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The impacts of a biofuel use on the gas turbine operating performance

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Abstract

The use of Pure Plant Oil (PPO) as a fuel blend in a power plant is mandatory as stipulated in the Ministerial Decree of Energy and Mineral Resource of the Republic of Indonesia. However, the implementation of PPO used in power generation has many obstacles due to a lack of information concerning the impacts of PPO used in the operating performance of the power generation engine. In this study, the effect of PPO as a blended fuel with High-Speed Diesel (HSD) was studied by using the gas turbine with a capacity of 18 MW. The PPO was blended based on volume with a ratio of 0%, 5%, 10%, and 20%. As the results, it is shown that the use of PPO with a blend ratio of 20% is the maximum fuel blend ratio according to the threshold value of a flue gas temperature and a vibration velocity in the gas turbine.

Keywords: Gas turbine power plant; pure plant oil; high-speed diesel; blended fuel.

I. Introduction

The Republic of Indonesia as the biggest palm oil producer country has a significant potential to utilize palm oil as an alternative energy source. The Ministerial Decree of Energy and Mineral Resource No. 25 year 2013 concerning on Amendment to the previous Ministerial Regulation No. 32 year 2008 concerning Provision, Utilization, and Trade of Biofuel as an Alternative Energy has been published. According to the Ministerial Decree, the use of Biodiesel and Pure Plant Oil (PPO) are mandatory in power generation plant with blend ratio determined gradually. The mandatory ratio of PPO used was 6% in 2014 and increased to 15% in 2015 and at last, was 20% in 2016. PPO is a pure vegetable oil extracted from palm oil that has no chemical change. It has been used as an alternative fuel to increase a reduction of fossil fuel consumption. Pure Plant Oil is also known as Straight Vegetable Oil (SVO).

However, until now, PPO as an alternative fuel of power generation plant is only implemented at Diesel Power Generation Plant only, with a used ratio of PPO is 50% [1]. The implementation of PPO that used in another kind of power generation plant is not yet conducted due to a lack of know-how related to the use of PPO, and there is a big concern about the impact on the engine operating performance. The previous studies show that studies on the use of SVO or PPO as a blended fuel in a gas turbine were conducted limited only for a micro gas turbine that has a capacity below 1 MW or only for laboratory scale study [2] - [5]. Therefore, the impact of PPO fuel blend on the gas turbine operating performance is still insufficient.

An increase in PPO blend ratio will increase a fuel viscosity, which affects an atomization condition in nozzles and a combustion condition in the combustion chamber. However, by increasing an injection temperature of PPO fuel, the effects of viscosity on an atomization pressure at the nozzle and an incomplete combustion at combustor chambers can be minimized [2], [3], [5]. The increase of the temperature in the combustor chambers leads to increase on NOx emission level and decrease on CO emission level [4], [5].

The impacts of PPO used on a safety and a stability of the gas turbine operating performance can be known obviously, after a long period of operating time. Unfortunately, there is no investigation

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regarding the impacts of PPO as a gas turbine fuel concerning a safety and a stability on the gas turbine performance for a long operating time.

This study aims to determine the impacts of fuel blend of High-Speed Diesel (HSD) and PPO on the gas turbine operating performances. The gas turbine operated at 100% load during peak hours for several days, with a total operating period of 40 hours. The ratio of PPO was 0%, 5%, 10%, and 20%, based on the volume. The HSD-PPO fuel blend was preheated and mixed homogeneously by using the blending facility dedicated built for this study. The impacts of HSD-PPO fuel blend on the gas turbine operating performance were observed by using the gas turbine operating parameters including the flue gas. The flue gas parameters were used as indicators for a qualitative evaluation of the combustion process.

II. Research Method

Figure 1 showed the flowchart of the experiment in this study. The viscosity and the spray angle test were conducted in the laboratory. The gas turbine operating performance test was conducted at the site where the gas turbine located.

In the viscosity test, a correlation between an enhancement in temperature and viscosity of the HSD-PPO fuel blend (here in after referred as to sample) was investigated by using a viscometer SV-10. The viscosity of the sample for PPO with a volume ratio of 0% (HSD 100%), 5%, 10%, 20%, and 30% was measured at each temperature rise of 5°C. The test was conducted based on ASTM D45.

A spray angle test was carried out to determine the temperature effect on the spray angle at the nozzle for each sample. The type and the size of nozzle were the same with the nozzle used in the gas turbine. The angle was measured by a visual measurement through a glass viewing window. The temperature of each sample was adjusted until the spray angle was the same as the standard spray angle of 60°.

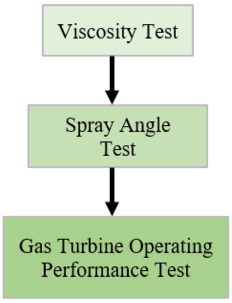

Figure 1. Flowchart of the experiment

Figure 2. Gas turbine PG 5341

The gas turbine operating performance test was conducted in the site by using the gas turbine as shown in Figure 2. The standard fuel of the gas turbine is HSD. During the study, there was no adjustment in the gas turbine engine including the A/F ratio.

The specification of the gas turbine was shown in Table 1 [6]. The gas turbine had been operated since 1983 and recently is operated as a peaker power plant, which operated at 100% load during peak hours every day. The capacity had derated to 18 MW from 21 MW.

The items and the data sources of the operating performance test were shown in Table 2. The monitoring item was monitored and recorded with a specific interval during 40 hours at a peak hour (20:00 - 03:00) for several days, at the maximum load. Load performances consist of a speed of a compressor and generator, frequency, and power output.

