Optimization of an Industrial Boiler Operation

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Abstract: Boilers are used in industry to generate the steam required for the production process. The efficiency and safety of a boiler directly influence their production rate. Therefore, the industrial boiler operation needs to be optimum in order to keep a continuous production of the industry. The corrosion and scale formation of boiler tubes are the main problems that can lead to boiler operation failure. One of the main reasons for this is the low quality of the water. Thus, the improvements in boiler water quality can help to prevent corrosion and scale formation, which eventually optimize the boiler operation. Feedwater that enters the boiler can be treated externally by installing a water softener plant, demineralization unit, or other treatment method, and can be treated internally by using chemicals. The usage of alternative fuel and reduction of heat losses in the boiler can reduce the cost of the boiler operation. Heat recovery from condensed water and flue gas can be employed to improve the efficiency of the boiler. Energy management activities also help to optimize the boiler operation. This article describes methods that can be used to optimize the industrial boiler operations.

Keywords: Alternative Fuels, Boiler, Boiler Water Treatments, Efficiency, Energy Management, Heat recovery, Optimization.

1 Introduction

Boilers are considered to be a crucial part of any industry or generation station, as it is the place where the fuel is used for producing the needed amount of heat. The primary function of a boiler is to convert water into steam at constant pressure and to supply it at a constant pressure [1].

Industrial boilers are mostly used by the glove factories, chemical processes, rice mills, textile industry, pharmaceutical factory, building material factories, dairy industry, garment factories, paper mills, brewery and food production, commercial building, power plants, cement and steel industry, hotels and etc. Many boiler systems operate with an efficiency of less than 75% regardless of the applications to increase boiler efficiency. Therefore, boiler modification systems must be added to a boiler system. At present many attempts have been made to improve the boiler efficiency by recycling flue gas heat using new methods and techniques. On the other hand, we must search for new renewable fuel sources for boilers because there is a considerable amount of greenhouse gas emissions that occur when boilers operate. Use of fossil fuel for the energy production process is one of the largest greenhouse gas emitters to the atmosphere which cause global warming [2].

In the boilers' radiation, convection and conduction are used to convert heat energy into steam energy. Proper boiler operation depends on several variables such as boiler feedwater quality, water flow, the water level within the boiler, furnace temperatures and pressures, burner efficiency, and airflow. Several commercial and industrial facilities use boilers to provide steam or hot water for heating or power application processes. Boilers are usually significant users of energy, and therefore boiler energy management is an essential factor. For that purpose, understanding the boiler management systems is very important. There are main components of energy management required to enhance the boiler efficiency in industries. If we can reduce significant losses in the boilers, we can increase boiler energy efficiency. This research is mainly focused on the

optimization of industrial boiler operation using boiler water treatment improvements, usage of alternative fuel in a boiler for cost reduction, Energy Management, Heat recovery, and Efficiency improvements.

2 Boiler water treatment improvements

Boiler safety and efficiency are the most important factors when it comes to boiler operation. The hardness of the water, alkalinity, P.H. value, and dissolved gasses of the water can be considered as the most important factors [3]. Alkalinity and P.H. values of the water, Oxygen content, hardness, and scale deposits are the common problems of feed water streams caused due to the improper water treatment. The recommended pH value of feed water is around 9.5, according to the accepted standards [4]. Boilers can be scaled, fouled, and also corroded because of untreated water. A boiler feedwater treatment system is essential to protect the tubes of the boiler and to increase the efficiency of the boiler. It helps to avoid breakdown of the boiler, boiler failure, and expensive maintenance cost of the boiler. The thermal conductivity of the formed scales is 10-100 times less than steel conductivity. This is the main reason for the damage and breakage of the boiler tubes. Therefore, avoiding the scale formation of the boiler tube is very important; otherwise, the breakdown of the boiler, reduction of boiler efficiency, and high fuel consumption can occur[5]. The formation of scales is minimized by pre-treatment of raw water. Decarbonization, ion exchange, and filtration are used in industries for the water treatment processes [6]. A boiler feedwater system should be able to remove dissolved solids, suspended solids, and organic materials from the water as well as different ions in water, such as Iron, Copper, Silica, Calcium, Magnesium, Aluminium, and Dissolved gasses [7]. Normally many contaminants like Ca^{2+}, Mg^{2+}, Fe^{3+}, Mn^{2+},…etc, cause the hardness of boiler water [8]. Mostly Calcium, magnesium, their compounds, and silica are precipitated in the tubes, increase the formation of scales, and reduce the heat exchange of a boiler [9].

