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## Analysis Efficiency Calculation on Boiler Using Direct (Input-Output) Method in Petrochemical Industry

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### Abstract

The industrial world, particularly the petrochemical industry, is currently experiencing significant growth and advancement. With this rapid development, companies need to pay close attention to the equipment used in the production process, one of which is the boiler. Boiler is one of the main components in the petrochemical plant, as it serves as the equipment responsible for generating steam. Over time, the boiler's performance will naturally decline due to continuous operation. Therefore, it is necessary to apply a method to evaluate the boiler's performance. The performance of a boiler is represented by its efficiency value. This value is essential to determine how effectively the boiler produces steam. The higher the efficiency, the better the boiler's performance. The boiler at the petrochemical plant under study is of the fire tube type. The boiler efficiency analysis in this study was carried out using the input-output method, also known as the direct method. The analysis was performed by comparing the energy obtained from the working fluid (water and steam) with the energy contained in the boiler fuel, represented by the Gross Calorific Value (GCV). Based on the analysis, the highest boiler efficiency was obtained on August 11, 2025, at 65.326858%, due to the high steam temperature of 224.0875°C. Meanwhile, the lowest efficiency was recorded on August 8, 2025, at 45.810117%, which occurred because the boiler had just restarted after a seven-day shutdown.

**Keywords :** Boiler, Efficiency, Direct (Input-Output), Industry Petrochemical

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## INTRODUCTION

The industrial world, particularly the petrochemical industry, is currently experiencing significant growth and advancement. With this rapid development, companies need to pay close attention to the equipment used in the production process, one of which is the boiler. The boiler plays an important role as it produces steam, which is the main output.

A boiler can be defined as a closed steam generator in which the process of converting water into hot steam takes place. The hot steam produced is then pressurized and utilized for various industrial processes. The steam boiler system consists of several parts: the fuel system, the steam system, and the feed water system. The fuel system includes all the components required to heat the boiler, and the type of equipment depends on the fuel being used. The feed water system supplies the necessary water into the boiler drum. The steam system collects the required steam and controls it according to production needs, while also regulating steam pressure as needed for operations (Camaraza-medina et al., 2021). Given the importance of the boiler's role, any problems that arise should be avoided as much as possible. If issues occur within the boiler system, the flow of steam will be disrupted, leading to a decline in plant production. To overcome this, regular maintenance must be carried out by performing periodic efficiency evaluations on the boiler (Bartnicki et al., 2021).

Boiler efficiency is a measure that indicates the relationship between the energy supplied into the boiler and the output energy produced by the boiler. Boiler combustion efficiency generally describes the capability of a burner to completely burn all the fuel that enters the boiler furnace. Boiler efficiency is calculated based on the amount of unburned fuel together with the amount of excess air from combustion (Purseth et al., 2021). Boiler combustion can be considered efficient if no fuel remains at the furnace outlet and if the amount of excess air is minimized.

Over time, a boiler will experience a decline in efficiency. This decrease in efficiency will affect both the performance of the equipment and the production output. Therefore, a method is needed to evaluate boiler performance. One such method is the input-output method, commonly known as the direct method. The boiler efficiency value is required to determine the performance of the boiler in producing steam. From the efficiency value obtained, a performance analysis of the boiler system can be carried out to improve its operation. In addition, routine maintenance can also be performed to prevent a drastic decline in boiler performance.

## RESEARCH METHODS

### Study Analysis on Boiler

A boiler is an instrument used to produce steam. Boilers can be classified into several types based on the type of fuel used, the flow of hot air and water, or their operating method. Based on the fuel, the most commonly used boilers in industry are oil-fired boilers and coal-fired boilers. Boilers that use coal as their fuel are commonly referred to as CFB (Coal Fired Boilers). Meanwhile, based on the flow of hot air and water, there are two types of boilers: fire tube boilers and water tube boilers.

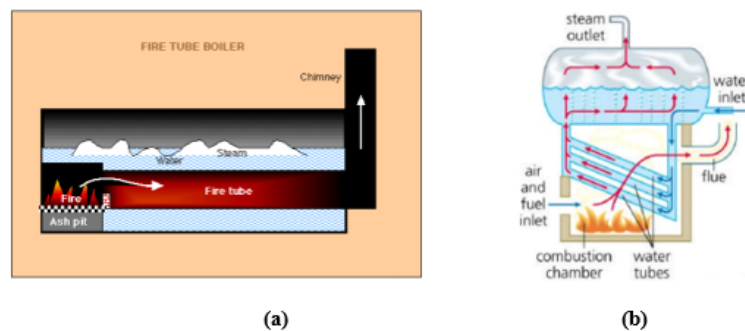


Figure 1. Fire tube boiler(a) dan water tube boiler (b)

In a fire tube boiler, hot gases pass through the tubes while the boiler feed water is contained within the shell to be converted into steam. This type of boiler is commonly used for processes that do not require a large amount of steam, operating at low to medium pressure. In a water tube boiler, the feed water flows inside the tubes while the hot gases are contained within the shell. This type of boiler is used to generate large quantities of steam at higher pressures.

