Optimization of an Industrial Boiler Operation in Sri Lanka

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Abstract— The boiler is one of the industry's significant units, which supplies steam and heated water to the industry. Steam is the best quality output product from the boiler, and there are two types of generated steam such as high-pressure and low-pressure steam. High-pressure steam uses drive turbines, and low-pressure steam purposes for other sub works drive process pumps and compressors. So, the boiler needs standard conditions with the best quality states to continue those processes. Feedwater treatment and feed fuels are causing to the Lifetime and efficiency of the boiler.

Index Terms—Alternative fuel, Blow-down, Calorific Value, Economizer, Evaporation ratio

1 INTRODUCTION

The boiler is the central part of every industry, likes the heart of the industry. It is the unit of steam and hot water generation. Most of the time, that generated steam uses to drive steam turbines. So, Thermal power plants also using boilers to drive massive steam turbines. So, steam includes the significant value of heat energy due to latent heat is getting a higher amount of water. However, industries need to face some challenges to continue the boiler process Since it needs to run with an excellent cost-effective condition. However, the quality of feed water, calorific value of feed fuel, etc. are caused to reduce the boiler efficiency. So, we can use alternative fuels with the best calorific values. The best way to treat boiler feedwater is to achieve good condition and quality of feed water and waste heat recovery methods to improve boiler efficiency.

Then we can use by-products to produce the best feed fuel to the boiler with the best calorific value. Sow adjust, Rice husk, Rice straw, Coconut husk, Bagasse can be used as alternative fuels and raw materials for manufacture designed and adjusted calorific value fuel. In adjusted and designed feed fuel manufacture cases, we can use papers and cow dung for bonding materials to make that fuel as brick shape or other best shape to increase usability [1].

2BOILER WATER TREATMENT PROCESS

The boilers need high-quality water to improve boiler operation. Feedwater is used in the boiler, a combination of the condensate water that returned as pure feed water after condensed steam and the freshwater or makeup water. Condensate water as feed water is already treated and pure. It is reduced usage of makeup water due to the causes of the treatment process. However, condensate water is not enough for the steam generation because of significant volume usage in industrial processes. So, raw water makes as makeup water by water treatment process removing impurities [2].

Impurities in the raw water which need be removed can be identified as below [4].

- ✓ Hard scale formers -> Calcium and magnesium salts.
- ✓ Dissolved gases -> Free Oxygen and free Carbon Dioxide.
- ✓ Suspended solids -> Mineral or organic particles.

- ✓ Alkalinity - Bicarbonate and Carbonate and Hydroxyl ion
- ✓ Dissolved solids -> Calcium Carbonates and Magnesium Carbonates and Sulphates

These impurities should be removed from the water because of avoiding potential problems in boiler such as [4],

- ✓ Formation of scale and deposition of porous material.
- ✓ Corrosion of the boiler.
- ✓ Reduce the efficiency level of steam purity.

Raw water is essential to treat feed water either mechanically or chemically to prevent these issues in boilers. Dissolved solids such as calcium and magnesium carbonates are concentrated and deposit in the boiler without treated before feed water to the boiler. It causes reducing heat transfer and the efficiency of the boiler. However, settled down sludge that can remove by the process of blowdown. As well as dissolved gases such as O2 and CO2 react with the boiler's surface, then corrosion occurs [3].

2.1 Boiler feedwater specification

Boiler feedwater quality for water tube boilers is summarized (Table 1) using water quality guidelines provided by the Society of Mechanical Engineers American [2].

Table 1. A.S.M.E. guidelines for water quality in boilers. [2]

Drum pressure (psi/g)	0-300	301-450	451-600	601-750	751-900
Iron (ppm)	0.100	0.050	0.030	0.025	0,020
Silica (ppm)	150	90	40	30	20
Total Hardness (ppm)	0.300	0.300	0.200	0.100	0.050
Total Alkalinity (ppm)	700	600	500	400	300

The quality of boiler feed water can be treated to maintain pure using various techniques. Makeup water (Feedwater) can pre-treat by external treatment or internal chemical treatment such as filtration, softening, de-alkalization, and de-aeration. Scale formation is the main significant problem in the boiler. The water's Hardness causes the water's Hardness and the scale-forming impurities such as silica, calcium, and magnesium.The boiler is impurities causing precipitation at the high-temperature time and forms a dense coating of material in the boiler tube; with high temperatures, these components' solubility decreases. This layer invoked a scale. However, the Hardness and impurities are removed by external treatment such as ion exchange using a deionizing unit or softener, reverse osmosis, and lime soda [2].