Figure 3 showed the schematic diagram of the operating performance test. Dotted line indicated the measurement instruments, which a part of the gas turbine system. Straight line indicated the measurement instrument, which installed during the experiment.

Fuel flow rate, pressure nozzle, flue gas temperature, vibration velocity, turbine speed, compressor speed, noise level, power output and

Table 1.
Specification of gas turbine [6]

Specification	Value
Type	PG 5341
Manufacturer	GEC Alstom
Capacity	18.0 MW
Compressor + Turbine speed	5,100 rpm
Compressor stages	17
Turbine stages	2
Combustor (Nozzle)	10 (10)
Generator speed	3,000 rpm

Table 2.
Operating performance parameters

No	Monitoring Item	Monitoring Point/ Data Resource
1	Load Performance	Data logger control room
2	Specific Fuel Consumption (SFC)	Flow rate taken from flow counter, kWh taken from kWh meter in the control room
3	Vibration	Point 1 (compressor bearing at the air inlet inside), point 2 (compressor body), point 3 (generator bearing at the front of generator shaft), point 4 (generator bearing at the behind of generator shaft).
4	Nozzle Pressure	Monitor in the control room
5	Deposit	Visual observation
6	Flue Gas	Flue gas duct
7	Flue Gas Temperature	Monitor in the control room
8	Noise Level	Monitor in the control room

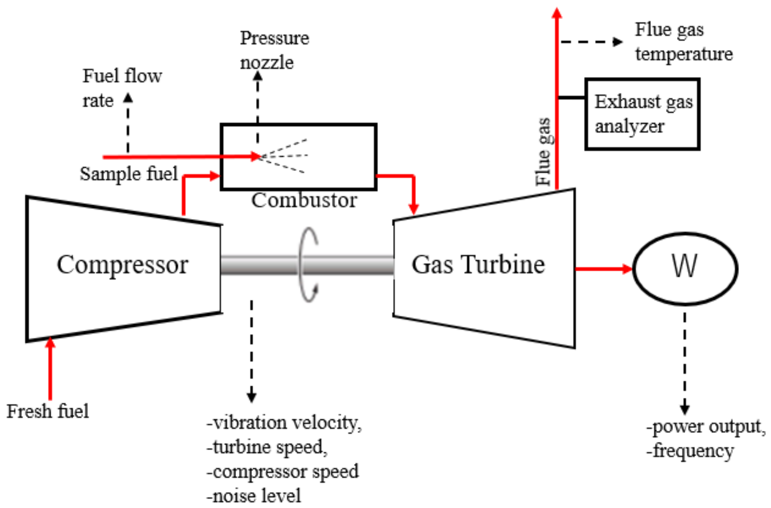

Figure 3. Flowchart of the experiment

frequency were measured by the existing measurement instruments, which was a part of the gas turbine system. The measured values were recorded manually taken from monitoring displays in the control room by a one-hour interval. Exhaust gas analyzer was installed during the experiment.The analyzer was used for measuring flue gas velocity and flue gas level. Vibration velocity was measured at four points located at air inlet side of the compressor bearing (point 1), at the compressor body (point 2), at front side (point 3) and behind the generator bearing (point 4). A measurement instrument of noise was at the side of the turbine and the side of the generator.

Specific Fuel Consumption (SFC) was the calculation result derived from a sample flow rate measured by the flow counter installed at the inlet supply pipe of the gas turbine and power generated which recorded by kWh meter in the control room. The interval recording was one hour.

Figure 4 showed the activity of making holes for the exhaust gas analyzer. The monitoring instrument of the analyzer was located below the flue gas duct. Flue gas level measurement was conducted according to several standards. To determine the number of sampling holes in a flue gas duct, Indonesia National Standard / Standar Nasional Indonesia (SNI) 7117.13:2009 was implemented.

Flue gas velocity was measured by type-S Pitot tube, and the measurement procedures were conducted according to SNI 7117.14:2009. To calculate the flue gas velocity, a weight of gas molecules and water content in the gas molecules was required to be known previously. SNI 7117.15:2009 and SNI 7117.16:2009 were used to calculate the flue gas velocity. All measurement related to the flue gas was conducted after the gas turbine operates steadily which usually achieved in two or three hours after the experiment had started. The measurement result was corrected to 15% of oxygen level to prevent the concentration of pollutant being achieved by dilution of the exhaust with air.

A visual observation of formed deposit at nozzles was conducted after the nozzle was released. It was carried out after the experiment for each sample completed, in the cold condition.

Figure 5 showed the blending facility that had a capacity of 8,000 ltr/hr. The facility was constructed to support this study and located behind the gas turbine plant. Using the blending facility, the sample was preheated and blended homogeneously.

Figure 6 showed sub facilities of the blending facility. There are four sub-systems in the blending facility. As shown in Figure 6, the functions of sub facility were a) to preheat PPO and the sample (indicated by a green line), b) to supply PPO from an HSD tank to a blending tank (indicated by a yellow line), c) to supply HSD from a HSD tank to a blending tank (indicated by a brown line) and d) to supply the sample from a buffer tank to the gas turbine (indicated by a red line).

