A Fuel Testing Analysis of B20 Biodiesel for Gas Turbines in Indonesia

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Abstract. Biodiesel fuel has been applied to diesel cars for more than ten years and used on power application (turbines, boilers, etc.) recently in whole or blended with fossil fuels. The advantage of using biofuels as a renewable source is the significant reduction of greenhouse gas emissions. This study investigates the possibility of using biodiesel for gas turbine power plant in Indonesia through fuel testing analysis. Some biodiesel produced from four separated factories has been selected as samples for analyzing and then comparing to the fuel specification of three different gas turbine technologies located in Tello, Belawan and Gresik. It is found that no B20 biodiesel meet the requirements of fuel specification from all gas turbine technologies. This study recommends standardizing B20 biodiesel in Indonesia in order to be suitable with the fuel specification of gas turbines. In addition, some technical issues has been proposed to be further research. It is also recommended to do a pilot project using appropriate biodiesel at some gas turbines technologies on operation mode within life cycle cost analysis.

Keyword - Biodiesel; Gas Turbine; Renewable; Fossil Fuel; B0; B20

1. Introduction

Biodiesel fuel (BDF) mainly refined from vegetable oil has been applied to diesel cars for more than ten years. It can be used on vehicles (cars, trucks, tractors, etc.), turbines, boilers, etc., in whole or blended with fossil fuels. The advantage of using biofuels is the significant reduction of greenhouse gas emissions. It is also advantageous because it is a renewable source of energy instead of fossil fuels (diesel, gasoline, kerosene, coal). There are several concerns about biodiesel comparing to the high speed diesel such as higher viscosity which will affect to the external combustion process. However it can be lowered by trans-esterification process, a cheaper method to make it meet the requirement of a regular diesel combustion engines [1] with a certain level of temperatures and pressure [2]. Other advantages of biodiesel are high cetane number, sulfur-free, and biodegradable. Biodegradable can be an advantage yet also a challenge because it can cause a corrosion problem to the engines and other mechanical parts [3].

Indonesia is one of the largest producers of crude palm oil (CPO) in the world along with Malaysia. On the other hand, Indonesia is an oil importing country since 2002. 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. Biodiesel commonly have been used for power plant blends of 20% biodiesel and 80% petro diesel (B20).
In Indonesia all over 2018, the energy generated by diesel engines using B20 is approximately 1085 GW within the consumption of 328.287 kilo liters fuel consumption (+0.08% total fuel consumption from diesel power station) [4]. According to the Indonesia National Energy Plan, Renewable energy fuel mix by the year 2025 should achieve 23% [5]. While Solar and Wind power are still facing an intermittency problem, the use of biodiesel for fuel-based power plants such as diesel or gas turbines is highly potential solution to support the acceleration of the renewable energy mix in Indonesia.

There are some recent studies in using biodiesel for gas turbine operation with the concern about operability and reliability of using less synthetic material. With more environmentally friendly than fossil-based fuel in terms of sulphur content, flash point, aromatic carbon content, biodiesel could be used in gas turbines without major modification[1]. Some research found that before using biodiesel in gas turbine, it needs to be heated until 40°C to reach a certain level of viscosity[6]. From the emission aspect, NO“x” emission level for biodiesel in gas turbine is lower compared to diesel fuel [7]. Other study shown that the maximum fuel blend ratio is 20% according to the threshold value of a flue gas temperature and a vibration velocity in the gas turbine. An adjustment of A/F (Air/Fuel) ratio to a certain kind of fuel blend was required to improve the combustion condition and to increase of combustion efficiency [8]. A gas turbine can operate with different types or blends of biofuels with a corrected power loss at around 4.26%, and the corrected heat rate of 8.38% higher than diesel fuel [6].

This paper discussed about technical requirement of some gas turbine power plants - located in Medan, Makassar, and Gresik - and B20 sampling in biodiesel feedstock which supply the power plants. It is also sampling and testing in B100 from biodiesel manufacturers. All the results from biodiesel laboratory test will be analyzed to compare with the requirement of gas turbine engines.

2. Gas Turbines and Biodiesel Samples

GAS TURBINE POWER PLANTS

In this study, the survey was conducted at 3 locations of gas turbine power plants with different engine manufacturers; Belawan Medan (Siemens), Tello Makassar (General Electric), and Gresik (Mitsubishi). Belawan and Gresik power plant mostly used as a base load, and for economical reason the fuel has been replaced by natural gas. While Tello power plant mostly used as a peak load or for emergency black start.

