Performance and Gas Emissions Analysis on Four Stroke Diesel Engine with Multi-Feedstock Biodiesel

Aminatus Sa'diyah*(1), Ahmad Anda Aulatama(1), Hilmy Destiandi Ramadhan(1) ,
Muchammad Nidhor Fairuza(1) , Enggar Alfianto(2)
[1] *Marine Engineering Department*, *Politeknik Perkapalan Negeri Surabaya*, Surabaya, Indonesia
[2] *Department of Electrical Engineering*, *Institut Teknologi Adhi Tama Surabaya*, Surabaya, Indonesia
Email address: * am.sadiyah@ppns.ac.id

***Abstract*— Biodiesel is one of the alternative fuels used in diesel engines. As the effectiveness of various biodiesel base materials varies, further studies on the effectiveness of biodiesel are needed. This study aims to evaluate the use of biodiesel from various sources as an alternative fuel. The methods in making multi-feedstock biodiesel are esterification and transesterification with palm oil, used cooking oil, and sunflower oil as raw materials. In this research, exhaust gas analysis and performance test on four stroke diesel engine were conducted. The mixture of biodiesel was then mixed with Pertamina Dex as High Speed Diesel (HSD) to produce B20, B35, and B100. The exhaust emission analysis focused on the concentration of (NOx) and (CO) gases at each rotation and load. The test result shows that B100 (100% multi-feedstock biodiesel) is the most optimal and environmentally friendly fuel with the same conditions of maximum load of 4000 watts and maximum rotation of 1400 rpm, NOx levels of 1396 mg/m3 and CO 474 ppm and has high power in all variations. On the other hand, HSD has the lowest gsfc in all variations.**

Keywords*— *biodiesel, exhaust emissions, four stroke diesel engine, multi-feedstock, performance

I. Introduction

Petroleum is an important factor in everyday life, especially in the transportation sector. The use of petroleum or fossil fuels has a negative impact on the surrounding environment and is one of the main factors of greenhouse gas (GHG) emissions that cause climate change. For 22 years, GHG emissions increased by an average of 5.2 per year in 4,444 industrial sectors [1]. On the other hand, the availability of fossil fuels is increasingly depleting, so that alternative renewable fuels are needed. Indonesia has potential in various fields, one of which is the utilization of biomass as a renewable fuel or biofuel such as bioethanol and biodiesel where the fuel raw materials are available and renewable [2]. Biodiesel is one of the fuels used in diesel engines. One of the materials in making biodiesel can use plant oils such as coconut and palm oil. Basically, biofuels can reduce exhaust emissions produced compared to fossil fuels, this is because the plants that are the source of biofuel materials will absorb carbon from the atmosphere. In the combustion process, carbon will be released into the atmosphere and reabsorbed to have the same balance [3]. This statement is proven in the implementation of biodiesel in Indonesia, which can reduce GHG emissions by 27.8 million tons of CO_2 by 2022 [4].

Biodiesel has the ability to influence engine performance. A study revealed that biodiesel affects the emission characteristics and engine performance, when compared to conventional diesel fuel. The study evaluated the impact of using oxidized biodiesel on emissions and engine performance, and showed that oxidized biodiesel has a different effect compared to other diesel fuels [5]. One of the advantages of biodiesel is that it is environmentally friendly, sulfur-free, and non-toxic. Biodiesel with 100% concentration has been studied to reduce emissions compared to diesel oil with details of reducing particulate emissions 40-60%, carbon monoxide (CO) gas emissions 10-50%, hydrocarbon (HC) gas emissions 10-50%, Aldehyde-Aromatic emissions 13% and toxic Polycyclic aromatic Hydrocarbon (PAH, Carcinogenic) gas emissions 70- 97% [6].

In general, biodiesel is produced from palm oil, on the other hand, biodiesel has 11% lower energy than diesel, so the power produced is smaller than fossil fuels. Biodiesel with palm oil has a low oxidizing quality because it has fatty acids, this affects the storage period and if for a long time it will turn into a gel, resulting in a blockage in the engine [8]. Used cooking oil raw materials in making biodiesel have the advantage of reducing 91.7% CO_2 emissions compared to diesel, high free fatty acid content requires a homogeneous acid catalyst [9]. Sunflower seeds have a high oil content to be utilized as biodiesel fuel. Sunflower seed oil is a triglyceride composed of fatty acids and glycerol which has a long carbon chain. Sunflower seeds contain 45%-50% lipids, making it possible to be used as biodiesel [10]..

Based on one study related to the blending of used cooking oil biodiesel with HSD and simulated on Two Stroke Marine Diesel Engine with the composition of B10, B20, B30. The characteristics of used cooking oil biodiesel mixed with HSD have a flash point of 176°C, a 40°C viscosity of 8.09 cst and a calorific value of 9325 Cal/gr. The higher percentage of used cooking oil biodiesel added to diesel oil (HSD) causes an increase in viscosity, namely at B10 2.90 cst, B20 3.23 cst, and B30 3.71 cst and for calorific value and flash point decreases, namely B10 10,764 Cal/gr, B20 10,657 Cal/gr, B30 10,450 Cal/gr and B10 77°C, B20 79°C and B30 85°C [11]. In 2017, Indonesia issued regulations related to Euro-4 emission standards for motor vehicles in the Minister of Environment and Forestry Regulation Number 20 of 2017. The Ministry of Environment and Forestry again released new types of vehicles in the M, N and O categories as vehicle types that are required to implement Euro-4 emission standards in accordance with the rules stated in the Permen LHK.

