JOURNAL OF RESEARCH TECHNOLOGY AND ENGINEERING, VOL 1, ISSUE 3, JULY 2020 ISSN 2714-1837

Industrial Boiler Operation

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Abstract— The rapid growth of industries these days also increasing the use of boilers in fulfilling their various manufacturing and other processes. Due to this increasing demand for boilers, it is also important to consider the efficiency and the performance of the boiler to get the maximum output and long-term use without any damage or interruption. This article is mainly focused on various methods of optimization of an industrial boiler including improvements in water treatment process, energy management techniques, heat recovery methods, boiler efficiency improvement techniques and some suggestions on usage of alternative fuels instead of fossil fuels.

Index Terms— Boiler efficiency, Energy management, Heat recovery, Industrial boiler, Water Treatment

1 INTRODUCTION

A boiler is a kind of enclosed vessel that provides a means for combustion and transfers heat to water until it becomes hot water or steam, then the hot water or steam under high pressure is then usable for transferring the heat to a process. This is one of the most needed and valuable assets of all most all the processing industries around the world. They play a crucial role in energy production while devoting significant investments on boilers, especially on boiler used fuels. If we consider boilers in Sri Lanka, the most widely used boilers are biomass boilers. Approximately four hundred biomass boilers are there, and it uses around 3200 metric-tons of biomass to compensate for the daily demand. Well-grown trees (especially rubber) are used as the fuel for those boilers. Most of the boilers are having over three tons of steam capacity. Some industries are running 24 hours per day while the majority of them run about 12 hours per day. Thus, they consume an enormous amount of biomass to continue their process for generating high-pressure steam [1]. A well-performing boiler does not consume fuel beyond the limits, and it is a positive impact on its efficiency. Although industries are very diverse, their steam system seems common, and they consume a more considerable amount of power to operate. That is why it is a bit complex to carry out energy efficiency measures to check whether their operation is going on well or not and evaluate the performance of the boiler by doing energy audits. The boiler efficiency can be increased by different practices such as water treatment, alternative fuel, energy management, and heat recovery.

2 BOILER WATER TREATMENTS

It is essential to consider about the boiler feed-water when we talk about boilers because it is essential to increase the effectiveness of boilers and to avoid the damages to the boiler tubes and shells. Boiler feed-water must be free from contaminants which can affect the whole operation of the boiler. So, the water required for steam generation must meet the standards. Primarily the water needs to be treated to remove the minerals and oxygen. There are several unit operations involving to treat the water, such as filtration, coagulation and sedimentation. To get rid of minerals - softening, demineralization and reverse osmosis processes can be used. To remove oxygen from the water, de-aeration and oxygen scavenging processes can be used.

Water treatment aims to minimize problems and sudden failures, to maximize the potential of condensate, to maintain clean and neat internal boiler surfaces, to the extent the lifetime of the equipment. The raw water may contain various pollutants. So, treatment is required to remove the suspended solids and other impurities in it.

And to minimize boiler water treatment, the raw water source should be clean and high in quality. Some of the common contaminants or pollutants in water have listed in Table 1**[2]**.

Table 1. Common pollutants in water

Name	**Description**
Iron and Manganese	Can exist in water as a dissolved cation but readily precipitates and cause discoloration and fouling
Turbidity	A finely suspended matter which appears as muddy or cloudy which does not settle.
Colour	Generally due to decayed organic matters
Total Suspended Solids - TSS	Exist in water as suspended particles. They can be mineral or organic particles, can be removed by filtration.
Total Dissolved Solids – TDS	There are scale forming and non-scale forming dissolved solids in water. The principal ones are calcium and magnesium carbonates and sulphates which form scales when heated.
Hardness	Calcium and Magnesium salts which are mainly responsible for scale formation.
Alkalinity	Bicarbonate (HCO_3) and Carbonate (CO_3) and Hydroxyl (OH) ions which cause the alkaline situation of the water
Silica	Most detrimental impurity in water. Usually exist in water as an anion or as a colloidal suspension
Dissolved gases	Oxygen and Carbon dioxide which dissolved in water. These gases are the main contributors to corrosion.

