CORRESPONDENCE TUITION SCHEME

COURSE FOR POWER PLANT OPERATORS

LESSON 5 - THE OPERATION OF THE MODERN BOILER

Contents

List of Figures

1 INTRODUCTION

Boiler operation is increasing in complexity as unit sizes, pressures i and temperatures increase.

Knowledge of the principles of operation is required, by the operating personnel so that accurate judgment and initiative can be applied to the varying conditions. It is possible for detailed operating conditions to be prepared for particular boilers but the aim of this lesson is to consider some of the factors involved in boiler Operation that the-student can apply and particularise them to the boilers with which he is associated.

A good operator will have detailed knowledge of the boiler on which he is working and an enquiring mind that will be constantly questioning the reasons why the boiler operates as it does.

2 COMBUSTION THEORY

2.1 Introduction

Those who have already taken the Course for Boiler Operators will recall that Lesson 5 in that Course dealt with Combustion, but a brief resume of the subject will not be out of place and will be of use to those members who have taken the Turbine Operators Course only.

2.2 An Outline of the Simple Facts

Combustion in the power plant consists of chemical reactions generating heat. These occur between the combustible matter in the fuel and the oxygen in the air. The combustible matter is chiefly carbon (C) and Hydrogen (H); the oxygen (0) is present as 23 per cent by weight of atmospheric air. The remaining constituent, of air is chiefly Nitrogen (N), generally considered as 77 per cent by weight and although this plays no part in combustion, it is heated up to the temperature of the other gases using some of the heat generated in the combustion process.

The chief concerns of the operator are to develop the maximum quantity of heat from the fuel burnt and to utilise this heat as far as possible through the boiler so that the quantity of heat escaping at the stack is kept to a minimum.

2.3 Some Combustion Equations

There complete combustion of coal or oil has taken place, the products will be carbon dioxide and water and these will be accompanied by a large quantity of nitrogen. There will also be some oxides of sulphur, mostly in the form of sulphur dioxide, and any excess air. A few simple chemical equations will express the reactions and show what substances take part and in what proportions:-

$$\mathrm{C} + \mathrm{O_2} = \mathrm{CO_2} \text{ or carbon dioxide}$$

$$2\,\mathrm{H_2} + \mathrm{O_2} = 2\,\mathrm{H_2O} \text{ or water}$$

$$\mathrm{S} + \mathrm{O_2} = \mathrm{SO_2} \text{ or sulphur dioxide}$$

Taking the first equation, this means that i atom of carbon has combined with 2 atoms of oxygen to form i molecule of carbon dioxide and it will be seen that this molecule therefore consists of 3 atoms.

2.4 Atomic and Molecular Weights

Atoms of elements have definite weights relative to each other and these are known as their atomic weights. The molecular weight of an element may be the same as its atomic weight or it may be some multiple of this. For instance a carbon molecule consists of i atom of carbon and its atomic and molecular weights are the same, 12, whereas a molecule of hydrogen can only exist freely as a molecule of 2 atoms so it has an atomic weight of 1, but a molecular weight of 2.

A list of substances that commonly take part in combustion together with their chemical symbols, atomic weight and molecular weight, are given in Table 1.

Table 1:

Material	**Chemical Symbol**	**Atomic Weight**	**Molecular Weight**
Hydrogen	H	1	2
Oxygen	O	16	32
Nitrogen	N	14	28
Carbon	C	12	12
Sulphur	S	32	32
Carbon Monoxide	CO	-	28
Water	H_2O	-	18
Carbon Dioxide	CO_2	-	44
Sulphur Dioxide	SO_2	-	64

2.5 Ignition Temperature

Before combustion can take place, the substances taking part must be at a certain minimum temperature and substances have different ignition temperatures as shown in Table 2.

Table 2: Ignition temperatures in air at normal atmospheric pressure

	Temprature	
Combustible Material	**°C**	**°F**
Sulphur	243	470
Charcoal	343	650
Fixed Carbon (Bit. Coal)	407	765
Fixed Carbon (semi-Bit. Coal)	466	870
Fixed Carbon (Anthracite)	449 - 602	840 - 1115
Hydrogen	574 - 590	1065 - 1095
Carbon Monoxide	610 - 657	1130 - 1215

2.6 Heat of Combustion

When a combustible substance burns, it gives out heat, but all combustibles do not give out the same amount of heat per unit of weight burnt. Table 3 gives approximately the heat evolved per pound of various substances and the difference in heat release between carbon and carbon monoxide should be noted.

Table 3: Heat of Combustion

Material	Heat of Combustion in B.T.U's per lb.
Sulphur	4,000 (When burned to SO_2)
Carbon	14,450 (When burned to CO_2)
Carbon	4,350 (When burned to CO)
Hydrogen	61,500
Carbon Monoxide	10,100 (When 1 lb. of Carbon in 2½ lbs. of CO is burned to CO_2)

2.7 Combustion Calculations

It is shown in Section 2.3 how in chemical reactions substances combine with others in definite proportions such as:-

$$C + O_2 = CO_2$$

that is, one atom of Carbon combines with two atoms of Oxygen to give one molecule of Carbon-dioxide.

Writing in the molecular weights (from Table 1) -

12 parts of Carbon combine with 32 parts of Oxygen to form 44 parts of Carbon Dioxide

$$\text{Therefore 1 lb. C} + \frac{32}{12}\text{ lb. } O_2 = \frac{44}{12}\text{ lb. } CO_2$$

(Divide by 12 as shown because the 12 parts of carbon is now considered as 1 lb.)

$$\text{or, 1 lb. C} + 2.66\text{ lb. } O_2 = 3.66\text{ lb. } CO_2 \qquad (1)$$

Taking the equation for water

$$2\,H_2 + O_2 = 2\,H_2O$$

and again putting in the atomic weights:-

$$(2 \times 2) + 32 = 2 \times 18$$

$$4 + 32 = 36$$

$$\text{or, } 1 \text{ lb. } H_2 + 8 \text{ lb. } O_2 = 9 \text{ lb. } H_2O \tag{2}$$

Applying this to a typical power station coal, the actual air requirements can be obtained.

Table 4: Coal Analysis

Carbon C	70%
Hydrogen H_2	4%
Moisture	7%
Ash	17%
Remainder *	2%

* The remainder is made up of small parts of other elements including sulphur.

The moisture and ash will not take part in combustion and the remaining 2% can be neglected for practical purposes.

Consider the combustion of 1 lb. of this coal -

7 lb. will consist of Carbon

.04 lb. will consist of Hydrogen

From equation (i) above -

$$0.7 \text{ lb. C} + (2.66 \times 0.7) \text{ lb. } O_2 = 3.66 \times 0.7 \text{ lb. } CO_2$$

$$0.7 \text{ lb. C} + 1.862 \text{ lb. } O_2 = 2.562 \text{ lb. } CO_2$$

and from equation (ii) given earlier, -

$$0.04 \text{ lb. } H_2 + (8 \times 0.04) \text{ lb. } O_2 = 9 \times 0.04 \text{ lb. } H_2O$$

$$0.04 \text{ lb. } H_2 + 0.32 \text{ lb. } O_2 = 0.36 \text{ lb. } H_2O$$

Therefore, One pound of coal requires $(1.862 + 032)$ lb. O_2

$$= 2.182 \text{ lb. of oxygen}$$

and as air contains 23% Oxygen by weight, then one pound of coal requires $2.182 \times \frac{100}{23}$ lb. air for complete theoretical combustion.

$$= 9.487 \text{ lb.}$$

The products of combustion then are:-

$$CO_2 = 2.562 \text{ lb.}$$

$$H_2O = 0.36 \text{ lb.}$$

$$N_2 = 7.305 \text{ lb. (which was part of the 9.487 ibs. of air)}$$

2.8 Excess Air

One pound of coal is made up of many millions of molecules of Carbon and Hydrogen. The above example of the combustion of one pound of coal assumes that each individual molecule of carbon and ' hydrogen can easily come into contact with the individual oxygen molecules necessary for combustion. In practice within the boiler furnace this is not possible and it is necessary to supply more than the theoretical quantity of air.

The difference between the theoretical and total quantity of air is called excess air.

Only sufficient excess air for complete combustion should be supplied. Too much air results in waste due to the unused air and the extra nitrogen carrying heat away from the boiler. Too little air is also wasteful and results in some of the carbon in the fuel not being burnt.

2.9 Time, Temperature and Turbulence

The three T's - Time, Temperature and Turbulence are the three essential requirements for combustion in practice.

Time is necessary so that each individual particle of fuel remains in the furnace long enough for combustion to be completed.

Turbulence is necessary to bring the individual molecules of oxygen, hydrogen and carbon into contact with one another.

Temperature has been referred in Section 2.5 having reached the ignition temperature the individual particle of fuel may have its temperature further increased during combustion, but if its temperature drops below the ignition point, combustion will cease.

3 THE OPERATION AND MAINTENANCE OF LARGE BOILERS

3.1 Centralised Control

All modern boilers have a centralised control system mounted either on the boiler control panel or, in the case of unit plants, on the unit control panel. Centralised control assists the operator, but even with the most modern boilers it is not possible to operate entirely from the control panel.

The controls found on a modern boiler can be divided into three groups, those infrequently operated, those intermittently operated and those continuously operated.

3.1.1 Infrequently Operated Controls

This group includes the electrical control switches with their associated ammeters. The ammeters are the guide to the operator's actions and a knowledge of the normal ammeter reading is essential. When an auxiliary is switched on the ammeter first gives considerably more than normal reading and then falls back to normal. If the reading does not return to normal, it may mean that the auxiliary unit is defective. If a fan is started with its dampers in the wide open position, the starting load on the motor will be excessive and care should be taken to avoid this happening.

3.1.2 Intermittently Operating Controls

The equipment associated with this group includes dampers for air heaters, economisers, superheaters, and reheater bypass dampers. The most simple way of remotely controlling these dampers is by means of a hydraulic system. Various manufacturers' hydraulic systems are installed in the Board's Stations, a common type being the Lockheed System as shown in Figure 1. In this system a small pump transmits power by means of a hydraulic fluid to a piston which operates its associated damper. The movement of the piston transmits an electrical signal back to the control panel and gives the operator an indication of the damper position. Depending on the particular boiler, any number of dampers may be remotely controlled. The operating pump can be used to actuate any piston by selecting the appropriate valve on the control panel.

In the event of power supply being lost to the pump motor, hydraulic power can be transmitted by operating the hand driven pump. The head tank absorbs the contraction and expansion of the fluid within the system and does not require "topping up" unless leakage occurs on the system.

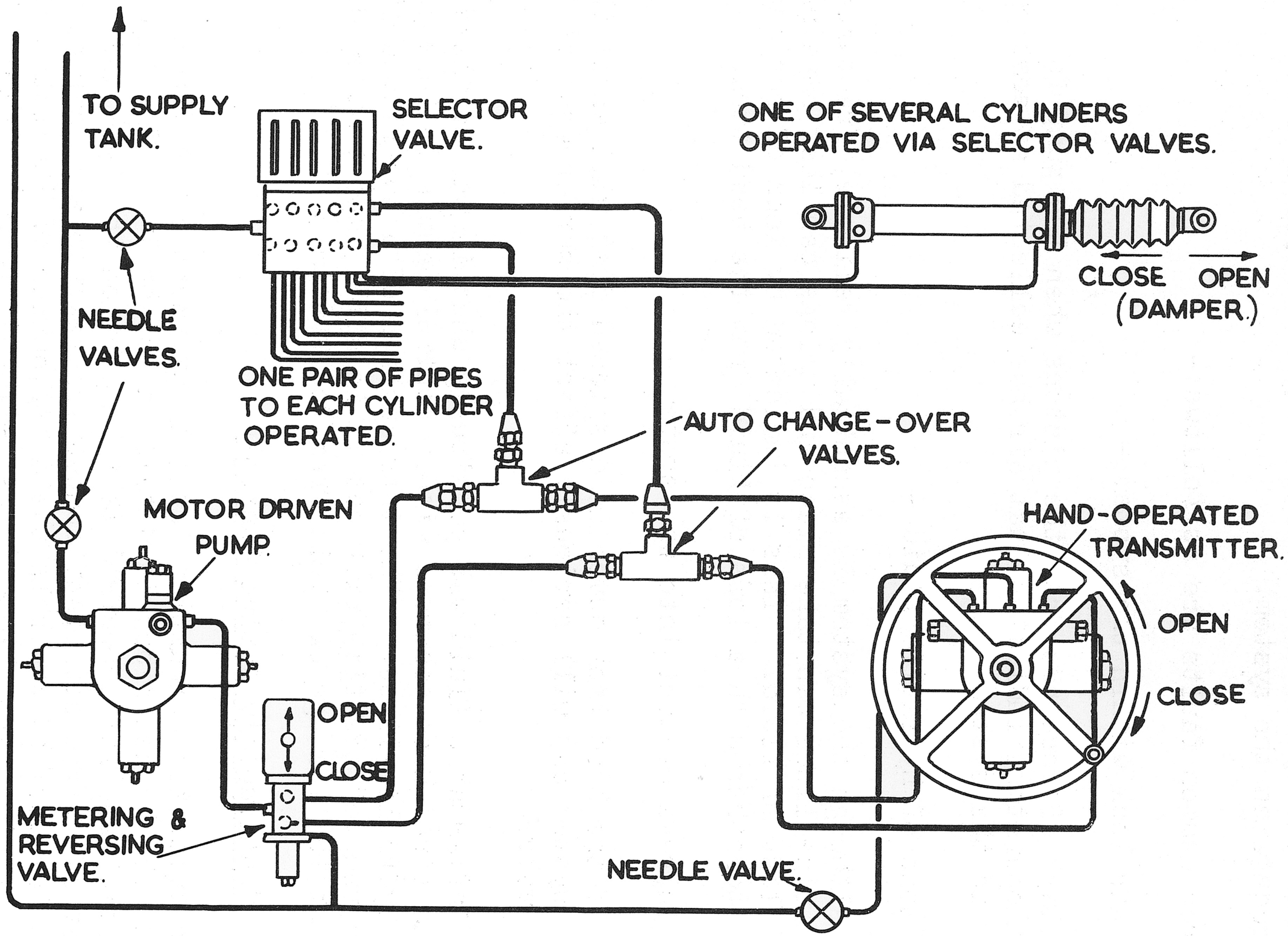

Figure 1: LOCKHEED HYDRAULIC REMOTE CONTROL SYSTEM

Three common faults are as follows-

(a) Air lock within the system-
Lack of response from the pistons when the pump is operating indicates that air has collected at some point in the system.

