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Influence of Ambient Temperature on Fuel Consumption and Efficiency of Gas Engine in Power Plant

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Abstract

The limited production of natural gas fuel derived from fossil sources, coupled with the increasing consumption demands across various household and industrial sectors, necessitates efforts to conserve fuel usage. One of the approaches that can be taken is to enhance fuel efficiency. This study aims to analyze the influence of environmental temperature on fuel consumption and efficiency. In this research, the data used is the date or duration of the measurement, including peak load time, environmental temperature and fuel consumption. The research findings indicate that higher environmental temperatures have an inverse impact on fuel efficiency while having a linear effect on fuel consumption. For instance, at an environmental temperature of 32.8 degrees Celsius, the efficiency reaches 12.04% with a consumption rate of 0.72 KG/H, whereas at a temperature of 36.8 degrees Celsius, efficiency decreases to 8.47% with a fuel consumption of 0.96 KG/H. These findings suggest that environmental temperature can influence fuel usage efficiency, and the relationship between environmental temperature and fuel consumption is linear. This research has significant implications for optimizing fuel usage in the context of changing thermal environments.

Keywords
Ambient Temperature, Fuel Efficiency, Specific Fuel Consumption

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INTRODUCTION

Business providing electricity supplies to fulfill life's needs and industry is what triggers the construction of this power plants, in this case Gas Engine Power Plant (GEPP) [1]. The electric power system must have a constant quality of electricity production to guarantee optimal service to consumers. An integrated system can improve quality and reliability so that it provides high safety value, works effectively and efficiently in the deployment process and is able to provide electricity with high economic value [2].

The main problem so far in the power generation industry is the high consumption of fuel, so that the power generation fuel will increase the cost of electricity production. Government efforts to reduce the use of fuel oil by using the gasification scenario more effective and efficient use of fuel by considering the use of natural gas, and its use is more practical and in terms of its emissions, it is more environmentally friendly when compared to the use of diesel fuel [3].

Gas engine power plants (GEPP) in Indonesia generally uses engines with two fuels, either with a dual-fuel or bi-fuel configuration. Because generally the engines used 0 two fuels, therefore the fuel system must also be able to accommodate both fuels. The fuels generally used are natural gas and diesel oil (HSD/MFO) [4].

Gas engine power plants (GEPP) are a type of power generation facility that utilizes natural gas to drive gas engine generators. Gas engine power plants play a vital role in meeting the current global energy demands. GEPPs have become the backbone of energy infrastructure in several regions, ensuring a reliable electricity supply for industrial, commercial, and residential sectors. Despite the advantages of GEPPs in terms of effectiveness, efficiency, practicality, and environmental friendliness [5].

Gas Generator Engine is a generating engine power that functions to change the energy of gas expansion into electrical energy. In general parts to produce gas consists of Heat Recovery Heat Exchanger, Engine, Control Panel and Generator [6].

Figure 1 is about cycle from Gas engine power plants (GEPP) [7].

(6 – 1) : Air enters the compressor to increase the pressure.
(1 – 2) : Air and gas are compressed isentropically.
(2 – 3) : The isobar combustion process is considered as a heat input process at constant pressure.
(3 – 4) : Isentropic work/expansion step
(4 – 5) : The exhaust process is considered as a heat expenditure process at constant volume. Exhaust gas enters the turbocharger. The turbine's work is used to drive the compressor.

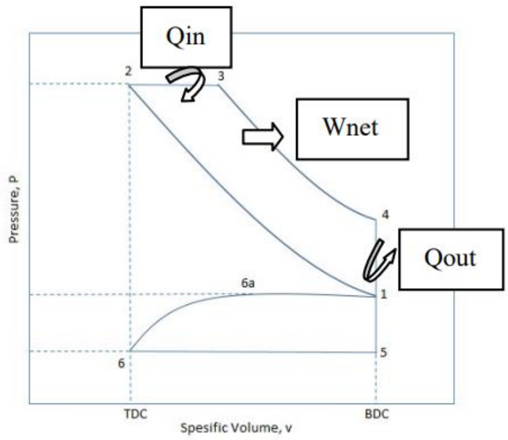

Figure 1. Cycle Gas engine power plants (GEPP)

They deal with the significant challenges in enhancing operational efficiency while minimizing environmental impacts. Additionally, economic factors play a crucial role in GEPP operation, as higher efficiency and lower fuel consumption that means to reduced operational costs for GEPP owners and operators. With increasing awareness of climate change impacts, energy efficiency and environmental sustainability have become central concerns in GEPP operation.

