Optimization of an Industrial Boiler Operation

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Abstract— The boiler system consumes a large amount of energy as a significant thermal source in most of the industries. Therefore a well-operated boiler system with higher efficiency is essential for ensuring better system performance. However, in practice, due to various reasons such as the outdated system control methods, oversized boilers, improper boiler operations, the existing operation of the boiler system not only increases the system energy consumption but also lead to much higher CO_2 emission. The paper discusses the main points an industry should consider in optimizing the boiler performance.

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

1 INTRODUCTION

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam [1]. The hot water or steam under pressure is then usable for transferring heat to a process. Steam produced in a boiler can be used for various purposes, including space heating, sterilization, drying, humidification, and power generation. A steam boiler plays a crucial role in many industries, such as the food processing industry, feed industry, paper industry, building materials, textile industry, etc.

Industrial boilers are welded from sturdy steel plates that are engineered to withstand intense heat and pressure. The construction of hot water boilers and steam boilers is very similar and depend on fuel to run. Therefore optimization of boilers means improving energy efficiency ensuring the complete combustion of fuel. Energy costs are directly linked to the effectiveness of the boiler. Inefficient boilers are expensive to maintain and lead to more pollution, mostly violating the emission guidelines. So industries should pay their attention as much as possible to optimize their boilers to take the maximum use from them. There are few ways that a boiler system can be made to improve its efficiency, function with less fuel, and reduce operating costs. The techniques commonly used in industries are; regular boiler maintenance, reuse of heat, boiler feed water treatment, optimization of combustion with the use of alternate fuels, and proper energy management practices.

2 BOILER WATER TREATMENT

Producing quality steam on demand depends on properly managed water treatment to control steam purity, deposits, and corrosion. When feed water enters the boiler, the elevated temperatures and pressures cause the components of water to behave differently. However, under heat and pressure, most of the soluble components come out of solutions as particulate solids, sometimes in crystallized forms or as amorphous particles. If the water entering a boiler is impure, then this impurities can carry over into the steam produced, causing several operational issues including;

- Contaminants build up on the surface of the control valves; this could reduce capacity and affect the way the valves operate.
- Contamination of heat transfer surfaces can increase thermal resistance, which in turn reduces heat transfer properties and affects how efficiently the boiler system operates.
- If the steam trap openings become restricted, this can eventually lead to the plant becoming waterlogged, and output can be reduced.

There are two significant types of boiler water treatments: internal and external water treatment.

1) **Internal water treatment**

Internal water treatment is carried out by adding chemicals to the boiler to prevent the formation of deposits by converting the deposit forming compounds to free-flowing sludge, which can be removed by blow down. But this method is limited to boilers, where feed water is low in hardness salts, little in pressure, and when only a small quantity of water is required to be treated.

2) External water treatment

External treatment is used to remove suspended solids, dissolved solids (calcium and magnesium ions), and dissolved gases (oxygen and carbon dioxide). First, it is necessary to remove suspended solids and colour from the raw water, because these may foul the resins used in the subsequent treatment sections. Pre-treatment methods include simple sedimentation in settling tanks or settling in clarifiers with the aid of coagulants, flocculants, and pressure sand filters. Several external treatment processes are available, such as softening (ion exchange), demineralization, reverse osmosis, and de-aeration [2].

- Ion exchange process(softener plant)

The ion exchange process is used for the efficient removal of dissolved ions from water using certain natural and synthetic materials. For example, in passing water through a pure cation exchange softener, all calcium and magnesium ions are removed and replaced. But this does not reduce the TDS content and alkalinity.

- Demineralization

Demineralization is the complete removal of all salts. It involves passing the water through both cation resin as well as anion resin. This process takes almost all the minerals out of the water.

- De-aeration

All-natural water contains dissolved gases in solution. Any amount of gases such as oxygen and CO_2 can be extremely corrosive to boiler equipment and piping when they attach to them, forming oxides and causing rust. This will contributes to reducing the life of the machine but also increases the amount of energy needed to achieve heat transfer. In de-aeration, these dissolved gases are expelled by preheating the feed water before it enters the boiler. De-aeration can be done by mechanical de-aeration, by chemical de-aeration or by both together.

- Reverse osmosis

If a high concentrated solution is pressurized through a semi-permeable membrane, purified water will flows to the dilute solution by trapping contaminants such as bacteria, salts, organics, and silica. This process is known as reverse osmosis. It is not always required in boiler feed water treatment, mostly used with high-pressure boilers where the concentration of suspended and dissolved solids needs to be extremely low. Taking all of this into consideration, having techniques in place to achieve and maintain good boiler water quality is essential for operating the boiler plant safely, for optimizing boiler efficiency from the heat transfer process and making optimum combustion.

