUILDING UP A PLAIN FIXED GRATE.



Hand-operated shaking or rocking grates are of particular advantage with a high-ash coal, and with a good low-ash coal it may be possible to run for days without hand-cleaning the furnaces. Watch the ashpits and when these begin to darken gently agitate the grate. These grates are useful when burning coal containing ash which melts at a low temperature as much of the ash can be removed as soon as it forms and before it has time to clinker. These grates reduce enormously the length of time that the firedoors need remain open during cleaning operations.

Care must be taken to ensure that the grate members are set flat after shaking for if the "fingers" stick up they may be burned. Also, careless use of the slice bar may result in breaking off some of the grate "fingers". If clinker gets caught between the grate members it should be removed, but no attempt should be made to crush it by forcing the grate lever or the grate may be damaged.

GRATE AREA.

The grate area must be suitable for the maximum load to be carried by the boiler and is also governed by the amount of heating surface, the draught available and the quality of the coal to be burnt.

Shortening the grate, and thereby reducing its area, is a proved method of economy during a long period of reduced (for example seasonal) loads. The grate can be shortened by covering a portion near the fire-bridge with firebricks. These bricks can easily be removed whilst the boiler is in operation, if found necessary.

The strength of the fireman limits the length of a grate for hand firing and it is much easier to keep a fire in good condition on a short grate than a long one.

A grate not longer than five feet is desirable for hand firing with six feet as the maximum length.

GENERAL TECHNIQUE.

CARBON LOSSES.

Losses of unburnt or partly burnt coal are referred to as "carbon losses". These losses may become very large and care must be taken to keep them as low as possible. They are:—

1. Loss of carbon in chimney grits.
2. Loss of carbon in riddlings through grate.
3. Loss of carbon contained in the ashes.

1. *Loss of carbon in chimney grits.*

This source of loss is of relatively recent occurence and arises through the modern practice of burning coal at high rates of combustion per sq. ft. of grate area. Apart from the nuisance which it causes to the surrounding property and danger in damage to eyes and to parts of machinery, it involves what may be a large loss of carbon up to, or even exceeding, 5 per cent. of the coal fired.

Grit will also tend to dirty the boiler and reduce the periods between cleaning the flues. It will also wear away induced draught fans.

The amount of grit depends, in the first instance, on the rate of combustion; it may be influenced also by:—

(*a*) *The size of the coal.*
As a general rule there will be more grit from a slack than from a sized coal, such as nuts.

(*b*) *The type of coal.*
There will generally be more grit with a free burning coal than with a coking coal.

(*c*) *The type of (mechanical) stoker.*
The sprinkler type of firing will tend to give more grit than the coking type, because in the sprinkler type the very fine particles are more readily caught up in the air stream as the coal is flipped on to the grate. The amount of grit will often be decreased if the coal is wetted so that it balls when squeezed in the hand. This also applies to hand firing.

(*d*) *The operation of the (mechanical) stoker.*
As far as possible disturbance of the fire should be avoided as this must necessarily tend to cause the finer particles to be carried away in the gas stream.

(*e*) *Draught.*
Increased suction over the fire with any type of grate increases the amount of grit.

2. *Riddlings.*

In all grates there is a tendency for coal to riddle through the bars. This increases with freeburning coals and coals with a high percentage of fines. It is also greater in moving grates than in stationary grates. It may be due to the bars being too widely spaced for the fuel burned.

The riddlings should be returned to the coal in as even quantities as possible. Sometimes riddlings are used for banking instead of adding them to the coal.

3. *Loss of carbon in Ashes.*

The clinker and ashes always contain a certain amount of unburnt coke. The amount of combustible in it depends upon the ash content of the coal and the skill of the stoker; under bad conditions it may amount to 5-10 per cent. of the coal burned.

As much of this coke as possible should be recovered by:—

A.. Hand Picking.
The amount and size of the coke pieces often warrants hand picking. Local inhabitants have been known to visit the ash heap of factories to pick coke for heating their greenhouses!

B. Forking.
Where supervision is good, large pieces of coke are rare, but the smaller material contains much carbon. The residue should be picked over with forks having ¾" spaces between the prongs, the undersize being returned to the fire and the oversize being discarded. In large installations this may be done mechanically. It may be found that a different size of fork spacing is preferable on some plants.

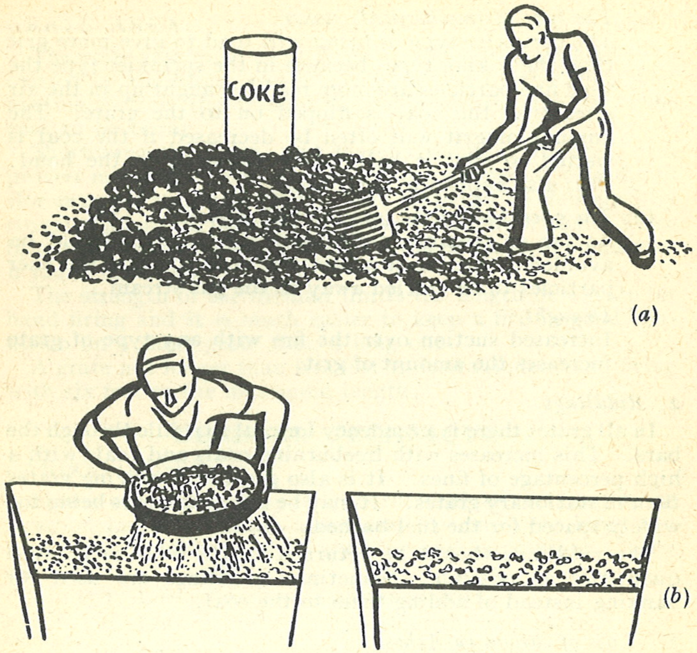


FIGURE 12.
(a) HAND PICKING OR FORKING ASHES; (b) SIEVING ASHES.

CLEANLINESS.

Soot and tarry deposits cling to the outside of heating surfaces, and scale forms on the inside. These deposits stop the heat from going through the boiler plates and tubes, and therefore cause loss of heat. This loss of heat becomes evident through an increase in the temperature of the chimney gases.

Experience alone can decide how often the heating surfaces should be cleaned, but the job should be done thoroughly at regular intervals

Wire brushes are useful for removing the soot and tar from the plates. Steam jet soot blowers if properly positioned and directed enable the tubes and sometimes the flues to be cleaned whilst the boiler is under load. A new method that is preferred by many is that of vacuum cleaning.

Many boiler houses are very dirty often because it has never occurred to anyone concerned with them that they could be anything else. A dirty boiler house has a depressing effect upon all who work in it, so remove all the unwanted odds-and-ends that have been lying about for months, make good the firing floor, brush the whole place down and whitewash it or adopt some other simple scheme of decoration. A clean boiler house is an inspiration to those who spend their working lives in it.

WATER LEVEL IN BOILERS.

The water in the boilers should be kept as near as possible to the level indicated by the boiler maker. This is done by careful regulation of the feed pump.

If the water level is maintained higher than this there is a danger of the steam carrying water with it. This water represents a waste of heat and may be dangerous if not removed before the steam reaches an engine or turbine. It is common practice to run Lancashire boilers with the water level several inches above that advised by the makers as an aid to meeting peak loads. This should never be done if it causes water to be carried over with the steam leaving the boiler.

At least once a shift the gauge cocks should be blown through to ensure that the steam and water passages are clear. This should be done by opening the drain and then closing and opening the steam and water cocks alternately. On closing the drain again, the water should return promptly to the true level. The steam and water connections to the water gauge should be kept in perfect order and no leaks permitted, otherwise the gauge may indicate a false level.

The water level should never be allowed to disappear from the gauge glass. If this should happen the first thing to do is to try the gauge cocks to determine whether the water is above or below the glass.

If the level has sunk *below* the glass, but the boiler crown does not appear to have become overheated, the following action should be taken:

(a) Shut the dampers and stop the fans (if any); this cuts off the air supply and stops combustion.
(b) Blanket the fire by throwing on it damp ashes, sand and any other incombustible matter.
(c) Turn the feed full on.
(d) If the boiler be one of a range, shut the steam stop valve.
(e) Ease the safety valve.

If the water level has sunk so low that the furnace crown has become red hot:—

(a) Shut the dampers and stop the fans (if any) *at once*.

(*b*) Turn off the feed.
(*c*) Blanket the fire as above.

No attempt should be made to draw the fire, as this may result in the stoker being killed.

(*d*) Warn everyone in the vicinity of possible danger and run to a safe distance until the boiler has cooled.
(*e*) The boiler must be emptied and inspected by the Insurance Inspector before being put into use again.

If the water has risen *above* the gauge glass, stop the feed and open the blowdown until the level reappears in the glass.

Even if automatic feed water regulators are fitted, inspection of the water level is still absolutely necessary.

BLOWDOWN.

Boilers are blown down to remove mud and loose scale deposited by the feed water and also to reduce the density of the water in the boilers. Failure to blow down at regular intervals increases the risk of corrosion, priming, overheating and damage to the boiler.

Some boilers have a system of continuous blow-down in which a constant stream of water is allowed to flow from the boiler. The heat in this water is often recovered by heat exchangers. Often the boilers are blown down at intervals by hand operated valves, and with this practice the heat is rarely recovered; consequently the amount of water rejected should be as little as is necessary for maintaining the boiler feed water sufficiently free from impurities and of the correct density.

The amount of blow-down must be settled by a water treatment specialist. No general rule can be safely given. The boiler fireman must, therefore, ask for instructions as to the amount and times of blow-down and must follow these exactly. The amount of blow-down must depend on the rate of steaming and on the character of the water used. Surging of the water in the gauge glasses is often an indication that the boiler should be blown down.

The blow-down cock should be opened at regular intervals, say once a shift, to ensure that it is not blocked. When sufficient water has been blown down the cock should be quickly opened wide and then closed. This moves any grit or scale lodged in the body of the valve.

BLACK SMOKE.

An efficient furnace does not make black smoke. Black smoke issuing from the top of a chimney is an indication of incomplete combustion. Although even dense black smoke may not contain more sooty material than amounts to a loss of 1% of the coal, it must be recognised that combustible gases

such as carbon monoxide usually accompany it and make the loss serious. In addition there is loss due to the fouling of the heating surfaces of the boilers and economisers, etc., by the soot which is a very good insulator and hinders the transfer of heat through the plates or tubes to the water.

The causes of black smoke are:

(*a*) Lack of air.
(*b*) Lack of mixture of air and volatiles above the firebed.
(*c*) Lack of temperature, and
(*d*) Lack of combustion space.

A light haze at the chimney top is an indication of efficient combustion. It is very helpful if the chimney top can be seen from the firing floor, if necessary by the use of mirrors.

BOILER HOUSE INSTRUMENTS.

Instruments are provided in the boiler house to assist the stoker. Some instruments are essential if reasonable efficiency is to be maintained; others are very advisable, but on account of their cost may only be justified for the larger installations.

The fireman should be interested in every instrument that is installed in his boiler house. He should learn the purpose of each instrument, and how to use the information it gives in the operation of the plant. It is this aspect which is particularly discussed here, and only those constructional details are given which are necessary for that purpose.

The instruments of particular value to the stoker are draught gauges, flue gas analysers, feedwater and steam meters. Pressure gauges and water level indicators (gauge glasses) are, of course, essential and the Law insists that they should be fitted to all steam boilers. Since all stokers are familiar with them, they are not further discussed here.

MEASUREMENT OF OUTPUT.

(*a*) *Water meters.*

One way of finding out how much steam is made is to measure the quantity of water fed to the boiler. In small plants the simplest way to do this is to fill a tank with the feed water, and note by how much the level falls in a given time, no water being allowed to enter the tank during that time. It is then possible to calculate the amount of water used from the size of the tank.

Care must be taken during the period of measurement that none of the water from the tank is used for any other purpose and that the blow-down cocks are not turned on and are not leaking. This applies to all measurements of output of steam based on water measurement.

A more convenient and continuous record can be obtained by the use of a water meter. Some of these instruments, such as the "V" notch and the tipping bucket, are designed to be installed on the suction side of the feed pumps; others, such as those using pistons or rotating vanes and the differential pressure types, are put on the pressure side between the feed pump and the boilers.

The accuracy of the instruments referred to in the preceding paragraph suffers if the flow is pulsating (or "jerky") and care must be taken to instal the instrument where the flow is least affected by any pulsation that may occur. A correction must be made for the amount of water blown down. Care must be taken that any water used for other purposes is drawn off from the supply *before* it has passed through the meter and not after, or the steam that appears to be made will be too high by this amount.

(*b*) *Steam meters*.

The steam meter, in addition to measuring the steam produced in the whole boiler plant or by each individual boiler, can also be used to measure the amount of steam being taken by the various departments about the works, or by individual machines or processes.

A steam meter on each boiler, so placed that it can be read as easily as the pressure gauge, is of great assistance to the stoker because it shows him the variations in the demand for steam and thus enables him to manipulate his furnaces accordingly. Any boiler not carrying its share of the load is at once detected. Moreover arguments cannot arise as to how much steam the factory is receiving.

Steam meters generally operate by measuring the pressure drop caused by putting in the steam main a resistance such as an orifice plate or Venturi tube.

As an example of what is meant by this, figure 13 shows an orifice plate inserted between the flanges of a steam main. These plates must be very carefully made. The engineers will then work out a factor by which the readings of the gauge can be multiplied to give the amount of steam passing in pounds per hour. Thus, from the pressure difference, shown in the figure as the difference between two mercury columns, the amount of steam passing is calculated. Instruments can also be graduated directly in terms of steam. Corrections must be made for variations in pressure in the steam main unless this is automatically done by the mechanism of the instrument.

Pulsating flows must be damped out (for example by placing a large chamber and a restriction or resistance in the piping between the source of the pulsation and the meter). Steam meters must not be placed near a constriction, a valve or a bend in the pipeline.

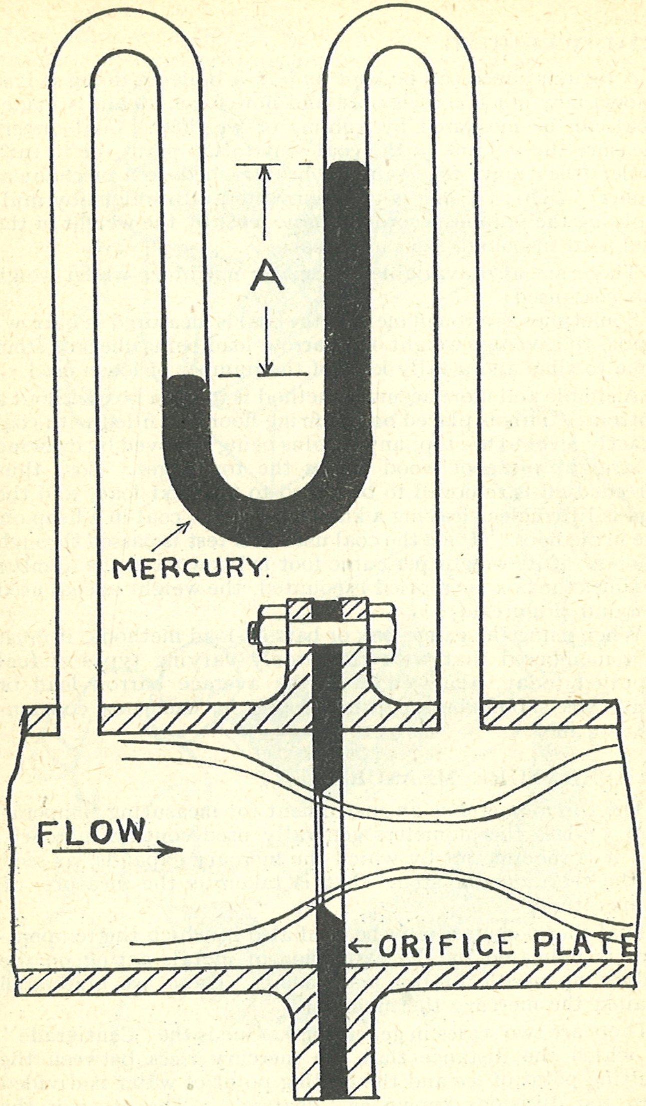


FIG. 13. ORIFICE PLATE INSERTED IN A MAIN TO MEASURE STEAM.

