Hittite Journal of Science and Engineering, 2019, 6 (3) 229-233
ISSN NUMBER: 2148-4171
DOI: 10.17350/HJSE19030000152

The Performance of Gas Turbine Power Plant Using 5% Biodiesel & 95% High Speed Diesel

Mujammil Asdhiyoga Rahmanta, Tiva Winahayu Dwi Hapsari, Bernaded Oka Anggraini
PLN Research Institute, PT. PLN (Persero), 12780, Jakarta, Indonesia

Article History:
Received: 201ί/oί/oΨ
Accepted: 201ί/Φί/Ψέ
Online: 2019/Φί/3Φ

***Correspondence to**: Mujammil Asdhiyoga Rahmanta*
PLN Research Institute, PT. PLN (Persero), 12780, Jakarta, Indonesia
Tel: +62 21 797 3774
Fax: +62 21 799 1762
E-Mail:mujammil1@pln.co.id

ABSTRACT

Indonesia is the largest producer of crude palm oil (CPO) in the world. Biodiesel containing fatty methyl ethyl ester (FAME) is oil produced as a derivative process from CPO. Biodiesel has properties similar to high speed diesel (HSD). The Minister of Energy and Mineral Resources (MEMR) made a policy of using biodiesel as a mixture of HSD to be used as fuel in the electricity and transportation sector. There are many problems in the implementation of these fuels, especially in gas turbine power plants such as the impact on performance and reliability. In this study, the effects of biodiesel mixed with HSD were studied using a gas turbine power plant with a capacity of 18 MW. The mixture of 5% biodiesel and 95% HSD (called B5) is used as fuel for testing for 1 month operation. Performance indicators such as load, fuel consumption, specific fuel consumption, exhaust gas temperature, and nozzle pressure are monitored during the testing. Performance data and results of inspection of hot gas lines from gas turbines operated for a month are then analyzed. As the results, B5 has reduced power production, increased fuel consumption, and the potential for heat corrosion in hot gas lines. After carrying out visual and deposit sampling inspections, found many deposits containing Carbon, Sodium and Sulphur. Sediment samples were tested in the laboratory to find out metal contaminants in deposits in the transition pieces, nozzle stages one, and nozzle stages two. The metal contaminants allegedly came from HSD and Biodiesel fuel.

Keywords:
Biodiesel; High speed diesel; Performance; Reliability; Corrosion; Hot gas path; Gas turbine

INTRODUCTION

The Republic of Indonesia is one of the largest producers of crude palm oil (CPO) in the world along with Malaysia [1]. In addition, Indonesia is an oil importing country. To reduce oil imports, the Minister of Energy and Mineral Resources (MEMR) issued a decree No. 25 of 2013 concerning changes to Ministerial Regulation No. 32 of 2008 concerning Provision, Use and Trading of Biofuel as Alternative Energy. According to the Ministerial Decree, the use of biodiesel in the electricity sector is targeted at 7.5% in 2013, 20% in 2014, 25% in 2015, and 30% in 2016 from total oil consumption.

PLN is an Indonesian state-owned electricity company that has many diesel engines and gas turbines for its generation. In diesel engine power plants, biodiesel and high speed diesel (HSD) mixed fuels can be implemented properly. Apart from not requiring engine modifications, this is because there are no major problems in terms of performance and reliability. However, in gas turbine power plants, there are many implementation problems in gas turbine power plants such as performance and reliability issues.

Biodiesel contains fatty ethyl methyl ester (FAME) which has similar properties as HSD oil especially with low viscosity characteristics [2, 3, 4, 5]. The most common method used in producing biodiesel is the CPO transesterification process. In this process, the raw material for lipids is converted into biodiesel. One mole of triglycerides reacts with three moles of alcohol to produce three moles of mono alkyl ester and one mole of glycerol. To increase the reaction rate and yield of biodiesel, the catalyst is usually added to excess alcohol, which shifts the equilibrium to the product side because of its reversible reaction [6, 7, 8]. Traditionally, the transesterification process uses solvents including ethanol or methanol and homogeneous catalysts such as KOH, NaOH, and H_2SO_4 [5, 9]. However, this method has several disadvantages such as extensive separation processes, generation of wastewater, and corrosion of equipment [9, 10, 11].

