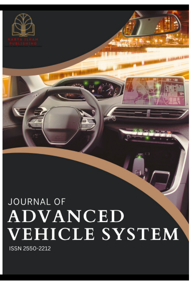
KARYA ILHAM PUBLISHING
CONNECTING MINDS, BRIDGING IDEAS, INSPIRING READERS

Journal of Advanced Vehicle System

Journal homepage:
https://karyailham.com.my/index.php/javs/index
ISSN: 2550-2212



Performance Evaluation of Jenbacher Type 3 Gas Engine Based on Heat Rate and Thermal Efficiency According to Electric Power Research Institute (EPRI) Standard at Bawean Island Gas Power Plant

Dava Maulana Yudha[1], Singgih Dwi Prasetyo[1,*], Pranoto Agung Sucipto[2]

[1] Power Plant Engineering Technology, Faculty of Vocational Studies, State University of Malang, Malang 65145, Indonesia
[2] Planning and Control Division, PT.PLN Nusantara Power Services, Bawean Island Gas Power Plant, 61181, Indonesia

ARTICLE INFO

Article history:
Received 1 January 2026
Received in revised form 28 February 2026
Accepted 30 May 2026
Available online 11 June 2026

Keywords:

Jenbacher type3; gas power plant; heat rate; thermal efficiency; part-load operation; Electric Power Research Institute (EPRI); fuel consumption optimization

ABSTRACT

Gas engine power plants are widely utilized in isolated and small-grid systems due to their operational flexibility and relatively high efficiency. However, performance degradation frequently occurs under part-load conditions, significantly affecting heat rate and thermal efficiency. This study evaluates the performance of a Jenbacher Type 3 gas engine based on heat rate and thermal efficiency parameters in accordance with Electric Power Research Institute (EPRI) standards. Operational data were collected at various load conditions ranging from low load to peak load at **PLTMG Bawean island**. Heat rate and thermal efficiency were calculated using fuel consumption rate and electrical output measurements. The results indicate that heat rate increases significantly under low-load operation, leading to a noticeable reduction in thermal efficiency. At peak load conditions, the engine demonstrates optimal performance and complies with EPRI efficiency benchmarks. The findings provide a technical evaluation reference for optimizing gas engine operation and minimizing fuel consumption in small-scale power generation systems.

1. Introduction

Gas-fired power plants (PLTMG) are one of the primary solutions for providing electricity in small-scale and isolated power systems due to their operational flexibility, rapid startup times, and relatively high efficiency compared to other conventional power plants [1]. Reciprocating gas engines, such *as the Jenbacher Type 3*, are widely used in island power systems because they can operate stably under varying loads and have good load-following capabilities. In practice, the performance of a gas engine is not only determined by its installed capacity but is also significantly influenced by actual operating conditions, such as load variations, the characteristics of the fuel gas, and the thermal and mechanical parameters that occur during the combustion process [2]. In the Bawean Island gas-fired power plant system, each gas engine unit has an installed capacity of 1 MW,

---

[*] *Corresponding author.*
E-mail address: singgih.prasetyo.fv@um.ac.id

with a total of three operational units. However, under actual operating conditions, the engines do not always operate at full load but rather within a load range of approximately 700–850 kW, equivalent to 70–85% of maximum capacity. This load variation is influenced by fluctuations in electricity demand within the distribution system, which can be observed through feeder current data and the generated electrical energy. Operational data obtained from the Central Control Room (CCR) and data loggers include various key parameters such as output power, natural gas consumption, temperature, pressure, and other electrical parameters. To provide an overview of the types of data used in this study, the main operational parameters obtained from the power plant's recording system are summarized in Table 1.

Table 1
Operational parameters of the gas engine used in this study
Parameter Used

Parameter	Description	Unit
Power Output	Electrical energy generated by the engine	KW
Gas Flow	Gas fuel flow rate	m^3/h
Electrical Energy	Total energy generated	kWh
Gas Temperature	Inlet gas fuel temperature	°C
Gas Pressure	Gas supply pressure	bar
Voltage	Generator output voltage	V
Current	Load current	A
Power factor (cos ϕ)	Electrical power efficiency	-
Oil temperature	Engine lubrication condition	°C
Coolant pressure	Engine cooling system	bar

The performance evaluation of gas turbines is generally conducted using the heat rate and thermal efficiency. The heat rate indicates the amount of fuel energy required to generate one unit of electrical energy, while thermal efficiency indicates the degree of energy conversion from fuel to electrical energy. Previous research has shown that the heat rate tends to increase under low-load conditions due to suboptimal combustion, leading to a decrease in thermal efficiency [3]. State that part-load operation causes an increase in specific fuel consumption as well as uneven temperature distribution within the combustion system. In industrial practice, one of the standards used to evaluate the performance of gas turbine power plants is the standard issued by the Electric Power Research Institute (EPRI). This standard provides an evaluation method that correlates power output, fuel consumption, and overall system efficiency [1-4].By using operational data such as gas flow rate, electrical power, and fuel calorific value, the heat rate and thermal efficiency parameters can be calculated directly.