When selecting a pre-treatment plant, the kind of water source and their water quality should be analyzed [5]. Many industries have now focused on membrane technologies like microfiltration, ultrafiltration, nanofiltration, and reverse osmosis over traditional technologies like coagulation, flocculation, and gravity separation for water treatment purposes [10]. To optimized the boiler function, water treatment should be simple, cheap, and efficient. As well as the usage of chemicals and energy-demand should be minimum. Reverse osmosis is a good technology over ion-exchange softener if the water treatment plant is large and water has high mineralization. Also though the ion exchange softening is cheap, it uses more chemicals than the Reverse osmosis technology [6]. Well-designed boiler feedwater treatment plant must essentially have an efficient water treatment method which is able to remove the harmful matter from water, control the chemistry of the boiler, highly use steam condensate return water, avoid return lines corrosion and boiler breakdowns and increase the lifetime of the water treatment unit [7].

The scale deposition of a boiler can be avoided by external treatment or internal treatment processes. Here, different types of equipment are used in the external treatment to prevent the formation of scales and dissolve gasses in the water, which enters the boiler. Chemicals are directly put into the boiler waters for internal treatments. As well as formed scales are can be removed by the boiler blowdowns [9]. The water treatment process and the type of installable devices depend on the type of water and impurities present on the water. Normally, a feedwater system consists of one or many of the following units.

- Filtration or ultrafiltration unit
- Ion exchange or softening unit

- Membrane processes (reverse osmosis and nanofiltration unit)
- De aeration/degasification unit
- Coagulation/ chemical precipitation unit

Controlling the level of total dissolved solids (TDS.) within the boiler, controlling depositions, and preventing the corrosion are the main objectives of the internal boiler water treatments. There is a possible risk of carrying water into the steam if the TDS. level increased. This can be controlled by either continuous or intermittent blowdown. Corrosion of tubes can be prevented by removing Oxygen using a de-aeration unit. Depositions can be controlled by controlling the level of carbonate or phosphates. When chemical dosing is done, it should be continuous and proportional to the water flow rate. Types of chemicals used for the boiler water treatment are Oxygen scavengers (Sodium Sulphate or Sodium bisulphite), Neutralizing Amines (prevent the formation of carbonic acid), Phosphates (to reduce scale deposition), Sludge conditioners (to keep precipitated salts in a mobile condition and they can be removed by blowdown) and Alkalinity Builders (used to raise the pH of the water) [11].

3 Usage of alternative fuel in a boiler for cost reduction

Different types of boilers use different types of fuel depending on the working principle of the boiler vessel. Each fuel has its unique chemical properties, which directly affect the combustion process. Boiler fuel can exist as a liquid, solid, or gas. In most industries, generated steam is directly used for the manufacturing process, rather than producing electricity. In the Sri Lankan context, there are several industries that use produced steam from biomass boilers and furnace oil boilers [12]. Table 1 shows the comparative global energy consumption of relative waste production for different fuel types from the year 1971-2030. The global energy consumption is predicted to increase in the coming decades between 2002 to 2030 by 60% with the bulk of the demand coming from developing countries [13]. With the depletion of primary energy sources, the world is seeking new renewable energy sources that can be used as alternatives for primary energy sources. The main problem of using primary energy sources in boilers isn't the lack of resources, but the emission of greenhouse gases cause climate change.

