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Thermal Efficiency of Cross Section Water Tube Boiler Based on Air Fuel Ratio and Water Level Control

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ABSTRACT

Boiler is a device or tool used to heat water into steam or steam that occurs in a closed vessel. This process is heated by heat energy that comes from burning fuels, such as diesel, gas, and coal. This research aims to analyze the effect of LPG air-fuel ratio and water level on Boiler performance using LPG gas fuel in order to create optimal performance and good thermal efficiency in the Boiler. To create good heat transfer in the Boiler, the Cross Section Double Drum Water Tube Boiler is used by using a double drum that is placed crosswise on the heat source and the position of the tube which is installed with a 65° slope which aims to accelerate the evaporation process of water molecules to produce optimal steam. The variables observed are the fuel air ratio (AFR) and the water level. The optimal LPG fuel air ratio is to achieve efficient combustion and reduce emissions. AFR used in this research are 17, 19, 21, 23 and 25. While the water level affects the heat transfer that occurs in the Steam Drum. The water level used is at the level of 20%, 30%, 40%, 50%, and 60%. From the results of the research that has been done, it is known that AFR and water level are very influential to achieve optimal performance on the efficiency value of the steam drum.

Keywords: *Boiler, LPG, Air Fuel Ratio (AFR), Water Level, Thermal Efficiency.*

1. INTRODUCTION

Energy is a fundamental necessity, integral to all human activities. In the industrial sector, energy is crucial for aiding production processes, from fuel energy to power industrial machinery to electrical energy that helps operate machines and provide lighting during production [1]. The use of boilers in manufacturing industries plays a vital role in optimizing the production process, as boilers generate energy that can be used to transfer heat in the form of thermal energy to a process [2].

Boiler is a device that heats water to produce high-pressure, high-temperature steam, using heat from the combustion of fuel in a combustion chamber [3]. The main components of a boiler include the steam drum and the combustion chamber. The steam drum is where the phase change from liquid to steam occurs, and it also determines the quality of the produced steam. If the steam still contains water, it results in poor steam quality. Another essential component supporting the steam generation process is the combustion chamber. A well-designed combustion chamber can enhance thermal efficiency and reduce CO emissions. To achieve a high reaction heat, the air-to-fuel ratio must be carefully managed, along with the heat generated by hydrodynamic processes.

Previous study conducted by Saputra, Putra, and Manggala (2020) aimed to analyze the effect of varying water levels on thermal efficiency in the production of saturated steam in a Cross Section Water Tube Boiler, a boiler featuring two opposite drums and vertical tubes. This study used gas and diesel fuel with water level variations ranging from 30% to 70%. The results indicated that there were still shortcomings in the equipment, with one of the factors contributing to suboptimal performance being inconsistent flame output and environmental factors, such as excess ambient air, leading to an unstable flame exiting the furnace [4].

The second study, conducted by Ayuni et al. (2021), aimed to analyze the thermal efficiency of a Water Tube Boiler based on the air-to-LPG fuel ratio for producing saturated and superheated steam. The study found that thermal efficiency did not significantly improve because the temperature of the produced saturated steam only increased by 1°C, and the low air-to-fuel ratio resulted in a minimal increase in utilized heat, leading to a low thermal efficiency value [5].

Therefore, in the current research, improvements were made to the Double Drum Cross Section by examining the impact of the LPG gas fuel ratio, based on Water Level Control (AM61-F), on continuous saturated steam production. The solution to this issue involved selecting a Double Drum type arranged crosswise with a tube inclination of 65° to ensure even heat transfer from the fluid in the tube to the steam drum, thereby increasing the amount of generated steam, enhancing Boiler performance, and improving thermal efficiency.

2. MATERIAL AND METHODS

This research investigates the thermal efficiency of cross section double drum water tube boiler effect of LPG fuel air ratio and water level in saturated steam production. The preparation and implementation of the research was carried out for five months, starting in February 2024 and ending in June 2024. The output of this research are various conceptual and empirical scientific data were obtained for the development of future processes in steam production using a boiler.

