

Availability of Palm Oil Biodiesel in Indonesia and Its Effect on Diesel Engine: A Review

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Abstract. Palm oil is one of the base ingredients that can be used in making of biodiesel which is an alternative fuel to replace diesel fuel. The ability of palm oil as biodiesel should be balanced with the quantity of palm oil as well as the level of biodiesel production capability. In this paper, authors try to analyze about palm oil as biodiesel starting from number of palm plantations up to the level of biodiesel production capability from palm oil. The analysis conducted in the first part of this paper can be used as a reference that shows the level of availability of the palm oil which can be processed into biodiesel as an alternative fuel in the future. In the next part, the authors tried to analyze the impact of biodiesel made from palm oil starting from engine performance, exhaust gas emissions, rate of wear, quality of lubricant, and deposit formed. It was is done in order to find out the advantages and disadvantages that occur from biodiesel so that it can be used as a reference or consideration in the use of biodiesel-fueled palm oil.

Keyword: *Biodiesel; Palm oil; Diesel Engine; Indonesia.*

Introduction

The continuous growth of global energy demands and the consequent environmental pollution over the last decades have turned into serious concern shared by policy-makers as well as the general public. On the other hand, the conventional resources of energy, such as oil, natural gas, and coal are non-renewable and fear of their depletion in the next century has also been the subject of intense debate, coal might be an exception though.

Currently, the Indonesian people's interest against the diesel fuel is quite high. If Diesel fuel consumption not controlled, then the existence of crude oil will be on the wane as time goes by. The natural declining rate that reaches 30% of the existing oil fields caused crude oil reserves become less and less as time passes. The decline in crude oil reserves impacted the lifting rate in Indonesia. The decline in crude oil production become a problem because fuel demand increases with increasing in economic growth [1]. Data published by the employment Unit Implementing Specific business activities Upstream Oil and Gas stated that the production of crude oil and condensate in Indonesia in the year of 2017 reached 801 thousand barrels per day (equivalent to 293 million barrels per year) [2]. Data published by the Agency Manager oil and Gas Downstream states that the consumption of fuel oil in

Indonesia in the year 2017 reach of 77 million tonnes (equivalent to 484 million barrels per year) [3]. Fuel consumption higher than its production led Indonesia to do the import of fuel from abroad.

Among several feasible alternative resources, biodiesel has been at the center of attention in recent years because of its particular advantages [4]. Hence, since the carbon contained in vegetable oil or animal fat are originated mostly from the carbon dioxide (CO₂) present in the air (i.e., biogenic), biodiesel is considered to contribute much less to global warming than its fossil-oriented counterpart [5]. This could be of interest in climate change mitigation policies [6]. Unlike petroleum diesel, biodiesel has more oxygen in its chemical formula which is considered as an important property of this alternative fuel [7]. Other technical and environmental benefits attributed to biodiesel compared with petroleum diesel include higher combustion efficiency, lower sulfur and aromatic content, higher cetane number, higher bio-degradability, higher flash point, and inherent lubricity [8], while both biodiesel and diesel share similar fuel properties paving the way for smooth replacement of biodiesel in the transportation sector [9].

Particularly, this review aims to: 1) analyze about palm oil as biodiesel fuel; 2) analyze the impact of biodiesel made from palm oil, starting from engine performance, exhaust gas emissions, rate of wear, quality of lubricant, and deposit formed; 3) discuss advantages and disadvantages of biodiesel. A future development of the biodiesel is also discussed in this present paper.

2. Palm Oil Biodiesel Availability in Indonesia

Government's effort to tackle the problem of diesel fuel is to establish a program called B20 program. The B20 program require the use of B20 biodiesel derived from palm oil [10]. Palm oil production in Indonesia are exceptionally high. It is shown from the data of the Central Bureau of statistics (2018) showing that palm oil production in the year 2017 from large plantation (managed by incorporated companies law) Indonesia reached 1.86 million tons, from civil plantation reach 12.72 million tons, and from private plantations reaching 19.89 million tons [11]. The magnitude of the Indonesia palm oil production each year also followed by an increase in palm oil production [11]. Increase of palm oil production each year shows that Indonesia has potential as a provider of primary source of raw materials in the manufacture of biodiesel. Produces palm oil as an alternative fuel in many countries, which are shown in Table 1. As shown in Table 1 Indonesia is the biggest supplier of palm oil in the world. In addition Indonesia has outpaced the other countries with considerable gap.

