Boiler systems optimization

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Abstract— Boilers required a high amount of water to make hot water or steam for the industrial process. It is essential to pay attention to increase boiler efficiency and to mitigate the boiler common problems such as corrosion and scale formation. Different kinds of fuels are used in the boilers to supply the required amount of heat for steam production. Prioritization takes place for fossil fuel because of high calorific value. But in Sri Lanka, the use of biomass as fuel is most popular because it is considered a green energy source. In every industry, energy is wasting in various ways, as a form of heat, noise, friction, etc. That is the reason for all industries focused on energy management to reduce energy waste, energy costs while increasing efficiency. Then this article describes water treatment improvements, alternative fuel usage, energy management, and efficiency improving techniques in the industrial boiler.

Index terms—Efficiency, Water treatment, Energy management, Heat recovery, Alternative fuel

1 INTRODUCTION

In Sri Lanka, a variety of industries used steam for their manufacturing process. Those industries are food and beverage industries, paper manufacturing industries, textile industries, and cement manufacturing industries. Approximately 400 biomass boilers are operating in Sri Lanka. In biomass boilers, rubberwood, paddy husk, coconut husk, sawdust, and dendro are used as fuel. Fossil fuel also used in some industries for steam boilers and diesel boilers [1]. Because each and every industry used boilers, there is an influence in the energy-saving measure in boiler efficiency. Therefore it is essential to identify places in which energy wastage occurs. Energy can be wasted in heat loss, including blow-down, radiation losses, and flue gas, as in Fig.1 [2].

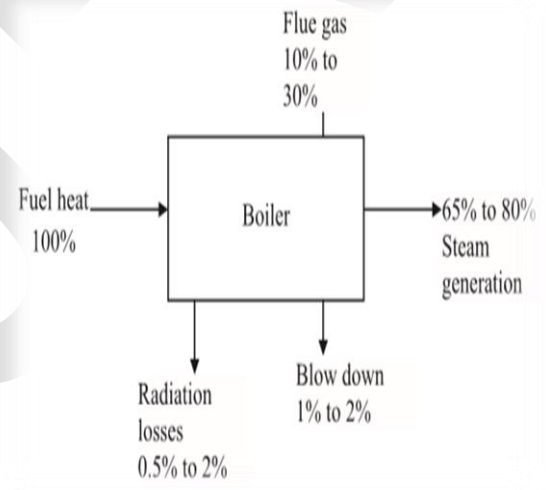

Fig. 1. losses of the boiler system [2]

Harvesting energy from flue gas and blowdown will make significant energy savings and efficiency improvements [3]. This can be done using an economizer to preheat feed water from flue gas heat and

preheat makeup water using a heat exchanger from blowdown. Also, improving insulation will make significant energy saving [4]. In this paper, we discussed water treatment improvements, Usage of alternative fuel in the boiler for cost reduction, Energy Management, Heat recovery, Efficiency improvements of the boiler.

2 BOILER WATER TRATMENT IMPROVEMENTS

The boilers use to produce steam or hot water is required high-quality water to improve the boiler operation. Water, which is used in the boiler, is called feed water. Feedwater is a combination of the condensate water that returned as pure feed water after condensed steam and the fresh water or make-up water. Using condensate water as feed water is advantageous because it is already treated and pure. It is reduced usage of make-up water, which causes the treatment process. However, condensate water is not enough for the steam generation as it is used in industrial processes. But, raw water takes as make-up water required a water treatment process due to having impurities in raw water and to make the water fate for using boilers. Impurities in the raw water which need be removed can be identified as below [1].

- 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 remove from water in order to avoid potential problems in boiler such as [6],

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

To prevent these issues in boilers, it is essential to treat feed water either mechanically or chemically. When steam produces, dissolved solids such as calcium and magnesium carbonates are concentrated and deposit in the boiler. It causes reducing heat transfer and the efficiency of the boiler. However, the sludge that settled down can remove by the process of blowdown. As well as the dissolved gases such as oxygen and carbon dioxide react with the surface of the boiler, and because of that, corrosion takes place.

