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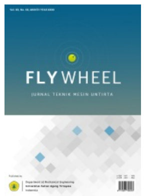

# Boiler Efficiency Analysis with Indirect Method PT. Indonesia Power UBP PLTU Lontar Unit 2

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## ABSTRACT

Boiler efficiency is one of the important factors in determining the performance and environmental sustainability of PLTU. This study aims to analyze the factors that cause a decrease in boiler efficiency unit 2 PLTU Lontar. This study uses the indirect method (heat losses), it is found that the efficiency is 81.05%, and several large heat losses are found, namely L2: losses due to moisture content in coal of 5.01%, L3: losses due to hydrogen content in coal of 6.92% and comparison of heat losses data of PLTU Lontar boiler in 2015 and 2024. The analysis shows that the efficiency of the Lontar PLTU boiler has decreased from 82.96% in 2015 to 81.05% in 2024. This decrease is caused by several factors, namely: Increase in L3 (loss due to hydrogen content in coal) and L5 (loss due to unburned carbon). Decrease in L9 (loss due to sensible heat in fly ash). Decrease in coal quality. Efforts to improve boiler efficiency need to be made, such as, maintaining coal quality is very important to maintain boiler efficiency, and conducting regular boiler maintenance. The implementation of these measures is expected to improve the boiler efficiency of PLTU Lontar, reduce pollutant emissions, and improve environmental sustainability.

**Keywords:** *Heat losses, boiler, efficiency, PLTU Lontar, coal*

## 1. INTRODUCTION

Boiler operating efficiency is of paramount importance in the power generation industry. This efficiency has a direct effect on productivity and environmental impact[1]. This research focuses on analyzing the boiler efficiency in Lontar Unit 2 PLTU owned by PT Indonesia Power UBP using indirect methods.

The indirect method, which is a common approach to boiler efficiency assessment, allows for quick and effective measurements using available data[2]. The significance of this study lies in providing insight into the factors affecting efficiency and the variables that can be optimized, thus enabling a comprehensive performance evaluation.

In addition, the study goes beyond simply calculating efficiency, but also assesses the viability of the boiler based on long-term operation. This holistic approach ensures sustainable and efficient boiler operation[3].

This research introduces a method of calculating heat losses based on ASME PTC 4.2013, a new approach to heat losses calculation. This method is in line with energy audit regulations, which emphasize efficiency and environmental impact [4].

The expected outcomes of this research include improved industry understanding of boiler efficiency using an indirect approach, comprehensive insights for PT Indonesia Power UBP PLTU Lontar Unit 2 in optimizing operations, practical recommendations for the company to improve boiler efficiency and performance, valuable scientific contributions to energy efficiency and PLTU operational efficiency, as well as a positive impact on the operational efficiency and sustainability of PT Indonesia Power UBP PLTU

Lontar Unit 2 and the power generation industry as a whole.

Although this research focuses on boiler technical efficiency and optimization, rather than on economic analysis, it lays the foundation for further research on the economic aspects of boiler operation. The contribution of the research to improved technical performance and reduced environmental impact is significant, paving the way for a more sustainable and efficient power generation industry.

## 2. METHODOLOGY

Data collection for this thesis was conducted using several methods, including:

(1) Literature Review

This method was employed to gather theories and formulas related to combustion performance in boilers. The results from this method were obtained from manuals, articles, journals, and other documents.

(2) Numerical Data Processing

Primary data and data obtained from the literature review were processed numerically using formulas derived from the literature. Ten types of boiler losses were analyzed using the formula (1)[4].

$$h(\%) = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9 + L_{10}) \quad (1)$$

where:

| | | |
|---|---|---|
| L1 | : | Dry flue gas loss (%) |
| L2 | : | Moisture loss in fuel (%) |
| L3 | : | Hydrogen content loss in fuel (%) |
| L4 | : | Loss due to moisture content in supply air (%) |
| L5 | : | Loss due to unburned carbon (%) |
| L6 | : | Radiation and convection losses of the boiler (value predetermined) |
| L7 | : | Unmeasured loss (value predetermined by the manufacturer) |
| L8 | : | Loss due to sensible heat in bottom ash (%) |
| L9 | : | Loss due to sensible heat in fly ash (%) |
| L10 | : | Loss due to carbon monoxide formation from incomplete combustion (%) |

(3) Consultation

Consultations were conducted to obtain more in-depth information related to the research. These consultations were carried out through discussions or interviews with operators, employees, supervisors, and experts in the field.

