
The President, Mr. W. H. Dobson, occupied the chair.

The minutes of the last regular General Meeting, held 24th June, 1948, were read and approved on a motion moved by Mr. E. J. McDonald, and seconded by Mr. C. Newstead.

General correspondence was reviewed.

Mr. D. MacSporran presented a paper, "Fundamental Principles of Boiler Design." A general discussion ensued and a very interesting series of pros and cons passed. Mr. Dobson (President) thanked the lecturer for his interesting presentation, and realised the immense amount of work involved in preparation.

A vote of thanks was carried by acclamation on a motion moved by Mr. L. L. Pemberton, and seconded by Mr. J. F. Trevorrow.

Meeting closed with light supper.

Confirmed, 28th October, 1948.

Wm. H. Dobson, Chairman.

**PAPER**

**FUNDAMENTAL PRINCIPLES OF BOILER DESIGN**

Mr. D. MacSporran.

This paper deals with boiler design in general, as you will appreciate that to give it in detail is quite beyond the scope of a short paper such as this.

Before proceeding further I would like to state that I believe boilers and accessories could, with advantage, be brought to a measure of standardization in this country as is being done to some extent in England for the major power stations. It has been found, for instance, that for the same job different boiler makers propose different fan sizes and it has been proposed to standardize the method of finding gas quantities. Also being examined is the possibility of standardizing the size of drums, tubes, pipe sizes, etc.

At the present day in Victoria and South Australia, interest is centred prominently in the burning of brown coal on mechanical stokers for industrial plants, and it appears as if finality has not been reached regarding the best method of firing. This, of course, only applies to industrial plants, as brown coal has been burned successfully on chain
grate stokers at Yallourn for the past twenty odd years. Practically any type of stoker will burn brown coal, but the overall efficiency must be the main yardstick by which the different types of firing are measured. My belief is that the Government would do a great service to steam users if they built a small test plant in collaboration with the boiler makers, and over a long period of time tested the various methods of firing. This would give the steam users confidence in brown coal as a fuel and would ensure a safe future for brown coal mining for industrial purposes. At present a great number of enquiries show that users hope that in the future black coal and briquettes will return to steady supplies, which shows a lack of certainty regarding brown coal. For other fuels available in Australia, the problems of firing are relatively simple and are largely a matter of preference.

When an enquiry is received there is a certain amount of information available:

1. Steam pressure.
2. Steam temperature.
3. Maximum continuous evaporation.
4. Feed temperature.
5. Fuel analyses.

The following must be found:

1. Type of firing equipment.
2. Air required per lb. of fuel (actual).
3. Gas quantity per lb. of fuel (actual).
5. Quantity of fuel required per hour.
6. Combustion chamber rating.
7. Stoker rating.

The answer to the type of firing equipment is sometimes given by the intending purchaser, but in Victoria one is usually asked to provide equipment suitable for burning black coal, brown coal, briquettes and coke for smaller size plants. For boilers in the class of 15 to 100 thousand pounds per hour, the choice usually lies between the spreader, chain or travelling grate stokers.

For built-up areas, the spreader is not very suitable owing to the grit emission, and it is very susceptible to grading of fuel. The problem of grit emission can be partially overcome with the installation of a grit arrestor, but if grit refiring is adopted for purpose of increased efficiency, the grit arrestor becomes less efficient owing to the reduction in size of grit. The provision of a high combustion chamber and high-pressure secondary air can cut down the percentage grit carryover. The secondary air nozzles should be of slit section and spaced reasonably close together, or if possible have the nozzles on both sides of boiler, with the nozzles higher on one side than on the other, and staggered with those on the opposite side. The pressure must be high enough to give penetration and should be in the region of 10 in. to 15 in., or higher if the length of penetration makes it necessary. The nozzles should be
designed to allow a pressure drop so that all of them receive their full share of air.

As the spreader does not carry the reserve of fuel which the chain or travelling grate carry, it is very delicate regarding load changes, and therefore automatic control is almost an essential. This can be a very simple form giving control of fuel feed and boiler damper. Owing to the fuel burned in suspension, up to 30 per cent. depending upon grading, the rating can be taken as higher than chain or travelling grate for finding grate area. Average rates can be taken as:

- N.S.W. Slack: 40-45 lbs./sq. ft.
- Victorian Brown Coal: 55-60 lbs./sq. ft.
- S.A. Brown Coal: 50-55 lbs./sq. ft.