Although many methods for evaluating gas turbine performance have been developed, the application of analysis based on actual field data in isolated power systems remains relatively limited. Specifically at the Bawean Island Gas-Fired Power Plant, few studies have integrated daily operational data such as output power, gas consumption, temperature, pressure, and other system parameters to evaluate engine performance based on EPRI standards. Furthermore, the impact of load variations from low-load conditions to peak load on heat rate and thermal efficiency values has not been thoroughly analysed using real-time data from the CCR. Based on this, this study is significant in providing a *technical evaluation of the performance of the Jenbacher Type 3 (figure 2) gas engine based on actual operational data*. Therefore, the objective of this study is to analyse the performance of the Jenbacher Type 3 gas engine based on heat rate and thermal efficiency parameters under conditions ranging from low load to peak load, in accordance with Electric Power Research Institute (EPRI) standards.

2. Methodology

2.1 Data Acquisition and Operational Parameter Identification

This study employs a quantitative approach based on operational data obtained directly from the Central Control Room (CCR) system via the Human Machine Interface (HMI) display on a Jenbacher Type 3 **fig. 2** engine operating in isolated mode. The collected data reflects the actual operating conditions of the engine, thereby serving as a representative basis for performance analysis.

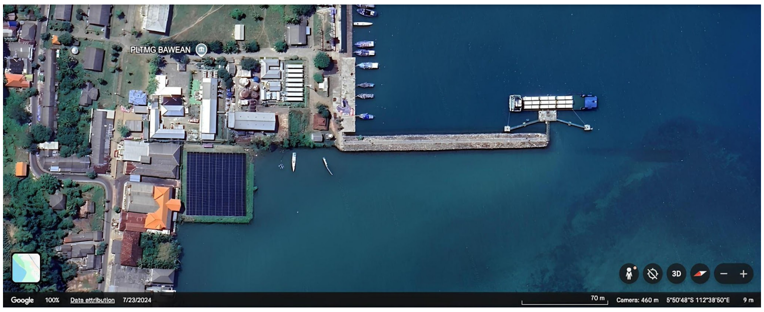


Fig. 2. *Jenbacher* type 3 engine

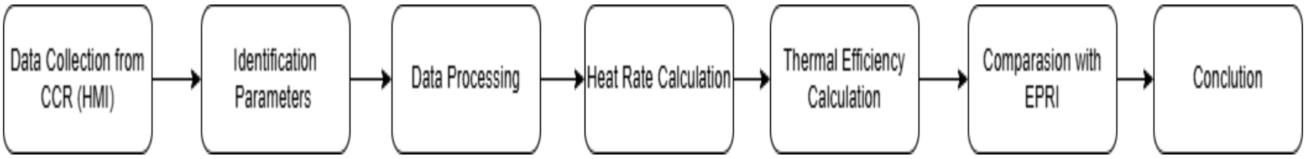


Fig. 3. Research methodology flowchart

The primary parameters observed include power output, reactive power, apparent power, frequency, and power factor. Additionally, process parameters such as exhaust gas temperature, system pressure, and combustion conditions are recorded as supporting variables that influence engine performance. Data obtained from the CCR was selected because it has a high level of accuracy and is real-time, thus capable of directly depicting the engine's operational performance. The power output values obtained are then used as the primary parameters in calculating the heat rate and thermal efficiency Figure 4.

Fig. 4. Parameters display on CCR *Jenbacher type 3*

Table 2
Parameter CCR

Parameter	Symbol	Value	Unit	Description
Power Output	P	850	Kw	Electrical power generated by the engine
Reactive Power	Q	320	kVAr	Reactive power of the electrical system
Apparent Power	S	918	kVA	Total apparent power supplied by the generator
Frequency	F	49.9	Hz	System operating frequency
Power Factor	cos ϕ	0.936	-	Ratio of active power to apparent power
Engine Speed	N	1497	Rpm	Rotational speed of the engine
Exhaust Gas Temperature	T_exh	537	°C	Temperature of exhaust gases from combustion
Charge Air Temperature	T_ca	85.2	°C	Temperature of compressed intake air
Gas Pressure	P_gas	1.33	Bar	Pressure of supplied fuel gas
Cooling Water Temperature	T_cw	69.8	°C	Temperature of engine cooling water
Mixture Temperature	T_mix	50.0	°C	Temperature of air-fuel mixture before combustion
Charge Air Pressure	P_ca	2.36	Bar	Pressure of compressed intake air
Oil Temperature	T_oil	83.2	°C	Temperature of lubricating oil
Oil Pressure	P_oil	4.01	Bar	Pressure of lubricating oil system

2.2 Data Processing and Heat Rate Calculation Method

The collected operational data is then processed to calculate the heat rate, which serves as the primary indicator of fuel efficiency. The calculation is performed using the following equation:

$$Heat\ Rate = \frac{V_{gas}\ X\ LHV}{P_{output}}$$

[7], [8]

Where is:

- V= gas flow rate (m^3/h)
- LHV = Lower Heating Value of gas (kJ/m^3)
- P= output power (kW)

The heat rate value obtained indicates the amount of fuel energy required to generate one unit of electrical energy. The lower the heat rate value, the more efficient the engine's performance.

2.3 Data Processing

Operational data obtained from the CCR is then subjected to a selection and validation process to ensure that the data used reflects normal operating conditions. Data excluded from the analysis includes conditions during startup, shutdown, and system disturbances.
The data is then classified based on the machine's load level, as follows:

- ***Low load (±700 kW)***
- ***Medium load (±800 kW)***
- ***High load / near peak load (±850–1000 kW)***

This categorization aims to analyse the impact of load variations on engine performance, particularly regarding fuel consumption and energy efficiency.

