Modern Trends In Boilers and Efficiency Improvement Programmes

By J.Gladstone Evans & C.Damodaran

1. INTRODUCTION:

Boilers are equipments used for heating water or producing steam. Boiler is thus an energy conversion equipment along with heat transfer duty.

The thermal energy required for transferring to the incoming water, is supplied by burning fuels. In the combined cycle schemes, the boiler accepts hot flue gases from gas turbines / diesel engines and produce steam from the waste heat. In such cases, the boiler will be called upon to give the heat transfer duty only.

2. COMBUSTION OF FUELS:

There are variety of fuels which are burnt in boilers for producing steam. These fuels can be classified into solid, liquid and gaseous variety. The combustion equipment required for burning these different fuels would also vary widely in their construction and operation methods. While it would be relatively simple to burn liquid fuels, sophistication increases further for burning gases and solids. The burning of solid fuels requires an elaborate preparation of the fuel before burning. It is also seen that the ignition temperature required is higher for solid fuels. Efficient combustion of solid fuels would therefore require pre-heating of combustion air.

3. HEAT TRANSFER:

The purpose of boiler is to generate either hot water or steam. The heat released by burning fuels (or the waste heat in the gases) is to be transferred efficiently to the incoming water. In the boiler practice, the heat is transferred in two modes: (a) by radiation and (b) by convection.

The radiation heat transfer occurs because of both flame radiation and non luminous gas radiation. The radiation heat transfer is governed by the 'inverse square law' and also the emissivity and temperature of the radiation source and the boiler heating surface.

The convection heat transfer can be either due to natural convection or forced convection. Various dimensionless numbers, characterising the flow of fluids, like Reymolds, Nusselt, Grasshoff, Prandtl etc. Density, viscosity and wetted perimeter of the flow channels are used to compute these dimensionless numbers.

4. BOILER LOSSES:

A boiler is said to be efficient, if it converts all the chemical energy in the fuel into heat energy and also transfer them fully to the incoming water. This however cannot be realised completely in practice. The slippages which prevent complete combustion of the fuel and also the complete transfer of the released heat to water, are grouped together as ' losses' . It is therefore necessary that these losses should be minimised to make the boiler more efficient.

5. TYPES OF BOILER LOSSES:

The computation of boiler efficiency by determining the losses have been standardised in various countries. These standards prescribe the method of determining the boiler losses and hence the boiler efficiency. The following types of boiler losses are reckoned with:

a. Loss due to unburnt fuel:

This loss directly reflects the efficiency of the combustion system. The unburnt fuel is retained generally with the solid combustion residue. It is generally found in the form of free carbon. The heat value of this free carbon found with combustion residue reflects the loss due to unburnt fuel.

b. Loss due to partial combustion:

The chemical energy of the fuel is released as heat through the oxidation process. Oxygen chemically reacts with the combustible matter in ' multi valent' mode. The amount of oxidation (and hence the amount of heat released) would therefore depend upon the valency under which oxygen combines with the combustibles. The most important example of this process would be burning of carbon to produce either carbon monoxide or carbon dioxide. The burning of carbon into carbon monoxide is an example of partial combustion. This would lead to a certain amount of unreleased heat from the fuel which is termed as ' loss due to partial combustion' .

c. Dry gas loss:

The products of combustion from any fossil fuel would contain water vapour as well as other gases. The total gaseous product of combustion is termed as ' flue gas' . The flue gas without moisture is termed in boiler technology as ' dry gas' . It is not possible to transfer out all the heat from the flue gases to the incoming water completely, as this would require impractically large heat transfer equipments. In practice it is therefore necessary to let out the flue gases at some convenient temperature which is higher than the temperature of the incoming water. This temperature however can be brought down by adopting extensive air pre heat. The sensible heat contained in the dry flue gases at the boiler exit is termed as the ' dry gas loss.

d. Loss due to fuel moisture:

Almost all the fuels contain a quantity of physical moisture along with the combustibles. In addition, the combustion of fossil fuel (which contains hydrogen) releases water vapour with the flue gases. This total quantity of moisture will also be leaving the boiler territory at a high temperature along with other products of combustion. In almost all the practical cases, this temperature would be higher than 100(C. Thus this total quantity of moisture takes away its requirement of latent heat of vapourisation and the sensible heat of water and steam from the calorific value of the fuel. This represents the ' loss due to moisture in fuel' . In the case of gaseous fuels, the basic moisture of the fuel would be already in the vapour form. It therefore does not require latent heat of vapourisation from the calorific value of the fuel.