Higher ratings can and are carried, but it is much better to err on the low than the high side, as the stoker maker won’t be thanked for the low initial, but high maintenance costs and high grit emission. The spreader stoker being designed in accordance with the best hand firing can fire almost anything with confidence and is very suitable for low ash content fuels.

The chain grate stoker began as a natural draught stoker for free burning coal, and was usually provided with a long front arch, no rear arch, and no control of air. Coal was burnt because the coal was good, but as the quality and grading deteriorated, this stoker became very inefficient. To meet the need for a stoker to burn low volatile coal with a high percentage of fines, the travelling grate was developed, and in conjunction with close control of air performed its function admirably.

The chain grate was then fitted with forced draught air closely controlled, and attention was paid to overcoming the problem of fines clogging up the sprockets. In conjunction with proper arch design, this stoker forged ahead and became a close competitor with the travelling grate up to lengths of 18 feet and widths of 14 feet.

With either of these stokers attention must be paid to arch design and secondary air, as the stoker depends on these for performance.

Nowadays the archless front setting is almost universally adopted, which usually means an ignition arch about 12 inches long. A rear arch is usually provided, and in the case of low-grade fuels is essential. For free burning coals front and rear secondary air are provided, but in the case of low grade fuels rear secondary air is an essential.

A refinement, which is also used sometimes with low-grade fuel, is to provide a slight suction in the first stoker compartment to maintain ignition. The main purpose in designing for this type of fuel is to ensure that the green fuel can see the flame and the flame must be taken forward as far as possible.

For chain and travelling grate stoker ratings average:

**Induced Draught only—**
- N.S.W. Slack—20/25 lbs. per sq. ft.
- Briquettes—35/45 lbs per sq. ft.

**Forced Draught—**
- N.S.W. Slack—25/35 lbs. per sq. ft.
- Briquettes—40/50 ft. per sq. ft.
- Vic. Brown Coal—35/40 lbs. per sq. ft.
- S.A. Brown Coal—30/35 ft. per sq. ft.
The quantity of air required per lb. of fuel is now the next step, and the theoretical air required is found by elementary chemistry based on finding the oxygen required to burn the carbon, hydrogen and sulphur, and finding the weight of air which contains the required weight of oxygen, that is, multiply by 100/23. The weight of gas is found at the same time by finding the weight of CO₂, H₂O and SO₂ and nitrogen. As the CO₂ analysis is taken dry, the weight of H₂O is neglected, when finding the theoretical CO₂ by weight. The next step is to find the theoretical CO₂ by volume, and this can be done by dividing each gas weight by its molecular weight to give a ration of volume and percentage CO₂ taken similarly as for weight. From past experience with similar type of firing with specified fuel, the CO₂ can be assumed and now the theoretical air is multiplied by the ration of theoretical to anticipated CO₂ to give the actual air, and the gas weight is this plus the weight of constituents including everything except the ash. This may appear to be rather a lengthy process to find something so simple as the quantity of air required, and I may say that unless the fuel is a new one, which would be unusual for Australia, then the complete analysis has been worked out and it is merely a matter of looking up the appropriate column of recorded figures. This is in the CO₂ in combustion chamber, and allowance must be made for leakage in boiler, economiser, air heater, etc. This is a matter for past experience only and for the boiler varies with the type of setting, whether brick or steel cased.

For the smaller type of boiler with medium pressure and temperature, either an airheater or economiser is provided, but not both. If necessary, however, both could be provided by installing a small airheater before the economiser and reducing the boiler surface accordingly.

An economiser goes hand in hand with black coal for over-all efficiency, and an air heater with brown coal for increased combustion, efficiency and increased output.

An exit gas temperature in the range of 400 deg. to 450 deg. can be taken as the basis for boiler efficiency. The losses to be expected are:

1. **Dry Gas Loss.** — Weight of gas multiplied by specific heat as assumed exit gas temperature multiplied by this temperature minus room temperature. This gives the sensible heat in flue gas going to waste up the chimney.

2. **Loss due to moisture in gas from burning hydrogen and from moisture in fuel.** This is combined weight multiplied by total heat of this moisture as steam at this temperature.

3. **Carbon Loss.** — This varies with the chain, travelling grate and spreader stokers, and also with the analysis and grading of fuels. The spreader loss is on the high side, which can be partially regained by grit refiring, as the largest loss is in particles carried over into boiler passes. However, when estimating this loss for any type of stoker with present day fuels, it is advisable to base on the generous side, which would be in the region of 4 per cent. for N.S.W. slack, 7 per cent. for Victorian brown coal, and 9 per cent. for Leigh Creek coal.