COAL WEIGHING

A regular check can be kept on how a boiler is doing if it is known how much coal is used and how much steam is made. Coal can be measured by volume or weighed. Coal meters measure the volume of the coal sent to the plant, or to each boiler (they may, for example, be attached to a mechanical stoker). This volume is then converted into weight by multiplying the volume recorded (cubic feet) by the weight of the fuel used in pounds per cubic foot.

There are also available automatic machines which weigh the coal used.

Sometimes as a rough method the coal is measured in barrow-loads, the average weight of a barrow-load being checked from time to time and a tally kept of the number of loads used.

A simple and more accurate method is to use a box without a bottom. This is placed on the firing floor and filled with coal exactly level to the top, any surplus being removed by drawing a straight piece of wood across the top edges. Coal thus screeded off is removed to be added to the next load, and the box is lifted clear leaving a known weight of coal in a heap on the firing floor. If all the coal used in a test is passed through the box, if its weight per cubic foot is known and the number of times the box is emptied is counted, the weight of coal used is found (Figure 14).

When using the gauge-box or barrow-load methods, it must be remembered that with the widely varying types of fuel supplied today, the weight of the average barrow-load or gauge box should be separately found for each new consignment of fuel.

TEMPERATURE MEASUREMENT

The thermometer is an instrument for measuring temperature. Glass thermometers generally used contain mercury, and it is the amount by which the mercury expands, as seen in the thermometer stem, that is taken as the measure of temperature.

Dial thermometers may be used also in which the temperature is indicated by the expansion of metals acting on the indicating needle of the instrument. These are graduated against the mercury thermometer.

There are two scales in general use. One is the "Centigrade" in which the distance that the mercury rises between the melting point of ice and the boiling point of water is divided into 100 divisions known as "degrees". The other is the "Fahrenheit" in which the same interval is divided into 180 degrees. Thus 1 degree on the Centigrade scale (written 1°C.)

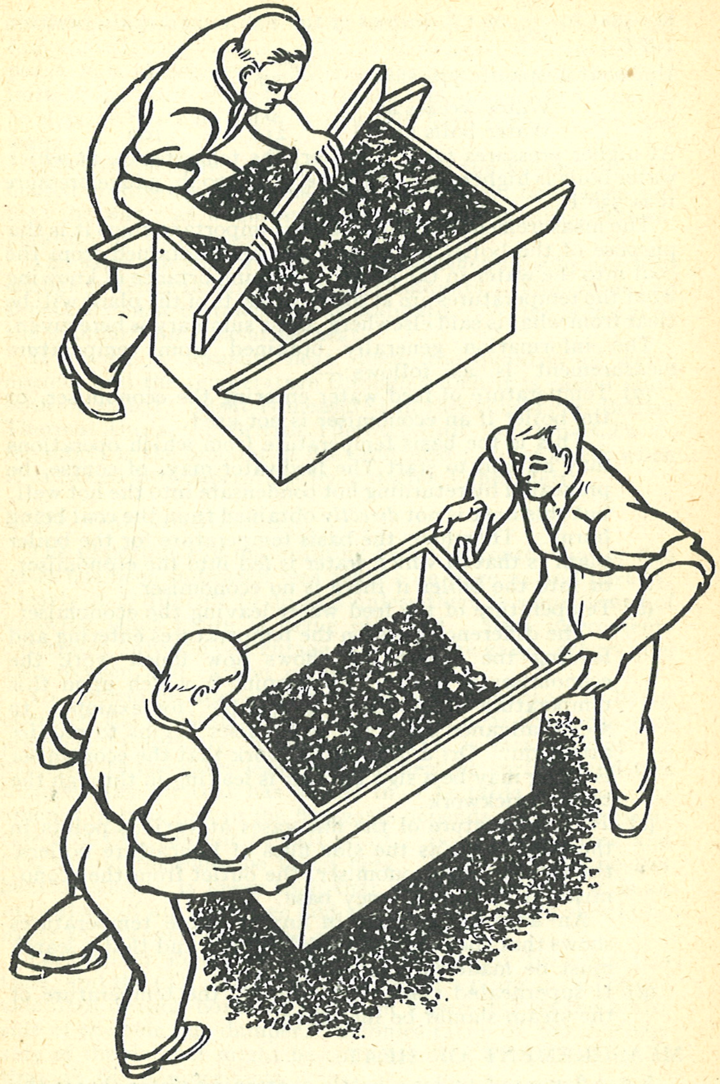


FIGURE 14. A GOOD METHOD OF MEASURING THE COAL BURNT DURING A TEST.

is equal to $\frac{180}{100}$ or 1·8 degrees of the Fahrenheit scale (written 1·8°F.).

Under atmospheric pressure:

	°F.	°C.
Water freezes at	32	0
Water boils at	212	100

At higher pressures (as in a boiler) the temperature at which water boils is higher than 212°F., e.g. at 100 lb. gauge pressure it is 338°F.

The measurement of temperature is important since it is the purpose of the boiler to transfer the heat obtained from the coal into the water in the boiler. The importance of knowing what the temperatures are at different parts of the plant will be clear from what is said elsewhere, but a summary is here given.

The information generally obtained from temperature measurement is as follows:—

(*a*) Temperature of feed water entering the economiser, or the boiler if an economiser is not used.

This is the basis temperature from which operations may be said to start. The feedwater may, of course, be preheated by returning hot condensate into the hot well, but this heat is not *directly* obtained from the coal being burnt. Therefore, the basis temperature for the boiler plant is that at which water is fed into the economiser, or into the boiler if there is no economiser.

(*b*) Temperature of the feed water leaving the economiser.

The difference between the temperatures entering and leaving the economiser shows how much work the economiser is doing. By keeping a watch upon this temperature difference it is possible, for example, to see in advance when the economiser begins to require attention. Or, a drop in the work that the economiser is doing may be a sign that air is leaking in through the boiler brickwork.

(*c*) The temperature of the flue gases at various points in the flues, such as the side flues of Lancashire boilers, the inlet to the economiser, the outlet from the economiser or at the chimney base.

An unusual increase in any of these temperatures shows that the efficiency is falling off, and that a search must be made for the cause.

(*d*) If superheated steam is produced, the temperature of the steam should be measured.

MEASUREMENT OF HEAT.

A gas flame put under a kettle containing water, heats the water. We can measure how hot the water becomes by taking

its temperature. If the water starts at 50 degrees on the temperature scale and is heated to 80 degrees, the rise in temperature is 30 degrees. This rise has been brought about by putting heat into the water. If the temperature had risen by 60 degrees twice as much heat would have been put into the water.

Likewise if there is 2 lb. of water in the kettle and it is heated 30 degrees, twice as much heat would have been put into the water as when only 1 lb. of water is raised in temperature by 30 degrees.

The same amount of heat will cause different substances to change in temperature by different amounts. Thus some one substance must be taken as the standard. Water is taken as the standard for measuring heat.

If we are to measure heat, then, the quantity of water heated, and the temperature through which it is raised must both be stated. Heat is measured in this country in British Thermal Units. 1 British Thermal Unit (written B.Th.U. for short) is the amount of heat put into 1 lb. of water when it is raised in temperature by 1 degree Fahrenheit.

FLUE GAS ANALYSIS.

The importance of maintaining high CO_2 content in the flue gases has been indicated (see table 2 on page 24 and part 5). Clearly it is difficult to do this unless there is some means of knowing what figure is being obtained. Most instruments determine only the percentage of CO_2 in the gases, others give also oxygen and carbon monoxide.

To determine the efficiency while the furnace is being operated the analysis should be taken as near the furnace as possible. Generally, however, the CO_2 is measured at the place where the gases leave the last heating surface, and this includes any air that has leaked in. As table 2 shows, the amount of heat loss in the flue gases depends on the temperature and CO_2 content at this point. Both temperature and CO_2 should therefore be taken here. If the CO_2 at the last heating surface is lower than that near the furnace, it is an indication of air inleakage and shows that a search should be made to discover where the air is getting in.

Each boiler should be checked individually from time to time, and the CO_2 should be measured at a point in one of the side flues of each boiler as shown in Figure 15, on the boiler side of the side flue damper. Samples taken on the chimney side of the damper might be contaminated by air leaking in through the damper slots.

Samples of flue gases for analysis must be taken from the centre of the gas flow (through a tube reaching the requisite distance into the flue) and not from a place where the gases may be stagnant.

Gas analysis apparatus can be obtained in the form of portable, hand-operated instruments, and also of recorders for permanent installation which produce a continuous record on a chart. Portable instruments are useful even when recorders are installed as they permit of tests being made at points in the system to which it is not worth while fixing a permanent recorder.

One of the best known is the Orsat. It is quite easy with a little practice to find the CO_2 content of the gases by this instrument and it can also be used to find their oxygen and carbon monoxide content.

MEASUREMENT OF DRAUGHT.

The force which causes the air needed for combustion (see part 5) to flow into the furnace and which moves the gases resulting from combustion through the flues, as has already been stated, is a difference of pressure between the several parts of the system and the outer atmosphere, and is known as "draught". This difference of pressure can be ascertained very simply by a gauge known as a "draught gauge".

With natural and induced draught the pressure is always less than that of the atmosphere wherever it may be measured, and is lowest at the chimney base or at the inlet to the induced draught fan.

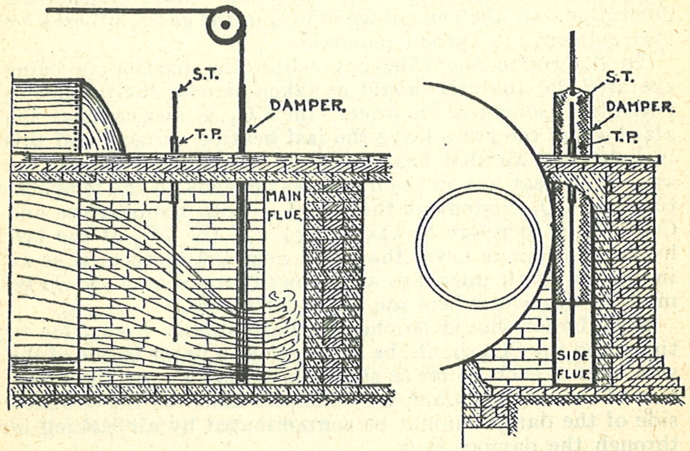


FIGURE 15. ONE OF THE SUITABLE PLACES FOR MEASURING CO_2, DRAUGHT AND TEMPERATURE OF FLUE GASES IN A LANCASHIRE BOILER PLANT.

With forced and balanced draught the pressure under the grate is always greater than that of the atmosphere; above the grate the pressure should be slightly less than atmospheric decreasing further until the bottom of the chimney (or fan inlet) is reached.

DRAUGHT GAUGES

The highest draughts used in connection with steam boiler plant are so small that it is impossible to measure them by the usual means adopted for measuring differences in pressure, namely, the ordinary types of vaccum and pressure gauges graduated in lb. per sq. inch. The method of measurement employed makes use of the height of a column of water.

Imagine a glass tube, bent in the form of a U and half filled with water (figure 16). One end is connected to a boiler flue and the other is open to the atmosphere. The pressure of the atmosphere, being greater than that in the flue, will push the water down in one limb. The water will rise in the other limb and this will continue until the pressure in the flue plus the difference in height of the two columns of water, balances the atmospheric pressure, as shown in the figure.

The difference in height between the two water columns measured by an inch scale is a measure of the draught because it represents the difference in pressure between the inside of the flue and the atmosphere.

If the difference in height is ½″ then the draught is ½″ or 0·5″, or 5-tenths of an inch, water gauge, and is written ½″ w.g. or 0·5″ w.g. or $\frac{5}{10}$ in. w.g. (figure 16c), all these meaning the same thing.

If the U-tube were connected below the grate of a forced draught furnace, the water would rise instead of fall in the atmospheric limb as the pressure under the grate is higher than that of the atmosphere. If this difference were able to support a column of water 3″ high then the draught would be 3″ w.g. (see figure 16b).

U-tube gauges cannot be read to sufficiently fine limits and consequently gauges such as the inclined tube and pointer types, in which the scales are magnified, are used instead, but it must be remembered that whatever mechanism may be used, all draught gauges are calibrated in "inches water gauge" or in "tenths of an inch water gauge."

There are three principal types of draught gauges available: (*a*) those in which moving liquids are used, of which the U-tube and the inclined tube are examples, (*b*) those using liquids and floats and (*c*) those in which some form of metallic bellows or diaphragm is used. All are graduated in inches or tenths of an inch water gauge.

Draught gauges should be connected to furnaces, flues or ducts by iron tubing placed at right angles to the flow of the gases and terminating flush with the inside wall or metal face.

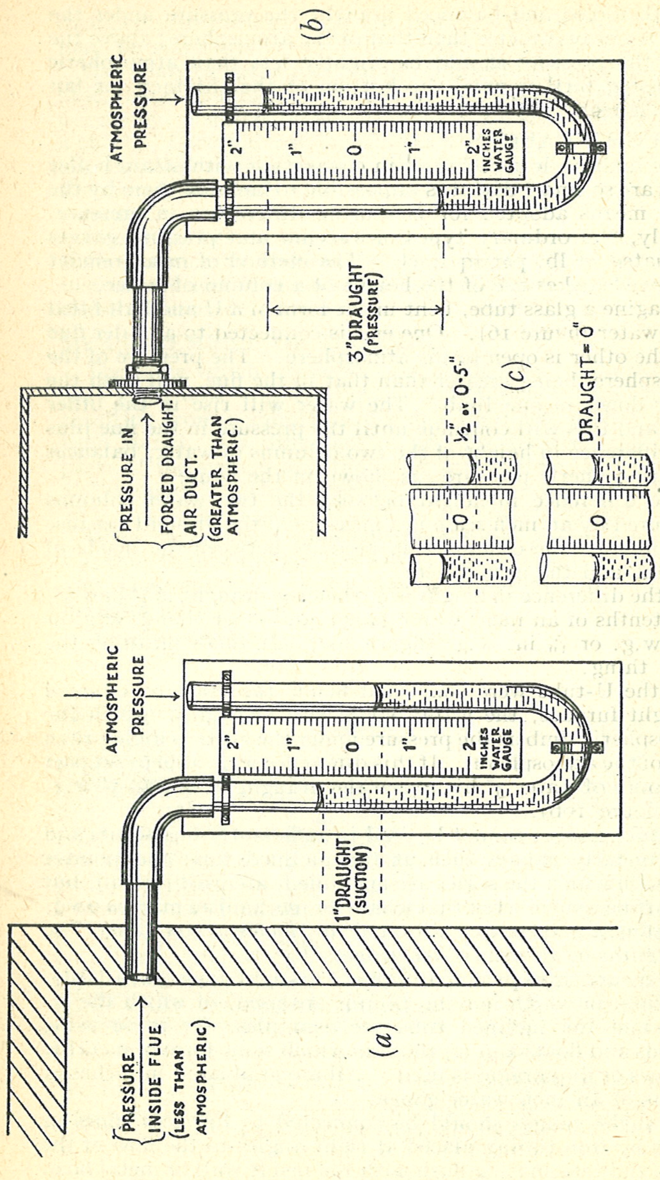


FIGURE 16. U-TUBE DRAUGHT GAUGE INDICATING (*a*) NATURAL OR INDUCED DRAUGHT. (*b*) FORCED DRAUGHT. (*c*) ILLUSTRATES DRAUGHT READINGS OF ½" AND 0" WATER GAUGE. THE SURFACE OF THE WATER IN EACH LEG ASSUMES THE SHAPE SHOWN WHICH IS CALLED THE "MENISCUS". USE THE CENTRES OF THE LOWER CURVES FOR READING PURPOSES.