(b) Loss Of hydraulic fluid-
Although the system is essentially reliable, fracture of pipe lines can take place and unions can leak causing loss of fluid. This is indicated by lack of response together with a loss of fluid from the head tank.

(c) Ingress of dust into the system-
If the head tank cover is displaced dust will enter the system and will seriously affect the performance of the valves.

An inflammable fluid was previously used in the Lockheed system and fires have occurred within control panels to leakage from the hydraulic lines. The introduction of a non-flammable fluid has removed the fire risk but it is still important to detect and prevent the leakage of fluid from the system.

3.1.3 Continuously Active Controls

The automatic combustion control equipment comes within this group and will be described in detail in Lesson 15. The object of automatic combustion control is to apportion the fuel and air so that at all times efficient combustion takes place, but no system so far devised controls the distribution of the total air supplied, the operator himself must still do this. Steam temperature is continuously monitored and controlled and an example of this is shown in Figure 2.

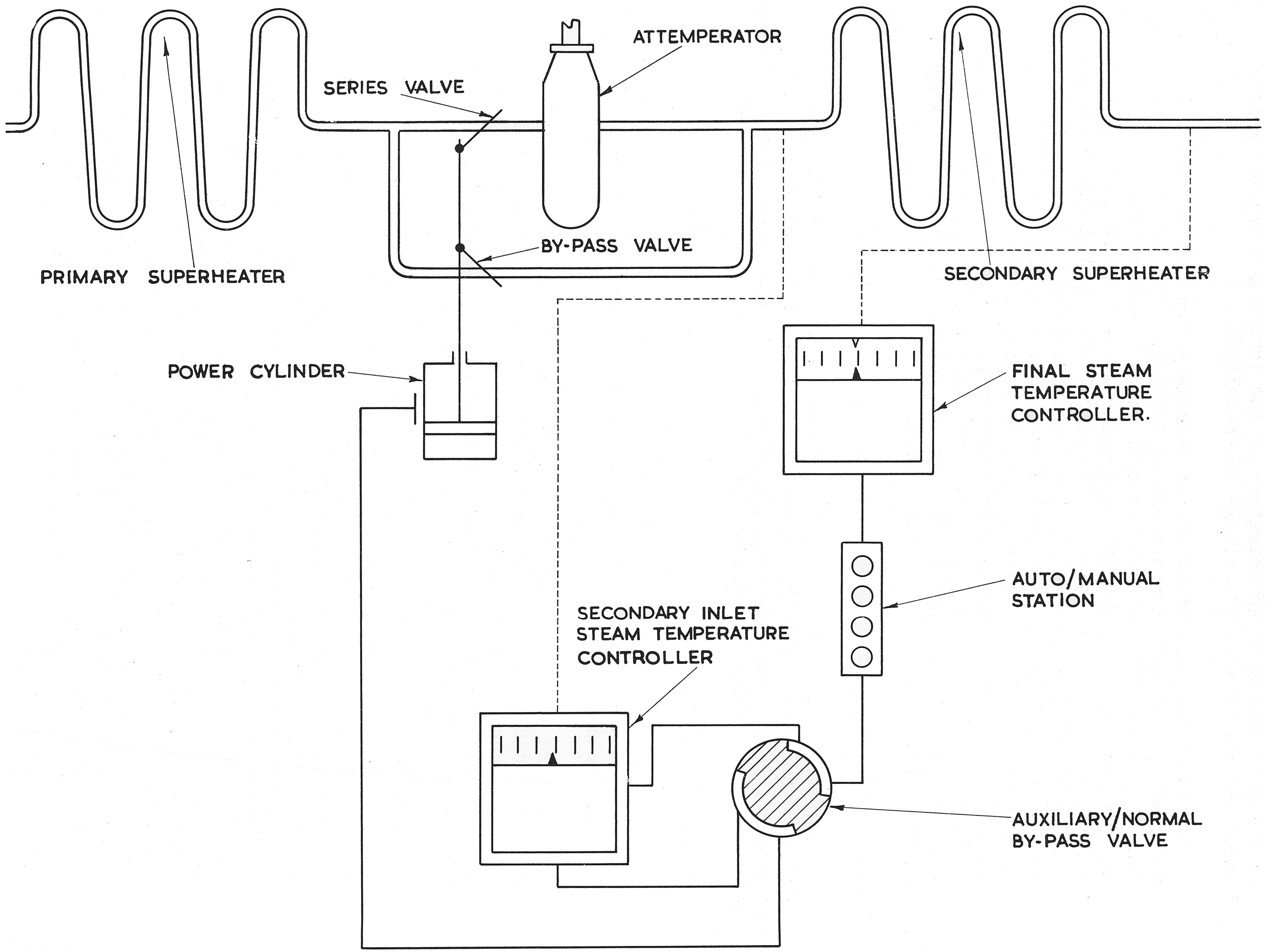

Figure 2: STEAM TEMPERATURE CONTROL SYSTEM

The attemperator and its by-pass are situated between the primary and secondary superheaters. Temperature control is effected by the combined operation of the series and by-pass valves which are positioned by a single power cylinder.

The steam temperature at the secondary superheater outlet is measured by the final temperature controller. The output signal from this controller sets the control point of the secondary superheater inlet temperature controller via the Auto/Manual station and the Normal/By pass valve. The output signal from the secondary inlet controller is relayed to the power cylinder. The normal/by pass valve is included to permit direct manual control from the auto/manual station. Illustrations of typical modern boiler control panels incorporating the features mentioned above are shown in Figures 3 and 4. The former illustrates the steam range type of control panel whilst the latter shows the boiler control section of a unit installation.

3.2 Starting Up

The three basic limitations which are imposed on any pressure raising technique are safety, drum metal differential temperatures and economiser, superheater and reheater metal temperatures, and these will now be considered in greater detail.

3.2.1 Safety

No attempt should be made to raise pressure on a boiler unless all permit-to-work cards are cancelled and clearance is given by the Engineer in charge.

Before commencing any operational work the condition of the boiler should be checked for valve positions, free damper movement, correct damper positions and that all air and gas duct access doors are securely fastened. The boiler should then be filled to a level just showing in the bottom of the gauge glass.

Having started the I.Do and F.D. fans and set the dampers for lighting up, the lighting-up oil burners can be inserted. If ignition of the oil is not obtained immediately the burners must be withdrawn and the furnace purged by the use of the fans for approximately five minutes to get rid of any oil vapour. The lighting up burners must be in use long enough to raise the furnace temperature sufficiently before commencing the main fuel firing. Also in both oil fired and P.F. fired boilers, it is necessary that the correct temperature should be obtained at the burners or mills respectively before attempting to commence firing. If the main fuel does not ignite, the possibility of an explosion will arise which may damage baffles and casings and eject hot dust and gases into the boiler house. It is necessary for flame stability to be checked frequently during the pressure raising period and in the event of loss of ignition at any time the furnace purging technique must be carried out.