TABLE 1. Engine Emission Quality Standard.

(Source: [7])

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

No.	Capacity	Fuel	Parameters	Maximum Level (mg/Nm3)
1.	101 - 500 KW	Oil	Nitrogen Oxides (NOx)	3400
			Carbon Monoxide (CO)	170
		Gas	Nitrogen Oxides (NOx)	300
			Carbon Monoxide (CO)	450
2.	501 KW - 1000 KW	Oil	Nitrogen Oxides (NOx)	1850
			Carbon Monoxide (CO)	77
			total particulate matter	95
			Sulfur Dioxide (SO_2)	160
		Gas	Nitrogen Oxides (NOx)	300
			Carbon Monoxide (CO)	250
			Sulfur Dioxide (SO_2)	150
3.	1001 KW - 3000 KW	Oil	Nitrogen Oxides (NOx)	2300
			Carbon Monoxide (CO)	168
			total particulate matter	90
			Sulfur Dioxide (SO_2)	150
		Gas	Nitrogen Oxides (NOx)	285
			Carbon Monoxide (CO)	250
			Sulfur Dioxide (SO_2)	65

-Convert ppm to mg/Nm^3 for CO:
1 ppm CO = 1.25 mg/m3 (assuming a standard temperature of 25°C and pressure of 1 atm)
-Conversion of % to ppm for CO_2
1 ppm = part in a million.
1% = 1 part in 100.

This research focuses on blending 3 biodiesel feedstocks namely palm oil, used cooking oil and sunflower oil or Multi-Feedstock biodiesel. The Multi-Feedstock biodiesel will be compared with biodiesel for performance test and exhaust emission test on diesel motor. As a comparison with biodiesel fuel, biodiesel will be mixed with Pertamina Dex with variations of B20, B35, and B100. The fuel is tested on a four-stroke diesel engine, testing is carried out with variations in engine speed of 1000 rpm, 1200 rpm, and 1400 rpm. The load given is a lamp load with variations of 2000 watts, 3000 watts, and 4000 watts. The next test is the analysis of exhaust emissions in the form of carbon monoxide (CO) and nitrogen oxides (NOx).

II. Methods

The method used in this research is experimental. This research aims to compare multi-feedstock biodiesel with biodiesel fuel applied to a four stroke diesel engine. The variation of multi-feedstock biodiesel is a mixture with HSD with a concentration of 20% (B20), 35% (B35), and 100% (B100) multi-feedstock biodiesel. Tests were conducted on a four stroke diesel engine with variations of 1000 rpm, 1200 rpm, and 1400 rpm. The lamp load capacity given is 2000 watts, 3000 watts, and 4000 watts. Exhaust emissions testing in the form of carbon monoxide (CO) and nitrogen oxide (NOx) gas collection. The method used in collecting data on exhaust emissions generated using air sampling techniques with the Direct Reading method, "Gas Analyzer" is a tool used in this method. The gas analyzer works by taking gas samples from the probe, then entering each sample cell. This tool is the most effective method used to measure the proportion and gas mixture of combined gases, such as carbon dioxide (CO), oxygen (O), and carbon monoxide (CO). The unit to be used in this test is part per million (PPM) or can also use percent units (%). In testing the power produced and the generator specific fuel consumption (gsfc). Performance test using calculations based on data obtained from testing as follows:.

- Power

Equation for calculation of 3 phase generator power:

$$P = \sqrt{3} \times V \times I \times \cos\varphi \quad (1)$$

- Fuel Consumption

The equation to find fuel consumption is :

$$FCR = \frac{V \times \rho}{t} \quad (2)$$

- Generator Specific Fuel Comsumption (gsfc)

Specific fuel consumption is a generator performance parameter that is directly related to its economic value. The equation used to calculate specific fuel consumption according to [12] is: The diesel engine used is a 4-stroke diesel engine with the following specifications:

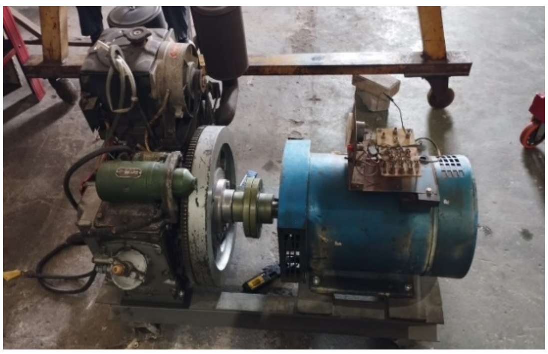
$$gsfc = FCR/P \quad (3)$$

TABLE 2. Specifications of 4-stroke Diesel Engine

Model	JD ZH1115N
Type	Single-cylinder, horizontal, 4-cycle
Combustion system	Direct injection
Diameter x stroke length (mm)	115 x 115
Step volume (mm)	1.195
Continuous power (HP/RPM)	24/2200
Cooling system	Hopper
Lubrication system	Combination of pressure & dispersion
System start	Hand/crank & starter
Net weight (kg)	180