THE USE OF THE DRAUGHT GAUGE.

Draught gauges, as has been stated previously, are very valuable aids to securing efficient combustion. They enable the stoker to manipulate his dampers correctly and to apply the draught most suited to the fuel that is being burnt. They help him to reproduce the conditions from day to day that make for maximum efficiency.

The reading of a draught gauge in the chimney flue on the boiler side of the damper shows the total force available for moving the combustion air into the boiler fire, and for taking the gases formed there through the flues, economisers, etc. Any resistance to the flow of these gases must be overcome by the draught, and naturally, the draught is reduced when it is used to overcome a resistance.

The total draught must be great enough to overcome all the various resistances, such as the flues (especially where the gases have to turn a corner), the economiser, and so forth, and to pull the air through the fuel bed. The draught available for pulling the air may be too low if:

(*a*) any of the resistances mentioned are too high (which may occur amongst other reasons if dust has collected in the flues or between the tubes of the economiser), or

(*b*) too much air is used for combustion, or is allowed to leak into the flues through cracks, leaking doors, etc.

The difference between two readings on an economiser, one on the gas inlet and the other on the gas outlet, will be a measure of the resistance of the economiser to the gas flow and will enable any abnormal increase to be detected immediately. The readings of the draught gauge can be used throughout the setting to detect abnormal conditions that require to be put right.

When using natural draught (chimney) or an induced draught fan alone, the draught above the fire is a very useful indication, and a sensitive gauge should be connected to this point (figure 17). The draught at the boiler outlet damper is also of importance and a gauge here helps in the setting of these dampers. Figure 18 shows draught gauges fixed to the front of two Lancashire boilers so that each gauge may be turned onto the furnace or side flue, whichever indication is desired.

To determine and maintain correct draught for the depth of the fire is an important use of the draught gauge. The depth of the fire can be measured by a scale chalked on the hoe or on a strip of iron with one end bent at right angles. An hour or two spent in varying the thickness of the firebed and determining the relation between draught, fuel thickness and CO_2 for the class of coal being burnt will be amply repaid by increased efficiency. An average of 12% CO_2 should be aimed at.

The damper controls, as has been previously stated, should be so arranged that they can be operated from the firing floor and draught gauges placed where they can be watched when adjusting the dampers. The dampers should be operated by the effect of the adjustment on the draught gauge because the extent to which the damper is opened or closed is not the same as its effect on the draught. That is to say, if the damper was three-quarters open and is reduced to half open, it does not

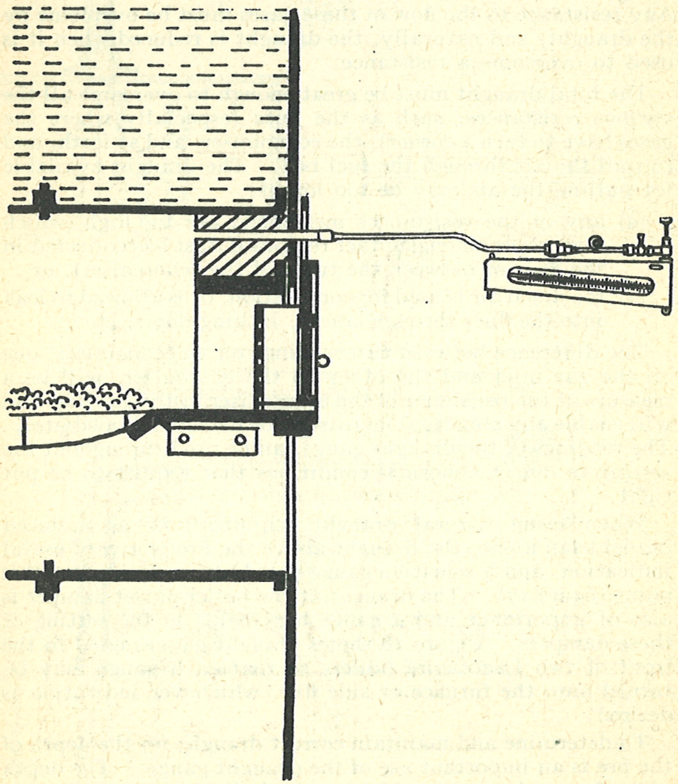


FIGURE 17. INCLINED TUBE DRAUGHT GAUGE CONNECTED TO INDICATE THE DRAUGHT IN A FURNACE.

follow that the draught is reduced in proportion; more probably the draught will be hardly affected by this change. It is towards the bottom of the damper travel where the effect is greatest. Therefore, damper controls should always be operated by the readings of the draught gauge.

Again, a sensitive draught gauge connected to the furnace becomes an indicator of the condition of the fuel bed. To illustrate this point, assume that such a gauge is connected with a furnace operating by natural draught and that it has been found that a reading of 3-tenths inch water gauge with a 4-inch firebed gives a good percentage of CO_2 in the flue gases with a proper output of steam. The dampers have been set for these conditions. If the fire is then allowed to burn thin,

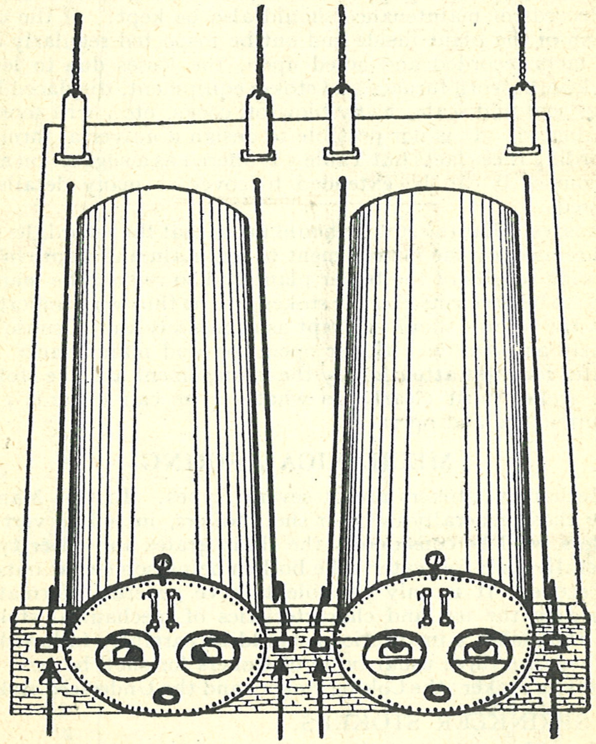


FIGURE 18. DRAUGHT GAUGES ARRANGED TO INDICATE EITHER THE DRAUGHT IN THE FURNACES OR SIDE FLUES.

or bare patches to develop, the gauge reading will become less. If the firebed becomes thicker than 4 inches, or dirty, the gauge reading will increase, the gauge indicates the condition of the fire.

BOOKKEEPING IN THE BOILER HOUSE.

Daily records of plant operation, including instrument readings, should be made and scrutinised by whoever is responsible for efficiency. In this way waste can be detected and the remedies applied without delay. Only those facts of which use can be made are usually recorded, because if the recording system is too elaborate it will break down.

Table 4 is a suggestion for a daily record or log sheet for a steam boiler plant equipped with superheaters and economisers.

Records of maintenance should also be kept. If the condition of the plant inside and out be inspected regularly and the facts recorded and acted upon, the losses due to leaky brickwork, worn furnace and stoker equipment, displaced lagging, soot and scale, leaky blow-off cocks, etc., will soon be eliminated. It is not possible to design a universal form for recording these facts but Table 5 is offered as a suggestion and, of course, it can be extended to cover as many details as desired.

It is well that the stoker should know that the records he fills up are used by the management to maintain and improve the working results of the boiler plant and so reduce the manual work to be performed by the stoker. It is thus very important that the records should be kept as accurately and as conscientiously as possible. Boiler operation and maintenance is a matter for joint attention by the management and the stoker. The stoker must clearly do whatever he can towards good maintenance and operation.

MECHANICAL FIRING

Mechanical stokers are of several types. In this Manual only those generally used for shell boilers, including vertical boilers, will be considered, the chain grates and other types generally used for water-tube boilers being somewhat outside the scope. It is only possible to give general information regarding the use and characteristics of mechanical stokers and the maker's instructions should be carefully followed.

There are three usual types of stokers for shell boilers; the Sprinkler stoker; the Coking stoker; and the Underfeed stoker.

(1) SPRINKLER STOKERS.

These throw the fuel all over the grate by means of shovels, flippers, or rotary distributors (figures 23-25) if they work with fixed grates. When working with self-cleaning grates, they

TABLE 4—TYPICAL BOILER HOUSE LOG SHEET
RECORDS OF OPERATION

DATE

Time	Boilers at Work	Fireman	Coal		Combustion		Economiser—Temperatures				Water Evap. or Steam produced	Steam	
			Weight Burnt	Ash Removed	CO_2 %	Draught in Furnaces	Gases Inlet	Gases Outlet	Water Inlet	Water Outlet		Pressure	Temp.
Totals or Averages													

DAILY FIGURES:—
Class of fuel used ....
Calorific value .... B.Th.U. per lb.
Water evaporated per lb. of coal burnt .... lb.
Overall heat efficiency .... %
Efficiency due to (a) Boiler .... %
(b) Economiser .... %
(c) Superheater .... %

REMARKS ....

Boiler Charge-Hand

Notes:—The items under "Daily Figures" would be filled up by the management. The stoker would only be able to record the figures in columns at the top of the sheet and to make the necessary remarks. The stoker should be told the "Daily Figures" each day.

SUGGESTED DAILY RECORD SHEET.

TABLE 5—RECORDS OF MAINTENANCE

DATE

Boiler	Condition of External Brickwork	Condition of Internal Brickwork	Scale Removed	Soot and Flue Dust Removed	Condition of Economiser	Condition of Economiser Chamber
1						
2						
3						
4						

Boiler	Condition of Stoking Equipment	Condition of Grate	Condition of Blow-down Cocks	Condition of Valves	Condition of Lagging	Condition of Instruments
1						
2						
3						
4						

REPAIRS NEEDED...

....

....

....Boiler Superintendent.

SUGGESTED MAINTENANCE RECORD SHEET.

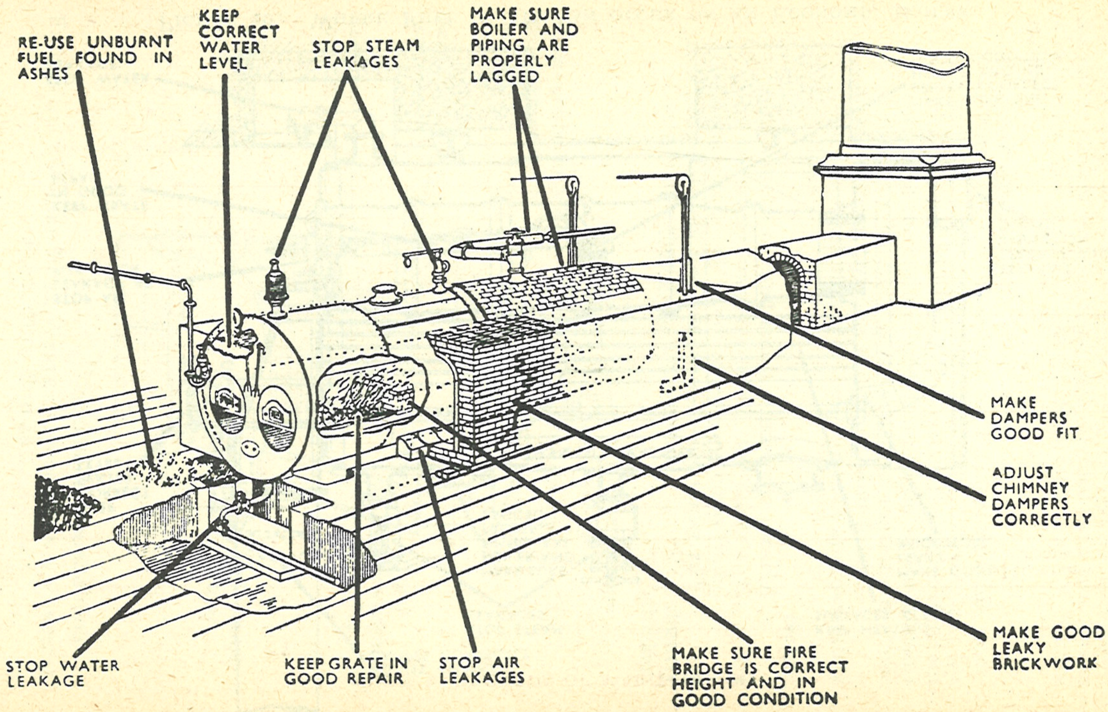


FIGURE 19. WHERE FUEL WASTE CAN OCCUR ON A LANCASHIRE BOILER.

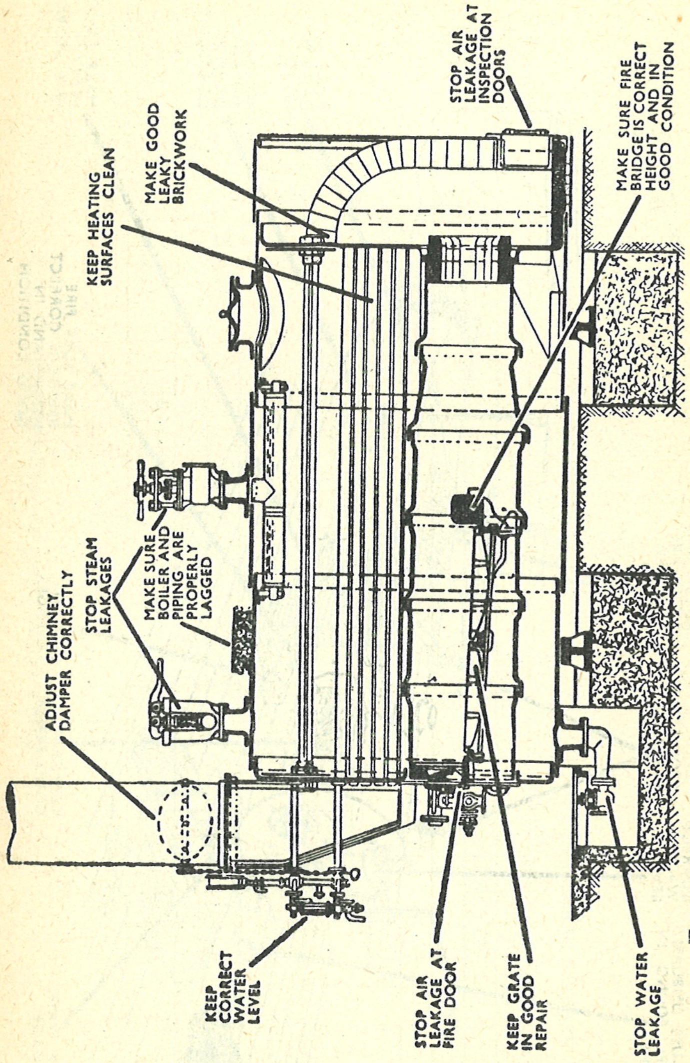


FIGURE 20. WHERE FUEL WASTE CAN OCCUR ON AN ECONOMIC BOILER.

drop coal more on the front part of the grate. They imitate the spreading method of hand-firing previously described. Sprinkler stokers may be again sub-divided into two classes which may be called (*a*) Shovel sprinklers and (*b*) Rotary sprinklers.

(*a*) *Shovel sprinklers.*

When the coal is spread by a shovel working intermittently, the grate bars generally move, i.e., the grates are self-cleaning. The coal is thrown to different sections of the grate in turn through the action of cams of different lengths; this type also imitates in some measure the side-firing system of hand firing.

The thickness of the fuel bed should be approximately as follows:—

	Inches.
Small slacks (½″) and small sized coals (pearls) of relatively low ash content, say under 10%	3-4
Larger slacks (1½″) and larger sized coals (nuts) of relatively low ash content, say under 10%	4-5
Coals higher than 10% ash content	slightly thicker.