2.4 Heat Rate Calculation Based on the EPRI Standaritation

Heat rate is one of the key parameters in evaluating the performance of gas-fired power plants, indicating the efficiency of fuel energy utilization in generating electricity. Based on the approach recommended by the Electric Power Research Institute (EPRI), heat rate is defined as the amount of fuel energy required to generate one unit of net electrical output. This parameter is widely used as a power plant performance indicator, particularly in evaluating operational efficiency under various load conditions, including partial load conditions [2].

In this study, heat rate calculations were performed using actual operational data obtained from the Central Control Room (CCR) system, which includes the fuel gas flow rate and generator output power parameters. The use of this actual data aims to obtain heat rate values that represent the real operating conditions of the Jenbacher Type 3 engine.

The calculation is based on the total fuel gas flow rate used by each engine, as shown in the operational parameters table. This value is then converted into input energy by taking into account the lower heating value (LHV) of the fuel gas. The heat rate equation used in this study is expressed as follows:

Table 3
Table data realtime from excel (flow gas,gas temp,press gas*)*

FLOW GAS (Qb)	M3/h	702,00	702,10	700,50	699,10	698,70	698,90	706,60	704,00	652,70	652,00	657,10	651,20	659,60
GAS TEMP.	°C	30,17	32,25	32,17	33,36	33,87	33,77	34,8	35,75	38,36	35,37	33,42	34,31	34,82
Press Gas	BAR	160	160	160	155	155	150	150	150	145	145	145	140	140
Total Flow Gas Engine 1	m^3	14689274,8	14689274,8	14689274,8	14689274,8	14689274,8	14689274,8	14690640,0	14690640,0	14690640,0	14690640,0	14691517,4	14691735,5	14691954,8

$$HR = \frac{V_{gas}\, x\, LHV}{P} \; \textbf{[9]}$$

Parameters:
- ***HR = Heat rate (kJ/kWh)***
- ***Qb = Gas flow rate (m³/h)***
- ***LHV = Lower Heating Value of gas (kJ/m³)***
- ***P = Output power (kW)***

In this equation,V_{gas} represents the fuel gas flow rate in standard cubic meters per hour (SM³/h), indicating the volume of gas consumed during the combustion process. This parameter serves as the primary indicator of energy input into the system. The Lower Heating Value (LHV) value indicates the specific energy content of the fuel gas in kJ/m³, which is used to convert the gas volume into thermal energy. Meanwhile,P_{output} represents the generator's output power in kilowatts (kW), which describes the electrical energy generated by the engine. The relationship between these three parameters determines the heat rate value, where the ratio of fuel input energy to electrical output energy serves as the primary indicator of the system's efficiency level [4,10].

This approach is based on the calculation principles used in the EPRI standard, where the accuracy of input data—such as fuel flow measurements and power output—is critical to the precision of the evaluation results. Consequently, the heat rate value obtained can serve as a basis for efficiency analysis and comparison against industry standards

2.5 Thermal Efficiency Calculation Based on the EPRI Standard

Thermal efficiency is a key parameter used to evaluate a power generation system's ability to convert the chemical energy of fuel into electrical energy. Based on the approach recommended by the Electric Power Research Institute (EPRI), thermal efficiency has an inverse relationship with heat rate, where an increase in efficiency results in a lower heat rate value [1]. Therefore, this parameter is used as a primary indicator in assessing power plant performance under various operating conditions [2].

In this study, thermal efficiency calculations were performed using actual operational data obtained from the Central Control Room (CCR) system, which includes generator output power and fuel gas flow rate parameters. This approach allows for the evaluation of engine performance based on real operating conditions, particularly under partial load conditions commonly encountered in field operations. Thermal efficiency is calculated based on the ratio of the electrical energy produced to the fuel energy input into the system. The fuel input energy is calculated from the gas flow rate multiplied by the lower heating value (LHV). The thermal efficiency equation used in this study is expressed as follows [1,3]:

$$\eta = \frac{P}{V_{gas\ X\ LHV}} X\ 100\%\ [2]$$

Parameter:

- ***η = Thermal efficiency (%)***
- ***P = Output power (kW)***
- ***Qb = Gas flow rate (m³/h)***
- ***LHV = Lower Heating Value of gas (kJ/m³)***

In this equation, P represents the generator's output power in kilowatts (kW), which describes the electrical energy produced by the engine. The parameter V_{gas} represents the fuel gas flow rate in standard cubic meters per hour (SM³/h), indicating the amount of fuel consumed during the combustion process. Meanwhile, the Lower Heating Value (LHV) represents the specific energy content of the fuel gas in kJ/SM³, used to convert the gas volume into thermal energy. These three parameters form the relationship between input and output energy that determines the system's thermal efficiency [2,3].

According to performance evaluation standards developed by EPRI, thermal efficiency is used as the primary indicator for assessing power plant performance under actual operating conditions. A high efficiency value indicates that fuel energy is optimally utilized in the power generation process. However, under partial load conditions, EPRI identified a decrease in thermal efficiency caused by increased specific fuel consumption and uneven temperature distribution within the combustion chamber [1].

Therefore, an analysis of thermal efficiency across various load levels from low load to peak load is essential for understanding the performance characteristics of the Jenbacher Type 3 engine (figure 2). The results of the thermal efficiency calculations in this study were then compared with the performance standards recommended by EPRI to identify performance deviations and potential opportunities for operational optimization of the engine [1,2].

2.6 Data Analysis Procedure

Data analysis in this study was conducted by comparing gas engine performance parameters under various load conditions, ranging from low load to near peak load. Operational data obtained from the Central Control Room (CCR) system and the gas flow measurement system were processed to calculate the heat rate and thermal efficiency values under each operating condition. This approach aims to evaluate fuel efficiency based on the actual operating conditions of the *Jenbacher Type 3 engine* ***(Figure 2)*** [11,12].

