BOILER OPERATION, MAINTENANCE AND TESTING

By S. G. HOLTON

Introduction

Boilers are akin to wives and their treatment is therefore a highly controversial subject. Although there are many of various shapes and sizes, no two react alike, but with encouragement, some are efficient. Others however, are simply temperamental and if neglected, all become dangerous and are liable to blow off steam. Providing sufficient care is taken of them, there is a fair chance of obtaining reasonable results, but the fellow who claims to know all the answers will surely get his fingers burnt.

Boiler Operation

Combustion

Good combustion depends on Temperature, Time and Turbulence, commonly known as the three T's. Anything combustible will burn if given sufficient time and temperature, but in this modern age time appears to be in short supply. With the advent of bigger and better boilers, assistance in the form of mechanical firing equipment, fans, economisers and air pre-heaters is necessary. The temperature is increased by preheating the combustion air and turbulence is created by the introduction of over-fire air known as "Secondary Air". These two features in conjunction with each other reduce the Time for the fuel to reach ignition temperature and burn to ash.

When we consider combustion in a furnace, we find that various practical aspects make it impossible to burn a pound of fuel with only the theoretical quantity of air. Losses occur due to the construction of the grate, furnace, and the fact that in practice the air and fuel cannot be sufficiently intermixed to ensure that every atom of carbon and of hydrogen combines with its complement of oxygen. In many instances, because of uneven fuel grading, the air takes the line of least resistance, with the result that some of the air passes into the furnace without combining and appears in the form of free oxygen in the flue gas. Where insufficient air has passed through the fire, the fuel is not completely consumed and there is a loss in efficiency arising from the unburnt carbon rejected with the ash.

While the application of excess air gives better mixing and reduces the unburnt gas loss and unburnt carbon loss, there is a limit to the quantity of excess air which can be used without introducing a further serious loss. Air introduced to a boiler unnecessarily will not only fail to serve any useful purpose but it will carry away an amount of heat depending on the difference between the chimney gas temperature and the ambient air temperature.

The art of efficient combustion is to find the best compromise between chimney loss and unburnt fuel loss.

The quantity of air used for combustion depends on the compromise made between chimney and unburnt fuel losses, but the pressure of the air required is closely related to the grading of the fuel. When burning coarse fuel a low undergrate air pressure is sufficient due to lack of fuel bed resistance, but a high air pressure is necessary when burning fines.

This feature was illustrated during my earlier days at sea on a "coal burner". The boilers were double ended Scotch Marine and the stokers were tough Liverpool Irishmen, who appeared to work only when broke. During the outward bound voyage the leading hand of each watch had the coal trimmers select the larger pieces of coal from the bunkers. This enabled the stokers to shovel huge quantities of coal onto the grates until the fuel bed thickness was anything from 10" to 12". The stokers were then able to sit on their shovels and relax whilst the fires burnt down with forced draught pressure rarely exceeding $\frac{3}{4}$" w.g. to maintain steady steam conditions. The last lap of the homeward voyage was a very different story. By this time the coal in the bunkers was mainly fines, which required to be thinly and evenly spread over the fires at frequent intervals. Regular slicing and raking of the fuel bed was essential to permit ingress of the forced draught now at $2\frac{1}{2}$" w.g., the maximum available from the F.D. fan. From this point on, a constant battle ensued between the engineers and stokers. Possibly it was only the king-size thirst and the thought of getting back to their local pubs that gave the stokers strength to produce sufficient steam to get us back to port! Luckily Father Neptune wasn't interested in smoke abatement, otherwise we would not have made it.

Fuels

When steam is used for process in a factory, the cost of the fuel greatly influences the price of the end product, and when fuel costs are high the steam generating plant must maintain the highest possible efficiency.

The efficiency aspect of the boiler plant however, becomes less acute when using bagasse or spent bark, as quantities of these products in excess of the normal requirements, can prove to be an embarrassment due to storage problems.

Although the cost of coal per ton delivered to the bunkers is constant, the amount of steam generated per ton of coal varies in accordance with the condition of its presentation to the boiler. Mechanical stokers can be even more temperamental than their Liverpool counterparts when faced with poor grading, bad conditioning and segregation.