2.1. Belawan Power Plant

Since 2010, the total capacity of Belawan power plant is 1.185,8 MW. HSD and MFO supplied from PT. Pertamina (Persero) while Biodiesel (B20) supplied both from Pertamina fuel depot and PLN fuel depo. Natural gas is supplied from Arun regasification facility which is delivered through LNG cargos from BP Tangguh, Papua and Medco block A Donggi Sengoro, Central Sulawesi. The emission from this power plant still contain significantly NO“x” and SO“x”.

2.2. Tello Power Plant

Tello General Electric (GE) gas turbine with capacity 2x33 MW has been operated since 1997. Tello Power plant is used for black start in case there is any disturbance in South Sulawesi grid system. It takes around 13 minutes for this power plant to do the independent start using diesel as a prime mover. Tello power plant using HSD in the first 10 days of 2019 with total consumption 128 KL. The emission test result shows that Tello power plant emission is still below maximum threshold according to Ministry of Environment and Forestry Regulation 15/2019.

2.3. Gresik Power Plant

Gresik power plant is operated by PT. Pembangkitan Jawa-Bali (a subsidiary of PLN) in Gresik, East Java. The total capacity is + 2140 MW consisting of:
- 2 x 100 MW Steam power plant using Gas.
- 2 x 200 MW Steam power plant using Gas/MFO.
- 2 x 20 MW Gas power plant using Gas/HSD operated for black start.
- 3 x 500 MW Combined cycle power plant using gas/HSD operated for load follower.
Recently fossil fuel is rarely used in Gresik power plant except in 2018 due to the problem with pipeline gas supply from East Java sea. For 3 days in 2018, HSD consumption in Gresik power plant is around 35.596 KL as follow:
- 34.743 KL for Steam Gas power plant
- 251 KL for Steam power plant
- 602 KL for Gas power plant (dual fuel with gas)

The specification of Gas turbine and fuel for each power plant can be seen at table 1. From the specification and operational historical data, Tello power plant is the most feasible power plant for biodiesel testing. It is operated as peaker or black start which means the trials won’t interfere power plant daily operation. There are 2 identical gas turbines with the same manufacture and technology, and one of it can be used for biodiesel trial test.

### Table 1. Gas Turbine Specification in Belawan, Tello, and Gresik

| Parameter                  | Belawan     | Tello       | Gresik       |
|----------------------------|-------------|-------------|--------------|
| Capacity                   | 120 MW      | 2 x 33 MW   | 2 x 20.1 MW  |
| Manufacturer               | Siemens V94.2 | GE MS6001B | Alstom PG 5341 |
| Year Operated              | 1993        | 1997        | 1978         |
| Fuel                       | Gas         | HSD         | HSD & Gas    |
| Status                     | Active      | Black Start | Black Start  |
| Rpm                        | 3024 rpm    | 5100 rpm    | 5100 rpm     |
| SFC                        | -           | 0.41 L/kWh Load 28 MW | 0.41 L/kWh Load 19 MW |
| Efficiency                 | 27.02 %     | -           | -            |
| HSD Feedstock              | TBBM PulauSambu | Depo      | Depo         |
| Nearest Bio diesel Feedstock | TBBM Belawan | N/A        | Depo         |
| Gas Source/Gas Installation| Gas Arun / Medco | N/A        | Gas Pipping from Madura Island |
| HSD Storage Tank           | -           | 2x5000 kL   | 2x5000 kL    |

**Biodiesel**

Biodiesel fuel (BDF) mainly refined from vegetable oil and is usually made from natural fat, main components of which are fatty acid methyl-esters. Vegetables oil based such as palm oils, soybean oil, coconut oil, rapeseed oil and many more is the most feasible biodiesel source that can be converted into biodiesel feedstock because they have similar chemical composition. The average lower heating value of BDF is approximate 38 MJ/kg, which is only 10% lower than that of usual petroleum diesel fuel [9].