4. **Radiation Loss.** — This is purely a figure of experience, as in the efficiency tests everything left over finds a home here. However, as a basis for medium size plants up to 30,000 lbs. per hour, and brick set, a figure of 5 per cent. would be usual with a reduction to 3 per cent. for 100,000 lbs. upwards and steel cased.
FUNDAMENTAL PRINCIPLES OF BOILER DESIGN.

The stoker and combustion chamber dimensions are set out on paper and the water walls set out to suit layout and as near the required heating surface as possible.

This is subtracted from heat liberated to give heat content of gases entering convection bank. By referring to the straight line graph this temperature can be found.

The ration equation is again used with area known, and heat radiated is found more or less accurately.

The convection surface required is found by using the exit gas temperature estimated originally and from these find the mean gas temperature. From the feed temperature entering boiler and the steam saturation temperature the mean steam temperature is found. The difference between the two gives the mean temperature difference. The heat transmission factor is found from a graph made up from previous installations for convection gas radiation to give total transfer. The convection formula is used—

\[ Q = h \cdot c + r \times A \times T_d \]

This area can then be set out and the calculation repeated in steps according to the passes in order to find the gas temperature entering the superheater.

A similar calculation is used for superheater and solved for area and the tubes set out to suit with provision of dummy tubes to give a margin of 10 per cent. in area if no desuperheater is provided.

Similar calculations are used for economiser and/or airheater to give required areas.

It will, of course, be realised that the heat transfer figures are not as easily found as may appear from this paper. This is not a paper on heat transmission, but is meant to be merely a stimulation of interest to those who make no claim to be specialists in this field. The only difficult portion of heat transmission lies in finding the transmission factors and for those who do not wish to be specialists my advice is not to bother trying to find out, but to use only those found by practice. If that point of view is such, then anyone can make quite a successful study of heat transfer and will save himself some very severe headaches. One of the most accepted books on heat transmission is that by William H. McAdams, issued by the McGraw-Hill Book Company, 1942 edition.

In making the calculations for heating surface it was necessary to assume a mass gas flow and when the boiler is being set out the gas passes must be designed to maintain this figure. With the boiler laid out it is now usual to go ahead with the details of accessories, which are just as important for the best operation of boiler.

The size of fans are worked out on the volume and temperature of air for combustion with a margin for overload conditions. The static pressure is based on the friction loss in ductwork, plus the friction loss through grate and fuel bed at overload conditions. A margin is added to the required water gauge to allow for bad operating conditions.
The losses are now added up and subtracted from 100 to leave the figure of efficiency, which would probably be in the region of 80 per cent. for N.S.W. slack, 68 per cent. for Leigh Creek, and 66 per cent. for Yallourn old cut brown coal.

The total heat of steam is taken from the steam tables and the gross calorific value of fuel as fired is multiplied by the boiler efficiency as a decimal to find the heat available in fuel. The heat in fuel divided by heat in steam gives the lbs. of steam per lb. of fuel, and the evaporation divided by this figure gives the total fuel required per hour. To cover a possible peak loading, this quantity is increased by 10 to 15 per cent.

Having decided upon a stoker rating the total fuel divided by this figure gives the area of stoker required. Experience again decides the shape of stoker, if chain or travelling grate, and the throw of spreader decides the width. The combustion chamber release is decided upon and the figure divided by stoker area gives the height of chamber necessary. Heat release figures range from 25 to 40 thousand B.T.U. per cubic foot for small installations with refractory walls to large installations, with water walls for chain or travelling grate stokers, and 15 to 30 thousand for spreader stokers.

The question now is whether or not to provide water walls. The analysis of fuel should give the ash fusion temperature, and the exit gas temperature from furnace must be low enough to ensure that the ash particles are not carried over to boiler surface in a molten state.

To revert to the back end of the boiler and begin with the assumed exit gas temperature and a furnace temperature is assumed. From these two temperatures a straight line graph can be drawn to show heat content of gases using specific heat at these temperatures and assuming that air leakage and specific heat vary accordingly.

Working on a heat absorption balance the gas temperatures can be estimated from the straight line graph for the entrance to air heater and/or economiser which is the boiler exit. The heat absorption by the superheater is found and added to the absorption by economiser and/or airheater. The actual heat liberated in combustion chamber is then found that is, heat content of fuel, plus air if preheated, less radiation loss and carbon loss. The remainder of heat losses plus heat absorption by air heater and/or economiser, is subtracted from heat liberated to give heat absorption by boiler surfaces by convection and radiation.