3 USE OF ALTERNATIVE FUELS

Most of the industries use fuels such as coal, furnace oil, and diesel for their boiler operation. But the consumptions of this petroleum-based oil are very costly, and it is not environmentally friendly. Therefore, it is essential to reduce these types of fuels and move to alternative fuels.

In Sri Lankan industries, one of the most used alternative fuel type is Refuse-derived fuel. Refuse-derived fuel is a fuel produced from various types of waste, such as municipal solid waste, industrial waste, or commercial waste. This recover high-quality fuel fraction from solid waste. Industrial waste such as paddy husk or any grain

husk, coconut shell, wood chips, sugar cane waste, rubber waste, chemical sludge is used as refuse-derived fuels [3]. Primarily, municipal and commercial waste, which are inorganics, are used as an alternative fuel. Refuse-derived fuel is the right solution for both energy crisis and waste management problems. Here, industries can use their waste to fulfill their energy needs. For example, rice mills use paddy husk for energy generation. Also, some industries buy waste materials to generate energy while some charge for taking those because it provides a better way for industrial waste management.

Briquettes are compressed blocks of combustible biomass material which can be used as a fuel or energy source. Charcoal, sawdust, wood chips, peat, papers, agricultural and yard waste are some materials used to produce briquettes. An important factor regarding briquette is the calorific value, and the amount of energy released depends on the shape, dimension, and the composition of the briquette. Therefore by changing the above factors, the energy production from the briquette can be changed. It shapes like a 6-8 mm cylindrical block, which has a 1-2 mm hollow inside it. This specific hollow structure increases the surface area. This structure helps oxygen to reach the briquette in the combustion process and will have complete combustion, which produces more energy [4]. In addition to biomass materials, water, and some binding materials can be used to produce briquettes. Other than the elements mentioned above, some industries can produce briquettes by mixing their waste. Garment industries can use their waste clothes, and Food production companies can use their grain husk (such as paddy husks, wheat husks, Barley husks). Like that, industries can use briquettes as an alternative energy source. It is cost-saving, reduces air pollution as well as the right solution for waste.

Bio Gas is another energy source that can be used as an alternative fuel in the industry. It is a mixture of gases produce by the breakdown of organic matter anaerobically—biogas created from non-food crop materials and predominantly wasted materials. If enterprises have Biodegradable waste, they can produce biogas. Food production companies can use their scraps to produce biogas quickly. At present, in every industry, water treatment plants are used to treat their wastewater. If it is a biological aerobic water treatment plant, the sludge can be used to produce biogas. If it is an anaerobic water treatment plant, biogas can be delivered as a by-product.

4 HEAT RECOVERY

Heat is a critical aspect of a steam boiler, which needs to maintain at an optimum temperature to generate steam as per the demand. Every industry wants to operate efficiently with minimum cost. So regular maintenance and reducing heat loss is very much essential. Usually, a boiler loses its heat in various ways. Roughly 25-40 % of energy wasted due to this heat loss. Flue gas loss accounts for a significant part among them. Also, due to causes like unburnt carbon, moisture in fuel, radiation, convection, and blow down of water, the boiler loss its energy. Blow down of bottom ash and flue gas heat losses can only be recovered using engineering solutions. The energy management strategies can control others from the very beginning. And also, considerable savings in fuel can be done by using condensate water as feed water again. Heat recovery contributes to reducing the carbon footprint of the company, which has a positive impact on the environment.

Heating feed water and furnace oil before entering the boiler indirectly affect fuel consumption. Most of the industries concern about this matter and invest in energy, improving devices that help to reduce the cost of operation by saving fuel. Economizer is one such device in the boiler that tends to make the system more efficient. Generally, the economizer is a heat exchanger, exchanging heat between the flue gas and feed water.

Usually, the exhaust of the boiler releases flue gas at 2700°C-3000°C temperature, causing a considerable loss of heat if any heat recovery system is not applied. The exhaust gas with high temperature is made to pass

through the economizer to exchange the heat to cool water before sending it to the feed water tank. It will reduce the heat load of the boiler to a great extent. The temperature of the flue gas can be decreased until nearly 1700°C. If it is decreasing below that temperature result corrosion on surrounded parts, roofs, and pipes because of the sulfur content increases when the temperature lowers.