2.1 Boiler feed water specification

Boiler feed water quality for water tube boilers is summarized (Table 1) using water quality guidelines provided by the American Society of Mechanical Engineers (ASME) [5].

Table 1. ASME guidelines for water quality in boilers.

Drum pressure (psig)	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

To maintain the quality of boiler feed water, it can be treated to make pure using various techniques. Makeup water can pre-treat by external treatment such as filtration, softening, de-alkalization, and dearation. One of the significant problems in boilers is scale formation. The hardness of the water and the scale-forming impurities such as silica, calcium, and magnesium are notable factors for scaling. When the boiler is at high temperature, impurities make precipitation and form a dense coating of material in the boiler tube. The solubility of these components reduces with high temperature. This layer of material called a scale. However, the hardness and those impurities remove by external treatment such as the ion exchange process using de-ionization unit or softener, reverse osmosis (RO), and using lime soda [7]. Thus, it minimizes entering contaminants in feed water to the boiler. Also, Impurities present in the water, such as Bicarbonate and Carbonate ions are caused to alkalinity. The alkalinity of water removes by the process of de-alkalization. Then the dearation process uses to remove dissolved gases like oxygen and free carbon dioxide, which cause corrosion in boiler parts. Only the dearation process is not enough to remove dissolved gases in water. Trace oxygen left by de-aerator removes using chemical treatment via adding oxygen scavengers such as sodium sulfite.

Apart from external treatment, the most economical long term approach is internal or chemical treatment. In the case of internal treatment, deposit control additives are introduced into the boiler water to make sludge non-adherent. Hence, the precipitated salts are removed by blowdown easily. As well as, chemicals are used to control corrosion cause factors such as pH, Alkalinity, and dissolved oxygen [6]. There are pH boosting chemicals to rice the pH value to the optimum level. Maintaining the pH level at 10.5-12 will avoid corrosion and scale formation [5]. If the feed water softening done in the external treatment is not removing hardness causing material such as calcium and magnesium sufficiently, chemical treatment can be done to further removing of calcium and magnesium by adding phosphate based chemicals.

3 USAGE OF ALTERNATIVE FUELS

Energy use in the world is increasing day by day. According to the high demand, the energy required for the population should be produced without a limit. In Sri Lanka, Most of the energy requirements fulfill by petroleum, biomass, and electricity. From the total energy generation, 42% of energy produces by using petroleum. 11% from coal. 38% of the energy supply by using biomass [8]. Household energy consumption is mostly based on biomass (82%). But Industrial energy consumption from the biomass is approximately 68.7% [9]. Many industries use biomass as an alternative fuel in their process, such as generating electricity by producing steam, producing hot water, producing steam for the process of rice mills. Because operating a boiler using a petroleum product is more expensive. As well as Using petroleum products for boiler causes for lots of environmental issues such as emitting CO_2, CO, and NOx. Because of that, most of the industries tend to use biomass as an eco-friendly energy source for sustainable manufacturing.

Biomass is a renewable source of energy and considers as a carbon-neutral fuel. In Sri Lanka, agricultural residue, sawdust, and fuel wood are mostly used as biomass. As an agricultural country, lots of residues

are wasted daily by burning or burying. If those residues burn in boilers as energy, it is more useful than burning them in vain. As well as using residues for composting can be causes for the environmental problem due to the emission of methane. Using agricultural residues help to reduce deforestation as well. It reduces the use of fuel wood as biomass.

Industries that are based on the agricultural sector are mostly consuming biomass as an energy source. Those industries are sugar industries, rubber, rice mill, and coconut and palm-based industries. They can produce their own electricity, steam, and hot air requirement on their own using agricultural waste. Rice husk and rice straw from a paddy field, coconut residues such as husk, coir dust and shell, bagasse from sugar cane and waste like maize stalk and maize cobs from maize plantation can be found as agricultural waste in Sri Lanka.

