

Performance Evaluation and Energy-Saving Prioritization of Thermal Oil Heater in Plastic Manufacturing Plant

Arya Bima Putra¹, Faiz Husnayain^{2*}

^{1,2}Department of Electrical Engineering, Universitas Indonesia, Indonesia

²Research Center for Advanced Vehicles (RCaVe), Universitas Indonesia, Indonesia

¹arya.bima41@ui.ac.id, ²faiz.h@ui.ac.id

*Corresponding author, faiz.h@ui.ac.id

Abstract— Heating systems are one of the main contributors to energy consumption in industry. This study was conducted on the Thermal Oil Heater (TOH) system at PT XYZ, a plastic manufacturing company in West Java, to evaluate TOH performance using the direct method, linear regression modeling, and the Energy Performance Indicator, as well as to identify and prioritize energy-saving opportunities in the TOH system using the Analytic Hierarchy Process. The results of the direct method show that the average TOH efficiency was 65.78%. The linear regression equation was $\eta = 1246.889 - 0.2428X_1 - 4.2929X_2$, where gas flow rate and thermal oil inlet temperature significantly affected TOH efficiency. The EnPI method produced a baseline value of 1.58. The identified energy-saving potential was 26%. Based on the AHP analysis, the priority order of the criteria is as follows: energy-saving potential, ease of implementation, impact on operations and production, and investment cost. The priority order of the alternatives is as follows: optimization of gas fuel consumption rate, improvement of monitoring and control of operating parameters, improvement of the TOH system maintenance program, more efficient operating temperature control, increasing the temperature difference, burner combustion optimization, periodic cleaning of heat transfer pathways, and improvement of pipe and TOH body insulation.

Keywords: Analytic hierarchy process, Direct method, Energy performance indicator (EnPI), Linear regression, Thermal oil heater.



This work is licensed under a [CC BY-NC](https://creativecommons.org/licenses/by-nc/4.0/). Copyright ©2026 by Author. Published by Universitas Riau.

INTRODUCTION

Improving industrial energy performance has become an important issue in energy management, especially for manufacturing industries that operate continuously and depend on thermal processes [1]. According to the Handbook of Energy and Economic Statistics of Indonesia (HEESI) 2024, the industrial sector recorded the highest share of energy demand by sector, at 45.94%, driven by high natural gas use [2]. This issue is also aligned with the Sustainable Development Goals (SDGs) 2030, particularly SDG 7, which emphasizes access to affordable, reliable, sustainable, and modern energy, and SDG 13, which focuses on climate action and the reduction of climate change impacts [3]. Thus, energy management in the industrial sector is not only about cost reduction but also about industry's responsibility to support a cleaner, lower-emission energy system.

Manufacturing industries commonly rely on heating systems to maintain production quality and process stability. Heating systems are among the main contributors to industrial energy

consumption, so their performance significantly affects overall energy efficiency [4]. One of the heating systems widely used in industry is the Thermal Oil Heater (TOH), a system that uses thermal fluid such as oil as a heat transfer medium to deliver heat to production processes [5]. Compared with direct steam systems, thermal oil systems are commonly selected when the production process requires stable high-temperature heat with controlled operating conditions [6]. Thermal Oil Heaters are available in two configurations: vertical and horizontal. The selection between them is generally based on a combination of technical considerations, space constraints, the required operating temperature, and the desired reliability and efficiency of the heating system [7].

This study was conducted at PT XYZ, a plastic manufacturing plant engaged in flexible packaging production in Citeureup, West Java, which relies heavily on Thermal Oil Heaters for its production processes, including coating, drying, and laminating. Specifically, this study examines a vertical-type TOH serving production lines 6 and 7, using natural gas as its energy source. Since TOH performance directly impacts the company's fuel consumption and energy costs, a thorough performance evaluation is an essential first step in supporting efforts to improve efficiency and sustainable energy management.

One fundamental approach to evaluating TOH performance is calculating thermal efficiency using the direct method, which compares the useful heat absorbed by the thermal oil with the energy input from fuel combustion [6]. In addition to direct efficiency calculation, linear regression can be used to analyze the relationship between operating variables and TOH efficiency [8]. Comprehensive energy performance monitoring further requires an indicator capable of comparing actual energy performance against an established baseline. In this context, the Energy Performance Indicator (EnPI) enables more consistent monitoring of TOH energy performance, in alignment with the principles of ISO 50001 and the technical guidance of ISO 50006.

Improving energy efficiency also requires the systematic identification and prioritization of energy-saving opportunities. In practice, companies often face multiple improvement options that cannot all be implemented simultaneously due to technical, financial, and operational constraints. Therefore, a structured decision-making approach is necessary. The Analytic Hierarchy Process (AHP) provides a method to prioritize energy-saving opportunities by evaluating multiple criteria and alternatives, helping management select the most appropriate actions to optimize energy efficiency and reduce overall energy costs [9].

Previous studies have mainly focused on specific aspects, such as temperature control optimization, fuel feasibility analysis, or burner maintenance management. However, none has integrated actual thermal efficiency evaluation, statistical performance analysis, EnPI-based energy performance monitoring, and multi-criteria prioritization of energy-saving opportunities within a single assessment framework. This study addresses that gap by evaluating the actual performance of a natural gas-fired Thermal Oil Heater in a plastic manufacturing plant and linking the performance findings to structured energy-saving prioritization.

To that end, this study evaluates TOH performance at PT XYZ using the direct method, linear regression, and the Energy Performance Indicator, and subsequently identifies and prioritizes energy-saving opportunities using the Analytic Hierarchy Process. The findings are expected to deliver a quantitative evaluation of TOH performance and actionable recommendations for improving energy efficiency in the industrial sector. By combining the direct method, linear regression, EnPI, and AHP within an integrated framework, this study contributes a systematic, data-driven approach to industrial energy management for improving TOH energy efficiency.

