International Journal of Advance Engineering and Technology
Volume 1 Nomor 2 November 2025
e-ISSN: 3089-767X; p-ISSN:3089-8439, Page 138-150
DOI: https://doi.org/10.63956/ijaetech.v1i2.37
Available online at: https://ijaetech.org/index.php/ijaetech/article/view/37

Comparative Analysis of Feed Water Temperature Before and After the Economizer on the Efficiency of a 240 Ton/Hour CFB Boiler

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***Abstract** ~ Increasing operational efficiency in power generation systems is crucial in overcoming the increasing energy demand, especially in the industrial sector. One solution to improve the efficiency is to optimize the use of economizer in the boiler of Steam Power Plant (PLTU). This study analyzes the impact of using an economizer in a 240 ton/hour capacity CFB boiler at PT X on system efficiency and fuel consumption. The results of the analysis show that the use of an economizer can increase the average feed water temperature from 207.73°C to 298.96°C, with a temprature increase of 91.23°C. This temperature increase reflects the economizer's ability to utilize flue gas heat to heat the feed water, which has an impact on reducing fuel consumption by 17.18%, from 45716.56 kg/hour to 37862.50 kg/hour. The boiler efficiency also increased significantly, from 68.36% to 82.54%, which shows the positive impact of the economizer on boiler performance. This study concludes that the use of economizer can improve energy efficiency and reduce fuel consumption, and is recommended to be applied to large capacity boiler systems to optimize energy savings and operational efficiency. Further research is needed to explore the influence of other variables on economizer and boiler performance in more depth.*

Keywords : *PLTU, boiler, economizer, efficiency, fuel consumption.*

INTRODUCTION

Global energy demand continues to rise in line with rapid economic and industrial growth, including in Indonesia, which is one of the countries with a continuously developing industrial sector (Shahab & Amna, 2023). Increased energy consumption, both for domestic and industrial needs, requires an increase in the capacity of efficient and sustainable power plants. Steam Power Plants (SPPs) are one of the most widely used solutions to meet these energy needs.

A PLTU is a closed system that works based on the Rankine cycle principle, which is a thermodynamic cycle that converts heat energy into mechanical energy (Putra & Nazir, 2023). The main component in a PLTU system is a boiler that functions to produce superheated steam to drive a turbine, which in turn drives a generator to produce electrical energy (Marga et al., 2023).

A decline in boiler operational performance can have a direct impact on boiler efficiency. Boiler efficiency is influenced by several main factors, including fuel consumption, steam production per hour, boiler feed water temperature, and the pressure and temperature of the steam produced (Sahda et al., 2022). Boilers consist of various supporting components, such as

Received: January 13, 2025; Accepted: January 21, 2025; Published: January 23, 2025
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chimneys, superheaters, steam drums, economizers, and other supporting components. One important factor in improving boiler efficiency is the regulation of the feed water temperature entering the boiler, particularly through the role of the economizer (Darmadi et al., 2023).

An economizer is a heat transfer device that functions to utilize the heat from the exhaust gas resulting from combustion to heat the feed water before it enters the boiler, thereby increasing the feed water temperature (Rif'ah et al., 2021). The use of an economizer not only increases the feed water temperature but also plays a role in fuel savings by utilizing the heat from the exhaust gas that would otherwise be wasted into the atmosphere (Sumarno, 2018). Previous studies have shown that optimal use of an economizer can significantly reduce fuel consumption and increase boiler thermal efficiency (Iliev et al., 2020).

Although many studies have examined the role of economizers in improving boiler efficiency, there is still a research gap regarding the understanding of the difference in feed water temperature before and after passing through the economizer and its impact on overall boiler performance. Most previous studies have focused more on analyzing boiler efficiency in general without distinguishing between the feed water temperature conditions at the two stages.

Research conducted by Nari and Rahman (2022) shows that an increase in feed water temperature affects an increase in combustion efficiency, but does not explain in detail the contribution of differences in feed water temperature before and after the economizer to the reduction in fuel consumption. Similar findings were also found in a study evaluating boiler performance with and without an economizer in a relatively small capacity boiler, namely 3 tons/hour (Lahijan & Supeni, 2018).

Another study discussing boiler efficiency analysis with the use of economizers was also conducted on boilers with a capacity of 75 tons/hour, which are still classified as medium-scale and do not represent large-capacity boilers (Muchlishiin & Erivianto, 2023). Meanwhile, Bhattacharya and Banerjee (2010) emphasized the importance of feed water inlet temperature control in improving power plant efficiency, but the approach used was more simulation-based and did not consider actual temperature measurements before and after the economizer under real operating conditions.

