BOILER OPERATION

EXISTING BOILERS—SMOKE AND EFFICIENCY

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The boilers of almost every naval steam vessel are of the closed boiler room three drum type to Admiralty design, and though they have many excellent features and were, at the time of their design, justifiably considered most suitable, they have been regarded for some years as having little margin on circulation in generator and superheater tubes ; this, with some other features, render them liable in some cases to tube failures. Admiralty and other design boilers now in service suffer from other shortcomings in design, maintenance and operation, the more serious of which are low thermal efficiency, brickwork, and smoke at high power. Remarks on these factors will be given in this and subsequent publications of the *Journal* ; this article deals with efficiency and smoke.

It is unlikely that there is any ship in which full power on the shafts can be developed with the consumption of oil the same as, or lower than, that used on the acceptance trial ; the position is that, in spite of a relatively low boiler efficiency on the acceptance trial, after a few years in service, the fuel consumption for the same power has increased by between 5% to 30% ; efficiency is correspondingly lower at all powers, with the result that endurance is reduced and, scarcely less important, the higher oil rate accelerates all-round deterioration of the boilers and propulsion auxiliaries and, at high powers, is often the primary cause of smoke. After making allowances for turbine efficiency—which is usually fairly well maintained—poor vacuum, astern leakage, inefficient use of auxiliary exhaust etc., it is impossible to escape the conclusion that, on a thermal efficiency basis, the performance of nearly all boilers in service is bad.

As an example of this fall of efficiency, the following figures have been abstracted or calculated from the contractors' and latest full power trial reports of four ships chosen from one class at random, and, while it is appreciated that figures in trial reports may not always be very accurate, the following are means and are believed to be substantially correct.

Ship	A		B		C		D	
Trial	Contractors'	Latest	Contractors'	Latest	Contractors'	Latest	Contractors'	Latest
Air Pressure ins. w.g. ...	5.4	7.6	6.0	7.7	5.7	8.0	5.3	9.3
Oil Burnt 1,000 lb/hr.	27.0	35.0	29.0	34.4	27.2	32.4	26.3	32.4
Uptake Temp. °F.... ...	720	730	710	740	690	650	670	650
Excess Fuel Burnt % ...	—	30	—	19	—	19	—	23
Lost Endurance due to Boilers %...	—	16	—	12	—	19	—	15

Reasons for Bad Performance

The reason for bad performance can be seen most easily by looking at the heat losses. Heat is lost in funnel gas, unburnt fuel, radiation, steam and water leaks and blowdowns. The funnel gas loss can be sub-divided into water vapour and dry gas losses ; both depend upon the composition and quantity of the fuel burnt, and the dry gas loss is also affected by the amount of air admitted to the boiler intentionally or otherwise. Unburnt fuel may take the form of carbon monoxide, but this is usually so only when the combustion air exceeds that theoretically required by a very small margin ; in practice, unburnt losses consist almost exclusively of black and white smoke and soot. The radiation loss varies little over the power range or over the life of the boiler, and is mainly dependent upon design. Water and steam leaks and blowdowns, though direct heat losses, are seen more clearly in their effect upon endurance. As the funnel gas loss is, by the nature of things, twenty to thirty times as great as the other losses, the line to follow, though not easy, is clearly pointed.

The irreducible bases of the funnel gas losses are the amount of air theoretically required for combustion and the boiler water temperature (or feed temperature with economisers and air temperature with preheaters) ; whilst it is physically impossible to reach either of these bases, one of the primary objects in design, maintenance and operation is to approach them as closely as possible. In design, something between 5% and 20% excess air is aimed at for, without some excess in practice, efficiency would suffer by incomplete combustion which would be shown by carbon monoxide, smoke etc. ; also, with regard to temperature, a figure considerably higher than the ideal is dictated in design by such factors as weight and size, external corrosion and fan power. The thermal efficiency of existing boilers fixed by the design was, and still is, satisfactory, but nowhere is this efficiency being achieved. While the present day quality of fuel may give some trouble, it has only a small effect upon efficiency compared with that from maintenance and operation.