METHOD

A. Calculation of Thermal Oil Heater (TOH) Efficiency Using the Direct Method

Energy efficiency is the ratio between the useful output of a process and its energy input [8]. In industrial heating systems, thermal efficiency is used to evaluate how effectively fuel energy is converted into useful heat energy [10]. Thermal Oil Heater efficiency can be measured using two methods: the direct method and the indirect method. The direct method calculates efficiency by comparing the useful heat energy absorbed by the fluid to the fuel input energy [5]:

$$\eta = \frac{Q_{out}}{Q_{in}} \times 100\% \quad (1)$$

where η is the thermal oil heater efficiency (%), Q_{out} is the useful heat energy absorbed by the thermal oil (kJ/h), and Q_{in} is the input energy from the gas fuel (kJ/h).

The useful heat energy (Q_{out}) is calculated from the thermal oil mass flow rate, specific heat, and temperature rise of the thermal oil:

$$Q_{out} = m_{oil} \cdot C_p (T_{out} - T_{in}) \quad (2)$$

where m_{oil} is the thermal oil mass flow rate (kg/h), C_p is the specific heat of thermal oil (kJ/kg·K), and T_{out} and T_{in} are the thermal oil outlet and inlet temperatures (°C), respectively.

The thermal oil mass flow rate (m_{oil}) is obtained from the volumetric flow rate and the density of the thermal oil:

$$m_{oil} = \rho \cdot V_{oil} \quad (3)$$

where ρ is the thermal oil density (kg/m³) and V_{oil} is the thermal oil volumetric flow rate (m³/h).

The energy input from the gas fuel is calculated based on the gas consumption rate and the higher heating value (HHV):

$$Q_{in} = V_{gas} \cdot HHV \quad (4)$$

where V_{gas} is the gas flow rate (Nm³/h) and HHV is the higher heating value of gas (kJ/Nm³).

B. Linear Regression Modeling of Thermal Oil Heater (TOH) Efficiency

Linear regression is a statistical method used to model the relationship between one or more independent variables and a dependent variable. Multiple linear regression identifies patterns of relationships between variables X and Y in the form of a linear equation [11]. In this study, TOH efficiency (η) is treated as the dependent variable, while gas flow rate and thermal oil inlet temperature are treated as independent variables. These variables were selected because the gas consumption rate directly represents the amount of energy input into the system, while the thermal oil inlet temperature reflects the initial thermal condition of the fluid before receiving heat from the combustion process. The multiple linear regression model is formulated as follows:

$$\eta = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (5)$$

where η is the thermal oil heater efficiency (%), β_0 is the constant (intercept), β_1 and β_2 are the regression coefficients for gas flow rate and inlet temperature respectively, X_1 is the gas flow

rate (V_{gas}), X_2 is the thermal oil inlet temperature (T_{in}), and ε is the error term representing the component not explained by the model.

Prior to using the regression model, several classical assumption tests were conducted to ensure the validity and reliability of the model, as described in the following subsections.

Normality Test

The normality test determines whether the residuals of a regression model are normally distributed, which is a fundamental assumption of linear regression. Normality can be assessed graphically using a normal probability plot or histogram, and statistically using the Kolmogorov-Smirnov, Shapiro-Wilk, or Jarque-Bera tests [12]. Residuals are defined as the differences between observed and predicted values. A variable is considered normally distributed if its p-value exceeds 0.05 [13].

Multicollinearity Test

The multicollinearity test determines whether a high correlation exists among the independent variables in a multiple linear regression model. Such correlation can distort the estimated relationship between the independent and dependent variables, making the regression coefficients unreliable. Multicollinearity is assessed using the Variance Inflation Factor (VIF). A model is considered free from multicollinearity if the VIF is less than 10 and the tolerance value exceeds 0.1 [14].

Heteroscedasticity Test

The heteroscedasticity test examines whether the variance of the residuals in a regression model remains constant across all observations [15]. A regression model must satisfy the condition of homoscedasticity (i.e., no heteroscedasticity). The absence of heteroscedasticity is indicated by a significance value greater than 0.05. Various statistical tests can be used to detect heteroscedasticity, including the Glejser test, the Park test, and the White test [15].

Linearity Test

The linearity test determines whether the relationship between an independent variable and the dependent variable is linear. This test is equivalent to a significance test within an Analysis of Variance (ANOVA) framework, which partitions the total variance between the dependent and independent variables. A significance value of less than 0.05 indicates a statistically significant linear relationship [16].

Correlation Test

Following the development of the linear regression model, the coefficient of determination (R^2) was used to assess the goodness of fit. According to ISO 50006, an R^2 value greater than 0.8 is the minimum acceptable threshold for confirming the adequacy of the regression equation [8].

Validation Test

Validation test was performed using the Mean Absolute Percentage Error (MAPE), which quantifies the average percentage deviation between simulated and actual values:

$$E_1 = \frac{[S - A]}{A} \times 100\% \quad (6)$$

where E_1 is the mean absolute percentage error (%), S is the average value of simulation results, and A is the average value of actual data. The model is considered valid if E_1 is less than 5% [17].

C. Determination of Energy Performance Indicators

An Energy Performance Indicator (EnPI) is a quantitative measure used to monitor and evaluate the energy performance of a system or organization. EnPI may take the form of a ratio, an index, or a statistical model linking energy consumption to relevant operational parameters [8][18]. ISO 50001 recognizes EnPI as a primary tool for monitoring and improving energy performance [19], while ISO 50006:2023 provides guidance on selecting the appropriate EnPI in accordance with an organization's objectives.

The use of EnPI enables organizations to identify changes in energy performance resulting from variations in operating conditions, thereby supporting the systematic and continuous identification of improvement opportunities. Energy performance improvements are assessed by comparing actual energy use against an established Energy Baseline (EnB) [20]. In this study, a thermal EnPI is applied, covering only the thermal energy consumption of the production process derived from natural gas and other thermal carriers [21].