e. Loss due to air moisture:

All fuels require air for combustion. The atmospheric air contains a small quantity of water vapour because of humidity. This water vapour gets heated up along with flue gases from atmospheric temperature to the temperature of gases leaving the boiler territory. The sensible heat picked up by the water vapour in this process, is termed as ' loss due to air moisture' .

f. Loss due to sensible heat of solid combustion residue:

The solid and liquid fuels contain a certain amount of non-combustible matter in them, which is known as ash. During the combustion process, the ash also gets heated up and is rejected from the boiler territory at some higher temperature. The sensible heat of this ash above the atmospheric temperature is termed as ' loss due to sensible heat of ash' . In most of the boilers firing solid fuels, a portion of the ash is rejected at the boiler furnace itself. Thus this portion of the ash will snatch away a higher quantum of heat from the system as loss. The major portion of the ash travels along with the flue gases and is termed as ' fly ash' . The fly ash then escapes from the boiler territory at the same temperature as outgoing flue gases. Correspondingly the fly ash takes away its sensible heat quantum as loss from the boiler.

g. Loss due to radiation:

Most of the boiler components work at fairly high temperature levels. These equipments would therefore lose some heat to the surrounding space. They are generally insulated from the surroundings. However, because of practical limitations, the boiler equipments' surface temperature would be higher than that of surrounding atmosphere. The boiler surfaces are therefore losing heat continuously to the surrounding space, through natural convection. There is some heat radiation, but this would be highly negligible. This type of loss of heat from the boiler surface to the atmosphere is termed as ' radiation loss' .

A typical Bagasse fired boiler loses anywhere between 30 to 33% of the input heat in various ways as explained before. The efficiency of the boiler would then be anywhere between 70 and 67%.

6. IMPROVEMENT OF BOILER EFFICIENCY:

In order to make the boiler more efficient, it is necessary to reduce the boiler losses:-

a. Reducing loss due to unburnt fuel:

In the present day technology of gaseous fuel combustion, it is possible to completely remove this loss. Most of the oil firing equipments would also ensure complete combustion of the oil. In the case of solid fuels however, there is always a certain quantum of unburnt carbon found along with the residual ash. The typical of values of unburnt carbon found in boiler ash is indicated in table 1. The unburnt carbon can be significantly reduced by improving the design and operation of combustion equipment. The combustion of fuels improves by increasing the temperature of the fuel and air as well as by increasing time available for combustion. By providing adequate turbulance to the combustion air, it will allow fresh molecules of oxygen to continuously come into contact with solid fuel particles and thereby ensure complete combustion. In order to achieve these results, we must increase the air pre-heat and the ' heat loading' in the furnace. Burners with high swirl numbers would improve the turbalance and assit in complete combustion of the fuel. The admission of combustion air at appropriate locations along the trajectory of the fuel particles would also enhance completeness of combustion. The reduction of this loss would therefore be posible by improving the combustion system design. The fluidised bed combustion is a very effective method of reducing unburnt fuel loss. Many advances have been achieved in the recent past, in the field of fluidised bed combustion technology.

b. Reducing dry gas loss:

Dry gas loss is directly affected by the temperature of the outgoing flue gases, as well as the excess air coefficient adopted. With modern combustion devices, it is possible to reduce the excess air coefficient significantly. The recommended values of excess air coefficient for various types of combustion systems are given in table 2. The reduction of flue gas outlet temperature however, would require extra investment for additional surfaces in air pre heater. It should also be remembered, that fuels containing sulphur should be dealt with carefully to avoid corrosion. Corrosion (due to sulphur in fuel) can also be minimised by using special alloy steels for the construction of last stage heat recovery surfaces. Thus the reduction of flue gas temperature (to increase the efficiency) would be largely a trade off between initial capital cost and revenue savings of fuel cost due to higher efficiency.

c. Reducing loss due to fuel moisture:

It is practically not possible to bring down flue gas outlet temperature to a value below 100(C. However, the loss due to sensible heat of super heating water vapour can be minimised. This can be achieved by pre-drying the fuel with separate equipments. It would also be possible to use boiler exhaust flue gas itself for pre-drying of fuels. This would be an especially attractive proposal for high moisture fuels like lignite and bagasse. Special fluidisers and agitators can be successfully adopted in such pre-dryers. In the recent days, non-metallic air preheaters and feedwater heaters have been developed to reduce outgoing flue gas temperature to values below 100(C which would then improve boiler efficiency considerably.

