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Analysis Of The Effect Of Excess Air On Boiler Combustion Efficiency At PT PLN Nusantara Power Paiton Unit 9

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Abstract

Boiler combustion efficiency is one of the important factors affecting the performance and operational reliability of steam power plants. One of the parameters that significantly influences combustion efficiency is excess air, which refers to the amount of air supplied exceeding the theoretical combustion requirement. This study aims to analyze the effect of excess air on boiler combustion efficiency at PT PLN Nusantara Power Paiton Unit 9. The research method used is a descriptive quantitative approach through field observations and operational data analysis obtained from the Distributed Control System (DCS). The analyzed parameters include oxygen content (O_2), excess air, boiler load, flue gas temperature, air flow, fuel flow, heat loss, and combustion efficiency. The results show that increasing excess air causes higher heat loss due to the increasing amount of heat carried away by flue gas, resulting in decreased boiler combustion efficiency. At low boiler loads, excess air tends to increase because the combustion process becomes less stable and requires additional air to maintain flame stability. Meanwhile, optimal excess air conditions provide more stable combustion, lower heat loss, and higher combustion efficiency. Therefore, controlling excess air properly is essential to maintain optimal boiler performance, improve operational efficiency, and reduce energy losses in the power generation system.

Keywords: Excess Air, Boiler, Combustion Efficiency, Heat Loss, Steam Power Plant, Flue Gas.

INTRODUCTION

The increasing demand for electrical energy in Indonesia requires power plants to operate reliably, efficiently, and continuously. Steam Power Plants (PLTU) play an important role in supporting the stability of the national electricity supply system because they are capable of producing large-scale electrical energy continuously. One of the main components that greatly affects the performance of a steam power plant is the boiler system. The boiler functions to convert water into high-pressure steam through the fuel combustion process. Therefore, maintaining optimal boiler combustion performance is essential to improve operational efficiency and reduce energy losses. (Basuki, 2019; Tim Training PLTU, 2022).

Boiler combustion efficiency is strongly influenced by the quality of the combustion process occurring inside the furnace. One of the important parameters affecting combustion quality is excess air. Excess air refers to the amount of combustion air supplied exceeding the theoretical air requirement needed for complete combustion. In boiler operation, excess air is required to ensure that all fuel can burn completely. However, excessive excess air can increase heat loss because additional air absorbs heat from the combustion process and carries it away through flue gas. Conversely, insufficient excess air can cause incomplete combustion, resulting in carbon monoxide (CO), soot formation, and unstable combustion conditions. (Basuki, 2019; Tim Training PLTU, 2022).

The amount of excess air significantly affects boiler efficiency because it is directly related to flue gas temperature, heat loss, and combustion stability. High excess air generally increases flue gas volume and heat loss, causing combustion efficiency to decrease. Meanwhile, optimal excess air conditions can produce more stable combustion with minimal energy loss. Therefore, controlling excess air is very important in maintaining efficient boiler operation and ensuring optimal power plant performance. (Fajari, 2024; Setiawan, 2023).

Several operational factors can influence excess air conditions in boiler systems, including boiler load, fuel quality, air flow, fuel flow, and combustion air distribution. At low boiler loads, excess air tends to increase because the combustion process becomes less stable and requires additional air to maintain flame stability. In addition, imbalance between air flow and fuel flow can also cause inefficient combustion conditions. Therefore, monitoring and controlling excess air continuously is necessary to maintain combustion efficiency and minimize operational losses. (Kevan & Sugiyono, 2023; Nugroho, 2022).

Based on these conditions, this study aims to analyze the effect of excess air on boiler combustion efficiency at PT. PLN Nusantara Power Paiton Unit 9. The analysis was conducted using operational data obtained from the boiler combustion system, including oxygen content (O_2), excess air, boiler load, flue gas temperature, air flow, fuel flow, heat loss, and combustion efficiency parameters. The results of this study are expected to provide insight into the relationship between excess air and boiler combustion performance as well as become a reference for improving boiler operational efficiency in steam power plants. (PLN Nusantara Power, 2024; Combustion Engineering Team, 2020).