The EnPI is defined as the ratio of fuel input energy to useful heat energy produced:

$$EnPI = \frac{Q_{in}}{Q_{out}} \quad (7)$$

where $EnPI$ is the ratio of fuel input energy to useful heat energy (dimensionless), Q_{in} is the fuel input energy from gas (kJ/h), and Q_{out} is the useful heat energy absorbed by thermal oil (kJ/h).

D. Analytical Hierarchy Process (AHP)

The AHP procedure implemented in this study followed these steps:

- Define the goal. The objective of this study is to determine the priority order of energy-saving opportunities for the TOH system.
- Identify the criteria. The evaluation criteria were derived from the literature review and the results of the TOH performance evaluation analysis.
- Identify the alternatives. The alternatives consist of energy-saving opportunities identified through the TOH performance evaluation.
- Construct the hierarchical structure comprising the goal, criteria, and alternatives.
- Develop a pairwise comparison questionnaire for each element at each level of the hierarchy. The questionnaire was validated by subject-matter experts prior to distribution.
- Conduct pairwise comparisons for each element at each level of the hierarchy using the fundamental scale presented in Table 1 [9].

The assessments were carried out by experts who completed a pairwise comparison questionnaire. Expert respondents were selected based on three criteria: demonstrated knowledge of thermal oil heater systems, decision-making authority or supervisory responsibility over relevant policy, strategy, and technical matters, and relevant educational background or professional experience in the field. The three respondents were the Head of the Utility Department at PT XYZ (representing management), the Boiler and Water Treatment Supervisor (responsible for day-to-day TOH operation), and the Senior Boiler Operator (directly involved in TOH operation).

- Construct pairwise comparison matrices for each element at each level of the hierarchy.
- Determine priorities and test consistency. The Consistency Ratio (CR) was calculated to verify the coherence of the expert judgments. An assessment is considered consistent if $CR \leq 0.1$. All CR values were calculated using ExpertChoice software.
- Rank the alternatives based on the overall priority weights to determine the priority order of energy-saving opportunities.

Table 1. AHP Fundamental Scale for Pairwise Comparisons

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two elements contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very Strong or Demonstrated Importance	One element is strongly favored over another; its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one element over another is of the highest possible order of certainty
2,4,6,8	Intermediate values	Used to express intensities between adjacent judgment levels
Reverse/ Reciprocal	If element i is assigned one of the above nonzero numbers when compared to element j , then j has the reciprocal value when compared to it	

RESULT AND DISCUSSION

A. Evaluation of Thermal Oil Heater Performance Using the Direct Method

The Thermal Oil Heater (TOH) efficiency in this study was calculated using the direct method, which compares the useful heat energy absorbed by the thermal oil to the input energy from the combustion of gaseous fuel, as formulated in Equations (1) through (4). The following presents a sample calculation using operational data recorded at 08:00-15:00 WIB.

$$m_{oil} = 240,000 \text{ kg/h}$$

$$C_p = 2.5 \text{ kJ/kgK}$$

$$\Delta T = 13^\circ\text{C}$$

$$Q_{out} = 240,000 \times 2.5 \times 13 = 7,800,000 \text{ kJ/h}$$

$$Q_{in} = 11,319,601.39 \text{ kJ/h}$$

Thus, the TOH efficiency is:

$$\eta = \frac{Q_{out}}{Q_{in}} \times 100\% = \frac{7,800,000}{11,319,601.39} \times 100\% = 68.91\%$$

The efficiency calculations for each time interval are summarized in Table 2. Based on 72 operational data points corresponding to the production of 147,774 tons of plastic, the TOH

efficiency ranged from 47.6% to 95.41%, with an average of 65.78%, which remains below the company's internal efficiency target of 85%. This finding indicates that although the TOH has technically operated under highly efficient conditions at certain times, such conditions have not been consistently maintained in daily operations, confirming that the overall TOH performance is not yet optimal.

Table 2. Results of the Direct Method Calculation

Time	Oil Flow (m ³ /h)	T _{in} (°C)	T _{out} (°C)	ΔT (°C)	Gas Flow (Nm ³ /h)	Q _{out} (kJ/h)	Q _{in} (kJ/h)	Efficiency (%)
08:00	320	257	270	13	304.29	7,800,000	11,319,601.39	68.91
09:00	320	257	270	13	340.92	7,800,000	12,682,146.00	61.50
10:00	320	258	270	12	343.74	7,200,000	12,786,957.12	56.31
11:00	320	258	270	12	228.22	7,200,000	8,489,701.04	84.81
12:00	320	258	270	12	356.28	7,200,000	13,253,446.11	54.33
13:00	320	257	270	13	304.29	7,800,000	11,319,601.39	68.91
14:00	320	257	270	13	307.11	7,800,000	11,424,412.51	68.27
15:00	320	258	270	12	346.55	7,200,000	12,891,768.24	55.85

B. Descriptive Statistics of Thermal Oil Heater Efficiency

Figure 1 illustrates the pattern of TOH efficiency variation over the observation period. As shown, the efficiency fluctuates over time with considerable variation, driven by changes in gas consumption rates and the inlet and outlet temperatures of the thermal oil.