The data analysis method used in this research involved collecting flue gas test data from the Air Pre-Heater (APH), selecting relevant data for boiler efficiency calculations in unit Y, performing calculations using the specified ASME PTC 4-2013, and carefully calculating to minimize errors[4]. The final stage of data processing involved analyzing the obtained results to confirm their accuracy, then comparing them with related journals that conducted research on similar boilers to identify factors related to the research object.

### Direct Method

Efficiency serves as a benchmark for a machine's performance. For a steam boiler engine, efficiency is defined as the comparison between the output energy (the steam produced) and the input energy (the fuel consumed). This is often called the direct or input-output method, as the efficiency value is calculated by dividing the energy output by the heat input[5].

With:

| | | |
|---|---|---|
| mMS | : | mass main steam (t/h) |
| hMS | : | enthalpy of main steam (kCal/kg) |
| mFW | : | feedwater mass flow rate (t/h) |
| hFW | : | feedwater enthalpy (kCal/kg) |
| mSHS | : | mass flow rate of spray superheater (t/h) |
| hSHS | : | enthalpy of spray superheater (kCal/kg) |
| mf | : | mass flow rate of fuel (t/h) |
| HHV | : | High Heating Value of fuel (kCal/kg) |

The direct method is a suitable choice for quick and easy boiler efficiency calculations. Its advantages lie in the fewer parameters required and the ease of measurement. However, the weakness of this method is its inability to detail each heat loss occurring in the boiler. In addition, the accuracy of the mass flow rate and fuel calorific value measuring instruments significantly affects the accuracy of boiler efficiency calculations. For example, if the actual boiler efficiency is 90% but there is a 1% measurement error, the obtained efficiency value will be 90% ± 0.9%, which is between 89.1% and 90.9%.

### Indirect Method

The indirect method provides a more in-depth understanding of the overall boiler performance. By knowing the value of each heat loss, operators can understand how factors such as fuel quality, operating conditions, and boiler design affect efficiency[6].

The process of calculating efficiency using the indirect method is as follows:

1. The first step is to calculate various heat losses occurring in the boiler, such as heat loss with flue gas, heat loss due to radiation, and heat loss due to leaks.

2. All values of individual heat losses are then summed up to obtain the total heat loss of the entire boiler.
3. Finally, boiler efficiency is obtained by subtracting the total heat loss from 100%.

The direct and indirect methods are two main approaches to calculating boiler efficiency. Each method has its own advantages and disadvantages. The direct method offers simplicity and ease of calculation. This method only requires a few parameters and can be done quickly. However, this method has limitations in terms of detail and accuracy. This method cannot determine the magnitude of each heat loss occurring in the boiler, and its accuracy depends on the accuracy of the measuring instruments[7].

On the other hand, the indirect method provides more complete information about boiler performance. This method allows for knowing the material and energy balance in each part of the boiler, thus helping to identify areas that can be improved to increase efficiency[8]. However, this method requires a long time and laboratory facilities for the analysis of fuel and flue gas samples.

The weakness of the direct method can be overcome by the indirect method, which calculates various heat losses in the boiler [9]. Efficiency can be obtained by subtracting the total heat loss from 100%. A significant advantage of this method is the minimal influence of measurement errors on efficiency calculations[10]. This is because the calculated heat loss is a small part of the entire boiler system. For example, if the boiler heat loss value is 10% and the indirect method has an error of 1%, then the actual boiler heat loss becomes 10% ± 0.1% = 9.9% to 10.1%. This means that the boiler efficiency is between 89.9% and 90.1%.

The heat loss method is also known as the indirect method. ASME PTC-4 has issued a standard for calculating boiler efficiency using the heat loss method, with the latest revision in 2013[4]. The calculation of heat losses is shown by equations (2)-(7).