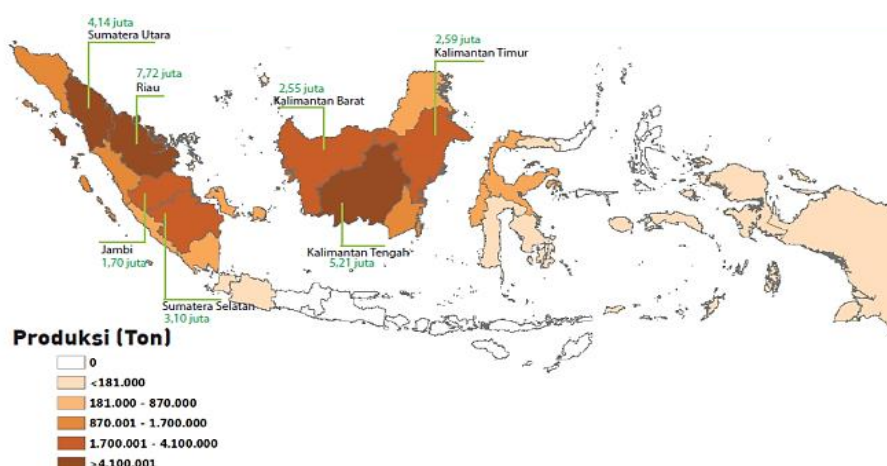


Figure 1. Palm oil production in Indonesia, 2017 [12].

Table 1. Palm oil production in different countries regions [13]

Rank	Country	Production (million ton)
1	Indonesia	33.000
2	Malaysia	20.500
3	Thailand	2.250
4	Colombia	1.108
5	Nigeria	0.930
6	Papua New Guinea	0.630
7	Ecuador	0.575
8	Ghana	0.495
9	Honduras	0.440
10	Cote D'ivoire	0.400
11	Guatemala	0.355
12	Brazil	0.340
13	Costa Rica	0.270
14	Cameroon	0.270
15	Congo	0.215
16	Philippines	0.135

3. Characterization of Palm Oil Biodiesel

3.1. Physical properties

Engines that produce energy with the use of palm oil and other low cost vegetable oils are likely to be relatively economical compared with virtually all other energy sources. Vegetable oils are typically denser than gas oil and have slightly lower caloric values and normally higher viscosities than diesel oil [14]. Blin et al. [14] and Sidibe et al. [15] compared diesel oil and some alternative fuels, as shown in Table 2; they observed numerous physical properties of diesel and vegetable oils, including density, viscosity, flash point, pour point, cloud point, cetane number, sulfur content, sulfur and iodine value. Based on table 2, several parameters in diesel oil including density, kinematic viscosity, and flash point have lower values while the cetane number content parameters have lower values than other vegetable oils.

Table 2. Physical properties of diesel and some vegetable oils [14-15].

Properties	Diesel	Soybean	Palm	Cotton	Jatropha	Corn	Rapseed	Sun-flower	Linseed
Density (kg/m ³) at 15 °C	820-890	914	918	915	940	910	912	916	924
Kinematic Viscosity (mm ² /s)	3-7.5	58-63	95-106	73	55	60-64	77	55-61	31-35
Flash point (°C)	93	330	280	243	240	277	320	316	241
Cetane number	50	37	40	35-40	39	38	32-36	37	35
Pour point (°C)	<-5	-4	31	-1	3	-1.1	-11	-5	-15
Iodine Value (gI ₂ /g)	-	109	48-58	103-115	82-98	103-128	105	125-140	180
Sulfur (wt%)	<1.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-
Carbon residue (%wt)	<0.15	0.24	0.23	0.24	-	0.24	0.3	0.27	0.22

3.2. Engine Performance

The relationship among fuel properties, such as viscosity, calorific value, specific density, and surface tension are affected by engine performance [16]. Research conducted by Suthisripok and Semsaran discusses the effect of B100 on agricultural diesel engines. The biodiesel was derived from palm oil. The test was carried out using a 14-hp Kubota RT140 DI diesel engine where the engine operates for 800 hours, running with a heavy load continuously at 1000 rpm for 12 hours every day. The results showed that the average fuel consumption of B100 was 10.6% higher than diesel fuel. This happens because the specific heating value of B100 is 11% lower than diesel fuel [17].