One of the factors affecting GEPP performance is the surrounding environmental temperature. Environmental temperature variability can have a significant impact on fuel consumption and gas engine operation efficiency. In this context, maintaining high efficiency and low fuel consumption are essential to reduce the carbon of GEPPs, lower greenhouse gas emissions, and ensure environmental sustainability.

However, economic aspects also play a vital role in GEPP operation. Lower operational costs can be a determining factor in the competitiveness of GEPPs in an increasingly competitive energy market. Improved efficiency and reduced fuel consumption lead to lower operational costs for GEPP owners and operators. In the long term, these cost savings can help offset the initial high investment in GEPP infrastructure.

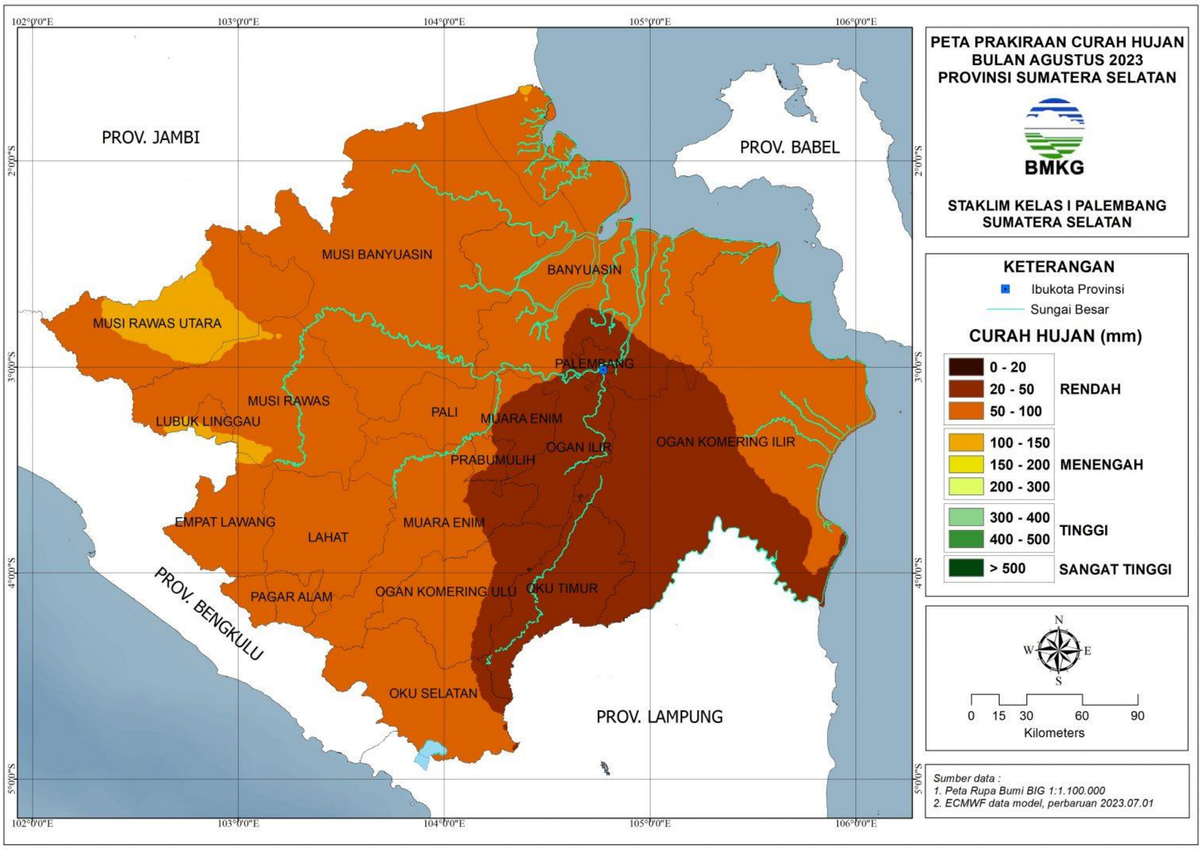

Figure 2. Rain Forecast for August 2023 in South Sumatera [8]

