Study of biodiesel specifications for heavy-duty gas turbine application

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Abstract. Implementing a 20% biodiesel blend in diesel fuel (B20) has been launched since January 1st, 2016, and it was increased to 30% (B30) on January 1st, 2020, implemented in all sectors, including power generators. Gas turbines utilized as power generators designed to use natural gas or diesel fuel as fuel. Therefore, a study to use biodiesel blend as fuel in gas turbines was required. A comparative study was conducted to analyze the fuel requirements of General Electric’s (GE) Heavy Duty (HD) Gas Turbine specification compared to either of SNI 7182: 2015 and EN 14214 specifications. An assessment was conducted on samples of two biodiesel quality levels called biodiesel and distilled biodiesel to meet the GE HD Gas Turbine’s requirements. This study indicates that the biodiesel quality standards, both SNI 7182: 2015 and EN 14214, are insufficient to meet the gas turbine fuel specifications of the GE HD gas turbine. It is required a more specific quality standard dedicated to gas turbines. On the other hand, among the two samples, distilled biodiesel fulfills the fuel requirements of GE HD gas turbines and might be utilized as fuel for this type of gas turbine. According to the result of this study, a test run of 100% biodiesel (B100) as gas turbine fuel can be proposed to be implemented immediately.

1. Introduction

Biodiesel or fatty acid methyl ester is an alternative diesel fuel derived from vegetable oil, animal fats, or other materials consisting mainly of triacylglycerols (triglycerides) and produced by a trans-esterification reaction [5, 11]. Biodiesel’s use becomes favorable as a mixture in diesel fuel since it can improve diesel engines’ combustion performance, lower emissions, low sulfur, and biodegradability, following the Paris Agreements 2016 in lowering gas emissions. Another advantage of biodiesel is its higher flash point than diesel fuel, therefore providing better safety during shipping and storage [19, 20].

In Indonesia, biodiesel is currently used in blends with petroleum diesel fuel, designated as Bxx, following the regulation of the Ministry of Energy and Mineral Resources (MEMR) the Republic of Indonesia No. 12/2015 to fulfill the target stated on National Energy Policy on the utilization of New and Renewable Energy (EBT) to reach 23% in the energy mix by 2025 [13-14]. The implementation of 20% biodiesel blend in diesel fuel (B20) has been launched since January 1st, 2016 and it was increased to 30% (B30) on January 1st, 2020, implemented in all sectors including transportations and power generators.

For the type of internal combustion engine, especially in transportation sectors, biodiesel
implementation has gone through a series of road tests and infrastructure trials with all stakeholders involved [10,14]. For better protection in consumer use, biodiesel must be produced according to a certain standard quality. In discussing biodiesel quality standards in the world, EN 14214 and ASTM D6751 standard is referred to by the majority of stakeholders [18]. In Indonesia, the quality of biodiesel used in higher biodiesel mixtures has been improved periodically. The quality standards and specifications for biodiesel B100 used for B20 blending have been regulated through the Decree of the Director-General of EBTKE No 332K /10/DJE/2018, while the quality standard of B100 used for B30 was improved by the Decree of the Director-General of EBTKE No 189.K/10/DJE/2019 [12, 15]. However, the standard of SNI 7182:2015 is designated as the national biodiesel standard of Indonesia [2].

In Indonesia’s power generator sectors, diesel fuel was utilized by diesel generators and gas turbines [16]. Currently, the utilization of diesel fuel in diesel generators has been reduced by mixing with biodiesel. However, biodiesel in gas turbines is still avoided since the research of biodiesel utilization in this engine is limited.

Unlike a diesel generator, a gas turbine consists of three main components, i.e., compressor, combustion chamber, and turbine. Gas turbines have a wide power range and are suitable to be modified according to the fuel supply system [23]. However, the development of gas turbine technology currently tends to design for one specific type of fuel, such as natural gas or diesel [9]. Gas fuel used must be condensed and solid particles free. To achieve a better process, this system is equipped with a knockout of out the drum to separate liquids that are still present in gas fuel a filter to filter solid particles [10, 19].