Furthermore, an analysis of the relationship between power output and fuel consumption (gas flow rate) was conducted to identify the engine's performance characteristics. This relationship was used to assess operational efficiency at each load level and to determine trends in performance changes in response to load variations. The calculation results were then visualized in graphical form to facilitate data interpretation and the identification of patterns in the relationships between parameters.

The results of the analysis presented in this study include the relationship between engine load and heat rate, the relationship between engine load and thermal efficiency, and the relationship between power output and fuel consumption. These three forms of analysis are used to provide a comprehensive overview of engine performance under various operating conditions. To ensure that the research process proceeds systematically and in a structured manner, these analysis stages follow a research workflow outlined in a flowchart, as shown in Figure 4. The flowchart illustrates the entire research process, from data collection and data processing to the calculation of performance parameters, and finally to the analysis and interpretation of results.

Figure 3 shows the research methodology flowchart used in this study. The process begins with the collection of engine operational data via the CCR system (Human Machine Interface), followed by the identification of key parameters such as power output, gas flow, and other supporting parameters. The data obtained is then processed to calculate the heat rate and thermal efficiency values. These calculated results are then compared with the standards recommended by EPRI to evaluate engine performance. The final stage of this process involves analysis and drawing conclusions based on the calculations and comparisons performed.

3. Results and Calculation

3.1 Engine Operational Data

Operational data for *the Jenbacher Type 3 engine* was obtained from the Central Control Room (CCR) system and the gas fuel consumption logging system during normal operating conditions. The data used in this study represents the actual operating conditions of the engine at various load levels, making it suitable as a basis for performance analysis and system efficiency evaluation.

The main parameters analyzed include power output, gas flow rate, gas temperature, and gas pressure. These parameters were selected because they have a direct influence on the combustion process and energy conversion within the engine. Power output represents the electrical energy generated, while gas flow rate indicates the amount of input energy used. Gas temperature and pressure serve as supporting parameters that influence combustion quality and engine operational stability

Observations indicate that the engine output power remains within a relatively stable range of approximately 750–850 kW, suggesting that the engine operates under controlled load conditions. However, the fuel gas flow rate exhibits more significant variations, ranging from 651 to 707 SM^3/h. This fluctuation in fuel consumption indicates discrepancies in operational conditions despite the relatively constant power output.

The key findings demonstrate that an increase in fuel consumption is not consistently accompanied by a proportional increase in power output. This suggests a decline in combustion efficiency under certain conditions, which may be attributed to factors such as suboptimal air-fuel distribution, partial load conditions, or variations in operating parameters, including gas temperature and pressure. Systemically, these conditions lead to an increase in specific fuel consumption, which directly elevates the heat rate and reduces thermal efficiency.

The relationship between fuel consumption and power output is a **vital metric** in assessing engine efficiency. Analyzing these variables establishes a strong basis for heat rate and thermal efficiency calculations, offering insights into **optimization opportunities** for gas-engine power plants.

Table 4
Operational data of *Jenbacher Type 3* engine based on actual CCR and gas measurement data

No	Power Output (kW	Gas Flow (Sm³/h	Gas Temp (°C)	Gas Pressure (bar)
1	850	698.70	33.87	1.55
2	850	698.90	33.77	1.50
3	**850**	**706.60**	**34.80**	**1.50**
4	850	704.00	35.75	1.50
5	850	652.70	38.36	1.45
6	850	652.00	35.37	1.45
7	850	657.10	33.42	1.45
8	**850**	**651.20**	**34.31**	**1.40**
9	850	659.60	34.82	1.40

Based on Table 4, it can be seen that although the engine's output power remains relatively constant, gas fuel consumption varies significantly. **The highest gas consumption value recorded was 706.60 Sm³/h, while the lowest was 651.20 Sm³/h.** This variation indicates that engine operating efficiency is not always constant at the same output power. Factors such as gas temperature, supply pressure, and combustion conditions within the engine can affect the amount of fuel required to generate a specific amount of electrical power.

In addition, **the gas temperature ranged from 33–38 °C and the gas pressure ranged from 1.40–1.55 bar**, indicating that fuel supply conditions were within normal operating limits. Thus, variations in fuel consumption were influenced more by engine performance characteristics than by external disturbances. This operational data is then used to calculate the heat rate and thermal efficiency as key indicators of gas engine performance.

3.2 Heat Rate Analysis

A heat rate analysis was conducted to evaluate the efficiency of gas fuel utilization in generating electrical energy in the Jenbacher Type 3 gas engine. This parameter indicates the amount of fuel energy required to produce one unit of electrical energy, making it a key indicator of power plant performance. In this study, the Lower Heating Value (LHV) of the gas used is 35,000 kJ/Sm³.