Table 3. Performance of biodiesel fuel engine as compared to diesel fueled engine.

Ref.	Engine	Fuel type	Test condition	Increased (vs. diesel)	Decreased (vs. diesel)
Lin and Li [18]	4C, DI	B0, B100 (Fish oil)	800-2000 rpm	BSFC	-
Benjumea et al. [19]	TC, DI	B0,B100 (Palm oil)	2000 rpm and 100 Nm	BSFC	BTE
Nabi et al. [20]	1C, NA, DI	B0, B10, B20, B30 (Cottonseed oil)	Constant speed: 850 rpm	BSFC	BTE
Gumus [21]	4C, DI, NA, AC	B0, B5, B20, B50, B100 (Hazelnut kernel oil)	Constant speed: 2200 rpm	BSFC	BTE
Pal et al. [22]	4C, DI	B0, B100 (Thumba oil)	1000-6000 rpm	Power, BTE	BSFC
Hasimoglu et al. [23]	4C, TC, DI	B0, B100 (Sunflower oil)	Speed 1100-1600 rpm	Power, torque, BSFC, BTE	-
Raheman and Ghadge [24]	Ricardo E6 engine, 1C	B0, B20, B40, B60, B80, B100 (Mahua oil)	Constant 1500 rpm	BSFC	BTE
Ramadhass et al. [25]	1C, DI, NA	B0, B100 (Rubber sees oil)	Speed 1500 rpm	BSFC	BTE
		B0, B20 (Sunflower oil)	1000-3000 rpm	Torque, BSFC	BTE, power
Aydin and Ilkilic [26]	1C, DI	B0, BE20 (20% ethanol in B100)	1000-3000 rpm	-	Torque, BTE; power, BSFC (less/similar)
Najafi et al. [27]	2C, DI, NA	B0, B10, B20, B30, B40, B50 (Waste cooking oil)	1600-3600 rpm	Power, torque, BSFC	-
Qi et al. [28]	1 C, NA, DI	B0, B100 (Soybean oil)	1400-2000 rpm	BSFC	Power (less or identical)
Gogoi and Baruah [29]	1C, 4 stroke	B0, B20, B40, B60 (Kanarja oil)	800-1800 rpm	Power, BTE	-
Altiparmak et al. [30]	Lombardini 6LD 400, 1C	B0, B50, B60, B70 (Tall oil)	1800-3200 rpm	Power, torque	-
Murillo et al. [31]	3C, DI, NA	B0, B10, B30, B50, B100 (Cooking oil)	950-3450 rpm	BSFC	Power, BTE

Engine codes:

NC= No. of cylinder; DI= direct injection; IC= intercooled; AC= air-cooled; TC= turbocharge; NA=naturally aspirated

Performance measuring codes:

BSFC= brake-specific fuel consumption; BTE= brake thermal efficiency

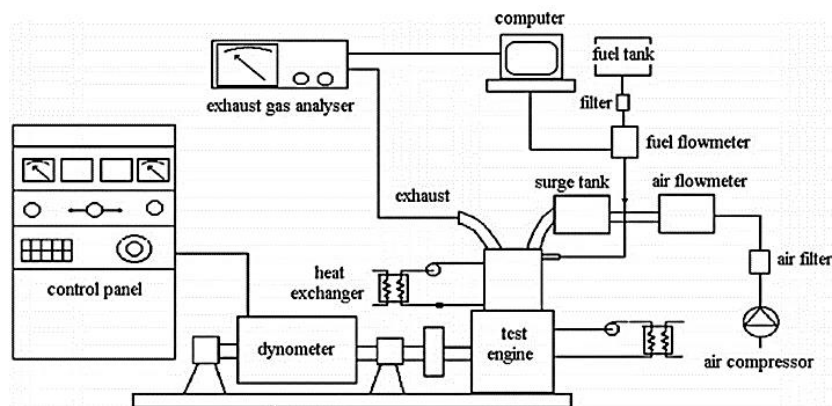


Figure 2. The test setup of performance and emission [45].