Figure 4. Installing sampling holes

Figure 5. Blending facility

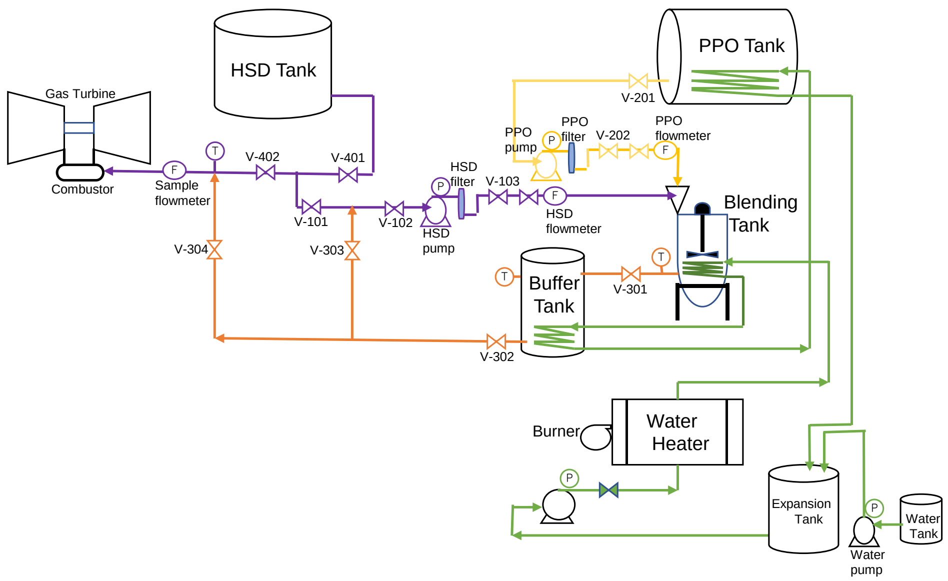

Figure 6. Sub-facilities of blending facility

A bi-metal thermometer was mounted on both tanks to monitor a sample temperature in the blending tank and the buffer tank. A blend ratio of PPO and HSD was a volumetric ratio, which was measured by two units of turbine flowmeters, and installed at both supply pipes to the blending tank. A blend ratio of HSD and PPO was manually controlled by valve mounted on both turbine flowmeters. A flow rate of the sample to be supplied into the gas turbine was measured by the existing flowmeter installed at the inlet pipe supply. A mini boiler was used to heat the water to preheat PPO and the sample (PPO and HSD fuel blend) at the PPO tank and the blending tank, as well as the buffer tank.

Table 3.
Characteristics of PPO and HSD

Fuel	Calorific value	Density	Viscosity
	kJ/kg	kg/m^2	cST at 40 °C
HSD	45.52	811	3.46
PPO	39.81	883	40.57

Table 4.
Sample composition

Sample	Composition
I	HSD100%
II	HSD95%-PPO5%
III	HSD90%-PPO10%
IV	HSD80%-PPO15%

In this study, the specification of HSD and PPO were analyzed at the laboratory by using ASTM standards. The analyzed result was shown in Table 3. Table 4 showed a blended fuel ratio composition for each sample. The blended fuel used in this study must comply the ASTM 2880 “Standards Specification of Gas Turbine Fuel Oil” to minimize the effects of viscosity on a fuel atomization, a fuel evaporation including a fuel combustion, and also to guarantee the stability and safety of the gas turbine during the operation time, the blended fuel used in this study must comply with ASTM 2880 “Standard Specification of Gas Turbine Fuel Oil.”

Table 5 showed the classification of gas turbine fuel which divided into five grades. HSD fuel as the standard fuel of the gas turbine was classified into Grade 2-GT. According to this classification, the kinematic viscosity of the sample must be between 1.9 - 4.1 cSt.

III. Result and discussion

A. Viscosity and spray angle test

Figure 7 showed the result of viscosity test. As shown in Figure 7, the viscosity increases in line with the increasing of PPO ratio and decreases with the increase of temperature. The same result is also indicated by Nozomu *et al.* [7], and Sallevelt *et al.* [5]. They had measured the effect of the temperature rise

Table 5.
Classification of gas turbine fuel

Characteristics	Unit	Grade				
		No.0-GT	No.1-GT	No.2-GT	No.3-GT	No.4-GT
Flash Point	°C	-	>= 38	>= 38	>= 55	>= 55
Kinetic Viscosity	cSt	-	1.3 - 2.4	1.9 - 4.1	= 5.5	= 5.5
Carbon Residue	%	<= 0.15	<= 0.15	<= 0.35	-	-
Ash Content	%	<= 0.01	<= 0.01	<= 0.01	<= 0.03	-
Water and Sediment	%	<= 0.05	'<= 0.05	<= 0.05	-	-

Table 6.
Spray angle measurement

Sample	HSD Vol. (ltr)	PPO Vol. (ltr)	Temp. Test (°C)	Viscousity cST	Press. Test Mpa	Spray Angle (°)
I	50	0	36	4.00	1.034	60
II	47.5	2.5	40	4.10	1.034	60
III	47.5	5.3	45	4.10	1.034	60
IV	47.5	11.9	55	4.10	1.034	60

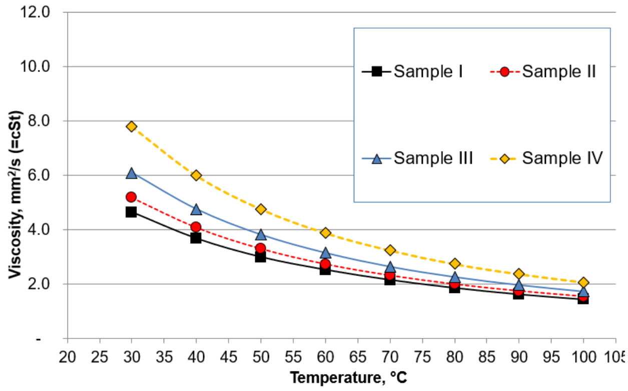

Figure 7. Effect of an increase in temperature on a sample viscosity

Figure 8. Spray angle of sample I and sample IV

on kinematic viscosity of biofuel, which derived from a palm methyl ester and a vegetable oil, respectively. As shown in Figure 7, at the ambient temperature, and the viscosity of sample II, III, and IV exceed the grade 2-GT with the range of 1.9 - 4.1 cSt. Therefore, these sample were impossible to comply the classification of Grade 2-GT without pre-heating.