It thus minimizes the infiltration of contaminants into the boiler in feed water. Also, Alkalinity is caused by impurities present in water, such as Bicarbonate and Carbonate ions. The de-alkalization process eliminates the Alkalinity of water. The de-aeration process then uses the removal of dissolved gases such as oxygen and free carbon dioxide, causing corrosion in boiler parts. Only the de-aeration process unable to remove dissolved gases in water. Trace oxygen left by the de-aerator removes by adding oxygen scavengers such as sodium sulfite, using chemical treatment. In addition to external treatment, internal or chemical treatment is the most economical long-term approach. In internal treatment, additives to the deposit control are introduced into the boiler water to make sludge nonadherent. The precipitated salts are thus easily removed by blowdown. Also,

chemical substances are used to control corrosion, causing factors like pH, Alkalinity, and dissolved oxygen [2]. Chemicals are boosted by pH to rice, the pH value to the optimum. Maintaining the pH at 10.5-12 will prevent the formation of corrosion and a scale. If the feed water softening performed in the external treatment does not sufficiently remove Hardness causing material. Such as calcium and magnesium, chemical treatment can be done by adding phosphate-based chemicals to remove Ca^{2+} and Mg^{2+} further.

3 Alternative Fuel manufacturing and usage

Worldwide energy use is on the rise day by day. According to the high demand, the energy needed for the population should be produced without a limit. In Sri Lanka, petroleum, Biomass, and electricity meet most of the energy requirements. Use petroleum, 42 percent of energy is produced from total energy generation. Coal 11 percent. By using Biomass, 38 percent of the energy supply. The consumption of household energy is based mostly on biomass (82 percent) [3].

Nevertheless, industrial biomass energy consumption is about 68.7 percent. Many industries use Biomass as an alternative fuel in their process, such as generating electricity through steam generation, producing hot water, and producing steam for rice mill processing. It is costlier to operate a boiler us a petroleum product. The use of petroleum products for the boiler causes many environmental problems such as CO2, CO, and NOx emissions. Because of this, most industries tend to utilize Biomass as an environmentally friendly source of energy for sustainable production.

The renewable energy source of Biomass and is regarded as a carbon-neutral fuel. Agricultural residues, sawdust, and fuelwood are mostly used as Biomass in Sri Lanka. As an agricultural country, lots of residues are wasted daily by burning or burying. If those residues burn as energy in boilers, it is more useful than burning them in vain. The use of residues for composting due to methane emissions can be causes for the environmental problem. The use of agricultural residues also helps to reduce deforestation. It reduces the use of wood as Biomass for fuel. Agriculturally-based industries mostly consume Biomass as an energy source. Such industries are the sugar, rubber, rice, and coconut and palm industries. Using agricultural waste, they can produce their electricity, steam, and hot air requirements on their own. In Sri Lanka, rice husk and rice straw from a paddy field, coconut residues such as husk, coir dust and shell, sugar cane bagasse, and maize stalk and maize cobs from maize plantation can be found as agricultural waste. [1]

Fig. 1. Rice straw [1]

Fig. 2. Rice husk [1]

The expected production of paddy over the year is 3.8 million metric tonnes, according to the statistics. The rice straw (Fig.1) and rice husk (Fig.2) from 1 t of rice is 292 kg and 220 kg. Six hundred fifty-six thousand seven hundred thirty metric tons of rice husk can be produced from 3.8 million metric tons, and rice husk has an energy potential of more than 9000TJ. The energy that rice husk can produce can be used to generate 3.87 million tons of vapor. Full filling of the demand for steam is enough for 246 days [3]. Many farmers in rural areas are generally used as waste for burning or disposing of rice straw in the paddy field. Hence it is better to use them as an energy by-product.

Fig. 3 Coconut Shell [1]

Fig. 4 Coconut Husk [1]

Fig. 5 Coconut Dust [1]

Coconut residues, such as shells, husks, and coir dust, can be used in boilers as an alternative fuel. Sri Lanka's major coconut plantation is in the coconut triangle, with total coconut production at 1.01 Mt in 2010, and 527 kt of coconut shells. All the coconut shell (Fig.3) that is produced is used in industry and households for energy purposes. Some industries use shells made from coconut to produce charcoal. The quantities of coconut shells that can be used for energy are 422 kt, as the excess quantity of coconut shells is available in the home. The coconut husk (Fig.4) and coir dust (Fig.5) is 1.04 Mt and 251 kt in 2010. However, most coconut husks in the domestic sector are used for cooking, and not all husks can be collected. Then, the amount of coconut husk available for energy purposes is 564 kt, and in 2010 there will be 8 kt of coir dust available for energy applications [1].