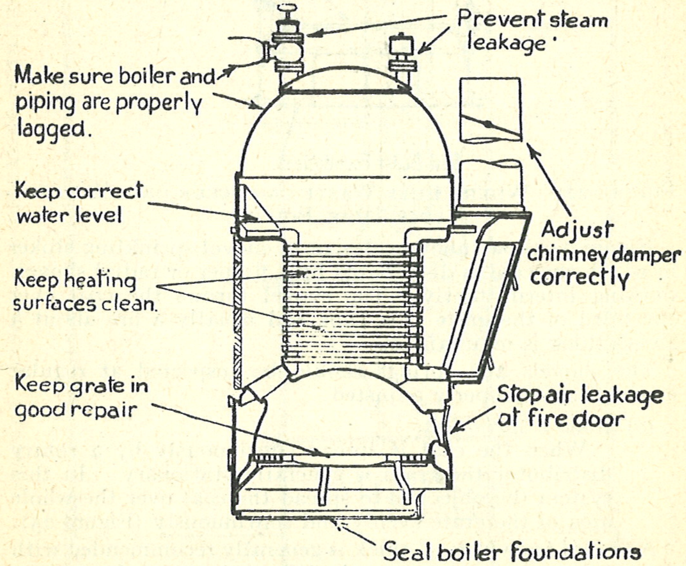


FIGURE 21. WHERE FUEL WASTE CAN OCCUR ON A VERTICAL FIRE TUBE BOILER.

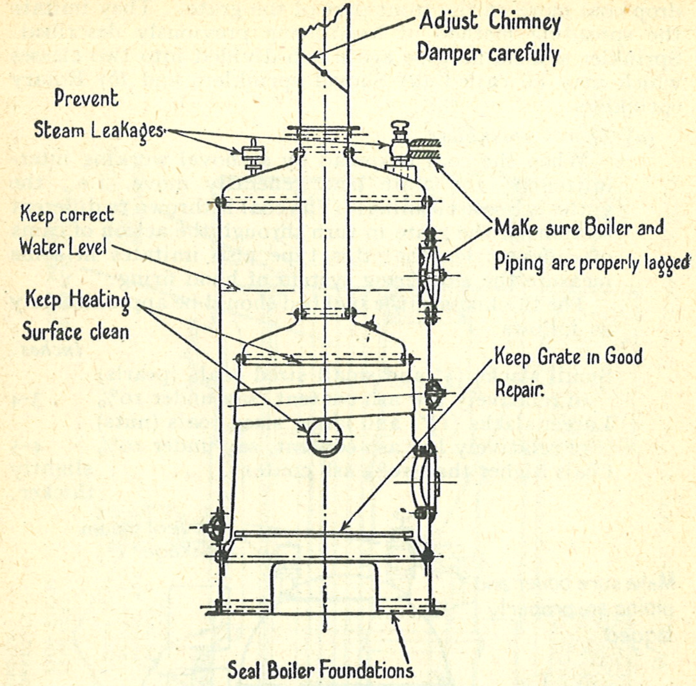


FIGURE 22. WHERE FUEL WASTE CAN OCCUR ON A VERTICAL CROSS-TUBE BOILER.

Figure 24 shows another design of shovel sprinkling stoker in which the coal is distributed by a flipper or radial shovel, working intermittently. The shovel throws the coal over one-third of the grate at a time and usually a fire about 3 inches thick is maintained.

The shovels and springs should be inspected at regular intervals and properly adjusted.

(*b*) *Rotary sprinklers*.

When the coal is spread continuously by a rotary distributor the grate is generally stationary. In this system the object is to spread the coal over the whole area of the grate evenly and continuously (Figure 25).

A firebed from 2″ to 3″ thick is generally recommended with these stokers, but it is extremely difficult to avoid the passage of unused air, i.e., excess air, through the firebed when it is only 2″ thick.

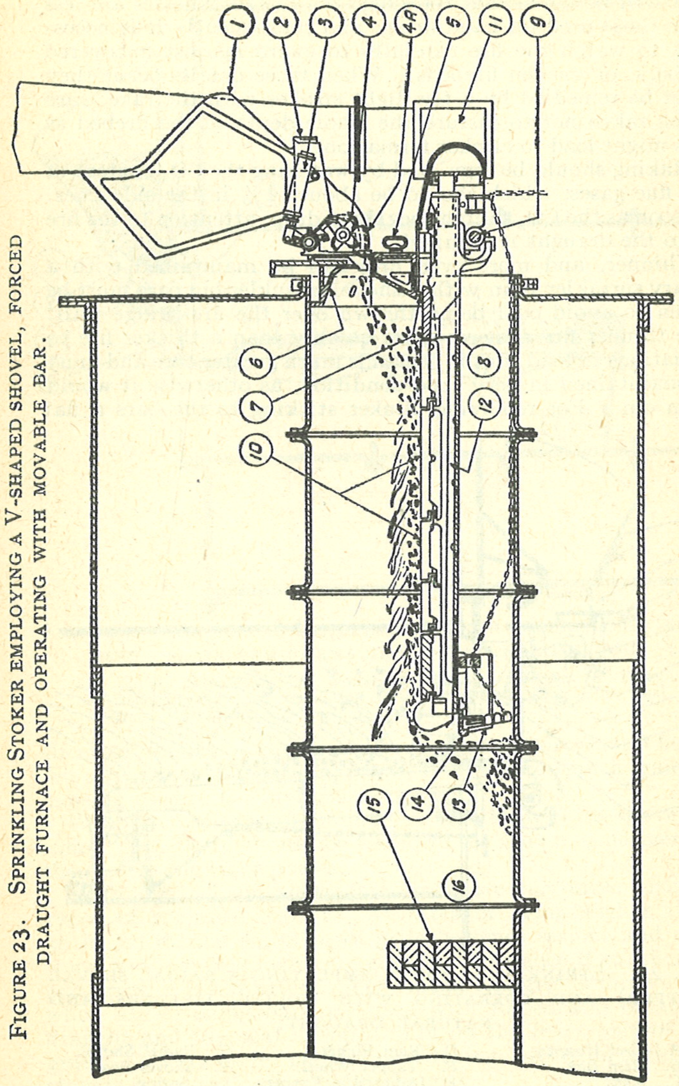


FIGURE 23. SPRINKLING STOKER EMPLOYING A V-SHAPED SHOVEL, FORCED DRAUGHT FURNACE AND OPERATING WITH MOVABLE BAR.

1. Fuel Hopper. 2. Fuel Feed Mechanism. 3. Pneumatic Shovel Gear. 4. Shovel Actuating Tappet. 4A. V-Shaped Shovel. 5. Firedoor. 6. Baffle Plates and Secondary Air Ducts. 7. Front Dead Plate. 8. Trough Section Bars. 9. Camshaft Driving Furnace Bars. 13. Renewable Grate Surface Grids. 11. Forced Draught Air Duct. 12 Automatic Cleaning Slides. 13. Ash Chamber Access Door. 14. Sealing Dead Plate. 15, Firebrick Bridge. 16. Ash Chamber.

Sprinkler stokers in general.

It will be noted that the suggested fire thicknesses are less than those used for hand firing, and consequently it is necessary to watch the fire carefully to guard against uncovered firebars, or uneven firebeds. When these defects occur they must be remedied by a few light strokes with the rake, care being taken not to disturb the whole depth of the firebed as this might lead to clinker formation.

Raking should be regulated by watching the CO_2 content of the flue gases, which should be about 12% in the side flues. As soon as the CO_2 content begins to drop, attention to the fire or to the draught is required.

Thinner, and more even fires can be maintained with a rotary sprinkler than with a shovel sprinkler but care must be taken to avoid coal being thrown over the fire-bridge wall. The thinner fire answers more quickly than a thicker fire to variations in load, but it demands much greater care and must be maintained in very good condition, as otherwise it would burn out. For removing clinker sticking to the bars a flat

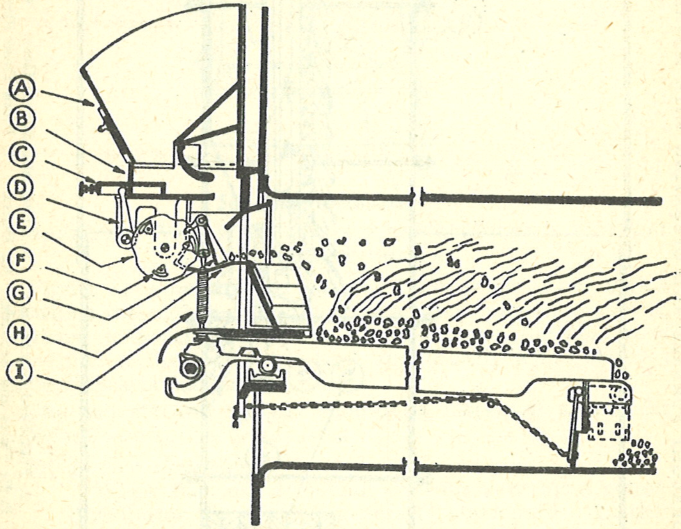


FIG. 24. SPRINKLING STOKER EMPLOYING A RADIAL SHOVEL (FLIPPER) AND OPERATING WITH MOVING FIREBARS AND NATURAL DRAUGHT.

A. Coal Hopper. *B.* Ram Box. *C.* Ram. *D.* Ram Finger. *E.* Tappet Wheel. *F.* Adjustable Tappet. *G.* Radial Shovel. *H.* Shovel Box. *I.* Spring.

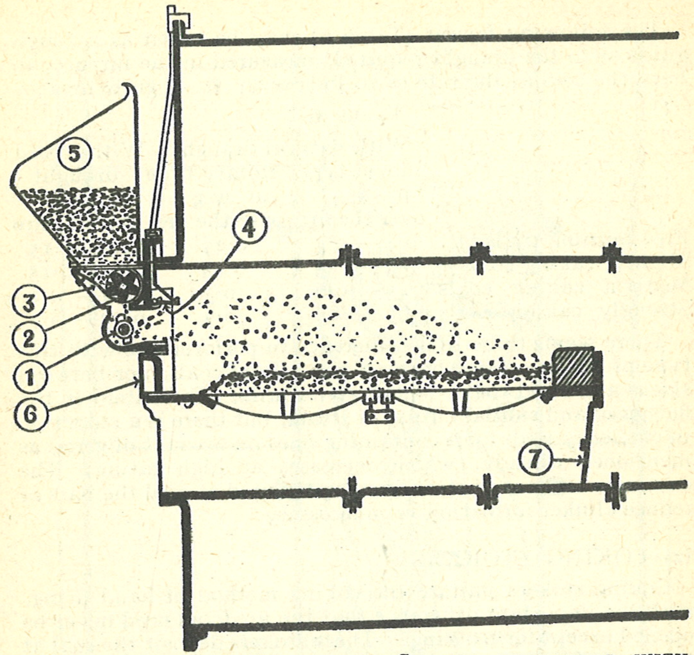


FIG. 25. ROTARY SPRINKLING STOKER OPERATING WITH FIXED PLAIN BAR FURNACE AND NATURAL DRAUGHT.

1. Rotary Distributor. 2. Spiral Feeder. 3. Feeder "S" Plate. 4. Deflector Plate for regulating throw of coal to grate. 5. Coal Hopper. 6. Furnace Door. 7. Ash-pit Door.

slice bar should be occasionally used. Draught should be as low as possible. If the CO_2 is low, probably too much draught is being used or the fuel bed is uneven.

When the boiler is off for cleaning the throw of the shovel or rotary distributor should be tested to see that it is delivering the coal to the right places.

With any fuel containing fines, grits are inevitable with all types of sprinkler stoker. At rates of firing higher than 30 lb./sq.ft. the emission of grits becomes serious and gets worse as the rating increases, causing a nuisance if an efficient grit arrester is not fitted. Very much less grit is thrown out when self-cleaning bars are used with forced and balanced draught and the coal dropped only on the front part of the grate. A very useful method of reducing grits from sprinkler stokers is to wet coal containing fines.

The following figures (Table 6) may be taken as a rough guide as to the draught required, measured in the furnace, to burn the coal at the rate of 30 lb. per sq. ft. of grate area:—

TABLE 6.

	With natural draught Shovel type in. w.g. over the fire	Rotary type in. w.g. over the fire	With forced draught in. w.g. over the fire
Free-burning coals ..	0·4— 0·5	0·25	0·1—0·15
Slightly caking coals	0·4—0·55	0·25	0·1—0·15
Medium caking coals	0·45— 0·6	0·3	0·1— 0·2
Strongly caking coals	0·65—0·85	0·3	0·15— 0·2

There seems to be little difference in performance with this type of stoker on free-burning and caking coals, nor between slacks and sized coals. Both give similar CO_2 content in the flue gases and similar output of steam, but there is a reduction in efficiency with fuels containing fines on account of grits, as mentioned already, which increases at high rating. The excessive amount of steam frequently used to cool the bars or reduce clinker formation is unnecessary.

(2) COKING STOKERS.

Coking stokers imitate the coking method of hand firing, with the important difference that the firedoors need never be opened except for banking. These stokers deposit the coal at the front of the grate from which position it is slowly moved to the rear by means of moving bars or rams (Figure 26). The effect of this is to drive off the gases at the front portion of the grate from which they have a long travel through the hottest portion of the furnace and over the incandescent firebed, thus producing good conditions for securing complete combustion and avoiding smoke. If smoke does occur it is generally a sign that the air supply needs correcting.

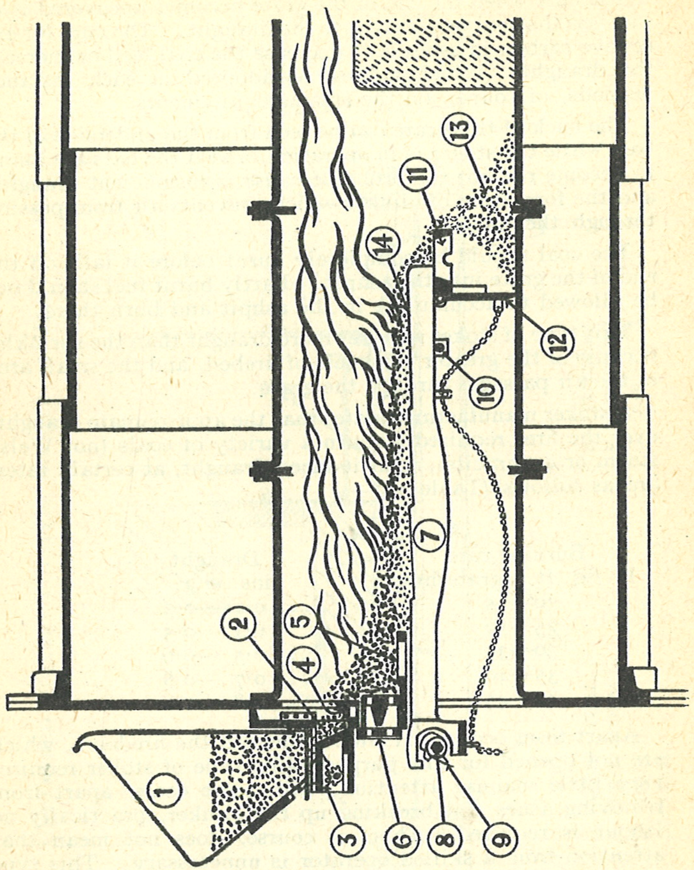
The method of feeding the coal is such that grit is generally negligible even with coals containing fines.

The coking stoker does not answer so quickly to load variations as the sprinkler type.

The coal used should not be of a *strongly* coking character. but if such coal must be used the hard masses of coke that form must be broken up

The standard thickness of fire is 12 to 14 inches at the front of the grate, tapering toward the back. Care should be taken to see that the fuel covers all parts of the grate. Bars too thinly covered at the back will admit cold air, while if the fuel bed is too thick at the back, live coal only partly burnt may be carried over with the ashes.

FIGURE 26. COKING STOKER.