This paper was presented orally in 18th International Conference on Sustainable Energy Technologies – SET 2019, 20th - 22nd of August 2018, Pulau Pinang, Malaysia and its abstract was published in the Conference Abstract Book.

Biodiesel has similar properties as HSD as indicated in Indonesian National Standard (SNI) No. 7182: 2015 quality requirements for biodiesel. For physical and chemical properties, biodiesel has a number that is relatively the same as HSD as stated in the decision of the Director General of Oil and Gas MEMR No. 14499K/14/DJM/2008 concerning Standards and Quality of Types of Diesel Fuel Marketed Domestically. But, naturally biodiesel has specific properties such as coagulants or clumps (at relatively low temperatures) and depressants (cleaning deposits in pipelines).

The 18 MW gas turbine power plant used in this trial is an industrial gas turbine produced by General Electric. Gas turbines have been designed to use gas and oil as fuel. This study is intended to determine the effect of performance and reliability of the use of 5% biodiesel and 95% HSD mixtures or B5.

MATERIALS AND METHODS

Shown in Figure 1 that B5 is used as fuel during testing. Biodiesel is mixed with HSD in tanks for 1 month operational consumption. Before being mixed, biodiesel and HSD were sampled and analyzed. Biodiesel and HSD fuels are supplied from two different companies. After being mixed in tanks with a fuel ratio of 5% biodiesel and 95% HSD, mixed fuels are sampled according to the ASTM D 4057 Standard Practice for Manual Sampling of Petroleum and Petroleum Products. Fuel samples were tested and analyzed in the laboratory before being verified and confirmed for use in experiments. Then the gas turbine is operated for a month with continuous base load conditions.

During the 1 month trial, performance parameters were monitored in the control room and locally. After 1 month of operation, visual inspection and deposit sampling is done to get the data to be analyzed.

Gas Turbine Specification

The specifications of the gas turbine power plant for testing are shown in Table 1. This power plant has been operating since 1993 for peak load conditions. The plant is installed with a capacity of 20 MW. Because it has experienced long operating hours for years, now it is only

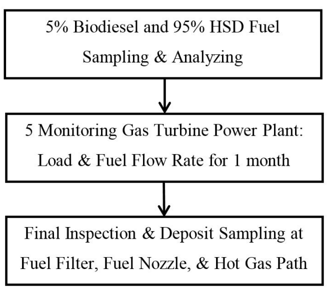

Figure 1. Flowchart of the experiment

Table 1. Specification of gas turbine

Specification	Value
Manufacturer	GEC Alstom
Installed capacity	20 MW
Compressor & Turbine speed	5,100 rpm
Compressor stage	17
Pressure ratio	10
Turbine impulse stage	2
Combustor (Nozzle)	10 multiple combustor reverse flow
Chamber arrangement	Concentrically located around compressor
Generator Speed	3,000 rpm

able to operate with a maximum load of 18 MW due to a decrease in the life of the material.

Gas Turbine Monitoring

During 1 month of testing, gas turbine power plants continued to be monitored as usual performance parameters as shown in Table 2. In this test, B5 fuel was sampled and analyzed four times during the 1 month test. This is done to find out and maintain the quality of the mixed fuel during testing as next as shown in Table 4.

Table 2. Operating performance parameters

No.	Monitoring Item	Data Resource
1	Fuel properties	Sample analyzing
2	Fuel flow	Flow meter counter
3	Load	Data logger export meter
4	Nozzle pressure	Monitor control room
5	Deposit	Visual and sampling observation
6	Flue gas temperature	Monitor in the control room
7	Flue gas	Flue gas duct

The schematic diagram [12] of the gas turbine operation performance test is shown in Fig. 2. The dashed line shows the measurement instrument of the operating process, such as fuel sample, fuel flow rate, pressure nozzle, load, exhaust gas, & gas temperature throw away. Turbine inspection and deposit sampling is carried out after 1 month of the gas turbine being operated. The deposit sample is tested in the laboratory to find out the metal material or composition. The results of the composition of the metal are used to determine whether it comes from fuel or gas turbine material.