Lin et al. [18] observed 0.371%, 0.667%, 0.889%, 1.30%, 2.37%, and 2.85% increase in brake-specific fuel consumption (BSFC) for B5, B10, B15, B20, B25, and B30 (palm biodiesel), respectively, compared with B0. Gumus [21] compared the performance of four-cylinder turbocharged DI engine for diesel and biodiesel/its blends. Results showed that brake-specific fuel consumption (BSFC) of biodiesel (376.68 g/kWh) was higher than that of diesel (299.89 g/kWh). On the other hand, brake thermal efficiency (BTE) of biodiesel (26.30%) was found to be lowered as compared to that in diesel (27.82%). Ramadhas et al. [25] found decreased brake thermal efficiency and increased BSFC (>14%) when rubber seed biodiesel was used against petroleum diesel. Similar results were also reported by Nabi et al. [20], Benjumea et al. [19], Raheman and Ghadge [24], and Ramadhas et al. [25] (Table 3). Increasing concentration of biodiesel (derived from used cooking oil) in blends decrease engine power and brake thermal efficiency [31].

Yusaf et al. [32] conducted a research on the effect of using crude palm oil (CPO) and ordinary diesel (OD) blends as fuel on the performance of diesel engine. Three different blends of CPO-OD (25%, 50%, and 75%) were investigated during a test. The engine used in this test was a direct injection stationary Perkins diesel engine model 4- 108V. The CPO-OD blends were preheated to about 60°C before the injection to reduce the viscosity of the blends. The engine was running at variable speed (1000 rpm through 3000 rpm) under fixed throttle opening. The results showed that maximum fuel consumption rate occurs at 1800-2200 rpm. At low speed range, the fuel consumption rate of OD fuel was lower than CPO-OD blends, but at high speed range (above 2000 rpm) the CPO-OD blends exhibit lower fuel consumption rate than OD fuel. The gross energy input rate of CPO-OD was higher than the OD at low engine speed (below 2000 rpm). However, at higher engine speed (above 2000 rpm) the gross energy input rate of CPO-OD was lower than the OD. This happens because less energy input is required for blends to maintain engine speed above 2000 rpm even though the blends have lower energy content. Torque and brake power produced by CPO-OD blends was higher than the OD at low engine speed (below 2000 rpm). Moreover, increasing of the CPO percentage in the blend increases the torque and brake power. However, at higher speed above 2000 rpm, the torque and brake power produced by the CPO-OD blends was slightly lesser than the OD fuel. The CPO-OD blends could produce higher torque and power in the low speed range because of their higher flow rate and energy input. BSFC of all CPO-OD blends at low engine speed was around 10% higher than the OD, while at engine speed between 2200- 2500 rpm, the BSFC of CPO-OD blends is lower than the OD. This shows the CPO-OD blends can burn well at the engine speed between 2200-2500 rpm.

3.4. Emission

Liaquat et al. [33] researched about the impact of using biodiesel blends in diesel engines, the study was done by comparing exhaust gas emissions from diesel fuel with biodiesel from palm oil (B20). Testing

was done using a direct injection diesel engine. The diesel engine was connected with eddy current dynamometer system as load. The engine run for 250 hours (8 hours per day) at 2000 rpm with load of 10 Nm. Before the run, engine was warmed up every each day. Emissions measurement was taken by portable BOSCH exhaust gas analyzer (model ETT 0.08.36) and Bacharach (Model CA300NSX) for measuring CO, HC and NOx. Exhaust emission measurement performed at 0, 60, 125, 180 and 250 hours. Conclusion gained from research was emissions for CO and HC on B20 lower than compared to the diesel. If decrease in CO and HC on B20 and diesel are compared, there is average percentage decrease by 11% for CO and 11.71% for HC. The content of CO generated by B20 is lower because B20 contains oxygen that can be used in the process of converting CO into CO₂ (carbon dioxide). Meanwhile, lower content of HC on B20 happens as result of oxygen content in B20 that led to perfect combustion so that the amount of unburned hydrocarbons (HC) will tend to be lower. B20 produces higher NOx content compared to the emission of NOx produces by diesel. Higher NOx content on B20 happens as result of oxygen content. Oxygen content in B20 causes increase in local temperature so that excess hydrocarbons oxidation occurs. Excess oxidation causes increase in combustion temperature. Temperature increase then triggers the formation of NOx in exhaust emissions. Average percentage increase in Nox with B20 compared with diesel is 3.31%.