1. COAL HOPPER.
2. RAM OR PUSHER.
3. RACK AND QUADRANT
4. TOP COKING OR DISTRIBUTING PLATE.
5. BOTTOM COKING PLATE.
6. FIREDOOR WITH BAFFLE PLATE.
7. FIREBARS WITH SPECIALLY SHAPED ENDS.
8. HEXAGONAL DRIVING SHAFT.
9. CAMS, DOUBLE AND SINGLE.
10. REVOLVING BEARER.
11. RACK BEARER.
12. ASHPIT DOOR.
13. ASHES ONLY: AVOID ACCUMULATIONS OF BURNING COAL.
14. DO NOT ALLOW ENDS OF BARS TO BECOME BARE OR ONLY THINLY COVERED WITH ASH.

The cure when the end of the grate becomes uncovered is to increase the coal feed or reduce the draught. The cure for excessive carbon in ashes is to decrease the coal feed or increase the draught. Which method is adopted in each instance depends, of course, on the steam requirements.

The back of this grate can be seen from the underside of the bars while the stoker is in operation, and if the bars are found to become red hot the probable cause is insufficient draught, and the formation of clinker which prevents air from passing through the bars.

The coal should be completely burnt before it falls off the end of the grate into the ashpit. Partly burnt fuel should not be allowed to accumulate in the ashpit and burn there.

This type of stoker requires more draught than the sprinkler because of the greater thickness of firebed, and the small area of the air passages through the grate.

A stoker manufacturer states that the approximate draughts over the fires required to burn a variety of coals (not Welsh steam or anthracite), with induced draught, at certain rates, are as follows (Table 7):—

TABLE 7.

Burning rate lb./sq. ft. grate/hr.	Draught ins. w.g.
20—25	0·25—0·3
25—30	0·4 —0·5
30—35	0·5 —0·6
35—40	0·7 —0·8
40—45	0·8 —1·0

Apart from occasional slicing through the firedoors, which are not opened for this purpose, this type of stoker requires very little manual attention; with some coals, apart from removing ashes and breaking up the clinker, practically no labour is required. This, of course, does not mean that attention from a skilled operator is unnecessary. This type of stoker requires less attention than the sprinkler type, provided reasonably good coal is available for full load requirements.

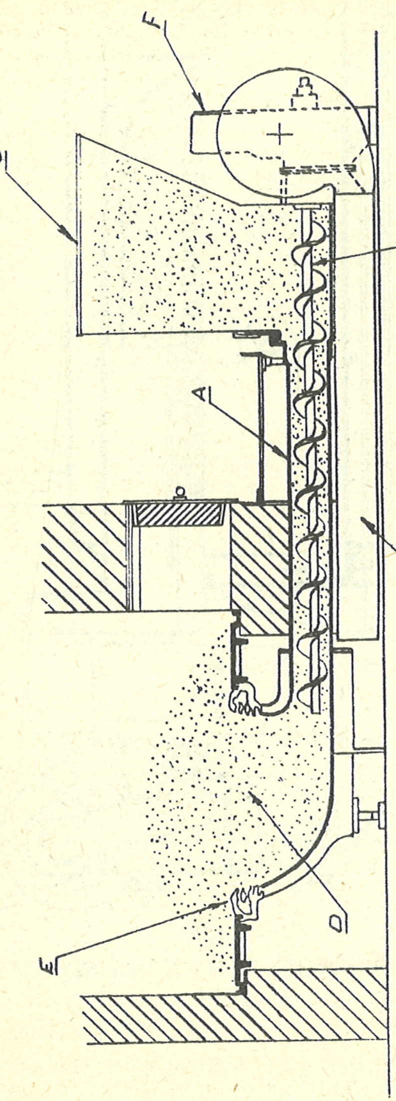
(3) UNDERFEED STOKERS.

Underfeed stokers have no counterpart in hand firing. They fall into two types:

(*a*) The pot type (Figure 27), the smaller sizes of which are used for vertical boilers and C.I. Sectional Boilers.

(*b*) The flue type (Figure 28).

FIGURE 27. UNDERFEED STOKER: POT TYPE APPLIED TO VERTICAL BOILER.



A. WORM TUBE.
B. FEED WORM.
C. HOPPER.
D. COAL.
E. TUYERES.
F. GEARBOX.
G. AIR DUCT.

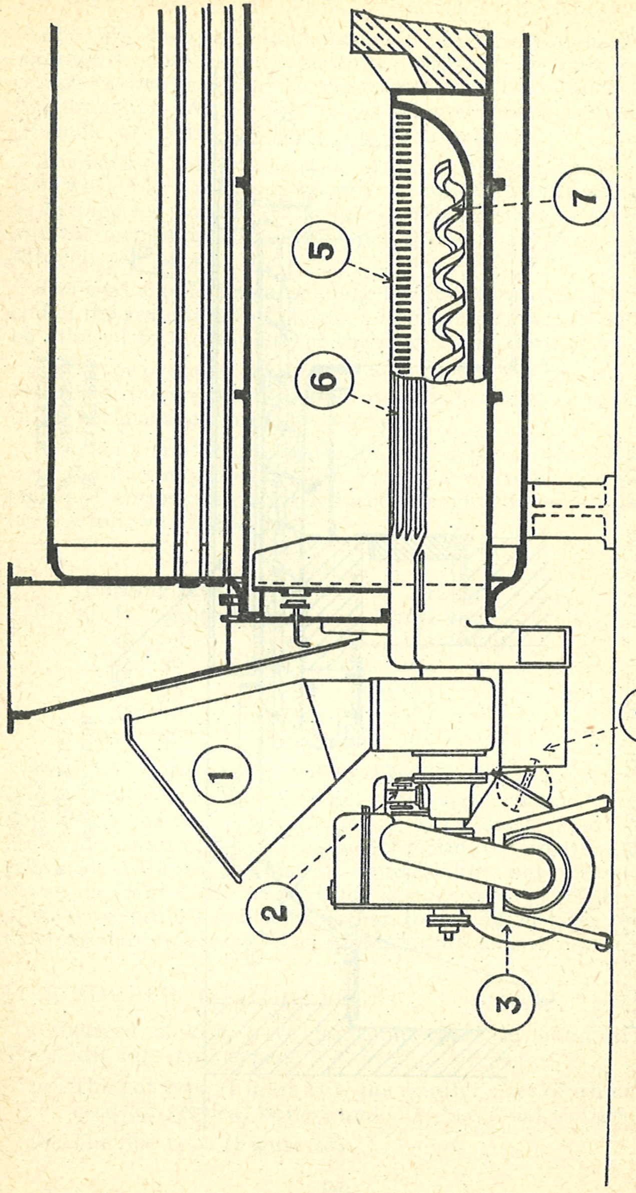


FIGURE 28. UNDERFEED STOKER: FLUE TYPE APPLIED TO SINGLE FLUE TYPE OF 'ECONOMIC' BOILER.

1. COAL HOPPER.
2. PULLING MOTOR.
3. FAN.
4. AIR DUCT.
5. RETORT. (note air inlets)
6. TERRACED GRATE BARS
7. WORM CONVEYOR.

The coal is fired mechanically from the bottom of the retort by means of rams or screws, the air for combustion being supplied by forced draught fans. As the coal rises in the retort, volatiles are driven off and when conditions are right burn on the top of the fire with a short, intense flame.

In the pot type the ash falls over the brickwork down the sides and back; in the flue type it falls towards the sides and remains on the grate. In both types it is withdrawn by hand.

The surface of the fire consists of a layer of incandescent burning coke. The air for combustion is introduced near the point where the fuel emerges from the retort. As the volatile gases are given off they are thoroughly mixed with air. The mixture passes up through the fuel bed where it encounters higher temperature zones and complete combustion of the gases occurs when the mixture passes through the intensely hot coke on the surface. All the air is put in through the fuel bed from below.

If smoke should be produced the air supply must be adjusted according to the analysis of the flue gases; high CO_2 means that more air is needed, and low CO_2 that the air supply should be reduced.

The adjustment of the stoker must be such that coal emerges from the retort throughout its entire length (flue type), or over its entire area (pot type); when properly adjusted, the fuel bed is automatically maintained clean as the ash is floated towards the dump plates.

These stokers are adapted for burning free-burning bituminous coals and slightly caking, low volatile coals.

MECHANICAL STOKERS—GENERAL

Any stoker will burn practically every coal with some degree of success but no stoker is equally successful with every coal.

Forced or induced draught, or both, are advantageous.

It is most important to lubricate the working parts of all types of mechanised stokers and to keep them in good repair.

PART 2.

SUMMARY RELATING TO STEAM BOILER PLANT.

HAND FIRING

1. Use the side-firing method and avoid incomplete combustion and black smoke by firing "little and often". Keep the fire off the dead-plate.

2. Use the dampers to regulate the draught according to the load. Use the air-grids in the firedoors for admitting extra (secondary) air when necessary. Aim at obtaining about 12% CO_2.
3. Keep the grates completely covered with clean, bright and level fires of suitable thickness (about 4 in. to 6 in. for most hand-fired fuels).
4. Clean the fires carefully to avoid removing unburnt fuel with the ashes.
5. Keep the water level correct by attention to the feed pump; feed continuously and steadily.
6. Inspect the plant thoroughly and at regular intervals for defects which allow air to leak in. Stop (or report) all cracks in brickwork, badly fitting fire and inspection doors, damper slots, and air leakages round the spindles of economiser dampers and deflectors, etc.
7. Keep all partition walls and seating blocks in good repair to avoid short-circuiting of the flue gases.
8. Reduce loss of heat in flue gases by keeping all heating surfaces free from soot, flue dust and scale.
9. Lag steam pipes and all exposed boiler surfaces including boiler fronts.
10. Report leakages of steam from pipes, boiler fittings and valves.
11. Watch the blow-down cocks to see that they do not leak.

CLEANING FIRES.

1. Wherever possible clean the fires when the load is low.
2. Clean the fires in rotation.
3. Burn the fires down before cleaning, but do not allow them to burn too low.
4. Before beginning to clean the fires, partly close the dampers to restrict the flow of cold air into the furnace.
5. Use the slice bar, hoe and rake.
6. Use the "side" method wherever possible in preference to the "front-and-back" method.
7. Do not quench ashes on the firing floor; avoid accumulations of ashes against the boiler fronts.

ASHES.

Recover unburnt carbon by forking and hand picking or sieving.

RIDDLINGS.

Collect and mix the coal, or use for banking.

BANKING WITH FIXED GRATES

1. Start with the bulk of the fuel red hot.
2. Clear the back of the grate and push all the good live fire on to the cleared space against the bridge wall.
3. Build up with fresh coal. About 1 cwt. per boiler is usually ample for over-night banking. About 3 cwt. is needed over a weekend.
4. Loosen any clinker on the remainder of the grate but leave it and the ash on the grate to hinder the passage of cold air through this portion.
5. Nearly close all dampers so that the draught is only just sufficient to prevent fumes escaping into the boiler house; it should be possible after half an hour or so to close the dampers still farther.
6. Close secondary air inlets.

RE-STARTING FIRES.

1. Raise all dampers and open secondary air inlets before disturbing the fires.
2. Remove ash and clinker.
3. Spread the fire over the grate.
4. Build the fire up gradually by firing little and often.

FIRING TOOLS.

1. Suitable firing tools are a necessity.
2. Tools should be as light as possible consistent with proper strength.
3. Use all tools except the shovel as little as possible; how much they must be used will depend on the coal.
4. Avoid knocking the fire about and mixing the ash with the burning coal.

CLINKER PREVENTION

1. Keep the fires as thin as possible.
2. Disturb the fire as little as possible. Run as long as possible without cleaning and then do it thoroughly.
3. Keep the fire level by careful firing.
4. Avoid accumulation of burning coal in the ashpit.
5. In bad conditions, to avoid shutting down, spray the bars from below with water or steam, or lower the furnace temperature by admitting excess air. These are to be regarded as methods of desperation when all other means have failed as they reduce the quantity of steam available for use in the factory obtainable from the weight of coal fired.

DRAUGHT.

Use the smallest draught that will carry the load and give 12% CO_2 in the flue gases.

Adjust the dampers by the readings of the draught gauge.

CLEANLINESS.

Keep the boiler house as clean as possible. Do not use it as a store house for scrap metal and other junk.

It helps if the house is well lighted and ventilated.

WATER LEVEL IN BOILERS.

Maintain the water level in the position indicated by the pointers fixed by the boiler makers.

If the levels are constantly much above this point wet steam and priming may result.

If the level falls dangerously low immediate action must be taken.

BLOW-DOWN.

Blow the boilers down regularly according to instructions received from the management.

BOILER HOUSE INSTRUMENTS.

Instruments are installed to aid the stoker and the engineer. Learn the purpose of each and be guided by the readings.

LOG SHEETS.

Records of operation and maintenance are valuable and should be kept accurately and conscientiously.

MECHANICAL STOKERS.

These relieve the stoker of much hard work but not of the necessity of using his brains. To control them efficiently requires as much skill as hand firing.

Mechanical stokers are machines and need treating as machines. Lubricate freely and replace (or report for replacement) worn parts as soon as possible. Follow the maker's instructions to get the best out of them.

BOILER LOSSES.

Figures 19-22 indicate where heat losses often occur in various types of boiler.

PART 3.

SECTIONAL CENTRAL HEATING BOILERS.

Note:—There are many important facts regarding plant management given in part 1 that on account of space limitations are not repeated in this section. It is therefore strongly recommended that those who operate sectional central heating boilers, even if they do not operate steam boilers, should also study part 1.

COMBUSTION CONTROL.

Most central heating boilers in this country are of the cast iron sectional hand fired type. Figure 29 illustrates a typical boiler which is provided with dampers for regulating primary air, secondary air and chimney draught.

The amount of air supplied to the fuel is regulated and the combustion rate is controlled by adjusting the openings of the primary air, chimney and check draught dampers. (The terms "primary" and "secondary" air are explained in part 5.)

The secondary air damper introduces air above the fuel bed and this, mixing with the combustible gases in the fire-box, completes the combustion.

HEATING SURFACES.

The hot gases, which now contain practically no combustible material, pass to the chimney by way of flues which constitute the secondary heating surface. The primary heating surface which is inside the firebox is generally known as the surface which "sees" the fire. Since the heat passes from the hot fuel and hot gases through the metal surfaces it is important to *clean the boiler flues and scrape the surfaces in the firebox at least once a week*.

DRAUGHT CONTROL.

Air is drawn in either below the grate at the primary air damper, or above the grate level at the secondary air damper.

The amount which is drawn in at either place depends not only on how far the dampers are open but also on the DRAUGHT (see parts 1 and 5). There are two important points to remember about the draught:—

1. The draught should always be the least amount that is sufficient to maintain the load.
2. The more constant the draught is maintained the easier is the control of the fire.