Air preheater is another device designed with the primary objective of improving the thermal efficiency of the boiler process. It's a heat exchanger used for preheating the air, which is fed to the boiler or furnaces for the combustion of fuels by extracting the waste heat from the flue gases leaving the boiler. They are installed in the exit flue gas ducts of the boilers allowing control over the temperature of gases leaving the stack. Installation of air preheater can lead to pre heat air to the extent of 1000°C with an exit waste heat temperature of 1800°C [5].

Continuous blow down of water is necessary to keep water impurities to an optimum level, which leads a considerable heat loss. For preheating cold water and inlet air entering the boiler, heat from the blow down water is recovered using a blow down heat recovery system. Furthermore, the use of condensate water saves more energy for the industry. Condensate water has a high temperature (980c-1930c). So only less amount of fuel is needed to heat the water. Then it can be even possible to reduce boiler energy need up to 10 % -20%.

5 ENERGY MANAGEMENT

Energy Management is the process that includes controlling, monitoring, and conservation of energy for a given system to make the system more efficient while saving the environment [6]. As a system, the power of a boiler has to monitor, control, and conserved to keep up efficiency. When managing the energy, first of all, performing an energy audit is essential. An energy audit for a boiler should cover the steam balance, performance of steam in the required space, turbine efficiency, condensate recovery, steam traps, and recycling waste.

Evaluation of a boiler Performance has two parameters, namely, evaporation ratio and efficiency.

- Evaporation ratio is the ratio between the quantities (1 kg) of steam generation to the fuel used. It depends on factors like the boiler type, fuel type, and calorific value of the fuel.
- The efficiency of a boiler is simply referred to as running the boiler with minimum losses and wastes to acquire the relevant output. This minimizing of losses and improving efficiency is the main objective of a sound energy management system.

There are four definitions for the efficiency of a boiler namely,

- Combustion efficiency - the capability to transfer fuel into usable heat.
- Fuel to steam efficiency – the overall efficiency of a boiler
- Thermal efficiency – the ratio of heat output to the input
- Boiler efficiency – substitution to the thermal or combustion efficiency

The best way for proper energy management of a system is to test the boiler efficiency, directly and indirectly, to find the energy losses and identify the opportunities to save energy.

Direct efficiency is referred to as the percentage ratio of the useful energy used to the energy Supplied. The equation given below further describes the direct efficiency calculation.

$$\text{Direct Efficiency} = (\text{Heat output}/\text{Hea t input}) * 100$$

Where,

- Heat output = the steam generated through the process or the usefully used heat
- Heat input = the heat generated by the combustion of fuel

Indirect efficiency is the deduction of the boiler's energy losses, such as flue gas loss, moisture loss, etc. from the 100 input. This is the most suitable testing method as it reveals every single failure and accurate efficiency of the boiler. This whole process of heat input and heat output as steam and heat losses are indicated in Fig. 1, which is abstracted from the literature [1]. Given below is the equation of indirect efficiency.

$$\text{Indirect Efficiency} = 100 - (i + ii + iii + iv + v + vi)$$

Where,

i. Percentage of heat loss due to dry flue gas.
ii. Percentage of heat loss due to the H2 in fuel.
iii. Percentage of heat loss due to moisture in fuel and the air (H2O).
iv. Percentage of heat loss due to incomplete combustion.
v. Percentage of heat loss due to surface radiation, convection, and other unaccounted.
vi. Percentage of heat loss due to unburnt fly ash and bottom ash.

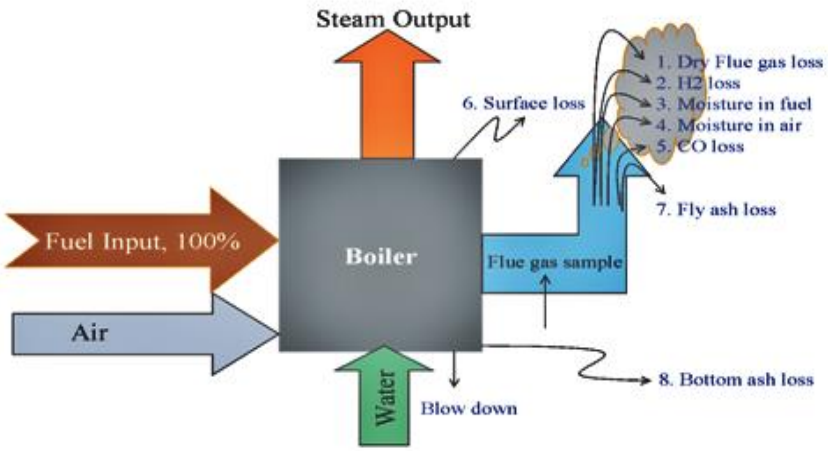

Fig.1.Heat losses occurring in the boiler

Given below are the ways of energy losses as indicated above and possible solutions to some of the losses to reduce them and to improve efficiency.