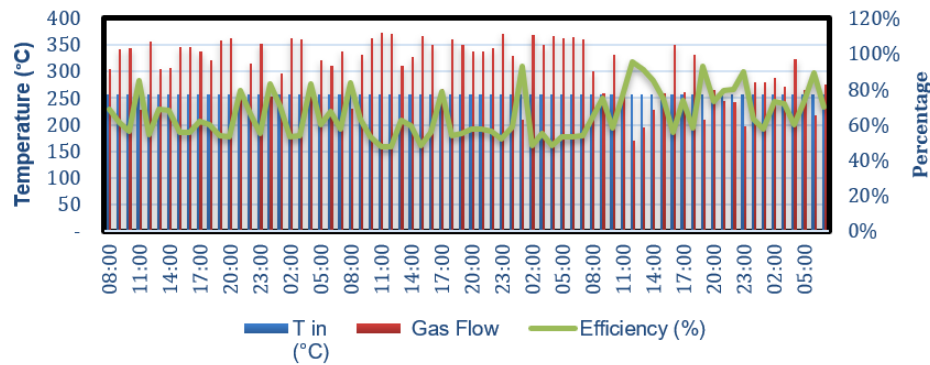


Figure 1. TOH Efficiency vs. Time

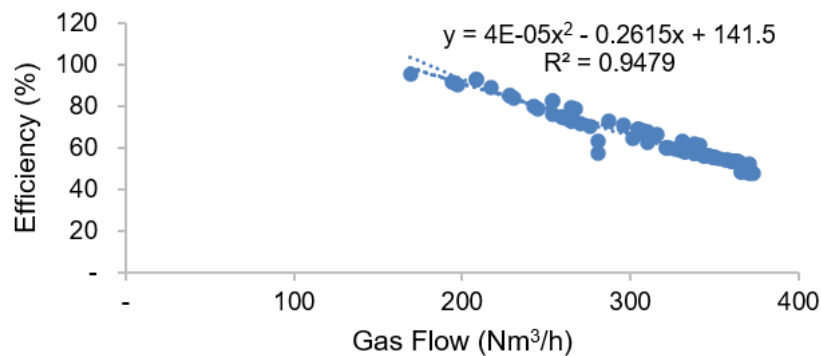


Figure 2. Relationship Between TOH Efficiency and Gas Flow Rate

Figure 2 further illustrates the relationship between TOH efficiency and gas flow rate. A clear decreasing trend is observed as gas flow increases, indicating that the additional fuel energy supplied is not fully converted into useful thermal output, thereby reducing system efficiency.

These findings confirm that TOH performance remains suboptimal and is significantly influenced by the gas flow rate.

C. Linear Regression Modeling of Thermal Oil Heater Efficiency

Linear regression analysis was performed to identify the operating variables that influence TOH efficiency. The dataset used for modeling is presented in Table 3, in which TOH efficiency (η) is defined as the dependent variable (Y), while gas flow rate (X_1) and thermal oil inlet temperature (X_2) serve as independent variables. These variables were selected because gas flow rate directly represents the fuel input to the system, while thermal oil inlet temperature reflects the initial thermal state of the circulating oil before heat is added. Both variables are measurable and can be routinely monitored during standard operation.

Table 3. Variables for Linear Regression Modeling

Gas Flow (Nm ³ /h)	T _{in} (°C)	Efficiency (%)
X ₁	X ₂	Y
304.29	257	68.91
340.92	257	61.50
343.74	258	56.31
228.22	258	84.81
356.28	258	54.33

The regression analysis results are presented in Table 4.

Table 4. Results of the Linear Regression Model

	Coefficients	Standard Error	t _{Stat}	p-value
Intercept	1246.888997	120.627143	10.33671996	1.17039E-15
X ₁	-0.24282322	0.003464214	-70.09475744	7.29327E-66
X ₂	-4.292921581	0.468421251	-9.164660177	1.49826E-13

The multiple linear regression model used is formulated as follows:

$$\eta = 1246.889 - 0.2428X_1 - 4.2929X_2$$

Statistical test for the Linear Regression Model

Table 5. Statistical Diagnostic Test Results of the Linear Regression Model

Statistical Test	Parameter	Result	Acceptance Criterion	Interpretation
Residual Normality	Shapiro-Wilk p-value	0.1551	p-value > 0.05	Residuals are normally distributed
Multicollinearity X ₁	VIF of gas flow rate	1.0062	VIF < 10	No severe multicollinearity
Multicollinearity X ₂	VIF of inlet temperature	1.0062	VIF < 10	No severe multicollinearity
Heteroscedasticity X ₁	Glejser P-value of gas flow rate	0.8008	p-value > 0.05	No heteroscedasticity is detected for gas flow rate
Heteroscedasticity X ₂	Glejser P-value of inlet temperature	0.0755	p-value > 0.05	No heteroscedasticity is detected for inlet temperature

The results of the statistical diagnostic tests for the regression model are summarized in Table 5. The Shapiro–Wilk test yielded a p-value of 0.1551, exceeding the 0.05 threshold, confirming that the residuals are normally distributed. The Variance Inflation Factor (VIF) values for both gas flow rate and inlet temperature are 1.0062, well below the threshold of 10, indicating no

severe multicollinearity among the independent variables. The Glejser test produced p-values of 0.8008 and 0.0755 for gas flow rate and inlet temperature, respectively, both exceeding 0.05, confirming the absence of heteroscedasticity. Consequently, the residual variance is considered constant, and the regression model satisfies all evaluated statistical assumptions.

Correlation and Significance Tests

Based on the ANOVA results, the Significance F-value of 9.416E-66 is substantially less than 0.05, confirming that the regression model is statistically significant and that gas flow rate and inlet temperature jointly have a significant effect on TOH efficiency. The coefficient of determination obtained is $R^2 = 0.9869$, indicating that 98.69% of the variation in TOH efficiency is explained by gas flow rate (X_1) and inlet temperature (X_2).

Validation Test

Validation test was performed using the Mean Absolute Percentage Error (MAPE) by comparing the actual efficiency values (Y) with the calculated values. The validation results are presented in Table 6. The average percentage error of 2.05% confirms that the model achieves very good predictive accuracy.

Table 6. Model Validation

Gas Flow (Nm ³ /h)	T _{in} (°C)	Efficiency (%)	Calculated Efficiency (%)	%E ₁ (%)
X ₁	X ₂	Y	Calculated Y	Error
304.29	257	68.91	69.7194	1.18
340.92	257	61.50	60.8254	1.10
343.74	258	56.31	55.8483	0.82
228.22	258	84.81	83.8987	1.07
356.28	258	54.33	52.8033	2.80
Average %Error				2.05

To further assess the generalizability of the model, validation was performed on a separate dataset, the results of which are presented in Table 7. The average MAPE of 1.67% confirms that the model maintains good predictive performance on unseen data, demonstrating that the regression equation can reliably estimate TOH efficiency based on gas flow rate and inlet temperature.