Fuel Characteristics

Fuel is tested before testing as shown in Table 3. HSD & biodiesel are tested by CV. Petrolab before mixing in the tank. As shown in Table 3, the properties of biodiesel are similar to HSD such as kinematic viscosity which is very important in the atomization process in a fuel nozzle. The gross calorific value of biodiesel is lower than HSD

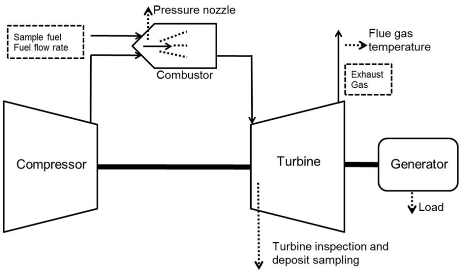

Figure 2. Simple cycle of gas turbine in the experiment

around 10%. But, the biodiesel flash point is higher than HSD around 20%. While impurity metals such as Sodium or Na and Lead or Pb have the same relative value. B5 mixture is tested as shown in Table 4 where the result of the mixed B5 parameter is between the results of HSD & biodiesel.

Table 3. HSD, Biodiesel, & B5 properties before performance test*

Parameter	Unit	Result			Method
		HSD	FAME	B5	
Spesific gravity at 60/60 °F	-	0,842	0,866	0,843	ASTM D1298
Kinematic viscosity at 40 °C	cSt	3,454	4,084	3,647	ASTM D445
Sulphur content	%	0,165	0,03	0,182	ASTM D4294
Water content	%	<0,05	0,08	<0,05	ASTM D95
Ash content	%	0,01	0,01	0,01	ASTM D482
Flash point PMCC	oC	82	108	80	ASTM D93
Gross calorific value	KCal/kg	10.516	9.175	10.120	ASTM D240
Carbon residue	ppm	0,01	0,05	0,02	ASTM 189
Vanadium, V	ppm	<0,1	<0,1	<0,01	ASTM D5708
Natrium, Na	ppm	1,52	1,76	1,84	ASTM D5709
Kalium, K	ppm	Nil	Nil	<0,01	ASTM D5710
Calcium, Ca	ppm	2,3	4,62	2,9	ASTM D5711
Timbal, Pb	ppm	2,66	1,93	<0,01	ASTM D5712
Besi, Fe	ppm	Nil	0,08	0,21	ASTM D5713

*Tested by CV. Petrolab Service

During 1 month operation, B5 is tested to determine the stability of its parameters. B5 fuel sampling is carried out on days 1, 11, 20, & 29. Shown in Table 4, the results of parameters such as viscosity, flash point, density, and heating value are relatively stable. But, the water content is not stable.

Table 4. B5's properties during the 1 month test

No.	Paramaeter	Unit	B5 Result** (day to)				Method
			1	11	20	29	
1	Viscosity 40 °C	cSt	3,21	3,12	3,15	3,17	ASTM D445
2	Flash point	°C	76	76	75	75	ASTM D 93
3	Water content	Ppm	113	523	380	133	ASTM D 95
4	Density 15 °C	g/ml	0,8415	0,8405	0,8395	0,8405	ASTM 1298
5	Heating Value	MJ/kg	46.567	46.245	46.036	45.903	ASTM 240

Table 5. The result of emission test during 1 month operating test

No.	Paramaeter	Unit	Result** (day to)				Restriction
			1	11	20	29	
1	NO_x	mg/m³	149	135	139	145	< 800
2	SO_x	mg/m³	296	-	12	23	< 1000
3	Opacity	%	5	5	5	5	< 20

***Measured by PLN Research Institute during the performance tests which held four times a month

RESULTS AND DISCUSSION

Emission Test

Compared with the limit value of the regulation of the Minister of Environment No. 21 of 2008 [13], the results of parameters such as NO_x, SO_x, & Opacity are lower than the limit value. The test is carried out four times a month, and all results do not exceed the limitation value.