The boiler used in the petrochemical industry is a coal-fired boiler (CFB) of the fire tube type. The selection of this boiler is based on its more economical operating costs, as the price of coal as boiler fuel is cheaper compared to oil. The fire tube boiler is chosen because, in the production process, the amount of steam required is not excessively high. The boiler capacity in the petrochemical industry can reach a maximum of 16 tons/hour with a maximum pressure of 19 kg/cm<sup>2</sup>, but it is usually operated at a capacity of 9.5 tons/hour. This boiler operates 24 hours a day with an average coal consumption of 36 tons/day. The boiler is equipped with safety equipment such as a safety valve, fusible plug, water level indicator, high–low–extra low water level control, boiler high-pressure alarm, and a motion detector.

### Overview of Boiler Efficiency and Method

Boiler performance parameters, such as efficiency and evaporation ratio, decrease over time due to poor combustion, dirty heat transfer surfaces, and irregular maintenance. Even for newly installed boilers, poor fuel quality and poor water quality can lead to reduced boiler performance. Several factors that affect boiler performance include boiler efficiency, evaporation ratio, movement on heat transfer surfaces, poor maintenance, as well as the quality and composition of fuel and water. Efficiency is defined as the percentage of input energy (heat) that is effectively used in the steam produced. To determine the efficiency of a boiler, two methods can be applied:

- Direct Method, which compares the energy gained by the working fluid (water and steam) with the energy contained in the boiler fuel. This method is also known as the input–output method.
- Indirect Method, which calculates the difference between the heat losses in the system and the input energy. This method is also often referred to as the heat loss method.

### Boiler Efficiency by the Direct Method

The direct method, also referred to as the input–output method, in calculating boiler efficiency requires the variables of steam output and heat input from the fuel to evaluate the efficiency value.

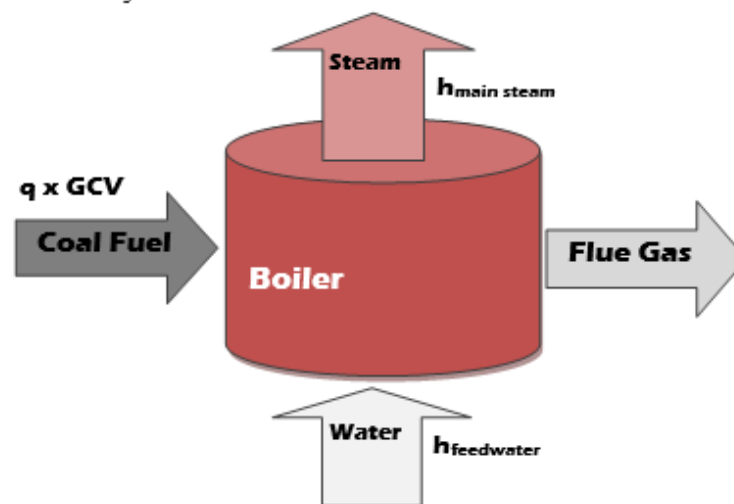


Figure 2. Illustration of boiler efficiency analysis using the direct method

From the illustration in Figure above, we can see in general which variables are required in calculating boiler performance efficiency using the direct method. Coal fuel serves as the fuel heat input and flue gas represents the losses, while the difference in enthalpy between water and steam becomes the heat output generated by the boiler. The complete translation of the mathematical formulation is as follows.

$$\eta = \frac{\text{heat in steam output}}{\text{heat in fuel input}} \times 100 \quad (1)$$

$$\eta = \frac{Q(h_{\text{main steam}} - h_{\text{feedwater}})}{(q \times \text{GCV})} \times 100 \quad (2)$$

Description:

- Q = main steam flow rate (kg/hour)
- h<sub>main steam</sub> = entalpi main steam (kJ/kg)
- h<sub>feedwater</sub> = entalpi feedwater s(kJ/kg)

q = The amount of fuel used (kg/hour)  
GCV = Gross Calorific Value (kJ/kg)

## RESULTS AND DISCUSSION

In this research, it is explained that the method used to calculate boiler efficiency in one of the petrochemical plants is the direct method, also known as the input-output method. This method is characterized by the fact that it only requires the output (steam) and the heat input (fuel) for efficiency evaluation. Data collection was carried out daily, except during boiler shutdowns, with a data recording interval of every 2 hours from August 1, 2025, to August 21, 2025. Therefore, 12 data points were obtained each day to determine the efficiency. The data used in the calculations were actual data obtained from the Central Control Room (CCR). These data were then processed to calculate the daily boiler efficiency using Equation 2. From the daily data collection, the average values for each day throughout August were obtained, as shown in Table 1.