A growing demand, with increased mining costs causes difficulty in obtaining a consistent size of coal. The quantity of explosives used per ton of coal extracted, has increased considerably over the past ten years, and this, together with mechanisation tends to increase the proportion of fines. A mechanical loader at the colliery has no discrimination in what it loads. It loads coal and shale and fines, and it loads them altogether.

Separation of the larger from the smaller coal is caused by movement. In general, it may be stated that when coal is in free movement the larger coal will move a greater distance. When a pile is formed either on the ground or in a boiler hopper from a central feed, the larger coal will be found at the outside edges of the hopper. Unless this is prevented, the zones of the fire which have received the coarse coal, burn rapidly with a long flame caused by the large quantity of excess air. The severe heat at the edges of the grate accelerates the furnace side wall deterioration. The zones of the fire which have received the finer coal burn more slowly due to air starvation and generally form clinkers containing large quantities of unburnt coal. Under these conditions, whilst the total air flow should be sufficient to give a good percentage of carbon dioxide in the flue gas, the size segregation of the fuel results in a double loss; i.e., low percentage of CO_2 and unburnt carbon.

Dry coal containing a high percentage of fines cannot be efficiently burnt on a stoker due to its high resistance to air flow. The addition of free moisture to the coal influences the facility with which air passes through the smalls because the surface moisture tends to agglutinate the fines, thereby reducing the fuel resistance to aeration. This is a physical action and probably independent of chemical properties.

The many complexities of coal preparation are beyond the scope of this paper.

Operation—General

The two most important factors in good operation are knowledge of the equipment and an interest in its performance. It is essential for an operator to observe the proper operating sequences and to understand the operations which are carried out automatically by the equipment. If an operator acquires a sound knowledge and understanding of the plant he automatically develops an interest in the operating records, and should a variation occur with the data being recorded he may possibly be able to take corrective action and avoid damage to equipment.

It is essential that any adjustments to the firing equipment are made gradually in order to maintain steady conditions. For instance, the outcome of any alteration to a fuel bed on a travelling grate will not be apparent for approximately half an hour, therefore any heavy-handed action could take up to an hour to correct.

For records, it is recommended that the following data be recorded hourly:

1. Water level.
2. Visual observation of the fire.
3. Steam and feed water temperatures, pressures and flow.
4. Temperature and pressure of air entering and gas exit from the principle portions of the boiler.
5. Percentage of CO_2 or O_2.

The term automatic control on a boiler is frequently mis-interpreted to infer that the unit is completely self-regulating thus rendering the services of an operator unnecessary. Unfortunately this condition only applies, and then only remotely, to such fuels as oil and gas and to a lesser degree pulverized coal where the conditions of moisture, calorific value and grading or viscosity of oil, remain constant with each consignment received. The use of automatic control can only be justified in the regulation of all functions which do not require the judgment of an operator, as the control equipment can only monitor the weight or volume of a fuel and then regulate the ratio of air for combustion to suit the steam demand. Variables in the fuel, such as grading, moisture and calorific value can only be corrected by visual observation and the controls then manually trimmed accordingly.

Care of Supheaters

The superheater drains should be fully opened prior to lighting fires.

Non-drainable superheaters require sufficient heat to boil the condensate out of the loops but in order to prevent abnormal temperature differences between the portion of the tube containing water, and the other, the gas temperature must be regulated not to exceed 900° F. Alternatively, the firing rate may be controlled to increase the saturation temperature 120° F per hour.

The most reliable method of determining the time required to raise pressure within safe limits is by the installation of a few thermo-couples on the outlet legs of the superheater. Since no steam will flow through a tube partially filled with water, the temperature recorded will read saturation temperature until the tubes are cleared. When a flow of steam is established the temperature will rise to approximately 75° F above the saturation temperature.

The superheater drains should be left open until the boiler is on range when a flow of steam through the superheater is assured. When a boiler is being brought up to pressure the air-vent should be closed only when the pressure has risen to 25 p.s.i. This will ensure the expulsion of all air.

Steam Quality and Purity

The amount of moisture in steam after separation in the steam drum is defined as quality and the amount of solids in it, as purity.