3.5. Wear of component

Depending on applications where sliding contact are involved, wear and friction are occurred. The common sliding components in automobile engine are cylinder liner, bearing, cam, tappet, crankshaft journals, pistons and piston pins, valve guides, valve system, etc. Lubricity of these components is normally provided by the fuel itself. Biodiesel inherently provides better lubricity than diesel fuel [34]. To understand the comparative wear in diesel and biodiesel, several laboratory investigations with four ball wear machine, pin-on-disk wear testing machine, reciprocating wear tester etc. Have been performed by some researchs. All these laboratory tests basically have been conducted in order to simulate the wear in engine parts that are in contact with biodiesel. The laboratory wear test data for biodiesel as compared to that in diesel fuel has been summarized in Table 4.

Table 4. Wear data from laboratory wear test: wear in biodiesel as compared to diesel.

Ref.	Method	Biodiesel	Results
Rashid et al [35]	HFRR	B100 (Moringa oleifera oil)	L
Goodrum and Geller [36]	HFRR	B (0.1-5) [rapeseed, soybean, castor]	L
Dalai et al. [37]	Roller on cylinder	B1 (Canola oil)	L
Kalam and Masjuki [38]	Four ball wear	B20 (Palm oil)	L
Masjuki and Maleque [39]	Pin-on-disc	B5	L
Wain [40]	Four ball test	B20 (Soybean)	L

L= less wear, S= similar wear, H= higher wear.

Masjuki and Maleque [39] researched about the anti wear characteristic of palm oil methyl ester (0%, 3%, 5%, 7%, 10%) in lubricant. They observed that 5% POME can provide better lubricity. Lubricant containing more than 5% POME cause higher wears damage due to oxidation and corrosion. Chourasia et al. [41] discussed the effect of using biodiesel-diethyl ether blend (B20A4) for long run test on diesel engine. The blend used in this test was B20A4 which was a composition of 20% biodiesel derived from *Jatropha* oil, 4% diethyl ether, and 76% diesel. The parameters observed in this study including wear on the piston, piston ring, cylinder liner, inlet valve, exhaust valve, and connecting rod bearings. The test was carried out for 512 hours which is divided into 32 cycles, each of 16 hours continuously at the prescribed conditions shown in IS 10.000 Part V. The engine was running at constant engine speed and engine load varies in each cycle. The results showed that the wear on B20A4 fueled engine was much lower than diesel fueled engine. The percentage of wear reduction in piston, cylinder liner, connecting rod bearings, inlet valve, exhaust valve, and piston rings dimensions of B20A4 fueled

engine were 52.7%, 63%, 19.2%, 25%, 54.13%, and 25% respectively. The percentage of wear reduction in weight of piston, cylinder liner, connecting rod bearings, inlet valve, exhaust valve, and piston rings dimensions of B20A4 fueled engine were 7.1%, 40%, 10.66%, 20%, 45.2%, and 54.49% respectively. This happens because B20A4 fueled engine has slow rate of the pressure rise, lower peak pressure, and smoother combustion. Besides the biodiesel blend has higher viscosity so the dilution of lube oil in B20A4 fueled engine is lower than diesel. Lower dilution of lube oil leads to lower wear on engine components.

3.6. Deposit

Research on deposit had been done by Suryantoro et al [42] which aimed to know the growth rate and characteristics of deposit formed from the use of biodiesel B10 and B50 made from Palm oil. Endurance research was done using Yanmar L48N diesel engine and single phase Dongdong generator with a 3.5 kW capacity. Bulbs were arranged in series to get constant power (75% of the maximum load of the machine). Research was conducted for 200 hours with a load of maximum engine torque. Deposit data retrieval done after 35, 100, and 200 hours on piston crown, piston groove, cylinder head, injector tip, intake valve, and exhaust gas. Retrieval of data was carried out by photography, whereas the mass of each component was weighted by mean of scraping, and using a JEOL JSM-6510 LA SEM-EDS to find out the composition of the deposit. Data in the form of image processed using software to manipulate photos and also the program MATLAB to obtain point coordinates and describe the injector in the form of graphs to determine the volume of deposit. From the research that had been done, it can be conclude that B50 produced higher deposit mass when compared with B10 for injector tip, intake valve, and exhaust valve.