To calculate boiler efficiency, data on the flow rate of steam, steam temperature, and feedwater temperature are required. These data are obtained from the Distributed Control System (DCS) in the Central Control Room (CCR), along with the fuel flow rate data. In this case, the coal flow rate is secondary data obtained from the boiler check sheet. The fuel flow rate data, being secondary and recorded manually, may lead to inaccuracies due to unclear handwriting, which often results in reading errors. The feedwater temperature ( $t_f$ ) and steam temperature ( $t_g$ ) are obtained from temperature measuring instruments installed on the boiler. These temperatures are then converted into their respective enthalpy values.

Based on the data presented in Table 1, it can be seen that the boiler experienced a shutdown for seven days, from August 2, 2025, to August 7, 2025. The shutdown occurred due to an unstable coal supply from the petrochemical plant. The boiler efficiency values calculated using Equation 2 indicate the amount of water that can be converted into steam by the boiler. The higher the efficiency value, the greater the amount of steam produced, which reflects better boiler performance. From the data, it can be observed that the highest efficiency was achieved on August 11, 2025, at 65.326858%, which was due to the high steam temperature of 224.0875°C. Conversely, the lowest efficiency occurred on August 8, 2025, at 45.810117%. The low efficiency on that date was due to the boiler having just restarted after a seven-day shutdown period.

Table 1. Data and Efficiency Calculation Results from August 1, 2025, to August 21, 2025

Water Totalizer (ton/hr)	Temperature of Feed Water (°C)	Enthalpy of Feed Water	Temperature of Steam (°C)	Enthalpy of Steam (kJ/kg)	Pressure of Steam (bar)	Flowrate of Steam (ton/hr)	Coal Counter		Flowrate of Coal (ton/2hr)	Flowrate of Coal (ton/hr)	Efficiency Steam %
507531.1889	94.74444444	396.8809	219.4544444	2801.977	15.22222	7.343333	6085.567	6237.733	2.188889	1.094444	56.05293
<b>SHUT DOWN</b>											
507694.1667	95.98888889	402.146	217.31	2797.452	15.43333	4.257778	6095.922	6248.089	2.244444	1.122222	45.81012
507856.275	95.21666667	398.878	222.3891667	2800.073	16.12727	8.543333	6106.658	6259.175	2.45	1.225	62.69145
508097.1917	95.45	399.8617	222.3016667	2800.028	16.125	8.548333	6121.608	6274.392	2.466667	1.233333	61.59301
508346.9083	95.43333333	399.7908	224.0875	2800.949	16.88333	10.15333	6137.35	6290.633	2.8	1.4	65.32686
508611.5	95.55833333	400.3189	223.1725	2800.477	16.26667	9.486667	6153.667	6307.175	2.716667	1.358333	63.74686
508878.1583	95.86666667	401.6216	223.0508333	2800.414	16.1	10.0825	6170.675	6324.458	2.941667	1.470833	61.26562
509146.0917	96.24166667	403.7662	223.5758333	2800.685	16.75	9.821667	6187.892	6342.033	2.891667	1.445833	61.16669
509410.0417	96.2	403.0272	221.3383333	2799.531	15.65833	9.761667	6204.85	6359.392	2.841667	1.420833	61.66062
509673.8667	96.24166667	403.2031	223.13	2800.455	16.23333	9.731818	6220.255	6376.367	4.5	2.25	49.00442
509936.2667	95.95	401.9715	222.9633333	2800.369	16.39167	9.730833	6238.2	6393.442	2.783333	1.391667	62.85434
510200.3833	96.24166667	403.7662	223.2833333	2800.534	16.425	9.725833	6255.367	6410.433	3.616667	1.808333	55.28399
510504.9333	95.66666667	400.7752	222.9208333	2800.347	16.51667	9.8525	6267.175	6427.217	10.675	5.3375	53.39473
510734.375	95.30833333	399.2622	222.7025	2800.234	16.38333	9.921667	6288.125	6444.308	2.841667	1.420833	61.90702
511000.3917	96.30833333	403.4847	222.3291667	2800.042	16.20833	9.8125	6305.525	6461.617	3.125	1.5625	62.18424

The following is the boiler efficiency graph for August 2025 at the petrochemical plant.