According to the statistic, expected paddy production is 3.8 million metric tonnes over the year [10]. Rice straw (Fig.02) and rice husk (Fig.3) production from 1 ton of rice are 292 kg and 220 kg [11]. From 3.8 million metric tonnes can produce 656,730 metric tonnes of rice husk, and there is energy potential more than 9000TJ from rice husk [12]. The energy which can produce by rice husk can be used to produce 3.87 million tons of steam. It is enough to full fill the steam demand for 246 days [1]. Normally, lots of farmers in rural areas are used to burn or dispose of rice straw in the paddy field as a waste. Therefore it is better to use them as a byproduct for energy purposes.

Fig. 2.Rice straw

Fig. 3. Rice husk

Coconut residues such as shells, husks, and coir dust can be used as an alternative fuel in boilers. Major coconut plantation of Sri Lanka is in the coconut triangle, and total coconut production was 1.01 Mt in 2010, and 527 kt of coconut shells were produced [13]. All the coconut shell (Fig.4) which is produced is used for energy purpose in industries as well as in household. Some industries are using coconut shells to produce charcoal. The amounts of coconut shells which can be used for energy are 422 kt as the excess amount of coconut Shells are available in the household. Coconut husk (Fig.5) and coir dust (Fig.6) production in 2010 is 1.04 Mt and 251 kt. But most of the coconut husks use for cooking in the domestic sector, and all husks cannot be collected. Then the amounts of coconut husk available for energy purposes are 564 kt, and 8 kt of coir dust is available for energy applications in 2010 [13].

Fig. 4. Coconut shell

Fig. 5. Coconut husk

Fig. 6.Coir dust

Another agricultural waste is bagasse (Fig. 7) from the sugar industry. 72500 tonnes of bagasse is produced by one of the major sugar industry in Sri Lanka [14]. All the bagasse produced is consumed within the factories for generating electricity and for the purpose of hot air. Therefore, they are not available as excess for other industries.

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Fig. 7. Bagasse

Maize cultivation is one of the major cultivation in Sri Lanka. Maize production in 2010 is 29kt. As a byproduct of Maize, 8kt of maize cob (Fig. 8) and 58kt of maize stalks (Fig. 9) is generating. Due to collecting problems, the amount of maize cob and maize stalk that are available for energy is 6kt and 35kt [13].

Fig. 8. Maize cob

Fig. 9. Maize stalk

Fig. 10. Gliricidia

Apart from using crop residues, the most common biomass sources are fuel wood. In Sri Lanka, rubber woods use as a byproduct of rubber industry. At present, Gliricidia sepium woods also use for energy purpose. Gliricidia (Fig.10) is important as fire wood because of its advantages. Its growth rate is high. Don't require replanting for 15-20 years. Can grow anywhere [15]. Using Gliricidia as fuel wood is helps to minimize deforestation as well. Above mentioned all fuel can be taken as an alternative fuel for boilers. They are mostly available in Sri Lanka at affordable cost.

4 ENERGY MANAGEMENT BOILER

Energy management can simply be described as saving energy in any industry, business, or organization [16]. Due to the increase of energy consumption and energy costs force industries, to use energy efficiently. Improve the awareness and knowledge of energy management by participation and involvement in all employees in industry will enhance energy management process [17]. Reduce energy loss and recover the waste heat is significant in energy management. In many industries waste heat generates in the process of heating [17]. Fig.11 shows the energy used in the U.S. Textile Industry. According to that, 28% energy used to generate steam in that industry [2]. In the process of steam production, variety of ways to lost energy. As an example, In Fig.01 flue gas emitted from the boiler have typically high-temperature range 150-250°C, that means it lost 10-30% of heat energy [3].