Table 6 showed the result of the spray angle test. The preheat sample was injected to the nozzle, when the spray angle of the sample was already the same with the standard angle, then the temperature sample was recorded. As an addition, by using Figure 7, a kinematic viscosity of each sample was estimated. As shown in Table 6, the estimated viscosity located in the range of grade No.2-GT.

Figure 8 showed the spray angle measurement condition for the sample I and IV. Through a glass viewing window, the spray angle was shown to be 60°. By using this experiment, it was proved that the high viscosity could be decreased by the increment of temperature, and a decrease in viscosity could keep the fuel atomization condition as indicated by the spray angle test.

This result was also supported by the following previous studies concerning a nozzle spray angle in biofuel use [8], [9]. They had found that high-temperature fuel injection reduced the kinematic viscosity value of the biofuel and could improve the biofuel spray atomization at a nozzle.

B. Gas turbine operating performance test

After the viscosity test and the spray angle test were conducted in the laboratory, the gas turbine operating test was performed. The results were explained in Figure 9 and Table 7. Figure 9 showed a power output profile of the gas turbine during the operation time for each sample. The fluctuation of power output was depending on the demand of the national grid at the operation time. There was no influence from an increase in PPO ratio.

The average value of the gas turbine operating performance was shown in Table 7. The gas turbine and the generator speed were constant. However, the output and the frequency were fluctuated due to the demand fluctuation at that time. An increase of PPO ratio did not give any effects on both of turbine speed and generator speed.

Table 8 showed the fuel blend/sample specification. The calorific value of sample was decreased in an increase of PPO ratio. However, the kinematic viscosity, the relative density, as well as the fuel flow rate were increased. Figure 10 showed the fluctuation

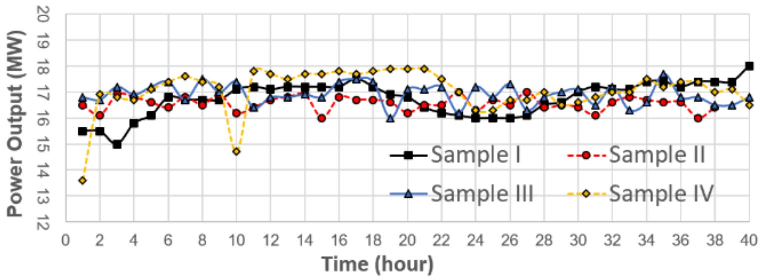

Figure 9. Power output

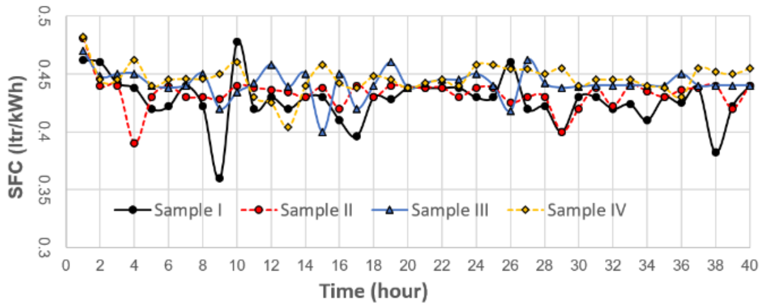

Figure 10. SFC profile

Table 7.
Gas turbine performance

Gas Turbine Performance	Unit	Sample I	Sample II	Sample III	Sample IV
Output	MW	16.75	16.56	16.92	17.06
Frequency	Hz	50.1	50.13	50.18	50.18
Turbine Speed	rpm	5,100	5,100	5,100	5,100
Generator Speed	rpm	3,000	3,000	3,000	3,000

Table 8.
Sample specification

Fuel Blend Specification	Unit	Sample I	Sample II	Sample III	Sample IV
Caloric Value	kkal/kg	10,879	10,811	10,743	10,606
Kinematic Viscosity	cSt	3.46	4.34	5.14	5.01
Relative Density	kg/m^3	811	836	837	837.5

profile of Specified Fuel Consumption (SFC) for each sample. The profile fluctuation of each sample was relatively stable, except for sample I. Sample I showed several excessive fluctuations due to load fluctuations. In general, SFC value of sample I was located at the lowest value because it has the highest calorific value.

As shown in Table 9, an average of SFC was increased with the increasing of PPO ratio. The increase in SFC was caused by a decrease in calorific value of the samples. The sample flow rate was increased automatically to maintain the gas turbine output. Chiramonti *et al.* [3] and Szalay *et al.* [10] studies showed a lower calorific value and obtained an increase in a flow rate supply of fuel blend by using a blend of diesel and biofuel.