Table 5
Result heat rate calculation based on operational data

No	Power (kW)	Gas Flow (Sm³/h)	Heat Rate (kJ/kWh)	Notes
1	850	698.70	28,77	
2	850	698.90	28,78	
3	**850**	**706.60**	**29,08**	**The higher consumption gas**
4	850	704.00	28,99	
5	850	652.70	26,88	
6	850	652.00	26,85	
7	850	657.10	27,06	
8	**850**	**651.20**	**26,81**	**The lowest consumption gas**
9	850	659.60	27,17	

Based on the result in Table 5, the heat rate values range from 26,800 to 29,100 kJ/kWh. **The highest value occurs at a natural gas consumption rate of 706.60 Sm³/h**, **while the lowest value occurs at a consumption rate of 651.20 Sm³/h**. These results indicate that an increase in fuel consumption at the same output power leads to an increase in the heat rate value, indicating a decrease in system efficiency. Conversely, lower fuel consumption results in a smaller heat rate value, indicating more optimal engine performance Although the engine's output power remains relatively constant at around 850 kW, variations in the heat rate indicate that engine efficiency is influenced by operating conditions such as gas temperature, supply pressure, and the stability of the combustion process. This suggests that the engine does not always operate under optimal conditions and that there is still potential for improving efficiency through optimization of the operating system.

3.3 Thermal Efficiency Analysis

A thermal efficiency analysis was conducted to determine the ability of the *Jenbacher Type 3 gas engine* to convert fuel energy into electrical energy. Thermal efficiency is a key parameter in evaluating power plant performance because it indicates how effectively fuel energy is utilized,result of **figure 5 and table 6.**

The equation shows that thermal efficiency is inversely proportional to the heat rate. The lower the heat rate, the higher the thermal efficiency.

Table 6
Thermal efficiency calculated based on operational data

No	Heat Rate (kJ/kWh)	Thermal Efficiency (%)
1	28,77	12.51
2	28,78	12.50
3	**29,08**	**12.37**
4	28,99	12.40
5	26,88	13.39
6	26,85	13.40
7	27,06	13.29
8	**26,81**	**13.41**
9	27,17	13.24

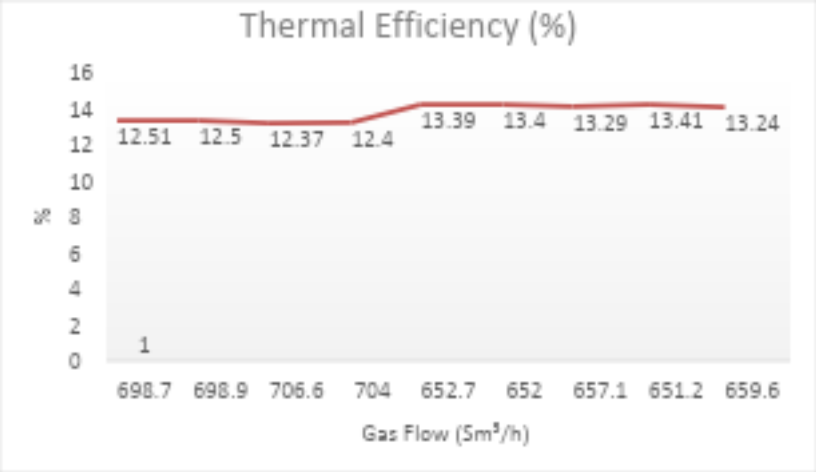
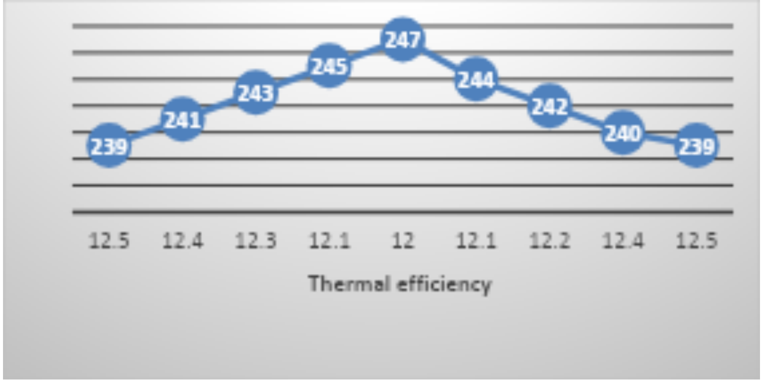


Fig. 5. Result graphic of thermal efficiency



The thermal efficiency of each engine ranges from 12.37% to 13.41%, which is relatively low. This is to be expected since the calculation is performed per engine, not as a combined total of all units, so heat loss and mechanical loss have a greater impact. Efficiency tends to increase slightly as gas flow decreases from its peak, indicating that the engine operates more optimally at certain loads. Low efficiency values are not an indication of damage, but rather are related to operating conditions, engine load, and the characteristics of *the Jenbacher gas engine*. For an overall performance assessment, plant efficiency must be calculated by summing the output of all engines, as a combined evaluation better reflects the plant's actual performance than individual engine measurements [11].

Based on Table 5 and figure 5, the thermal efficiency values range from 12.37% to 13.41%. **The highest efficiency was achieved under conditions with the lowest heat rate, which was 26,810 kJ/kWh**, **while the lowest efficiency occurred under conditions with the highest heat rate of 29,080 kJ/kWh.** These results indicate that thermal efficiency is significantly influenced by gas fuel consumption. Under conditions where fuel consumption increases to produce the same power, system efficiency decreases. Conversely, lower fuel consumption results in higher efficiency. [7], [9], [13]

Although the engine's output power remains relatively constant at around 850 kW, variations in thermal efficiency indicate that the engine's operating conditions are not always at the optimal point. This can be influenced by factors such as fluctuations in fuel supply, gas temperature and pressure, as well as combustion process characteristics.

These results are consistent with previous heat rate analyses, which showed that engine performance can vary even under identical load conditions. This indicates that controlling operating conditions is crucial for maintaining optimal engine efficiency.