Performance Test Result

During the 1 month operation test, we conducted performance tests from fuel sampling to analyze performance characteristics for four times. Shown in Table 6, the turbine exhaust temperature is limited to below 500 °C. Ex-

Table 6. The result of the gas turbine performance (base load continuous) operated with B5

No.	Paramaeter	Unit	Result (day to)			
			1	11	20	29
1	Compressor air inlet temp	°C	32,5	28,47	29,28	32,14
2	Barometric pressure	mbar	1016	1015,44	1015,5	1015,5
3	Compressor inlet humidity	% RH	51,44	79,72	75,44	65,89
4	Fuel oil consumption	liter	15203	15320,5	14804	14579
5	Turbine Exhaust temp,	°C	495,13	494,87	494,96	495,08
6	Active Load	MW	17,83	17,5	16,74	16,38
7	Gross power output	kWh	35806,32	35285,14	33603,86	
8	Gross SFC	l/kWh	0,4246	0,4342	0,4405	0,4444
9	Gross Heat Rate	kCal/kWh	3819,415	3881,265	3949,043	3997,38

M.A. Rahmanta et. al./ Hittite J Sci Eng, 2019, 6 (3) 229–233

Table 7. The result of specific fuel consumption of the gas turbine after 1 month operated with B5

No.	Parameter	Before start	After shut down	Total
1	Counter kWh	308,866,900	321,227,000	12,360,100
2	Counter fuel (liter)	1,404,410	6,707,659	5,303,249
3	SFC (liter/kWh)	-	-	0.429062

penses decreased from the first day of 17.83 MW to 16.38 MW on day 29th. The cost decreased by 8.13%. Meanwhile, specific fuel consumption (SFC) increased from the first day 0.4246 to 0.4444 days on day 29th. The actual SFC for a month shown in Table 7 is 0.428 l/kWh. The increase in SFC is 4.66%.

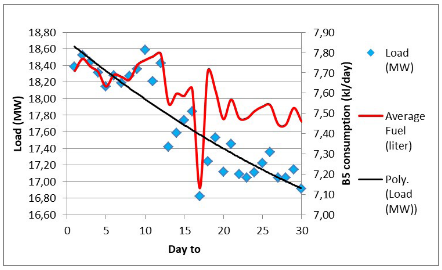

Figure 3. Graph of load and fuel (B5) consumption for a month

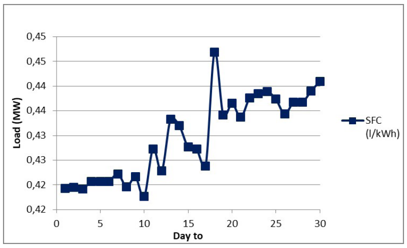

Figure 4. Graph of SFC for a month

Shown in Fig. 3, the load and fuel consumption decrease from the first day to the 30th day. The SFC value increases because the load decreases from the first day to the 30th day as shown in Fig. 4. The nozzle pressure trend lines 1 to 10 are shown in Figure 5 & 6. The gas turbine has 10 combustion chambers, so 10 nozzles are installed. The average nozzle pressure is shown in Fig. 7, it appears that the average nozzle pressure decreases because the load decreases.

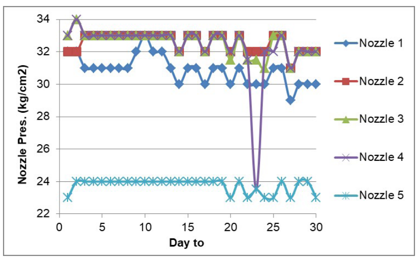

Figure 5. Graph of nozzle pressure from nozzle 1 to 5

Inspection Result

Shown in Fig. 8, the no. 2 fuel nozzle condition is divided into three different conditions. Seen from the picture, the deposit is formed on the nozzle after being operated by HSD and B5. A white deposit is formed in the combustion liner after being operated with B5 as shown in Fig. 9 (c).