Fig. 6 Bagasse [1]

Another agricultural waste is Bagasse (Fig. 6) from the sugar industry. Seventy-two thousand five hundred tonnes of Bagasse is produced by one of the significant sugar industry in Sri Lanka. All the Bagasse produced is consumed within the factories for generating electricity and for hot air. Therefore, they are not available as excess for other industries.

4 Energy management

Any field or any industry in the present world that is most needed is energy. To do day-to-day work and to continuously Carry out industrial works or services of essential useful energy sources. Likewise, in the economic environment, any industry does its affairs. They focus primarily on their profit and their advantage. [4]

Therefore "Energy Management" was expected people "Energy management can broadly define as organized, proactive and systematic management of energy use in a building/organization to satisfy environmental and economic requirements." Industries use the most numerous methods for controlling their energy, but any industry focuses mainly on a few steps for controlling its energy management [4].

- Collecting the energy data and metering your energy consumption.
- They are identifying opportunities to save energy.
- They are taking action to save energy.
- You are tracking progress and ongoing improvement.

4.1 Heat recovery (Heat-Exchanger)

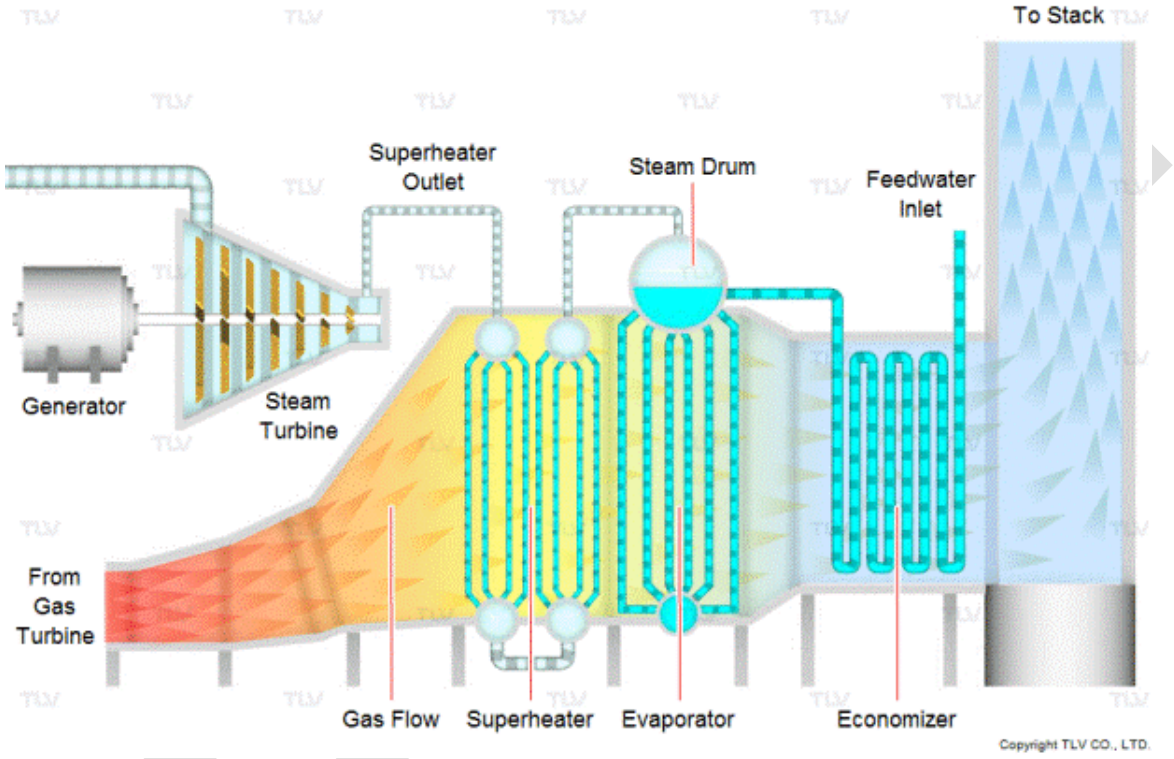

Fig 7. Heat Recovery System [5].

