Industrial Boiler Operation - Energy Optimization

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Abstract— Growing industrialization is mainly leading to an increase in the usage of boilers in various industries. They use for heating, cooling, power generation, and also production process and, etc. According to the high demand for industrial boilers, there is a need for a well-operated boiler system with high efficiency. This study focuses on discussing the various optimization methods of the industrial boiler operation through water treatment, boiler energy efficiency improvements, boiler heat recovery, and suggestions to use alternative fuels and new boiler energy management methods.

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Index Terms— Boiler, Heat recovery, Efficiency, Energy management.

1 INTRODUCTION

The boiler is one of the most important and valuable assets of all most all the processing industries around the world. They play a vital role in energy production while devoting significant investments to boilers, especially boiler-feeding fuels. If we consider biomass boilers in Sri Lanka, around 400 biomass boilers are operating, and it uses approximately 3200 MT of biomass to produce the daily demand. The fuel sources for most of the biomass boilers are well-grown trees. Most of the biomass boilers are over 3 tons of steam capacity. Some of the industries are operating 24 hours daily, while the majority is around 12 hours daily routine. Therefore, they consume an enormous amount of firewood to maintain their process for generating high-pressure steam [1].

On the other hand, the demand for coal increased in 2017 with increased power generation using coal gradually. Such as 92.7 KT in 2005, 108.1 KT in 2010, 1606.6 KT in 2014, 1881.5 KT in 2015, 2404.6 KT in 2016, and 2527 KT in the year 2017 according to Sri Lanka energy balance in 2017 which was done by Sri Lanka Sustainable Energy Authority [2]. A well-performing boiler means it does not consume fuel exceeding the limits, and it is positively affected for the boiler efficiency. Although industries are very diverse, their steam system is common, and they consume a significant amount of power to operate. That is why it is crucial for carrying energy efficiency measures to check whether their operation is going on well or not and evaluate the performance of the boiler by doing energy efficiency calculations. Then we can implement the best and most cost-effective boiler efficiency-boosting steps in many aspects such as,

1. Boiler water treatment improvements
2. Usage of alternative fuel in the boiler for cost reduction
3. Energy management and heat recovery
4. efficiency improvements to fulfil the main idea behind this study.

That is the optimization of industrial boiler operation while resulting in enormous profits for the organization.

2 BOILER WATER TREATMENT

The boiler feedwater must be free of contaminants that could affect boiler operation. Hence the water chemistry required for steam production must meet standards. The water needs to be filtered and remove the minerals and oxygen. Sedimentation and filtration can use to clean the water coagulation. To remove minerals softening, demineralization and reverse osmosis can use. To remove oxygen, de-aeration and oxygen scavenging can use.

The treatment of boiler feed water is vital to increase the effectiveness of boilers.

- The water should be cleaned because the raw water can come from a variety of sources and can contain a composition of various pollutants. Hence this step required to remove the suspended solids on that water. To optimize boiler water treatment, we should have clean & quality water sources as our raw water system. If we are unable to do that, we should get water through the water intake plant to meet our boiler feedwater requirements. If the pollutants are lower in the raw water, that makes it cost-effective for using chemicals to purify the raw water. When suspended solids are less, the boiler blowdown can automatically minimize because we can serve large water stream; otherwise, it will send for the wastewater treatment as blowdown water.

- The raw water becomes fresh-water when the cleaning has done. The maintenance of the intake plant is must essential otherwise, purification is not happen properly. If we can increase the efficiency of the water treatment plant, ultimately, we can improve the fresh-water quality. That makes many advantages because the quality of fresh-water reduces significant chemical usage, and it is cost-effective for boiler operation.

- The wastewater generates from the boiler such as boiler blowdown water & due to poor operation and maintenance, practically condensate water stream may become wastewater. That wastewater can purify under the biological treatment processes because it is cost-effective rather than adding chemicals after the treatments that wastewater can reuse as boiler feedwater.

- Control the blowdown rate is essential. If the boiler is not blown down regularly, a scale will accumulate on heat transfer surfaces. Scale forms on the inside of the tube in water tube boilers so this scale will impede the heat transfer, reducing our boiler efficiency.

- All the condensate should return as boiler feed water because it is purified once. It gives many advantages like reducing regeneration frequency, reducing makeup water treatment, and being cost-effective; otherwise, it becomes our loss.

- The maintenance of the accessories of the boiler like valves, steam traps, plugs is essential. Especially, regular surveying the steam traps are much more necessary. Because the steam traps are not working correctly, the condensate system is pressurized due to this hammering. The lines will leak, flash chamber release steam, and condensate becomes wastage. So poor maintenance finally reduces the efficiency of the boiler [3].