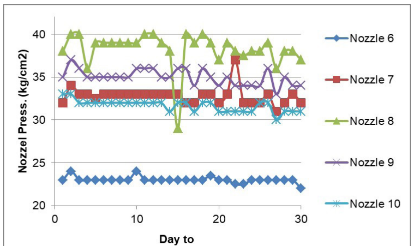

Figure 6. Graph of nozzle pressure from nozzle 6 to 10

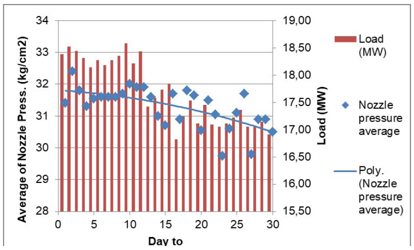

Figure 7. Graph of nozzle pressure average for a month

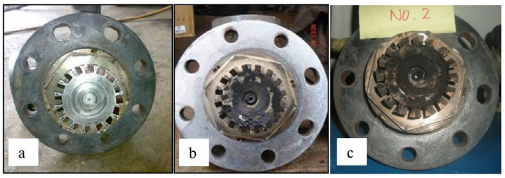

Figure 8. Visual inspection of fuel nozzle no. 2 (a) before operated (b) after

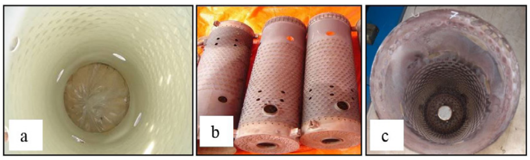

Figure 9. Visual inspection of combustion liner no. 2 (a) before operated (b) after operated by HSD taken on Major Overhaul (c) after operated with B5 for 1 month

Figure 10. Visual inspection of transition piece (a) before operated (b) after operated by HSD taken on Major Overhaul (c) after operated with B5 for 1 month

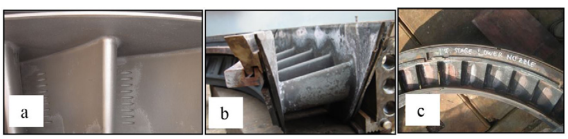

Figure 11. Visual inspection of 1st stage turbine nozzle (a) before operated (b) after operated by HSD taken on Major Overhaul (c) after operated with B5 for 1 month

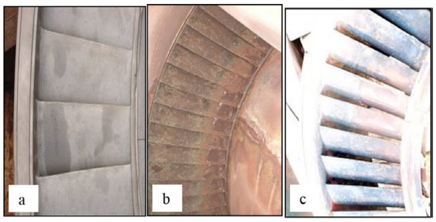

Figure 12. Visual inspection of 2nd stage turbine nozzle (a) before operated (b) after operated by HSD taken on Major Overhaul (c) after operated with B5 for 1 month

The white deposit is in the transition piece in Fig. 10 (c), the first stage nozzle in Fig. 11 (c), and the second stage nozzle in Fig. 12 (c) is taken after testing. The samples are analysed in the laboratory then the results are shown in Table 7. The deposits mostly contain Na, S, Fe, and Ni. Based on X-ray Diffraction and Dispersive Energy Spectroscopy (EDS), the compounds formed on the deposit are Sodium Sulphate (Na_2SO_4) which has the potential to make heat corrosion [14] to peel off the thermal barrier layer, and to lead corrosion in the basic ingredients contained with Fe & Ni as shown in Fig. 13. Deposits such as Na and S are likely to come from impurities in the fuel either HSD or biodiesel.