Another study compares the performance of large-capacity power plants, namely 500 MW, but does not specifically focus the analysis on feedwater temperature differences, but rather on general operating variables such as pressure and plant load (Jang & Moon, 2024). In addition, there is also research that discusses exhaust gas temperature control to improve economizer performance, but the main focus is on flue gas rather than boiler feed water temperature, and does not consider large boiler capacities such as 240 tons/hour (Xiao et al., 2019).

One of the main distinguishing aspects of this study compared to previous studies is the boiler capacity used. Most previous studies examined small to medium capacity boilers or did not specifically mention the capacity. This study specifically focuses on a 240 tons/hour Circulating Fluidized Bed (CFB) boiler, which has different operational characteristics and energy consumption compared to smaller capacity boilers.

This study aims to analyze the difference in feed water temperature before and after passing through the economizer on the efficiency of a 240 tons/hour capacity boiler at PT X. The main focus of the study is to understand how changes in feed water temperature at these two stages affect fuel consumption and boiler operational efficiency.

The novelty of this study lies in its quantitative approach, which directly compares the feed water temperature before and after the economizer in a large-capacity CFB boiler system. This approach has rarely been used in previous studies, especially with comprehensive capacity specifications and temperature parameters. Thus, this study is expected to contribute new scientific insights into the development of thermal efficiency systems in large-scale steam power generation industries.

METHODS

This study uses a quantitative approach with descriptive and analytical research types. The main data source is CFB boiler operation data at PT X with the following specifications:

Table 1. Boiler specifications

***Boiler* CFB**	
Description	**Quantity and Unit**
Flow steam capacity	240 ton/jam
Maximum temperature	540°C
Maximum Pressure	9,81 MPa

Table 1 explains the specific boiler specifications used in this study. The data collected to support this study is as follows:

Table 2. Required data

***Boiler* CFB**	
Description	**Unit**
Feed water temperature after the economizer	°C
Feed water temperature before economizer	°C
Feed water Pressure	MPa

Boiler CFB	
Description	**Unit**
Main steam Pressure	MPa
Main steam Temperature	°C
Main steam	MPa
Temperature before the economizer	°C
Fuel consumption	Ton/hour
Steam production	Ton/hour
Caloric value of coal	kJ/hour

Data Collection Process

Data collection was carried out through a Distributed Control System (DCS) and Manual Logsheet recorded every hour for a full 24 hours, specifically on October 27, 2024. The measuring instruments included:

1. Thermocouple sensor for monitoring feed water temperature.
2. Pressure transmitter for steam pressure.
3. Digital fuel flow meter for fuel consumption.

Data accuracy was maintained by installing sensors at several points and cross-validating them by field operators with the main control room supervisor. Inconsistent data or data with extreme deviations was eliminated to maintain measurement reliability. The research stages carried out were as follows:

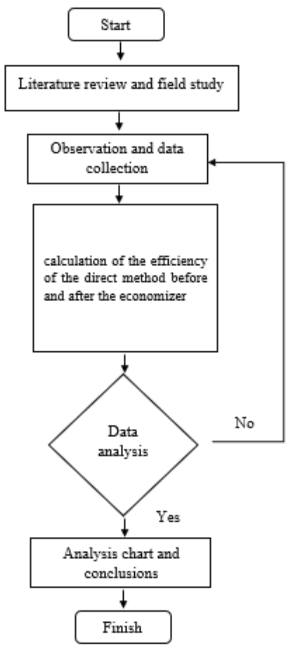

Figure 1. Research stages

Boiler Efficiency Analysis

Boiler efficiency is calculated using the direct method. The collected data is analyzed to understand the pattern of feed water temperature's effect on boiler efficiency. The formula used to calculate boiler efficiency is as follows:

$$\eta\ Boiler = \frac{Qin}{Qout}\ \text{X}\ 100\% \tag{1}$$

$$\eta\ Boiler = \frac{ws\ x\ (hs - hw)}{wf\ x\ CGV}\ \text{X}\ 100\% \tag{2}$$

Where:

Ws = Steam production (kg/h)

Hs = Superheated steam enthalpy (kJ/kg)

Hw = Boiler feed water enthalpy (kJ/kg)

Wf = Fuel consumption (kg/h)

CGV = Coal calorific value (kJ/kg)

Analysis of Feed Water Temperature Changes

To determine the average difference in feed water temperature before and after passing through the economizer, the following formula can be used:

$$\Delta T = T\ \text{after} - T\ \text{before} \tag{3}$$

T after: Average water temperature after passing through the economizer.