The most potential vegetable oil based in Indonesia is coming from palm oil with total production about 20-25 Ton/ha/year and biodiesel potential around 4-6 kL/ha/year [10]. Biodiesel manufacture in Indonesia is divided based on the quality. For domestic quality, the biodiesel product needs to meet the requirement of SNI 7182-2015 or Dirjen EBTKE Regulation No. 332K/10/DJE/2018, for the export quality the requirement is ASTM D6751 and EN 14211 Standard.

The sampling is taken from biodiesel factories which supply both domestic and export market. Based on the production capacity, we assumed that these factories will supply the biodiesel for gas turbines fuel when the project is implemented.
- PT. LDC, Lampung
- PT. TBL, Lampung
- PT. WBI, Dumai
- PT. KRN, Balikpapan
Apart from the biodiesel plant, sampling is also carried out from each of the existing biodiesel tanks in each power plant. Each sample is tested at independent laboratory and different codes are given to make it easily identify and analyze following the fuel test standard.

For laboratory purpose and to make to make it simple, the sample from every site named with a code to separate each of the sample result. The code given are:

- PT. LDC (Lampung) - A
- PT. TBL (Lampung) - C
- PT. WBI (Dumai, Domestic Quality) - F
- PT. WBI (Dumai, Export Quality) - G
- PT. KRN (Balikpapan) - L
- B0 From Gresik Power Plant - D
- B20 From Gresik Power Plant - E
- B20 From Belawan Power Plant – H
- B0 From Belawan Power Plant - I
- B20 From Tello Power Plant - J
- B0 From Tello Power Plant - K

3. Methodology
The sample test result from the laboratory is compared with the several standards that comply to the requirement for gas turbine fuel properties. Indonesian government has a regulation about the quality standard for gas turbine fuel as written in Dirjen Migas regulation No. 28.K/10/ DJM.T/2016 which states about the content of B20. Instead of Indonesia standard, ASTM D 2880 is specifically describing the fuel for gas turbine yet not discuss about the impurities factors such as Na, K, Ca, V, Pb, Ni and Zn, that can affect the performance of gas turbine.

Besides those standards, the test result is compared to the engine manufacture specification. The engine manufacturers are General Electric, Siemens, and Mitsubishi for both Heavy Duty (HD) and aeroderivative technology. At the end, the results will show which biodiesel or B20 fuel that meet the requirement of the gas turbine engine in terms of biodiesel properties and specification.

4. Result and Discussion
There are 15 parameters tested throughout the samples (Biodiesel, B0, and B20). The test procedure and result based on several ASTM Standard, and be compared with the engine specification as shown in table 2.

4.1. Biodiesel Test Result
From the test result, Biodiesel sample with code F from PT. WBI Dumai for domestic supply doesn’t meet the requirement for every engine specification. It failed in Na + K parameters which represent Sodium and Potassium level. Sample F test results show a value of 1.45 mg/Kg, while the highest limit on the engine specifications is 1 mg/Kg. It can be seen at Figure 1 below.

Sodium (Na) and Potassium (K) can be found both in liquid and gaseous fuels. Na and K are a form of metal contain that bring impurities to the fuels and contribute to corrosion and fouling of the engine component such as turbine and hot gas path [11]. In flash point parameter, sample F (168°C) failed to meet the requirement of GE Aeroderivative (93.3°C), Siemens HD (55-80°C), and Siemens Aeroderivative (38-80°C). Sample F result also doesn’t meet the requirement of Lead (Pb) parameter for Siemens HD. The result is 0.12 mg/Kg compared to 0.1 mg/Kg from engine specification. Samples code A, C, G, and L meet all the requirements for GE HD engine and Mitsubishi HD one.
Table 2. Test Parameter and Engine Specification