All gas turbine manufacturers established a fuel quality required to ensure the engine operates appropriately and maintain the lifetime of the gas turbine’s main components. Therefore, it is necessary to understand the composition and specification of the fuel utilization in a gas turbine to minimize the adverse impacts on its operating performance. That causes damage to turbine blades and, in some cases, also impacts combustion emissions, depending on the type of combustion chamber [4, 8].

The performance and component life of gas turbine power plants depend strongly on the chemical properties of the operating media. The corrosion and fouling risk can be strongly reduced by controlling the impurity levels in the media air, fuels, and water. The potential impurities in liquid fuel, or in this case biodiesel, comes from metal contaminants (Na, K, Ca, V, Pb, Ni, Zn), moisture content and sediment [3-4]. Metal contents in the fuel may cause reactions between those metals and turbine components such as blades and hot gas lines. As a result, damage to the turbine and a decrease in engine performance may occur. Therefore, the content of metals and other impurities in fuel must be limited to avoid the effect of corrosion on the performance of the gas turbine [8].

In addition to impurity levels, gas turbines’ performance is influenced by the types of biodiesel feedstock. The biodiesel with a higher saturated fatty acid content has a higher viscosity and surface tension than unsaturated biodiesel, making it challenging to atomize the fuel in the gas turbine. Saturated biodiesel has higher NOx emissions than unsaturated biodiesel because saturated biodiesel has a higher catalytic effect in forming NOx compounds. For the performance of gas turbines with saturated biodiesel fuel to be relatively equivalent to unsaturated biodiesel, the operating pressure with saturated biodiesel fuel must be lower than unsaturated biodiesel [3, 12].

Based on the explanation above, as a gas turbine engine works differently from an internal combustion engine, it may require different biodiesel specifications. Therefore, it is necessary to conduct a comparative study to analyze the fuel requirements of gas turbine specifications compared to biodiesel standards and analyze biodiesel’s quality from the market according to both specifications. Hence, a recommendation for the implementation of biodiesel for gas turbine applications will be obtained.
2. Methodology

This research was conducted through a comparative study of biodiesel standard based on SNI 7182: 2015 (national biodiesel standard of Indonesia), EN 14214 (biodiesel standard in Europe, also referred to as a standard for exported biodiesel from Indonesia), and fuel standards specifications required by a gas turbine manufacturer [1, 2, 6]. The gas turbine manufacturer referred to in this study is General Electric (GE), provided with a type of Heavy Duty (HD) and Aero derivative. By comparing fuel specifications required by both classes, GE type HD (mentioned as GE HD) was considered less strict in fuel quality. Besides, GE HD produced in a large capacity compared to GE Aero derivative. Thus, biodiesel’s successful implementation in the GE HD type may promote biodiesel’s higher performance, especially in Indonesia.

The next study is to conduct quality testing of biodiesel samples according to fuel specification required by GE HD gas turbine manufacturer and SNI 7182: 2015 and EN 14214. The biodiesel samples obtained from a biodiesel plant in Riau Province, Indonesia with two levels of quality: (1) biodiesel following SNI 7182: 2015, from hereafter mentioned as ” biodiesel,” (2) biodiesel under EN 14214, from hereafter cited as ” distilled biodiesel” (also refers as export quality).

3. Results and Discussions

In discussing biodiesel quality standards globally, EN 14214 and ASTM D6751 are referred to by the market. However, based on detailed quality in impurities of biodiesel, EN 14214 regulates more parameters than ASTM D6751 [21-22]. Furthermore, the limit of metal requirement in EN 14214 is more stringent than in ASTM D6751. Because of the fuel requirements of the gas turbine, GE type HD emphasizes metal content. EN 14214 was used as a reference in this study.

A comparative study was conducted by observing the biodiesel quality standards presented in Table 1, consisting of SNI 7182: 2015, EN 14214, and Fuel Requirement of GE type HD. This table shows several biodiesel parameters in EN 14214 that are not regulated in SNI 7182: 2015, such as the content of Ca + Mg, Na + K, total contaminants, saturated methyl esters, levels of methanol, triglycerides, and diglycerides. In several parameters such as kinematic viscosity, sulfur content, and monoglyceride content, EN 14214 imposes more stringent limits than SNI 7182: 2015. On the other hand, there are several parameters regulated in SNI 7182: 2015 that are not held in EN 14214 such as 90% recovery distillation temperature, carbon residue, cloud point, moisture and sediment content.