The water in a boiler accumulates suspended and dissolved solids, which unless checked will lead to the contamination of the steam. Steam is always contaminated to a greater or lesser degree and even if the water delivered to a boiler is chemically pure, it is possible for droplets of water to be carried with the steam into the superheater. Excessive amounts of moisture in the steam will cause loss of superheat, corrosion, scaling and eventual failure of the superheater. It is most important to prevent "carry-over" and whereas the design of the boiler drum internals takes care of the usual sources of moisture and impurity with extremely high efficiency, the system cannot cater for severe overloading. These internals must be given an opportunity to function and if they become submerged by a high water level or choked with chemicals, superheater failure will occur.

A brief explanation of what happens in the steam drum may assist in stressing the importance of maintaining correct chemical condition and level of the water.

As steam bubbles travel from the riser pipes into the drum and reach the water level, they burst into fragments causing drops of moisture to be projected into the steam space. The height to which these drops rise above the water level depends upon their size and velocity. As the velocity of the droplets is less than that of the steam rising from the surface, the carry-over varies from small amounts of atomised mist to heavy carry-over, when the capacity limits of the drum internals are much exceeded. The size and velocity of the droplets is greatly increased when steaming the boiler in excess of its designed rating, or when there is a sudden drop in steam pressure. A drop in pressure leaves the water substantially superheated above the boiling point associated with the higher pressure. This results in a greatly increased quantity of steam bubbles causing the boiler contents to swell considerably above the former level. Under severe conditions of priming, steam may carry as much as 50% of moisture by weight which represents less than 1% by volume. Slugs of water carried over can cause serious damage to the plant as they contain dissolved and suspended solids, which become deposited in the superheater tubes or on the turbine blades. The main danger is that solids trapped in the superheater form an insulation between the steam and the metal, resulting in eventual failures of the metal through overheating.

Additional factors which tend to promote priming are: too high a water level; excessive alkalinity of the water; excessive total solids; organic matter and sludge.

The water gauge does not accurately indicate the true water level in the drum. For instance, when a boiler is under load the water level in the steam drum is always higher than that indicated by the gauge because the solid column of water in the glass has a higher density than the steam/water mixture in the drum against which it is balanced.

Blowing Down

Most plants use the chemical analyses of the water from the boiler as a guide to determine the amount and frequency of blowing down. Where such analyses are not made, the boiler should be blown down at least once every 24 hours. The amount of blowdown will depend upon the class of feed water and quantity of steam generated. Economisers and water cooled furnace walls should never be blown down whilst the boiler is in service as it is possible to create steam pockets or even reverse the circulation which could result in tube failures. Blow down valves for the above mentioned equipment should be padlocked whilst the boiler is in service.

Balanced Draught

All large boilers are equipped with forced and induced draught fans and in most instances secondary air fans.

Balancing the draught is effected by adjusting the induced and forced draught fan pressures until the furnace draught gauge indicates no pressure difference between the inside of the furnace and the outside atmosphere. In actual practice the furnace is always maintained under a slight suction thus permitting a slight ingress of air which prevents the setting from overheating and provides a precaution against possible blow-back and injury to the operating personnel.

On modern boiler plant equipped with instrumentation a change of CO_2 or O_2 in the flue gas indicates to the operator that there has been a change in combustion conditions and this, with visual inspection of the fire, will help him to adjust the draught suitably.

Economisers

Economisers with a recirculating connection should have the valves open whilst pressure is being raised preparatory to operation. This is to ensure that the tubes are at all times completely full of water. When the boiler is on range and the economiser has been taking feed water for approximately 5 minutes, only then should the recirculating valve be closed.

Water-washing

The constituents of the flue gases which cause fouling of the economiser are dust, fly-ash particles and acid forming substances. Loose dust collects initially on the down stream side of the bank of tubes mainly because of the reduction in the velocity of the gases leaving the bank. The worst fouling occurs during the period the boiler is being sootblown. These deposits are effectively removed by mechanised waterwashing. The apparatus consists of a motor driven oscillating nozzle lance installed above the top bank of tubes and provides a slowly moving curtain of water directed at right angles to the horizontal tubes. 2 to 3 gallons per minute per sq. ft. of projected area should be used during this process to effectively dilute the acid solution, and also to ensure that sludge or solid matter, displaced from the upper banks does not accumulate in the lower bank.

The duration of the washing period will vary with operating conditions and characteristics of the fuel, but washing should be continued until the wash water effluent is clean.

Cast iron airheaters are waterwashed in a similar manner.