**Loss due to dry flue gas ($L_1$)**

$$L_1 = \frac{HDFgLvCr\ x\ MFrDFg}{HHV}\ x\ 100\% \quad (2)$$

Where:

| | | |
|---|---|---|
| HDFgLvCr | : | enthalpy of dry flue gas leaving the air preheater (excluding air leakage in the air preheater) (kJ/kg) |
| MFrDFg | : | mass of dry flue gas leaving the boiler (kg/kg-fuel) |
| HHV | : | High Heating Value of coal (kJ/kg-fuel) |

**Loss due to moisture content in coal ($L_2$)**

$$L_2 = \frac{MFrWF\ x\ (HstLvCr - Hw)}{HHV}\ x\ 100\% \quad (3)$$

Where:

| | | |
|---|---|---|
| MFrWF | : | moisture content in fuel (kg/kg-fuel) |
| HstLvCr | : | enthalpy of steam (evaporation of water) leaving the air preheater (excluding air leakage in the air preheater) at 1 psia (kJ/kg) |
| HW | : | enthalpy of water at reference air temperature of 33°C (kJ/kg) |

**Loss due hidrogen content in coal ($L_3$)**

$$L_3(\%) = \frac{MfrWH2F\ x\ (HstLvCr - Hw)}{HHV}\ x\ 100 \quad (4)$$

Where:

| | | |
|---|---|---|
| MFrWF | : | moisture content in fuel (kg/kg-fuel) |
| HstLvCr | : | enthalpy of steam (evaporation of water) leaving the air preheater (excluding air leakage in the air preheater) at 1 psia (kJ/kg) |
| HW | : | enthalpy of water at reference air temperature of 33°C (kJ/kg) |

**Loss due moinsture content in air supply ($L_4$)**

$$L_4(\%) = \frac{MfrWH2F\ x\ (HstLvCr - Hw)}{HHV}\ x\ 100 \quad (5)$$

Where:

| | | |
|---|---|---|
| MFrWA | : | moisture content in air supply (kg/kg-fuel) |
| HWvLvCr | : | enthalpy of steam leaving the air preheater with no air leakage (kJ/kg) |

**Loss due unburn carbon content in coal ($L_5$)**

$$L_5(\%) = MpUbC\ x\ \frac{HHVCRs}{HHV}\ x\ 100 \quad (6)$$

Where:

| | | |
|---|---|---|
| MpUbC | : | unburn content in coal, % mass |
| HHVCRs | : | heating value of carbon residue 33.700 kJ/kg |

**Losses due to radiation and convection** from the boiler wall surface, the value of which is specified by the boiler manufacturer (%).

**Unaccounted losses**, the value of which is specified by the boiler manufacturer (%).

**Losses due to sensible heat in bottom ash ($L_8$)**

$$L_8(\%) = \frac{xUcb\ x\ MFrR\ x\ Hcba}{HHV}\ x\ 100 \quad (7)$$

Where:

| | | |
|---|---|---|
| xUcb | : | losses due to sensible heat in bottom ash |
| MFrR | : | mass of ash residue from combustion (kg/kg-fuel) |
| Hcba | : | entalpi bottom ash (kJ/kg) |

**Losses due to sensible heat in fly ash ($L_9$)**

$$L_9(\%) = \frac{xUcf\ x\ MFrR\ x\ Hcfa}{HHV}\ x\ 100 \quad (8)$$

Where:

| | | |
|---|---|---|
| xUcf | : | ratio of fly ash to total ash |
| MFrR | : | mass of residual ash from combustion (kg/kg-fuel) |
| Hcfa | : | enthalpy of fly ash (kJ/kg) |

**Losses due to carbon monoxide formation from incomplete combustion ($L_{10}$)**

$$L_{10}(\%) = \frac{23630\ kJ\ x\ DVpCO\ x \frac{MpCb}{(DVpCO+DVpCO_2)}}{HHV}\ x\ 100 \quad (9)$$

Where:

| | | |
|---|---|---|
| MpCb | : | carbon burned (%) |
| DVpCO | : | CO concentration in flue gas at air preheater outlet (%) |
| $DVpCO_2$ | : | $CO_2$ concentration in flue gas at air preheater outlet (%) |

## 3. RESULTS AND DISCUSSION

Boiler performance data is crucial in evaluating the efficiency and operational performance of a boiler in a power plant. Analysis of this data provides a clear picture of how the boiler operates, including combustion efficiency, fuel consumption, and overall system performance. By understanding boiler performance data, companies can identify areas for improvement to enhance operational efficiency and reduce environmental impact.

This sub-chapter provides a comprehensive overview of boiler performance data at Boiler Unit 2 of PT. Banten 3 Lontar POMU and an in-depth analysis of its implications for overall power plant operations. Boiler performance data for February 2024 at 100% load.