The main work is the high-temperature steam produced by any boiler. The boiler's firebox comprises the combustion air and selected fuel. When combustion changes cold water to hot steam in the burner process, steam passes through the steam lines. Instead, fuel has chemical or bio-energy before combustion. After the combustion, the chemical or bioenergy will change to heat-energy. A certain amount of useful thing, maybe when generating heat energy. However, some energy mounts cannot be used for useful things. That unusable energy exits with flue gas by an excess gas line. If the excess energy can be recovered, called the heat recovery system, some devices are called heat recovery devices. If some boiler system uses heat recovering methods, that can increase boiler efficiency [6]. There using heat recovering devices are,

Economizer

Heat exchange devices are used in boiler economizers, which heat fluids and usually water up to but not generally beyond that fluid's boiling point. Economizers are so named because they can use the enthalpy in hot,

but not hot sufficient fluid streams for a boiler. Recovering more useful energy, the economizer will improve boiler efficiency. The economizer is build of an aluminum and stainless steel alloy.Economizer, therefore, is cost-effective equipment, but it saves energy. An economizer is very important for a part of heat recovery. In the economizer, the structure has a pipeline to flow water—the economizer. Therefore, economizer use high-temperature flue gas when cold water changes to hot water flow. After hot water goes to the boiler process, the boiler system's heat recovery method [6].

Air preheater

The Air Preheater is another heat recovery device. An original word to word meaning is a device used to heat the air before further use is called Air Preheater. Using to increase the boiler output in air pre-heating devices. Air preheaters are mostly installed across a line or pipe of high-temperature flue gas. Air is coming into the air preheater after the air draft fan. Then heat the room temperature air and finally heat the airflow for the combustion by the high-temperature excess flue gas. High heat conductivity metals are used to manufacture air preheaters [6]. Like that,

- air pre-heating devices can save waste energy, and boiler efficiency can be increased.

4.2 Boiler Efficiency

When considering boiler most crucial factor is the "boiler performance." The heat output in the steam / the fuel given by the fuel is the boiler's percentage performance. Parameters of design values are essential for boiler performance. When measuring boiler performance, the steam quantity, steam pressure, and temperature are using for parameters. The boiler output can be calculated primarily by two types. These are "efficiency" and "evaporation ratio." However, efficiency is the ability to reduce waste of energy, materials, or other resources to achieve desired results. The boiler's thermal efficiency can be defined as the heat output ratio used effectively for the process and heat input supplied by the fuel [6]. The boiler efficiency thus has two main types, "direct method" and "indirect method."

- **Direct methods**

  The heat input of the burning fuel and heat output of the working fluid are both found in direct boiler efficiency systems. Sometimes, this method is called the "input-output method." There is no loss of heat or energy. Bellow has a direct process efficiency calculated using the formula [7].

$$\textbf{Boiler Efficiency} = \{\textbf{Heat output/Heat input}\} * \textbf{100\%}$$

$$\textbf{Boiler Efficiency} = \textbf{Q X } (h_2 - h_1) \textbf{ / (q X GCV) X 100\%}$$

- Q = Quality of steam generated. (Steam flow rate – kg/s)
- h_2 = Enthalpy of steam at output of boiler.
- h_1 = Enthalpy of feed water
- Heat Input = q X GCV
- q = Fuel Quality (Fuel flow rate - kg/s)
- GCV = Gross calorific Value

The disadvantage of the direct method

- It does not give the operator any clues as to why system efficiency is low.
- It does not quantify the various losses to compensate for different rates of performance.
- Evaporation ratio and efficiency can be misleading when the steam is exceptionally humid due to water transfer.

- **Indirect methods**

While considering the indirect boiler efficiency process, the measurement of efficiency is achieved by subtracting heat loss fraction from 100 and calculating all related heat losses. This method is simply called a calculation method of heat loss efficiency [6].