2.1 Materials

The raw materials used for this experiment are 1,11 L/min of water, 0,1 kg/min of LPG, and 25,43 m/s of air. The equipment used for the study is a unit of Cross Section Double Drum Water Tube Boiler (CSDDWTB), anemometer, thermogun, and gas analyzer.

2.2 Methods

The initial steps for starting the research involve preparing the equipment and materials that will be used. This begins with setting up one unit of the Cross Section Double Drum Water Tube Boiler (CSDDWTB). Then, you prepare the raw materials, including boiler feed water, LPG, and air, which will be used for the combustion process in the furnace. Piping design of cross section water tube boiler can be seen in figure 1.

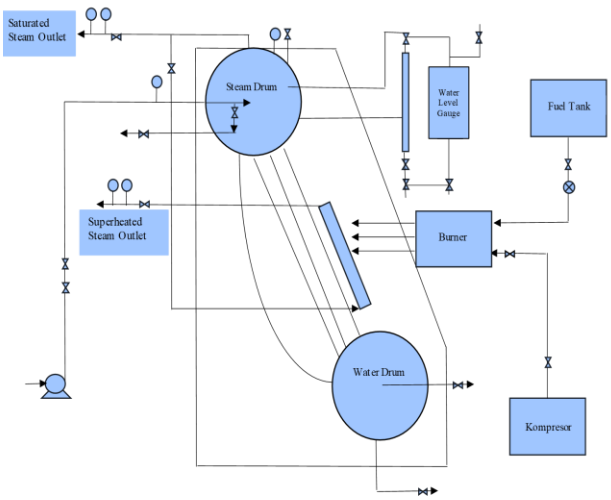

Figure 1. Piping Installation of Cross Section Water Tube Boiler

Following this, the research process will involve preparing a research matrix for the variables to be observed, specifically the Air-Fuel Ratio (AFR) at levels of 17, 19, 21, 23, and 25. Additionally, we observe the variables related to the water level height at 20%, 30%, 40%, 50%, and 60%.

3. RESULTS AND DISCUSSIONS

In this research, we are using a Cross Section Double Drum Water Tube Boiler with Water Level Control to produce saturated steam. The study is conducted over 25 trials according to the established procedure, aiming to address all issues identified in the research background and to scientifically understand the related concepts. When the equipment operates properly and involves constant variables like the air fuel ratio at 17, 19, 21, 23, and 25, water level at 20%, 30%, 40%, 50%, and 60%, the data obtained becomes consistent and stable. At a water level of 50%, optimal operating conditions were observed. At a 60% water level, a near maximum point was reached, where the operating conditions achieved the appropriate temperature and pressure for saturated steam.

3.1 Effect of AFR on Flame Temperature

AFR (Air Fuel Ratio) is a key factor influencing the flame temperature during the combustion process. AFR represents the ratio between the amount of air and fuel burned in this process. In the case of LPG, which consists of propane and butane, maintaining the correct AFR is crucial for achieving efficient combustion and optimal flame temperature. Overall, to attain the optimal flame temperature and maximum combustion efficiency when using LPG, it is essential to keep the AFR close to the stoichiometric ratio. However, in certain specific applications, this ratio might be slightly adjusted to control temperature, emissions, or to meet desired operating conditions.

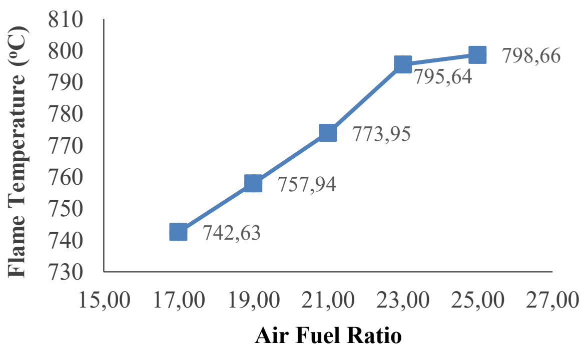

Figure 2. Effect of Air-Fuel Ratio on Flame Temperature

The following chart shows the effect of AFR on flame temperature, as illustrated in Figure 2. The flame temperature in the cross-section water tube boiler increases as the air-fuel ratio (AFR) rises, particularly in the AFR range of 20-25, which directly correlates with thermal efficiency. The optimal AFR for burning LPG in continuous steam production is 23, as it results in a significant temperature increase of 795,64°C. An AFR of 25 is also efficient, ensuring perfect combustion and lower CO emissions. The AFR plays a crucial role in determining thermal efficiency, and while excess air is necessary for complete combustion, too much can decrease flame temperature and reduce thermal efficiency [6].