**Table 1.** Numerical calculation results using the transfer matrix method

| No | Boiler performance | Unit | Value |
|---|---|---|---|
| 1 | $CO_2$ Content | % | 12.87 |
| 2 | $O_2$ Content | % | 3.64 |
| 3 | Flue Gas temprature | °C | 160.19 |
| 4 | Ambient Temperature | °C | 30 |
| 5 | Air Moisture | kg/kg | 0.02 |
| 6 | Radiation Loses | % | 2.5 |
| 7 | Fuel Higher heating Value | kcal/kg | 4,223.51 |

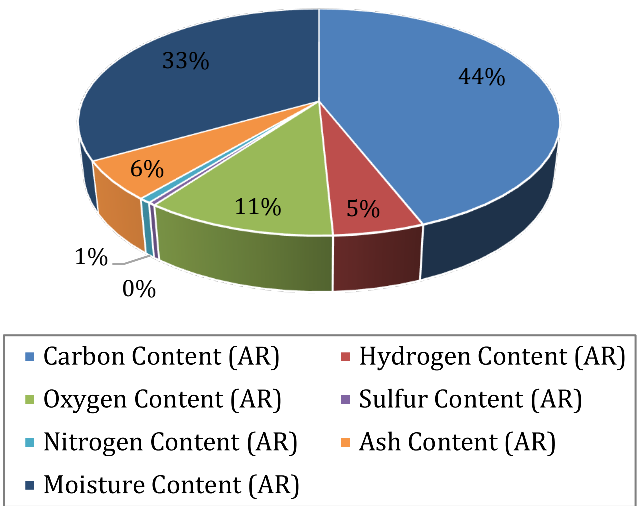


**Figure 1.** Chart content

Primary and secondary data from the literature review were numerically processed using the formulas derived from the literature. This study only analyzed 10 types of losses in boilers. The calculation of boiler efficiency with heat loss used the following equation.

$$\eta(\%) = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9 + L_{10})$$

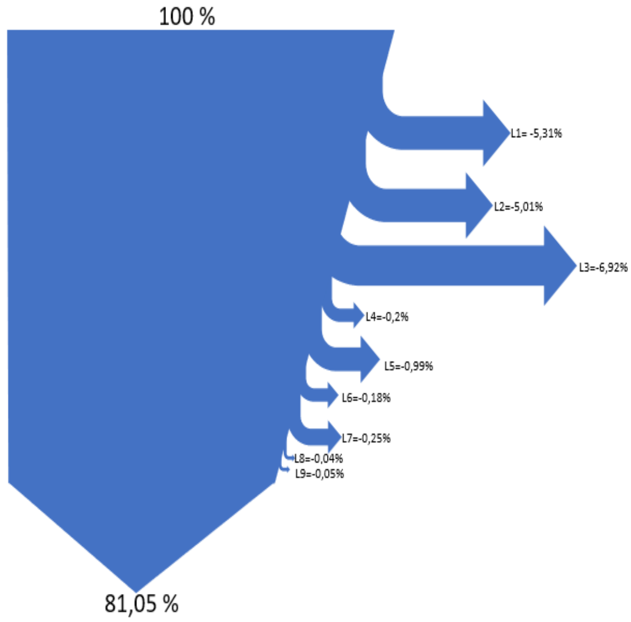


**Figure 2.** Loses diagram

Analysis of Boiler Efficiency Calculation Results, Unit 2, PT Indonesia Power UBP Banten 3 Lontar. Based on the provided data, the following is an analysis of the calculated efficiency of Boiler Unit 2, PT Indonesia Power UBP Banten 3 Lontar:

**Heat Losses**

- Dry gas loss (L1): 5.31%
- Moisture in coal loss (L2): 5.01%
- Hydrogen in coal loss (L3): 6.92%

- Moisture in combustion air loss (L4): 0.20%
- Unburned carbon loss (L5): 0.99%
- Radiation and convection losses from boiler wall surface (L6): 0.18% (manufacturer's specified)
- Unaccounted losses (L7): 0.25% (manufacturer's specified)
- Sensible heat loss of bottom ash (L8): 0.04%
- Sensible heat loss of fly ash (L9): 0.05%
- CO loss (L10): 0.00%

**Total Losses**

Total heat loss in Boiler Unit 2, PT Indonesia Power UBP Banten 3 Lontar is: $L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9 + L_{10}$ = 18.95%