Then total heat radiated equals heat absorbed by radiation plus heat content of gases entering boiler.

An assumption is made for the furnace leaving temperature to suit the ash fusion temperature and the heat content of this is then found. This subtracted from the heat liberated gives the heat to be absorbed by radiation.

The area required is then found as a first estimate by the Stefan Boltzmann law—

\[ Q \text{ (heat absorption)} = 0.1723 \times A \times C \left( \frac{T}{100} \right)^4 \]

The constant will depend upon type and emissivity of water walls.
The induced draught fan follows along the same lines as Forced Draught Fan and also control of output. The secondary air fan is usually based on a capacity of 10 to 15 per cent. of air for combustion with a pressure of 10 to 15 in. water gauge. The control of air is usually by damper, but for best results this could be done by variable nozzle diameter.

If automatic control is necessary the type is usually a matter of preference or economics. For the small installations the best is naturally the simplest owing to the necessity for employing skilled technicians for the more intricate. The simple type has a pressure controller with power cylinders for controlling the speed of chain grate stoker or fuel feed of the spreader, and controlling the induced draught fan inlet damper.

A feet water regulator is a good friend to have on a boiler, with steam control valve in steam line to pumps for reciprocating pumps. The feed regular valve is always installed before economiser owing to the danger of excess pressure in economiser if the valve shuts off suddenly.

A high and low alarm is a necessity, but I have been told that in China this is not allowed on a boiler, as the attendant is apt to fall asleep on his shift, depending on the alarm to wake him up. Special attention must be paid to the installation of the alarm if it is an external type, as it is apt to give a false level if not lagged sufficiently, or if it is installed on the opposite side of boiler to the water gauges.

For the same reason the water gauge pipes should be well lagged and the water gauges should be blown down frequently, but this is beyond the scope of the designer and lies mostly in doubt.

In smaller installations with water walls the feeder pipes to water walls are usually based on an empirical formula derived from practice. Large drain valves should not be provided for water walls owing to the danger of faulty operation, but they should be large enough to pass something more than water; 1/2 in. diameter valves are usually in order. The feeders to headers should be designed so that there is no danger of some of the heated tubes being starved.

When designing the superheater, attention must be paid to steam velocity to ensure that it is high enough to prevent burning out of tubes. Baffling of steam in drums is a very important point which was receiving due attention in England and Europe before the war and is developing still further now. If the baffling is efficient the necessity for a steam receiver is not paramount unless it is used as a steam drum with the steam release taking place there, giving a long reserve of water before the danger point is reached, as is being done at present in Scandanavia.

The quality of steam to superheater is important for any installation and grows more critical as the steam temperature rises.

Efficient steam baffling, therefore, plays a very important part in the performance of superheater as it can cut down or eliminate scale deposits in the superheater tubes.

The velocity of steam in the tubes is very important, and this velocity is gained by a pressure drop from boiler to superheater outlet. When the velocity is low some tubes are starved of steam and burn out very quickly.
On large installations with P.F. firing, and on two-shift operation, the question of starting up has serious complications for the superheater, and in England now the accent is on self draining superheaters.

This does not apply to the same extent for medium and small installations with stoker firing.

For the control of superheater on large boilers there is a choice of several types.

Heat exchanger.
Direct water injection.
Gas bypass.
Gas recirculation.

The most popular is the heat exchanger or a combination of this and gas by pass.

A desuperheater allows a margin of surface in the superheater, but without control the surface must be met. This is simply done for small units, but it is usual to allow a proportion of dummy tubes to cover possible errors in estimation. This is not a sign of weakness, but merely a show of virtuous caution.

One point to be remembered in designing the superheater is to make provision that the superheater safety valve lifts before the drum safety valves as this ensures a flow of steam when the demand cuts down suddenly.

The method of feed to boiler is usually based on the maker's standard practice and ranges from a simple internal pipe below the water level to some form of discharge in the steam space.

The feed connections to drum are a point to be watched so that the possibility of thermal stresses being set up in the opening are eliminated.

Some instruments are usually included for any installation where the engineers is interested in more than just quantity. The minimum requirements should be a combustion chamber draught gauge and steam flow meter, with a hand or sat for periodic testing of CO₂. The draught gauge should be set as low as possible in the combustion chamber, as this eliminates the error in reading caused by the chimney effect in the furnace. In addition a draught gauge for boiler and economiser outlets will tell the operator when the boiler and economiser tubes require cleaning.