Any air which enters the boiler except through the dampers provided for this purpose will cause waste. It is not possible to make all the doors fit their frames so that there is no gap through which air can enter, but the amount which enters can

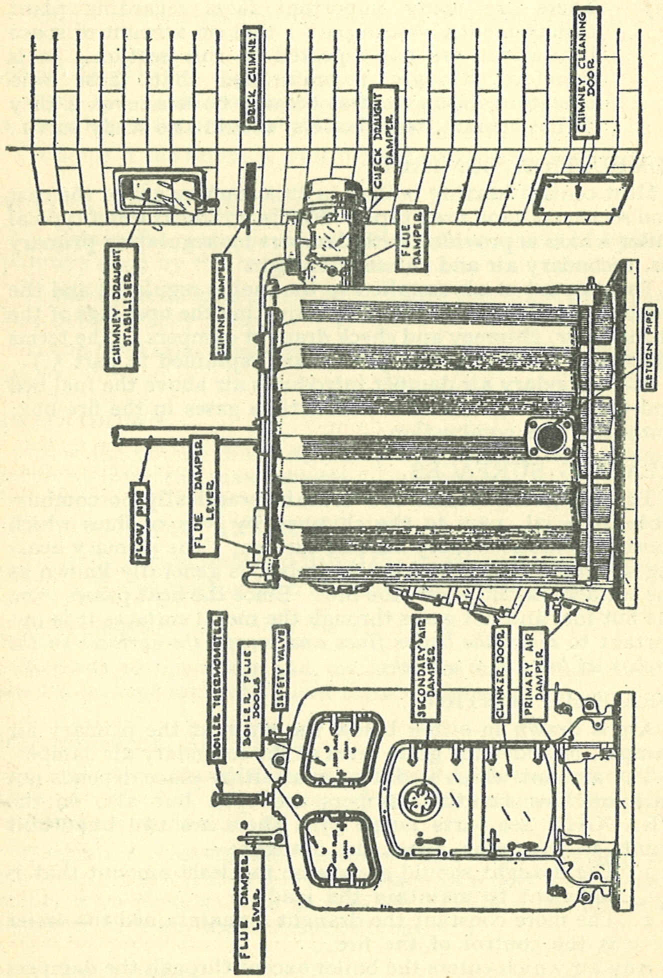


FIGURE 29. TYPICAL HAND-FIRED CENTRAL HEATING BOILER.

be reduced to negligible quantities if, (1) the chimney draught is the lowest possible to give the required output and, (2) the *fit of the doors to their frames is as close as it can be made*. There should be no difficulty in restricting the gap to not more than ten thousandths of an inch, which is roughly the thickness of a thin postcard. The doors may become so badly distorted that is not possible to reach this standard; but if this is so immediate steps should be taken to have them overhauled. Instructional notes for the overhaul of dampers and doors are given later.

FLUE AND CHECK DRAUGHT DAMPERS.

All boilers are provided with flue dampers which may be either of the sliding plate or butterfly valve types. No damper should be capable of completely closing the boiler flue pipe, but a part of the damper (about 10%) is usually cut away so that the flue cannot be entirely closed. This enables the boilers to be banked with the dampers in the "closed" position The clearance allowed for the passage of flue gases should not be excessive, however, otherwise control will be lost.

A check draught damper or door is sometimes fitted on the chimney side of the flue damper. It is used to reduce the chimney draught by permitting air to enter and thus cool the flue gases. A check draught damper, or alternatively, a plate damper in the chimney itself, is essential wherever the uncontrolled chimney draught is too great.

CHIMNEY DRAUGHT STABILISER.

For ideal control over the air entering the boiler the draught should be constant and independent of wind and air temperature. This can be achieved by using a chimney draught stabiliser.

One type of balanced draught stabiliser, of which there are a number of different models on the market, is shown in Figure 29. It consists of a pivoted metal plate so balanced that variations in the suction produced by the chimney draught cause it to open or close.

AMOUNT OF DRAUGHT.

The draught required to give the full rated output of various central heating boilers depends chiefly upon the fuel bed depth, fuel size and design of the boiler flue ways. It does not depend upon boiler output only. It will usually be found to be 1 to 2 tenths of an inch water gauge. Most chimneys will give more draught than this and it is therefore necessary to use the check damper.

SECONDARY AIR.

In the operation of hand fired central heating boilers the fuel is fired at intervals of generally not less than every 5 hours and the fuel bed depth may vary over this period from 18 to 7 inches. The fuel bed temperature will rise as the load on the boiler is increased and fall during banking and periods of low load. Since the composition of the combustible gases above a fuel bed varies both with the depth and temperature of the bed the amount of secondary air required to burn these gases will also vary.

To obtain the highest boiler efficiency the opening of the secondary air damper or slide should be adjusted to give the highest possible percentage of CO_2 in the flue gases when the boiler is working under average load and when the fuel bed is of average depth. The opening of the secondary air slide should therefore be determined by experiment and analysis of the flue gases. When a gas analysis apparatus is not available, a good guide is to allow from 1 to 1½ square inches of secondary air opening for each 50 lb. of coke or other smokeless solid fuel burned per hour.

INLEAKAGE OF AIR AT BOILER FOUNDATIONS.

A common cause of failure to control the heat output of a central heating boiler is air leakage into the ashpit between the boiler and its foundations. Few central heating boilers are of the closed ashpit type and the expansion and contraction of the side walls of the ashpit cracks the cement and causes air leaks. The ashpit should therefore be examined as soon as the boiler is put to work at the start of the heating season and all defects made good.

OVERHAUL OF BOILER DAMPERS, FIRE-FLUE AND ASH-DOORS.

The prevention of waste is largely dependent on the closeness with which the doors and dampers fit their frames. Defects of this character should be made good only by a skilled craftsman, as unskilled work may make matters worse. Defects, such as warped doors, should be reported for attention without delay.

The first step towards making a damper or door fit closely to its frame is thoroughly to clean all material from the face of the damper and its frame; if necessary use a scraper to remove any hard material. Next make sure that the hinges are clean, free from dust, and that the hinge pin is in good condition and has not become badly worn or warped. A simple and effective way of finding whether fit is satisfactory is to arrange a light (electric lamp, candle, etc.), to shine behind the door, when, if the fit is satisfactory, little or no light will be seen. If light does come through see whether the door will fit correctly if the position of the hinge is slightly altered. Should the clearance still be excessive, it will be necessary to file or grind down the high spots.

In refacing doors it is most important that no metal should be removed from the hinge end unless absolutely necessary. Try to get the rest of the door fitting well before touching the hinge end. Decide, and carefully mark, which of the high spots should be removed and whether it is the door or its frame which is at fault. Generally it will be found advantageous to make the door fit the frame. It is better to file off a little at a time rather than make a high spot into a depression. Finally, when little or no light can be seen, try the door with a feeler gauge, when for the best results the clearance should be less than 10 thousandths of an inch.

Figure 30 shows the commonest types of door. In all types it is usual to have some means whereby the door is held tightly against its frame. It is obvious that this will not happen if the door hinge pin is too tight a fit, and sometimes a door can be made to fit better simply by using a smaller diameter hinge pin. This can be tested by trying the door with the hinge pin removed.

There is little that can go wrong with the wedge and catch type of mechanism, but frequent use will reduce the tension of a spring, and the latch of the latch type will wear. All these points should be examined and put right before doing any filing.

Figure 31 shows the commonest types of primary air damper. Of these the chute type is in many ways the easiest to make reasonably air tight.

The method of "facing up" the primary air doors is precisely similar to that used for flue doors, etc. Where a boiler has been in use for a number of years without any overhaul of dampers and doors, it may not be possible to get the doors to fit as closely as the advocated maximum clearance of ten thousandths of an inch; when this happens new doors and/or frames should be obtained from the makers.

A slight adjustment or repair will generally be all that is necessary, and the time spent in finding out whether the boiler dampers and doors are in good condition will be amply repaid by more economical working.

FUEL SIZE.

The fuel size limits for a central heating boiler depend principally on the dimensions of the grate but, except for the smaller boilers, there is considerable latitude in the size limits of the fuel which may be used satisfactorily. Whilst there are advantages to be gained in having fairly close limits of size there is generally little difference between using for example either a 1 inch to 2 inch or a 1 inch to 2½ inch fuel. It is important however that the fuel should not contain more

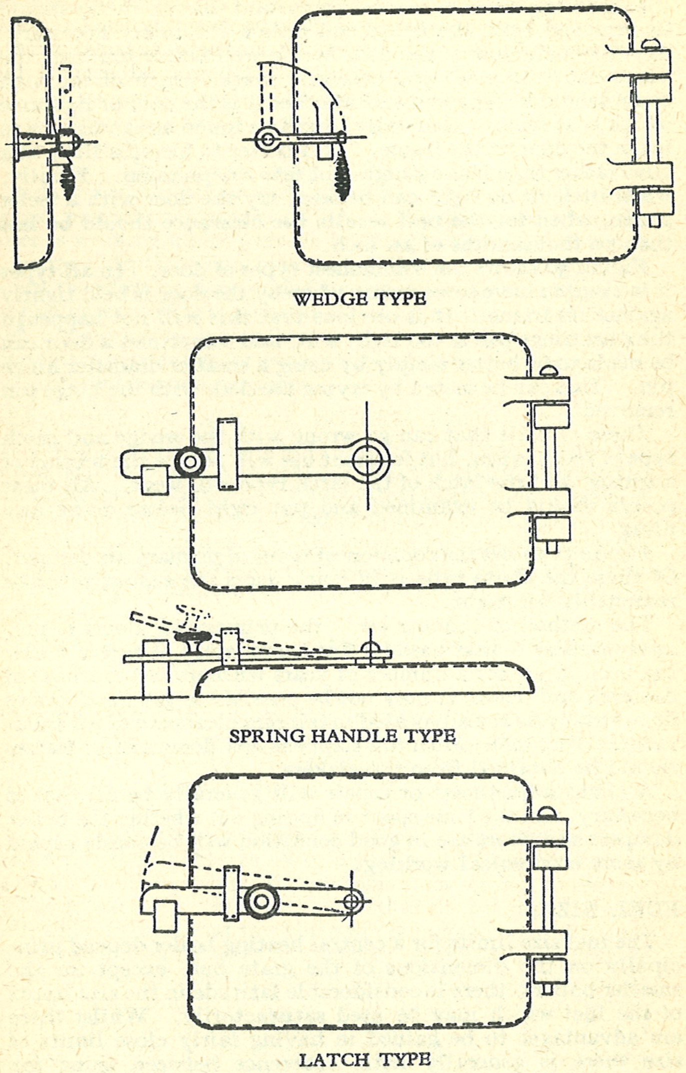


FIGURE 30. COMMONEST TYPES OF DOOR FITTED TO SECTIONAL BOILERS.

than 5% of its weight below $\frac{3}{8}$ inch, as this may lead to much clinker formation. Table 8 will be of assistance in selecting a suitable size of fuel. The nearest commercial size to the dimensions given should be chosen.

TABLE 8.

Grate Area. sq. ft.	Approximate Heat Output B.Th.U/hr.	Fuel Dimensions inches.
1—5	50,000—300,000	1—2
5—11	300,000—750,000	1—2 or 2—3
above 11	above 750,000	2 to not more than 5

DAY-TIME WORKING

Each morning open the chimney and ashpit dampers and leave them open until the fire is hot enough not to go out when it is being cleaned. Remove excess ash and refuel if necessary, taking care that the fuel is evenly distributed over the whole surface of the grate. Thin patches must be avoided and if present filled up at once. As the fire will have been thoroughly cleaned in the evening before banking, the removal of ash in the morning should occupy very little time.

In cleaning the fire never poke the fuel from the top; this causes breakage which upsets the combustion conditions.

Fuel bed thickness.

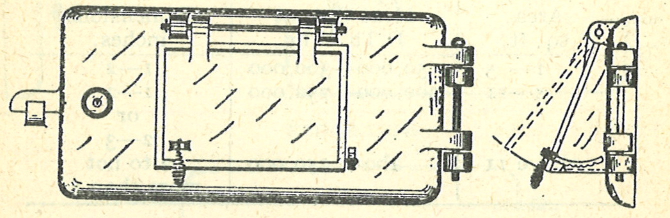
Special attention should be paid to the thickness of the fuel bed. Too deep a fuel bed causes waste by shielding the heating surface of the boiler from direct radiation and by the loss of unburned gases. On the other hand, the fuel bed should not be allowed to burn down so low that unnecessary air passes through it and cools the heating surfaces.

When using coke of 1-2 inches the fuel bed thickness should be maintained as far as possible between the limits of 9-15 inches, while for sizes of 2-3 inches and over, the limits can be 12-18 inches. For anthracite and Welsh smokeless coals the corresponding limits are 6-10 inches and 8-15 inches.

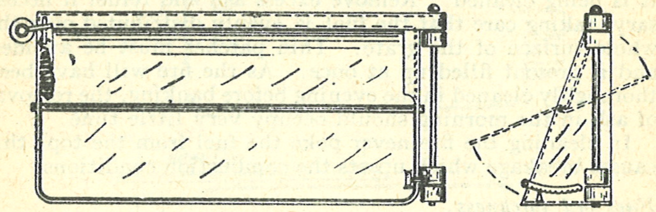
Setting of Dampers.

Much time and labour can be saved if, after the fire has been cleaned and refuelled, the combustion control dampers can be set to a position which will produce the heat output necessary to maintain the required temperature in the building. Accurate setting of these dampers requires (1) practice; (2) careful observation of cause and effect; (3) anticipation of weather conditions, and (4) a routine that ensures that the fire is as nearly as possible in the same condition each morning.

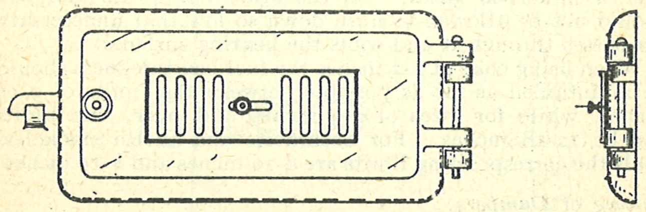
This may sound complicated but experience soon shows the correct setting of dampers and the total attendance time for a boiler of about 500,000 B.Th.U/hr. output need not exceed



Chute Type fitted to ash-pit door.



Butterfly type fitted to ash-pit door.



"Hit-and-miss" type fitted to ash-pit door.

FIGURE 31. COMMONEST TYPES OF PRIMARY AIR DAMPER FITTED TO SECTIONAL BOILERS.

about one and a half hours per day or two hours if the weather is very cold and extra stoking is necessary.

One of the first things to be done is to determine what should be the boiler water temperature in relation to the outside temperature for the required building temperature. Table 9 is a guide but more accurate figures should be found by experience for each installation. It will be realised that is not possible to give precise figures as the construction of buildings, the radiation surface provided and a number of other factors can vary over wide limits.

TABLE 9.

Morning Outside Temperature	°F.	55	50	45	40	35	30
Approx. Boiler Flow Water Temperature	°F.	105	120	135	150	165	180

The atmospheric shade temperature should be taken at about the same time each morning and the dampers adjusted accordingly. Where the boiler attendant is keen he will be able to amplify the above table so that adjustments are made for abnormal wind conditions which will cause a more rapid cooling of the building.

Intelligent anticipation of the weather is a big factor in maintaining comfortable conditions in the building and at the same time avoiding waste by overheating. December, January and February are the coldest months.

When the air temperatures are high during September, October, November, March, April and May, there is an advantage to be gained by reducing the draught below that required to give the rated output of the boiler. With the lower chimney draught any inleakage of air at flue doors, etc., will be reduced and the loss of boiler efficiency by the cooling of the flue gases avoided. A higher draught can be used when this is required during December, January and February.

NIGHT-TIME WORKING.

When a building is not in use at night, the fires should be banked. To bank the fires remove surplus ash and thoroughly clean the fuel bed. With coke, the firebox should be filled to three-quarters capacity and levelled. With anthracite and Welsh smokeless coals, the firebox should be half full.

Care should be taken in setting the dampers for banking so that the building temperature does not drop to such a point that it is necessary to force the boiler in the morning. On the other hand the dampers should not be left open to such an extent that the fire burns out causing delay in starting next day.

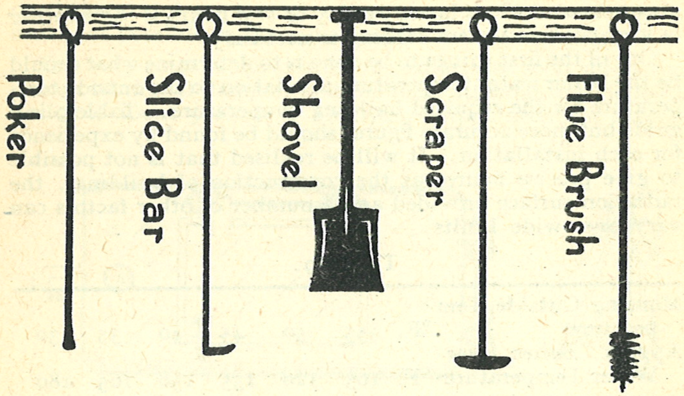


FIGURE 32. APPROVED SET OF STOKING TOOLS FOR SECTIONAL BOILERS.