**Boiler Efficiency**

Boiler efficiency can be calculated using the formula: Efficiency (%) = 100% - Total Losses (%). Therefore, the efficiency of Boiler Unit 2, PT Indonesia Power UBP Banten 3 Lontar is (100%-18.95%) = 81.05%

Based on the analysis above, it can be concluded that the efficiency of Boiler Unit 2, PT Indonesia Power UBP Banten 3 Lontar is 81.05%. This value is considered good and indicates that the boiler is operating quite efficiently. However, it should be noted that there is still 18.95% of energy lost as heat. This suggests that there is still potential to improve boiler efficiency by optimizing several aspects, such as:

- Reducing dry gas loss (L1): This can be done by improving coal quality or using more advanced combustion technology.
- Reducing moisture in coal loss (L2): This can be done by drying the coal before use.
- Reducing hydrogen in coal loss (L3): This can be done by selecting coal types with lower hydrogen content.
- Reducing moisture in combustion air loss (L4): This can be done by using a dehumidifier to reduce moisture in the combustion air.
- Reducing unburned carbon loss (L5): This can be done by improving combustion quality or using more advanced combustion technology.

By optimizing these aspects, it is expected that the efficiency of Boiler Unit 2, PT Indonesia Power UBP Banten 3 Lontar can be improved, thus saving energy and operating costs.

A comparative analysis of boiler efficiency at Unit 2 of PT. Indonesia Power UBP PLTU Lontar is presented, encompassing the initial design, a 2015 journal study on Unit 3, and a recent evaluation in February 2022. The primary goal is to discern efficiency trends over time and pinpoint the underlying causes. Insights from this study will serve as a roadmap for optimizing boiler performance and efficiency in future operations. Detailed efficiency data and influencing parameters will be provided.

**Table 2.** Numerical calculation results using the transfer matrix method

| Boiler model | DG1025/17.4-II13 | | |
|---|---|---|---|
| Manufactur | Dong Fang Boiler Group Co.Ltd | | |
| | Parameter | BMCR operating condition | BRL operation condition |
| Superheated steam | Max. Continuous Evaporation (t/h) | 1025 | 976.2 |
| | Outlet Pressure (MPa) | 17.4 | 17.32 |
| | Outlet Temperature (°C) | 541 | 541 |
| Reheated steam | Flow (t/h) | 839.4 | 802 |
| | Inlet/Outlet Pressure (MPa) | 3.76/3.58 | 3.59/3.41 |
| | Inlet/Outlet Temperature (°C) | 329/541 | 324/541 |
| | Flue Gas Temperature of Corrected (°C) | 131 | 131 |
| | Feedwater Temperature (°C) | 281 | 278 |
| | Drum Pressure (MPa) | 18.77 | 18.77 |
| | Design Efficiency (%) | 93.26 | 93.71 |

The Figure 3 illustrates the trend of boiler efficiency at PLTU Lontar from its initial operation in 2011 (93.26%) to 2015 (82.96%) and 2024 (81.05%). The analysis reveals a significant disparity between the design efficiency and the actual performance in subsequent years. To understand the factors contributing to the decline in efficiency between 2015 and 2024 and to devise strategies for maintaining optimal efficiency, a heat loss analysis will be conducted.

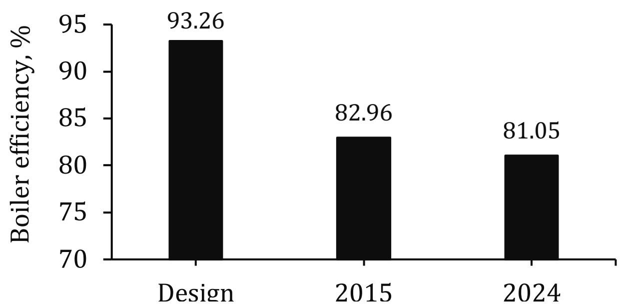


**Figure 3.** Comparison eficiency chart

**Table 3.** Comparison boiler heat losses

| Parameter | Unit | 2015 | 2024 |
|---|---|---|---|
| L1: Flue gas loss | % | 6.13 | 5.31 |
| L2: Moisture loss in coal | % | 4.92 | 5.01 |
| L3: Hydrogen loss in coal | % | 4.98 | 6.92 |

| Parameter | Unit | 2015 | 2024 |
|---|---|---|---|
| L4: Moisture loss in combustion air | % | 0.32 | 0.2 |
| L5: Carbon in refuse loss | % | 0 | 0.99 |
| L6: Radiation and convection losses (manufacturer's specified) | % | 0.18 | 0.18 |
| L7: Unaccounted losses (manufacturer's specified) | % | 0.25 | 0.25 |
| L8: Sensible heat loss in bottom ash | % | 0.04 | 0.04 |
| L9: Sensible heat loss in fly ash | % | 0.55 | 0.05 |
| L10: Carbon monoxide loss | % | 0 | 0 |
| Boiler Efficiency | % | 82.67 | 81.05 |