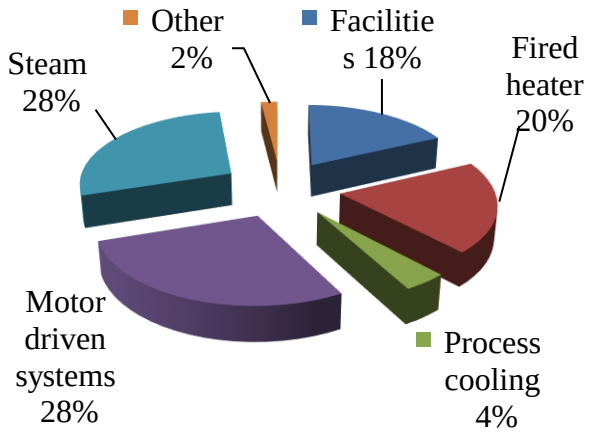

Fig.11. Final Energy End-Use in the U.S. Textile Industry [2]

Process of steam generation, how much fuels used to generate the stem per day, and how much stem does boiler consume for a day, etc [16]. To save energy it is necessary to find energy losses in the system.

Boiler energy losses can be categorized into four,

- Energy losses due to heat caring by the flue gas
- Heat caring by hot water vapor, including sensible and latent heat.
- Heat losses by sunburned fuel, incomplete combustion and heat lost from the insulation of boiler in convection and radiation from the outer surface.
- Heat loss from blowdown. [3]

These are the energy saving opportunities in the boiler. In this step take the action to save energy. For that, we need to upgrade the boiler system and improve the insulation.

Recovering heat from blowdown to heat makeup water,

- Consider the capturing radiation and convection heat from the boiler shell for pre-heating combustion air.
- Improve insulation of Insulate pipes, flanges, fittings and other equipment.
- Install equipment to capture heat on the flue gas system. This includes economizers, combustion air preheaters and flue gas condensers.
- Consider about using remaining heat in the flue gas for space heating, or used to dry biomass or product.
- Install a system to use pressurized condensate return without removing as wastewater [18].

Here we have to achieve the predicted limit of energy saving because we have invested some money on upgrading and insulation. So we have to prove that we have met the goal of energy saving. The benefits of energy management are that it reduces the cost of energy, carbon emissions from the industry will reduce, and reduces the risk of increasing energy prices by reducing the demand for energy [16]. The above facts are discussed in detail in further topics.

5 HEAT RECOVERY SYSTEMS

In every industry, energy efficiency can be enhanced through heat recovery systems. With the development of the technology, there are some heat recovery systems which can be introduced for boilers. When talking about heat recovery systems, they have the capability to provide additional energy to the system by capturing and transferring heat from the same system or another system [19]. There are several types of heat recovery systems that can be introduced to a boiler system. When considering the heat recovery systems, heat exchangers are essential to be considered. Heat exchangers are devices that transfer heat from one medium to another medium and they have the capability to recover latent heat and sensible heat [20]. Feedwater can be heated by the residual heat of the flue gas with the presence of the economizer.

Air Preheater

Air preheaters can be used to recover the heat from the exhaust and that energy is used to heat the intake air [19]. These devices can be used to acquire the low to medium temperatures. There are two types of air preheaters and they are heat pipe type and plate type exchangers. In heat pipe type exchangers, a container consists of sealed pipes which are placed in a parallel way. This container has two sections as inlet and outlet. This container consists of a working fluid which absorbs heat and transfers heat from hot area to cold area. But in plate type air preheaters, the plates are placed in perpendicular to the incoming cold air. Then the hot exhaust air is transferred towards the plates by creating the hot channels. Then it caused to transfer heat from hot air to cold air.

5.1 Heat recovery from flue gas

Normally 20% of heat losses happen from the flue gas but fortunately, at present 50% of heat can be recovered from heat exchangers [20]. A flue gas heat recovery system which is implemented for a fire tube boiler can be explained as below [21, 22]. Then it will help to gain knowledge on the heat recovery systems.