Boiler Operation

There is no reason to believe that operation of boilers, particularly at high power, is much at fault. At low powers, even in temperate climates, it is sometimes the case that flaps are left open on registers not in use ; the only engineering grounds upon which leaving an extra flap open would be justified is as an alternative to running an additional fan to give a higher air pressure, but this special case usually reflects as much on maintenance as operation. At full power, the possible faults in boiler operation from the thermal efficiency aspect are : an air pressure in excess of the minimum required for a very light haze ; fans not at same speed ; too low an oil temperature ; incorrectly positioned sprayers or flaps ; wrong size or dirty sprayer caps or brick quarls ; leaving open unnecessary vents or louvres. All these faults contribute to the actual air pressure used. In a given boiler, approximately the same relationship exists between air pressure and quantity as, in a given sprayer, between oil pressure and quantity, that is, approximately as the square root of the pressure. Full power trial reports show that the ratio oil pressure : air pressure differs very little from that at the acceptance trial, and there are more cases better than there are worse. These, then, are the reasons for believing that these faults are not the primary cause of bad performance.

Boiler Maintenance

As regards maintenance, and bearing in mind the earlier deduction that funnel loss is by a factor of twenty or thirty the greatest loss, the causes which will increase either or both the funnel gas quantity and temperature are : heating surfaces dirty internally or externally ; mal-assembly of sprayers, registers and brick quarls ; casing leakage. The list is very short, and it might have included defective superheater gas baffles, were it not for the fact that these baffles primarily affect final steam temperature, and have but little effect on thermal efficiency.

Dirty heating surfaces, because they offer resistance to the transfer of heat from gas to water, almost certainly lower boiler efficiency ; the precise effect is not yet fully known but, apart from abnormal cases, there is no evidence to show that it has much effect. Internal cleaning is dictated mainly by the corrosion and boiler safety aspects, and the same is true for external cleaning. It is very doubtful whether, all other things being equal, oil pressure after cleaning is less than before, and from this the inference is that efficiency has not been improved—indeed, if re-assembly of boiler parts is faulty, the efficiency may be worse. If external and internal deposits had a marked effect, the efficiency after retubing would be noticed to improve, but it is not. Although it is with the best intention, it is probable that from the efficiency aspect, external cleaning is done too frequently. The regular use of soot blowers at least once and preferably twice every day when steaming main or auxiliary would probably obviate much of the need for external cleaning. Accumulations of soot and ash are fire and corrosion hazards and must be removed frequently.

Register Maintenance

Mal-assembly of sprayers, registers and brick quarls causes impingement of the oil spray on tubes or brickwork. It can readily be seen that impingement leads in turn to : carbon deposition ; higher uptake temperature ; smoke ; more air ; more work for stokers ; damage to quarl bricks ; non availability ; last, but not least, because the funnel gas quantity and temperature are increased, more oil is required for the same output. There is no doubt whatever but that frequent and careful checks on sprayer, register and quarl alignment pay a dividend in improved thermal efficiency out of all proportion to the relatively small labour involved ; in addition, there is a modest bonus in that there are fewer brickwork defects. It has also been shown that any mal-assembly increases the tendency to pulsation and consequent damage to brickwork.

Casing Leakage

Casing leakage is a term which covers leakage of air through the gas casing into the gas space anywhere except after the last heating surface ; with preheaters, this means anywhere between the air outlet from preheater through the boiler to the preheater gas outlet or with economisers, anywhere from registers to the economiser gas outlet. Casing leakage also covers idle register leakage, and although this is not effective at full power, it usually has a very adverse effect at other powers. Casing leakage increases the quantity and lowers the temperature of the gas. The quantity is increased and the temperature reduced in approximately direct proportion to the amount of air leakage. In approximate terms the amount of heat transferred to the water increases as the square root of the quantity and reduces directly as the temperature difference between gas and tubes ; this temperature difference, of course, is lowered a little more than the actual temperature is lowered. Thus an air leakage of 20% will increase the gas quantity and lower the gas temperature both by 20%, and the gas/tube temperature difference will be lowered by, say, 22% ; the heat transferred from gas to water will therefore be lowered to 90%, or in other words, a loss of 10%. Similarly a leakage of 30% will lower the heat transferred by 15%. Whether or not the uptake temperature is higher or lower than at the acceptance trial depends upon the relative amount of oil being burnt and the amount and positions of air leakage, but, irrespective of uptake temperature, casing leakage must necessarily lower the thermal efficiency because of the greater loss of heat in the funnel gas, which means that for the same power, oil consumption is higher. To quote a specific example, a shore test boiler which was comparatively very well maintained and was sited in a boiler house with the greatest possible ease of access all round, was found to have casing leakage equivalent to nearly 20% of the full power air quantity ; after careful attention the leakage was reduced to 5%. In addition to the loss of boiler efficiency by casing leakage, there is a further loss by the increased fan steam consumption, and since the fans fitted, for example, in fleet carriers are about 1,500 h.p. and in new construction fleet carriers will be 11,000 h.p., this aspect should not be overlooked.