MECHANICAL STOKERS.

Mechanical stokers can be fitted to heating boilers and, with thermostatic control, will maintain any required temperature by day and by night.

PART 4.

SUMMARY RELATING TO CENTRAL HEATING BOILERS

1. Clean the boiler fires and scrape the water surfaces in the firebox at least once a week.
2. Operate the boiler with the least possible chimney draught.
3. See that the doors fit the frames closely.
4. Fit a flue damper with a clearance of 10% of the area of the flue pipe.
5. Where the chimney draught is excessive a check damper, or alternatively a plate damper in the chimney is advisable.
6. The chimney draught may be kept constant and independent of wind and air temperature by fitting a draught stabiliser in the chimney.
7. Operate the boiler to produce the highest possible percentage of CO_2 in the flue gases when working under an average load and with fuel bed of average depth. If the

percentage is lower than 11% partly close the secondary air damper and examine for leakage round fire, cleaning or flue doors; then take another test.

8. When using coke, anthracite or Welsh smokeless coals, the boiler can be operated with the secondary air damper open only to a very small extent.
9. Prevent air leakage at boiler foundations.
10. Inspect and when necessary report for overhaul boiler dampers, fire-flue and ashpit-doors in order to cut down the loss due to the infiltration of cold air to a minimum.
11. A suitable size of fuel for small and medium sized boilers is 1″ to 2″. Sizes above these are more suitable for large boilers.
12. When a fire is banked at night, each morning open the chimney and ashpit dampers until the fire is hot enough not to go out when being cleaned. Remove the ash and refuel if necessary.
13. Fill thin patches in the firebed as soon as possible.
14. Never poke the fire from the top.
15. Pay special attention to fuel bed thickness.
    With coke: Size 1″ to 2″ maintain thickness between limits 9″ to 15″.
    Size 2″ to 3″ and over maintain thickness between limits 12″ to 18″.
    For anthracite and Welsh smokeless coals the corresponding limits are 6″ to 10″ and 8″ to 15″.
16. Set the combustion control dampers to give only the heat output necessary to maintain the required temperature of the building.
17. Determine by observation and experience the boiler water temperature in relation to the atmospheric shade temperature to give the required building temperature.
    For hot water service boilers the temperature in general should not exceed 140°F.
18. Adjust the dampers in accordance with the outside shade temperature.
19. When banking remove the ash and thoroughly clean the firebed. When using coke, fill the firebox to three-quarters capacity and level the fire. With anthracite or Welsh smokeless coals half fill the firebox.
    Set the dampers in such a position that the temperature does not drop so far as to make forcing necessary in the morning.
20. Use proper tools (Fig. 32)

PART 5.

THE PRINCIPLES OF BOILER FIRING.

Parts 1 to 4 of this Manual deal with the *practice* of boiler firing rather than with the principles involved. It is the line of least resistance to do a job by rule of thumb or just to follow instructions. But often things happen that cannot be put right by the rules, and require someone who knows "why" as well as "how" .Many stokers are sufficiently interested in their job to want to know something about "why", and it is for them that this section has been written.

Parts 1 to 4 are, however, complete in themselves and can be followed if desired without reading Part 5; but it is strongly recommended that Part 5 be read as well.

COMBUSTION.

(*a*) *The combustible.*

Some substances, when raised above a certain temperature, unite with oxygen and give off heat and light. This chemical process is known as combustion or burning and the substances that behave in this manner are termed "combustibles" or "fuels".

Coal, coke, oil producer gas and coal gas (town gas) are fuels or combustibles in common use in connection with steam and heating boilers. They are not wholly combustible as each (except perhaps oil fuel) contains a certain amount of matter that will not burn.

When a combustible substance in contact with air is raised to a temperature called the "ignition temperature" the process of combustion commences and is continued by the heat developed by the process so long as a supply of oxygen is available.

(*b*) *The air needed for combustion.*

The supply of oxygen necessary for combustion to take place is obtained from the air.

Air, which contains 21% of oxygen and 79% of nitrogen, by volume, is as necessary as the fuel. The nitrogen does not burn but passes through the furnaces and flues unchanged, except that it becomes hot, and as it escapes hot it carries away heat.

For convenience oxygen is called the "supporter of combustion" but the action between it and the fuel is mutual and air can also be regarded as a fuel. This point can be illustrated by reversing the usual positions of the fuel and supporter of combustion. Take a lamp glass and fit it up with two corks and three tubes and connect one tube to a gas supply, as shown in Figure 33. Close the end of the top tube and light the gas

issuing from the bottom tube. Open the top outlet and the flame will be drawn inside the lamp glass and air will flow into it and burn in the atmosphere of coal gas. Ignite the gas issuing from the top tube and there will be seen simultaneously air burning in gas and gas burning in air.

IGNITION TEMPERATURE

Combustion cannot take place below the ignition temperature of the fuel. This point also can be illustrated by means of a gas flame and a piece of wire gauze. In Figure 34a the cooling effect of the wire gauze prevents the gas, which is burning above it from igniting the supply from the burner.

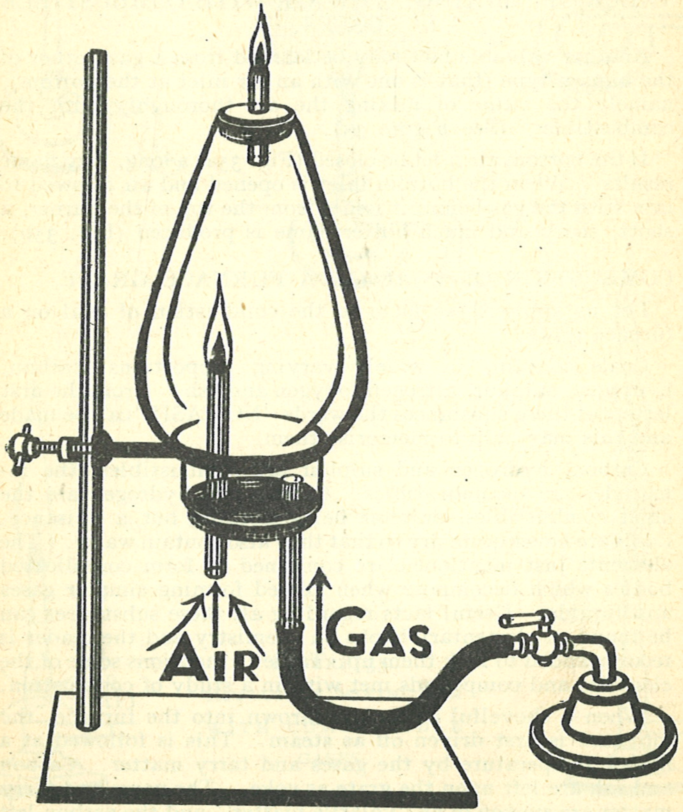


FIGURE 33. AIR BURNING IN GAS AND GAS IN AIR.

In figure 34b the gauze is cooling the gas below its ignition temperature and allowing some to escape unburnt as may be proved by applying a light above the gauze (34c).

Different fuels have different ignition temperatures and it is useful to know that the ignition temperatures of the combustible gases given off from the coal when it is heated are all higher than the ignition temperature of the carbon left burning on the grate. From this it can be seen that if the furnace temperature is not kept high, combustible gases, containing a large amount of heat, can pass up the chimney unburnt.

VALUE OF "MIXING" THE AIR WITH COMBUSTIBLE GASES.

Another valuable fact may be learned from a gas burner of the bunsen type (that is one with an air inlet at the bottom), namely the value of mixing the air thoroughly with the combustible. (See Figure 35).

If the bottom air inlet be closed (Fig. 35a) a long, lazy flame results. When the bottom inlet is opened and air allowed to mix with the gas before it issues from the top of the burner, a short, sharp and much hotter flame is produced (Fig. 35b).

COMBUSTION OF COAL ON A FURNACE GRATE.

Let us apply these facts to the combustion of coal on a furnace grate.

Coals contain, in widely varying proportions, carbon, hydrogen, sulphur, nitrogen, oxygen and ash. From the first letters of these substances the words "NO CASH" can be made and this may help to memorise them.

Carbon, hydrogen and sulphur are combustibles, the remainder are incombustibles. Carbon and hydrogen are the chief combustibles, sulphur being nothing but a nuisance. Coals are never quite dry so that they also contain water. The elements just mentioned are combined to form complicated bodies which decompose when heated forming simpler gases and liquids. Useful facts regarding all these substances can be found in elementary books on chemistry and the reader is recommended to look them up. Table 10 mentions some of the elements and compounds met with in a study of combustion.

When a shovelful of coal is thrown into the furnace, the moisture is first driven off as steam. This is followed at a higher temperature by the gases and tarry matter. Carbon and ash are left upon the grate as coke. The gases and tarry matter are spoken of as "volatile matter" and the carbon left on the grate as "fixed carbon". Thus, coal can be divided

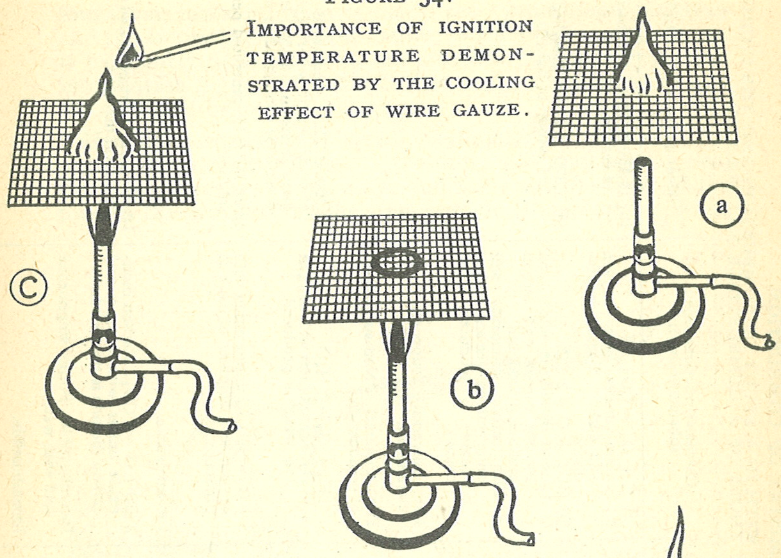


FIGURE 34.
IMPORTANCE OF IGNITION TEMPERATURE DEMONSTRATED BY THE COOLING EFFECT OF WIRE GAUZE.

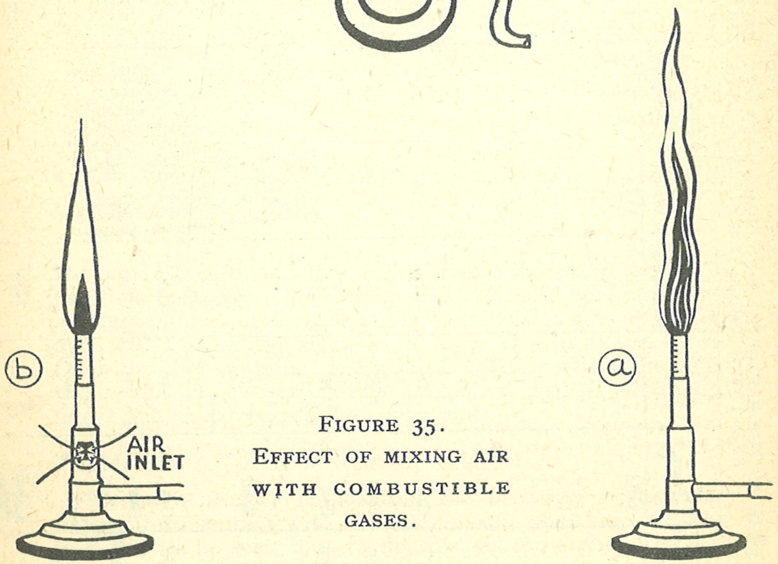


FIGURE 35.
EFFECT OF MIXING AIR WITH COMBUSTIBLE GASES.

TABLE 10.—THE CHEMISTRY OF COMBUSTION.

SOME OF THE ELEMENTS AND COMPOUNDS MET WITH IN A STUDY OF COMBUSTION AND THE CHEMICAL REACTIONS WHICH TAKE PLACE WHEN THOSE OF A COMBUSTIBLE NATURE BURN.

Element or Compounds	Form	Atomic Symbol	Molecular Symbol or Formula	Approximate Atomic Weight	Approximate Molecular Weight	Chemical reactions when substances burn	Heat generated or absorbed
Carbon	Solid	C	—	12	—	(*a*) $C + O_2 = CO_2$ Carbon unites with oxygen and carbon dioxide is produced (*b*) $CO_2 + C = 2\,CO$ Carbon dioxide is acted upon by hot carbon and carbon monoxide produced This carbon monoxide will unite with oxygen and carbon dioxide is produced. (See below).	(*a*) 14,450 B.Th.U. generated per lb. of carbon (*b*) 5.870 B.Th.U. absorbed per lb. of carbon in the CO_2.
Oxygen	Gas	O	O_2	16	32	The universal "supporter" of combustion	
Nitrogen	Gas	N	N_2	14	28	The universal "Non-supporter" of combustion.	
Hydrogen	Gas	H	H_2	1	2	$2H_2 + O_2 = 2\,H_2O$ Hydrogen unites with oxygen and water is produced	52,000 B.Th.U. generated per lb. of hydrogen if water remains in gases as steam. 61,500 B.Th.U. if steam is condensed to water.
Sulphur	Solid	S	—	32	64	$S + O_2 = SO_2$. Sulphur unites with oxygen and sulphur dioxide is produced.	4,000 B.Th.U. generated per lb. of sulphur.
Carbon dioxide	Gas	—	CO_2	—	44	Incombustible.	
Carbon monoxide	Gas	—	CO	—	28	$2\,CO + O = 2\,CO_2$. Carbon monoxide unites with oxygen and carbon dioxide is produced.	10,150B.Th.U. are generated per lb. of carbon involved.
Sulphur dioxide	Gas	—	SO_2	—	64	Incombustible Forms sulphurous acid with water.	
Water	Liquid Steam Vapour	—	H_2O	—	18	Incombustible.	

into moisture, volatile matter, fixed carbon and ash. These four items make up what is called the "proximate" analysis and the amount of each obtainable from a given sample of coal is frequently determined in the laboratory because from this information a good idea can be formed in advance as to how the coal will behave on the grate.

Here is an experiment that all may try for themselves. Put some coal (not anthracite) in the bowl of a clay pipe. Seal the top of the bowl with clay, and then put the bowl of the pipe in the fire, leaving the stem outside (Figure 36). When

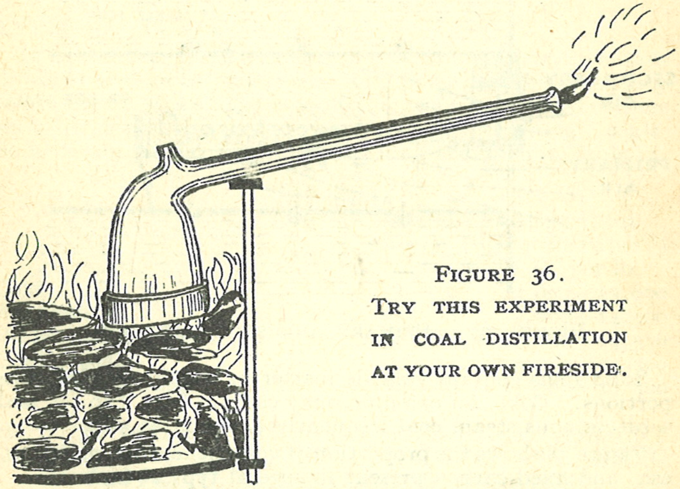


FIGURE 36.
TRY THIS EXPERIMENT IN COAL DISTILLATION AT YOUR OWN FIRESIDE.

the bowl has become hot it will be found that from the end of the stem is coming GAS, which will light and will burn with a bright flame. After a time the flame will not be as bright, and will finally die away as a blue, non-luminous flame. Open the clay stopping, and a solid, COKE, will be found in the bowl. If the stem is then broken, it will be possible to find TAR in it towards the cooler end.