Table 7. Validation of Regression Model Accuracy Using MAPE on Different Dataset

Gas Flow (Nm ³ /h)	T _{in} (°C)	Efficiency (%)	Calculated Efficiency (%)	%E ₁ (%)
X ₁	X ₂	Y	Calculated Y	Error
338.1004	257	62.02	61.51	0.82
321.1954	258	60.26	61.32	1.76
357.8229	258	54.09	52.43	3.07
361.9104	258	53.48	51.43	3.82
264.8453	257	79.17	79.30	0.16
315.5604	257	66.45	66.98	0.81
352.1879	258	54.96	53.80	2.11
253.5753	257	82.69	82.03	0.79
Average %Error				1.67

D. Performance Evaluation of Thermal Oil Heater Using Energy Performance Indicators

In this study, EnPI is defined as the ratio of the average fuel input energy to the average useful

heat energy produced. Based on the observational data, the baseline EnPI value is calculated as follows:

$$EnPI = \frac{Q_{in}}{Q_{out}} = \frac{11,411,438}{7,216,666.67} = 1.58$$

A baseline EnPI value of 1.58 was obtained, representing the average ratio of energy input to useful heat output. This value serves as the reference baseline for energy performance evaluation.

E. Identification of Energy-Saving Opportunities for the Thermal Oil Heater

Energy-saving opportunities were assessed by comparing actual gas consumption against the amount required to achieve the company's internal TOH efficiency target of 85%. The energy-saving potential for each time interval is presented in Table 8, and the corresponding energy and cost savings calculations are summarized in Table 9.

Table 8. Calculation of Energy Savings Potential

Time	Gas Flow (Nm ³ /h)	New Gas Flow (Nm ³ /h)	Gas Flow Difference (Nm ³ /h)	Q _{out} (kJ/h)	Q _{in} (kJ/h)	New Q _{in} (kJ/h)	Eff (%)	New Eff (%)
08:00	304.29	246.68	57.61	7,800,000	11,319,601.39	9,176,470.59	68.91	85.00
09:00	340.92	246.68	94.24	7,800,000	12,682,146.00	9,176,470.59	61.50	85.00
10:00	343.74	227.70	116.03	7,200,000	12,786,957.12	8,470,588.24	56.31	85.00
11:00	228.22	227.70	0.51	7,200,000	8,489,701.04	8,470,588.24	84.81	85.00
12:00	356.28	227.70	128.57	7,200,000	13,253,446.11	8,470,588.24	54.33	85.00
13:00	304.29	246.68	57.61	7,800,000	11,319,601.39	9,176,470.59	68.91	85.00
14:00	307.11	246.68	60.43	7,800,000	11,424,412.51	9,176,470.59	68.27	85.00
15:00	346.55	227.70	118.85	7,200,000	12,891,768.24	8,470,588.24	55.85	85.00

Energy savings were quantified in MMBTU using the natural gas heating value specified in this study. Cost savings were estimated by multiplying the daily energy savings by the assumed gas price and exchange rate. Under the base-case scenario, a gas price of USD 11.8/MMBTU and an exchange rate of IDR 14,400/USD were applied, yielding an estimated daily cost saving of IDR 11.53 million. Emission reductions were estimated by multiplying daily energy savings by the natural gas emission factor of 53.06 kg CO₂/MMBTU [24], resulting in an estimated reduction of 3.60 tons CO₂e per day.

Table 9. Results of Energy and Cost Savings Potential Calculations

Potential Savings	Value
Difference in Gas Consumption (Nm ³ /day)	1,884.67
Potential Energy Savings per Day (MMBTU)	67.85
Potential Cost Savings per Day	Rp 11,528,766.06
Potential Monthly Cost Savings (30 days)	Rp 345,862,981.82
Energy Saving	26%

Figure 3 presents a comparison between the actual and optimized gas flow rates, illustrating the gap between current operations and the target efficiency condition.

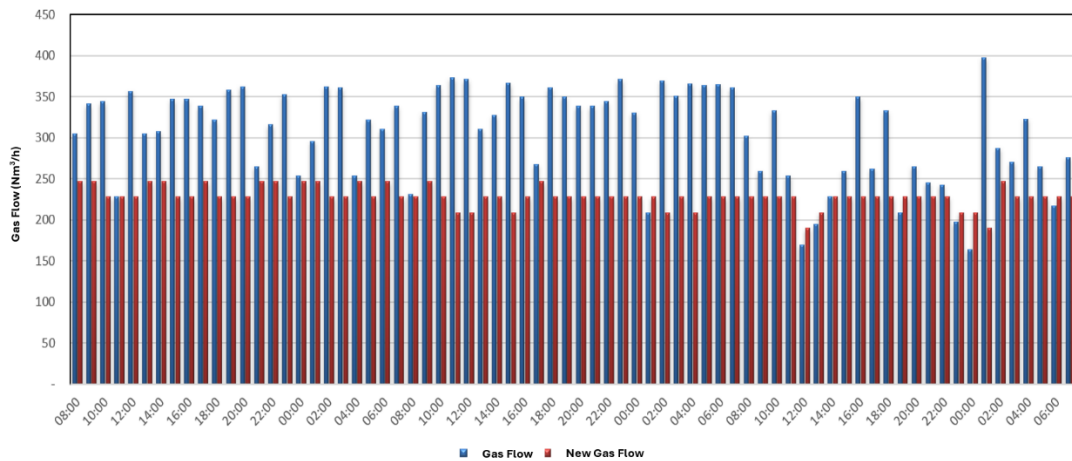


Figure 3. Comparison of Actual and Optimized Gas Flow Rates

The results show that achieving the 85% efficiency target would require a reduction in natural gas consumption of 1,884.67 Nm³/day, equivalent to 67.85 MMBTU/day, which corresponds to a daily carbon emission reduction of 3.60 tons CO₂e and daily cost savings of IDR 11,528,766.06. The overall energy-saving potential is 26%. Using the EnPI framework, the target EnPI at 85% efficiency is:

$$EnPI_{target} = \frac{1}{0.85} = 1.18$$

The difference between the baseline and target EnPI is:

$$\Delta EnPI = 1.58 - 1.18 = 0.40$$

This indicates that, on average, energy input requirements can still be reduced by approximately 0.40 units per unit of useful heat output if the TOH is operated at the target efficiency. This gap is substantial and confirms that the energy-saving potential at PT XYZ is significant at an industrial scale.