The occurrence of casing leakage may be shown in several ways. Full power trial reports often show that fans were running at their trip speed and, as stated earlier, this is usually associated with an air pressure which corresponds with the oil consumption. Although fan margins vary somewhat, the general rule in the past has been to provide twice the designed full power quantity ; even allowing for miscellaneous vents and louvres being open unnecessarily, when the air quantity being delivered from the fans is related to the oil consumption it can be shown that leakage is considerable ; this can be checked in individual ships. After full power trials, if the causes for the increase of oil consumption over that at the acceptance trial are analysed, particularly noting fan speeds, air pressure, uptake temperature and smoke, it is not difficult to deduce to what extent casing leakage is occurring ; this check can also be applied for any other power for which reliable contractors' consumption trials figures exist. For a boiler in a given state of maintenance and at near full power the uptake temperature should rise about 30°F. when the quantity of oil burnt is increased by 10%.

In addition to the analytical approach given in the preceding paragraph, a visual examination of casings will often reveal such faults as : half the cotters missing ; panels distorted by heat or by repeated levering off with a chisel bar ; joints broken ; holes left by a missing bolt or instrument ; one panel edge ledged on another ; panels and bearers made or assembled badly ; brick-bolts and register air flaps are often sources of considerable leakage. Lighting up under natural draught when the boiler and funnel are quite cold may show the existence of leakage points by smoke issuing into the boiler room through casings and shut registers.

To facilitate the detection of casing leakage an instrument is being developed ; it is a simple vane type air flow meter called a velometer, which can be used to measure the air velocity in funnels and, by connecting one of 4 or 5 adaptors, can also be used to detect specific points of leakage ; for example, by merely looking at a brick bolt and nut, it is practically impossible to determine whether it is leaking, but by using a cup shaped adaptor and placing it over all bolts in turn, the deflection of the needle will clearly and quickly show which are leaking badly ; it can also be used for joints. While the wholesale refitting of boiler casings is impossible, those which leak to such an extent as to increase fuel consumption by, say, 5% over acceptance trial figures would justify thorough repair, and the order of taking in hand for casing repair should to some extent be influenced by the relative degree of leakage. At present no suitable basis exists, so it is under consideration to issue velometers to Fleet Engineer Officers for measuring the air flow in funnels with an air pressure in the boiler room and with all flaps shut ; the air pressure would be fixed as approximating to that required for full power and for comparison purposes this pressure would be used in all vessels of a class. The velometer will give a velocity reading which, multiplied by the cross sectional area of the funnel at the position at which the velocity was measured, will give the quantity. These readings will provide valuable data and will show whether boilers are so badly below average in this respect as to justify special measures to refit the casings. As an adjunct to show specific points at which leakage occurs, a suitable smoke making substance for use inside furnaces is being sought. The boilers of two ships have recently been tested with the velometer. In each case the leakage was measured from the mean air speed up the funnel and the funnel area ; all registers and vents were shut, and it was found necessary to use all fans to give an air pressure corresponding with that used at full power. The first case was a Town Class cruiser on completion of a large refit, during which some attention had been given to the state of the boiler casings ; the leakage in the two boilers tested was 45,000 and 46,500 cubic feet per minute respectively, which represents half the total fan output and the full amount of air corresponding to the full power oil consumption. The second case was an aircraft carrier in which the boilers were new and the casings had not been touched since first fitting ; in this case, the leakage in the two boilers tested was 13,000 and 15,000 cubic feet per minute or about 25% of that required for full power. A point of interest in the first case is that in spite of the serious leakage of the boiler casings still occurring, the attention given to them during the refit enabled more than full power to be developed without smoke ; it was, in fact, possible to generate full evaporation with a clear funnel, whereas previously it was impossible to generate more than 80-90% without thick black smoke. Two further examples can be quoted of cruisers in which the ships' staff refitted their casings ; the improvements are very satisfactory :—