PRIMARY AND SECONDARY AIR.

We have already emphasized the necessity of bringing oxygen into contact with the fuel. From what has just been said it will be seen that to do this air must not only flow through the firebed but oxygen must be present over the top of the fire to burn the combustible volatile matter.

By working with a very thin fire it may be possible for the air flowing through the grate to supply all the oxygen necessary for complete combustion. But when the fires are thicker than about 4 inches no free oxygen can pass through them; it is then necessary to allow air to flow over the top of the firebed by opening the air grids in the fire-doors.

The air which flows up and through the firebed is called "primary" air and that which enters above the fire "secondary" air. (See Figure 37.)

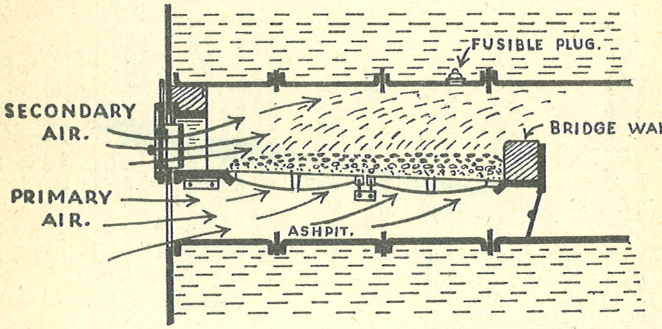


FIGURE 37. PRIMARY AND SECONDARY AIR.

Solid fuels contain volatile matter in widely varying proportions. Coke, for example, may contain from 1 to 4% and a bituminous steam coal frequently as much as 32%.

Figure 38 shows the proportion of volatile matter, moisture, ash, and fixed carbon present in several typical fuels.

The flow of secondary air must be regulated according to the percentage of volatile matter in the fuel. With coke. so little secondary air is required that it may be possible to work with the air grids in the firedoors shut, relying upon leakage round the firedoors to meet secondary air requirements. On the other hand, with a highly volatile bituminous coal it may be necessary to have the air grids full open for at least a short period after firing by hand, and then to close them gradually by the appropriate amount as the volatile matter burns off.

CARBON MONOXIDE.

When air meets the red hot carbon, carbon dioxide is produced. If this gas as it rises through the firebed, comes in contact with more red hot carbon at a spot where there is no free oxygen, the carbon takes oxygen from the carbon dioxide

and reduces it to carbon monoxide as shown in Table 10. If there is no oxygen present to burn the carbon monoxide as it rises from the fuel bed, it will cause a serious waste by escaping unburnt up the chimney.

Secondary air is therefore needed to burn any carbon monoxide which may be produced in the firebed, as well as to burn the volatiles.

A skilful fireman adjusts the flow of primary air by means of his dampers and the flow of secondary air by means of the air grids in the firedoors to suit the requirements of the particular fuel he is burning.

TYPES OF COALS

It has already been mentioned that different coals contain different amounts of volatile matter. Some coals become pasty in the fire and cake together to form coke when heated; others show no sign of this and are known as "free-burning" coals. Some examples of commercial solid fuels are given in Table 11.

TABLE 11.

	Volatile matter %	Heating value ("calorific value") B.Th.U. per lb.
Coke	1— 2	12,000—13,000
Anthracite	4— 8	14,000—14,500
Welsh steam coals	8—16	14,000—14,500
Coking coals	20—34	13,000—13,500
Freeburning coals	34—40	11,500—12,500

HOW TO MAKE SURE THAT THE RIGHT AMOUNT OF AIR FOR EFFICIENT COMBUSTION IS BEING SUPPLIED WHEN COAL IS BURNING

The method is to analyse the flue gases (a CO_2 recorder does this automatically); if an average of 12% CO_2 is present and no carbon monoxide, the air supply is right.

How does the percentage of CO_2 in the flue gases show whether the right amount of air is being used?

To explain this imagine that the coal is all carbon. Since 100 volumes of air contain 21 volumes of oxygen and 79 volumes of nitrogen (Figure 39a), if the carbon were burnt completely, without any excess or surplus air, all the oxygen would be used up and its place taken by 21% CO_2. That is, 21% CO_2 in the flue gases would indicate perfect combustion. (See Figure 39b).

If the air supply is twice as much as is needed for perfect combustion, that is 100% excess, then the volume of CO_2 becomes 21 parts in 200 or 10·5%. (See Figure 39c).

Suppose three times as much air is used. This dilutes the CO_2 still further and it becomes 21 parts in 300, or 7%. (See Figure 39d).

Thus, if the CO_2 percentage in the flue gases be determined the amount of excess air being supplied to the furnaces is known.

Coal is not pure carbon and no fuel can be burnt completely without the presence of excess air. In the ordinary boiler house an average of 12% CO_2 without the presence of carbon monoxide is good, and 14% excellent. These percentages indicate approximately 55% and 33% excess air. If the percentage is as low as 7 then about 160% excess air is entering (see Table 2 on page 24)

Excess air carries heat up the chimney to waste and is usually responsible for the greatest single loss than can occur with any fuel-burning plant. The temperature at which the excess air leaves the last heating surface considered by itself is not a reliable indication of the heat lost, as a low temperature may be the result of the presence of large volumes of excess air. It is necessary to take into account the volume (or weight) of waste gases as well as temperature, and this can be deduced from the percentage of CO_2 in them.

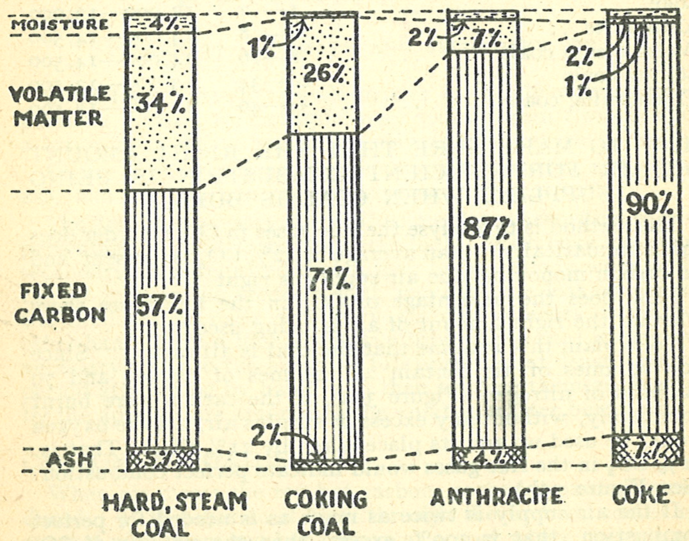


FIGURE 38. "PROXIMATE" ANALYSIS OF FOUR TYPICAL FUELS.

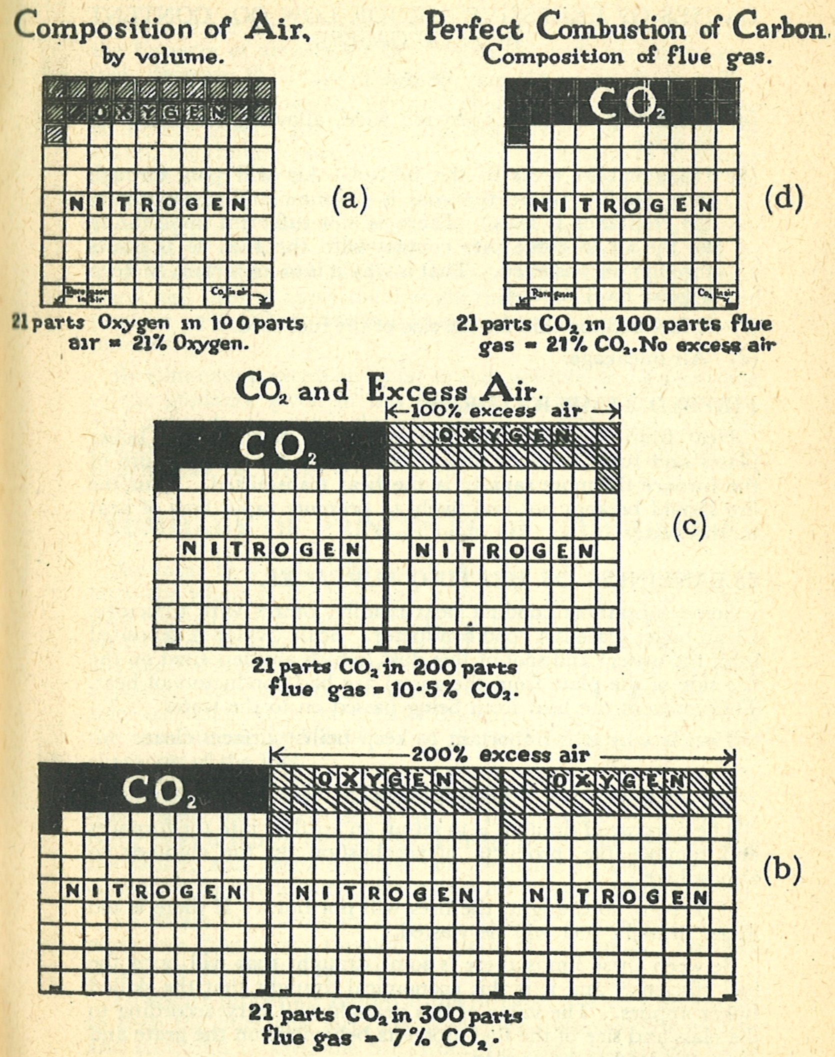


FIGURE 39. EFFECT OF EXCESS AIR ON THE PERCENTAGE OF CO_2 IN THE FLUE GASES.

CAUSES OF EXCESSIVE AIR (OR LOW CO_2 CONTENT IN FLUE GASES).

Too much excess air may be due to :—

(*a*) Secondary air slides open too wide, allowing too much air to enter.

(*b*) Holes or bare spots in the firebed. Air will pass through most readily where the coal is thinnest and consequently the resistance is least. There is not sufficient opportunity for the air to come into contact with the fuel, so it passes through unconsumed. That is why it is so important to keep a good level firebed.

(*c*) A fuel bed too thin for the size of the fuel used.

(*d*) Air inleakage.

FIREBED TEMPERATURES.

Heat from combustion of the fuel must pass through boiler plates and tubes to the water. The higher the temperature of the furnace the more rapidly is the heat transmitted. Thus, the fire should be kept hot and lively to promote rapid flow of heat to the water.

CLEANLINESS OF HEATING SURFACES.

Some substances conduct heat readily, others with difficulty. Clean boiler plate is a good conductor. Scale (which is deposited from the water) and soot or flue dust (which are deposited on the fire side of the plate from the gases) are bad conductors of heat. They prevent the heat from being passed on to the water.

That is why it is important to keep boiler surfaces clean.

DRAUGHT.

The purpose of draught is to set up an air flow into the furnaces and remove the products of combustion up the chimney to atmosphere.

If there is no draught, the fires will not burn. If there is too much draught fuel will be wasted.

Between these limits there is some draught that will burn the fuel efficiently and it is this economical draught that the skilled stoker applies. The value of this draught will vary according to the class and size of the fuel, upon its behaviour on the grate and upon the load to be carried.

An adequate draught may be rendered insufficient by the inleakage of cold air into the boiler settings through cracks and

holes, damper slots, inspection doors, etc. Such leakages rob the furnaces of air needed for combustion and, besides wasting fuel, decrease the boiler capacity.

Draught is also wasted by dirty flues as they hinder the flow of the flue gases. Also, if the fires are carried too thick on the grates, the draught available may not be sufficient to overcome the resistance they set up to the flow of air through them. The result is that it may be found difficult to raise enough steam. Working with a thinner fire is often the remedy for an apparent shortage of draught. The aim of the skilled stoker should be to determine the most suitable thickness of fire for the fuel being burnt and then to apply the draught that will carry the load and produce 12% CO_2 in the flue gases without the presence of any unburnt gases.

By eliminating excess air as far as ever possible, firing according to the guidance given in this Manual, and using the dampers and air-grids properly, the percentage of CO_2 and also the efficiency of the furnaces can be raised to a level of which the stokers may be proud.

SUMMARY OF PRINCIPLES OF COMBUSTION.

Air must be supplied for combustion in sufficient quantity to burn the whole of the fuel, and it must be brought into contact with the fuel in the furnaces where the temperature is high. The air required for combustion is divided into primary and secondary air, and the amounts admitted at the two places must be correctly adjusted. Care is needed in making this adjustment and in firing, since secondary air is more easily drawn in than primary air, and the amount required depends on the rate of firing and on the character of the fuel.

Some of the greatest sources of heat loss in boiler plants arise from using too much excess air. The quantity of excess air being used is shown by the CO_2 content of the flue gases leaving the boiler, and every effort should be made to keep the CO_2 content in the neighbourhood of 12 per cent. (when burning coal).

To obtain the maximum output of steam it is essential to promote free flow of air through all parts of the grate. The fire should be kept hot and lively.

To ensure proper air supply at the furnace, it is very important to keep the flues and auxiliary plant free from deposits of dust and soot, and to keep the brickwork free from cracks and other faults that allow air inleakage.

To pass the heat to the water as rapidly as possible all the heating surfaces must be kept clean.

MINISTRY OF FUEL AND POWER BULLETINS

(*Continued*)

No. 29. The Industrial Use of Compressed Air. 4d. (5d.)

No. 30. The Unorthodox Use of Economisers. 4d. (5d.)

No. 31. Fuel Economy by Water Saving. 4d. (5d.)

No. 32. Fuel Economy at Collieries—Compressed Air. 6d. (7d.)

No. 33. Steam for Power. 1s. (1s. 2d.)

No. 34. The Efficient Operation of Steam Engines. 6d. (7d.)

No. 35. Blowdown. 4d. (5d.)

No. 36. Creosote—Pitch Mixture. 6d. (7d.)

No. 37. Small Vertical Boilers, Steam Cranes and Shunting Engines. 4d. (5d.)

No. 38. The Maintenance of Industrial Boiler Plant. 6d. (7d.)

No. 39. Water Treatment. 4d. (5d.)

No. 40. Combined Power and Heating. 1s. (1s. 2d.)

No. 41. How to look after a Boiler Plant. 4d. (5d.)

No. 42. The Recovery of Waste Heat from Flue Gases. 6d. (7d.)

No. 43. The Furnaceman's Manual. 9d. (10d.)

No. 44. The Operation of Gas Producers. 9d. (10d.)

No. 45. The Installation and Maintenance of Boilerhouse Instruments. 6d. (7d.)

No. 46. How Glasshouse Growers can save Fuel. 1s. (1s. 2d.)

No. 48. Fuel, Power and Heat Costing. 1s. (1s. 2d.)

No. 49. The Handling and Storage of Coal. 4d. (5d.)

No. 50. Fuel Saving in Factories and Commercial Premises. 4d. (5d.)

No. 51. Heat and Power Linkage. 6d. (7d.)

Bulletins 1, 2, 3, 4, 6, 7 and 47 are out of print.

Prices in brackets include postage.

Obtainable from

HIS MAJESTY'S STATIONERY OFFICE

at the addresses shown on page 4 of the cover or through any bookseller.

A6921 Wt.2408 K40 7/50 Gp.959 Fosh & Cross Ltd., London.

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE

To be purchased from

York House, Kingsway, LONDON, W.C.2   429 Oxford Street, LONDON, W.1
P.O. Box 569, LONDON, S.E.1

13a Castle Street, EDINBURGH, 2
39 King Street, MANCHESTER, 2
2 Edmund Street, BIRMINGHAM, 3
1 St. Andrew's Crescent, CARDIFF
Tower Lane, BRISTOL, 1
80 Chichester Street, BELFAST

or from any Bookseller

1945

(Reprinted 1950)

Price 6d. net

S.O. Code No. 41—86