Table.1. World total fuel consumption (Mton) [13]

	1971	**2002**	**2010**	**2030**	**2002-2030(%)**
Coal	617	502	516	526	0.2
Oil	1893	3041	3610	5005	1.8
Gas	604	1150	1336	1758	1.5
Electricity	377	1139	1436	2263	2.5
Heat	68	237	254	294	0.8
Biomass and waste	641	999	1101	1290	0.9
Other renewable	0	8	13	41	6.2
Total	4200	7075	8267	11176	1.6

Approximately there are about 400 biomass boilers in Sri Lanka [12]. This is because there is enough biomass supply throughout the year, and it is very cheap compared to petroleum oil. Rubber trees are widely used in biomass boilers due to its availability and high calorific value. The economic life of a rubber plantation is 25-30 years [14]. After the economic period of rubber plantations, people cut the rubber plantations and sell as firewood. But people do not start rubber plantations again in those lands. Because of that, deforestation is widely taken place to fulfil biomass demand in Sri Lanka. Therefore, it is very important to introduce other possible alternative renewable energy sources that can sustainably replace biomass and petroleum oil. That can be suggested as briquettes from waste cotton dust, rice husk, rice straw, biodiesel, coconut shells, and sawdust, bagasse.

Some major advantages of biodiesel are mentioned below.

- Renewable fuel, Produced from vegetable oils or animal fats.
- It has low toxicity when compared to Diesel fuel.
- Rapidly degrades than diesel fuel, minimizing the environmental impacts of biofuel spills.
- Low emission of contaminants: carbon monoxide, particulate matter, hydrocarbons, polycyclic aromatic, and aldehydes.
- It has low health risk, due to minimized emissions of carcinogenic substances.
- No sulfur dioxide (SO_2) emissions.
- Higher flash point (100°C minimum).

4 Boiler Energy management

Many businesses and industrial facilities use boilers to provide steam or hot water for the heating process. Boilers are generally significant users of energy, and therefore the boiler energy management is important. Understanding boiler management systems is also very essential. There are primary components of energy management required to enhance the boiler efficiency in industries. If we reduce significant losses in our boiler, we will increase boiler energy efficiency [15].

The main energy losses in boilers

- Loss due to dry flue gas
- Loss due to gas in the fuel
- Loss due to moisture in the fuel
- Loss because of moisture in the air
- Loss due to carbon monoxide
- Loss because of surface radiation, convection and other unaccounted
- Unburnt losses in fly ash
- Unburnt losses in bottom ash

Flue gas losses:

These kinds of heat losses occur due to the temperature of the flue gases and a function of flue gas and combustion air, as well as the excess air temperatures [16].

Feedwater losses:

Low feed water quality results in an inflated blowdown rate, and other losses on the distribution system due to scale build-up.

Radiation losses:

This is the heat loss from the boiler casing. This loss happens from the external surfaces of the operating boiler. For any boiler at operational temperature, the loss is constant. It is expressed as a share of the boiler's heat output. The loss will increase as boiler output is reduced [17].

Blowdown losses:

Heated water is regularly discharged from boilers to control the concentration of suspended solids and stop sludge formation [16].

Losses due to moisture:

The hydrogen component of fuel leaves the boiler as water vapor, taking with it the total heat (or heat content) corresponding to its conditions of temperature and pressure. The vapor is steam at low pressure but with a higher stack temperature. The enthalpy loss is about 11 % for gas and 7 % for fuel [17].

Boiler Energy management potentials

To minimize the heat lost by boilers and to extend their energy efficiency, the following options can be implemented.

- Management of boiler combustion

This aims to reduce excess air in combustion as the hotter Oxygen and nitrogen escapes as the flue gas and additional energy are lost. The oxygen concentration of the flue gas is analyzed and can then be controlled and adjusted. Flue gas temperature is also an important indicator of boiler efficiency. By measuring flue temperature and comparing its changes against steam load, ambient temperature, and oxygen content, boiler efficiency can be monitored. Flue gas temperature ought to be kept as low as possible to extend energy efficiency.