Boiler indirect Efficiency = 100 – (1 +2 + 3 + 4 + 5 + 6 + 7)

1. Percentage of heat loss from dry flue gas
2. Percentage of heat loss due to evaporation of water formed due to H2 in fuel
3. Percentage of heat loss because of evaporation of moisture present in the fuel
4. Percentage of heat loss from the moisture presents in the air.
5. Percentage of heat because of unburnt in fly ash
6. Percentage of heat loss because of unburnt in bottom ash
7. Percentage of heat loss because of radiation and other unaccounted loss

The disadvantage of the indirect method

- Time-consuming
- Requires lab facilities for analysis

4.3 Boiler Efficiency Improvements

The majority of the world's factories use "Boilers" for their energy needs.As a basic boiler word, "boiler is the steam producing unit." They concentrate their attention on "energy management" for the boiler operating system in boilers using any industry. If industries manage any boiler operator or relevant engineer uses their energy use for their boilers, the energy management system, there are some steps,

Combustion and Waste Heat Recovery System.

Some boiler types are used in various industries. However, different types of fuel have been used for each boiler. Most importantly, a chosen fuel is used for each boiler, and higher combustion can be achieved. However, for some reason, it is selected as the most suitable fuel for relevant boilers. The fuel should be checked before combustion in the boiler by using the boiler fuel. For example, Biomass should calculate its calorific value like this [7].

Another thing is that after using some energy and going to the environment freely excess energy. When doing energy management, that wasted energy should be recovered for useful work. To capture the excess energy, some treatment or some tools are used. Air pre-heat devices such as this, for example, economizer.

Makeup Water Management System.

Consider the subject of boiler management; the most critical factor is the water required. In the boiler water level is the majority of cases are for the boiler to run correctly. There is any form of the boiler, and if there is more water than the water level, the boiler cannot provide adequate output. Likewise, because in that case, the boiler faces any technical issues with water less than water level and cannot get proper work from the boiler [7].

Steam and Condensate System Management.

Steam and condensate control system is another essential component of boiler energy management. After the steam is produced, steam moves through the steam line system. And then the hot steam adjusts to the temperature difference. In this case, every boiler system uses the condensate system. Every fluid is transferred to high pressure by low pressure, and the fluid becomes vapor. The condensate device condenses the low-temperature vapor, which produces a pressure differential between the vapor lines. Steam can then be quickly transported from one position to another. The steam and condensate system works well and can be controlled with energy [7].

Steam Generation Management.

In steam production, the main work of each boiler is. However, the industry only uses the necessary energy from the steam. Therefore, the boiler must generate the necessary steam when the boiler produces a higher steam quantity than the required quantity, the energy waste from steam. Like that, when the boiler produces a lower quantity of steam than the required quantity, the planned works cannot be performed. The essential factor for boiler energy management is proper steam production. Moreover, there are few active factors for proper steam generation, and there is "proper combustion, adequate water level, the pressure inside the boiler [6].

5 CONCLUSION

The boiler is the industry's central unit that helps generate hot water and vapor. The boiler efficiency is causing the volume of output for the industry. So that boiler efficiency is also significantly controlled at the level. Boiler water treatment improvements and alternative feed fuels with the best calorific values are suggested as the solution to it. So we can keep boilers cost-effectively and efficiently. Another thing about alternative fuels industries is that it positively affects developing the country's economy and the labor market. Thus, the best part of the industry is energy management. In this case, the energy management boiler unit is the best way to run the industry cost-effectively and with considerable efficiency.

6 REFERENCES

[1] Udara S.P.R. Arachchig, SakunaSandupama P.W., Alternative fuel for biomass boilers in Sri Lanka, International Journal of chemical studies, 07, 729–733, 2019.

[2] U.S.P.R. Arachchige, P.W. SakunaSandupama, Purpose of purifying industrial boiler water, International Journal of Chemical Studies, volume 06 Issue 04, Page 634 – 635, 2019

[3] T.G.A.H.R. Thalagahawaththa, Tharakie G.M, Sithari G.M., Boiler systems optimization, Journal of Research technology and Engineering. 1, 150–160, (2020

[4] MohdFaizal Fauzan, M.H. Hamzah, A. Navaretsnasinggam, Study on the thermodynamics performance of industrial boiler; https://www.researchgate.net/publication/263878729

[5] Heat recovery system, https://www.tlv.com/global/ME/steam-theory/waste-heat-recovery.html, (google photo), [accessed on 06/06/2020]
[6] M. Parvez, Steam Boiler, Sci. Am. https://doi.org/10.1038/scientificamerican09201884-179b51, 179–179, (1884).
[7] Chuah TG, Wan Azlina A.G.K., Robiah Y, Omar R., Biomass as the Renewable Energy Sources in Malaysia, An overview. International Journal of Green Energy, 3(3), 323-346, 2006.