Based on the data presented in the Table 3, there were several changes in boiler heat losses between 2015 and 2024. The following is a comparative analysis:

**Decrease in Heat Losses**

- L1 (losses due to dry gas): decreased from 6.13 to 5.31%. This indicates more complete combustion and better heat transfer efficiency in 2024.
- L4 (losses due to moisture content in combustion air): decreased from 0.32 to 0.20%. This indicates drier combustion air and more efficient combustion in 2024.
- L6 (losses due to radiation and convection from the boiler wall surface): A constant value of 0.18% indicates that this factor does not affect the overall change in heat losses.
- L7 (unmeasured losses): A constant value of 0.25% indicates that this factor does not affect overall changes in heat losses.
- L8 (losses due to sensible heat in bottom ash): A constant value of 0.04% indicates that this factor does not affect overall changes in heat losses.
- L9 (losses due to sensible heat in fly ash): Significantly decreased from 0.55% to 0.05%. This indicates better fly ash processing and higher combustion efficiency in 2024.
- L10 (losses due to carbon monoxide formation caused by incomplete combustion): A constant value of 0.00% indicates that complete combustion was achieved in both years.

**Increased Heat Losses**

- L2 (losses due to moisture content in coal): increased slightly from 4.92% to 5.01%. This may be due to variations in the moisture content of the coal used in 2024.
- L3 (losses due to hydrogen content in coal): increased significantly from 4.98% to 6.92%. This may be due to changes in the composition of coal used in 2024.
- L5 (losses due to unburned carbon): increased significantly from 0.0% to 0.99%. This indicates incomplete combustion in 2024, which could be caused by several factors such as suboptimal burner settings, low coal quality, or suboptimal boiler operating conditions.

Based on the increase in heat losses above, the researchers attempted to compare the coal composition used at the two different times. After comparing the coal composition, it was proven that the decrease in efficiency in 2024 was largely due to the decline in coal quality, as indicated by the coal composition used in 2024. In 2024, the water and hydrogen content in the coal was higher compared to the coal composition in 2015. Additionally, the unburned carbon loss indicates low coal quality, as shown in the Table 4.

**Table 4**. Compare coal content in boiler

| No | Coal content | Unit | 2015 | 2024 |
|---|---|---|---|---|
| 1 | Carbon Content (AR) | % | 46.20 | 44.19 |
| 2 | Hydrogen Content (AR) | % | 3.59 | 5.16 |
| 3 | Oxygen Content (AR) | % | 12.64 | 10.85 |
| 4 | Sulfur Content (AR) | % | 0.46 | 0.42 |
| 5 | Nitrogen Content (AR) | % | 0.70 | 0.69 |
| 6 | Ash Content (AR) | % | 3.71 | 5.56 |
| 7 | Moisture Content (AR) | % | 32.70 | 33.38 |
| 8 | HHV of Coal | kCal/kg | 4,547 | 4,223.51 |

## 4. CONCLUSION

A comparative analysis of the boiler efficiency of Unit 2 at PT. Indonesia Power Banten 3 Lontar revealed a decline from the initial design efficiency to the efficiency achieved in 2024. A further comparison with a similar boiler in 2015 showed a similar trend. To investigate the root causes of this efficiency degradation, a detailed analysis of coal quality was performed. The results indicated that the deterioration in coal quality, specifically the higher moisture and hydrogen content in the coal used in 2024, was a major contributing factor.

To mitigate this issue and improve boiler efficiency, several strategies can be adopted, including:

1) Utilizing higher quality coal with lower moisture and ash content and higher carbon content.
2) Implementing a rigorous maintenance program for the boiler system, focusing on the heating, combustion, and heat removal systems.
3) Adopting advanced technologies and more efficient fuels to enhance boiler performance.

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