Table 8. The composition of trace metal in the deposit after 1 month operated by B5

No.	Paramaeter	Unit	Deposit located at****		
			Transition piece	1st stage nozzle	2nd stage nozzle
1	Natrium, Na	%	33,16	34,26	32,31
2	Magnesium, Mg	%	1,77	2,29	3,42
3	Aluminium, Al	%	-	0,97	-
4	Silika, Si	%	-	0,33	0,35
5	Sulfur, S	%	38,64	41,96	36,05
6	Kalium, K	%	0,58	0,37	0,74
7	Calcium, Ca	%	0,86	1,40	0,74
8	Chromium, Cr	%	2,91	2,90	3,21
9	Mangan, Mn	%	0,21	0,22	0,81
10	Ferrum, Fe	%	7,62	3,28	10,51
11	Cobalt	%	-	9,25	6,65
12	Nickel, Ni	%	11,46	2,43	4,02
13	Zink, Zn	%	1,10	0,37	0,52
14	Molibdenum, Mo	%	0,28	-	0,39
15	Plumbum, Pb	%	0,81	-	-

****Tested by Metallurgy Laboratory at University of Indonesia

Figure 13. Visual inspection of 1st stage turbine nozzle (erosion material) after operated with B5

CONCLUSION

The use of B5 in gas turbine power plants has decreased in output power, increased SFC fuel consumption, and led sediment materials that increase the potential for corrosion of hot gases in hot gas path material from gas turbines. Fuel that is clean of impurities and sulphur is needed to reduce this risk.

ACKNOWLEDGEMENT

This research is fully funded by PT. PLN (Persero), a state owned electricity company of Indonesia. The test was conducted and facilitated by PT. Pembangkitan Jawa Bali (PJB) as the subsidiary company of PT. PLN (Persero).

REFERENCES

1. Directorate General of Estate Crops of The Ministry of Agriculture of Republic Indonesia, 2016, Tree Crop Estate Statistics Of Indonesia 2015-2017, Jakarta: Secretariate of Directorate General of Estate Crops of The Ministry of Agriculture of Republic Indonesia.
2. Enagi I, Al-attab KA, Zainal ZA., 2018, Liquid biofuels utilization for gas turbines: a review. Renew Sustain Energy Rev.
3. Gupta KK, Rehman A, Sarviya RM., 2010, Bio-fuels for the gas turbine: a review. Renew Sustain Energy Rev,14:2946–55.
4. Sajjadi B, Raman AAA, Arandiyan H., 2016, A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: composition, specifications and prediction models, Renew Sustain Energy Rev., 63:62–92.
5. Gashaw, A.; Getachew, T.; Teshita, 2015, A. A review on biodiesel production as alternative fuel. J. For. Prod. Ind., 4, 80–85.
6. Ma. F., Hanna, M.A. 1999, Biodiesel production: A review. Bioresour, Technol, 70, 1–15.
7. Duran, E.A., Tinoco, R., Perez, A., Berrones, R., Eapen, D., Sebastian, P.J., 2014, A comparative study of biodiesel purification with magnesium silicate and water. J. New Mater. Electrochem. Syst., 17, 105–111.
8. Stamenkovic, O.S., Todorovic, Z.B., Lazic, M.L., Veljkovic, V.B., Skala, D.U., 2008, Kinetics of sunflower oil methanolysis at low temperatures. Bioresour. Technol., 99, 1131–1140.
9. Talha, N.S., Sulaiman, S., 2016, Overview of catalysts in biodiesel production. ARPN J. Eng. Appl. Sci., 11, 439–448.
10. Lotero, E., Liu, Y., Lopez, D.E., Suwannakarn, K., Bruce, D.A., Goodwin, J.G., 2005, Synthesis of biodiesel via acid catalysis. Ind. Eng. Chem. Res., 44, 5353–5363
11. Saifuddin, N., Samiuddin, A., Kumaran, P., 2015, A review on processing technology for biodiesel production. Trends Appl. Sci. Res., 10, 1–37..
12. Borman G.L., 1997, Combustion Engineering, Singapore: McGrawHill Book Co.
13. Minister of Environment Republic Indonesia, 2008, Regulation of Minister of Environment Republic Indonesia No. 21 of 2008, Quality Standards for Non-Moving Source Emissions for Businesses and / or Thermal Power Generation Activities.
14. Eliaz, N., 2000, Hot corrosion in gas turbine components, Engineering Failure Analysis, Pergamon 9, pp 31-43.