After steam transfers its heat to any of the industrial processes, it converts to a liquid phase called condensate. Condensate water is highly pure and does not require additional treatment to reuse. So, that can be reused as boiler feedwater, and it reduces the treatment cost. As the boiler blowdown water leaves at high temperature, it can be used to preheat the boiler makeup water. A proper controlling of the blowdown will reduce the formation of scale inside the surface of water-tube boilers. Scale formation will slow down the heat transfer; thus, reduce the boiler efficiency.

3 USAGE OF ALTERNATIVE FUEL IN A BOILER

A boiler needs a fuel system to convert feed-water into steam or hot water. The fuel system is an important part and playing a vital role in every boiler. Most commonly, fossil fuels such as coal, petroleum-based oils, natural gases and biomass are used as the fuel for the boilers which are high in cost. Refuse Derived Fuel (RDF) is a kind of alternative solid fuel that is derived from domestic or industrial municipal solid wastes such as non-recyclable plastics, paper cardboard, labels and generally corrugated materials (Fig. 1). RDF poses huge environmental benefits and reduces fuel cost as less and less fossil fuel is required. Calorific value of the RDF is around 16.72 MJ/kg [**1**].

Fig. 1. RDF fuels from Industry

Palm fibres and shells are the residues produced during the crude palm oil and crude palm-kernel-oil production processes. Sri Lankan palm oil industries use this as fuel for boiler [3]. The calorific value of palm fibres 9.2 MJ/kg and calorific value of palm shells is 16.9 MJ/kg [**1**].Fig. 2 representing palm shell and Fig. 3 representing palm fibre.

Fig. 2. Palm Shell

Fig. 3. Palm Fibre

Dried sawdust is used as fuel in many furniture factories. And most of the fabric companies in Sri Lanka also run their boilers using sawdust as fuel. Calorific value is 14.65 MJ/kg [1] (Fig. 4).

Fig. 4. Saw Dust

In sugar industries in Sri Lanka, the by-product of sugar production is the fibrous waste of sugar cane called bagasse, and this is used as an alternative fuel for the boilers to generate electricity [4]. Calorific value is 9.6 MJ/kg [2].Picture of Bagasse from sugarcane is shown in Fig. 5.

Fig. 5. Sugarcane bagasse

Rice hull is a byproduct of rice production during milling and it is readily available, and easy to collect. An additional benefit of rice hull as biomass fuel is the ash after the rice hull combustion, that ash is particularly high in silica. Food and rice mill industries have used these types of rice hull as boiler fuel [5]. The calorific value of rice hull 13 to 19 MJ/kg. Fig.6 represents the rice hull.

Fig. 6. Rice hull

Typically, 70 to 80% fuel can be saved by using wood chips as boiler fuel. These boilers function like fossil fuel boilers. Wood is made up of Carbon, Nitrogen, and Oxygen; therefore, their calorific value is much higher, and due to that, the boiler efficiency also increased. Mostly these types of alternative fuels are used in soft drinks, laundry, and rubber industries in Sri Lanka. Calorific value is 17 to 21 MJ/kg [2]. Image of wood chip is shown in Fig. 7.

Fig. 7. Wood Chips

In chemical industries, hydrogen is produced as a by-product. Some of the hydrogen produced is used for creating hydrochloric acid and remaining are wasted. So wasted hydrogen can be utilized as an alternative fuel for boilers instead of furnace oil [6]. The process of crude oil refining produces more substantial amounts of oily sludge as waste, which contains oil, benzenes, and other substances. Oily sludge consists of hydrocarbons and the high calorific value about 16.32MJ/kg. Therefore, it can be used as boiler fuel by adequately treating the sludge [7]. Fig. 8 represents oily waste sludge. Furthermore, usage of fossil fuel can be replaced by ways as mentioned earlier, and they are readily available everywhere, are more environmentally friendly. Moreover, this will be a solution for the disposal issues for industrial waste. Mainly, it reduces fossil fuel costs, and significantly reduce the carbon emission too.

Fig. 8. Oily Sludge

4 ENERGY MANAGEMENT

A process of analyzing how efficiently energy is being used in a system is called energy management. A mostly higher amount of energy usage is occurred due to the operation of the boiler. Under the energy management concept, we can take several efficiency-maximizing steps to improve boiler performance. An idea about boiler performance can be obtained through boiler efficiency and evaporation ratio calculations [8].