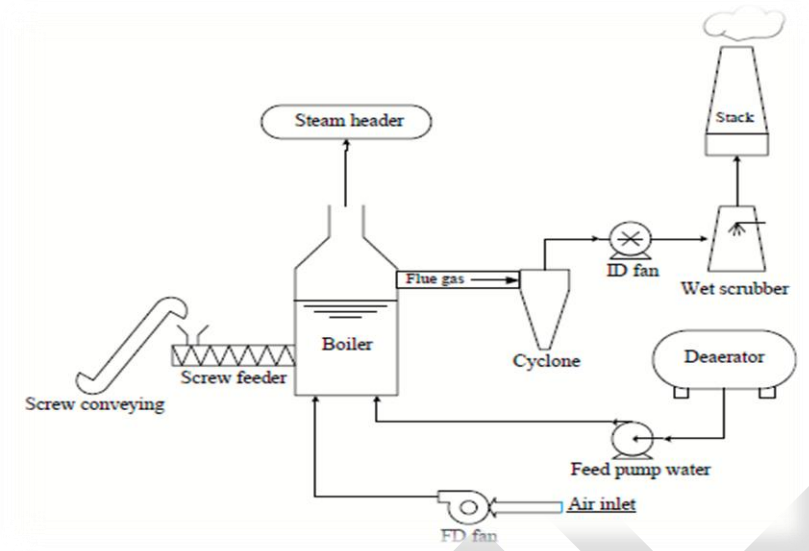

Fig.12. Steam production system without heat recovery system [22]

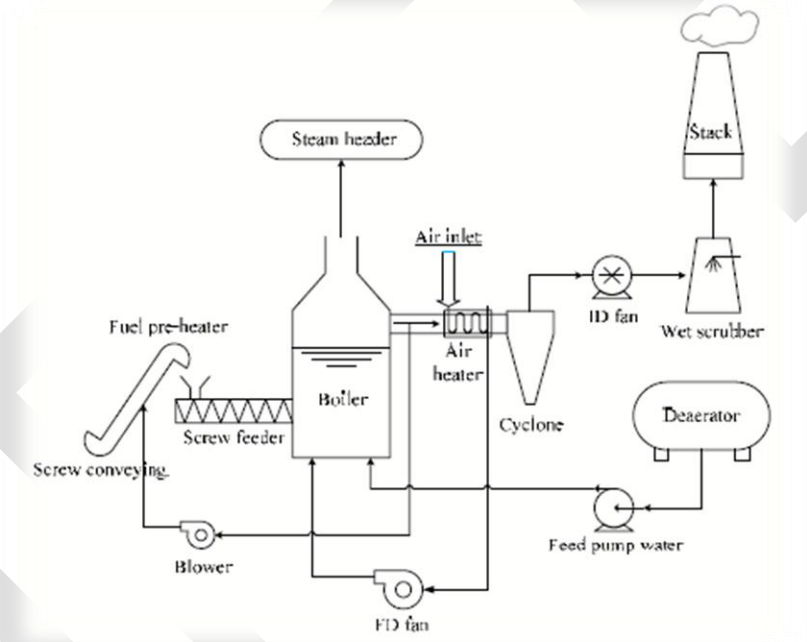

Fig.13. Steam production system with heat recovery system [22]

A boiler system without heat recovery system is in an industry is shown in Fig.12. In Fig.13, a part of flue gas is used to directly dry the fuel and another part of flue gas is heated by using an air heater to preheat the air which enters the combustion chamber. This system shows that a heat recovery system is very important to convert the boiler system to a more effective one.

5.2 Heat recovery from blowdown

Another one is heat can be also recovered from the blowdown of the boiler. Total dissolved solids in the boiler is controlled by this blowdown system. The main advantage of it is, the energy can be recovered from the boiler blowdown water [24]. Those systems can be varied according to the user's primary requirements. One way is introducing a heat exchanger between the boiler blowdown water and make-up water [23]. In Fig.14, boiler blowdown water flows towards the flash tank and from the flash tank, the heated water will flow to the heat exchanger. Then the heat will be extracted by make-up water which flows towards the boiler. That is the one simple way to recover the heat from the boiler blowdown. This blowdown heat recovery system can be developed in many ways. One of the developed systems is a two-stage blowdown heat recovery system [25].