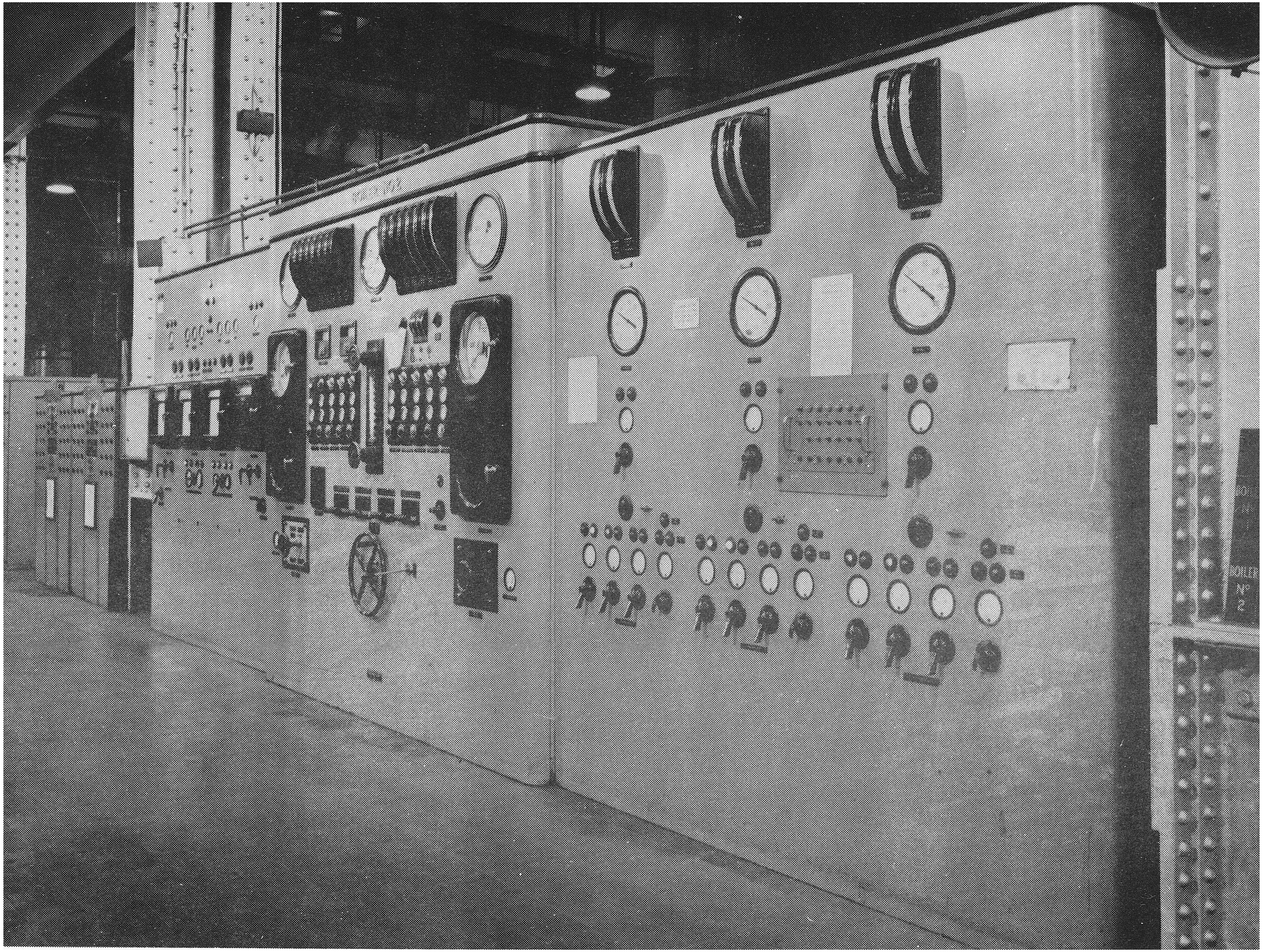

Figure 3: MODERN BOILER CONTROL PANEL. RANGE BOILER

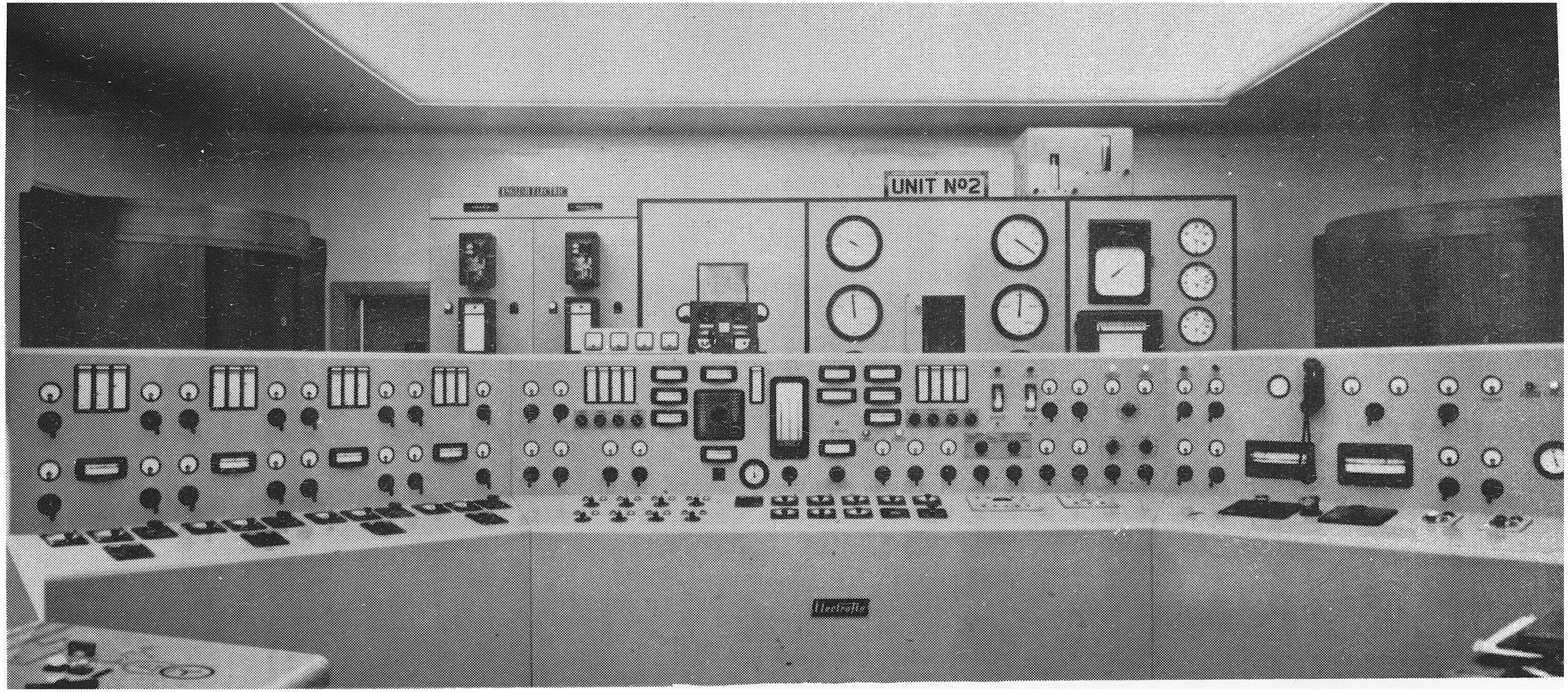

Figure 4: MODERN BOILER CONTROL PANEL, UNIT INSTALLATION

3.2.2 Drum Metal Differential Temperature

It has been known for a number of years that it is necessary to protect drums against thermal stresses caused by differential temperatures. This becomes increasingly important as drum wall thickness increases with the higher pressure boilers. The permitted differential temperatures across the drum may govern the time taken to raise pressure on a boiler. To control differential temperatures to safe limits, an increase in saturation temperature of 67°C. (120°F.) per hour has been applied in the past, but recent investigations in America and elsewhere have shown this limitation to be too conservative and whereas three and a half hours have been necessary to bring a cold 900 p.s.i. boiler up to full pressure, it is now regarded as safe to do this in one hour. In America, where this is now widely practised, no ill effects appear to have resulted.

3.2.3 Economiser, Superheater and Reheater Metal Temperatures

Economisers
Most modern boiler economisers are equipped with a recirculating connection. This recirculating connection should be opened during the pressure raising period and ensures that natural water circulation takes place within the economiser so preventing the formation of static steam bubbles which could lead to overheating of the tube metal.

Superheaters
The complete steam output of a boiler passes through the superheater when the boiler is on load and although under these conditions the superheater may have gases up to 1,093°C. (2,000°F.) passing the tubes, the steam flow within the tubes keeps the metal temperature to safe limits. However, during the pressure raising period the only.flow through the superheater tubes is that which passes to the drains and is only a very small proportion of the full load steam flow. During this condition it is possible for excessive metal temperatures to occur if the firing process is not strictly controlled.

In the pendent type superheater water may lie in the bottom of the loops so preventing any steam flow and this must be evaporated without exceeding safe metal temperatures.

The safe metal temperatures will be dependent on the type of metal used in the superheater construction and some examples are shown in Table 5 below-

Table 5:

	Max. Working Metal Temperature	
Tube Material	**°C**	**°F**
Carbon Steel	482	900
½% Molybdenum Steel	538	1000
1% Chromium ½% Molybdenum Steel	566	1050
2¼% Chromium 1% Molybdenum Steel	593	1100
18% Chromium 11% Nickel (Austenitic)	649	1200

It is, therefore, necessary to know either the temperature of the gases passing the superheater or better still, the tube metal temperature especially during the pressure raising period. Gas temperatures can be measured by traversing the superheater chamber with a long thermometer probe which is connected to an indicating and/or recording temperature instrument.

Thermo-couples can be attached to the superheater tubes which when connected to a suitable instrument will record the metal temperature.

Reheaters
The reheaters in modern boilers are placed in various positions in the gas passes according to the particular boiler design. They may be of the fully radiant, combined radiant/convection, or fully convection types. In all cases, however, there is no steam flow through them until the associated turbine is taking steam. It is vital that the metal temperatures should not rise above the safe limits. Where reheater bypass dampers are installed, they should be fully open until the turbine is taking steam.

It is the usual practice during the commissioning period on a new boiler for a safe pressure raising technique to be determined by the manufacturer, taking into account the above limitations. This technique will vary from boiler to boiler but whatever technique is established must be rigidly carried out. Operating experience or changes in the load requirements may in time dictate a change in the pressure raising technique.

3.3 Shutting Down

3.3.1 Emergency Shut Down

Emergency shut down can arise from two main causes:-

Factors external to the boiler such as sudden loss of turbine load or a serious failure of the boiler pressure parts.

Loss of Load
Rapid loss of turbine load will result in a sudden increase in boiler pressure causing the safety valves to lift. Firing must be stopped as rapidly as possible under this condition as safety valve seats may distort under prolonged flow and much condensate will be lost, apart from the noise nuisance created.

When the burners have been extinguished, a quantity of fuel will remain in the mills and these should be purged as soon as possible to prevent the possibility of mill explosions. I.D. fans must be kept running until the. whole fuel and gas system is completely purged. The drum water level should be maintained.

Failure of a Boiler Pressure Part
In the event of a serious failure requiring, the boiler to be shut down immediately, the following procedure should be adopted:-

(a) Cease firing.

(b) Stop forced draught fans.

(c) Stop flow of feed water to boiler.

(d) Shut boiler stop valve.

(e) Adjust induced draught fans-to the minimum level which will prevent the escape of water or steam from the boiler casing.

(f) Purge mills of any residual fuel.

The flow of water should be immediately stopped to prevent damage by comparatively cold water to the hot metal parts of the boiler. Residual heat in a modern boiler is very small and overheating is unlikely to arise from this. The above procedure applies to P.F. and oil fired boilers only. In the case of a stoker fired boiler, the drum water level should be maintained until the fires are run off the grate or extinguished.

3.3.2 Normal Shut Down

When shutting a boiler down for a short period owing to load requirements, the aim should be to conserve as much heat in the boiler as possible.

After purging the mills of all residual fuel content, I.D. fans should be stopped and all-gas and air duct dampers should be shut. On boilers equipped with rotary type-air heaters, it may be necessary to-keep these running, as this type of air heater may seize if stopped whilst the boiler is still hot.

Where the boiler is not shortly required for further service and is to be cooled, there is no danger in cooling it as rapidly as possible, subject to the procedure laid down to safeguard drum temperature differential. The cooling process can be accelerated by running the I.D. fans on maximum loading. As the boiler cools, the load on the I.D. fans may become excessive due to the cold air being handled and the ammeter readings must be frequently noted, cutting the fan loading back as indicated by the reading.

If the boiler is to be out of service for a period, all soot blowers should be operated prior to the boiler coming off load and all ash and dust removed when the boiler is off load.

Where the boiler is to be emptied, blow downs should be opened at 30 p.s.i. Air cocks must be opened at this pressure whether the boiler is to be emptied or not because failure to do so may produce a vacuum within the boiler, probably causing failure of cap and drum joints.

3.4 On Load Operation

The object of the boiler operator is to produce steam as efficiently as possible under standard conditions of temperature and pressure.

3.4.1 Nature of Coal

Coal consists of a number of elements, the two major combustible elements being carbon and hydrogen. Carbon is present partly in a free state and partly in combination with the hydrogen as hydro-carbons. These hydro-carbons are given the collective name of Volatile Matter and as coal is heated on entering the furnace, the volatiles distill off and burn with intense heat.

The volatile content of coals in this country varies from approximately 35% (Bituminous) down to as low as 6% (Anthracite).

This leads to the consideration of an important point in pulverised fuel firing, namely, flame propagation.

3.4.2 Flame Propagation

If a trail of gunpowder were ignited, the flame would travel along the trail away from the ignition point and the speed at which the flame would move is known as the "Rate of Flame Propagation".

Likewise as a stream of P.F. enters a furnace and ignites, the flame tends to travel back towards the burner at a speed equal to the velocity of the air fuel mixture at the burner nozzle and the point of ignition appears to be fixed at a point in space beyond the burner.

If the rate of flame propagation is less than the nozzle velocity, the ignition point will move away from the burner which will, be extinguished. Where the flame propagation rate is greater than the nozzle velocity, the point of ignition will move towards the burner nozzle and will probably damage the burner tips.

Factors which control the nozzle velocity and which should be carefully watched in operation are -

(i) Primary air/fuel ratio.

(ii) Mill load.

(iii) Quantity of secondary air supplied.

Flame propagation rates are affected by the following.

(i) Fineness of grinding
The surface area of a given quantity of coal will increase as the fineness of grinding increases and combustion will be more rapid and effective.

(ii) Volatile Content
As the volatile content of coal increases, ignition becomes more easy and rapid.

(iii) Fuel/Air/Temperature
The allowable temperature of the fuel/air mixture leaving the mill varies with the volatile content of the coal. The temperature should be maintained as near this maximum as possible as it encourages early ignition.

(iv) Secondary and Tertiary Air Temperature
Within permissible limits, these should be as high as possible.

(v) Furnace Temperature
If the furnace temperature is too low, ignition will be delayed or may not be obtained.

(vi) Air Supply
Too little, or badly distributed air will delay ignition and cause incomplete combustion. Too much air may have a similar effect by causing the flame to move too far away from the burners.

Within certain limits flame propagation rates are self regulating. By careful control of the factors mentioned, it should be possible to maintain the ignition point as near the burners as practicable without causing damage to the burners themselves.

3.4.3 Boiler Efficiency Losses

Boiler Efficiency Losses are grouped under four headings as follows:-

(i) Dry flue gas loss.

(ii) Loss due to incomplete combustion of carbon in the fuel.

(iii) Loss due to moisture in the fuel and the moisture arising from the combustion of hydrogen.

(iv) Radiation and unaccounted losses.

Items (i) and (ii) are under the direct control of the boiler operator and are considered in detail as follows:-

(i) Dry Flue Gas Loss

The temperature at which the gases leave the air heater affect the efficiency of the boiler and must be maintained as low as possible without reaching the dew point. Dew point is the temperature for a given boiler condition at which the moisture in the gases condenses on the heat exchanger or other surfaces forming, with the sulphur dioxide, a corrosive acid.

The magnitude of the loss can be seen from the curve shown in Figure 5. For a flue gas containing five and a half per cent oxygen, an increase in final flue gas temperature from 138°C. (280°F.) to 160°C. (320°F.) results in an increased boiler loss of over 1%. When this is applied to a medium sized modern boiler the increased fuel cost can be over £20 per day

Causes of abnormally high final gas temperature are as follows :-

(a) Furnace Slagging

Any slag deposited on the furnace walls will reduce the heat transfer at this point and cause the furnace exit temperature to rise. Slag can arise from a shortage of air creating a high furnace temperature resulting in the ash particles becoming molten and sticking to the walls. It can also be caused by flame impingement on the furnace walls.

Frequent inspection of furnace walls should be made so that corrective action cam be taken if necessary. Total air supply may be correct but the distribution of this air may be incorrect. If this is so, adjustment of secondary and tertiary air dampers must be made to produce a flame condition which fills the furnace as much as possible without flame impingement on the walls. Examples of the flame conditions brought about by various damper settings for a down fired boiler are shown in Figures 6 to 9.

(b) Faulty Sootblowers

Modern boilers are equipped with automatic sootblowers. The function of the sootblowers is to remove the deposits such as fly ash from the heat exchanging surfaces so as to maintain a high heat transfer rate. If a fault on a blower develops, which prevents the automatic operation of the blower, it..should be hand operated until repaired.

(c) Gas and Air Bypassing

Gas and air circuits have bypasses installed, controlled by dampers and incorrect setting of these dampers will cause a rise in final gas temperature. When checking the overall condition of a boiler, the damper positions should be noted and checked with the indicators (where fitted) on the control panel. Gas pass baffle walls are sometimes holed, causing bypassing with resulting high flue gas temperatures and where possible, these walls should be inspected during routine checking.

(d) Low Final Feed Water Temperatures When the feed water temperature to the boiler is below normal, the total amount of heat required to convert the water into steam will be increased and this would result in the final gas temperature being increased for any given loading.