T before: Average water temperature before passing through the economizer.

Δ T: Average temperature difference of water before and after passing through the

$$\Delta\eta\ boiler = \eta\ boiler\ with\ Economizer - \eta\ boiler\ without\ Economizer \tag{4}$$

Ŋ boiler with Economizer: Average boiler efficiency percentage using an economizer.

Ŋ boiler without Economizer: Average boiler efficiency percentage without using an economizer.

Δ η: Average difference in boiler efficiency percentage before and after passing through the economizer.

Calculating Fuel Consumption Without Using an Economizer

To determine fuel consumption without using an economizer, the following formula can be used:

$$wf = \frac{(hs-hf)\ x\ ws}{\eta\ Boiler\ x\ CGV}\ x\ 100\% \quad (5)$$

Fuel Savings Percentage

After determining the amount of fuel consumption without using an economizer, the fuel savings percentage can be calculated using the following formula:

$$\frac{\Delta\ wf}{wf\ average\ without\ economizer}\ x\ 100\% \quad (6)$$

Δ Fuel Consumption: The difference between the average fuel consumption without an economizer and the average fuel consumption after using an economizer.

3. Results and Discussion

The data used to calculate boiler efficiency at PT X were recorded on a log sheet monitored hourly for 24 hours on Sunday, October 27, 2024.

Direct Boiler Efficiency Calculation

Table 3. Results of direct boiler efficiency calculation using feed water temperature after the economizer

Fuel consumption wf (kg/h)	Temperature after the economizer (°C)	Efficiency %
39100	299	84,03
38000	299	87,27
40200	299	83,80
38500	298	85,82
38100	297	88,04
39300	299	86,10
38000	298	87,66
39500	297	86,73
37900	300	79,51
37500	299	81,44
37200	299	81,61
38500	298	79,13
36700	301	85,24
37700	300	82,03
38500	299	79,98
36900	301	83,04

Fuel consumption wf (kg/h)	Temperature after the economizer (°C)	Efficiency %
37400	301	78,29
36500	298	81,58
37800	299	77,18
37500	300	79,88
37400	299	79,80
38000	298	79,85
37700	298	79,01
34800	299	83,91

Boiler Efficiency Calculation Without Using an Economizer

Table 4. Direct method efficiency calculation results using feed water temperature before the economizer

Fuel Consumption Without Economizer (Kg/H)	Feed Water Temperature (Before Economizer) °C	Efisiensi %
47360	205,8	69,37
45977	206,5	72,12
48552	207,3	69,39
46359	208	71,27
45757	207,6	73,30
47566	206,7	71,14
45708	208,5	72,88
47389	208	72,29
46088	205,2	65,39
45208	208,5	67,55
44974	207,2	67,50
46198	210,7	65,94
44667	206,5	70,03
45625	208,2	67,78
46336	209,7	66,46
44894	206,4	68,25
45439	207,2	64,44
43869	209,2	67,88
45634	207,8	63,93
45368	208,3	66,03
45179	207,6	66,06
45669	209,1	66,44
45253	209,5	65,82
42117	206	69,33

Table 3 and 4 show the results of direct boiler efficiency calculations, where the average difference in feed water temperature before and after passing through the economizer is 91.23 °C. A graph comparing the economizer water temperature can be seen in Figure 2.

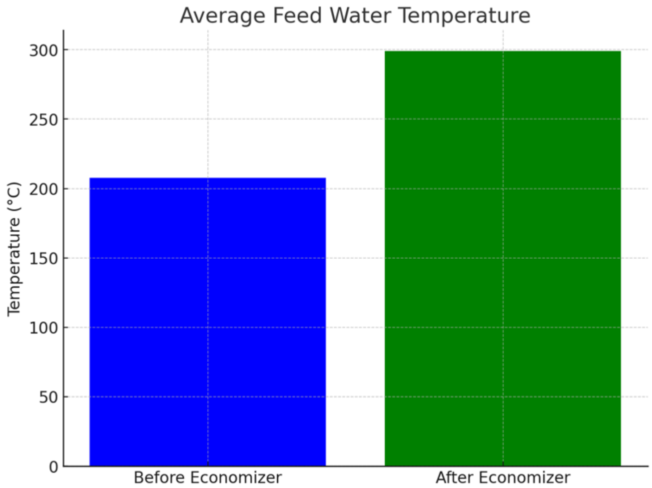

Figure 2. Comparison of average feed water temperature before and after the economizer