Figure 11 showed a vibration velocity profile measured at the generator and the compressor of the gas turbine. As shown in Figure 11, the vibration velocity at point 1 was located at the highest range of 0.76 - 0.99 cm/s and followed by the vibration velocity at point 2, which located in the range of 0.48-0.74 cm/s. The vibration velocity was wider at point 3, with a range of 0.53 - 1.14 cm/s and at point 4 with a range of 0.21 - 1.02 cm/s, respectively.

The average vibration velocity at point 1 was the highest, and the range of vibration velocity at point 4 was the widest. The vibration velocity profile at the point 1 and 2 were relatively stable. However, the excessive fluctuation was seen at the point 3 and 4, especially for sample IV. Since a combustion and a fuel atomization of the gas turbine system was designed to be used for the sample I.

As shown in Figure 10, the vibration velocity profile of sample I was in general appears to be the most stable and located at the lowest level at all measurement points. It can be predicted that a mixing of sample I with a combustion air was in an optimal combustion condition.

Table 9.
Average SFC

Sample	I	II	III	IV
SFC (ltr/kWh)	0.428	0.433	0.442	0.446

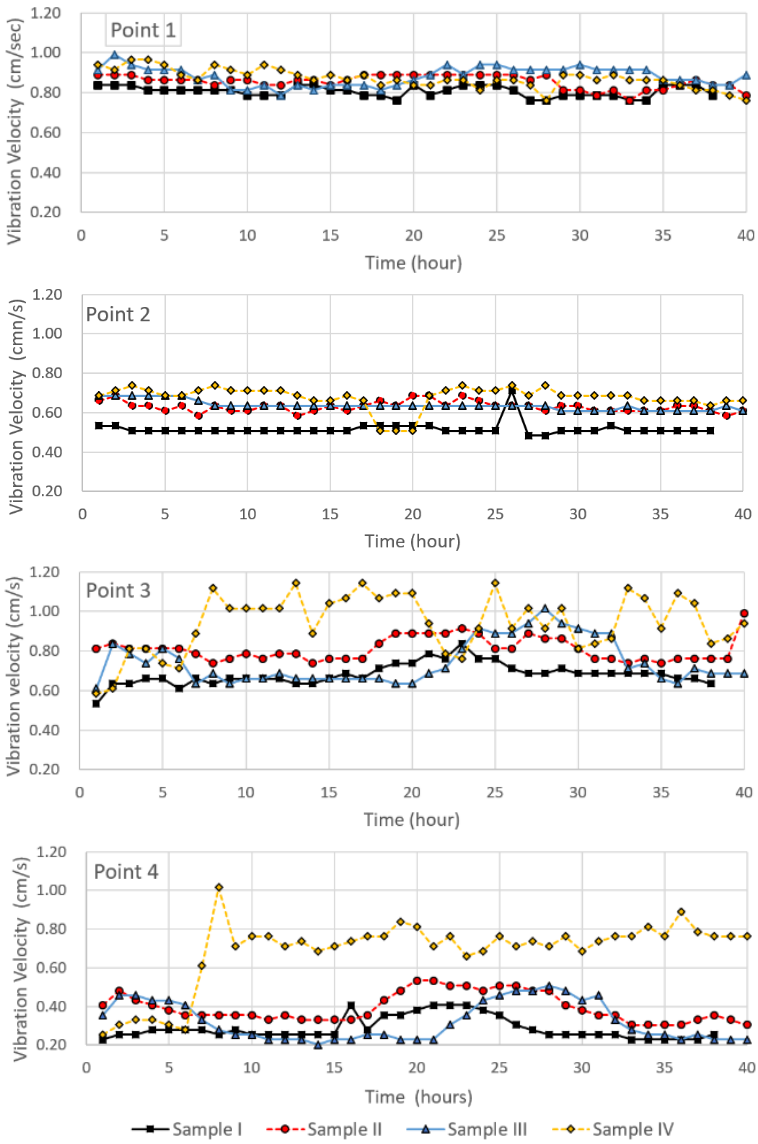

Figure 11. Vibration velocity profile

The vibration at point 1 was induced by a rotating part vibration, while other vibrations induced by other mechanisms. The oscillations were known induced by the combustion. The effect of an increase in PPO ratio was represented by the combustion-induced oscillations. As explained by Othman *et al.*, the heated flow in the combustor was resulted in a higher vibration level, since the temperature had induced the higher turbulence intensity in a heated flowing medium. Othman *et al.* also showed the effects of fuel kind on induced vibration in a gas turbine, and a combustion-driven oscillation tends to increase with C/H ratio [11]. PPO had a carbon/hydrogen (C/H) rate higher than HSD, as a consequence, an increase in PPO ratio might generate an accumulation of soot inside the combustion chamber or turbine blades [12]. The velocity vibration at point 2 decreased due to the measurement location that had a distance from the rotating part as the main vibration source. The measurement point was in the compressor body. The vibration velocity at point 3 and 4 were induced by the same kind vibration resources of at point I. However, the rotating parts were the generator shaft with a speed of 3,000 rpm, which lower than a speed of the gas turbine compressor of 5,100 rpm. This lower speed induced a wider vibration velocity at point 3 and point 4 as shown in Table 10.

Table 10 showed an average vibration at the four locations of measurement point for each sample. The effect of an increase in PPO ratio on the vibration velocity was readily apparent at point 3 and 4, which induced by rotating part with speed of 3,000 rpm. However, in the higher rotating part speed of 5,100, the effect was not shown explicitly at point 1. The highest average vibration velocity was shown by sample IV. At the point 4, the average velocity was the lowest value except for sample IV.