1. Makeup water management
   - Keep records on makeup water to detect any leak or loss.
   - Maximize the efficiency and the capacity of the existing feed water preheating system.
   - Improve feed water treatments to minimize blow down losses.
   - Use economizers to preheat makeup water.
   - Use a heat exchanger to preheat makeup water by using the heat of blowdown water.
2. Condensate and blowdown system management
   - Utilize condensate return in greater percentage will reduce the energy required to produce steam.
   - Monitor the quality of condensate return.
   - Properly control the blowdown. improper control may lead to scale formation inside the boiler resulting in overheating and ultimately causing boiler tube failure.
   - Take blowdown flash steam into a flash steam tank and use it for other heating applications such as for de-aerators
3. Improve boiler combustion and waste recovery system
   - Use continuous oxygen monitors for making adjustments to keep excess air at an optimum level.
   - Avoid subjective judgments of operators based on flame or colour of flue gas to control excess air supply.
   - An automatic combustion control system can be added to automatically adjust the combustion airflow.
   - Maintain regular inspections, maintenance and housekeeping activities to ensure optimal heat transfer.
   - Adjust burners properly to have complete combustion.
   - Check and eliminate the entrance of unwanted air into the boiler and flue gas exhaust.
   - Using economizer to reuse heat in the flue gas.
   - Using air preheaters, regenerators to preheat combustion air.
4. Steam and condensate system management

- Keep steam quality by doing regular chemical treatments and blowdown properly.
- Identify steam and condensate leakages and fix them.
- Keep insulation on steam and condensate lines properly.
- Having proper drainages to eliminate water hammer and losses of steam and condensate recovery.
- Set up steam trap inspection and maintenance procedures.
- Add measuring, metering, and monitoring equipment to the boiler and fuel flow, steam flow, feedwater flow, condensate flow and blowdown flow.

5 HEAT RECOVERY

Almost every industry in Sri Lanka have boilers to fulfil their production process needs. Although having boilers, in some industries there are no proper methodologies to handle the losses in the boiler. One of the big problems is heat loss because of the heat losses in the boiler system; the overall efficiency of the boiler decreases. By the heat recovery mechanism efficiency of the boiler can be improved further, and thus it will economically benefit the relevant industry too. There are various technologies and methods to recover waste heat emitted from the boiler to improve efficiency and decrease energy consumption. Below are some methods listed,

1. Preheating Feed-Water and Inlet Air

If there is a more considerable difference in temperature between the inlet air feeding location and the ceiling of the boiler room, this may be due to the boiler and stack losses [9]. We can either extend the air intake upward or force the hot air to the inlet location. If the heat loss is mainly due to the boiler wall insulation, the boiler should be considered. Also, we can recover heat from the exhaust gas to heat feed-water supply and inlet air to save energy and fuel. These methods are used in most industries, Sri Lanka.

2. Boiler Blowdown Heat Recovery

The blowdown process is used to control the TDS inside the boiler by releasing boiler water and sediments through the blowdown valve. Through the blowdown, a considerable amount of heat also released to the surrounding. By using a plate type heat exchanger, this heat can be recovered and transferred to preheat the boiler feed-water[10].

3.Condensate Water Return system

After the steam is supplied the relevant process, it is condensate into the water but still having high-temperature value. A well-designed condensate-return heat recovery system to use this heat back to preheat the boiler feed-water will reduce the energy required to heat the feed-water into steam. Implementing and maintaining such a system will economically benefit the industry.

4. Waste-Heat Boilers

This kind of boilers is used for heat recovery in big industries which having many boilers, gas turbines, incinerators, etc. Flue gas of those boilers and turbines flows through a series of water tubes. Thus, the water vaporized in the tubes and collected in a steam drum. The pressure and rate of steam generation mainly depend on the temperature of waste-heat. If this is not enough, we can use a separate burner to acquire the required state[11].

5. Heat Transfer Medium

Most commonly water is used as a heat transfer medium for all the boilers as it is readily available everywhere. Instead of using water, Thermic fluids can be used as a heat transfer medium. The main advantage of Thermic fluid over water is, there is mostly no heat lost by the media, only heat transfer happens. So, this will eliminate the need for blowdown as there will be no settling particles in it.