In Figure 2, The weather conditions in the South Sumatra region in August were observed to be very hot, this is what triggered the performance of the PLMGT to decrease and the use of fuel consumption to increase. Considering these considerations, this research aims to analyze the influence of environmental temperature on fuel consumption, operational efficiency, and the economic impact of GEPPs based on in the gas engine. This research will combine experimental approaches and data analysis to identify the relationship between changing environmental temperatures and the economic performance of GEPPs. The results of this study are the higher the environmental temperature, the more and more the fuel consumption required to produce the same output power, and conversely, fuel efficiency tends to decrease. This indicates that environmental temperature is a determining factor in fuel performance in GEPPs.

METHOD

For the implementation of this study, the methodology used is the analytical method. Prior to conducting calculations and analysis, the initial step of the research involves obtaining a comprehensive understanding of the fundamental characteristics of the gas engine, which is extensively documented in the Table 1 [9].

Table 1. Basic specification of gas engine

ITEM	Specification
Engine model	CAT 3516LE
Engine cylinder	16
Rated power	975 KW
Rated voltage	6600 V
Phase	3
Wire	6
Power factor	0,8
Rated Frequency	50 HZ
Rated current	107 A
Rated RPM	1500 RPM
Cooling system	Water Cooled
Ignition System	Electronic Electric System (EIS) Air Starting System

Fuel Gas

Natural gas is a mixture of hydrocarbon gases containing methane gas as a component the most. Natural gas is found in wells (reservoir) well combined with petroleum as associated gas, or in gas wells without petroleum content, as a non-associated gas. Dry natural gas does not contain high hydrocarbons or condensate, but natural gas containing liquid hydrocarbons above 0.3 gal/ MCF, then the gas is categorized as gas wet (wet gas) [10]. Natural gas is often referred to as swamp gas which is a fossil fuel gaseous form consisting mainly of methane (CH4), which is the shortest chain hydrocarbon molecule and lightest. Natural gas also contains molecules heavier hydrocarbons ethane (C2H6), propane (C3H8) and butane (C4H10), as well as gases containing sulfur (sulfur) also contains helium [11].

Fuel Mass Flow Rate

With a profound understanding of the GEPP specifications, the next step in this research is to perform fuel mass flow rate calculations. Fuel consumption calculations are carried out by applying the Barton Chart calculation method, which utilizes well-established formulas in gas engine efficiency analysis. The selected formulas play a fundamental role in evaluating the specific fuel consumption (SFC) and further examining the energy conversion efficiency of the gas engine GEPP unit. The formulas used are shown in equation 1.

$$\dot{m} = (814{,}41\ X\ 1\ X\ \sqrt{Diff x}\ (STC + 14{,}73))\ x\ 28.3168 \tag{1}$$

The symbols and values provided have the following meanings:

ṁ : Fuel Mass Flow Rate (kg/h)
Diff : Value on the Red-lined Barton Chart
STC : Value on the Black-lined Barton Chart

Specific Fuel Consumption

The main objective of calculating the SFC value in this research is to determine the fuel consumption per unit of time, which will then be used to assess the fuel efficiency of the engine GEPP unit. The formula used for this calculation is shown in equation 2.

$$SFC = \frac{\dot{m}}{W} \tag{2}$$

The symbols and values provided have the following meanings:
SFC : Specific Fuel Consumption (Kg/kWh)
$\dot{m}$: Fuel Mass Flow Rate (KG/H)
W : Output Power (kW)

Gas Engine Fuel Efficiency

After obtaining the Specific Fuel Consumption (SFC) value, the next step is to calculate Fuel Efficiency. Fuel efficiency is a critical indicator for evaluating how effectively an engine can convert the energy contained in the fuel into useful work. The thermal efficiency in a machine is defined as the ratio between output energy and chemical energy incoming which is put into the fuel in the form fuel sucked into the combustion chamber [12].