3.2 Effect of AFR and CO Concentration in Flue Gas

The effect of AFR (Air-Fuel Ratio) and the concentration of CO (carbon monoxide) in flue gas indicates that a higher AFR (more air compared to fuel) tends to result in more complete combustion. This leads to a reduction in CO produced during the combustion process because there is enough oxygen present to convert CO into CO_2. Conversely, a lower AFR (more fuel compared to air) results in incomplete combustion, which can increase the concentration of CO in the flue gas, as there isn't enough oxygen available to convert all the CO into CO_2 [7]. Below is a graph showing the relationship between AFR and CO concentration in flue gas, as illustrated in Figure 3.

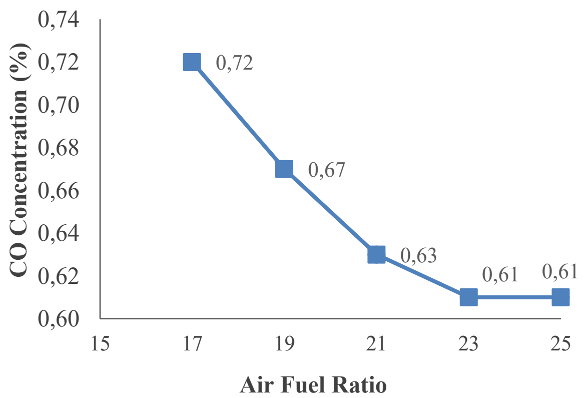

Figure 3. Effect of Air-Fuel Ratio and CO Concentration in Flue Gas

To reduce CO concentration in flue gas, it is essential to control the AFR to meet the optimal combustion process requirements. As shown in Figure 5, CO levels decrease as AFR increases, with a reduction from 0,72% at AFR 17 to 0,61% at AFR 25. This decrease is due to partial combustion of different gas components, which increases CO_2 concentration. Optimal conditions were observed at AFR 23 with a CO concentration of 0,61%. Maintaining AFR close to the stoichiometric ratio is key to minimizing CO emissions, though careful adjustments are needed to avoid combustion instability. Lower-than-stoichiometric AFR should be avoided to prevent incomplete combustion and higher CO levels.

3.3 Effect of AFR and Water Level on Boiler Thermal Efficiency

Boiler thermal efficiency is significantly influenced by two main factors: the air-fuel ratio (AFR) and the water level in the boiler. To achieve optimal thermal efficiency in the boiler, it is crucial to maintain the AFR close to the stoichiometric ratio and the water level at an optimal range. Both of these factors must be carefully managed to ensure efficient combustion and maximum heat transfer, resulting in high thermal efficiency and safe, reliable boiler operation [8]. The graph depicting the relationship between AFR and water level on boiler thermal efficiency is shown in Figure 4.