6 EFFICIENCY IMPROVEMENTS

Boiler efficiency can be improved by adopting an energy-saving measure to avoid energy waste. Mainly the efficiency of boilers is affected by the heat losses. Such as radiation, blow-down, flue gas, fly ash, and bottom ash losses. To operate a boiler more efficiently, identifying the sources of energy waste and recover the energy which is wasted. The boiler efficiency can be calculated as a "ratio of the net amount of heat used by the processes to the quantity of heat supplied to the boiler". Below are some methods which can improve the efficiency of a boiler,

1. Proper Boiler Insulation.

To minimize the heat losses by radiation and convection through the valves, steam pipes and outer walls of the boiler, those should be adequately insulated. For the insulation ceramics, fibres will be used which are having lower heat capacity to allow enough resistance to heat transfer.

2. Air Preheater.

Air preheaters help to maintain the air temperature of flue gasses and the incoming air. The efficiency of the boiler gradually increases with the decrease of flue gas temperature. Preheater efficiency may be affected by seal leakages, erosion, corrosion effects, dry and wet losses [12].

3. Improving Combustion Efficiency.

The stoichiometric air-fuel ratio for various fuels may vary according to the formula. The stoichiometric ratio indicates the minimum amount of air required for the whole combustion process. Incomplete combustion can occur due to the shortage of oxygen within the combustion chamber, and heat loss will happen. For that, we can conduct flue gas analyses to test the live air percentages and measuring the quantity of unburned carbon in the bottom and fly ashes. However, gaseous and liquid fuels have more efficiency than solid fuels. Furthermore, a remote oxygen analyzer or oxygen trim system will help to manage excess air and oxygen content in flue gas

through a properly designed interface [11].

4. Heat Loss Due to Moisture Within the Fuel.

During combustion, the moisture or liquid water percentage within the fuel take into account and heat to become super-heated steam. For biomass storage setup, it leads to Last in First Out way of using the wood. Longer storing results in ruin, the biomass, and it makes it less effective. Using the First in First Out method for biomass storing and feeding, Pre drying biomass before feeding to the boiler can improve the boiler efficiency.

5. Economizer.

The purpose of the economizer is to recover heat from the flue gas by preheating feed-water or combustion air. But there's a problem that affects the efficiency of the economizer because of corrosion and condensation, due to acid condensation that is related to flue gas heating recovery. Therefore, to forestall acid condensation, the flue gas temperature can be minimized to a specific temperature which is well above the acid temperature [12].

6. Installing Variable Speed Drive Controllers for Forced/Induced Draft Fans.

Boiler efficiency will be maximized by minimizing the loss in the supply by optimizing excess air ratio by installing a variable speed drive to the induced draft or forced draft fans and control the speed of the fan programmatically.

7. Removing Fouling and Scaling of Boiler Heat Transfer Surface.

Fouling, scaling, and soot builds a layer in the inner surface of boilers act as insulators and it is cause for the reduction of heat transfer. The scale is forming due to calcium, magnesium, and silica in most water suppliers. The combustion system must be repaired or returned and relevant actions should be performed to boost water softening and maintaining a lower level of total dissolved solids [12].

6 CONCLUSION

Boiler feed-water must be treated to increase the boiler performance and lower the failures and damages. It is essential to calculate boiler efficiency to have proper operation. Using an indirect method to calculate boiler efficiency than the direct approach is the best practice. Although it is bit complex, it gives a clue for all the possible heat losses in the boilers and minimizing these losses are very important to improve boiler performance. Switching to alternative fuels will not only economically benefit the industry but also reduce the negative impact on the environment due to fossil fuel burning as fossil fuels are one of the main reasons of excessive greenhouse gas emission.

Moreover, proper energy management procedures like energy auditing and close look on condensate return, boiler feed-water, make-up water, boiler blowdown-water and many more will reduce wastage and will increase the output. Proper insulation from preventing heat from escaping out from the boiler and it's any parts will also minimize the heat loss; thus, improve boiler performance. Last but not least, implementing and following proper cleaning and proper maintenance procedure will also increase the efficiency of the boiler; therefore, ultimately

maximize the boiler performance.

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