d. Reducing loss due to radiation:

The ' Radiation Loss' is a misnomer. This loss is due to natural convection on the insulated surface of the boiler. The general practice for insulation is, to design the insulated skin temperature to be 20(C) above the ambient temperature. Generally this would keep down this loss to a value less than 200 KCAL/M2/hr. However, the insulation thickness can be reduced or increased depending on the special site conditions. In the indoor type boilers, there is reduced natural convection and hence can economically accommodate relatively higher skin temperatures. The skin temperature of the insulated surfaces is also governed by safety requirements. Wherever there is a possibility of human beings, moving close to the insulated surfaces, it should be ensured that the insulated surface skin temperature should not be higher than 60(C).

The American Boiler Manufacturers' Association have made detailed studies in the past on the quantum of ' Radiation Loss' in boilers. Figure 4 gives the chart of acceptable radiation loss in various boilers.e. Reducing loss due to wastage of steam and hot water:

Since this is a ' Non Technical Loss' , it does not figure in the boiler efficiency computations. However, this loss is very real and requires great attention. Leaky valves and flanges contribute significantly to this loss. Many times soot blowing cycles are adopted carelessly in the boilers without proper assessment, leading to wastage of super heated steam. Soot blowing need be resorted to only when the flue gas out let temperature (for a given load) increases by more than 3(C. It is also necessary to have a check on the boiler blow down. Excessive blow down without relation to steam purity requirements would only waste thermal energy. The steam purity achieved, would vary with the boiler water concentration in the drum. The recommended boiler water concentration values are given in table 3. Blow down should be adopted only when the concentration exceed these limits.f. Reducing loss of electrical energy:

There are many electrical drives adopted for the boiler auxiliaries. The electrical power consumed by these auxiliaries also require careful attention since electrical energy is basically costlier than thermal energy. Adoption of suitable power factor correction devises and correct sizing of the motors would be helpful. The adoption of controls for motor speeds would be generally economical in cases where the connected power is 100 KW and above.7. CONCLUSION:

Boilers consume significant quantity of fuel and electricity in their operation. The improvement in boiler efficiency will directly result in fuel and electricity economy. A typical 80 TPH boiler with bagasse firing would require about 34.7 tons of bagasse per hour. Even a 0.5% increase in the boiler efficiency for these boilers, can result in 10,60,000 Kg. of bagasse saving for a duration of Six months. With the present price of Rs.500/- per ton of bagasse, this would mean a monetary saving of Rs.5,30,000/- per six months. It would thus be economical to spend even Rs. 10 lakhs to achieve this marginal increase in efficiency. The continuous vigilance on the operating methods and planned preventive maintenance on the boiler components would go a long way in achieving highly efficient boilers.

TABLE 1 TYPICAL VALUES OF UNBURNT CARBON FOUND IN ASH.

Sl. No.	Type of Fuel/Furnace	Unburnt Carbon Percentage (W/W in Residue)	
		Furnace	Fly Ash
1.	Travelling Grate Furnace - Coal Firing	10 - 20	8 - 15
2.	Dry Bottom Furnaces - Bituminous Coal Firing	2 - 8	1 - 5
3.	Dry Bottom Furnaces - Brown Coal / Lignite Firing	2 - 6	1 - 5
4.	Circulating fluidised bed furnaces - Biomass Firing	-	6 - 12

TABLE 2 RECOMMENDED VALUES OF EXCESS AIR COEFFICIENTS.

Sl. No.	Type of fuel/firing systems	Excess air co-efficient
1.	Bagasse/wood/bark on grates/stokers	1.30 - 1.40
2.	Coal/Lignite on grates/stokers	1.30 - 1.40
3.	Pulverised coal firing/dry bottom	1.18 - 1.25
4.	Pulverised coal firing/wet bottom	1.12 - 1.20
5.	Fluidised bed combustion	1.10 - 1.20
6.	Oil Firing	1.02 - 1.10
7.	Natural Gas Firing	1.05 - 1.10

TABLE 3 RECOMMENDED BOILER WATER CONCENTRATIONS..

Boiler operating pressure (atg)	Max. Allowable total dissolved solids in feed water (ppm)	Recommended total dissolved solids in boiler water (ppm)
Upto 20	6	1500
21 - 40	3	1000
41 - 60	1	250
Above 60	0.2	150