Fuel efficiency is measured as a percentage of the fuel's energy that the engine uses to perform useful work, compared to the total energy in the fuel consumed. This efficiency reflects how much of the fuel energy is spent in the power generation process. Equation 3 is the formula for calculating fuel efficiency[13].

$$\eta t = \frac{W}{\dot{m} \text{ x Qhv x } \eta c} x\, 100 \quad (3)$$

The symbols and values provided have the following meanings:
ηt : Gas Engine Fuel Efficiency
W : Output Power (kW)
$\dot{m}$: Fuel Mass Flow Rate (kg/h)
Qhv : The fuel's calorific value, which is 47,500 KJ/KG
ηt : The combustion efficiency, which has a value of 0.97

RESULT AND DISCUSSION

The data in Table 2 has been analyzed in this study and is based on daily peak load imposed on the gas engine. The data displayed are data fuel mass flow rate, fuel consumption, Specific fuel consumption, temperature ambient and Fuel Efficiency in Gas Engine Power Plants (GEPPs), offering valuable insights for operational optimization and environmental impact reduction in power generation systems.

Table 2. Research data processing.

Date of August 2023	Fuel mass flow rate (MMSCFD)	Fuel consumption (kg/h)	SFC (kg/kWh)	Power Output (kW)	Gas Engine Fuel Efficiency (%)	Ambient Temperature (°C)
1	0.03375	0.955692	0.00021969931	4350	9.88	36.3
2	0.036	1.0194048	0.00022933741	4445	9.46	36.2
3	0.036	1.0194048	0.00022805477	4470	9.52	36.1
4	0.035083333	0.993447733	0.00022681455	4380	9.57	36.2
5	0.034125	0.9663108	0.00024401788	3960	8.89	31.3
6	0.03375	0.955692	0.00023862472	4005	9.10	30.8
7	0.036208333	1.025304133	0.00023302367	4400	9.31	36.7
8	0.03375	0.955692	0.00021995213	4345	9.87	35.9
9	0.03375	0.955692	0.00022619929	4225	9.59	36.3
10	0.033958333	0.961591333	0.00022362589	4300	9.71	37.0
11	0.035291667	0.999347067	0.00022999932	4345	9.44	36.8
12	0.030541667	0.864842267	0.00020839573	4150	10.41	32.8
13	0.025458333	0.720898533	0.00018067632	3990	12.01	32.8
14	0.030666667	0.868381867	0.00020504885	4235	10.58	37.0
15	0.037333333	1.057160533	0.00025230562	4190	8.60	37.0

16	0.031541667	0.893159067	0.00021599977	4135	10.05	37.0
17	0.031541667	0.893159067	0.00023473300	3805	9.25	33.0
18	0.033333333	0.943893333	0.00022473651	4200	9.66	37.0
19	0.0325	0.920296	0.00024541227	3750	8.84	33.0
20	0.034125	0.9663108	0.00025631586	3770	8.47	36.8
21	0.036	1.0194048	0.00024534412	4155	8.85	36.8
22	0.036208333	1.025304133	0.00024587629	4170	8.83	37.0
23	0.036208333	1.025304133	0.00024499501	4185	8.86	37.0
24	0.036625	1.0371028	0.00025050792	4140	8.66	35.0
25	0.036208333	1.025304133	0.00025099244	4085	8.65	37.5
26	0.031541667	0.893159067	0.00023817575	3750	9.11	30.8
27	0.031541667	0.893159067	0.00022989937	3885	9.44	33.0

In the analysis of data related to the impact of environmental temperature on fuel consumption and efficiency in the GEPP, several interesting findings emerged during the observation period. On August 8 and August 11, 2023, despite generating the same power output of 4345 KW, there was a significant difference in Specific Fuel Consumption. On August 8, the fuel consumption reached 0.955 KG/H, while on August 11, it increased to 0.999 KG/H. This difference was also reflected in the environmental temperature, with the temperature being 35.9 degrees Celsius on August 8 and 36.8 degrees Celsius on August 11.

Another comparison is evident on August 12 and August 25, 2023. Despite producing higher power output on August 12, which was 4150 KW compared to 4085 KW on August 25, the Specific Fuel Consumption on August 12 was lower, at 0.864 KG/H, compared to 0.966 KG/H on August 25. This fact can be seen in the context of the lower environmental temperature on August 12, which was approximately 32.8 degrees Celsius, compared to 37.5 degrees Celsius on August 25, 2023

On August 7 and August 23, 2023, similar results were observed regarding the fuel mass flow rate, which was 1.025 KG/H, despite different power outputs. On August 7, the generated power reached 4400 KW, while on August 23, it was 4185 KW, with a power difference of 215 KW. This difference was also related to the higher environmental temperature on August 23, reaching 37.3 degrees Celsius, compared to 36.9 degrees Celsius on August 7.