B50 produced bigger and softer deposit particles with an oily/wet characteristics that caused by presence of residues of fuel so that the deposit are flammable. In addition, the structure of the deposits that form a spherical indicate the presence of long hydrocarbon chain and unstable compounds. While the B10 produce smaller dan sharper deposit particle with harder and drier characteristics but more brittle at the cylinder head/piston crown. Even so, structure deposit of some components such as piston groove and intake valve was not influenced from the use of B10 and B50. As for the composition of the deposit, the deposit on piston crown produced by B50 contained more calcium than B10. For carbon and oxygen content (O/C), deposit on the injector tip resulted by B10 tend to be higher than B50. For piston groove, composition of the deposits tend to be the same for the B10 and B50. For deposit on intake and exhaust valve, it is known that the content of O/C resulted by B10 were likely higher in comparison with the B50. On the intake valve there are elements of Fe, Mg, and Mo which is particles of wear. For the exhaust valve, there are aluminum metal wear indicated wear of piston ring that cause ring sticking.

A Research was conducted by Suthisripok and Semsamran [17] to determine how the characteristics of deposits produced by diesel engines when using B100 made from palm oil and diesel fuel on cylinder head, pistons, valves and fuel Injector. Testing was conducted using Kubota RT140 direct injection diesel engine with 14 HP power used to drive paddlewheel aerator in fish pond for 12 hours daily with 1000 rpm from 6 pm to 6 am. Research was conducted for approximately 800 hours. Visual inspection was done after the machine with diesel fuel ran for 100 hours by disassembling the machine. After the visual inspection was done, the machine was reassembled and filled with biodiesel B100. Later, the machine was running again for 100 hours and 700 hours for next visual inspection. From the test that had been done, it can be concluded that the deposits formed in cylinder head, pistons, valves and fuel injectors that use diesel fuel have an oily characteristic (varnish like deposit). While the deposits formed in cylinder head, pistons, valves and fuel injectors that use B100 have dry characteristics.

Raheman et al [43] conducted research about deposits of diesel engine with biodiesel made from Mahua oil mixed with simarouba oil with ratio of 50:50. Biodiesel B10 and diesel fuel were tested on a 10.3 kW single cylinder-diesel engine DM14 with direct injection, and water cooling. Loading on the machine using an AWM 15-model SAJ hydraulic dynamometer. The research was conducted by running

the machine for 100 hours consisting of 16 cycles with each cycle of 6.25 hours. Testing was done for both types of fuel with the loading system refers to the Indian Standard (IS) Part 9. After 100 hours of engine operation, the engine was disassembled for analysis of cylinder head, piston, and fuel injectors. Deposit measurement was done by taking photos and weighing deposits from cylinder head, piston, and fuel injector by scraping using a wooden scraper. From the measurement, it can be concluded that the deposits formed in cylinder head, piston, and fuel injectors from B10 is less than diesel fuel. It is known that deposit formed from B10 is less about 21% when compared to the diesel fuel due to better combustion of B10.

3.7. Lubricant

The results of research conducted by Suthisripok and Semsamran [17] who tested diesel engine durability for 800 hours to aerate fish ponds with B100 biodiesel fuel showed the viscosity of the lubricant at 100 °C for the lubricant research sample which was 13-15% higher than the new lubricant (Figure 3). This shown that the lubricant must be changed and marked with a deteriorating oil film. Lubricating oil is fuel contamination that is removed from components such as pistons that are repaired with fuel.

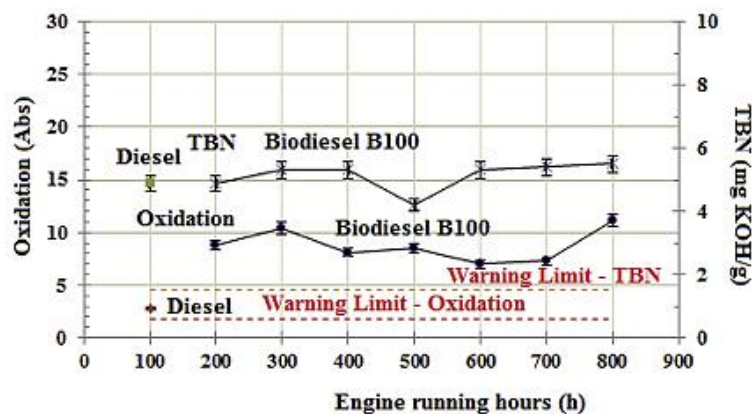


Figure 3. Viscosity of all lubricant samples at 100 °C.