RESEARCH METHODS

Research Approach

This study employed a descriptive quantitative method to analyze the effect of excess air on boiler combustion efficiency at PT. PLN Nusantara Power Paiton Unit 9. The research was conducted through direct field observations and analysis of operational data obtained from the boiler combustion monitoring system. The descriptive quantitative approach was used to describe the actual operational conditions of the boiler and evaluate the relationship between excess air, heat loss, and combustion efficiency during boiler operation.

The research process began with field observations to understand the operating conditions of the boiler combustion system, including combustion stability, air supply conditions, fuel flow conditions, and boiler operating load. Operational data used in this study were obtained from the Distributed Control System (DCS), which continuously records boiler operating parameters during the power generation process.

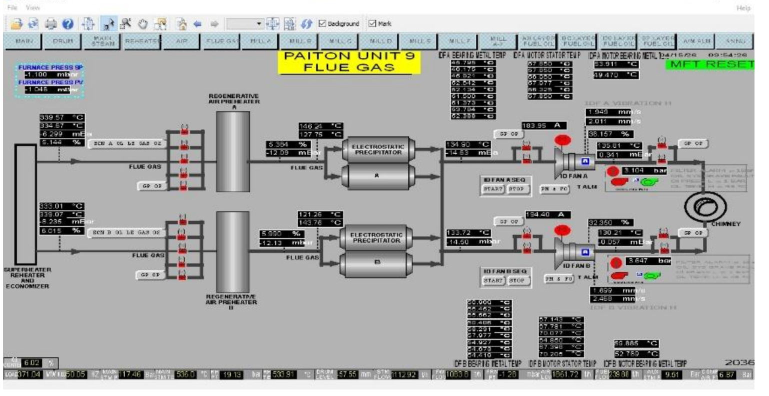

Figure 1 Distributed Control System

Several parameters analyzed in this study include oxygen content (O_2), excess air, boiler load, flue gas temperature, air flow, fuel flow, heat loss, and combustion efficiency. These parameters were selected because they directly influence combustion quality and boiler operational efficiency. The collected data were then analyzed to determine the effect of excess air on combustion efficiency under different operating conditions, particularly during low and high boiler load conditions.

The analysis results were compared with combustion theory and boiler operational principles to evaluate the optimal excess air condition in maintaining stable combustion, minimizing heat loss, and improving boiler combustion efficiency. Through this approach, the study is expected to provide a better understanding of the relationship between excess air and boiler performance in steam power plant systems.

Flow Chart

The research flow chart was used to systematically describe the stages of the study conducted to analyze the effect of excess air on boiler combustion efficiency at PT. PLN Nusantara Power Paiton Unit 9. The research process began with problem identification related to boiler combustion efficiency and excess air conditions during boiler operation. After identifying the problem, a literature study was conducted to understand the theories of boiler combustion, excess air, heat loss, and combustion efficiency.

The next stage involved field observations and operational data collection from the boiler system through the Distributed Control System (DCS). Several operational parameters were collected, including oxygen content (O_2), excess air, boiler load, flue gas temperature, air flow, fuel flow, heat loss, and combustion efficiency. The collected data were then processed and analyzed to determine the relationship between excess air and boiler combustion efficiency under different operating conditions.

After the data analysis process was completed, the results were evaluated to determine the optimal excess air condition for maintaining stable combustion and minimizing heat loss. Finally, conclusions were drawn based on the analysis results to provide recommendations for improving boiler combustion performance and operational efficiency.

Field Observation

Field observations were conducted at the boiler system of PT. PLN Nusantara Power Paiton Unit 9 to understand the actual operating conditions of the combustion process and evaluate the relationship between excess air and boiler combustion efficiency. The observations were carried out while the boiler was operating under normal conditions to obtain representative operational data.