(ii) Heat Loss due to incomplete combustion of carbon in the fuel

It must be realised that there is a difference between perfect combustion and complete combustion. Perfect combustion results when only the amount of oxygen theoretically required for the complete oxidation of the fuel is used and the whole of this oxygen is used in burning the fuel. Complete combustion also results in the complete oxidation of the fuel but does not necessarily mean that only the theoretical amount of oxygen required has been supplied.

In practice, perfect combustion of the carbon in the fuel is not possible, but the extent of complete combustion is more or less within the control of the operator. In P.F. firing, the percentage of carbon in dust is used as a measure of the loss due to the incomplete combustion of carbon, but for a given quantity of carbon so lost, this percentage will vary of course with the ash content of the coal as shown in Figure 10.

Factors which affect the carbon loss are as follows:

(a) Fineness of Grinding

Combustion is more rapid and complete when the coal is ground very finely. When coarse grinding occurs, Characteristic 'sparklers'. Will be seen dropping %6 the furnace bottom and will cause a high carbon loss.

(b) Excess Air

Any shortage of the required quantity of total air (theoretical air + excess air) for a given fuel input will result in unburnt carbon being deposited in the ash hopper and in the dust hoppers.

Samples of ash and dust are. taken at varying intervals in different stations to determine the carbon in dust. These may indicate the necessity for varying the quantity of excess air supplied but whilst doing this, the effect on the final flue gas temperature must be noted. The situation sometimes develops where a reduction in carbon loss increases the dry flue gas loss and a compromise has to be made.

(c) Air Distribution

The automatic combustion control system installed on modern boilers matches the total fuel requirement with the total air requirement. Distribution of air is determined by secondary and tertiary air damper settings which are not automatically controlled. These damper settings are varied according to the combustion characteristics of the fuel.

A low volatile coal requires a longer time to burn completely and the proportion of secondary to tertiary air is therefore smaller than when burning high volatile fuels. With the latter, ignition is rapidly obtained on leaving the burner and the fierce combustion of the volatile hydrocarbons adjacent to the burner assists the fixed carbon to reach ignition temperature and burn off much quicker with a shorter flame length than is possible with the low volatile coals.

Under these conditions, however, care must be taken to prevent the ignition point being too near the burner and secondary air may have to be increased to cause the flame to move further away.

(d) Smoke

The emission of smoke is an offence under the Clean Air Act. Smoke is comprised of very fine carbon particles and is a waste of fuel. It results from the incomplete Combustion of the fine carbon particles and hydro-carbons which have dropped below their ignition temperatures. One cause of smoke is admitting fuel to a burner without first admitting the correct air through the appropriate dampers.