Analysis of fuel efficiency showed the highest peak on August 13, 2023, reaching 12.01%, and the lowest peak on August 20, reaching only 8.47%. This relationship is evident in the context of the environmental temperature, with the temperature being around 32.8 degrees Celsius on August 13 and reaching 36.8 degrees Celsius on August 20. These findings indicate that environmental temperature has an impact on fuel consumption and efficiency in the GEPP, possibly related to engine settings, combustion performance, and characteristics of more efficient combustion at lower temperatures.

In figure 3, the data has been presented in graphical form to facilitate the analysis of the environmental temperature's impact on fuel consumption and efficiency in the gas engine power plant. if temperature in the environment is low then the energy produced by the turbine will getting bigger, and the environmental temperature is high the power produced by the turbine will be decrease thus affecting thermal efficiency [14]. The data represented in the graphs were obtained during the period from August 1, 2023, to August 27, 2023. In the graphs, the blue line represents the fuel efficiency of the gas engine, while the orange line depicts the environmental temperature (ambient temperature).

In the analysis conducted regarding the "Comparison Graph of Environmental Temperature and Fuel Efficiency" in the above figure, fuel efficiency has been examined considering a range of values found, approximately between 8 and 12 percent. The results of the analysis indicate that during the observation period, fuel efficiency in the GEPP varied within this range. The lowest efficiency was recorded on August 20, 2023, at 8.98%, when the environmental temperature reached 36.8°C. Conversely, the highest efficiency occurred on

August 13, 2023, reaching 12.64%, with an environmental temperature of approximately 32.8°C. The graph comparing environmental temperature to combustion efficiency also reveals an interesting relationship.