Several operational aspects were monitored, including combustion stability, flame condition, combustion air supply, fuel flow, boiler load, and flue gas conditions. Data were also collected through the Distributed Control System (DCS), covering parameters such as oxygen content (O_2), excess air, air flow, fuel flow, flue gas temperature, heat loss, and combustion efficiency.

The observation results were used as the basis for analyzing the effect of excess air on combustion efficiency. Through these observations, the operational characteristics of the boiler and factors affecting heat loss and combustion performance under different load conditions could be identified.

Operational Data Collection

Operational data used in this study were collected from the Distributed Control System (DCS) at PT. PLN Nusantara Power Paiton Unit 9. Data collection was carried out while the boiler was operating under normal and stable conditions to obtain representative information regarding the combustion process and overall boiler performance.

The collected data included several operational parameters related to combustion efficiency, namely oxygen content (O_2) in the flue gas, excess air percentage, boiler load, flue gas temperature, air flow, fuel flow, heat loss, and combustion efficiency. These parameters were recorded periodically to observe changes in combustion performance under different operating conditions and load variations.

Oxygen content was used as the primary parameter for determining excess air conditions because it indicates the amount of unused oxygen remaining after combustion. In addition, boiler load, flue gas temperature, air flow, and fuel flow data were analyzed to evaluate combustion quality, heat loss, and the balance between air supply and fuel consumption. The collected data were then processed and analyzed to determine the effect of excess air on boiler combustion efficiency and identify optimal combustion operating conditions.

Excess Air Analysis

Excess air analysis was conducted to determine the amount of combustion air supplied exceeding the theoretical air requirement needed for complete combustion in the boiler system. Excess air is an important parameter in evaluating boiler combustion performance because it directly affects combustion stability, heat loss, and boiler combustion efficiency.

In this study, the excess air value was determined based on the oxygen content (O_2) measured in the flue gas. The oxygen content data were obtained from the Distributed Control System (DCS) during boiler operation. The O_2-based method was selected because it is widely used in boiler operational monitoring systems and allows real-time evaluation of combustion conditions.

The excess air calculation used the following equation:

$$Excess\ Air\ (\%) = \frac{O_2}{21 - O_2} \times 100 \quad [1]$$

Where:

- O_2 = Oxygen content in flue gas (%)

The calculation results were then analyzed to determine the relationship between excess air and boiler combustion efficiency. High excess air values indicate that the combustion air supplied to the boiler is greater than the theoretical combustion requirement. This condition can increase flue gas volume and heat loss because additional air absorbs heat from the combustion process and carries it away through the flue gas system.

Conversely, low excess air values indicate insufficient combustion air supply, which may cause incomplete combustion, unstable flame conditions, carbon monoxide (CO) formation, and soot production. Therefore, maintaining optimal excess air conditions is important to ensure stable combustion and improve boiler operational efficiency.

The excess air analysis in this study was also conducted under different boiler load conditions to evaluate the effect of operating load on combustion performance and excess air characteristics in the boiler system.

Combustion Efficiency Analysis

Combustion efficiency analysis was conducted to evaluate the performance of the boiler combustion process based on excess air conditions during operation. Boiler combustion efficiency indicates the effectiveness of converting fuel energy into useful heat energy for steam generation. In this study, the combustion efficiency analysis focused on the relationship between excess air, heat loss, and boiler operating conditions.

The analysis was performed using operational data obtained from the Distributed Control System (DCS), including oxygen content (O_2), boiler load, flue gas temperature, air flow, and fuel flow. These parameters were analyzed to determine how excess air affects heat loss and boiler combustion efficiency during the power generation process.

High excess air conditions generally increase flue gas volume and flue gas temperature because additional combustion air absorbs heat from the furnace and carries it out through the exhaust gas system. This condition increases heat loss and reduces the amount of heat effectively utilized for steam generation. As a result, boiler combustion efficiency decreases when excess air becomes excessively high. Conversely, insufficient excess air conditions can cause incomplete combustion due to limited oxygen supply in the furnace. This condition may result in unstable combustion, formation of carbon monoxide (CO), soot accumulation, and reduced combustion efficiency because not all fuel energy can be converted into heat effectively.