- Carry-over should be reduced. Carry-over is any contaminant that leaves a boiler with the steam. Boiler water carryover can contain impurities such as dissolved solids etc. The carryover can cause deposits in valves, heat exchangers, superheater, and pressure regulators around the steam distribution system by producing a lot of damage and increased maintenance. Carry-over also depends on feed water quality, so we should deeply consider feedwater treatment [3].

- In the demineralization process, the rate of regeneration and backwash rates should do correctly; otherwise, the removal of minerals from the water has not done correctly. And also, then demineralization plant quickly exhausts in a short time; it is the cost for change ion beds for the demineralization plant.

- The de-aeration process is also essential to optimize boiler operation. The de-aeration is done to remove gases from the boiler water. The steam injects, caustic will inject to correct pH, trisodium phosphate is added to remove hardness so that quality raw water and fresh-water and proper deionization can reduce chemical cost in this stage. Otherwise, if de-aeration is not done correctly, the moisture presenting tubes can be failed. And also high-pressure condensate system can reduce steam usage of deaerator.

- The steam quality highly depends on the quality of boiler feed water. If there are particles or unwanted composition in the water, the generated steam also can have T.D.S., and that can damage turbines, compressors, and pumps, and other equipment. So it becomes a significant loss for the industry. So monitoring and treating boiler feed water up to the standard value is much essential.

- Ultimately, maintain water chemistry is the main thing we can have done for more effective boiler operation through the feedwater treatment improvements. The raw water, fresh-water & boiler feed water always should be sampled and monitored. The values should maintain in a standard range by maintaining and operating in a standard way we can have improved efficiency of the boiler.

3 ALTERNATIVE FUEL FOR COST REDUCTION

Fuel systems are playing a significant critical role in each boiler system. The fuel source is needed for the boiler to convert water to steam or hot water. The most commonly used fuels in boilers are fossil fuels (coal, petroleum-based oils, natural gas) and biomass fuel (firewood). From those fuels, fossil fuels became more expensive. So using alternative fuels in boilers are economically feasible for each industry. Currently, a variety of alternative fuels are used in many industries today such as,

- Briquette
- Palm fibres and shell
- Urban solid waste
- Bagasse
- Rice husk and straw
- Hydrogen
- Oily sludge
- Dendro

Let's see how these alternative fuels in boilers can contribute to cost reduction.

3.1 Briquette

Sawdust, wood chips, wood logs can be considered as briquette. For example, dried sawdust is used as fuel in many numbers of furniture factories. At the sametime, most of the fabric companies in Srilanka, their biomass boilers are operated by sawdust burning. They pay around Rs 4.00 per one kilogram of sawdust. Moreover, wood chips, wood logs boilers function much like fossil fuel boilers. Using these types of biomass, typically 70 to 80% fuel can be saved. Wood is made up of Carbon, Nitrogen, and Oxygen; therefore, their calorific value is much higher, and due to that, boiler efficiency also increased. These alternative fuels are mostly used in soft drinks, laundry, and rubber industries in Srilanka.

3.2 Palm fibres and shells

Mainly, palm fibres and shells (Fig.1) are the residues of crude palm oil and production processes used as boiler fuel in the palm oil industry in Sri Lanka.

Fig. 1. Remaining Palm shells [4].

3.3 Urban solid waste

Normally, organic parts of the residues are turned into compost, and others are sent to the storage fields because they cannot be recycled. So, Refuse derived fuel (RDF) is a kind of alternative solid fuel derived from domestic or industrial solid wastes such as plastic, glass, metal, etc. Recently, cement production using RDF as an alternative fuel was an economically feasible option to reduce fuel costs and reduce landfill disposal.

3.4 Bagasse

In the sugar industry, Srilanka, sugarcanes (Fig.2) are crushed first and squeezed in a mill to extract sugar content, and remaining fibrous are called bagasse. That is used as an alternative fuel for power boilers.

Fig. 2. Bagasse from sugarcrane [5].

3.5 Rise husk and straw

Rice husk (Fig.3) is a byproduct of rice growing, readily available, and easily collected. An additional benefit of rice husk as biomass fuel is from the ash after the rice husk has been combusted and ash particularly high in silica. Mainly, food and rice mills industries have used these types of rice husk boilers.

Fig. 3. Rice husk[6]

3.6 Dendro

Dendro is a short rotating cropping species and only needs around six months. This plant can grow in most areas in Sri Lanka and avoiding soil erosion. To overcome the steam demand from biomass boilers, we can use dendro woods (Fig. 4), and it is required to maintain around 13000 hectares of Dendro plantation annually. Table 1 indicates that the calorific values of alternative fuels.

Fig. 4. Dendro Wood [7].