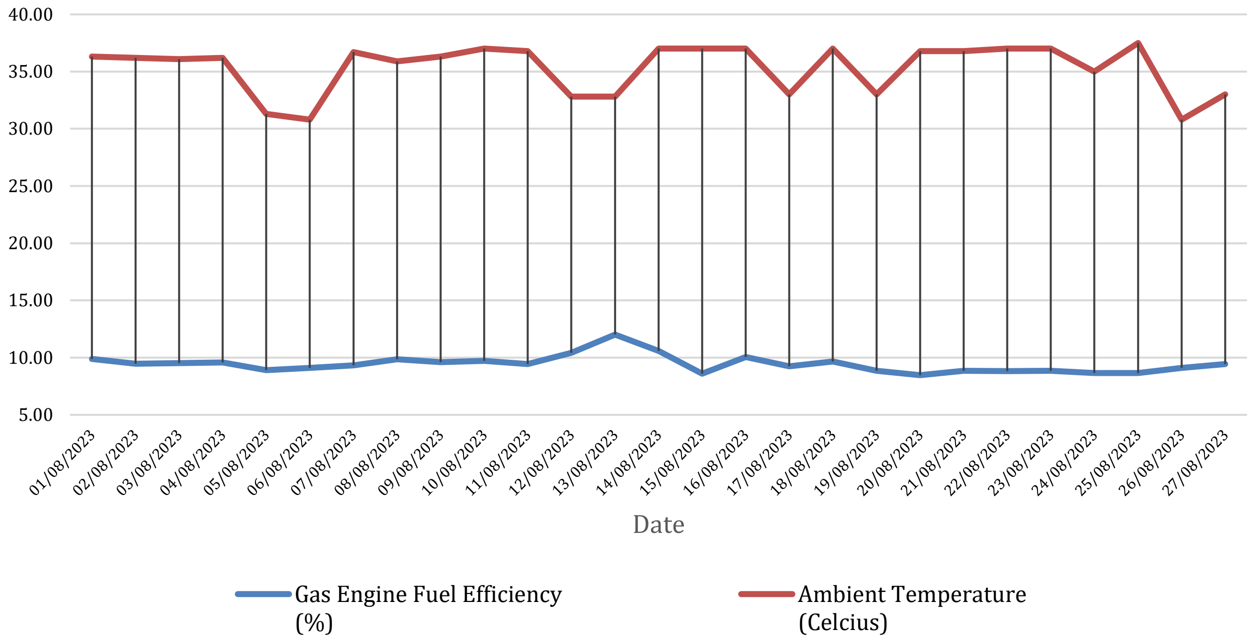

Figure 3. Graph of Environmental Temperature vs. Fuel Efficiency Comparison

Analysis of the graph shows that overall, there is a correlation between environmental temperature and fuel efficiency in the GEPP. This relationship can be explained as an inverse relationship, meaning that as environmental temperature increases, fuel efficiency in the GEPP tends to decrease. The mechanism behind this phenomenon involves the influence of environmental temperature on combustion characteristics and engine performance. This is because at higher environmental temperatures, the risk of detonation in the combustion chamber increases, and the engine control through the Engine Information System (EIS) must be adjusted to prevent this. Additionally, higher temperatures can also lead to increased heat losses and resistance in the combustion system, both of which contribute to a decrease in the efficiency of converting thermal energy into mechanical energy in the engine. In this analysis, the correlation between environmental temperature and fuel efficiency in the GEPP has proven to provide a deeper insight into how environmental factors can affect engine performance and combustion efficiency in the context of power generation.

In this study, the data has been presented in graphical form to facilitate the analysis of the environmental temperature's impact on fuel consumption and efficiency in the gas engine power plant. if temperature in the environment is low then the energy produced by the turbine will getting bigger, and the environmental temperature is high the power produced by the turbine will be decrease thus affecting thermal efficiency [14]. The data represented in the graphs were obtained during the period from August 1, 2023, to August 27, 2023. In the graphs, the blue line represents the fuel efficiency of the gas engine, while the orange line depicts the environmental temperature (ambient temperature).

By knowing the specific fuel consumption, you can explain how optimal engine performance is to increase generating power and Minimize fuel waste thereby creating opportunities to save production costs [15]. In this study that analyzed the impact of environmental temperature on the performance of the gas engine power plant.

Environmental temperature data and specific fuel consumption of the gas engine were meticulously collected during the observation period, which spanned from August 1, 2023, to August 27, 2023. Each data point was recorded over the same time intervals to identify potential correlations between environmental temperature and specific fuel consumption. Our graphical representation clearly illustrates this relationship, with the blue line indicating the specific fuel consumption of the gas engine and the orange line representing the ambient environmental temperature. The findings from this research are expected to provide valuable insights for power plant operators in enhancing their operational efficiency, particularly in the context of significant environmental temperature variations.

In the analysis conducted regarding the "Comparison Graph of Environmental Temperature and Specific Fuel Consumption (SFC)," at figure 4 the variable fuel consumption has been examined, considering a range of values found, approximately from 18 x 10 -4 kg/kWh to 24 x 10-4 kg/kWh. The results of the analysis indicate that during the observation period, Specific Fuel Consumption in the GEPP varied within this range. The lowest Specific Fuel Consumption was recorded on August 13, 2023, at 18.06 x 10-4 kg/kWh, when the environmental temperature reached 32.8°C. Conversely, the highest Specific Fuel Consumption occurred on August 20, 2023, reaching 25.63 x 10-4 kg/kWh, with an environmental temperature of approximately 36.8°C. The graph comparing environmental temperature to Specific Fuel Consumption depicts the relationship between these variables.