Additional Note on Thermal Efficiency Results (must be noted)

It should be noted, though, that the values obtained in this study for thermal efficiency are relatively lower compared to the theoretical values of the typical gas engines. This is because the fuel consumption values used in the analysis represent the total system gas flow and not the fuel consumption rate per unit engine. under actual conditions, the values of the gas flows, as monitored, represent the overall fuel consumption or the fuel consumption based on a certain basis, not the actual fuel consumption rate per unit engine. At the same time, the output power used in the analysis is the output power of a single unit engine, Engine 1, and is approximately 850 kW.

This discrepancy in the values used in the analysis, namely the fuel consumption and the output power, makes the obtained value of the input energy relatively higher than the output energy, hence the high heat rate and the lower thermal efficiency.

In addition, other factors that can contribute to low thermal efficiency include:

- fluctuations in the gas fuel supply during operation
- variations in gas temperature and pressure
- combustion conditions that are not always optimal
- as well as the engine’s partial load characteristics

The thermal efficiency values obtained in this study are more appropriately used as indicators of relative performance based on available operational data, rather than as a representation of the gas engine’s absolute efficiency. To obtain a more accurate thermal efficiency value that approximates ideal conditions, it is necessary to use specific fuel consumption data per engine measured directly and synchronized with power output data at the same time.

3.4 Discussion Based on EPRI

Based on measurement data for gas flow, pressure, temperature, and power output for each *Jenbacher Type 3 engine*, a comparison of the performance of each unit was conducted, along with an evaluation of thermal efficiency in accordance with EPRI (Electric Power Research Institute) guidelines. This comparison aims to assess performance consistency, the relationship between gas flow and power output, and the resulting heat rate.

Table 7
Result engine

Engine	Gas Flow (SM^3/h)	Output Power (kW)	Heat Rate (kJ/kWh)	Thermal Efficiency (%)
1	244,7	850	10964	12,51
2	239,4	850	11032	12,5
3	247,4	850	10987	12,37

Note: The data above represents the average of several measurements, showing minimal variation between engines under steady-state operating conditions **(coverall the result**)[3,4]

3.4.1 Comparison graph of thermal efficiency vs. gas flow

(Graphs can be taken from the previous file; example: line chart of Thermal Efficiency (%))

- The graph shows a slight increase in thermal efficiency as gas flow decreases from its peak value, indicating that the engine operates more optimally at a specific load.
- All engines exhibit relatively stable efficiency, ranging from 12–13.5%, consistent with the characteristics of the Jenbacher Type 3 engine [13].

3.4.2 Performance analysis based on EPRI (analysis by study at location)

- Thermal Efficiency:

Calculations based on the number of engines have shown low thermal efficiency because the analysis does not take into account all the engines in the plant, which is known as plant efficiency. EPRI has noted that thermal efficiency is more applicable when the entire plant is taken into account, and the heat and mechanical losses occur throughout the system.

- Heat Rate:

The heat rate per engine varies from 10,964 to 11,032 kJ/kWh, and this shows that the energy consumption is relatively high. Small variations from one engine to the next indicate consistent performance and control of gas flow.

- Gas Flow and Output Power:

There is a relationship between gas flow rate and thermal efficiency. Too much gas flow rate does not necessarily mean maximum efficiency, as there is a loss of efficiency in the form of heat. The optimum rate of gas flow, as designed for the engine, will give maximum efficiency.

- Engine Comparison:

Based on the data, the thermal efficiency of **Engine 1 is the highest at 12.51%,** followed by **Engine 2 at 12.50%**, and then **Engine 3 at 12.37%.** These figures show minor differences, which could be attributed to minor differences in the control of gases, conditions of the cylinders, and

3.4.4 Conclusion on gas flow and heat rate utilization

Based on the results of the comparative performance analysis of the three *Jenbacher Type 3 engines*, it can be concluded that the distribution of gas flow among the engines is relatively even, with **values ranging from 239.40 to 247.36 SM³/h**. Nevertheless, these slight differences in gas flow rate still affect the heat rate and thermal efficiency of each engine. Engines with higher gas consumption tend to produce a higher heat rate, indicating increased fuel energy consumption to generate the same power. Conversely, engines with lower gas consumption exhibit a lower heat rate, making them more efficient in fuel energy utilization [13,14].

Table 8
Probability between calculation and EPRI

Parameter	***Calculation 1***	***Calculation 2***	***Calculation 3***	***Calculation 4***	***Calculation 5***	***Calculation 6***	***Calculation 7***	***Calculation 8***	***Calculation 9***	***Standart EPRI***	***Description***
Power Output (kW)	*850*	*850*	*850*	*850*	*850*	*850*	*850*	*850*	*850*	*±850 kW*	*Stabil*
Gas Flow (SM3/h)	*239*	*241*	*243*	*245*	*247*	*244*	*242*	*240*	*239*	*-*	*Distribution*
Heat Rate (kJ/kWh)	*10900*	*10920*	*10950*	*11000*	*11050*	*11010*	*10970*	*10930*	*10900*	*8000–10000*	*Highest standar (parsial load)*
Thermal Efficiency (%)	*12.5*	*12.4*	*12.3*	*12.1*	*12.0*	*12.1*	*12.2*	*12.4*	*12.5*	*35–45*	*Lowest (per engine)*

Operational conditioni	*Normal*	*Normal*	*Normal*	*Normal*	*Normal*	*Normal*	*Normal*	*Normal*	*Normal*	*Optimal (full load)*	*none abnormalitas*

In Table 8 overall, the thermal efficiency values obtained remain relatively low, at around 12–13%. This is due to the analytical approach being conducted at the individual engine level rather than at the overall plant level. Under actual operating conditions, system efficiency would be more accurately assessed by calculating it based on the total power output and total fuel consumption of all engines simultaneously, as recommended in the EPRI reference. Therefore, the efficiency values obtained in this study better represent the individual performance of each engine rather than the overall performance of the power generation system [15].