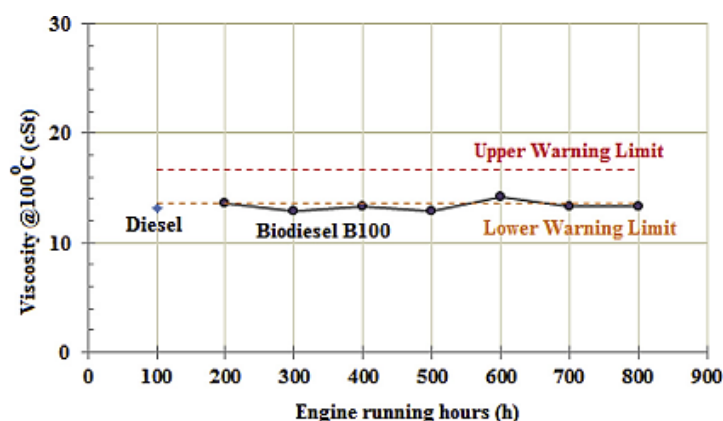


Figure 4. Oxidation and TBN throughout the sample.

The oxidation results in Figure 4 also found that diesel engines running using B100 biodiesel were much higher than when using diesel fuel, based on the analysis that there are fewer acidic products from the oxidation process under the same operating conditions. Oxidation of hydrocarbons that occurs in oxygen and heat produces carboxylic acids and depletes additive antioxidants in lubricants [44]. Carboxylic acids can cause corrosion in engine components if the concentration is high enough. Engine

temperature and load will accelerate the oxidation process, which can be seen in the form of corrosion, oil thickening, sediment formation, and accelerated wear.

According to Suthisripok and Semsamran [17] the level of wear of the components detected on the B100 fuel oil indicates that the engine is experiencing normal wear levels. This is obtained from the amount of fine wear elements such as Fe, Sn, Pb, Cu, Al, and Cr which were detected in all lubricant samples used. The number of Pb and Cu particles detected (possibly from piston rings, camshaft bearings, and connecting rod bearings) throughout the sample is quite stable which indicates the level of wear that occurs is normal. As for the detected Al particles (possibly originating from connecting rods and bearings) the high metal content occurred at the beginning of the test (the first 200-400 hours), but after that the Al metal content decreased to the last 800 hours.

In another research, examined the effect of biodiesel fuel from rapeseed oil for 150 hours on the value of TBN (Total Base Number) and TAN (Total Acid Number) lubricants. From the results of his research, lubricant TBN had decreased with increasing operating hours of diesel engines while the TAN value is the opposite. The decrease in TBN value and the increase in TAN value that occurs in the use of biodiesel was greater than diesel fuel. This is due to the nature of vegetable oil as a biodiesel feedstock which is more easily oxidized so that the acid content that contaminates the lubricant is higher [17].

4. Conclusion

The potential for the production of palm oil which is high in Indonesia is characterized by an increase in the number of the production of crude palm oil annually. In the year 2017 production of CPO in Indonesia reached 12.3 million tons of CPO increased 2.98 million tons from the year 2016. The CPO increased production coupled with an increase in the consumption of diesel fuel in Indonesia. In the year 2017 Indonesia oil fuel consumption reached 77 million tonnes of biodiesel, so it became a very potential fuel for Indonesia.

Based on various tests that have been carried out including performance, emissions, wear, deposits, and lubricant testing it can be concluded that biodiesel has similar characteristics with diesel oil even better. The resulting emissions indicate lower levels of HC (hydrocarbon) and CO (carbon monoxide) gas, but for NO_x gas it has a higher amount than diesel oil. For the performance of biodiesel fuels have better performance such as torque, RPM, and thermal efficiency but for specific fuel consumption is higher compared to diesel oil. Biodiesel fuel has a lower level of wear compared to diesel oil, such as piston components, cylinder liners, connecting rod bearings, inlet valves, exhaust valves, and piston rings. Deposits formed in biodiesel are higher than diesel fuel. The higher the value of biodiesel meal the higher the value of the deposits formed. As well as the engine oil using diesel fuel is generally better than using biodiesel. This can be proven in the value of viscosity, total base number, and sulfate ash content formed. Besides the metal content contaminated in lubricants such as Fe, Cu, Al, and Cr metal is much higher compared to biodiesel fuels.

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