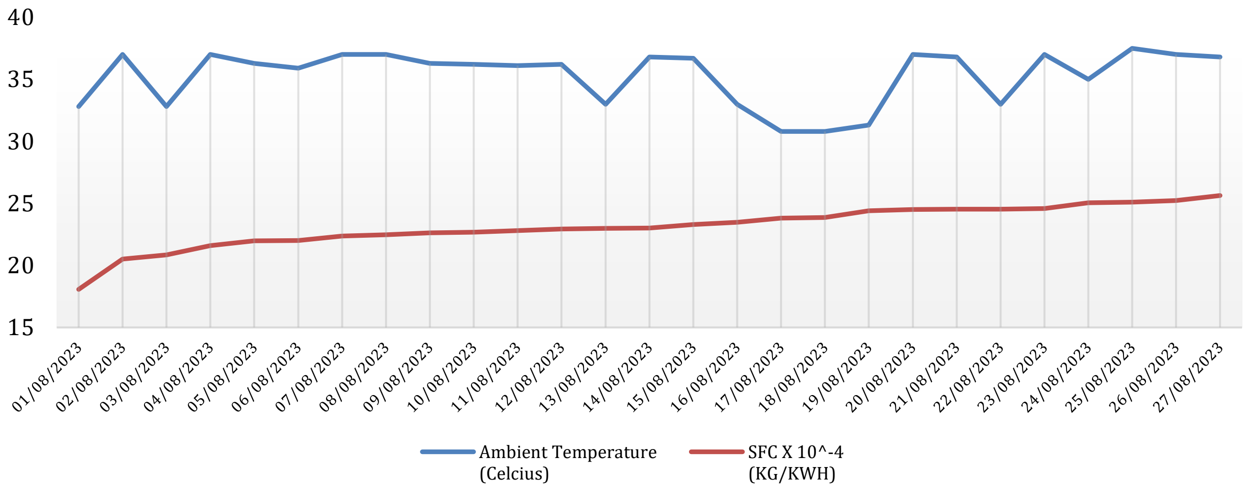

Figure 4. Graph of Environmental Temperature vs. Specific Fuel Consumption Comparison

Analysis of the graph shows that, overall, there is a correlation between environmental temperature and Specific Fuel Consumption in the GEPP. This relationship can be explained as a positive linear relationship, meaning that as the environmental temperature increases, Specific Fuel Consumption tends to rise, making fuel consumption more inefficient. The mechanism behind this phenomenon involves several factors. At higher environmental temperatures, there is an increase in the temperature of the air entering the combustion chamber, resulting in a decrease in air density. This condition leads to a lower air-fuel ratio, which, in turn, affects less efficient combustion. More fuel is required to achieve the same level of efficiency. Additionally, higher temperatures trigger increased heat losses, resulting in a significant portion of energy produced during combustion being wasted as useful heat. This is the hypothesis put forward to explain why Specific Fuel Consumption tends to increase with rising environmental temperatures [16].

Analysis of the Causes of Environmental Temperature Increase

Changes in data related to fuel consumption and fuel efficiency in gas engine power plants can be influenced by several factors related to environmental temperature fluctuations. Some of the factors that can impact these changes include:

1. Fluctuations in environmental temperature due to climate changes and measurement time variations can affect engine performance. Higher environmental temperatures can lead to increased intake air temperatures in the combustion system, ultimately influencing combustion efficiency and fuel consumption.
2. Overheating of the engine due to suboptimal cooling systems or coolant malfunction can result in excessive temperature increases. Overheating can damage engine performance and cause decreased combustion efficiency, leading to increased fuel consumption.
3. High environmental temperatures can disrupt combustion performance in the engine. Elevated temperatures can cause fuel to burn less efficiently, resulting in lower combustion efficiency and increased fuel consumption.
4. Suboptimal distribution of exhaust gases, such as loose connections or air leaks in the exhaust pipe, can affect the temperature conditions inside the engine. This is because hot exhaust gases can raise the intake air temperature or contaminate it, disrupting combustion performance, ultimately affecting fuel efficiency.
5. The use of engines operating in certain conditions can generate higher heat. Some engines may inherently produce more heat than others, and the operation of engines in this mode can affect environmental temperature and, consequently, impact combustion efficiency and fuel consumption.

Additionally, external factors such as hot weather conditions and operational time that may affect overall environmental temperature can also play a role in changes in fuel consumption and efficiency in gas engine power plants. Considering all these factors, it is important to identify and address the causes of environmental temperature changes to maintain optimal operational efficiency and combustion efficiency.

CONCLUSION

In this research aimed at analyzing the influence of environmental temperature on fuel consumption and efficiency in the GEPP, the following conclusions can be drawn regarding the role of temperature. First, Environmental temperature plays a crucial role in influencing fuel consumption and efficiency in the GEPP. This indicates that environmental temperature is a determining factor in fuel performance in the GEPP. Factors identified during the analysis point to climate change as a contributor to variations in environmental temperature.

Second, higher environmental temperatures lead to increased fuel consumption required to generate the same power output, and conversely, fuel efficiency tends to decrease.

And the last, additionally, other factors such as engine overheating due to suboptimal cooling systems can be a primary cause of elevated environmental temperatures. Reduced combustion performance can also occur due to high environmental temperatures, resulting in suboptimal combustion efficiency. Optimization of air distribution systems and the operation mode of the engine also contribute to environmental temperature increases.

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