Figure 2 illustrates the difference in feed water temperature before and after passing through the economizer, where the blue bar shows the average feed water temperature before the economizer, while the green bar shows the average feed water temperature after the economizer on the (X) axis. while the Y-axis shows the range of feed water temperature increase between 207.73°C to 298.96°C, which is a temperature increase of 91.23°C.

Analysis of the Impact of Fuel Consumption Comparison

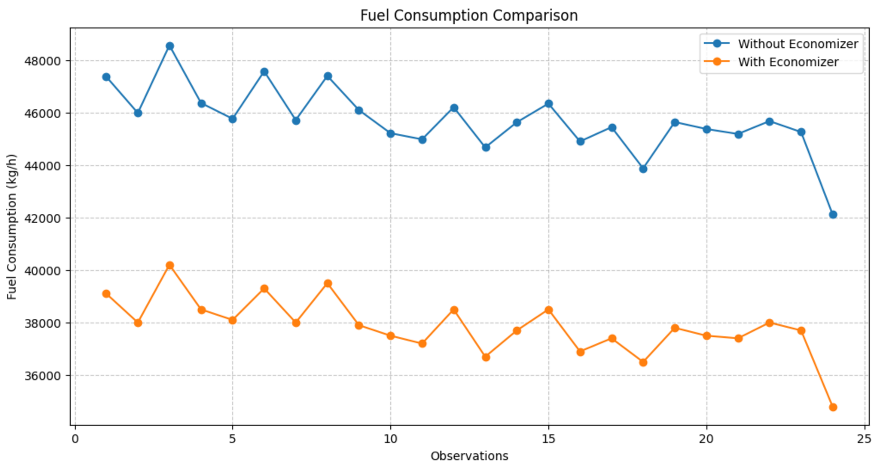

Figure 3. Comparative analysis of fuel consumption

Figure 3 explains that the use of an economizer can have a significant impact on fuel efficiency, with the X-axis representing the observation time over 24 hours, while the Y-axis shows fuel consumption (kg/h), where the average fuel consumption without an economizer is 45714.74 kg/hour, while with the use of an economizer, fuel consumption decreases to 37,773.83 kg/hour. This shows that the use of an economizer can reduce fuel consumption by 7,940.91 kg/hour.

Fuel Consumption Savings Percentage

To determine the fuel consumption savings percentage, use the following formula:

$$\frac{\Delta\ fuel\ consumption}{wf\ average\ without\ economizer}\ X\ 100\%$$

$$\frac{7854{,}06}{45716{,}56}\ \mathrm{X}\ 100\%$$

= 17,18 %

From the above calculations, the average fuel savings percentage achieved by using the economizer is 17.18%.

Results of the Analysis Comparing Boiler Efficiency Before and After Using the Economizer

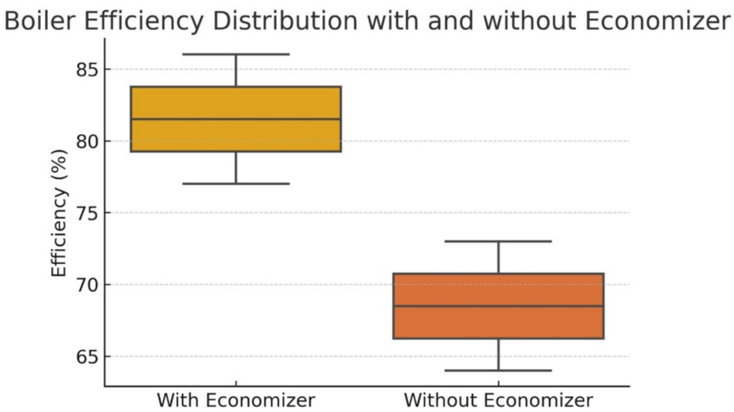

Figure 4. Boxplot Graph of Efficiency Distribution

Figure 4 presents the distribution of boiler efficiency before and after the use of an economizer in the form of a boxplot. This visualization illustrates the variability and consistency of system performance under each condition.