The heat loss value was calculated using the following equation:

$$Heat\ Loss(\%) = \frac{(T_g - T_a)x\ (O_2 + 1)}{100} \quad [2]$$

Where:

- T_g= Flue gas temperature (°C)
- T_a= Ambient temperature (°C)
- O_2= Oxygen content in flue gas (%)

The combustion efficiency value was then determined using the following equation:

$$\eta = 100\% - Heat\ Loss \quad [3]$$

Where:

- Heat Loss = Total heat loss during combustion process (%)

The combustion efficiency analysis was also conducted under different boiler load conditions to evaluate the influence of operating load on combustion performance. At low boiler loads, excess air tends to increase because the combustion process becomes less stable and requires additional air to maintain flame stability. This condition causes higher heat loss and lower combustion efficiency. Meanwhile, at higher boiler loads, combustion conditions become more stable and excess air can be reduced, resulting in lower heat loss and higher combustion efficiency.

The analysis results were used to determine the optimal excess air condition capable of maintaining stable combustion, minimizing heat loss, and improving overall boiler operational efficiency in the steam power plant system.

Data Analysis Techniques

The data analysis technique in this study was carried out to determine the effect of excess air on boiler combustion efficiency at PT. PLN Nusantara Power Paiton Unit 9. The collected operational data were analyzed systematically to evaluate combustion performance under different boiler operating conditions.

The analysis process began by calculating the excess air value based on oxygen content (O_2) data obtained from the Distributed Control System (DCS). The calculated excess air values were then compared with other operational parameters such as boiler load, flue gas temperature, air flow, fuel flow, heat loss, and combustion efficiency to identify the relationship between these variables.

The analysis also focused on the effect of boiler load on excess air conditions and combustion efficiency. Under low boiler load conditions, the combustion process tends to become less stable, causing excess air values to increase. This condition leads to higher heat loss because excessive combustion air absorbs heat from the combustion process and carries it away through the flue gas system. Meanwhile, at higher boiler loads, combustion conditions become more stable, resulting in lower excess air values and improved combustion efficiency.

In addition, heat loss analysis was performed to evaluate the amount of energy lost through flue gas during boiler operation. Higher flue gas temperatures generally indicate larger heat losses and lower combustion efficiency. Therefore, the relationship between excess air and flue gas temperature was analyzed to determine the optimal combustion condition for minimizing energy losses.

The analysis results were then evaluated based on boiler combustion theory and operational principles to determine the optimal excess air condition capable of maintaining stable combustion, minimizing heat loss, and improving boiler operational efficiency. Through this analysis technique, the study provides an understanding of how excess air affects boiler combustion performance in steam power plant systems.

RESULTS AND DISCUSSION

Boiler Operational Data

Operational data collected from the Distributed Control System (DCS) during boiler operation at PT. PLN Nusantara Power Paiton Unit 9 were used to analyze boiler combustion performance. The observed parameters included oxygen content (O_2), flue gas temperature, ambient temperature, heat loss, and combustion efficiency, as presented in Table 1.

Table 1 Data Obtained

No	Time	O_2 (%)	Flue Gas Temp (°C)	Ambient Temp (°C)	Heat Loss (%)	Efficiency (%)
1	12:00:00	5,80	136,49	31,72	7,12	92,88
2	13:00:00	5,84	137,10	31,01	7,26	92,74