Oil Burnt per Boiler lb/hour

Trial	Contractors	Recent	After casing repair
Ship L	13,370	14,280	13,330
Ship S	15,800	17,300	15,400

An anemometer is usually available in dockyards and some larger ships ; this instrument, if anything, is more suitable than the velometer for measurement of flow in funnels. To take these readings, the position selected should preferably be at the outlet end of a parallel or smoothly converging length of uptake or funnel and at least three feet above any major obstruction such as a grating ; the cross-sectional area of the uptake at this position should be measured. The anemometer should be slowly moved round a path approximately half way between the centre and walls of the uptake ; time should be taken by stop-watch. The anemometer readings can be read outside the uptake before and after the test. It is advisable to wear a pattern 230 breathing mask.

It may be wondered, if boiler casing leakage has such an adverse effect, why more has not been said about it. One of the reasons is that it is almost wholly a naval problem. The majority of large shore boilers work on the balanced draught principle, in which the furnace pressure is kept only one or two tenths of an inch below the external pressure ; under these conditions, although there are doubtless many points of leakage, the volume of leakage is negligible. An example from a new liner which has balanced draught boilers will illustrate this point ; while at steady full power, with oil quantity and overall draught loss kept constant (by adjustment to the forced and induced draught fans), it was noted that, with the normal furnace pressure of 0.2 in. w.g. below boiler room pressure, the CO_2 was 14.5%, but with a furnace pressure 2.8 in. below boiler room pressure the CO_2 fell to 13.0%. This lower CO_2 represents an increase in air of 10%, all of which is leakage.

Boilers now under design or manufacture will have casings of greatly improved design ; before acceptance the boilers will be air pressure tested and be shown to leak not more than 3% of the total air required to steam at full power. A feature of the casing design is that maintenance of tightness in service will be relatively easy. Instead of asbestos cloth, the new jointing material is brass sheathed asbestos ; the new material, together with an asbestos putty, will in due course be available in naval stores for use in existing boilers.

Smoke

Having discussed some of the more important factors related to bad thermal performance the solution to the problem of smoke at high power is, for the general case, already answered. All ships on acceptance are required to develop full power with no more than a light haze at the funnel ; the most probable explanation of why so many ships now make thick black smoke at and near full power is that they find it necessary to burn more oil, and that registers are out of alignment or in other ways do not correspond with the drawings. Register arrangements which were satisfactory for certain air and oil quantities may be very unsatisfactory if those quantities are considerably increased ; maldistribution of air and instability of burning may be the direct result. Poor atomization may be an additional cause of smoke, particularly now that furnace fuel oil may be of higher viscosity and specific gravity ; generally, the higher the viscosity at the sprayer the greater the output, so for the same steam output a slightly lower oil pressure is required ; the lower pressure, higher viscosity and the higher specific gravity combine to give larger and heavier droplets which may aggravate impingement ; the remedy is to lower the viscosity at the sprayer by keeping the temperature well up and to use the highest practicable oil pressure ; at whatever the power, oil pressures below 100 p.s.i. should be avoided if possible for caps larger than No. 3, and 70 p.s.i. for smaller caps.

Conclusion

The probability thus exists that by careful attention to register details and the tightness of boiler casings, endurance can be improved by anything from 5% to 20%, general wear and tear of boiler room auxiliaries and brickwork will be reduced, and it should be possible for full power to be developed without smoke. It will be apparent that these possibilities are of the greatest importance.