F. Analysis of Analytic Hierarchy Process (AHP) Results

Following the TOH performance evaluation, an AHP hierarchical structure was developed comprising three levels: the goal level, the criteria level, and the alternative level, as illustrated in Figure 4. The AHP analysis was conducted using data from three expert respondents representing management, supervisory, and operational levels, processed using ExpertChoice software. The combined criteria prioritization results are presented in Figure 5.

As shown in Figure 5, the combined consistency score at the criteria level is 0.08 (8%), which is below the 0.1 threshold, confirming that the expert judgments are consistent. The priority order of the criteria for achieving the energy-saving objective is as follows: energy-saving potential (0.418), ease of implementation (0.294), impact on operations and production (0.207), and investment cost (0.081). The prioritization results at the alternative level, based on the highest-ranking criterion of energy-saving potential, are presented in Figure 6.

Figure 6 shows that the combined consistency value at the alternative level is 0.04 (4%), confirming that the expert judgments are consistent. The priority order of the alternatives based on the energy-saving potential criterion is as follows: optimization of gas fuel consumption rate (0.210), improvement of monitoring and control of operating parameters (0.139), improvement of the TOH system maintenance program (0.129), more efficient operating temperature control (0.124), increasing the temperature difference (0.112), burner combustion optimization

(0.109), periodic cleaning of heat transfer pathways (0.095), and improvement of pipe and TOH body insulation (0.083). These results indicate that optimizing the gas fuel consumption rate is the highest priority, as it directly influences fuel input, energy costs, and emissions. This finding is consistent with both the direct method and regression analysis results, which demonstrate a strong relationship between gas flow rate and TOH efficiency. Monitoring and control of operating parameters ranks second, as stable regulation of gas flow, inlet temperature, outlet temperature, and temperature difference is essential for sustained efficient operation. The TOH maintenance program ranks third, highlighting the importance of regular maintenance activities in sustaining heat transfer performance, burner reliability, and insulation condition.