Furthermore, the relationship between gas flow and heat rate indicates that an increase in gas flow does not necessarily lead to an improvement in performance. This indicates that there exists an optimum limit in the amount of fuel supplied, such that any amount of gas in excess of the optimum merely increases the amount of energy lost in the form of heat without a corresponding contribution to performance. This indicates the importance of proper gas flow control in order to maintain a balance between fuel consumption and performance. Overall, the results of the analysis performed in this chapter confirm that optimization of gas flow distribution among the engines has a significant effect on performance, in terms of reducing the heat rate and increasing thermal efficiency. Therefore, precise control of the operation of the engines, including synchronization of fuel supply and engine load, is necessary in order to attain efficient operating conditions and optimum performance in accordance with the characteristics of the *Jenbacher Type 3 engine.*

4. Conclusion

4.1 Conclusion

The performance of the Jenbacher Type 3 engines demonstrates stable operating conditions, with an average power output of ±850 kW per unit. **Gas flow distribution across the three engines is relatively even, ranging from 239.40 to 247.36 SM³/h**, indicating that the fuel distribution system is functioning properly and there are no supply imbalances between the engines. The heat rate calculation, derived from the ratio of fuel energy consumption to electrical power, shows relatively consistent values across the engines. The heat rate values are in the range of ±10,900–11,050 kJ/kWh, indicating that fuel consumption for generating electrical energy is stable and shows no significant deviations. This consistency is also supported by operational parameters such as gas pressure and temperature, which remained within normal ranges during data collection.

However, the calculated thermal efficiency yields relatively low values, ranging from 12% to 13%. This value is influenced by the calculation method, which is performed per engine (partially) rather than based on the total power generation system. According to EPRI references, efficiency calculated individually tends to be lower because it does not account for the overall energy integration within the plant. Therefore, this efficiency value better represents the performance of each individual engine rather than the total system efficiency. Overall, no indications of abnormal performance were found in the engines. All three engine units are operating under normal conditions with minor parameter variations that remain within tolerance limits. This indicates that the power generation system is operating optimally from an operational standpoint, although there is potential for efficiency improvement if evaluation and optimization are conducted at the plant-wide level.

The example used is low fuel consumption 651.20 Sm³/h with a relatively low heat rate of 26.81 kJ/kWh, and a thermal efficiency of 13.41%, which is the highest percentage among the nine other calculations.

4.2 Discussion Summary

The analysis results indicate that there is a direct relationship between gas flow and engine performance, particularly with regard to heat rate and thermal efficiency. Based on the data obtained, the gas flow distribution in each engine falls within a relatively uniform range, namely approximately 239–247 SM³/h, resulting in a stable power output in the range of ±850 kW. This indicates that the fuel distribution system is functioning properly and there is no imbalance in gas supply between engines.

The thermal efficiency values obtained in this study are relatively low, at approximately 12-13%. This low efficiency is not due to a decline in engine performance but rather because the calculations were performed at the individual engine level, not for the power generation system as a whole. At the individual level, various factors such as heat loss, friction loss, and combustion imperfections have a more significant impact on efficiency. When compared to references from the Electric Power Research Institute (EPRI), *the performance of the Jenbacher Type 3 engine* in this study remains within acceptable limits for partial-load operation. EPRI states that the optimal efficiency of gas engines ranges from 35–45% with a heat rate of approximately 8,000–10,000 kJ/kWh under full-load conditions. Meanwhile, the study results show a higher heat rate, approximately 10,900–11,050 kJ/kWh, which is inversely proportional to the lower efficiency value.

This different indicates that the engine is not operating under overall optimal conditions, **but rather under partial-load conditions commonly encountered in field operations**. Therefore, these research results remain valid as a representation of operational performance per engine and can serve as a basis for evaluating efficiency improvements, particularly through load distribution optimization and integrated system operation (total plant evaluation).

4.3 Recommendations
4.3.1 Operational optimization

Based on the analysis results, *the performance of the Jenbacher Type 3* engine indicates stable operating conditions; however, it has not yet reached optimal efficiency levels. Therefore, it is recommended to optimize load sharing among the engines so that each unit can operate close to full load conditions. Operating at higher loads will help improve thermal efficiency and reduce the heat rate. additionally, periodic evaluation of the fuel supply system is necessary to ensure that gas flow distribution remains even. Although gas distribution was already considered good in this study, minor deviations over the long term can affect overall engine performance.

4.3.2 System-level evaluation

This study shows that efficiency calculations at the individual engine level yield lower values compared to industry standards. Therefore, it is recommended that performance evaluations be conducted at the system level (total plant evaluation) to accurately reflect the actual efficiency of the power plant as a whole. This approach aligns with recommendations from EPRI, which states that the efficiency of gas engine power plants is more representative when calculated in an integrated manner, including waste heat recovery, cooling systems, and other supporting equipment.