Table 10.
Average vibration

Fuel	Average Vibration (cm/sec)			
	Point 1	**Point 2**	**Point 3**	**Point 4**
Sample I	0.89	0.66	0.64	0.23
Sample II	0.86	0.64	0.79	0.38
Sample III	0.89	0.64	0.74	0.33
Sample IV	0.86	0.69	0.94	0.69

The maximum increase of vibration velocity was still below the threshold value for the vibration velocity of 2.03 cm/sec, which the threshold value was set at 1.27 cm/sec. According to the safety standard for gas turbine operation, it should be wary of the impact of an increase in vibration on the shaft of the compressor and the generator.

Figure 12 showed ten chambers of combustion installed circumferentially. The nozzle was mounted inside each the combustor chamber. Figure 13 showed the fluctuation profile of pressures at nozzle 1, 3, 5, 7, and 9 for each sample. These nozzle pressure profiles were considered to be represented others nozzle

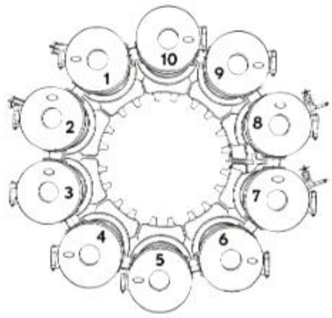

Figure 12. Combustor chambers [6]

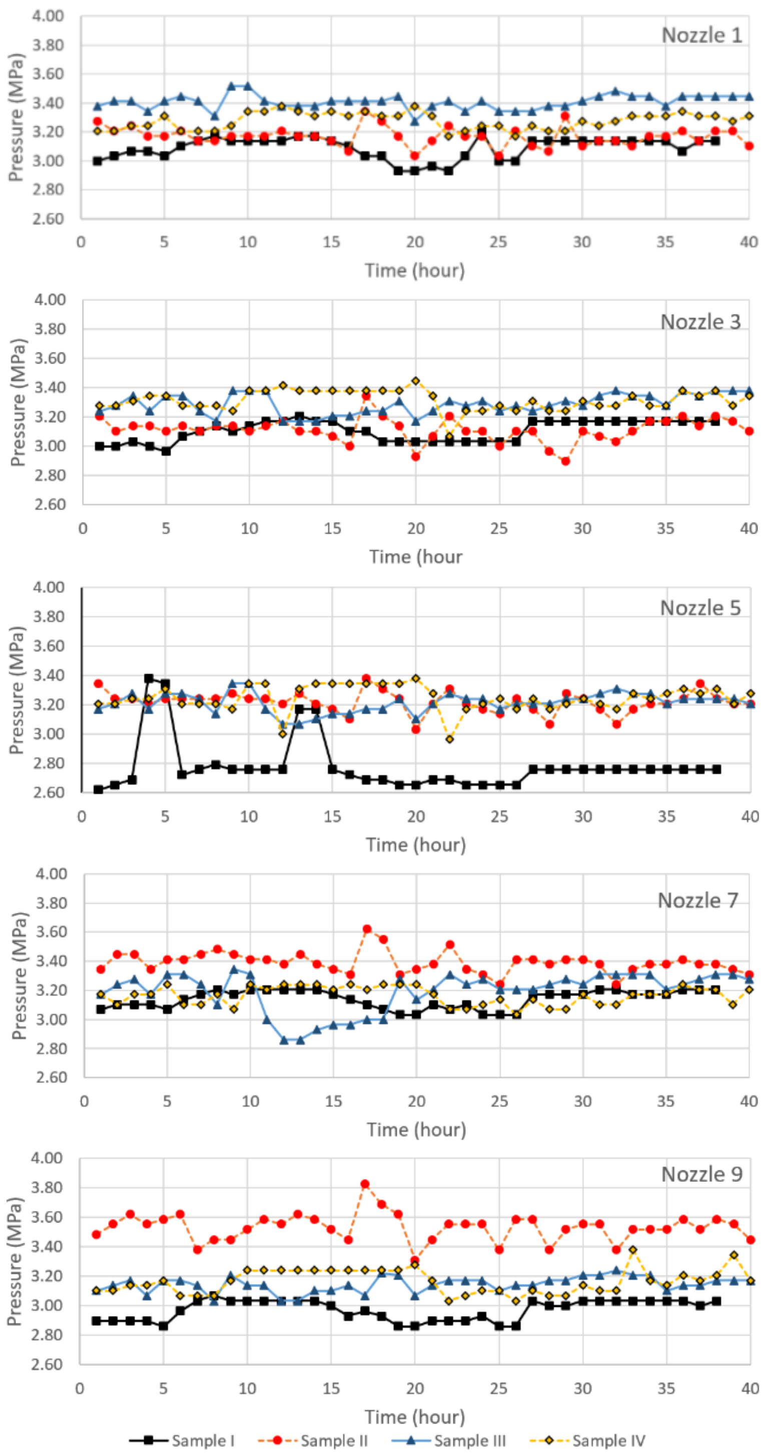

Figure 13. Nozzle pressure profile

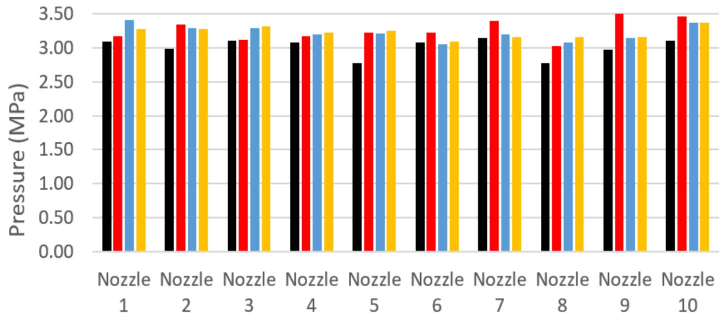

Figure 14. Average value of nozzle pressure

pressure profile. Therefore, the other profiles were not shown in this paper. As shown in Figure 13, compared to the other nozzle pressure profile, the nozzle pressure profile of sample I indicated the lowest value at all nozzle for each sample. A pressure nozzle affected to fuel atomization condition, therefore, a higher-pressure nozzle indicated high pressurized atomization.