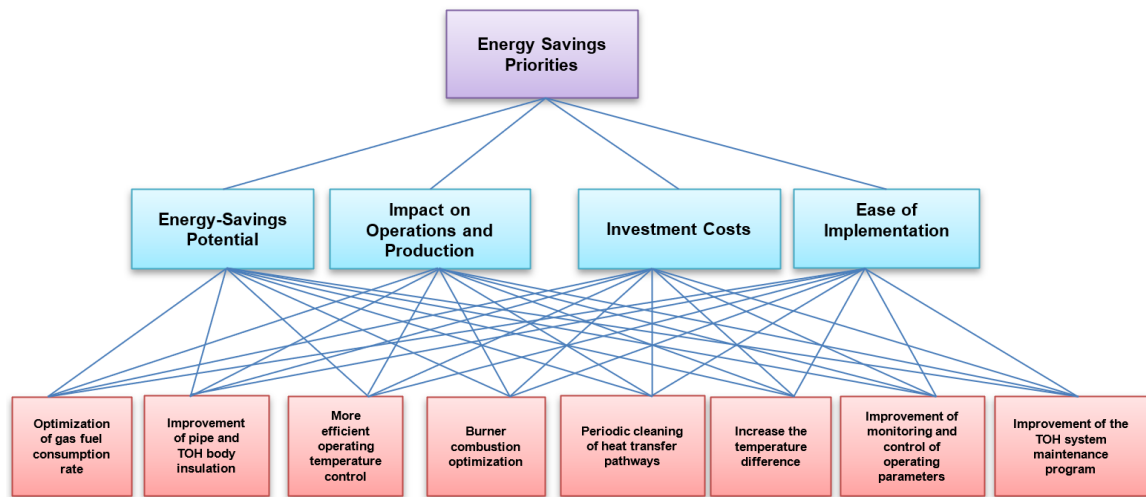


Figure 4. Hierarchical Structure of the Analytic Hierarchy Process

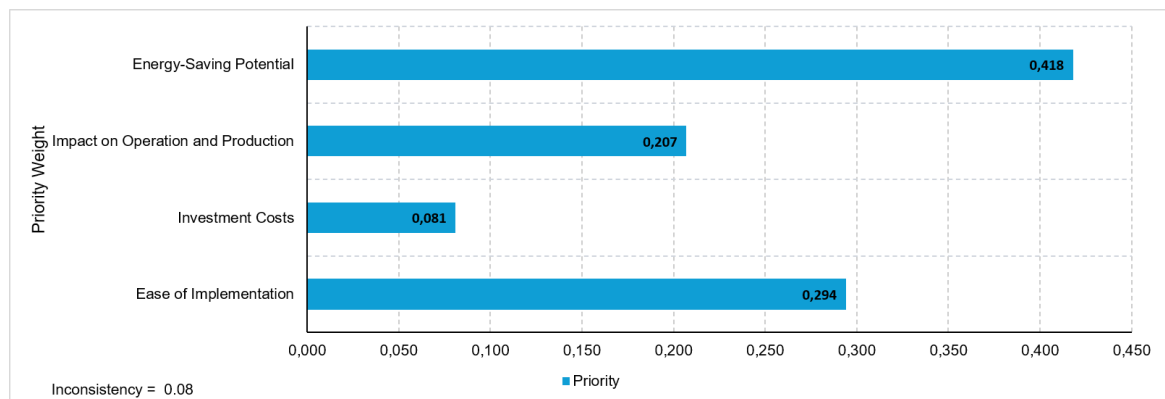


Figure 5. Combined Criteria Prioritization Results of Expert Respondents

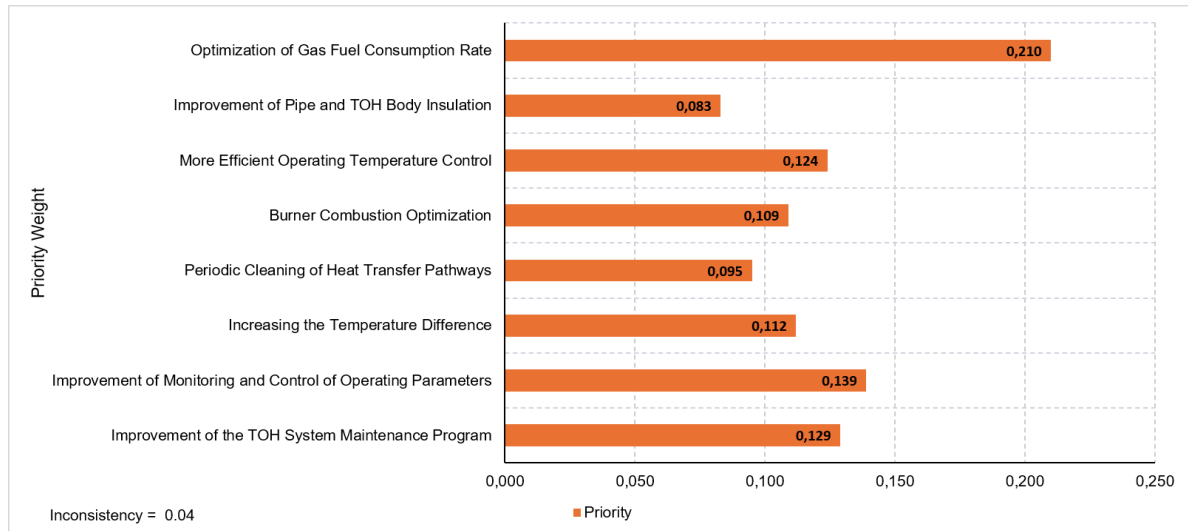


Figure 6. Priority Results of Alternative Levels Based on the Energy-Saving Potential Criterion

CONCLUSION

This study evaluated the performance of the Thermal Oil Heater (TOH) at PT XYZ using the direct method, linear regression modeling, the Energy Performance Indicator (EnPI), and the Analytic Hierarchy Process (AHP). The direct method revealed an average TOH efficiency of 65.78%, which remains below the company's internal target of 85%, indicating that TOH performance is not yet optimal. Linear regression modeling produced the equation $\eta = 1246.889 - 0.2428X_1 - 4.2929X_2$, demonstrating that gas flow rate and thermal oil inlet temperature together account for 98.69% of the variation in TOH efficiency ($R^2 = 0.986$). Model validation using MAPE yielded an average error of 2.05%, confirming very good predictive accuracy. The EnPI evaluation produced a baseline value of 1.58, serving as the reference for energy performance monitoring. The gap between the baseline EnPI (1.58) and the target EnPI at 85% efficiency (1.18) represents a potential reduction of 0.4 units of energy input per unit of useful heat output. Based on the performance evaluation, an energy-saving potential of 26% was identified, corresponding to a reduction in natural gas consumption of 1,884.67 Nm³ (67.85 MMBTU) per day. This translates into potential cost savings of IDR 11,528,766.06 per day (IDR 345,862,981.82 per month) and a reduction in carbon emissions of 3.60 tons CO₂ per day, representing a significant environmental and economic benefit at an industrial scale. The AHP analysis, based on assessments by expert respondents from management, supervisory, and operational levels, identified energy-saving potential as the highest-priority criterion. The top three prioritized improvement alternatives are optimization of gas fuel consumption rate (0.210), improvement of monitoring and control of operating parameters (0.139), and improvement of the TOH system maintenance program (0.129). These priorities are consistent with the regression and direct method findings, which confirm that gas flow rate is the primary driver of TOH efficiency.

REFERENCES

- [1] R. Saidur, N. A. Rahim, H. H. Masjuki, S. Mekhilef, H. W. Ping, and M. F. Jamaluddin, "End-use energy analysis in the Malaysian industrial sector," *Energy*, vol. 34, no. 2, pp. 153-158, 2009, doi: 10.1016/j.energy.2008.11.004.
- [2] Ministry of Energy and Mineral Resources Republic of Indonesia, *Handbook of Energy and Economic Statistics of Indonesia 2024*. Jakarta, Indonesia: Ministry of Energy and Mineral Resources Republic of Indonesia, 2025.