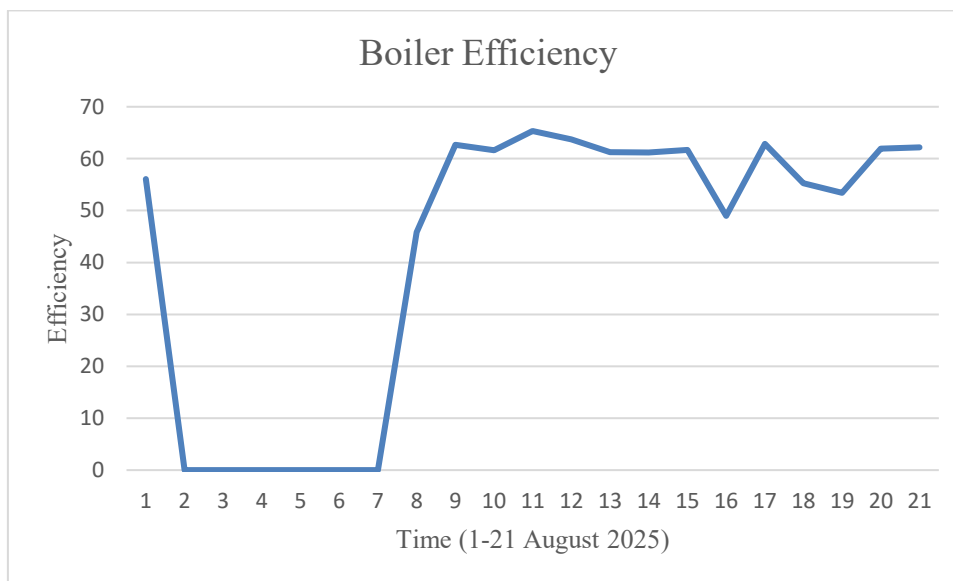


Figure 3. Boiler Efficiency Graph for August 2025

The boiler at the petrochemical plant has been in operation since 2006 and runs 24 hours a day. Since it began operating, the boiler has experienced several shutdowns due to maintenance activities or temporary production halts caused by delayed coal supply. During operation, the boiler performs water blowdown three times every hour, each lasting for three minutes. This procedure is carried out to maintain the water conductivity value below 2000, as exceeding this limit could reduce the quality of the production output. This is one of the main reasons why the boiler efficiency at the petrochemical plant is relatively low, ranging between 45% and 65%. However, when compared to the boiler's initial condition—where, according to data from the petrochemical plant, its efficiency at the start of operation was 70%—the current efficiency level

of 45%–65% can still be considered acceptable, as the decline is not too significant. According to (Bureska, 2017), the standard efficiency for a well-performing boiler is 85%. Therefore, the boiler efficiency at the petrochemical plant being studied can be classified as below optimal, as it does not yet meet the general performance standard for boilers. Nevertheless, the relatively low efficiency can be justified, as the petrochemical plant does not require as much heat as larger facilities such as power plants.

As previously explained, the boiler at the petrochemical plant under study is a CFB (Coal-Fired Boiler), which means the fuel used is coal. The coal is supplied by two different suppliers, each providing coal of varying quality. To meet the heat requirements of the boiler, coal from both suppliers is mixed. The mixing process is carried out in specific proportions that are adjusted according to process needs; therefore, there is no fixed mixing ratio. The difference in coal quality results in less efficient combustion, which in turn affects the overall boiler efficiency.

From the calculations and analysis, it can be concluded that the boiler condition at this petrochemical plant is still fairly good. However, measures should still be taken to improve boiler efficiency, because good efficiency leads to better production outcomes and operational cost savings. Boiler efficiency is influenced by the boiler's age, the type of fuel used, and inaccurate instrument readings. The efficiency analysis above still relies on secondary data. Further analysis using primary (actual) data is required through flowmeter measurements for the variables of steam quantity produced (Q) and fuel consumption (q). Steam and fuel flowmeters would allow a more accurate evaluation of the boiler's performance.

Several methods can be implemented to improve efficiency, one of which is increasing the feedwater temperature by utilizing flue gas. The flue gas exiting the boiler still has a temperature of around 200°C. Extracting heat from this flue gas can be used to preheat the boiler feedwater, thereby improving efficiency by reducing the amount of heat lost from the boiler. The use of flue gas heat to raise the feedwater temperature can increase boiler efficiency by up to 15.5% (Ernest & David, 2023). The boiler at the petrochemical plant has undergone regular maintenance or overhauls. In the future, this maintenance must continue to be carried out routinely as an effort to restore the boiler's condition to its original design performance. In addition, regular calibration of measuring instruments such as pressure indicators and temperature indicators is necessary to ensure accurate readings. Furthermore, it is recommended to conduct additional research on boiler efficiency analysis using the indirect method, to identify which components experience heat and energy losses within the boiler system.

## CONCLUSION

The conclusion of this research is that the boiler used at the petrochemical plant is a Fire Tube Boiler, which functions to heat the feedwater into steam. The control systems implemented in the boiler at the petrochemical plant include temperature control, pressure control, and water level control systems. The highest boiler efficiency obtained at the petrochemical plant using the direct method was 65.33%.

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