International Journal of Technology (2016) 5: 921-927
ISSN 2086-9614

EXERGY ANALYSIS OF GAS TURBINE POWER PLANT 20 MW IN PEKANBARU-INDONESIA

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(Received: June 2015 / Revised: November 2015 / Accepted: June 2016)

ABSTRACT

The performance of a 20 MW gas turbine power plant was described by using the exergy analysis and data from the plant's record books. The first and second laws of thermodynamics, as well as the mass and energy conservation law, were applied in each of the components. The results show that more exergy destruction occured in the combustion chamber up to 71.03% or 21.98 MW. Meanwhile, the lowest exergy occured in the compressor at 12.33% or 3.15 MW. Thermal efficiency of the gas turbine power plant, according to the first law, was 33.77%, and exergy efficiency was 32.25%.

Keywords: Exergy destruction; Exergy efficiency; Gas turbine power plant

1. INTRODUCTION

World energy demand, including electricity, is projected to grow significantly as a result of economic growth, high population growth and industrial expansion. Electricity energy demand growth will cause a significant electrical energy crisis all over the world, including in Indonesia. To cope with this electrical energy crisis, the new power plant construction program should be started and the efficiency of existing power plants should be increased. One of the power plants in Pekanbaru-Riau is a gas turbine power plant with a capacity of 20 MW. As a first step to improving power plant efficiency, this plant has been identified as the location of the largest loss in power plant by exergy analysis.

Currently, most power plants are designed based on the first law of thermodynamics only. Useful energy loss cannot be justified by the first law of thermodynamics because it does not differentiate between the quality and quantity of energy, and it does not provide detailed analysis on how much losses occur in every component of the power plant. In this paper, the exergy performance of power plants is evaluated based on the second law of thermodynamics. Exergy analysis based on the first and second laws of thermodynamics is developed as a very useful method for design, evaluation, optimization, and improvement of power plants. Exergy analysis is used to determine magnitude, location, and cause of the irreversibility, and it is also able to find the efficiency of power plant components (Kaushik et al., 2011).

Exergy analysis on power plants has been discussed and carried out by several authors (Cengel & Boles, 2006; Moran & Shapiro, 2006; Aljundi, 2009). Kotas (1985) developed a method to determine chemical and physical exergy for various components of plants. Khaliq and Kaushik (2004) introduced the theoretical second-law approach for the thermodynamic analysis of the

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Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v7i5.1329

reheat combined Brayton/Rankine power cycle. Reddy and Mohamed (2007) present exergy analysis of a natural gas-fired combined cycle power generation unit. It is performed to investigate the effect of gas turbine inlet temperature and pressure ratio on exergetic efficiency for the plant and exergy destruction for the components. Ebadi and Gorji (2005) conducted an exergy analysis of a gas turbine cycle of a 116 MW power plant and concluded that the impact of rising input temperature on the gas turbine may improve total exergetic efficiency of the gas turbine cycle, and may reduce exergy destruction. Chand et al. (2013) conducted exergy analysis on a gas turbine power plant with a capacity of 112.4 MW in India. Chand et al. analyzed the influence of compression ratio, compressor inlet air temperature, and turbine inlet temperature to irreversibilites of each component of the gas turbine power plant. Al-Doori et al. (2012) conducted exergetic analysis for a Baiji plant with a gas-turbine of capacity 159 MW. It was identified that the exergetic efficiency and the exergy destruction are considerably dependent on alterations in the turbine inlet temperature. A similar study conducted by Ameri and Ali (2013), with case studies of the Montazer Ghaem gas turbine power plant located near Tehran, revealed that the annihilation the highest exergy occurs in the combustion chamber.

The aim of this research is to evaluate the performance of gas turbine power plants and identify major components that occur as the highest exergy destruction.

2. METHODOLOGY

2.1. Data Collection

Data such as average daily power generated, pressure, and temperature of different points as shown in Figure 1, mass flow rate (air, fuel and gas of combustion) used for this study were collected from the gas turbine power plant's record log books. Parameters that could not be directly measured were derived using appropriate existing equations such us combustion temperature, outlet temperature from combustion chamber, and inlet turbine. From the record of log books, the ambient temperature is 300.03 K and the ambient pressure was assumed to be 1.01325 Bar.