Table 1. Calorific values of Alternative fuels [1]

Alternative fuel	Calorific value (M.J./kg)
Sawdust	14.65
Palm fibers	9.2
Palm shells	16.9
Bagasse	9.6
RDF solid fuel from urban solid waste	16.75
Rice husk and straw	13-19
Wood chips	17-21
Dendro	20.5

3.7 Hydrogen

In chemical industries, hydrogen is produced as a byproduct. So some part of hydrogen is used for creating hydrochloric acid and other components are getting wasted. So this can be utilized as an alternative fuel in boilers in place of furnace oil [8].

3.8 Oily sludge

The process of crude oil refining creates large amounts of oily sludge, which contains oil, benzenes, and other substances. Oily sludge consists of hydrocarbons and high calorific value, which above 16.32MJ/kg. Therefore by treating this sludge, we can utilize it as a fuel for boilers [9]. According to these data, we can conclude that these alternative fuels can be obtained quickly by replacing them because they are readily available everywhere. And also, it helps to get solutions for the disposal issues in industrial materials' waste. Furthermore, these are more environmentally friendly, reduces fossil fuel export costs, and significantly reduced carbon emissions.

4 ENERGY MANAGEMENT AND HEAT RECOVERY

Energy Management is the process of analyzing how efficiently energy uses in a system. From this, it finds ways to reduce the energy consumption of a boiler while minimizing energy costs and justifying environmental effects. Under the energy management concept, we can take several boiler efficiency-boosting steps to improve boiler performance. We can get an idea about boiler performance through boiler efficiency calculations and boiler evaporation ratio calculations. Boiler efficiency can be calculated in two methods. That is the direct method and the indirect method. But from the direct method, it doesn't give any information about individual energy losses and magnitudes. The indirect method calculates all possible heat losses that can be happened in a boiler. For the energy management process, it's very much important the boiler efficiency calculations.

4.1 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 adjust the combustion airflow automatically.
- Do regular inspections, maintenance, and housekeeping activities to ensure optimal heat transfer.
- Adjust burners properly to occur complete combustion.
- Check and eliminate the entrance of unwanted air into the boiler and flue gas exhaust.
- Replace burners. (If we have an old, inefficient, and oversized burner, it's better for replacing a modern, efficient and adequately sized burner).
- Decrease moisture percentage of boiler feeding fuel by using various drying methods.
- Use heat recovery systems to recover heat loss of flue gas.

4.2 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.

4.3 Feedwater, condensate and blowdown system management

- Return condensate in higher percentages is very efficient because condensate is already hot and needs less heat to produce steam than feed water.
- Use condensate monitors to check the quality of it.

- Add an automatic chemical feed system for boiler feed water.
- Use boiler blowdown heat recovery to preheat makeup water.
- Take blowdown flash steam into a flash steam tank and use it for other heating applications such as for de-aerators.
- Use an automatic monitoring system to notice any failure of steam traps.

4.4 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.
- Steam and condensate recovery network should have proper drainages to eliminate water hammer and losses.
- Set up steam trap inspection and maintenance procedures and replace faults of steam traps as soon as possible.
- Repair faulty insulation on boilers.
- Add measuring, metering, and monitoring equipment to the boiler and to fuel flow, steam flow, feedwater flow, condensate flow, and blow downflow.

4.5 Boiler maintenance

- Improve boiler insulation.
- Repair air leaks. Because air leaks reduce heat transfer to steam and increase energy consumptions of the forced draft and induced draft fans.
- Do the replacements of refractory lining [10].

Heat recovery is a significant concept in the energy management system. In Sri Lanka, almost every industry has a boiler to run its operations. There are many problems in the boiler industry; one of them is the heat losses due to these heat losses in the boiler system efficiency decreases. The main reason to improve efficiency through heat recovery is economical. There are various technologies and methods to recover waste heat to improve efficiency and decrease energy consumption.

4.6 Preheating feed water and inlet air

If we have a significant temperature difference between the inlet air feeding location and the ceiling of the boiler room, this may be due to boiler and stack losses. We can either extend the air intake upward or force the hot air to the inlet location. If the heat loss mainly due to the boiler wall insulation, the boiler should be considered.

4.7 Condensate Water Return system

After steam supplying into the machine's heat exchangers, steam condensate into the water, but still, it has a high temperature. We need to design a good system and implement it to recover that heated water back into the boiler feedwater; this reduces the energy required to heat the water to steam. Implementing and maintaining the condensate return water system gives huge economic benefits.

4.8 Waste heat Boilers

Waste heat boilers are kind of boilers that use for heat recovery in larger industries that has many boilers, gas turbines, incinerators, etc. Flue gas of those flow through a series of water tubes. Then water vaporized in the tubes and collect 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].

4.9 Boiler Blowdown Heat Recovery

The blowdown process is an essential process of a boiler that is used to control the T.D.S. inside the boiler. Sediments release through the blowdown valve to control the T.D.S. value of water. Blowdown releases a considerable amount of heat to the surrounding. To recover this heat, we can use a plate type heat exchanger and transfer it to boiler feed water [12].