- Feedwater pre-treatment

Feedwater treatment involves the removal of impurities that may cause sludge build-up within the boiler and scale build-up on the distribution system. Feedwater clarification and filtration remove suspended material, while demineralization removes dissolved impurities.

- Boiler insulation

In order to minimize the heat losses due to radiation from the boiler casing, use of correct insulation techniques, the maintenance of insulation layers is needed. Insulation should be ensured to be free from contamination by water or alternative liquids, which may affect its ability to retain heat.

- Blowdown heat recovery

Blowdown water contains significant energy that may be recovered. There are two main strategies for blowdown heat recovery. In one method, blowdown water from either the blowdown stream or the liquid drain of the flash steam vessel can be used to pre-heat feed water using a heat exchanger. And also Flash steam is formed after blowdown happens. If the blowdown streams are directed to a flash steam vessel, the flash steam can be used for low-pressure steam applications.

Heat recovery

Heat recovering of the boiler is one of the most important topics that we should discuss. It can result in a reduction of cost, utilization of fuel, increase efficiency, and reduction of harmful emissions to the environment. The ways that heat recovery can be made are mentioned below.

- Economizer

After generating steam, flue gas comes out from the system. But some heat energy remains in the flue gas when it exits. Therefore, a boiler economizer can use a portion of this remaining energy of the flue gas to heat feed water supply of the boiler. Because of the heat energy given to the feed water, the requirement of fuel for producing steam can be optimized.

- Condensate water

The condensate water consist of negligible amount of impurities. Condensate water is practically 100% pure, clean, and very hot water, which makes it perfectly suitable for boiler feed water. If the condensate cannot be returned to the boiler, then the boiler needs to fed with freshwater, which needs to be pre-heated by burning fuel [18]. The bottom line is, if we can return most of your condensate and keep it hot, we can save tons of money in energy.

- Air preheater

Air is important in a Boiler for combustion of fuel. According to the stoichiometry calculations, the required quantity of air along with excess air is fed into the furnace for the combustion process [19]. When the combustion of fuel takes place, the temperature of the fuel is increased up to the ignition temperature. Therefore, it increases the efficiency of the combustion process as a boiler, and also, the hot air is fed to the furnace for the combustion of fuel. Generally, the air is pre-heated using the flue gas of the boiler system.

- Fuel preheater

Mostly fuel preheaters are used in furnace oil boilers. They are used to pre-heat the fuel oil to make combustion in the boiler efficiency. The fuel is pre-heated by the steam generated in the boiler or an electric heating coil.

- Blowdown recovery

The blowdown process is essential to continue the process of the boiler smoothly. There is a huge energy loss to the environment during the blowdown process. Part of the Energy that is lost by a boiler blowdown can be recovered by using a flash vessel or a heat recovery exchanger.

Efficiency Improvement in Industrial boilers

The boiler is one of the key components in most of the industrial process, and it is used in different kinds of industries. Industrial boilers are pressured tanks of steam that are utilized for the heating of water or generation

of steam that gives heating ability in industries for the generation of electricity by running steam turbines for many applications [20]. There are many types of fuel-based boiler used by industries. Such commonly used boilers are coal-based boiler, natural gas-based, and diesel-based boiler. These boilers use several sources of fuel to generate steam. Around 45% of the world's electricity is generated from steam while the generation from natural gas is about 20%, and from Nuclear energy is about 15% [21]. These processes use a boiler steam turbine system to rotate the turbine and convert its potential energy to electrical power generation. Therefore, ensuring the efficiency of the boiler is also of top importance for most industrial sectors. Energy cost and fuel costs are directly associated with efficiency because inefficient boilers are expensive to maintain. Moreover, the older boilers are not very efficient and cause emission of more pollutants and become non-compliance with emission rules and regulations [22].

Boiler efficiency depends on many factors, such as the fuel-air ratio, fuel combustion, and economizer capacity. The efficiency of the boiler, therefore, has a high impact on energy saving related to heating. Hence, it is important to maximize the transfer of heat to the water and decrease the losses of heat in the boiler [23].