- [3] LOCALISE SDGs Indonesia, "Sustainable Development Goals," 2026. [Online]. Available: <https://localisesdgs-indonesia.org/17-sdgs>. [Accessed: Jun. 5, 2026].
- [4] A. Thumann and D. P. Mehta, *Handbook of Energy Engineering*, 8th ed. Boca Raton, FL, USA: CRC Press, 2021.
- [5] E. I. Gunawan, M. Ali, and H. Nurohmah, "Optimasi Thermal Oil Heater menggunakan PSO sebagai tuning PID controller," *Nucleus*, vol. 1, no. 2, pp. 53-64, 2022, doi: 10.32492/nucleus.v1i2.43.
- [6] A. F. M. Mokhtar and A. M. Mustafah, "Awareness of heat transfer fluid degradation in thermal oil heater in Malaysia manufacturing industries," *Science, Engineering and Health Studies*, vol. 15, p. 21040003, 2021, doi: 10.14456/sehs.2021.8.
- [7] I. Cahyadi, T. Hidayat, Y. Ahda, and T. Sutardi, "Enhancing energy efficiency of thermal oil system in gas processing plant," *AIP Conference Proceedings*, vol. 3069, no. 1, p. 020132, 2024, doi: 10.1063/5.0205761.
- [8] International Organization for Standardization, *ISO 50006:2023, Energy Management Systems: Evaluating Energy Performance Using Energy Performance Indicators and Energy Baselines*. Geneva, Switzerland: ISO, 2023.
- [9] R. Monika and I. Garniwa, "Energy audit and assessment of energy saving opportunities using Analytical Hierarchy Process in public health center buildings in Jakarta to optimize energy efficiency," *International Journal of Computer and Information Systems (IJCIS)*, vol. 6, no. 2, pp. 132-144, 2025, doi: 10.29040/ijcis.v6i2.236.
- [10] S. F. Dina, "The utilization of palm shells as a substitute for industrial fossil fuel on system Thermal Oil Heater: Energy conservation," *Jurnal Rekayasa, Teknologi Proses dan Sains Kimia (REPROKIMIA)*, vol. 1, no. 2, pp. 63-73, 2022.
- [11] E. Sarwono, M. C. Fatah, and I. M. I. M. Brunner, "Persamaan regresi linier berganda untuk memprediksi efisiensi boiler," *Jurnal Rekayasa Mesin*, vol. 15, no. 2, pp. 587-603, 2024, doi: 10.21776/jrm.v15i2.1179.
- [12] A. D. A. S. Budi, L. Septiana, and B. E. P. Mahendra, "Memahami asumsi klasik dalam analisis statistik: Sebuah kajian mendalam tentang multikolinearitas, heterokedastisitas, dan autokorelasi dalam penelitian," *Jurnal Multidisiplin West Science*, vol. 3, no. 1, pp. 1-11, Jan. 2024, doi: 10.58812/jmws.v3i01.878.
- [13] R. Mardiatmoko, "The importance of classical assumption testing in multiple linear regression analysis: A case study of developing an allometric equation for young kenari (*Canarium indicum* L.)," *Barekeng: Jurnal Ilmu Matematika dan Terapan*, vol. 14, no. 3, pp. 333-342, 2020, doi: 10.30598/barekengvol14iss3pp333-342.
- [14] P. G. Anggraini, P. W. C. Ayu, A. H. Saragih, and M. T. Dharsana, "Do Sharia and non-Sharia listing securities investors respond differently to tax avoidance," *Jurnal Akuntansi dan Keuangan Indonesia*, vol. 18, no. 1, Art. no. 3, Jun. 2021, doi: 10.21002/jaki.2021.03.
- [15] H. Glejser, "A new test for heteroskedasticity," *Journal of the American Statistical Association*, vol. 64, no. 325, pp. 316-323, 1969, doi: 10.1080/01621459.1969.10500976.
- [16] R. A. Wahyuni and A. Salim, "Pengaruh burnout academic terhadap perilaku konsumtif mahasiswa," *EduInovasi: Journal of Basic Educational Studies*, vol. 5, no. 1, pp. 578-590, 2025, doi: 10.47467/edu.v5i1.6633.
- [17] P. F. E. Adipraja and D. A. Sulisty, "Pemodelan sistem dinamik untuk prediksi intensitas hujan harian di Kota Malang," *Jurnal Ilmiah Teknologi Informasi Asia*, vol. 12, no. 2, pp. 137-146, 2018, doi: 10.32815/jitika.v12i2.272.
- [18] T. Rackow, T. Javied, T. Donhauser, C. Martin, P. Schuderer, and J. Franke, "Green Cockpit: Transparency on energy consumption in manufacturing companies," *Procedia CIRP*, vol. 26, pp. 498-503, 2015, doi: 10.1016/j.procir.2015.01.011.

- [19] International Organization for Standardization, ISO 50001:2018, Energy Management Systems: Requirements with Guidance for Use. Geneva, Switzerland: ISO, 2018.
- [20] D. Putra and M. Effendy, "Evaluasi konsumsi energi pada operasi kompresor menggunakan energy performance indicator type engineering model base on ISO 50006," *Jurnal Teknik Mesin*, vol. 12, no. 3, pp. 31-38, 2024.
- [21] G. Bruni, A. De Santis, C. Herce, L. Leto, C. Martini, F. Martini, M. Salvio, F. A. Tocchetti, and C. Toro, "From energy audit to energy performance indicators (EnPI): A methodology to characterize productive sectors: The Italian cement industry case study," *Energies*, vol. 14, no. 24, p. 8436, 2021, doi: 10.3390/en14248436.
- [22] T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*, 2nd ed. New York, NY, USA: Springer, 2012.
- [23] R. M. Hutabarat, "Transformer equipment assessment model using the Analytic Hierarchy Process to determine optimal maintenance," M.S. thesis, University of Indonesia, Jakarta, Indonesia, 2021.
- [24] U.S. Environmental Protection Agency, GHG Emission Factors Hub 2024. Washington, DC, USA: U.S. EPA, 2024. [Online]. Available: <https://www.epa.gov/climateleadership/ghg-emission-factors-hub>. [Accessed: June. 22, 2026].

BIOGRAPHIES OF AUTHORS



Arya Bima Putra received the S.T. degree in Mechanical Engineering from the National Institute of Science and Technology, Jakarta, Indonesia. He has been working in the field of mechanical and electrical engineering since 2013. He is currently a master's degree student at the Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia. His research interests include industrial energy management and renewable energy systems.



Faiz Husnayain received the S.T. and M.Sc. degrees in Electrical Engineering from Universitas Indonesia, Indonesia, and NTUST, Taiwan, in 2010 and 2013, respectively, and the Ph.D. degree from Shizuoka University, Japan, in 2023. Since 2024, he has been an Assistant Professor with the Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia. His research interests include energy conversion, motor control, smart grid, renewable energy integration, and power electronics. He is a member of IEEE.