| No | Parameter       | Unit  | Test Method | GE HD | GE AERO DERIVATIVE | SIEMENS AERO DERIVATIVE | MITS HUBIS HI HD |
|----|----------------|-------|-------------|-------|--------------------|-------------------------|------------------|
| 1  | Phosphorus     | wt %  | ASTM D4951  | -     | 2, Max             | -                       | 2, Max           |
| 2  | Acid Number    | mg KOH/g | ASTM D664 | -     | -                  | 0.6, Max                | 0.01, Max        |
| 3  | Flash Point    | °C    | ASTM D93    | -     | 93.3, Max          | 55 – 80                 | -                |
| 4  | Ca+Mg          | mg/kg | ASTM D7111  | 2, Max| 2, Max             | 0.1, Max                | 2, Max           |
| 5  | V              | mg/kg | ASTM D7111  | 0.5, Max | 0.2, Max | 0.1, Max | 0.5, Max | 0.5, Max |
| 6  | Pb             | mg/kg | ASTM D7111  | 1, Max| 1, Max             | 0.1, Max                | 0.5, Max         |
| 7  | Cu             | mg/kg | ASTM D7111  | -     | non-detectable     | -                       | -                |
| 8  | Zn             | mg/kg | ASTM D7111  | -     | non-detectable     | 0.1, Max                | 0.1, Max         |
| 9  | Na + K         | mg/kg | ASTM D7111  | 1, Max| 0.2, Max           | 0.1, Max                | 1, Max           |
| 10 | Li             | mg/kg | ASTM D7111  | -     | 0.2, Max           | -                       | -                |
| 11 | Demulsification| min   | ASTM D1401  | -     | 20, Max            | -                       | -                |
| 12 | Distillation 10% Recovery | °C | ASTM D86 | - | Report | - | - | - |
| 13 | Distillation 50% Recovery | °C | ASTM D86 | - | Report | - | - | - |
| 14 | Distillation 90% Recovery | °C | ASTM D86 | 338, Max | 357, Max | 360, Max | 360, Max | 338, Max |
| 15 | Distillation End Point | °C | ASTM D86 | - | 385, Max | - | - | - |

More comprehensive testing is done to sample A and sample G as a sample that meet the criteria for GE HD engine. The test consists of much parameters such as Water and Sediment, Sulfated Ash, Carbon Residue, Sulphur, Iodium Number, Pour Point, Particulates, etc. The results from the test in sample G, the sulphur content parameter is the only parameter that cannot meet GE HD engine requirements (7.8 mg/Kg compared to maximum 1 mg/Kg engine spec).

4.2. B0 and B20 TEST RESULT

Same issue with the B0 and B20 biodiesel test result, from Figure 2 below 3 sample out of 6 (D,E,J) didn’t meet the requirement of all engine specification in Na+K Parameter. Sample K meet the requirement for GE HD, Siemens Aeroderivative, and Mitsubishi HD for Na+K parameter but fail exceed the maximum limit for several parameters such as:
- Distillation 90% Recovery parameter (GE HD, GE Aeroderivative, Mitsubishi HD)
- Ca parameter (Siemens HD)
- Acid Number (Siemens Aeroderivative)

Sample H and I, from Belawan power plant, meet all requirement for GE HD, and Mitsubishi HD engine. Same case with the previous biodiesel section, a further test is done to sample H. The test result
shows that there is no major issue comparing to the GE HD engine. Nonetheless for GE Aeroderivative, sample H have an issue in Sulphur parameter with the result 201.6 mg/kg compared to maximum 1 mg/kg engine spec.

![Figure 1. Na+K Sample F biodiesel compared to Engine](image1)

![Figure 2. Na+K B0 & B20 sample compared to engine specification](image2)

5. Conclusion

Based on the fuel testing results, not all biodiesel B20 in Indonesia meet the requirements of fuel specification from all gas turbine manufacturers. Some of biodiesel are suitable for some type of gas turbines at all parameters (C, G, and L). There is biodiesel that failed to meet some requirement for all gas turbine technologies (F). In contrary there are biodiesel which meet all fuel parameters but only for some gas turbines (A, H, I and G). However, this study shows that no B20 biodiesel in Indonesia can meet all fuel specification requirements for all technologies.

Referring to the study findings, there is an urgent need to produce B20 at all biodiesel fuel plants in Indonesia based on such standard which meet with the fuel specification of gas turbines. In addition, pre-treatment should be conducted to solve the impurity of the biodiesel. A technical notice should be concerned about the Sodium and Potassium content which can potentially cause corrosion in the engine. The next research is highly recommended to do a pilot project using “suitable biodiesel” at some gas turbine technologies on operation mode for a maintenance cycle period.

From economic point of view, it is necessary to do a further study about the investment costs if additional installations are needed to accommodate the use of biodiesel in turbine gas power plants. Considering the price of palm oil which changes frequently and will affect the price of biodiesel on the market, an economic study should estimate the optimal price for power plant’s operational expenditure based on a life cycle financial approach.

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