Soot-blowers

The frequency of soot-blowing depends upon the nature of the fuel but generally systematic cleaning should be a regular feature of operation. Normally once a day is sufficient. The soot-blowing sequence should commence at the front of the boiler, working toward the rear. This is to drive the loosened deposits out of the boiler system. During soot-blowing routine the furnace draught should be increased to give sufficient suction to prevent a furnace pressure through the released steam and to assist the flight of the fly-ash.

Boiler Maintenance

Boiler maintenance falls into two distinct groups of activities. One is the checking and overhaul of mountings, boiler auxiliaries, firing equipment and control gear. The other is the cleaning and inspection of pressure parts, supporting structures, brickwork, baffles, casings and ducting.

Depending upon their size and cost, boiler mountings are often, as a routine measure, replaced with reconditioned spares during short outages so that many of the smaller items on a boiler are always in a good state of repair and need no special attention when the unit is shut down for its periodic overhaul. The same applies to certain auxiliary equipment and control gear.

The checking and overhaul of major auxiliary plant and boiler equipment is usually carried out only when the boiler is shut down for overhaul, and, if this is the case, it is necessary to ensure that the checking and overhaul programme is so thorough and comprehensive that the equipment concerned can be relied upon for good service until the next scheduled outage.

Boiler pressure parts are subject to statutory inspection and testing and internal and external cleaning of the boiler is required by the Government Inspectors to enable them to carry out their examinations satisfactorily.

In regard to internal cleaning, it is, of course, possible using modern plant and techniques to approach the ideal in steam raising by using feed water which will not give rise to any deposits on the internal surfaces of boilers. In many cases, however, where the control of the water conditioning plant is faulty or inadequate, deposits of various sorts occur inside boilers and high maintenance costs are incurred in removing them. Apart from the desirability of removing deposits for inspection of pressure parts, there is also an imperative need to remove them because of their effect on heat transfer through tube walls or other pressure parts and the possible failure of these items through local overheating. In addition to sludge or scale formation other characteristics of the feed water may give rise to corrosion of boiler and superheater tube surfaces, and the serious problem of caustic embrittlement has also sometimes to be faced when feed or boiler water conditioning has been neglected. The internal cleaning and inspecting phase is therefore vital, and must be geared to suit the circumstances existing in each case. Much the same applies to external cleaning and inspection.

External corrosion of pressure parts, ducting, airheaters and fans, fouling of gas-passes by fireside deposits of various types, damaged brickwork, fire damaged parts and sometimes erosion by fly-ash are among the unpleasant discoveries one can make during an inspection.

Inspections must be carried out by competent personnel, and an appraisal of all causes and effects should be made the responsibility of senior technical staff.

Boiler Efficiency Testing

Some boiler plants are so fully instrumented and staffed that it is always possible to ascertain without difficulty what efficiency is being attained. At the other end of the scale there are boilers equipped only with the instruments required by law.

When fuel costs are a serious consideration, boiler plant manufacturers are nearly always faced with contractual obligations to meet specified efficiencies on tests after the erection of new plant, and the user during the subsequent life of the boiler is also likely to be interested in the results of periodic efficiency checks.

In some cases the efficiency of the steam consuming section of the plant is constant and the total weight of product obtained from the steam consuming section of the plant can be directly related to the amount of steam delivered to it from the boiler house. Should this condition apply it is possible that some continuous check on the efficiency of the steam raising plant can be obtained readily by comparing the weight of the final product obtained during a period of time with the amount and calorific value of the fuel supplied during the same period.

When this is not possible there are two other ways in which the efficiency of a boiler can be assessed. Both methods require a great deal of care if any reliance is to be placed on the results.

The direct method of boiler testing entails the measurement of the weight of the fuel used during a specified time, and its calorific value, the measurement of the weight, temperature and pressure of the steam supplied by the boiler in the same time and the measurement of the feed water temperature. In a variation of this the quantity of feed water supplied to the boiler is measured instead of the steam quantity. These measurements are sufficient for the purpose of assessing the efficiency of the boiler proper, as it is clear that the nett heat imparted by the boiler to the steam can be calculated as can the total heat supplied by the fuel to the boiler in the same time. In some cases, however, the efficiency of the boiler plant as a whole is required, and an allowance must be made in the calculations for the consumption of power by essential auxiliary plant such as fans and feed pumps.