3	14:00:00	5,86	137,50	29,67	7,39	92,61
4	12:00:00	5,75	135,80	31,00	7,06	92,94
5	13:00:00	5,91	138,20	30,75	7,42	92,58
6	14:00:00	5,87	137,80	30,47	7,37	92,63
7	12:00:00	6,09	139,50	30,74	7,71	92,29
8	13:00:00	6,20	141,00	30,47	7,96	92,04
9	14:00:00	6,17	140,20	30,46	7,87	92,13
10	12:00:00	5,81	136,90	31,89	7,24	92,76
11	13:00:00	5,88	137,60	31,57	7,35	92,65
12	14:00:00	5,85	137,20	31,13	7,33	92,67
13	12:00:00	5,81	136,90	31,89	7,24	92,76
14	13:00:00	5,88	137,60	31,57	7,35	92,65
15	14:00:00	5,85	137,20	31,13	7,33	92,67
16	12:00:00	5,84	137,10	31,16	7,36	92,64
17	13:00:00	5,84	137,20	30,82	7,37	92,63
18	14:00:00	5,85	137,40	30,71	7,38	92,62
19	12:00:00	5,83	136,90	31,90	7,23	92,77
20	13:00:00	5,83	137,00	31,68	7,25	92,75
21	14:00:00	5,86	137,50	31,43	7,35	92,65

Based on the operational data in Table 1, higher oxygen content (O_2) and flue gas temperature contribute to increased heat loss in the boiler combustion process. This condition causes combustion efficiency to decrease because a portion of the combustion heat is lost through the exhaust gas system. Meanwhile, lower heat loss values result in higher combustion efficiency and more effective fuel utilization.

Heat Loss Calculation

The heat loss calculation was conducted to determine the amount of thermal energy lost through the flue gas during the boiler combustion process. Heat loss is an important parameter in evaluating boiler combustion performance because excessive heat loss reduces the amount of useful heat energy utilized for steam generation.

The heat loss value in this study was calculated using the following equation:

$$Heat\ Loss(\%) = \frac{(\mathrm{T_g} - \mathrm{T_a})\mathrm{x}\ (\mathrm{O_2} + 1)}{100} \qquad [4]$$

Where:

- T_g= Flue gas temperature (°C)
- T_a= Ambient temperature (°C)
- O_2= Oxygen content in flue gas (%)

Example of heat loss calculation:

$$Heat\ Loss(\%) = \frac{(136{,}49 - 31{,}72) \times (5.80 + 1)}{100}$$

$$Heat\ Loss(\%) = 7.12\%$$

Based on the operational data presented in Table 1, the heat loss values ranged from 7.06% to 7.96%. The lowest heat loss occurred at an oxygen content of 5.75% with a flue gas temperature of 135.80°C, while the highest heat loss occurred at an oxygen content of 6.20% with a flue gas temperature of 141.00°C.

The calculation results indicate that increasing oxygen content (O_2) and flue gas temperature contribute to higher heat loss during the combustion process. Higher oxygen content indicates excessive combustion air entering the furnace, causing more thermal energy to be carried away through the flue gas system.

In addition, higher flue gas temperatures also increase thermal energy losses because more heat escapes through the exhaust gas system. This condition reduces the amount of useful heat utilized for steam generation and decreases boiler thermal performance. Therefore, maintaining optimal combustion air conditions is important to minimize heat loss and improve boiler combustion efficiency during operation.

Combustion Efficiency Calculation

Combustion efficiency calculation was conducted to evaluate the effectiveness of converting fuel energy into useful heat energy during the boiler combustion process. Combustion efficiency is strongly influenced by the amount of heat loss occurring during operation. Lower heat loss values produce higher combustion efficiency, while higher heat loss reduces boiler thermal performance.
The combustion efficiency value in this study was calculated using the following equation:

$$\eta = 100\% - Heat\ Loss \qquad [5]$$

Where:

- Heat Loss = Total heat loss during the combustion process (%)
  Example of combustion efficiency calculation:

$$\eta = 100\% - 7.12$$

$$\eta = 92.88\%$$

Based on the operational data presented in Table 1, the combustion efficiency values ranged from 92.04% to 92.94%. The highest combustion efficiency occurred when the heat loss value was lowest, while the lowest combustion efficiency occurred when the heat loss value was highest.

The analysis results indicate that combustion efficiency is inversely proportional to heat loss. Increasing heat loss causes combustion efficiency to decrease because a portion of the combustion heat energy is lost through the flue gas system instead of being utilized for steam generation.