Causes of Boiler inefficiency and tips for improvement

The world's energy demand is increasing with increased industries and population while the resources are declining and becoming more scarce. Alternative fuels are gaining markets, but the deposit level is high. Therefore, the use of more efficient fuel and energy sources are becoming important. Boiler efficiency improvement not only helps to protect the environment and climate but also helps to minimize the plant operation cost, and it will help in saving resources and money. Following are some ways to improve the industrial plant efficiency;

- Boiler Maintenance

Boilers are used regularly during in industries. Aging of equipment is the major cause of inefficiency. As discussed earlier, older boilers tend to be in bad conditions than newer ones and thus run less efficiently[24]. Therefore, the maintenance of the boiler is very important, and it should be regularly maintained. Maintenance keeps boilers running efficiently and smoothly.

- Low heat transfer

Air preheater faces the problem of low heat transfer. Air preheater has a heating component with a surface area of $19m^2$. The surface area and heat transfer are directly proportional to each other. Corrosion and erosion of heating elements reduce the heating area. The deposition of dust particles over the heating component at the cold end also reduces the transfer of heat. Low heat conductivity causes a high flue gas temperature at the outlet and low air temperature at the outlet. This results in boiler efficiency reduction[25]. Therefore, heating components should be kept clean by appropriate dirt puffing with steam. Hot end baskets should be exchanged with the middle baskets as soon as the component height starts falling. Dual rolled baskets can be used in cold ends to raise the heat transference.

- Combustion optimization

The overall operating ability of the boiler totally depends on combustion efficiency. In theory, an ideal ratio of fuel to air will amplify combustion for a given amount of input, in spite of the fact that since conditions are never impeccable in the real world, a light amount of excess air is important. If there is too low excess air, then not all the combustion will completely be burnt. If much excess air, heat will be lost through flue gas flow. The introduction and installation of a transmitter or oxygen sensor will provide this amount to be optimized and monitored[26].

- Blow Down

Blowdown in the boiler is used for the removal of water from the boiler, and it is noticed that blow down from the boiler is a continuous process. It limits the boiler water parameters to minimize scale, and it helps in removing suspended Solids from the boiler. Nowadays, automatic blowdowns are available in the market and can be installed. It involves continuous monitoring of automatic blowdown orders and conductivity. This automatic blowdown system can save energy and help in the improvement of industrial boiler efficiency[27]. Ambient Temperature

A temperature caused by the operation of the boiler process, which has an impact on the rise in temperature is known as the ambient temperature. The ambient temperature is obsessed with[27] the forced flow fan, which also has an effect on the control of the boiler's efficiency and affects the chimney efficiency. A 40-degree change in temperature can impact the efficiency of the boiler up to 1%[28].

5 Conclusion

Water quality is an essential factor that affects boiler safety and efficiency. The scaling of boilers due to hardness in water, suspended oils, grease, and chemicals is an issue which reduces boiler efficiency. Therefore, the water used in boilers should undergo external and internal treatments. These treatment methods should be a cost-effective and efficient method. Most industries use petroleum and biomass as their energy source. But they have resulted in many adverse effects such as the greenhouse effect, deforestation, climatic change, and environmental pollution. Therefore, Sri Lanka should change into renewable and environmentally friendly energy sources like briquettes from waste, cotton dust, rice husk, rice straw, biodiesel, coconut shells, sawdust, and bagasse to improve sustainability. Both the energy management and heat recovery of the stream systems are essential in business view because they are considering contributing to the optimize the efficiency and overall cost of the system in many ways. Various losses can happen in the boiler system during the whole process. Few solutions can apply for them, such as economizer, pre-heat methods, insulations, blowdown recovery, and condensate water recovery. Also, improving efficiency once can lead to a tremendous positive gain in terms of energy efficiency, resource-saving, cost-saving, and pollution control. These monetary benefits can be gained by using the techniques mentioned earlier. Problems related to fuel and energy should be attended carefully. This will provide sustainability to industries and uplift the economy.

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