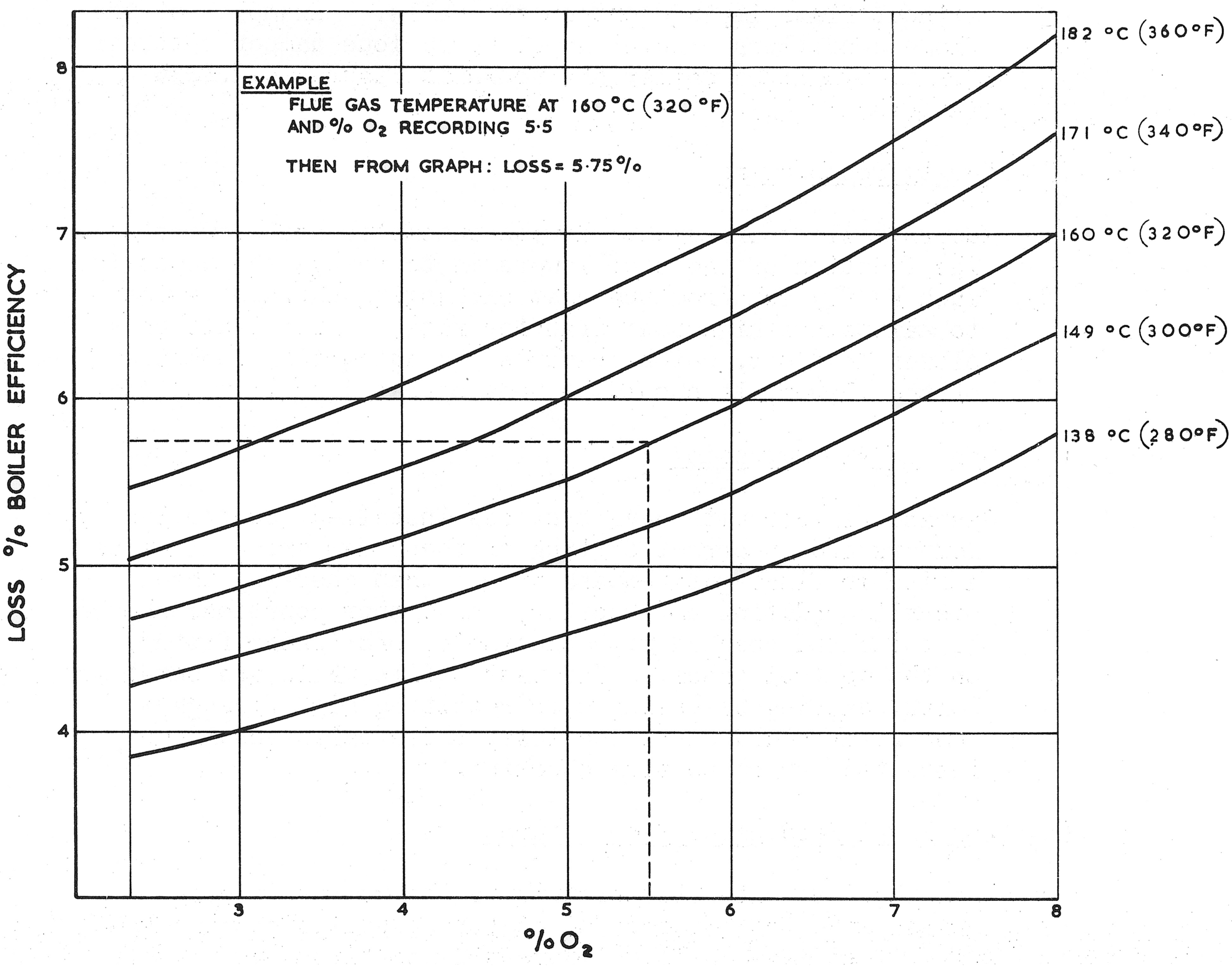

Figure 5: LOSS IN BOILER EFFICIENCY DUE TO DRY FLUE GAS LOSS

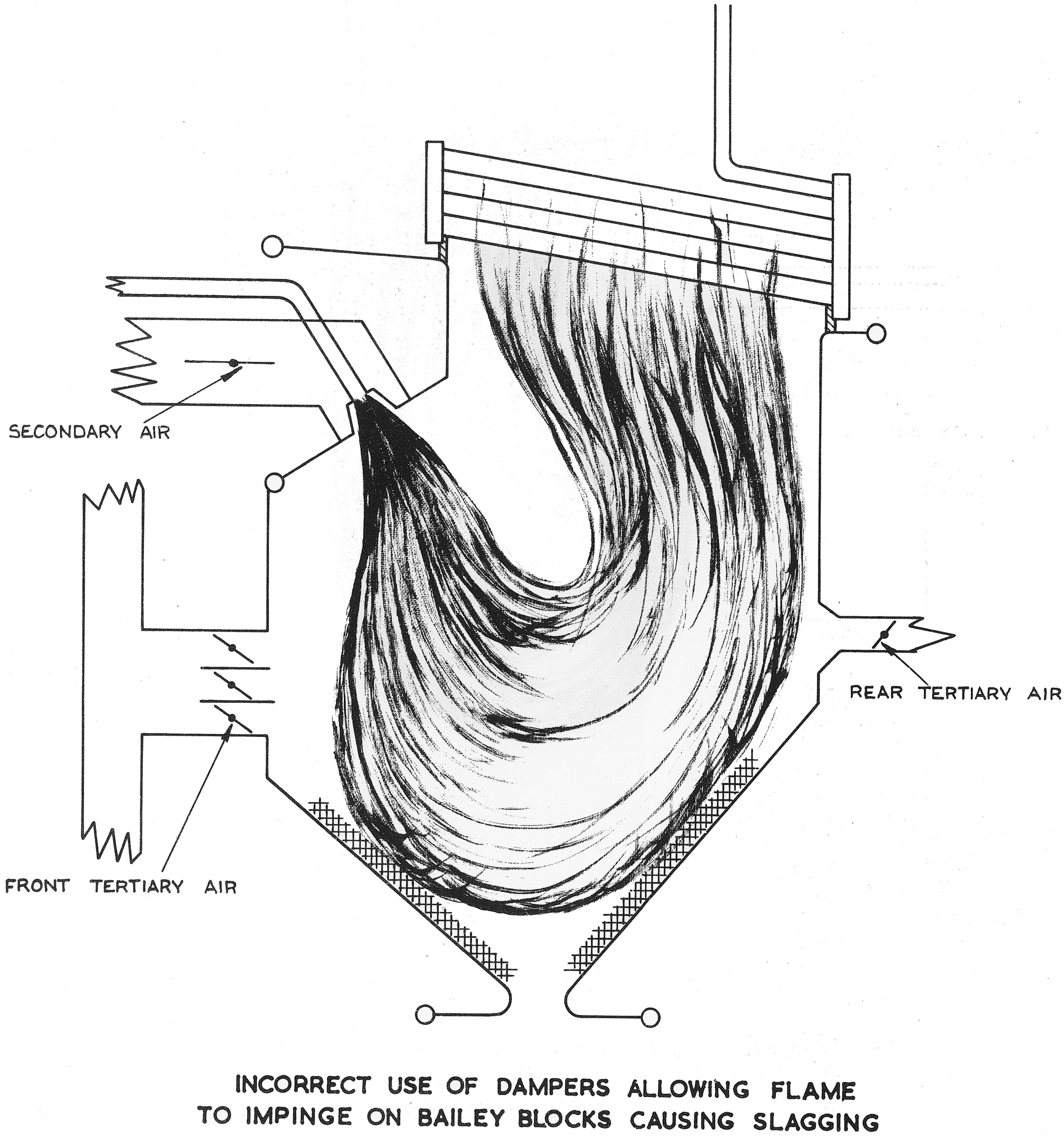

Figure 6: VARYING FLAME CONDITIONS WITH DIFFERENT DAMPER SETTINGS ON A DOWN FIRED FURNACE

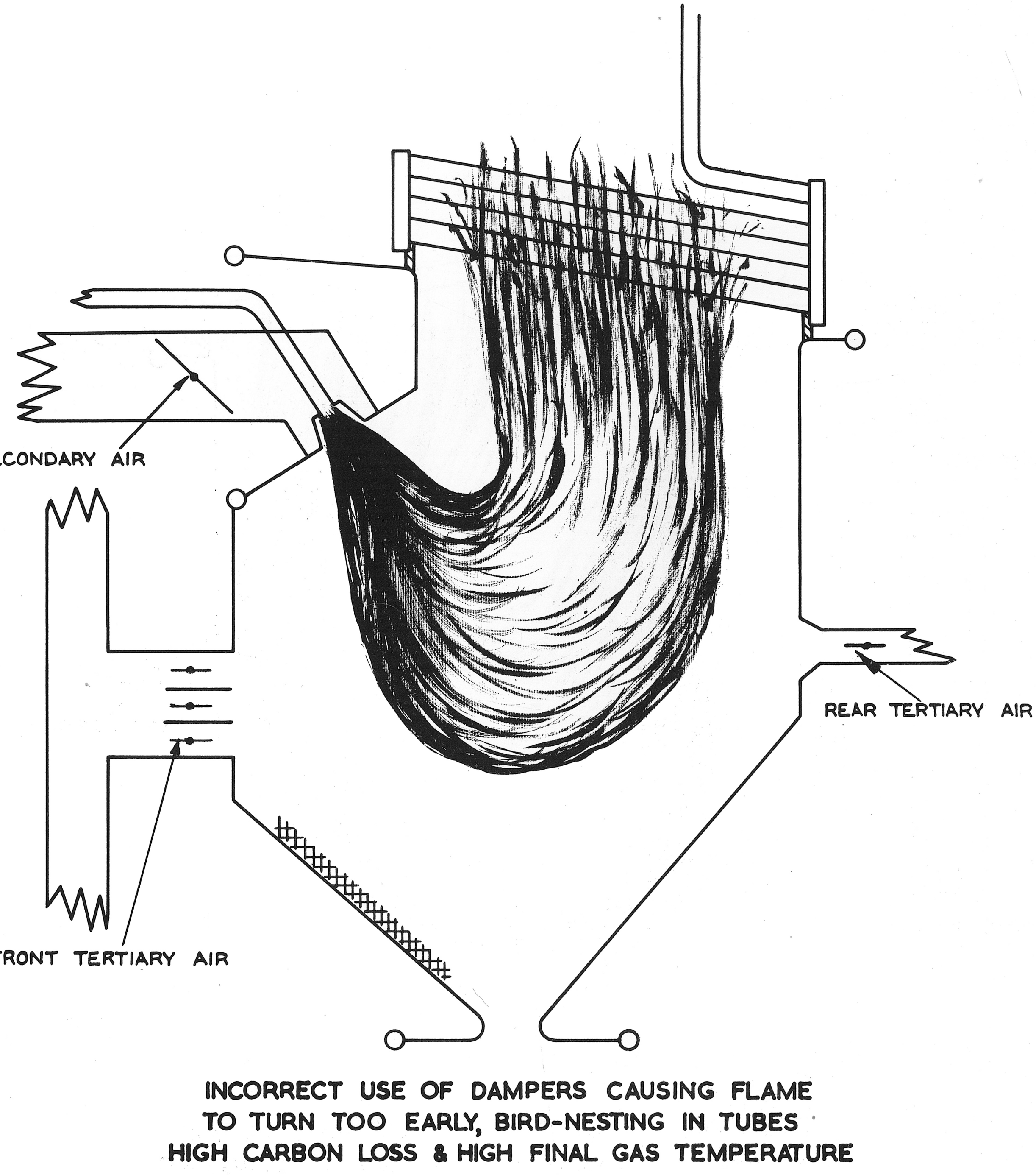

Figure 7: VARYING FLAME CONDITIONS WITH DIFFERENT DAMPER SETTINGS ON A DOWN FIRED FURNACE

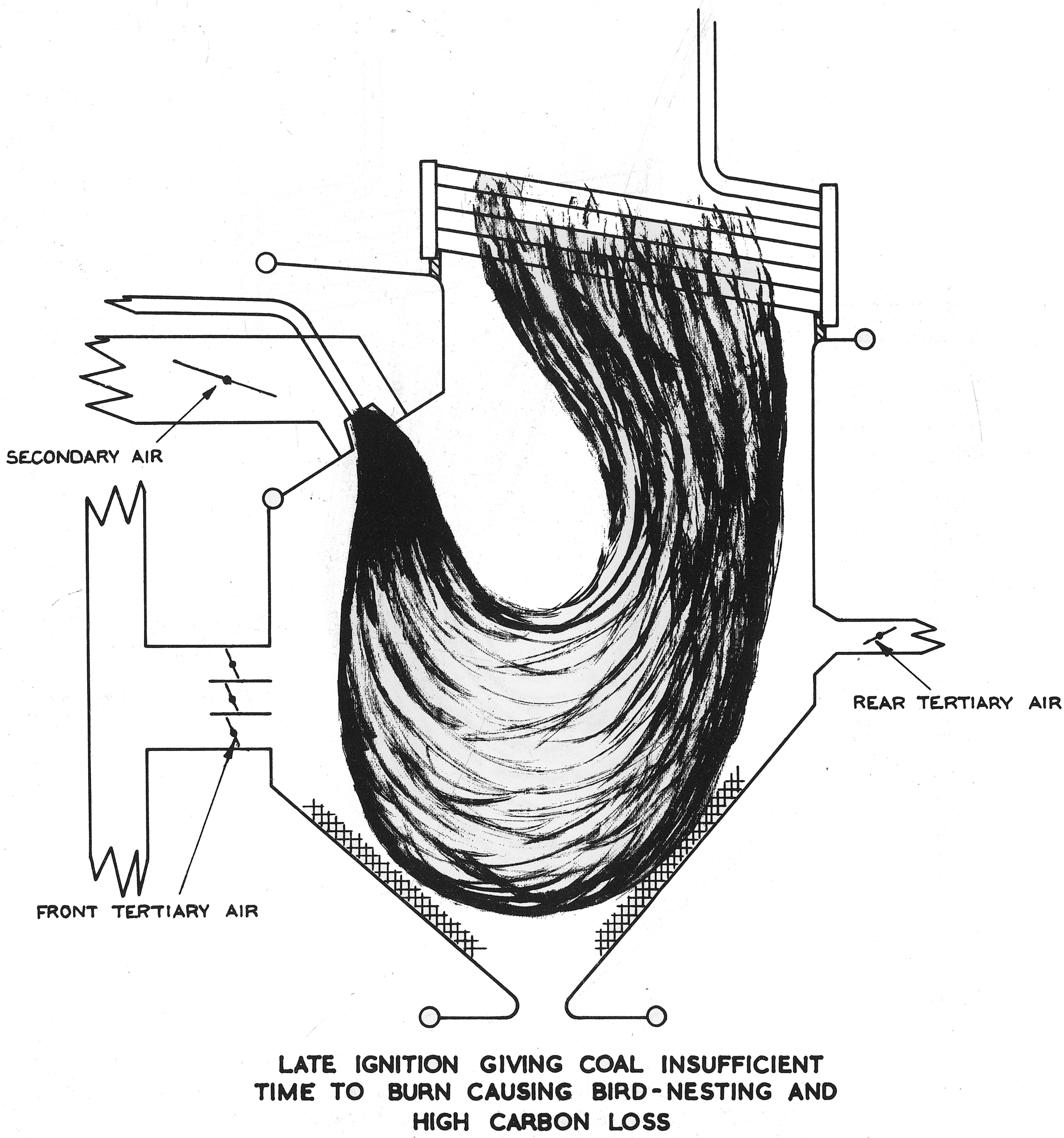

Figure 8: VARYING FLAME CONDITIONS WITH DIFFERENT DAMPER SETTINGS ON A DOWN FIRED FURNACE

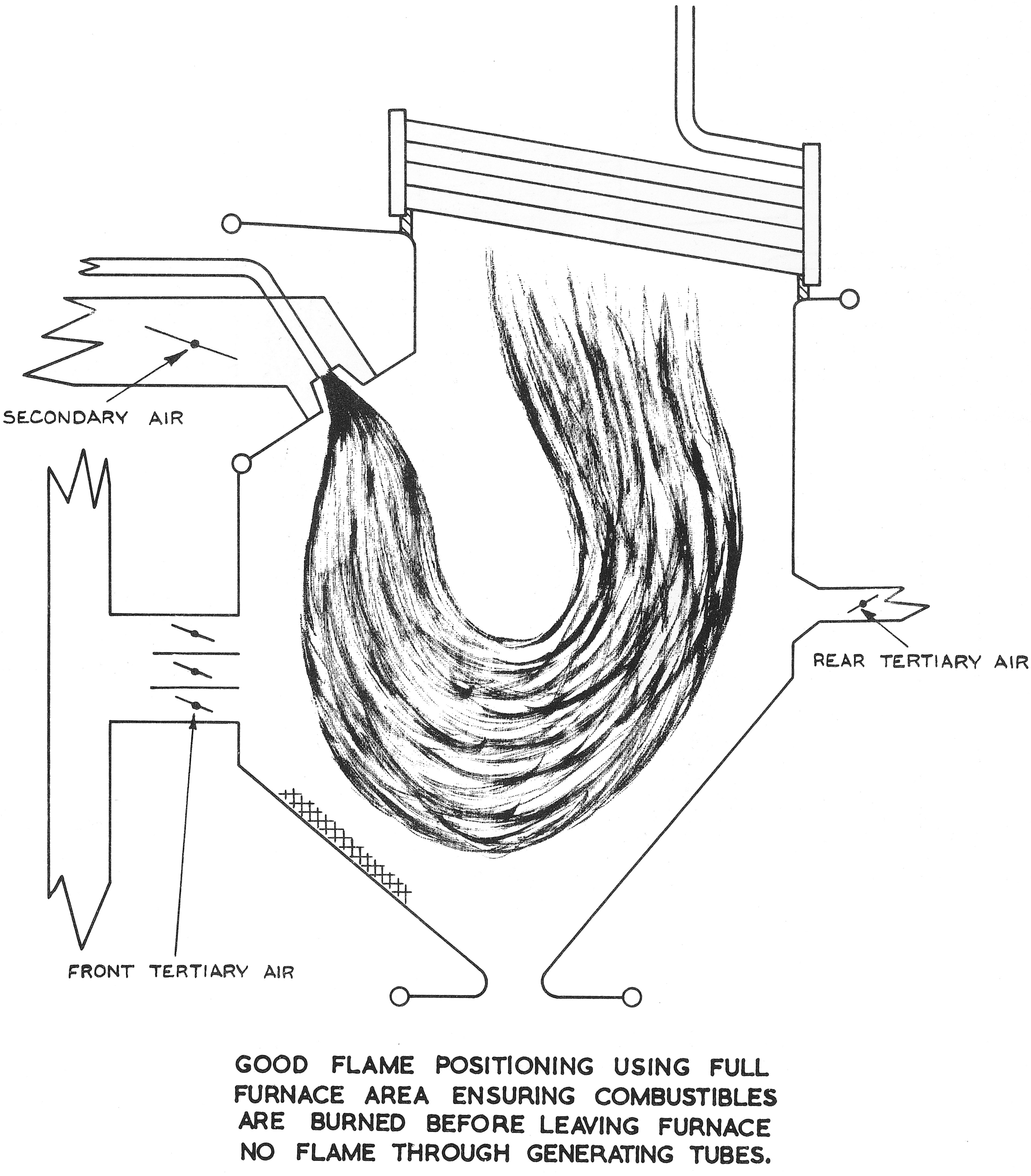

Figure 9: VARYING FLAME CONDITIONS WITH DIFFERENT DAMPER SETTINGS ON A DOWN FIRED FURNACE

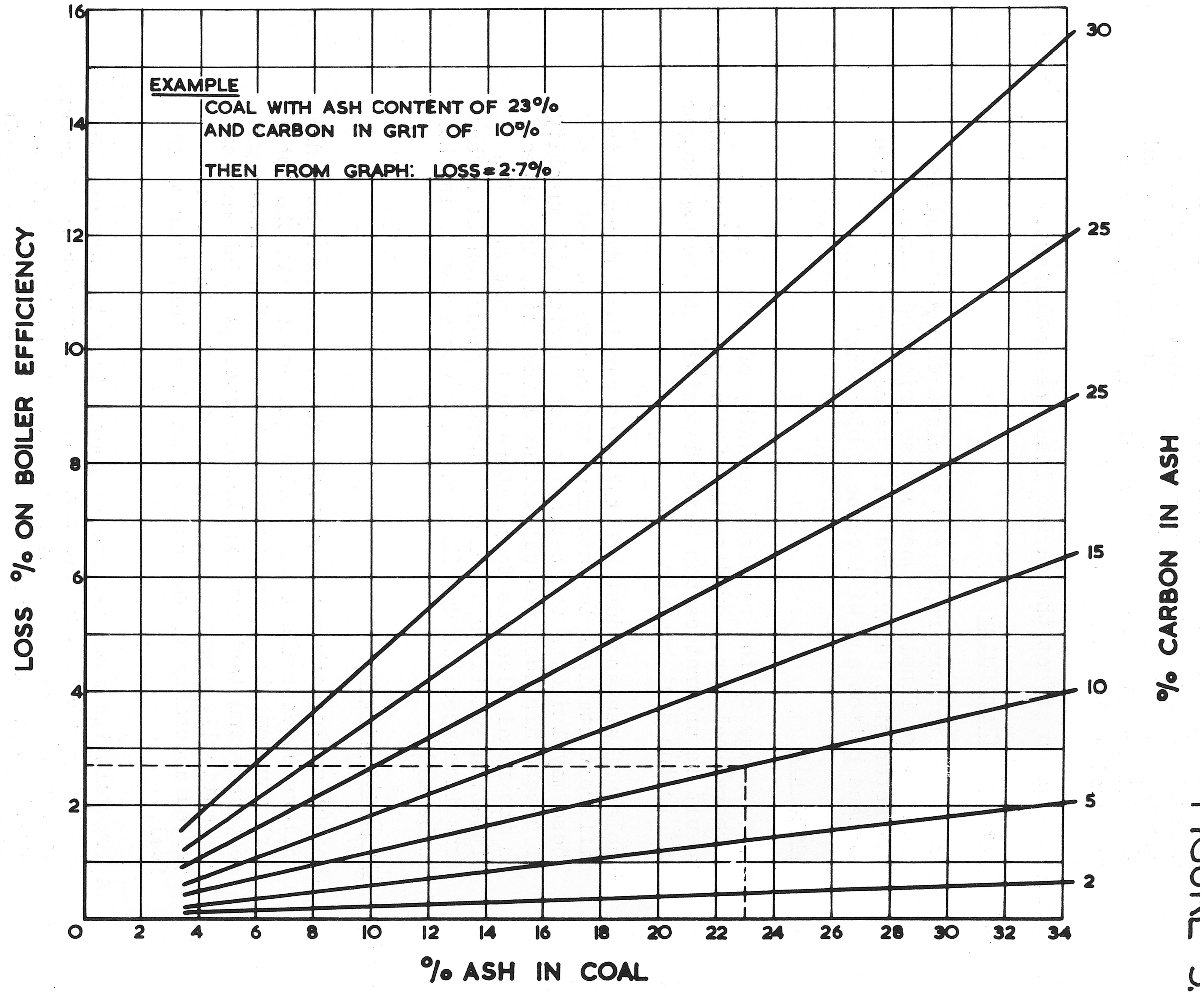

Figure 10: LOSS IN BOILER EFFICIENCY DUE TO CARBON IN ASH

3.4.4 Routine Checks

The practice of routine checks is common to all stations but the equipment included in these checks, together with frequency of inspection, will vary from station to station. Certain items are, however, common to all stations and are considered below.

Water Level
The water level in a boiler must be known to the operator at all times. For this purpose, remote and local water level indicators are installed.