- Loss due to dry flue gas

The flue gas generated due to the combustion process with a higher temperature has higher energy stored as heat. Stacking this flue gas and by exchanging the heat from the flue gas to the feed water, the energy needed to heat the feed water gets reduced. This whole process referred to heat recovery and discussed in the above section. By heat recovering the energy could be managed to a higher amount.

- Loss due to hydrogen in fuel (H_2)

In the process of combustion of fuel, the hydrogen will produce water as a product. In relation to this water production, the energy gets lost as latent heat due to the conversion of steam.

- Loss due to moisture in fuel and the air (H_2O)

The energy loss takes place as the moisture in air and fuel when producing superheated steam.

- Heat loss due to incomplete combustion

The energy loss due to the insufficient air, insufficient time, inadequate space. To reduce the loss, increase the above factors with a piece of proper knowledge is necessary.

- Loss due to surface radiation, convection, and other unaccounted

Insulations of the boiler is essential; if not, the heat will lose to the environment via the boiler vessel. These losses are difficult to measure and referred to as insignificant losses.

- Losses due to unburnt fly ash and bottom ash (Carbon)

Because of the unburnt fuel particles, the heat energy supposed to be used in the combustion process gets reduced, and the required heat will not be supplied. Due to this situation, more fuel has to be provided to drag the energy needed. To minimize this loss, the amount of air required should be supplied by calculating the amount of air needed for complete combustion.

By minimizing the above losses, it is possible to increase efficiency. Below are some other general steps to be taken.

- Feed water treatment, which is discussed above, is crucial in energy management as it will save energy usage.
- The boiler could operate efficiently with proper cleaning. The scale produced in the water tubes or on the fire tubes may increase the heat energy used to heat the water rather than on melting the size on the machines. With the proper cleaning, this over usage of heat could be reduced and managed.
- The temperature of ash after the combustion is high. The heat energy store in ash will lose to the environment. An engineering solution should be implemented, like making water preheat by passing water tubes around the ash.
- The unwanted air should be removed from the boiler. If not will damage the boiler system by seeping through the leakages, gaskets, or other openings.
- The boiler water Blow down or only the removal of water from the boiler is used to removes the

Suspended solids. This process mainly minimizes the corrosion, scale, etc. in the boiler. If the amount of suspended solid is less, the blow down process could be minimized. By blow down reduction, the fuel and water usage for the boiler will be reduced.

- The condensate steam produced in the boiler with high temperature as latent heat could be recover and used. The heat needed to boil the water continuously could be minimized by making a closed-loop system for the condensate steam.
- As discussed in the heat recovery, an economizer is a component used to recover the heat, which loses with the exhaust air. By the installation of an economizer for every flue gas system, the boiler efficiency could be increased.

6 CONCLUSION

Opportunities for optimizing an industrial boiler system are investigated, and the importance of optimizing the boiler for the industry are discussed. The following key points are identified regarding the optimization of industrial boiler operation.

- For industries using a boiler for its facility, a boiler feed water treatment system is usually necessary to ensure an efficient process and quality steam generation. A proper boiler feed water treatment system will help the facility avoiding costly plant downtime, expensive maintenance fees, and boiler failure as a result of scaling, corrosion, and fouling of the boiler. There are two significant types of boiler water treatments, namely, internal water treatment and external water treatment. An efficient and well-designed boiler feed water treatment system should be able to;

✓ Efficiently treat feed water and remove harmful impurities before entering the boiler.
✓ Maximize use of steam condensate
✓ Control return line corrosion
✓ Avoid boiler failure

- There are boiler designs that can burn alternative fuels such as refuse (trash), wood, and biomass. There are two basic methods of burning waste; mass burning (burning debris as received) and refuse-derived fuel. Even if these alternatives cannot entirely avoid the usage of petroleum-based fuel, their quantity can be reduced to a certain extent. Refuse-derived fuel, briquettes and biogas are some of the types of alternatives that can replace petroleum-based fuels like coal and diesel.
- Heat recovery is another critical factor that should be considered in optimizing boiler performance. Recovery of waste heat has a direct effect on the efficiency of the process. Cost reduction, reduction of pollution, reduction in auxiliary energy consumption are some benefits of heat recovery.
- Energy management related to boiler efficiency includes; combustion and waste heat recovery management, makeup water management, feed water, condensation and blow-down management, and steam generation management. Proper energy management will show how energy can be used wisely to save money and to limit environmental impacts.

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