4.10 Thermodynamic Cycles

Heat recovery from waste sources can be directly conducted to obtain electrical energy and improve the energy efficiency of a process through the use of thermodynamic cycles. The organic Rankine Cycle and Kalina Cycle suggested that the use of thermodynamic cycles that employ organic working fluids enables a cost-effective and capable way of energy recovery from medium grades of waste heat sources [13].

5 EFFICIENCY IMPROVEMENTS

We can improve the efficiency of the boiler by undergoing the steps which are discussed in the energy management section. To improve boiler efficiency, we must adopt an energy-saving measure to avoid wasting a significant amount of energy. It's essential to acknowledge sources of energy wastages and recover the energy, which is wasted to run a boiler more efficiently.

5.1 Air preheater

It helps to balance the air temperature of flue gasses and the incoming air. So, the efficiency of the boiler maximizes the rise within the combustion air temperature utilized in the furnace. The efficiency of the boiler gradually increases with the decrease of flue gas outer temperature. seal leakages, erosion, and corrosion effects, and dry and wet losses are the reason for the decrease in the preheater efficiency [14].

5.2 Improving combustion efficiency

Stoichiometric air for various fuels should differ because of the formula. Stoichiometric air indicates the minimum amount of air than required for the whole combustion process. Incomplete combustion can occur due to the shortage of oxygen within the combustion chamber and the loss of warmth. For that, we can conduct a flue gas analysis test to measure air percentages and measuring the quantity of unburned carbon in bottom and ash. However, gaseous and liquid fuels have more efficiency than solid fuels. Furthermore, an online oxygen analyzer or oxygen trim system will help manage excess air and oxygen content in flue gas [15].

5.3 Heat loss due to moisture within the fuel

During combustion, the moisture or liquid water percentage within the fuel takes sensible and heat to become super-heated steam. Some boilers use Last in First out method to feed fuel for the boiler. It increases the time that fuel is exposed to the atmosphere. Then the moisture content of the fuel increases, It takes a significant

amount of heat to evaporate this moisture, and the calorific value of the fuel also decreases. We can avoid this by using first in first out method for feeding fuel into the boiler.

5.4 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 affecting the efficiency of the economizer due to corrosion and condensation, acid condensation, 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 [16].

5.5 Improve boiler insulation

To minimize heat loss from radiation and convection through the valves, steam pipes, and outer walls of the boiler must insulate them. For that ceramics, fibres will be used, which are having lower heat capacity to allow enough resistance to heat transfer.

5.6 Installing V.S.D controllers for ID/FD fans

Boiler efficiency will be maximized by minimizing this loss, supplying optimizing excess air ratio employing a V.S.D. (Variable Speed Drive). By installing V.S.D. controllers to the ID/FD fans, electricity consumption at the boiler section will be reduced, and it can change the excess air ratio.

5.7 Removing fouling and scaling of boiler heat transfer surface

Fouling, scaling, and soot build a layer in the inner boiler surface, act as insulators, and it causes the reduction of warmth transfer. That scale is going on due to calcium, magnesium, and silica in most water suppliers. For that combustion system must be repaired or retune, and appropriate methods should be taken to boost water softening and maintaining a lower total dissolved solids (T.D.S.) level [16].

6 CONCLUSION

For the optimization of boiler performance, it is essential to treat for boiler feed water. Boiler feedwater must be free or must meet standards calcium magnesium irons, which are caused by hardness, scales, sediments, and dissolved solids. It's crucial to follow external treatment methods such as sedimentation, filtration, softening, etc. and internal treatment methods such as adding chemicals to increase P.H., decrease scales, and oxygen of feed water. Using alternative fuels such as sawdust, palm fibres, shells, bagasse, rice husks and straws, wood chips, etc. is economical and environmentally friendly instead of using fossil fuels like boiler feeding fuel. It's crucial to calculate boiler efficiency, especially in the indirect method to evaluate boiler performance. Because it shows all possible losses such as heat loss due to dry flue gas, heat loss due to moisture in combustion air, heat loss due to moisture in fuel, heat loss due to hydrogen in fuel, heat loss due to carbon monoxide, unburnt losses in fly and bottom ashes of the boiler. Those values are very much essential to establish boiler efficiency-boosting steps to improve boiler performance. By using efficiency calculations, energy management procedures can be implemented for steam, condensate return, boiler feed water, make up water, boiler blowdown water, and so on. Improving boiler efficiency through heat losses recovery by using diverse technologies such as implementing air preheaters to preheat ambient air, implement economizers to preheat boiler feedwater by utilizing the waste heat of flue gas, implement a condensate return system, employ organic working fluids enables to recover from medium grades of waste heat sources is very much economical. This way, we can optimize boiler performance properly.

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