The local gauge glass must be tested in the following sequence which will ensure accuracy and prevent damage:-

(a) Crack open drain valve for half a minute This allows the glass and fitting to gradually reach its maximum temperature.

(b) Close steam and water cocks and open wide the drain valve.

(c) Test steam connection by opening steam valve gradually to full open position and allow steam to blow through the drain cock. Close steam valve.

(d) Open water valve gradually and allow water to blow through drain cock.

(e) Close water valve.

(f) Close drain cock and open steam and water Valves. Water should promptly return to its true level. Any sluggishness of the water movement in the glass indicates blockage in the steam or water connections.

Bi-Colour Gauge Glass
The Bi-colour gauge glass is tested in the same way as the local gauge glass and the levels compared.

Remote Water Level Indicator
There are various types of these mamufactured, a common one being the Igema. The indicated level can only be checked by comparing with the local gauge glass. Any difference should be reported immediately.

High and Low Water Alarm
High and Low water alarms must be tested at least once weekly by adjusting the water level in the drum and should be checked by reference to the local gauge glass.

Feed Water Regulator
Automatic feed water regulators are installed to ensure as far as possible a steady water level in the boiler drum under all conditions. The Copes Regulator is an example and is installed in many stations. On modern boilers this regulator will be of either the two or three element type. The two element type is illustrated in Figure 11 and the principle of operation is as follows.

Thermostatic Tube Element (First Element)
The thermostatic tube element consists of a heavy metallic tube mounted on a base frame and set at an angle to the boiler drum. The top end of the tube has a connection to the steam space and the other end a connection to the water space of the drum. Thus the water levels

in the tube and drum are equal. One end of the tube is held fast to the frame by a tensioning handle whilst the other end is free to expand and contract and to this free end is attached a lever carrying a rod and a chain which passes around a sprocket on the G.A. valve control arm, so that any expansion or contraction of the tube results in a movement of the G.A. valve. The steam connection is lagged and the water connection un-lagged so that the steam supply to the tube is hotter than the water and the effect of a rise or fall in the drum water level is to increase or decrease the temperature of the tube, causing it to expand or contract and so operate the lever which opens or closes the G.A. valve.

Flowmatic Element (Second Element)
The flowmatic element consists of a spring stabilised rubber diaphragm housed in a suitable metal container° The diaphragm is connected to a rod which in turn has a lever attachment connected to a chain which runs over the G.A. valve operating arm sprocket and is then connected to the tension thermostat lever. One side of the diaphragm is subjected to boiler drum pressure and the other side to the pressure at the primary superheater outlet Header. As the pressure drop across the superheater increases or decreases so the diaphragm will move upwards or downwards actuating the rod, lever and chain attachments which operate the G.A. valve.

Both elements then, exert a controlling influence on the opening or closing of the G.A. valve and give a much steadier water level than is possible with the thermostatic tube alone as will now be shown.

When the rate of boiler firing is reduced, the gauge glass water level falls owing to the collapse of steam bubbles in the system. Simultaneously the pressure drop across the superheater is reduced by the fall off in load. Remembering that the water levels in the drum and Copes thermostat tube are at all times equal, the lowering of water level in the tube follows that of the drum. This allows more steam to enter the tube which then expands, so operating the lever to open the Go.o valve.

The pressure drop across the superheater being reduced by the fall off in load, reduces the pressure at the drum pressure-side of the Flow-matic diaphragm allowing the spring on the other side to expand and move the diaphragm downwards. This movement is transmitted through the rod, lever and chain to restrict the movement of the G.A. valve caused by the. operation of the thermostat and bring it toward the closed position, thereby preventing water surging in the boiler drum. The procedure is reversed when the rate of firing is increased.

When a two element Copes Regulator has been out of service and steam and water connections have been isolated the following procedure should be adopted for recommissioning.

Care must be taken when operating Valves A, B and C to prevent the controller diaphragm from being subjected to more than the pressure difference across the superheater.

Pressure must never be admitted to one side only of the controller and the three valves should never all be open at the same time.

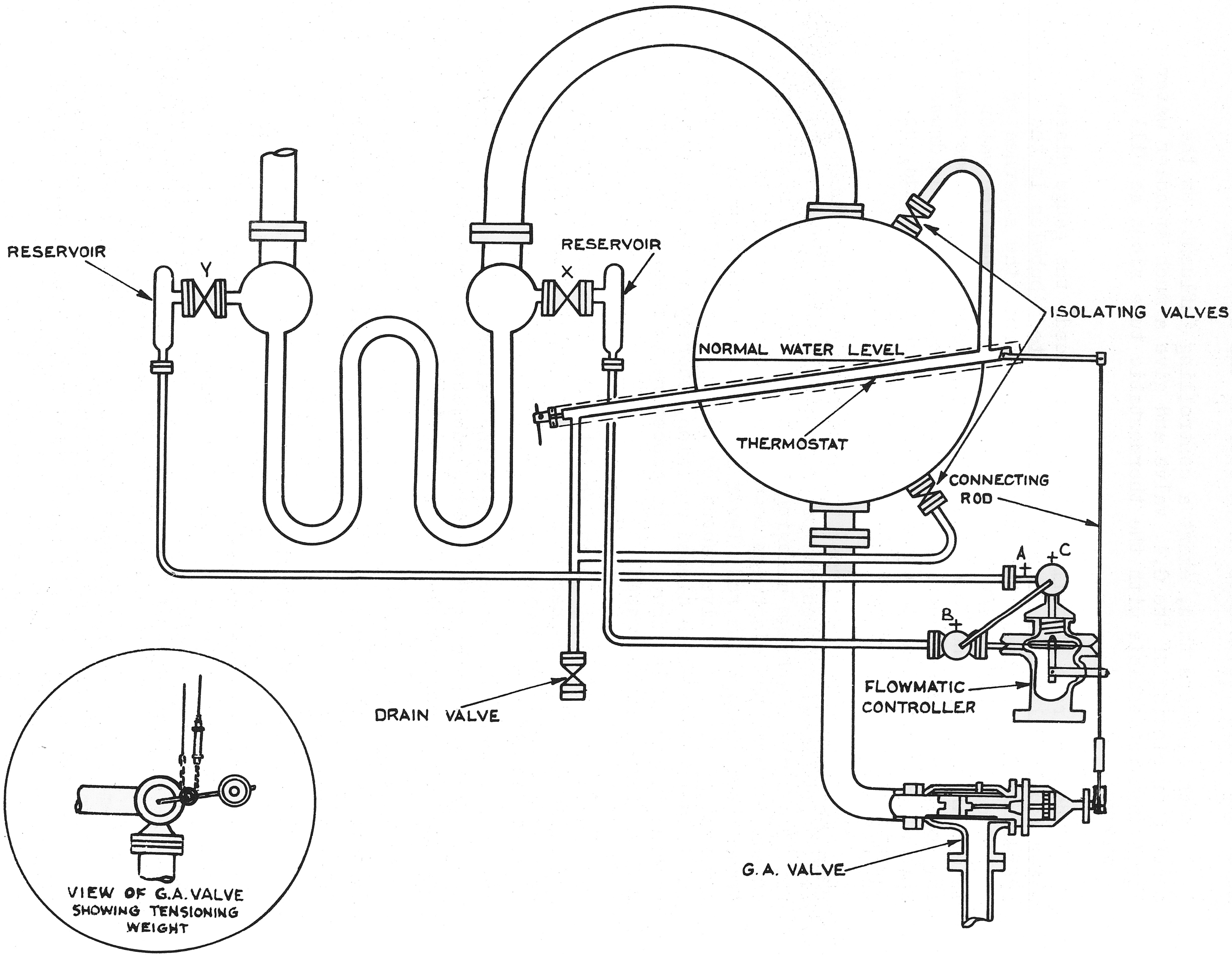

Figure 11: COPES TWO ELEMENT FLOWMATIC WATER LEVEL REGULATOR

Whilst the boiler is steaming with the feed being hand controlled, open the equalising valve (C) after ensuring valves A and B are shut. Crack valves X and Y at superheater inlet and outlet. The two reservoirs will now commence to fill with condensed steam. Allow ample time to fill. Now. crack valve B, allowing pressure to both sides of the diaphragm.

Remove the two air release plugs on the controller whilst it is filling until water escapes. Replace plugs. Fully open valves X and Y, crack valve A, shut valve C and fully open valves A and B.

Blow through the steam and water lines separately for one minute by fully opening the drain valve and just cracking in turn the isolating valves. Now close drain valve and fully open isolating valves.

Allow twenty minutes for the thermostat tube to reach its working temperature.

Place the cam handle at the end of the thermostat tube in the vertical position. Whilst tightening the inner adjusting nut at the lower end of the thermostat, the check valve in feed line to the G.A. valve should be slowly opened until fully open. Close watch on the water level should be made during this operation.

The regulator is now in commission but the controlled water level may require further adjustment. If level rises above normal, the inner adjusting nut should be tightened. If level falls, slacken nut. The nut movement is critical and should not be moved more than one sixth of a turn at a time. The effect should be observed before making further adjustment.

Whenever the boiler is shut down, the cam handle should be placed in the horizontal position to prevent strain on the thermostat tube when it cools.

If no work has been carried out on the regulator, it should be placed into service as follows.

With the feed flow under manual control, place the cam handle in the vertical position. Gradually open the check valve to the G.A. valve whilst closing in the other feed valve until the G.A valve takes over control of the water level.

The thermostat steam and water connections should be blown through at weekly intervals. Whilst doing this, the check valve in the feed to the G.A. valve should regulate water flow until the thermostat has reached its working temperature again.

It is necessary on boilers of say 550,000 pounds per hour and above for the water level control to be very sensitive and rapid. The three element regulator (illustrated in Figure 12) meets this requirement. Water level, steam flow and water flow are metered and signals from the metering units are summated and balanced on a special standardising relay. The output signal from this relay actuates a slave unit operating the water regulator valve.

Safety Valves

Safety valves are installed to protect boilers against excess pressure. Superheater outlet safety valves must lift at a lower pressure than drum valves to ensure that there is a flow of steam through the superheater under excess pressure conditions. When the pressure returns to normal after valves have lifted it is vital that the valves should seat tightly as leakage will cause damage to the valve seats. Safety valve tightness should be noted during routine inspection of the boiler.

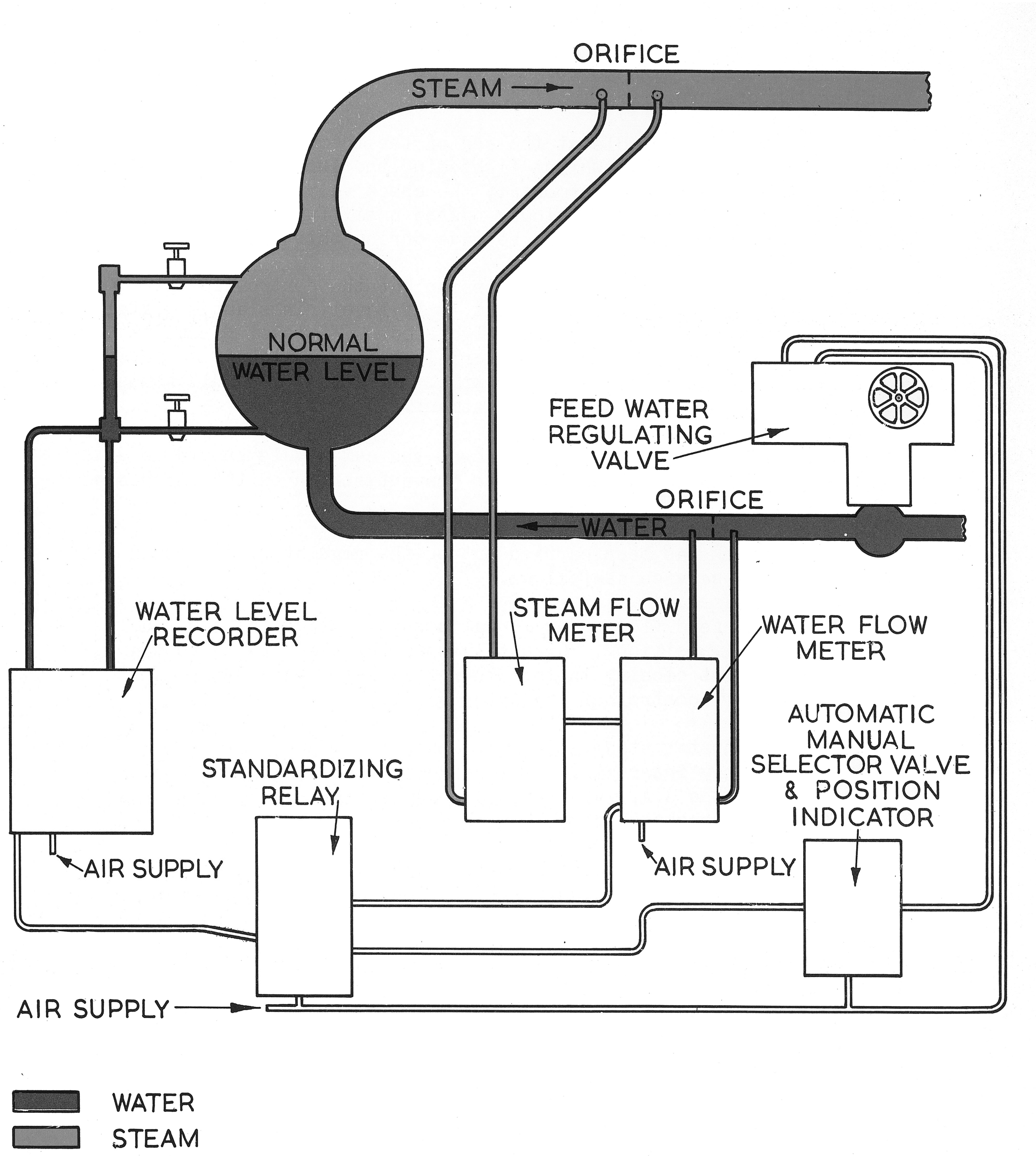

Figure 12: COPES THREE ELEMENT TYPE FEED WATER REGULATOR

Boiler Water
The Station Chemist takes frequent samples of boiler water and if necessary, dependent on his analysis, requests the injection of chemicals into the boiler and/or blowing down.