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In addition, higher oxygen content (O_2) and flue gas temperature contribute to increased heat loss, which subsequently reduces combustion efficiency. Excessive combustion air entering the furnace carries more thermal energy through the exhaust gas system, resulting in reduced boiler thermal performance.

Therefore, maintaining optimal combustion air conditions and controlling flue gas temperature are important to minimize heat loss and improve combustion efficiency during boiler operation.

Effect of Excess Air on Heat Loss and Combustion Efficiency

Excess air has a significant influence on boiler combustion performance because it directly affects heat loss and combustion efficiency during operation. Excess air refers to the amount of combustion air supplied exceeding the theoretical air requirement needed for complete combustion inside the furnace.

Based on the operational data analysis presented in Table 1, increasing oxygen content (O_2) indicates higher excess air conditions in the combustion system. Higher excess air increases the amount of flue gas produced during combustion, causing more thermal energy to be carried away through the exhaust gas system.

The analysis results show that higher excess air conditions increase heat loss during boiler operation. This occurs because excessive combustion air absorbs heat energy from the furnace and transfers it to the flue gas system. As a result, a portion of the combustion heat energy is wasted instead of being utilized for steam generation.

In addition, increasing heat loss directly affects combustion efficiency. Higher heat loss values reduce combustion efficiency because less useful heat energy is available for the steam generation process. Conversely, lower excess air conditions reduce heat loss and improve combustion efficiency due to more effective utilization of combustion heat energy.

The operational data also indicate that optimal combustion conditions occur when oxygen content and excess air are maintained within an appropriate operating range. Excessively high excess air causes unnecessary heat loss, while excessively low excess air may result in incomplete combustion, unstable flame conditions, soot formation, and reduced boiler performance.

Therefore, proper control of combustion air supply is important to maintain stable combustion, minimize heat loss, and improve overall boiler combustion efficiency during power plant operation.

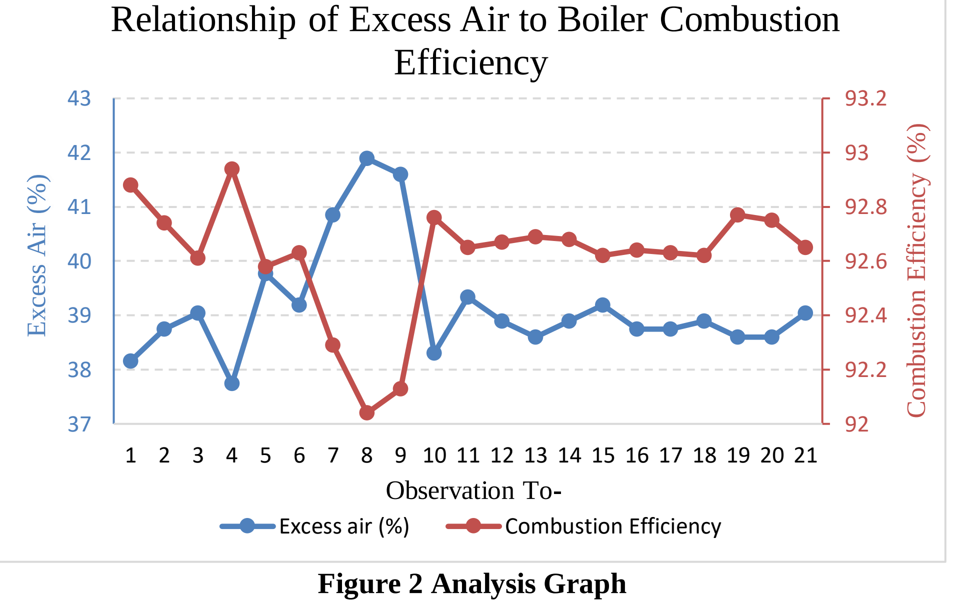

Figure 2 Analysis Graph

The graph illustrates the relationship between Excess Air (%) and Combustion Efficiency (%) based on 21 observations under low unit load conditions. In general, there is a noticeable inverse relationship between the two variables, although it is not very sharp due to the relatively narrow data range.