4.3.3 Future research

For future research, *it is recommended to include additional parameters such as exhaust gas temperature, system pressure, and combustion efficiency*. These parameters can provide a more comprehensive picture of engine performance. Additionally, further research could focus on a comparative analysis between partial-load and full-load operations, thereby quantitatively determining the effect of load on efficiency and heat rate. The use of simulation methods or system modeling could also serve as an alternative approach to enhance the accuracy of the analysis.

5. Final Conclusion

Based on the results of the performance analysis of the Jenbacher Type 3 engines, it can be concluded that all engine units are operating under stable conditions with an average power output of approximately ±850 kW. The gas flow distribution across each engine falls within a relatively uniform range, specifically around 239–247 SM³/h, indicating that the fuel supply system is functioning properly without any significant imbalances between units. This indicates that the engines' operational performance is within normal parameters, and no abnormal indications were detected during data collection.

Calculation results show that the heat rate is in the range of approximately 10,900–11,050 kJ/kWh, with a thermal efficiency of ±12–13%. This efficiency value is relatively low when compared to industry standards, such as those recommended by EPRI, which typically range from 35–45% under full-load conditions. However, this discrepancy stems from the calculation approach applied at the individual engine level, and thus does not yet represent the overall efficiency of the power generation system. Overall, the results of this study indicate that *the performance of the Jenbacher Type 3 engine* remains within acceptable operating limits under partial-load conditions. Therefore, further evaluation is recommended at the system level (entire plant) to obtain a more representative picture of efficiency. This study can serve as a foundation for efforts to optimize operations and improve the efficiency of gas engine-based power plants [16]

Acknowledgement

This publication was developed as a formal deliverable of the Internship Program facilitated by the Power Plant Engineering Technology Faculty of Vocational Studies at the State University of Malang. We thank the institution for providing the opportunity to integrate industrial experience with academic research.

References

[1] Hiermy, Ulpen, Muhamad Affris Freza Frananda, and Mochammad Zoehry. "ANALISIS EFEKTIVITAS PLATE HEAT EXCHANGER PADA GAS TURBIN: ANALISIS EFEKTIVITAS PLATE HEAT EXCHANGER PADA GAS TURBIN." *Ramatekno* 5, no. 2 (2025): 92-102.

[2] Hiermy, Ulpen, Muhamad Affris Freza Frananda, and Mochammad Zoehry. "ANALISIS EFEKTIVITAS PLATE HEAT EXCHANGER PADA GAS TURBIN: ANALISIS EFEKTIVITAS PLATE HEAT EXCHANGER PADA GAS TURBIN." *Ramatekno* 5, no. 2 (2025): 92-102.

[3] Saputra, Deka Darma, Muhammad Amin Fauzie, Raden Kohar, Akbar Imam, Martin Lutther King, and Muhammad Lazim. "Analysis of parameters that affect the efficiency of gas power plants." *International Journal of Research in Vocational Studies (IJRVOCAS)* 3, no. 1 (2023): 26-31. doi: 10.53893/ijrvocas.v3i1.197.

[4] Cameretti, Maria Cristina, and Roberta De Robbio. "Computational and Data-Driven Modeling of Combustion in Reciprocating Engines or Gas Turbines." *Energies* 17, no. 16 (2024): 3863.doi: 10.3390/en17163863.

[5] "Developing Updated Performance Parameters for EPRI's Heat Rate Improvement Guidelines EPRI Heat Rate Improvement Conference-2013 Bill Kettenacker, PE Scott Nedrow."

[6] “0.01 Technical Data (at module) ____ 4 Main dimensions and weights (at module) 5 Connections 5 Output / fuel consumption 5 0.02 Technical data of engine ____ 6,” 2022.

[7] “Mapping Heating and Cooling Loads to Assess the Potential of Thermal Energy Networks 0,” 2024. [Online]. Available: www.epri.com

[8] Tsou, J. "Heat rate improvement reference manual." *Electric Power Research Institute, Inc., Pleasant Hill* (1998).

[9] Dahham, Rami Y., Haiqiao Wei, and Jiaying Pan. "Improving thermal efficiency of internal combustion engines: recent progress and remaining challenges." *Energies* 15, no. 17 (2022): 6222. MDPI. doi: 10.3390/en15176222.

[10] Gao, Zhiming, Philip Zoldak, Jacques Beaudry-Losique, Tony Mannarino, Jonathan Mansinger, Maysam Molana, Mingkan Zhang et al. "Development of a micro-combined heat and power powered by an opposed-piston engine in building applications." *Nature Communications* 15, no. 1 (2024): 4404. doi: 10.1038/s41467-024-48627-0.

[11] Suijs, Ward, and Sebastian Verhelst. "Scaling Performance Parameters of Reciprocating Engines for Sustainable Energy System Optimization Modelling." *Energies* 16, no. 22 (2023): 7497. Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/en16227497.

[12] Corral-Gómez, Lis, Fernando J. Castillo-García, José A. Soriano, and Octavio Armas. "Macroscopic parameters of fuel sprays injected in an optical reciprocating single-cylinder engine: an approximation by means of visualization with Schlieren technique." *Sensors* 23, no. 15 (2023): 6747. doi: 10.3390/s23156747.

[13] Epri, “Thermal Performance of the ABB GT24 Combustion Turbine (Peaking Service Experience at GPU Gilbert Station).” [Online]. Available: www.epri.com

[14] “EPRI2009HeatRateConference FINAL”.

[15] E. J. Project Manager Tsou, “Heat Rate Improvement Reference Manual,” 1998. [Online]. Available: www.epri.com

[16] “JENBACHER TYPE 3,” 2022. [Online]. Available: www.innio.com/en/company/providers