The indirect method of boiler testing is carried out by examining the channels by which heat is rejected, and therefore wasted by the boiler. It entails careful sampling and an ultimate analysis of the fuel, collection and weighing of ash, riddlings and dust and the determination of the percentage combustible material remaining in such refuse. A careful analysis of the flue gas and measurement of flue gas temperature, and that of the ambient air is also required. Certain losses such as radiation losses, cannot be measured and it is necessary to assume a figure for these based on a heat balance compiled from the results of a complete boiler test by the direct method.

Many tests have been failures and of no real value through insufficient care in obtaining or recording the data obtained. To illustrate the importance of being meticulous and obtaining correct data, Alfred Cotton, an authority on boiler testing, summarises the possible errors that occur even with greatest care.

Coal

Weighing	± 0.5%
Estimating the amount of fuel in the stoker hopper at the start and end of the test	± 0.5%
Error in Coal weighing . . .	± 1.0%
Failure of moisture sample to represent bulk	± 1.0%
Failure of C.V. sample to represent bulk	± 0.5%
Error in analysis	± 1.5%
The total error in the coal is therefore.	± 2.5%

Water

Weighing or metering between starting and stopping . . .	± 0.5%
Failure of steam sample to represent bulk steam as to entrained water	± 0.5%
Now the total error in water evaporated is	± 1.0%

These values could vary the BTU value of the coal from 97.5% to 102.5% and that of the water evaporated from 99.0% to 101%. If all these errors combine in one direction, the report may show an efficiency of 75.4% or 80.8% for an efficiency that is actually 78%. Under these conditions it is clear that regardless of how carefully a test is conducted, the efficiency could not be guaranteed closer than ± 3%.

Summary

Boiler Operation

Any combustible substance will burn if its temperature is high enough for ignition, and if given sufficient time to ignite. Turbulence of the air and increased temperature will reduce the time for complete combustion. Badly graded dry coal containing a high percentage of fines must be conditioned prior to presentation to a boiler to avoid patchy fires, poor combustion and loss of efficiency.

If hourly readings of the boiler performance are logged, a reasonably consistent standard of operation can be obtained. Superheater tube failures occur due to raising pressure too rapidly after lighting up, and also by carry over of impurities entrained with the saturated steam. Carry over can be caused by operating with the boiler water level too high, steaming in excess of the rated capacity of the boiler, or a high concentration of impurities in the boiler water. The high concentration of impurities can be reduced by regular blowing down. Fireside deposits on the boiler tubes are removed by soot-blowing and from the economiser by water-washing.

Boiler Maintenance

It is better to be sure than sorry, should be the slogan during boiler overhauls. The external and internal cleaning must be thorough and inspections carried out by experienced and competent persons.

Boiler Efficiency Testing

The performance and efficiency of a boiler can be determined in three ways:

(a) By the overall method whereby the weight of the manufactured product is compared with the weight and C.V. of the fuel consumed over a certain period to produce the process steam used.

(b) By the Direct Method, by measurement of the weight and C.V. of the fuel consumed and measurement of the quantity, pressure and temperature of steam produced during a specified time.

(c) By the indirect method (losses method) in which the heat rejected in the solid refuse and in the flue gas is ascertained by analysis and calculation.

All methods require a great deal of care if accurate results are required.

Mr. Hulett (in the chair): Mr. Holton has rightly pointed out the great importance of fitting instruments to boilers.

Mr. Heslop: What is the effect of intermittent boiler operation, as practiced in the sugar industry compared to continuous operation with an annual shut-down?

Mr. Holton: Frequent heating up and cooling down causes spalling of the brickwork or refractories and unless correct lighting up procedure is adhered to on *every* occasion, thermal stresses will eventually cause failure of the pressure parts. Superheater tubes are particularly vulnerable to damage during this period.

Mr. Griffiths: Is it possible to waterwash superheaters?

Mr. Holton: We have off-load washed superheaters prior to examining them for erosion. Rust caused by water on the tube surfaces clearly indicates any portion that has been subjected to erosion. Great care must be taken to avoid wetting the brickwork and the grate. We normally cover the grate with tarpaulins.

Mr. Steffen: Do you recommend waterwashing economisers whilst steaming, or during the weekend shutdown?

Mr. Holton: Definitely during the weekend and preferably before the boiler has cooled down. This will give the metal surfaces time to thoroughly dry out prior to the unit returning to service.