Valves
The condition of the boiler must be checked at least once per shift, including the condition of valves. Where two valves are fitted in series, the valve nearest the pressure is regarded as the isolating valve, whilst the other is the regulating valve. The isolating valve must be either fully open or fully closed, whereas the regulating valve can be used for throttling. The use of valves in this manner gives a reasonable assurance of one valve remaining tight for isolation purposes.

Sequence Operation
The auxiliaries on modern boiler installations are started in definite sequence and are interlocked electrically. This arrangement ensures the safety of the plant. Figure 13 illustrates a form of sequence interlocking for a P.F. fired boiler. The loss of any auxiliary in the sequence would cause operational difficulties and danger if the other auxiliaries kept running. Electrical interlocking ensures that all these auxiliaries will trip in the event of trouble on any of them.

Periodic testing of the sequence tripping should be carried out by tripping a particular auxiliary out of sequence during shutting down of the plant.

3.5 Remote Control of Valves

Many of the valves on the modern boiler are operated remotely from the main control panel. The drive is usually electric but may also be by air or hydraulic means through a clutch. Means of de-clutching is provided in the event of power failure. Limit switches are fitted which prevent the valve travelling beyond its fully open or fully closed positions. The time taken for any remote operated valve to close will be known to the operator by experience and in the event of this time being exceeded the drive should be stopped and the valve inspected. The cause of the trouble, is likely to be either a slipping clutch or failure of the limit switch.

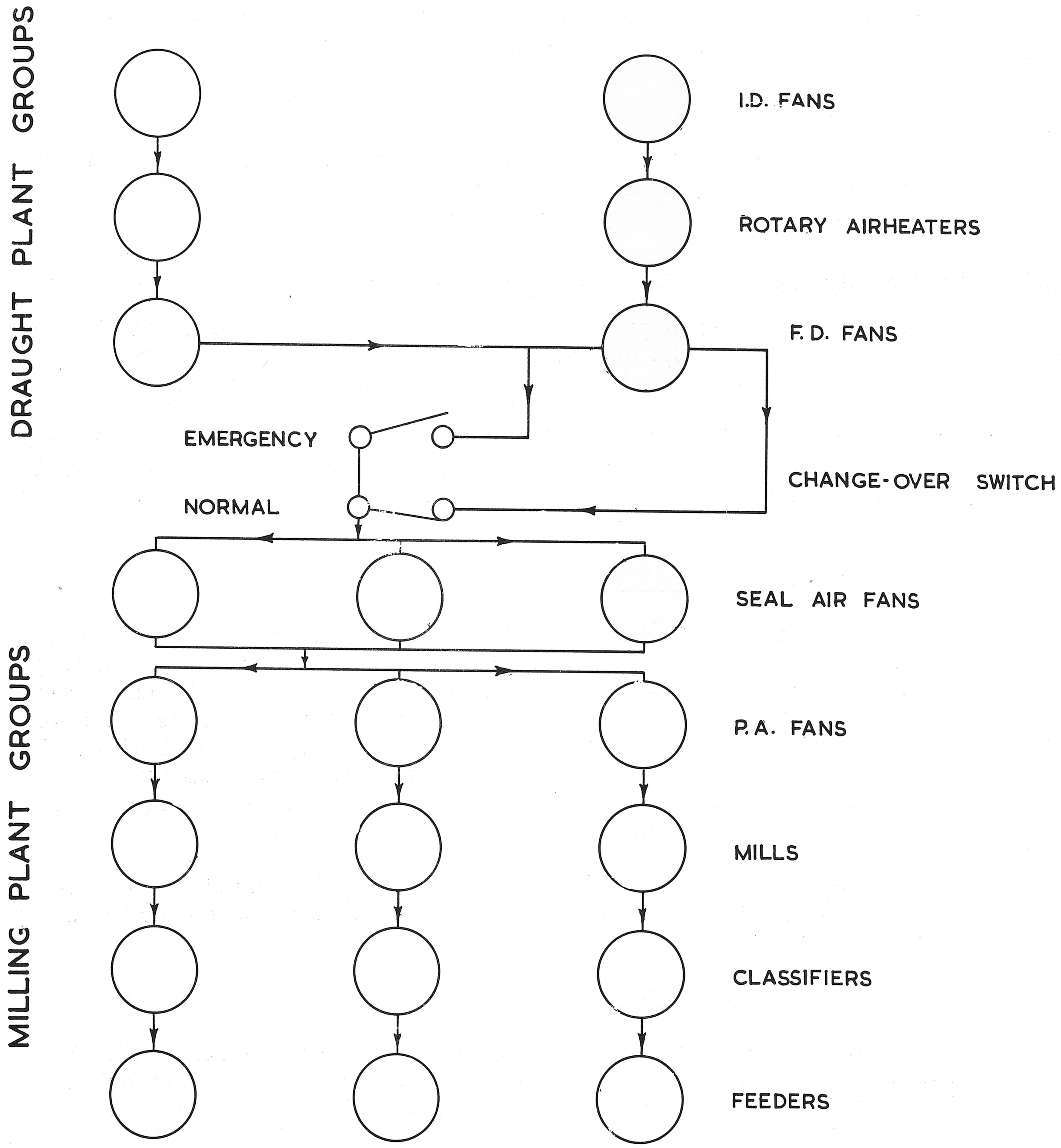

Figure 13: SEQUENCE INTERLOCKING OF BOILER AUXILIARIES

3.6 Valve Position Indicators

All valves are equipped with an indicator which shows the position of the actual valve. No attempt should be made to operate a valve beyond its indicated limits.

3.6.1 Parallel Slide Valve

Figure 14 illustrates a type of parallel slide valve. It will be seen that two discs are attached to the valve spindle, and depending on the pressure differential, one of these will press on one of the seats. As the pressure differential increases, the force tending to prevent leakage past the valve will increase. External force has no influence on this type of valve. The position indicator usually travels along the line of the valve spindle on a travelling nut giving external indication of the internal valve position.

3.6.2 Screw Down Non-Return Valve

This type of Valve allows flow in one direction only but, also allows the valve to be shut externally by means of the handwheel. Figure 15 shows that the internal section of the spindle acts as a guide to the valve. When the valve spindle is turned to the open position, flow through the valve will commence as the inlet pressure becomes greater than the outlet pressure. The valve will then open guided by the spindle. It follows that the external, valve indicator, when in the open position, is not necessarily proof of the valve being open. On the other hand, if the valve is screwed down on to its seat, effective isolation is obtained.

3.6.3 Uniflow Type Valve

This is another type of self-seating non-return valve, depending on differential pressure for tightness. It will be seen from Figure 16 that the valve when operated travels through 180° across its valve seat. The spring shown in the drawing applies only a moderate force to ensure that the faces rub one another during travel so tending to clear any fine particles from between the faces. The indicator is externally attached to the spindle and carries numbers showing the extent of opening. This valve is frequently used for regulating purposes.

3.6.4 Valve Operation

All valves should be operated with care and newer over-strained. Wheel keys must not be used on valves as they are likely to cause internal and external damage.

Joint failures frequently arise from faulty operation of valves. The cause can be from either a thermal shock when a valve is opened suddenly or from water pressure shock (water hammer).

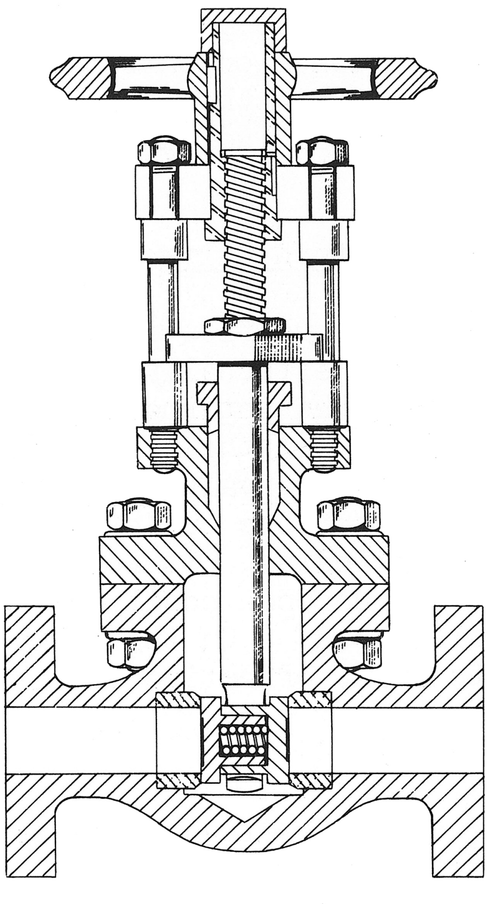

Figure 14: PARALLEL SLIDE VALVE

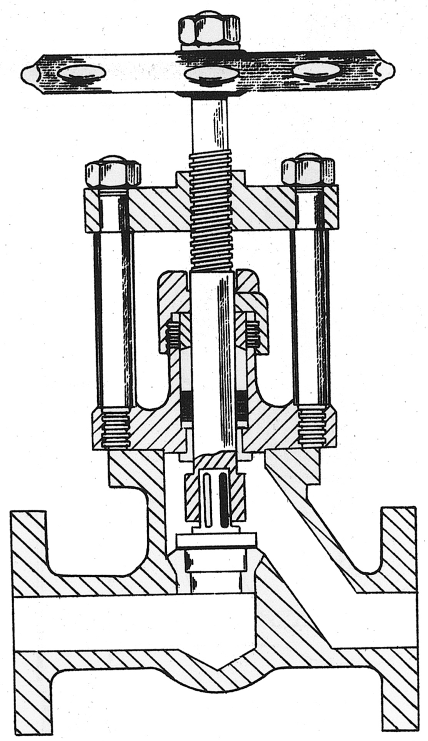

Figure 15: SCREW DOWN NON-RETURN VALVE

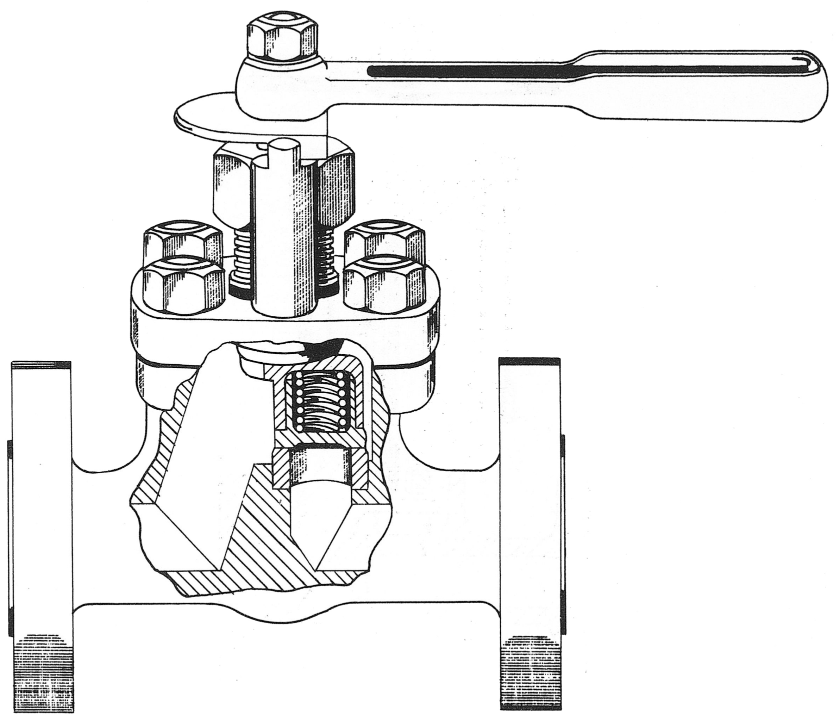

Figure 16: UNIFLOW VALVE

3.7 Operation Aspects of Maintenance

Operation and maintenance activities are interdependent on each other. Poor operation can create the need for maintenance and poor maintenance can in turn result in poor operation.