In the initial observations (data points 1 to 4), the excess air values range from 38.16% to 39.04%, with relatively high combustion efficiency values of approximately 92.61% to 92.94%. The highest efficiency recorded is 92.94%, occurring when the excess air is at its lowest point, 38.16%, indicating an optimal combustion condition.

As the observations progress, particularly when excess air increases toward its maximum value of 41.89%, combustion efficiency decreases to its lowest level of around 92.04%. This is clearly observed when excess air is in the range of 40.85% to 41.89%, where efficiency drops to approximately 92.04%–92.29%. This condition indicates that excessive air leads to increased heat loss.

In the subsequent observations until the end of the dataset, excess air tends to stabilize in the range of 38.3% to 39.34%, while combustion efficiency also remains relatively stable between 92.63% and 92.77%. This suggests the existence of an optimal excess air range of approximately 38% to 39%, where combustion operates more efficiently.

From a technical perspective, this phenomenon can be explained as follows:

- Too low excess air can result in incomplete combustion, potentially producing CO gas and reducing efficiency.
- Too high excess air increases heat loss because the excess air absorbs heat and carries it away with the flue gas.

Therefore, based on the obtained data, it can be concluded that increasing excess air beyond the optimal range of 38% to 39% will reduce combustion efficiency. Hence, controlling the amount of combustion air is crucial to maintaining optimal boiler performance, especially under low load conditions.

Discussion of Optimal Excess Air Conditions

The analysis results indicate that excess air has a significant influence on boiler combustion performance at PT PLN Nusantara Power Paiton Unit 9. Based on operational data and combustion calculations, the optimal combustion condition was achieved when the excess air value was maintained within the range of approximately 38%–39%. Under this condition, the combustion process remained stable while maintaining relatively high combustion efficiency and minimizing heat loss through the flue gas system.

The presence of excess air is necessary in boiler combustion systems because perfect mixing between air and fuel is difficult to achieve under actual operating conditions. Additional air is required to ensure complete combustion and prevent the formation of carbon monoxide (CO), soot, and unburned fuel. However, excessive excess air causes a large amount of unused oxygen and additional gas mass to pass through the furnace and leave the system through the stack. As a result, a portion of the combustion heat is absorbed by the excess air and discharged as flue gas heat loss.

During low boiler load conditions, excess air tended to increase because additional combustion air was needed to maintain flame stability and ensure safe boiler operation. This condition is consistent with combustion theory, where low load operation generally produces less stable air-fuel mixing and requires additional air supply to avoid incomplete combustion. However, the increase in excess air also caused higher flue gas temperatures and greater heat losses, which reduced overall combustion efficiency.

Conversely, under higher boiler load conditions, the combustion process became more stable and the air-fuel mixing improved. In this condition, the required excess air could be reduced while still maintaining complete combustion. As a result, heat loss through the flue gas system decreased and combustion efficiency improved. This shows that maintaining proper control of air flow and fuel flow is essential for achieving optimal boiler performance.

The relationship between excess air and combustion efficiency demonstrates that both insufficient and excessive air supply can negatively affect boiler performance. If the excess air is too low, incomplete combustion may occur, leading to the formation of CO, soot deposition, unstable flame conditions, and lower thermal efficiency. On the other hand, if the excess air is too high, the increased volume of flue gas carries more heat out of the boiler system, resulting in higher heat loss and unnecessary energy consumption.

Therefore, maintaining excess air within the optimal operating range is essential to achieve efficient and stable combustion. Proper monitoring of oxygen content (O_2), air flow, fuel flow, and flue gas temperature through the Distributed Control System (DCS) enables operators to maintain the balance between combustion stability and thermal efficiency. By optimizing excess air control, boiler performance can be improved, operational energy losses can be minimized, and overall power plant efficiency can be enhanced.