Table 1 also describes the fuel specifications set by the GE brand gas turbine manufacturer for the Heavy Duty (HD) type. The manufacturer requires only specific metal content parameters (such as Ca + Mg, V, Cu, Zn, and Na + K) and the distillation temperature of 90% recovery [7]. As previously stated, the way a gas turbine works is different from an internal combustion engine, so that the fuel requirement is also different. Fuel parameters that support the combustion and avoid metal corrosion are required.

Comparing the fuel requirement of GE HD with the EN 14214 standard shows that EN 14214 regulates the metal content of Ca + Mg and Na + K but does not regulate the content of other metals (V, Cu, and Zn). The Ca + Mg and Na + K levels required by the HD type GE (max. 2 mg/kg and 1 mg/kg) are much more stringent than those stated by EN 14214 (max. 5 mg/kg and 5 mg/kg). On the other hand, a parameter of distillation temperature of 90% recovery is not available in EN 14214. Thus, it can be concluded that EN 14214 is not sufficient as a fuel standard for the gas turbine of GE HD.

Furthermore, the fuel requirement of GE HD was compared with SNI 7182: 2015. This comparison shows that the emphasized parameters of metal content are not regulated in SNI 7182:2015. In terms of parameter of distillation temperature of 90% recovery, the requirement of GE HD is more stringent (max. 338 °C) than of SNI 7182:2015 (max. 380 °C). The parameter of distillation temperature of 90% recovery mentioned by SNI 7182: 2015 may only consider the internal combustion engine manufacturer’s interests and not view the parts of the gas turbine.
manufacturer. Therefore, it can be concluded that SNI 7182:2015 is not sufficient as a fuel standard for the gas turbine of GE HD.

![Table 1: Comparison of Biodiesel Specifications on SNI 7182: 2015, EN 14214, and GE type HD](image)

| No | Parameters                          | Units        | Method             | SNI 7182:2015 | EN14214 | GE-HD |
|----|------------------------------------|--------------|--------------------|---------------|---------|-------|
| 1  | Phosphorus, max                     | wt %         | ASTM D4951         | 4             | 4       | -     |
| 2  | Total Acid Number, max              | mg KOH/g     | ASTM D664          | 0.5           | 0.5     | -     |
| 3  | Flashpoint, min                     | °C           | ASTM D93           | 100           | 101     | -     |
| 4  | Ca + Mg, max                        | mg/kg        | ASTM D7111         | -             | 5       | 2     |
| 5  | V, max                              | mg/kg        | ASTM D7111         | -             | -       | 0.5   |
| 6  | Pb, max                             | mg/kg        | ASTM D7111         | -             | -       | 1     |
| 7  | Na + K, max                         | mg/kg        | ASTM D7111         | -             | 5       | 1     |
| 8  | Distillation 90% Recovery, max      | °C           | ASTM D86           | 360           | -       | 338   |
| 9  | Density at 40 °C                    | kg/m³        | ASTM D1298         | 850 - 890     | 860 - 900 | -     |
| 10 | Kinematic viscosity at 40 °C        | cSt          | ASTM D445          | 2.3 - 6.0     | 3.5 - 5 | -     |
| 11 | Cetane number, min                  |             | -                  | 51            | 51      | -     |
| 12 | Cloud point, max                    | °C           | ASTM D2500         | 18            | -       | -     |
| 13 | Copper strip corrosion (3 hours in 50°C) |             | ASTM D130 nomor 1 | nomor 1       | -       | -     |
| 14 | Carbon residue                       | wt%          | ASTM D524          | 0.05          | 0.3     | -     |
| 15 | Water and sediment, max             | %volume      | ASTM D2709         | 0.05          | -       | -     |
| 16 | Sulfated ash, max                   | wt%          | ASTM D874          | 0.02          | 0.02    | -     |
| 17 | Sulfur content, max                 | mg/kg        | ASTM D5452         | 50            | 10      | -     |
| 18 | Free glycerol, max                  | wt%          | ASTM D6584         | 0.02          | 0.02    | -     |
| 19 | Total glycerol, max                 | wt%          | ASTM D6584         | 0.24          | 0.25    | -     |
| 20 | Methyl ester content, min           | wt%          | -                  | 96.5          | 96.5    | -     |
| 21 | Iodine value, max                   | g I₂/100 g   | AOCS Cd 1-25       | 115           | 120     | -     |
| 22 | Oxidation stability (Rancimat), min | minute       | EN 15751           | 480           | 480     | -     |
| 23 | Monoglyceride content, max          | wt%          | ASTM D6584         | 0.8           | 0.7     | -     |
| 24 | Water content, max                  | ppm          | ASTM D 6304/EN     | 500           | 500     | -     |
| 25 | Total contamination, max            | mg/kg        | ASTM D5452/EN      | -             | 24      | -     |
| 26 | Metil ester asam linoleat, max      | wt%          | EN 14103           | -             | 12      | -     |
| 27 | Metil ester polyunsaturated         | wt%          | EN 15779           | -             | 1       | -     |
| 28 | (=4 unsaturated), max               |              | -                  | -             | 0.2     | -     |
| 29 | Methanol content, max               | wt%          | EN 14110           | -             | 0.2     | -     |
| 30 | Triglyceride content, max           | wt%          | ASTM D6584         | -             | 0.2     | -     |