2.2. System Description

The gas turbine power plant of 20 MW used in this study is an open cycle single shaft system and is located at Pekanbaru, Riau. The schematic of the 20 MW gas turbine power plant is shown in Figure 1. The system consists of an Air-Compressor (AC), Combustion Chamber (CC), and Gas Turbine (GT).

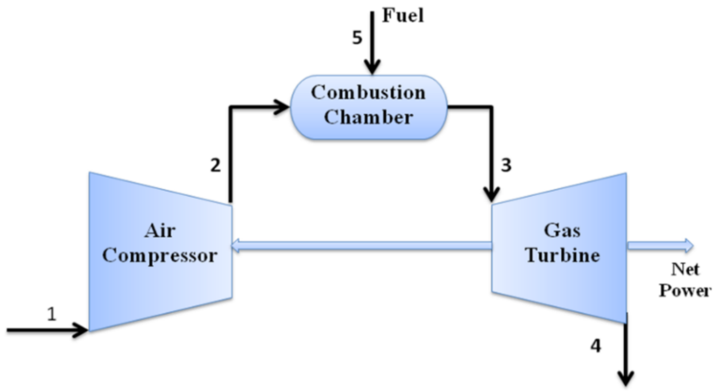

Figure 1 Schematic of methodology

Isentropic efficiency of the compressor and gas turbine are assumed to be 86% (Siahaya, 2009), and the pressure drop through the combustion chamber is assumed to be 3% (Tiwari et al., 2013; Ebadi & Gorji, 2005).

2.3. Exergy Analysis of Gas Turbine Power Plant

Exergy analysis is a method that implements the conservation of mass and energy principles together with the second law of thermodynamics for analysis, design, and improvement of energy systems. The exergy method is a useful tool for furthering the goal of more efficient energy resource use, for it enables the locations, types, and true magnitudes of wastes and losses to be determined (Dincer & Rosen, 2013).

Total exergy of a system is divided into four components: physical exergy ($\dot{X}^{PH}$), chemical exergy ($\dot{X}^{CH}$), kinetic exergy ($\dot{X}^{KN}$) dan potential ($\dot{X}^{PT}$) that is given as follows (Bejan, 1996):

$$\dot{E}_x = \dot{E}_x{}^{PH} + \dot{E}_x{}^{CH} + \dot{E}_x{}^{KN} + \dot{E}_x{}^{PT} \quad (1)$$

Exergy potential and kinetic exergy value is assumed to be zero. Physical exergy can illustrate the simple case of an ideal gas. The relationship between the enthalpy (h) and entropy (s) is shown by the following equation:

$$\dot{E}_x{}^{PH} = \dot{m}.\left[c_p.(T - T_0) \ - T_0.(s - s_0)\right] \quad (2)$$

where

$$s_1 - s_0 = C_p \ln\left(\frac{T_1}{T_o}\right) - R\ln\left(\frac{P_1}{P_o}\right) \quad (3)$$

And heat specific (C_p) is obtained by polynomial form as a function of temperature as given by Equation 4 (Cengel & Boles, 2006);

$$\overline{C}_p = a + bT + cT^2 + dT^3 \quad (4)$$

In this case, no chemical reactions or combustion is seen in the turbines and compressors, and the chemical exergy value of both components is considered to be 0. An approximation formula for specific chemical exergy of hydrocarbon fuels is given as C_aH_b (Moran & Shapiro, 2006);

$$\frac{\bar{e}_f^{CH}}{LHV} \cong 1,033 + 0,0169\frac{b}{a} - \frac{0,0698}{a} \quad (5)$$

Exergy destruction of each component is given by;

$$\dot{E}_D = \dot{E}_{x\,in} - \dot{E}_{x\,out} \quad (6)$$

While the efficiency exergetic of each component of the gas turbine power plant is given as;

$$\eta_{II} = \frac{\dot{E}_{x\,out}}{\dot{E}_{x\,in}} \quad (7)$$

The inlet exergy rate, the outlet exergy rate, the exergy destruction, and exergetic efficiency of each component is calculated by the following equation in the Table 1.