In this study, the fuel atomization condition at nozzle in a combustor chamber was not observed. However, the effect of the nozzle on the fuel atomization could be predicted based on the following studies. Nozomu *et al.* showed that an increase in the nozzle pressure had influences on a decrease in Sauter Mean Diameter (SMD) and an increase in NOx emission level [7]. As an addition, the effect of nozzle pressure on SMD was expressed by the equation proposed by Ee Sann Tan *et al.* [13].

Figure 14 showed an average of nozzle pressure at all nozzles for each sample. The sample I was usually at the lowest value for all samples at all nozzles. In general, an increase in PPO ratio caused an increase in the average value of nozzle pressure.

Figure 15 showed a condition of nozzle 1 after used sample I (left side) and sample III (right side). According to the visual observation, deposit at nozzle I was found with various thickness and attachment conditions.

For all sample, the deposit was black and brittle. The deposit was formed at the nozzle due to the incomplete combustion, whereas, the formation velocity of deposit was depended on the fuel characteristics. The deposit amount of sample III exceeded the deposit amount of sample I. This result was supported by the argument of Gökalp *et al.* concerning an increase in PPO ratio that might generate an accumulation of soot inside the combustion chamber or turbine blades [13].

In this study, according to the visual observation, it was concluded that the amount of deposit increases with an increase in PPO ratio. The formed deposit at the nozzle induced the nozzle pressure. The nozzle pressure increased due to the formed deposit at nozzle that was a possibility to cover the nozzle holes. It was known that the carbon content in sample I was higher than sample III, then the more carbon content in fuel molecule, the more likely it to produce soot [14]. In this study, conversely, since the A/F ratio was fixed, there was no balance adjustment of a combustion air flow rate to an increase in fuel flow rate supply (an increase in SFC). It leads an incomplete combustion and generates soot. Nozomu *et al.* showed that an increase in O_2 (a combustion air) supply would decrease the soot [7]. Deposit amount in the nozzle was related to an increase in PPO ratio and the fix of A/F ratio.

Deposit at nozzle might cause a difficulty in a releasing nozzle. This condition will potentially change a nozzle maintenance interval. Based on the deposit observation result at the nozzles, it should be a possibility that deposit was also attached to turbine blades and duct surface.

The increase of nozzle pressure as shown in Figure 13 could predict a result of the deposit formed in the nozzles. The deposit was formed due to incomplete combustion since no adjustment of the A/F ratio. Increasing in PPO ratio required more O_2 to combust the sample containing PPO, completely. Although PPO contained O_2, it is unlike enough to combust it completely.

Figure 15. Deposit at No 1 Nozzle, after used Sample I (left side) and Sample III (right side)

Table 11
Flue gas (mg/m^3)

Emission	Sample I		Sample II		Sample III		Sample IV	
	Average	**15% O_2**	**Average**	**15% O_2**	**Average**	**15% O_2**	**Average**	**15% O_2**
CO	0	0	0	0	18.5	25.9	2,5	3.5
NOx	65.7	87.2	94.3	133.2	235	332	222	310
SO_2	84	165	16.2	11.5	60	84	49	69
O_2	16.9	15	16.8	15	16.5	15	16,7	15

Table 12.
Flue Gas Temperature

	Sample I	Sample II	Sample III	Sample IV
Temperature (°C)	459.1	464.9	478.7	478.8

Flue gas emission was used as indicators combustion performance evaluation. Table 11 indicated flue gas content, which consists of Carbon Monoxide (CO), Nitrogen Oxide (NOx), Sulphur (SO_2) and Oxygen (O_2) emission level. The correction value used 15% of Oxygen was also shown.

The flue gas was formed by a combustion process, in which the composition of flue gas depends on a kind of fuel and a combustion condition, such as A/F ratio, fuel atomization condition. The flue gas level for each sample was below the threshold value stipulated by Ministerial Decree of Environment and Forestry, No.21 of 2008, which the threshold value of Nox = 450 mg/Nm^3, and SOx = 650 mg/Nm^3, respectively.

As shown in Table 11, CO increased for Sample III and IV. Using SVO from rapeseed, sunflower and soybean, Cavarzere *et al.* presented that CO emission level from SVO fuel blend ratio up to 20% was almost same with the CO emission from pure diesel. Beyond 20% of SVO fuel blend ratio, the CO emission was known higher than the emission from pure diesel [2]. A lower CO indicated a good combustion characteristics and a complete combustion occurred or it close to the stoichiometric conditions. The factors affected CO emission level were A/F ratio, engine speed, injection time, atomization rate and kind of fuel [15], [16]. In this study, CO emission increased as a result of the PPO ratio increment, since the combustion system was designed for diesel fuel. This situation was also found in Cavarzere *et al.* study [3].