Under conditions with an economizer, efficiency shows a narrower range and a higher median of 82%, indicating improved performance and system stability.

Conversely, without an economizer, the efficiency median is only around 68% with a wider range, reflecting less stable performance.

The increase in the median from 68% to 82% and the decrease in variability support the findings of Lahijani & Supeni (2018), who noted a significant increase in efficiency through field tests. These findings are also in line with the study by Muchlishiin & Erivianto (2023), which reported an efficiency increase of up to 19% and a fuel consumption reduction of around 24% after the application of an economizer.

Thermodynamic Analysis and Mechanism of Efficiency Improvement

The increase in boiler efficiency after using an economizer can be explained through the basic principles of the Rankine cycle, where the efficiency of a thermal system is highly dependent on the enthalpy of the feed water before it enters the boiler. An economizer functions as a heat recovery device that utilizes the thermal energy from combustion exhaust gases, which would otherwise be wasted into the atmosphere, to increase the temperature of the feed water.

With the increase in feed water temperature, the energy required to be supplied by fuel combustion to achieve superheated steam temperature will be significantly reduced. This directly reduces fuel consumption and improves boiler thermal efficiency.

In addition, reducing the temperature difference between the feed water and the boiler pipe walls also reduces inefficient heat transfer rates and reduces thermal wear on the pipes, which can extend the life of the equipment. The reduction in burner workload also results in reduced exhaust gas emissions and increased boiler operating stability.

Therefore, in addition to improving energy efficiency, the presence of an economizer also plays an important role in supporting the sustainability of power plant operations and reducing long-term operating costs.

CONCLUSION

Based on the results of data analysis, the use of an economizer in a 240 ton/hour CFB boiler has a significant impact on increasing boiler efficiency. The average feed water temperature increased from 207.73°C before passing through the economizer to 298.96°C after passing through it, an increase of 91.23°C. This reflects the effectiveness of the economizer in utilizing energy from exhaust gases to heat feed water.

In addition, fuel savings of 17.18% were achieved, from 45716.56 kg/hour to 37862.50 kg/hour. Boiler efficiency also increased from 68.36% to 82.54%, an increase of 14.18%. With these results, the use of an economizer has been proven to increase boiler system efficiency and significantly reduce fuel consumption.

Further analysis shows that boiler efficiency is not only influenced by feed water temperature, but also by other variables such as steam pressure stability and variations in coal calorific value. These variables can cause minor variations in daily efficiency results.

The main limitation of this study is that the scope of observation is limited to one day of operation under relatively stable load conditions. This may limit the representation of the actual boiler operational dynamics, especially during load fluctuations, weather variations, or changes in fuel quality. In addition, this study has not examined aspects of economizer performance degradation over time, such as the effects of fouling or corrosion on heat transfer efficiency.

Therefore, further studies are highly recommended to involve longer observation periods, taking into account additional variables such as the type of coal used, daily operational load variations, and surrounding environmental conditions. This approach will provide a more comprehensive and applicable understanding of economizer performance in various industrial scenarios.

LIMITATION

This study has several limitations that need to be mentioned to provide a clear context for interpreting the results. First, data collection was limited to one day of boiler operation, with observations recorded over a 24-hour period under relatively stable load conditions. Although this approach allows for a clear comparison between operating conditions with and without an economizer, the results of this study do not fully represent long-term operating variations, such as load fluctuations, seasonal changes in ambient temperature, and variations in fuel quality.

Second, the analysis in this study focused primarily on the effect of differences in feed water temperature before and after passing through the economizer on boiler efficiency and fuel consumption. Other operational parameters that also have the potential to affect boiler performance, such as excess air ratio, flue gas composition, fouling levels in economizer pipes, and variations in coal calorific value during long-term operation, have not been analyzed in depth.

Third, this study has not evaluated the long-term degradation of economizer performance. Factors such as ash fouling, corrosion, erosion, and decreased heat transfer capacity on the economizer pipe surface, which can affect the effectiveness of the economizer over time, were not included in the analysis. Therefore, the results of this study are more representative of economizer performance under short-term and relatively clean operating conditions.

Thus, the results of this study need to be interpreted in accordance with the established operational and methodological limitations. Further research is recommended to involve longer observation periods, variations in operating load conditions, and the addition of analysis parameters in order to obtain a more comprehensive evaluation of economizer performance in large-capacity CFB boiler systems.

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