Table 1 Exergy existing equilibrium of each component

Component	$\dot{E}_{x\,in}$ (MW)	$\dot{E}_{x\,out}$ (MW)	$\dot{E}_D$ (MW)	η_{II} (%)
Compressor	$\dot{W}_c + \dot{E}_{x1}$	$\dot{E}_{x\,2}$	$\dot{W}_c + \dot{E}_{x1} - \dot{E}_{x\,2}$	$\frac{\dot{E}_{x_2}}{\dot{W}_c + \dot{E}_{x_1}}$
Combustion C.	$\dot{E}_{x\,2} + \dot{E}_{x5}$	$\dot{E}_{x\,3}$	$\dot{E}_{x\,2} + \dot{E}_{x5} - \dot{E}_{x3}$	$\frac{\dot{E}_{x_3}}{\dot{E}_{x_2} + \dot{E}_{x_5}}$
Gas Turbine	$\dot{E}_{x\,3}$	$\dot{E}_{x\,4} + \dot{W}_{GT}$	$\dot{E}_{x\,3} - (\dot{E}_{x4} + \dot{W}_{GT})$	$\frac{\dot{E}_{x_4} + \dot{W}_{GT}}{\dot{E}_{x_3}}$

The Exergy efficiency of the overall power plant is obtained:

$$\eta_{II,Power\ plant} = \frac{W_{GT,Net}}{\dot{Ex}_3} \tag{8}$$

3. RESULTS

Physical properties and chemical exergy flows at various state points in the gas turbine power plant at rated conditions at various state points in the cycle are shown in Table 1. These flow rates were calculated based on the values of measured properties, such as temperature, pressure, heat capacity, and mass flow rate.

Table 2 Physical properties and chemical exergy flows at various state points in the gas turbine power plant at rated condition (for state number refer to Figure 1)

State	Fluid type	t (K)	P (Bar)	C_P $\left(\frac{kJ}{kg.K}\right)$	$\dot{m}$ *(kg/s)*	$\dot{E}_X^{PH}$ (MW)	$\dot{E}_X^{CH}$ (MW)	$\dot{Ex}$ *(MW)*
1	Air	300.03	1.013	1.004	67.30	0.00	0.00	0.00
2	Air	554.35	8.688	1.047	67.30	18.05	0.00	18.05
3	Combustion gas	1311.14	8.427	1.266	68.65	68.50	0.00	68.50
4	Combustion gas	775.15	1.013	1.152	68.65	18.12	0.00	18.12
5	Fuel	300.88	22.182	2.197	1.36	1.17	71.25	72.42

Using the value given by Table 2, the inlet exergy rate, the outlet exergy rate, the exergy destruction, and the exergetic efficiency are calculated by using Table 1 and the result shown in Table 3.

Table 3 Exergy rate, exergy destruction, and exergetic efficiency in each component

Component	$\dot{Ex}_{in}$ (MW)	$\dot{Ex}_{out}$ (MW)	$\dot{E}_D$ (MW)	$\dot{E}_D$ (%)	η_{II} (%)
Air Compressor	21.87	18.05	3.81	12.33	82.56
Combustion Chamber	90.47	68.50	21.98	71.03	75.71
Gas Turbine	68.50	63.35	5.15	16.65	92.48

The Grassmann diagram of the gas turbine power plant is shown in Figure 2. It shows the percentage exergy input and exergy loss in each device, and the exhaust based on the results of the exergy analysis.