The use of fuel that does not meet the gas turbine manufacturer’s requirements may affect the engine performance. Still, it may damage the gas turbine’s blades and combustion chamber due to incomplete combustion. Thus, based on the above discussion, it can be concluded that SNI 7182: 2015, as well as EN 14214, is not sufficient as a fuel quality requirement for gas turbines of GE type HD.

Furthermore, the biodiesel samples (biodiesel and distilled biodiesel) quality test results are presented together with the quality standards above (Table 2). Table 2 shows that both models meet the requirement of SNI 7182:2015 and EN 14214. Distilled biodiesel is biodiesel that is given further processing using distillation column(s). The acid number, moisture, sediment content, and metal content of the distilled biodiesel are better than those of the biodiesel. It can be concluded that distillation processing may reduce the metal content of biodiesel. However, weakness should be considered in that the oxidation stability of distilled biodiesel is lower than biodiesel.

In Table 2, the result of sample analysis can be compared with GE type HD specification. It showed that distilled biodiesel meets all-metal requirements of the GE HD Specification. In contrast, biodiesel does not fulfill the GE HD Specification, especially for the metal content of Na + K. In terms of temperature distillation at 90% recovery, both biodiesel and distilled
biodiesel fulfill the GE HD Specification. This result shows that Biodiesel (SNI 7182: 2015) needs quality improvement to satisfy GE HD specifications. Based on sample analysis, to meet the fuel requirement of the GE HD gas turbine, quality improvement of biodiesel may be conducted through the distillation process.

According to the above discussion, it is necessary to provide a specific quality standard dedicated for gas turbine application to support the combustion process and to avoid metal corrosion. This particular standard may be derived from the current fuel standard. However, to justify the above standard for gas turbine application, a test run of 100% distilled biodiesel (B100) as a gas turbine fuel can be proposed to be implemented immediately. The result of that test run will become references to formulate a biodiesel standard for gas turbine application. Finally, this effort may increase the utilization of biodiesel in power generator sectors, improve the achievement of using new and renewable energy in the national energy mix target, and expand the utilization of biodiesel in the world.