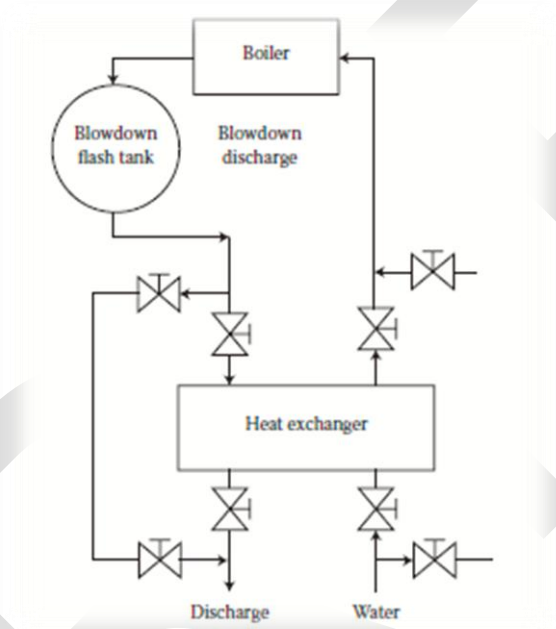

Fig .14. Heat recovery from blowdown [23]

5.3 Heat recovery from bottom ash

Other than the flue gas and blowdown, heat can be also recovered from the bottom ashes which can be collected from the boiler [26]. That process is called cooling bottom ash. This system is a heat exchanger that transfers heat from the hot ash plate to the fluid. As well as the highest temperature of the ash caused to damage the equipment. Then it is very useful to cool the bottom ash. This system allows to heat the feedwater and combustion air to high temperatures.

6 EFFICIENCY IMPROVMENTS

Boiler system needs to be more efficient to improve continuous development in any industry. It is impossible to convert all of the energy from one form to another. In boiler systems also several losses can be accounted when calculating boiler efficiencies. In these systems, the major losses are categorized as unburnt carbon losses, stack losses and convection and radiant losses [27]. The cost effective energy conservation measures for boiler system can be explained as in follows [25].

1. Load reduction

- Insulation should be done in distribution system, heat exchangers etc.
- Steam leaks should be repaired.
- Condensate recovery.
- Boiler blowdown management.
- Improve feed water and make-up water treatment.
- Reduce the loss happened by flash steam.

2. Waste heat recovery.
   - Flash steam utilization.
   - Feed water and make-up water should be pre heated by an economizer.
   - Combustion air preheating with a recuperator.
   - Installation of condensate heat recovery system.

3. Efficiency improvements.
   - Control systems installation for combustion efficiency.
   - Shutdown unnecessary boilers.
   - Low excess air burner installation.
   - Faulty burners replacement.
   - Improve feed water and make-up water treatment
   - Heat transfer surfaces should be cleaned.

4. Fuel cost reduction by fuel switching.

5. Other opportunities.
   - More efficient pumps and motors should be installed.
   - Installation of variable speed drives.

6 CONCLUSION

The boiler system is an important energy converting system that mostly used in industries. Then it is essential to pay attention to energy management and other factors of boilers. The boiler needs to be maintained well to improve efficiency. Boiler water treatment is the most important one as it reduces the scale formation inside the boiler. As well as alternative fuels can be used to improve the boiler efficiency and to reduce environmental pollution. Another main point is heat recovery systems. Industries can enhance the efficiency of the boiler systems by implementing various heat recovery systems. And there are other several methods like boiler management systems etc. From this study, it can be concluded that there is still a lack of improvements in boiler systems in the industry. To overcome all these challenges industries can implement the systems in this article and they can consider the ways to make the boiler system to a more advanced one with at least 90%.

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