rekayasa mesin JURNAL
Vol. 15. No.1
ISSN 2477-6041 articles 29, pp. 329 – 337, 2024

EFFECT OF COMPRESSOR INLET TEMPERATURE ON THERMAL EFFICIENCY ROLLS ROYCE RB211 GAS GENERATOR IN COMBINED CYCLE POWER PLANT

Nanang Yulistio [1) ✉], Muhammad Prihadi Eko Wahyudi [1)], Qoriatul Fitriyah [1)]

[1)]**Power Plant Engineering Department**
Politeknik Negeri Batam
Batam Centre, Teluk Tering, Batam, Riau Islands, Indonesia
nanangyulistio26@gmail.com
prihadieko@polibatam.ac.id
fitriyah@polibatam.ac.id

Abstract

The combined cycle power plant must operate 24 hours without stopping so that in operation at any time an increase in the temperature of the gas generator RB211 can occur. The RB211 gas generator works well when the ambient temperature is low. The X combine cycle power plant uses a chiller to lower the inlet air temperature so that the air entering the compressor will be lower. The purpose of this study was to analyze and conclude the effect of the compressor inlet temperature on the thermal efficiency of the Rolls Royce RB211 gas generator in the combined cycle power plant. Data was collected by requesting historical data on September 5-11, 2022 in the central control room. The method used in this study is simple linear regression analysis because it only involves two variables. The independent variable is the inlet temperature of the compressor and the dependent variable is the thermal efficiency of the gas generator. It is known that the highest efficiency is at a temperature of 292,94 kelvin with a thermal efficiency value of 36,87% while the lowest efficiency is at a temperature of 301,89 kelvin with a thermal efficiency value of 35,61%. The regression analysis equation is $\hat{Y}$ = 0,60665231-0,00082223X so the hypothesis results obtained through the significant F test with F table is that there is a significant effect between the compressor inlet temperature on the thermal efficiency of the gas generator.

Keywords: *Combined Cycle Power Plant, Gas Generator, Thermal Efficiency, Regression Analysis.*

1. INTRODUCTION

The combined cycle power plant is an equipment installation that is used to convert heat energy from burning natural gas fuels to produce electrical energy that is useful and has a sale value. The combined cycle power plant is a combination of a gas power plant and steam power plant because the hot temperature of the exhaust gas of the power plant is utilized by the heat recovery steam generator to produce working fluid steam which will be used to rotate the steam turbine [1].

Currently, the combined cycle power plant must operate 24 hours without stopping so that in operation at any time an increase in the temperature of the RB211 gas generator can occur. The climate in Batam City has an average temperature between 26º Celcius to 34º Celcius so it can affect the temperature rise in the RB211 gas generator [2]. The RB211 gas

Corresponding Author:
✉ **Nanang Yulistio**
Received on: 2023-03-20
Revised on: 2023-05-19
Accepted on: 2023-08-13

DOI: 10.21776/jrm.v15i3.1505

generator works well when the ambient temperature is low. The X combined cycle power plant uses a chiller to lower the inlet air temperature so that the air entering the compressor will be lower. Air with a low temperature has a high density so it will affect the work on the RB211 gas generator [3].

The purpose of this study was to analyze and conclude the effect of the compressor inlet temperature on the thermal efficiency of the Rolls Royce RB211 gas generator in the X combined cycle power plant. The limitation of the problem in this study is the analysis carried out regarding the effect of the compressor inlet temperature on the thermal efficiency of the Rolls Royce RB211 gas generator in the X combined cycle power plant.

2. MATERIALS AND METHOD

The combined cycle power plant is a theoretical application of the Brayton cycle and the Rankine cycle of thermodynamics. The Brayton cycle is the theory of a gas generator [4].

Baris pertama dari chapter tertentu.

2.1 Gas Generator

The gas generator is a driving machine by utilizing natural gas as fuel to produce a working fluid flow [5]. There are three components in the gas generator, namely the compressor, combustion section, and turbine.

The compressor functions to compress the incoming air into high pressure air. The combustion section functions as a chemical reaction process between the fuel, ignitor, and compressed air from the compressor [6]. The turbine functions as a tool to convert energy from the compression and combustion processes into rotational mechanical energy.

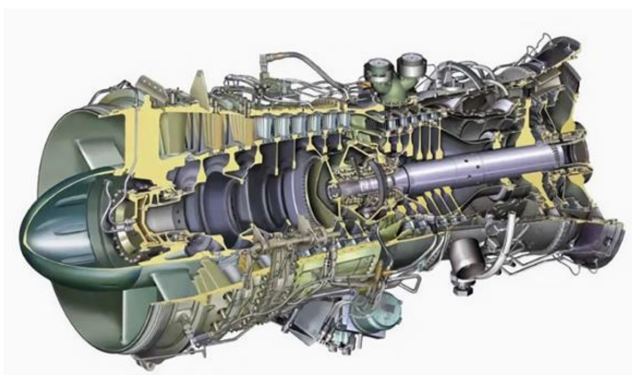

Figure 1. Gas generator [7].