The increase in CO level was resulted from a decrease in A/F ratio and a calorific value of the sample. The A/F ratio of the gas turbine was the specified ratio value for sample I. As a consequence for others sample used, the A/F ratio should be adjusted due to an increase of sample flow rate. However, since A/F ratio was fixed, the CO emission level increased due to insufficient air for combustion. This result was supported by Nozomu *et al.* [7], who used biofuel blend as fuel in a gas turbine. CO emission level can be decreased by an increase in A/F ratio [7]. A decrease in the calorific value of sample III and IV caused an increase in fuel flow rate and also causes combustion condition moves to rich mixture condition (a decrease in A/F ratio).

Table 11 showed NOx level that increased with an increase in PPO ratio, except for sample IV. The increase of NOx caused by several factors which can be explained by several hypotheses proposed by Lapuerta *et al.* [17] and Cheng *et al.* [18], such as:

(i) At combustion phase, a flame of PPO with a cetane number of 62 ignited faster compared to flame of HSD with cetane number of 45. Therefore, the combustion result of PPO had a longer residence time which caused an increase in thermal NOx emission level [18], [19].
(ii) At pre-mixed burn fraction, PPO contains high oxygen which was resulted in a rise of Nox [20].
(iii) PPO had a higher adiabatic ignition flame than HSD. Therefore, it produced more NOx.

As shown in Table 11 and Table 12, NOx level and flue gas temperature increased with the increasing of PPO ratio. Hence, as indicated in both the tables, the effects that generated due to hypotheses (i) - (iii) were dominant in the combustion system.

As shown in Table 11, SO_2 emission level did not show a relation with an increase in PPO ratio. The SO_2 emission level depended on the Sulphur content in the sample [20]. Based on the laboratory analysis result which measured according to ASTM D 2622-03, it was indicated that Sulphur content (% wt) in HSD and PPO were 0.22% and 0.03%, respectively. It can be understood that a level emission of SO_2 in sample I was higher than others sample. The effect due to an increase in PPO ratio to O_2 emission level was not shown.

Figure 16 showed flue gas temperature profile during the experiment for each sample. Red line indicated Tmax. In general, the flue gas temperature of sample I was lower, and sample IV was higher compared to others. The flue gas temperature for sample II and III was fluctuated. In general, the flue gas temperature for sample II was lower compared to the temperature of sample III, both fluctuated each other. Flue gas temperature had a close relation with a temperature in the combustion chamber and a NOx emission level.

Table 12 showed an average of flue gas temperature, $T_{average}$. $T_{average}$ increases with an increase in PPO ratio for each sample. An increase in $T_{average}$ was caused by an increase in temperature of the gas turbine combustor, which was indicated by an increase in NOx emission level as shown in Table 12. An increase in $T_{average}$ was still below the flue gas

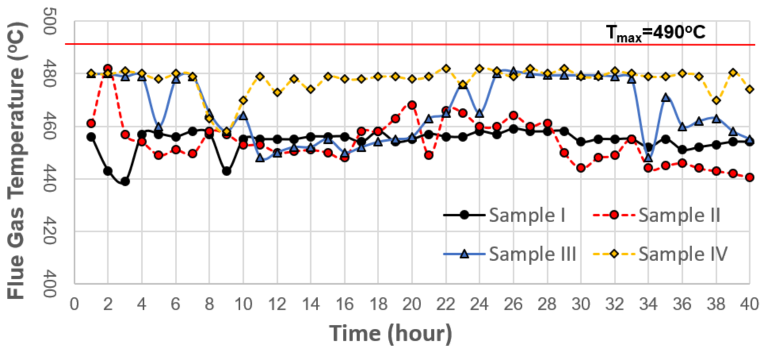

Figure 16. Profile of flue gas temperature

Table 13.
Noise Level

Fuel	Noise Level (dB)	
	Turbine	Generator
Sample I	97.14	95.16
Sample II	98.91	95.67
Sample III	100.29	96.39
Sample IV	99.21	91.09

temperature threshold of the gas turbine, T_{max} = 490°C. However, the increase in flue gas temperature should be supervised concerning of the operational safety standards of the gas turbine.

Table 13 showed an average of noise level at the turbine and the generator. The noise level was tended to increase with an increase in PPO ratio. However, it was shown a decrease in sample IV. The maximum noise level occurred at the turbine for sample III. The decrease in noise level for sample IV was resulted by the decrease of the vibration for sample IV. It can be predicted that in this case, the noise source was mainly induced by a mechanical vibration of equipment due to the combustion vibration in the combustors, and others vibration and oscillation induced by the combustion vibration. The threshold value of noise was 120 dB, respectively.

IV. Conclusion

Based on the standard operation of the gas turbine, the use of fuel blend with PPO ratio of 20% was the maximum blend ratio in this study. By using this ratio, the maximum temperature of flue gas, the noise level, and the velocity vibration which achieved in this study were 478.8°C (97.7% of the threshold value), 100.29 dB (83.6% of the threshold value), 0.86 cm/sec (67.7% of the threshold value), respectively. They were almost close to the threshold value of 490°C, 120 dB, and 1.27 cm/sec, respectively.

An adjustment of A/F ratio to a certain kind of fuel blend was required to improve the combustion condition and to increase of combustion efficiency. The generated soot at the nozzles due to use of a higher PPO blended ratio and an adjustment of A/F ratio to certain kind of fuel will be an object for the next study before the HSD-PPO fuel blend implemented widely as the obligation for power generation company.

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