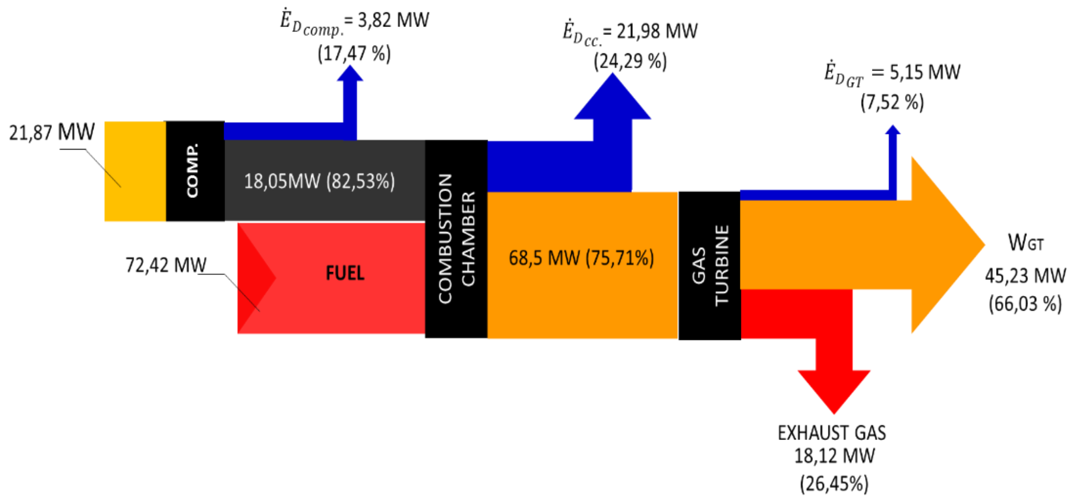

Figure 2 Grassmann diagram of gas turbine power plant

4. DISCUSSION

Table 3 and Figure 2 show the exergy destruction of the compressor, combustion chamber, and gas turbine. The largest exergy destruction occurs in the combustion chamber and it is equal to 21.98 MW (71.03%), followed by the gas turbine with 5.15 MW (16.65%), and the smallest is the compressor with 3.81 MW (12.33%). Exergy efficiency is also often referred to as the efficiency of the second law of thermodynamics and, as shown in Table 3, the exergy efficiency of the compressor, combustion chamber, and gas turbine are 82.56%, 75.71%, and 92.48%, respectively. It can be concluded that the highest exergy destruction rate and the lowest exergetic efficiency are found in the combustion chamber. The lowest exergy destruction rate is found in the air compressor, and the highest exergetic efficiency is found in the gas turbine. Generally, this agrees with the results of some references shown in Table 4.

Table 4 Exergy destruction rate and exergetic efficiency

References	Exergy destruction rate $\left(\dot{E}_D(\%)\right)$			Exergetic efficiency $(\eta_{II}(\%))$		
	Air compressor	Combustion chamber	Gas turbine	Air compressor	Combustion chamber	Gas turbine
Igbong & Fakorede, (2014)	3.53	86.38	10.12	93.07	54.05	65.27
Egware et al., (2014)	3.63	93.34	3.02	92.05	45.46	96.39
Egware et al., (2013)	3.69	93.10	3.21	91.95	45.85	96.17
Abam et al, (2012)	12.04	61.25	26.74	70.20	30.67	60.35
Siahaya, (2009)	17.81	92.00	7.20	91.00	87.00	98.50

The highest exergy destruction rate and the lowest exergetic efficiency occurs in combustion chamber caused of unburnt fuel, incomplete combustion, and heat loss to the surrounding area through to the combustion process (Dev & Attri, 2012).

The energy and exergetic efficiency of the gas turbine power plant were calculated as 33.77% and 32.25%, respectively, which are similar to the results of Igbong and Fakorede (2014), which shows energy and exergetic efficiency as 31.05% and 30.81%, respectively. Exergetic efficiency of the gas turbine is lower than the energy efficiency. The calculation of exergetic efficiency involves environment parameters, and exergy is lost because of the irreversibility in the system.

5. CONCLUSION

The performance of a gas turbine power plant was calculated by using exergy analysis. From the results, it was found that the highest and the lowest exergy destruction was up to 71.03% or 21.98 MW, which occurred in the combustion chamber, and 12.33% or 3.15 MW, which occurred in the compressor. The thermal efficiency and exergy efficiency of the gas turbine power plant are 33.77% and 32.25%, respectively. It can be concluded that irreversibility occurred due to the fact that there are large temperature differences between the combustion chamber and the working fluid.

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