2.1. Brayton Cycle

The Brayton cycle is an ideal cycle that is applied to gas generators because it is found in the compressor, combustion section, and turbine sections. Air from the environment enters through the air inlet to the compressor to provide compressed air which will be used in the combustion section. Air from the combustion section will be free to expand toward the turbine.

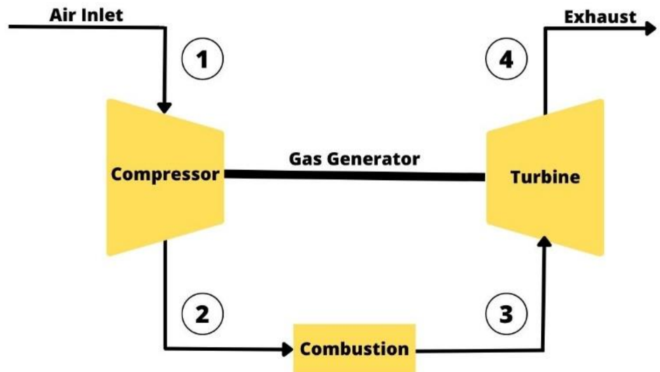

Figure 2. Gas generator cycle diagram.

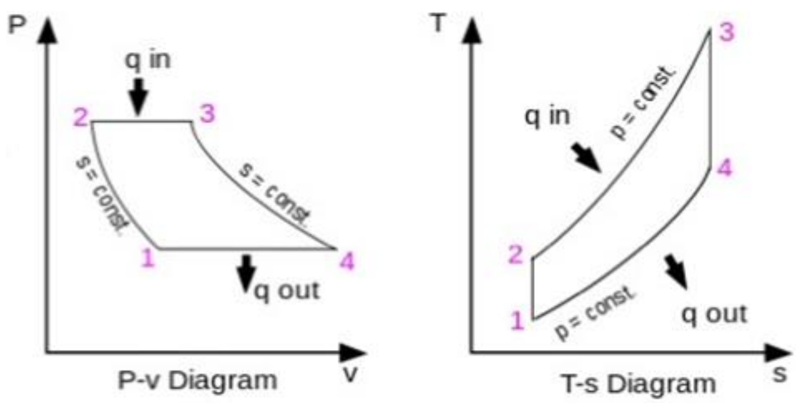

Figure 3. P-V and T-S diagram.

The phenomenon of the Brayton cycle includes an isentropic compression process that occurs in phase diagrams 1-2. The isobaric combustion process occurs in phase diagrams 2-3. The process of isentropic expansion occurs in phase diagrams 3-4 and the process of dissipation of hot gas occurs in phase diagrams 4-1 [8].

In determining the enthalpy entering the compressor (h_1), leaving the compressor (h_2), and leaving the turbine (h_4) you can use an interpolation system using the ideal gas table. The interpolation formula is listed in equation (1) as follows [9]:

$$Y = Y_1 + \frac{(X - X_1)}{(X_2 - X_1)} \times (Y_2 - Y_1) \quad (1)$$

Y1 = Initial enthalpy from the range of ideal gas table values
Y2 = The final enthalpy of the range of ideal gas table values
X1 = Initial temperature or pressure from the range of ideal gas table values
X2 = The final temperature or pressure of the range of ideal gas table values
X = The temperature or pressure to find the enthalpy value
Y = Results

If the turbine inlet temperature is not known, then finding the enthalpy value entering the turbine can use Pr_3 interpolation in the ideal gas table in equation (1). To find out Pr_3 use the following equation [4]:

$$\mathrm{Pr}_3 = \mathrm{Pr}_4 \frac{(P_3)}{(P_4)} \quad (2)$$

Pr3 = The relative pressure of the gas inlet the turbine

Pr4 = The relative pressure of the exhaust gases from the turbine

P3 = Turbine inlet pressure

P4 = Turbine exhaust gas pressure

The relative pressure of the gas leaving the turbine (Pr_4) and the theoretical compressor outlet enthalpy (h2') is obtained through the interpolation formula through the ideal gas table in equation (1) so that finding the ideal air temperature leaving the compressor (T'_2) can use the following formula [10]:

$$T'_2 = T_1 \frac{(P_2)}{(P_1)}^{\frac{k-1}{k}} \quad (3)$$

T'_2 = The ideal air temperature exits the compressor

T_1 = Compressor inlet temperature

P_1 = Compressor inlet air pressure

P_2 = Compressor exhaust air pressure

K = Air constant value

Finding the theoretical exhaust enthalpy value (h_4') can use the interpolation formula in equation (1) so that finding the ideal air temperature value leaving the turbine (T'_4) can use the following equation [10]:

$$T'_4 = T_3 \frac{(P_4)}{(P_3)}^{\frac{k-1}{k}} \quad (4)$$

T'4 = The ideal air temperature exits the turbine

T3 = Turbine inlet temperature

P3 = Turbine inlet pressure

P4 = Turbine exhaust air pressure

K = Air constant value

Calculating compressor efficiency can use the following formula [11]:

$$\eta ca = \frac{(h_2' - h_1)}{(h_2 - h_1)} \times 100\% \quad (5)$$

ηca = Compressor efficiency

h2' = Theoretical compressor outlet enthalpy

h1 = Enthalpy inlet the compressor

h2 = Enthalpy out of the compressor

Finding the heat of combustion can use the following formula [12]:

$$Qin = mf \times LHV \quad (6)$$

Qin = Combustion heat supply
mf = Fuel gas flow
LHV = Lower heating value

Calculating the mass flow rate of air can use the following formula [12]:

$$ma = \frac{Qin - (mf \times h_3)}{(h_3 - h_2)} \tag{7}$$

ma = Air mass flow rate
Qin = Combustion heat supply
mf = Fuel gas Flow
h_2 = Enthalpy out of the compressor
h_3 = Enthalpy inlet the turbine

Calculating compressor work using the following formula [12]:

$$Wca = \frac{ma(h_2 - h_1)}{\eta ca} \tag{8}$$

Wca = Compressor work
ma = Air mass flow rate
h1 = Enthalpy inlet the compressor
h2 = Enthalpy out of the compressor
ηca = Compressor efficiency

Finding the turbine efficiency value can use the following formula [13]:

$$\eta ta = \frac{(h_3 - h_4)}{(h_3 - h_4')} \times 100\% \tag{9}$$

ηta = Turbine efficiency
h_3 = Enthalpy inlet the turbine
h_4 = Enthalpy exhaust of the turbine
h_4’ = Theoretical turbine exhaust enthalpy

Calculating turbine work can use the following formula [12]:

$$Wta = (ma + mf)(h_3 - h_4) \times \eta ta \tag{10}$$

Wta = Turbine work
ma = Air mass flow rate
mf = Fuel gas flow
h3 = Enthalpy inlet the turbine
h4 = Enthalpy exhaust of the turbine
ηta = Turbine efficiency

Gas generator thermal efficiency can be determined by the following formula [14]:

$$\eta T = \frac{(Wta - Wca)}{(mf \times LHV)} \times 100\% \tag{11}$$

ηT = Thermal efficiency
Wta = Turbine work
Wca = Compressor work
mf = Fuel gas flow
LHV = Lower heating value

2.2. Research Methods

The research data used is in the form of secondary data because it is obtained indirectly [15]. Data collection by requesting historical data on September 5-11, 2022 in the central control room. The data taken is in the form of compressor inlet temperature (T_1), compressor exit temperature (T_2), turbine exhaust temperature (T_4), compressor inlet air pressure (P_1), turbine inlet air pressure (P_3), fuel gas flow, and LHV.

The data that has been calculated with the Brayton cycle formula then obtains thermal efficiency data so that a number of two variables are used in determining the research methodology approach. The method used in this study is simple linear regression analysis because it only involves two variables, namely one independent variable and one dependent variable. The independent variable is the compressor inlet temperature and the dependent variable is the thermal efficiency of the gas generator [16].

2.3. Simple Linear Regression

Almost all fields such as industry, economy, employment, and so on can use regression analysis. Regression analysis helps to know the independent variable influences the dependent variable. The simple regression analysis has the following equation [17]:

$$\hat{Y} = a + bX \tag{12}$$

Ŷ is the prediction of the dependent variable and X is the independent variable. The constant ɑ is a constant value and b is the gradient value that determines the forecast [18].

3. RESULTS AND DISCUSSION

Gas generator thermal efficiency data can be determined by calculating the Brayton cycle. Compressor inlet temperature and thermal efficiency data used are 24-hour data totaling 168 starting from September 5-11, 2022.