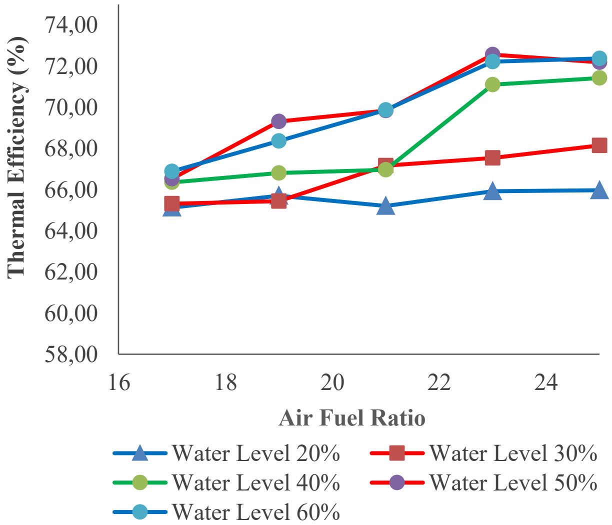

Figure 4. Effect of Air-Fuel Ratio and Water Level on Boiler Thermal Efficiency

The thermal efficiency of the Water Tube Boiler increases with both the air-fuel ratio (AFR) and water level. Efficiency rises steadily from an AFR of 17 to 25, with the optimal efficiency achieved at an AFR of 23 and a 50% water level, yielding a thermal efficiency of 72,56%. Beyond AFR 23, efficiency gains are minimal due to the steam drum filling with water. The study concludes that an AFR of 23 and a 50% water level are ideal for maximizing thermal efficiency in LPG combustion within the Cross Section Double Drum Water Tube Boiler.

3.4 Effect of AFR and Water Level on Q-Loss

The Air-Fuel Ratio (AFR) is the ratio of the mass of air to fuel used in the combustion process of a boiler. The goal of AFR is to achieve complete combustion. To do so, an optimal amount of air is required. Too little air leads to fuel wastage, as not all the fuel burns and turns into energy. On the other hand, too much air causes incomplete combustion because the excess oxygen and nitrogen absorb energy during combustion, and the remaining exhaust gases pass through the stack gas, resulting in wasted energy and a decrease in operating pressure. The thermal efficiency of the Water Tube Boiler increases with both the air-fuel ratio and water level. The higher the air-fuel ratio, the higher the thermal efficiency achieved. Similarly, increasing the water level also results in higher thermal efficiency [9]. Below is a graph showing the relationship between AFR and water level and its impact on Q Loss in Figure 5.

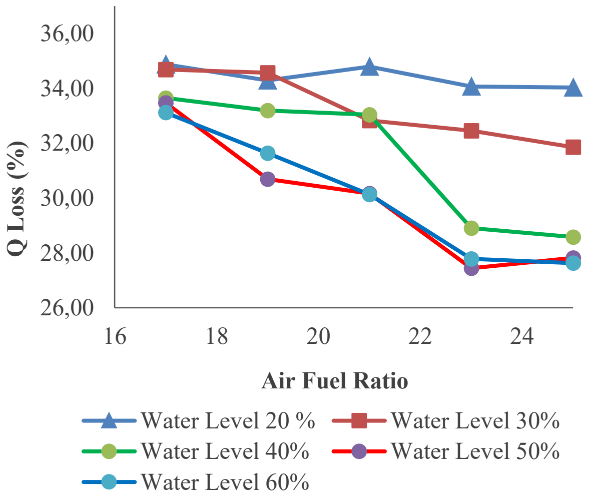

Figure 5. Effect of Air-Fuel Ratio and Water Level on Q Loss (%)

The graph in Figure 5 shows that an increase in the air-fuel ratio significantly affects Q Loss. The most optimal Q Loss, at 34,30%, occurs at a 50% water level with the fourth air-fuel ratio of 23. The air-fuel ratio should neither be too high nor too low. The minimum amount of air required for complete combustion is known as the stoichiometric air amount.

To reduce Q Loss, it's important to maintain an optimal AFR and consider the effect of water level on engine performance. Proper AFR adjustments and advanced engine control technology can help optimize combustion and reduce Q Loss under various operating conditions. Overall, both AFR and water level influence combustion efficiency and the amount of Q Loss in internal combustion engines [10]. Proper adjustments to these factors are crucial for optimizing energy efficiency and reducing thermal losses.

4. CONCLUSIONS

After conducting research on the effect of the LPG air-fuel ratio based on Water Level Control (AM61-F) in a Boiler feed water system with LPG fuel on the boiler's thermal efficiency in saturated steam production, it can be concluded that AFR is a critical parameter for optimal combustion in the Boiler. It ensures that the amount of air and fuel entering the Boiler is balanced for complete combustion. The water level plays a vital role in maintaining the correct water level in the Boiler, with the heating surface area through heat transfer increasing efficiency to produce steam. The optimal operating conditions for continuous saturated steam production using the Cross Section Double Drum Water Tube Boiler are achieved with an air-fuel ratio of 23 and a water level of 50% in the steam drum, resulting in a thermal efficiency of 72,56%.

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