No mention has been made of pulverised fuel fired installations and the reason for that is that this type of firing is usual only in the larger sized units, and is a highly-specialised work, of which very little is done in this country.

The main types of mills are the slow speed ball mill and the high speed beater mills. The ball mill is unsuitable for coal, having a moisture content, but can handle high ash content coals admirably without high maintenance. The high-speed beater mill is very suitable for friable coals, having a high moisture content.
However, as explained previously, this is a very specialised subject, and for anyone who desires an understanding of the problems therein I would recommend them to the volume of papers discussed at the Conference on pulverised fuel, June, 1947, published by the Institute of Fuel.

I should have like to have covered some ground in describing boiler designs which have a great measure of interest to many of us. However, this would have meant giving a great deal of time going through a large volume of collected articles to sift out the best, and this would have taken up more time than I had available. One point to be made, though, in this connection, is the remarkable progress that has been made over the last fifteen years in natural circulation boiler design. Possibly some of this progress has been due to the competition from the forced circulation boiler, as about ten years ago the forced circulation boiler, and particularly the La Mont Boiler forged ahead tremendously, and it looks as if the natural circulation boiler was doomed. However, the fact now is that the natural circulation has overtaken the forced circulation boiler and has again assumed the leadership.

The old type of boiler, with multiple drums and convection banks, has virtually disappeared and its place has been taken by the single or two drum type with almost 100 per cent. radiant surface and large economiser and airheater.

Having high absorption heating surfaces the circulation is in almost the same category as the forced circulation boiler.

As the years have gone by the size of boiler has decreased in relation to output and it is quite safe to say that the space occupied by a boiler built fifteen years ago can now be occupied by a boiler having double the evaporation.

To conclude this paper I wish to say a few words of encouragement to those who are standing on the fringe of boiler design, and wish to plunge into the centre, but don't quite know how and are afraid to ask advice for fear of appearing foolish. Well, quite a number of people have a general knowledge of everything connected with boilers, and also quite a number of people have specialised knowledge of something connected with boilers, but I don't think that anyone has yet lived long enough to have a specialized knowledge of everything in boiler engineering. After a long period of study and experience one must come to a point when realization comes of a terrifying lack of knowledge, and it is then that one realizes what little time there is to make any appreciable progress. If a pleasant life is desired, devoid of worry, then the best thing to do is to never to come to the stage of finding out the lack of knowledge. Next, if one is not content with this and wishes to make a good job of the business, then the best thing is to concentrate on one small branch at a time and master it as thoroughly as possible before going on to another, but this takes infinite patience. Also, the sequence of study should be orderly and to a definite pattern. There are many branches in boiler design:

Combustion, with its knowledge of the best method of burning any fuel, semi-butilinuous, bituminous, and sub-bituminous coal, lignite, brown coal briquettes, tar and pitch, coke and coke breeze, fuel oil, bagasse, wood logs, logged wood, sawdust, all of which are used in Australia, although so far no client has stipulated that the furnace equipment must be suitable for burning all of them.
Heat Transfer, for which a knowledge is required, and although, perhaps rarely used, of the methods of computing heating surfaces and draught loss in tube banks, superheater, economiser, air heater, feed water heater. A knowledge should also be gained of circulation problems in the boiler circuit, and the correct methods of testing a boiler and analysing the results should be mastered so that future assumptions can be made with confidence.

Material Design—which covers drums, tubes, headers, piping and hangers, steelwork, chimney, bunkers, etc.

General—which would cover a knowledge of fans, motor, switchgear, instruments, grit collectors, mountings and fittings, pumps, dampers and installation.

Ash Handling, Coal Handling, Feed Water Treatment.

The mastery of any one of these groups would be a major success, but the mastery of all of them would be a miracle.

A simple rule is not to hide lack of knowledge except under suitable circumstances. However, if one is diffident about this, one very good approach is to ask advice, and when given it merely remark that that is exactly what one had in mind, but only wanted confirmation, which is a formula very much in use in engineering.

This paper will probably receive a mixed reception, but if it has by any chance given anyone a germ of interest in pursuing further the fascinating subject of boiler design, then I shall feel that my nights of labour have not been entirely passed over unburnt to the ash hopper.

If any one has sufficient interest to let me know where, in their opinion, I have erred, then they will have my very deep gratitude, and if they can write to me regarding it I should be still more pleased, as it would allow me to absorb it better. Like quite a large number of Scotsmen, I like to ruminate over contentious problems in solitude.
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