### Table 2: Comparison of Biodiesel Specifications on SNI 7182: 2015, EN 14214, and GE type HD

| No | Parameters | Units | Method | Biodiesel | Distilled | SNI 7182:2015 | EN14214 | Spec. |
|----|------------|-------|--------|-----------|-----------|--------------|----------|-------|
| 1  | Phosphorus | wt %  | ASTM D4951 | 0.45 | 4, max | 4, max | - |
| 2  | Total Acid Number | mg KOH/g | ASTM D664 | 0.207 | 0.151 | 0.5, max | 0.5, max | - |
| 3  | Flash point | °C | ASTM D93 | 168 | 174 | 100, min | 101, min | - |
| 4  | Ca + Mg | mg/kg | ASTM D7111 | 1.05 | 0.39 | - | 5, max | 2, max |
| 5  | V | mg/kg | ASTM D7111 | 0 | 0 | - | 0.5, max | - |
| 6  | Pb | mg/kg | ASTM D7111 | 0.12 | 0 | - | 1, max | - |
| 7  | Na + K | mg/kg | ASTM D7111 | 1.45 | 0.15 | - | 5, max | 1, max |
| 8  | Distillation 90% Recovery | °C | ASTM D86 | 332 | 334 | 360, max | - | 338, max |
| 9  | Density at 40°C | kg/m³ | ASTM D1298 | 874.4 | 874.1 | 850 - 890 | 860 - 900 | - |
| 10 | Kinematic viscosity at 40°C | cSt | ASTM D445 | 4.679 | 4.425 | 2.3 - 6.0 | 3.5 - 5 | - |
| 11 | Cetane number | - | ASTM D2500 | 16 | 16 | 18, max | - | - |
| 12 | Cloud point | °C | ASTM D130 | 1A | 1A | nomor 1 | nomor 1 | - |
| 13 | Copper strip corrosion (3 jam pada 50°C) | wt% | ASTM D324 | 0.030.12 | 0.030.12 | 0.05, max | - | - |
| 14 | Carbon residue | %volume | ASTM D2709 | 0.02 | 0 | 0.05, max | - | - |
| 15 | Sulfated ash | wt% | ASTM D874 | 0.002 | 0.002 | 0.02, max | 0.02, max | - |
| 16 | Sulfur content | mg/kg | ASTM D3542 | 6.29 | 7.8 | 50, max | 10, max | - |
| 17 | Free glycerol | wt% | ASTM D5884 | 0.01 | 0.02 | 0.02, max | 0.02, max | - |
| 18 | Total glycerol | wt% | ASTM D5884 | 0.2 | 0.19 | 0.24, max | 0.25, max | - |
| 19 | Methyl ester content | wt% | ASTM D5884 | 98.16 | 98.08 | 96.5, min | 96.5, min | - |
| 20 | Iodine value g I₂/100 g | ASTM D130 | 50.12 | 50.69 | 115, max | 120, max | - |
| 21 | Oxidation stability (Rancimat) | min | ASTM D1571 | 23.2 (jam) | 22.6 (jam) | 480, min | 480, min | - |
| 22 | Monoglyceride content | wt% | ASTM D5884 | 0.45 | 0.44 | 0.8, max | 0.7, max | - |
| 23 | Water content | ppm | ASTM D | 500, max | 500, max | - | - | - |
| 24 | Total contamination | mg/kg | ASTM D5452/EN | - | - | - | - | 24, max |
| 25 | Metil ester asam linoleat | wt% | EN 14103 | - | - | - | 12, max | - |
| 26 | Metil ester polyunsaturated | (≥ 4 unsaturated) | wt% | EN 15779 | - | - | - | 1, max | - |
| 27 | Methanol content | wt% | EN 14110 | n.d | n.d | - | - | 0.2, max |
| 28 | Diglyceride content | wt% | ASTM D6584 | 0.15 | 0.14 | - | 0.2, max | - |
| 29 | Triglyceride content | wt% | ASTM D6584 | 0.14 | 0.15 | - | 0.2, max | - |

### 4. Conclusions

The biodiesel quality standards of SNI 7182: 2015 and EN 14214 are not sufficient to meet gas turbine fuel specifications of GE type HD. Distilled biodiesel meets the requirements to be used as fuel in gas turbine GE type HD. Meanwhile, biodiesel needs quality improvement
to fulfill the specification of GE type HD. It is required to formulate a more specific quality standard dedicated to gas turbine application. To justify the above standard for gas turbine application, a test run of 100% distilled biodiesel (B100) as a gas turbine fuel can be proposed to be implemented immediately.

Acknowledgments
The authors would like to acknowledge PT. PLN (Persero) which has funded this research activity.

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