3.7.1 On Load Maintenance

All modern boilers are equipped with comprehensive sootblowing installations. The purpose of these equipments is to maintain the heat exchange surfaces in as clean a condition as possible. Blowers should be operated in a sequence starting at the high temperature zones and working towards the lower temperature end of the gas passes. The control of the blowers can be either by automatic sequential operation or by manual remote control from a panel associated with the boiler control equipment. Whenever possible, the individual blower action should be inspected to note that the blower travel and arc of action are correct. Any type of sootblower which travels into the gas pass during its action is prevented from overheating by the cooling effect of the steam. If the power drive fails during the operation of a sootblower head steam must be kept on whilst the head is manually withdrawn. Care must, however, be taken not to leave a blower with steam on in one position for any length of time as otherwise the jet will cause damage by cutting the tubes. Incorrect drainage on a sootblower installation can also cause severe tube erosion due to water impingement.

Where particularly bad deposits on tube surfaces occur, on load air or water lancing is sometimes carried out. This can be particularly effective in clearing deposits but only if the operation is carefully controlled. Damage to supports and refractories can result if the cold jets are allowed to impinge on these surfaces.

3.7.2 Off Load Maintenance

Immediately prior to a boiler being taken out of service, all sootblowers should be operated and all dust and ash hoppers should be emptied when the boiler is shut down. This eases conditions for maintenance work within the gas passes.

An internal inspection is then carried out including checking for signs of burner mal-alignment, sootblower impingement, extent and type of deposits.

The rate of fouling in boilers has been shown to be related to the cleanliness of the boiler on returning to service and, therefore, it is essential that all surfaces be cleaned down to the bare metal. The most effective way of doing this is by means of water Washing care being taken to prevent damage to refractories. Large quantities of water should be used so that any acids formed during the initial saturation are diluted and washed away. The boiler should be slowly and completely dried out as soon as possible after the washing is completed.

The statutory obligation of the Factories Act requires the examination of riveted drum boilers once every fourteen months. There are special regulations now under governmental consideration for the modern boilers having forged or fusion welded drums. The examination must be carried out by a 'competent person' and in the case of the Generating Board, a 'competent person' means a representative of an appropriate insurance company. He can and does often require much additional maintenance work to be carried out and certifies the safe Condition of the boiler including the witnessing of safety valve floating before the boiler is returned to normal service.

4 THE USE OF INSTRUMENTS

4.1 The Use of Instruments for the Supervision of the Boiler

Instruments are provided to assist and guide the operator. As with all forms of equipment they are subject to faults and errors. The operator should be aware of anticipated values from his knowledge of the boiler under varying conditions. Where these normal values have departed from the instrument reading they can often be crosschecked from other instruments installed on the same unit.

Two common types of error are frequently met on instruments, the zero error, or the reading which exists on the instrument when it should be reading zero, usually a constant error over the whole scale of the instrument and a variable error which can often be noted by reference to normally expected readings.

Instrument accuracy varies according to the requirements and type of instrument. For example a steam temperature indicating instrument with a range of 550°C. (1,022°F.) would usually have an accuracy of $\pm$ 0.25% of full scale deflection.

4.2 Indicators, Recorders and Spot Readings

Instruments have differing scales and they may be linear or nonlinear. In the case of the linear scale, the distance for a value at one point on the scale is the same as all other points on the scale. The non-linear scale, however, has varying distances for values at different points of the scale.

4.2.1 Indicators

Ammeters, pressure gauges and draught gauges are usually of the indicator type. The indicator on the draught gauge frequently moves between two points under the influence of the draught conditions and the average of the upper and lower limits is the correct reading.

4.2.2 Recorders

This group usually covers excess air expressed as either CO_2 or O_2, steam temperature, steam flow/air flow and water flow. These instruments are invaluable for studying boiler performance over any past period but can be rendered useless by allowing the ink to be badly smudged or in some cases allowing the ink-reservoir of the pen to become dry and these points should be carefully watched. The time scale of the charts should be corrected to true time whenever an error is apparent.

Some of these instruments may additionally have a controlling function. An example is the steam temperature recorder when acting as a control signal station to the steam temperature regulator.

4.2.3 Soot Readings

This type of instrument allows the indication on one instrument scale of a number of different temperature points but not more than one temperature point can be selected at a time. The indicator should be allowed to settle before a reading is taken.

All instruments have delicate mechanisms and rough handling and the penetration of dust can cause inaccurate readings and create defects.

5 THE IMPORTANCE AND INTERPRETATION OF READINGS

5.1 Steam Pressure

Turbine performance is partly dependent upon the pressure of steam supplied and deviation from the standard pressure is undesirable. For instance, for a certain type of 60 MW machine on full load, a reduction of one half per cent efficiency results when the pressure supplied is twenty pounds per square inch below standard.

The deviation from standard pressure on a boiler results when the heat input is unbalanced with the heat output. This can arise due to a rapid change in turbine load or a rapid change in the fuel supplied. Station load indicators (in the case of range installations) or unit load indicators will readily show the operator whether or not the cause of pressure deviation is external to the boiler.

5.2 Steam Temperature

Any steam cycle efficiency is greatly dependent on the correct final steam temperature being maintained and maximum efficiency Will only be achieved at this temperature. Care must be taken, however, not to exceed the permitted maximum temperature as metal damage may result to tubes, piping and H.P. turbine casings.

The variation of boiler final steam temperature can arise from any one of a number of causes or from a combination of them. Some of these causes are now discussed.

5.2.1 Fouling of Heat Exchange Surfaces

The effect of dirty heat exchange surfaces is to reduce the efficiency of heat transfer from gas to steam or water circuits. A dirty combustion chamber can result in increased steam temperature, whereas superheater fouling may reduce the steam temperature and, where a convection reheater follows, increase the reheat steam temperature. A check on gas temperatures together with visual inspection will usually give guidance as to the position of the fouled surfaces.

5.2.2 Gas Bypassing

All modern boilers have a number of gas passes separated by baffles and sometimes equipped with bypass openings controlled by dampers. Bypassing can arise from incorrect setting of dampers or from damaged and leaking baffles but in either case, the result will be too high gas temperatures after the point of bypassing. Here again the effect may be either an increase or reduction in steam temperature depending on the position of the heat exchange surface that is being bypassed.

5.2.3 Steam Temperature Regulating Equipment

Means of regulating final steam temperatures are installed on all modern boilers. They may be surface type attemperators, spray type attemperators, gas bypass dampers, tilting burners or a combination of some of these. They are usually automatically controlled and a fault in the control system can result in incorrect setting. Position indicators of the regulator setting are often fitted to the boiler control panel and a check on these sometimes indicates that the automatic control is defective. Linkage defects on tilting burners and surface type attemperators can also arise. Again intelligent interpretation of instruments, together with visual inspection, will identify the cause.

5.2.4 Final Feed Temperature

A reduction in the feed temperature to a boiler will result in an increased steam temperature. The amount of heat necessary to raise the water to boiling point becomes greater and the firing rate is consequently increased. A greater mass flow of gases across the superheater follows and thus the steam temperature is elevated.

5.2.5 Delayed Combustion

When combustion conditions badly deteriorate, it is possible for the combustion zone to be elevated towards the superheater zone resulting in high steam temperature. Frequent observations of combustion conditions should be made and any necessary corrective action taken.

5.3 Final Gas Temperature and CO_2 Content

The loss in boiler efficiency arising from the heat in the flue gases leaving the air heater was referred to in Section 3.4.3(i).

The measurement of the true final gas temperature (as with all gas temperatures on a boiler) presents considerable difficulty. Gas flow in a duct varies in velocity across the duct and results in varying temperature values across the gas flow. Both the gas sampling and the temperature probes can give misleading values unless the location of these]probes is carefully fixed. It is now customary for a "search" of the duct to be carried out before fixing the permanent probe position. This "search" involves taking the temperature and samples of the gas at say twenty-four equally Spaced points across the duct. The final probe position is placed at the point giving the temperature and gas analysis nearest to the average of the twenty-four readings.

In service the probes are subject to constant erosion which can ultimately either shorten or destroy them, resulting in incorrect readings. The probes are, therefore, carefully examined during any boiler inspections. Many stations have portable gas analysers and temperature probes which are used to Check the results from the permanent probes.

The causes of change in final gas temperatures were explained in Section 3.4.3(i)

Gas temperatures and O_2 or CO_2 readings sometimes vary between the two or more ducts installed on a boiler. The explanation may be fouling of the heat exchange surfaces on one side of the boiler more than the other. Usually, however, the cause is incorrect distribution of air through the secondary and tertiary air dampers relative to the fuel supply or unbalanced firing through some burners.

On boilers equipped with rotary air heaters, the air leakage which takes place from the air to gas side lowers the final gas temperature to some extent but this air leakage across the air heater seals is inevitable even when the seals are correctly set. The extent of the leakage can be checked from time to time by measuring the CO_2 content of the gases before and after the air heater. This is important because fan power will increase as the leakage increases.

5.4 Draught Loss

Comparatively few modern boilers suffer from an increasing draught loss. Readings of draught loss for equivalent conditions over a period will indicate the extent and rate of fouling of boiler surfaces and are used as a guide in deciding when to take the boiler out of service for cleaning.

Sudden changes in draught loss are usually caused by faulty damper settings or open access doors.

5.5 Differentiation between Cause and Affect

From what has been said and from the reader's own experience, it will be apparent that there may be a number of causes to any single affect. In attempting to differentiate between cause and affect no definite system of approach can be laid down but factors to be considered are as follows:-

- Is the instrument reading correct? Cross check with other instruments installed or with a portable instrument.
- Have there been any changes in operating factors during the time shortly before the unusual condition was observed? For example, where fuel burnt on a station comes from a number of pits having coals of different characteristics, then the fuel burnt on a particular boiler may change in a very short time.
- What are the causes that can contribute to the unusual condition? Examine and eradicate them one by one.
- What is the most important factor where a number of unusual factors exist? Develop and apply a sense of proportion. For instance attention to an unreliable feed water regulator obviously requires priority when compared with an increase of 5°C. (9°F.) in final gas temperature occurring at the same time.

6 FUTURE TRENDS

The rate of technical development is extremely rapid with the result that some of the stations at present building are, technically speaking, already outdated.

Stations with unit sizes up to 550 MW have already been commissioned and many more are under construction including units with supercritical steam conditions. The high pressures and temperatures associated with such units demand a large degree of reliable instrumentation. Installations are being tried out at several of these new stations to relieve the operators of the necessity to record on their log sheets the large amount of information presented by the instruments. This equipment, known as automatic data logging, prints out on an electric typewriter at any pre-selected frequency such information as is presented to it. The associated control panel instruments transmit to the automatic logger electrical impulses representative of the instrument reading. One advantage of this equipment is that the speed of recording a complete set of readings is so high that all readings are taken at practically the same instant. The variables associated with manually recording a set of readings taking up to ten minutes are therefore eradicated.

As pressures approach the critical point of 3,208 p.s.i. (that is, the pressure at which the density of water and steam at saturation temperature are the same value) the difficulties of satisfactory design using natural circulation increase and assisted circulation becomes necessary. Beyond the critical point forced circulation is essential. Very high pressure pumps of extreme dependability are installed to ensure positive circulation and complete control of them is vital.

Some of the 200 MW boilers in commission with operating pressures of 2,500 p.s.i., are of the assisted circulation type whilst forced circulation boilers, of 4,500 p.s.i., are in commission in America. Reheat has now become standard on unit sizes of 120 MW and higher. Two stages of reheat are likely as operating pressures approach and exceed the critical point.

Multi-furnace boilers are likely to develop more in the future with reheater sections in one or more furnaces and the superheater in another This will enable independent temperature control to be obtained by adjusting firing rates.

Increases in boiler efficiency will most likely be obtained by further reducing the final gas temperature. The associated potential corrosion problem has yet to be solved by either special corrosion resisting materials or the installation or easily and cheaply replaceable materials.

The use of television equipment for monitoring furnace combustion conditions and water levels will develop considerably, particularly as this equipment becomes more reliable.

Investigation into fully automatically controlled power stations is proceeding, and computer controlled systems are being installed in new stations which will operate the plant to a predetermined programme arranged by the operating staff. These systems are more fully described in Lesson 15.

7 REFERENCES

- The Efficient Use of Fuel - H.M Stationery Office
- Steam - Its Generation and Use - Babcock and Wilcox N.Y. (1955)
- Boiler Availability - Committee Reports

Questions on Lesson 5 - The Operation of the Modern Boiler

Please answer any four of the following questions

1. A coal supplied to a Power Station has the following analysis: -

   Carbon C 68% Hydrogen H_2 5% Moisture 8% Ash 19%

   (a) Calculate the theoretical amount of air required for the complete combustion of one pound of this coal and the resulting products of combustion.

   (b) What quantity of heat per pound is released in burning this coal?

2. Why is it necessary to guard against overheating superheater tubes during pressure raising?

   What equipment is used to measure superheater metal and gas temperatures?

3. What is "Flame Propagation"?

   Why is the rate of flame propagation important and what functions influence it?

4. What are the factors that contribute to a high dry flue gas loss on a boiler?

   What causes slagging?

5. A boiler is equipped with a Copes two element flowmatic regulator. The rate of firing is equivalent to a steam flow of 300,000 pounds per hour and the water level is being steadily controlled. The firing rate is now rapidly increased to 400,000 pounds per hour. How could this affect the water level and in what way does the regulator respond to keep the water level steady under the changing conditions?

6. "Carbon in grit" is one of the important losses on a boiler within the control of the operator.

   Discuss the factors which affect the Carbon loss on a modern P.F. boiler.