Operational Implications for Boiler Performance

The results of this study show that proper excess air control is highly important for maintaining boiler performance and operational efficiency at PT PLN Nusantara Power Paiton Unit 9. Excess air directly affects combustion quality, heat loss, fuel utilization, and the stability of boiler operation. Therefore, maintaining excess air within the optimal range becomes one of the key factors in achieving efficient and reliable power plant operation.

From the operational perspective, excessive excess air increases the amount of flue gas flowing through the boiler system. This condition causes more thermal energy to be carried away through the stack, resulting in higher heat loss and lower combustion efficiency. In addition, larger flue gas volumes increase the workload of equipment such as the Induced Draft Fan (ID Fan), which leads to higher auxiliary power consumption. Consequently, excessive excess air not only reduces thermal efficiency but also increases operational energy usage.

On the other hand, insufficient excess air may cause incomplete combustion due to inadequate oxygen supply. This condition can result in the formation of carbon monoxide (CO), soot, and unburned fuel particles. The accumulation of soot and ash deposits on heat transfer surfaces may reduce heat transfer effectiveness and potentially cause fouling problems inside the boiler. If this condition continues for a long period, boiler reliability and operational safety may also be affected.

The study also indicates that boiler load significantly influences excess air conditions and combustion stability. During low-load operation, operators tend to maintain higher excess air to stabilize the flame and prevent combustion disturbances. However, under high-load operation, the combustion process becomes more stable and efficient, allowing the excess air value to be reduced while still maintaining complete combustion. This demonstrates the importance of adaptive combustion control based on operating load conditions.

In practical operation, monitoring combustion parameters through the Distributed Control System (DCS) plays a critical role in maintaining optimal combustion conditions. Parameters such as oxygen content (O_2), air flow, fuel flow, and flue gas temperature must be continuously monitored to ensure the balance between combustion stability and efficiency. Proper calibration of combustion instruments and oxygen analyzers is also necessary to maintain accurate operational data and reliable control performance.

Overall, optimizing excess air control provides several operational benefits, including improved combustion efficiency, reduced heat loss, lower fuel consumption, minimized pollutant formation, and enhanced boiler reliability. Therefore, effective excess air management is essential for supporting efficient, stable, and sustainable boiler operation in steam power plants.

CONCLUSIONS

Based on the analysis conducted on the boiler combustion system at PT PLN Nusantara Power Paiton Unit 9, excess air has a significant effect on combustion efficiency and overall boiler performance. The operational data indicate that increasing excess air causes higher heat loss due to the greater amount of thermal energy carried away through the flue gas system. As a result, boiler combustion efficiency decreases because part of the generated heat cannot be effectively utilized for steam generation.

The study results show that maintaining excess air within the optimal range of approximately 38%–39% provides more stable combustion conditions and relatively higher combustion efficiency. Under this condition, the combustion process can operate safely and efficiently while minimizing heat loss. Excess air values above this range tend to increase flue gas temperature and heat loss, whereas excessively low excess air may lead to incomplete combustion, soot formation, unstable flame conditions, and lower combustion quality.

The analysis also demonstrates that boiler load significantly influences excess air conditions and combustion stability. During low-load operation, excess air tends to increase to maintain flame stability and ensure safe combustion. Conversely, higher boiler loads generally produce more stable combustion conditions with lower excess air requirements, resulting in improved efficiency and reduced energy loss.

In addition, the study confirms that proper control of air flow and fuel flow is essential to maintain the balance between combustion stability and thermal efficiency. Continuous monitoring of oxygen content (O_2), flue gas temperature, air flow, and fuel flow through the Distributed Control System (DCS) enables operators to maintain optimal combustion performance and minimize operational losses.

Overall, effective excess air management plays an important role in improving boiler efficiency, reducing heat loss, minimizing fuel consumption, and maintaining reliable boiler operation. Therefore, optimizing excess air control is essential for supporting efficient, stable, and sustainable operation of steam power plants.

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