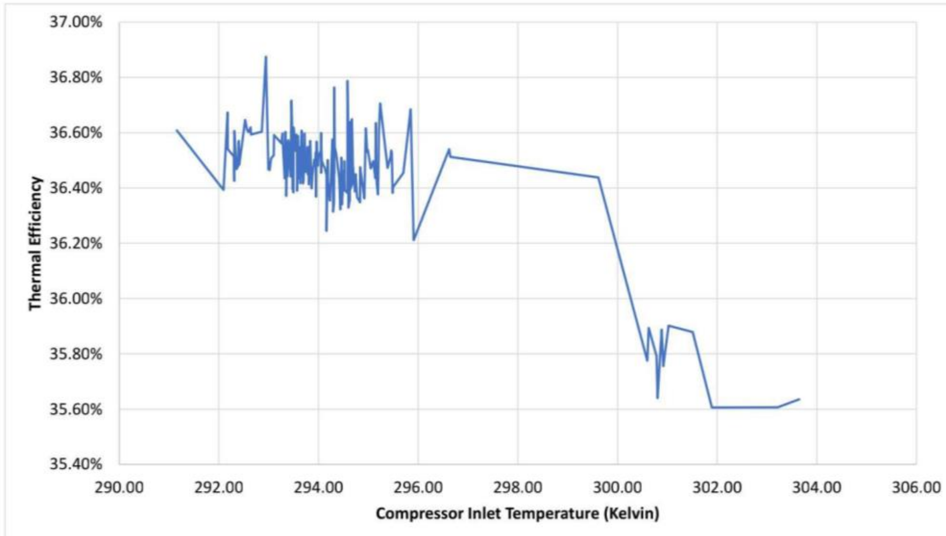

Figure 4. Effect of compressor inlet temperature on thermal efficiency gas generator diagram.

Through on Figure 4: Effect of compressor inlet temperature on thermal efficiency gas generator diagram the average compressor inlet temperature on September 5-11, 2022 is 294,53 kelvin while the average gas generator thermal efficiency is 36,45%. It is known that the highest efficiency is at a temperature of 292,94 kelvin with a thermal efficiency value of 36,87% while the lowest efficiency is at a temperature of 301,89 kelvin with a thermal efficiency value of 35,61%. The influence of the high compressor inlet temperature, the thermal efficiency tends to be low, while the compressor inlet temperature is low the thermal efficiency tends to be high.

Based on the manufacturer's datasheet, the RB211 performance has an efficiency value of 39,1% at a compressor inlet temperature of 291,15 kelvin while the lowest efficiency is 36,5% at a temperature of 313,15 kelvin [19]. When compared to the Figure 4: Effect of compressor inlet temperature on thermal efficiency gas generator diagram in the operating data on September 5-11, 2022, the efficiency of the gas generator has decreased in efficiency from the RB211 manufacturer's performance datasheet, so it can be concluded that the efficiency of the gas generator on September 5-11, 2022 is lower than the RB211 manufacturer's performance datasheet.

The results of the correlation analysis are included in the powerful category because the correlation value obtained is -0,82673. The negative sign on the correlation value explains that the relationship between the compressor inlet temperature and the thermal efficiency of the gas generator has an inverse value if the compressor inlet temperature is high, the thermal efficiency value of the gas generator will tend to be low.

The R square value explains that the compressor inlet temperature can explain the predicted thermal efficiency of the gas generator of 68,34%. The hypothesis obtained through the significant F test with the F table is that there is a significant effect between the compressor inlet temperature on the thermal efficiency of the gas generator. The regression analysis equation obtained is $\hat{Y} = 0{,}60665231 - 0{,}00082223X$.

4. CONCLUSION

The average compressor inlet temperature on September 5-11, 2022 is 294,53 kelvin while the average gas generator thermal efficiency is 36,45%. It is known that the highest efficiency is at a temperature of 292,94 kelvin with a thermal efficiency value of 36,87% while the lowest efficiency is at a temperature of 301,89 kelvin with a thermal efficiency value of 35,61%. The results of the correlation analysis are included in the powerful category because the correlation value obtained is -0,82673. The negative sign on the correlation value explains that the relationship between the compressor inlet temperature and the thermal efficiency of the gas generator has an inverse value if the compressor inlet temperature is high, the thermal efficiency value of the gas generator will tend to be low. The regression analysis equation is $\hat{Y} = 0{,}60665231 - 0{,}00082223X$ so the hypothesis results obtained through the significant F test with F table is that there is a significant effect between the compressor inlet temperature on the thermal efficiency of the gas generator. When compared to the operating data on September 5-11, 2022, the efficiency of the gas generator has decreased in efficiency from the RB211 manufacturer's performance datasheet, so it can be concluded that the efficiency of the gas generator on September 5-11, 2022 is lower than the RB211 manufacturer's performance datasheet.

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