TABLE 3. Generator specifications

Model	A.C.SYNCHRONOUS
Type	STC-5 GENERATOR
Power	5Kw/6.3 KVa
Voltage	380/660V
Electric Current	5.5 A
Cos	0.8
Number of Phase	3
Frequence	50 Hz
Speed	1500 RPM
Excit Volt	82 V
Excit Current	3.6 A



https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

Fig. 1 Jiandong's ZH1115N Diesel Engine coupled with generator

(source: personal documentation)

The picture above is a Jiangdong *Four-Stroke Diesel Engine* coupled with the generator used in this study. Table 2 describes the specifications of the 4-stroke diesel engine and table 3 describes the specifications of the generator used.

This research has detailed stages in the form of problem formulation, pre-experimentation, making multi-feedstock biodiesel, making (B20, B35, and B100), analyzing the characteristics of multi-feedstock biodiesel, and testing and data collection. The scheme is presented in Figure 2 below:

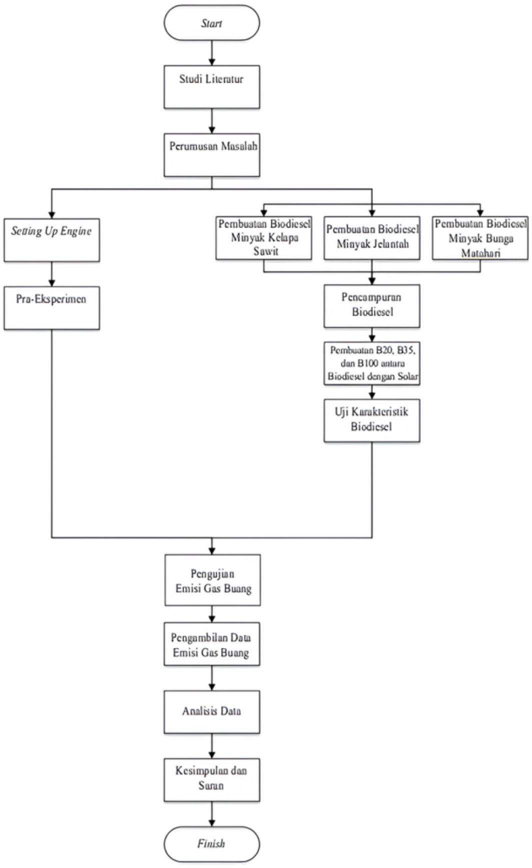


Fig. 2. Flow chart of the research

A. Manufacture of multi-feedsstock Biodiesel

Multi-feedstock biodiesel is produced from a mixture of palm oil biodiesel, used cooking oil biodiesel, and sunflower oil biodiesel. The three types of biodiesel (palm oil biodiesel, used cooking oil biodiesel, and sunflower oil biodiesel) are produced in the same way, namely through an esterification process followed by a cleaning process. The esterification process is carried out on vegetable oil to convert wet fatty acids into glycerin through reaction with alcohol and catalyst. This process uses methanol alcohol and a basic catalyst in the form of NaOH. The esterification process is carried out by heating the vegetable oil on a hot plate until the reaction temperature reaches 55°C. After reaching the reaction temperature, mix the vegetable oil with a mixture of methanol and NaOH. The volume ratio of vegetable oil to methanol is 5:1 and NaOH is 3 grams of 1 liter of oil. The reaction process lasts for 1 hour with a constant stirring frequency and a temperature of 55°C. After the purification process, palm oil biodiesel, used cooking oil biodiesel and sunflower oil biodiesel are mixed directly with a volume ratio of 1: 1: 1 so that multi-feedstock biodiesel is obtained.

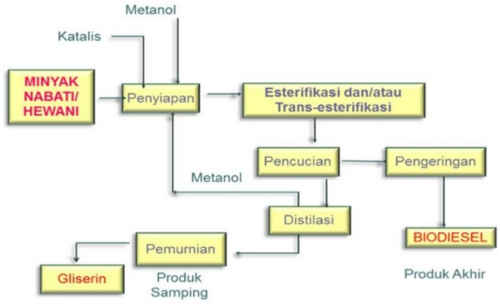


Fig 3. Schematic of biodiesel production

(Source: ebtke.esdm.go.id) [13]

B. Manufacture of B20, B35, and B100

The preparation of B20, B35, and B100 fuels is by mixing multi-feedstock biodiesel with HSD. The percentage ratio between multi-feedstock biodiesel and HSD is presented in Table 4 below:

TABLE 4. Percentage Composition of Multi-feedstock Biodiesel Blends with Pertamina Dex

Code	Multi-feedstock Biodiesel	Pertamian Dex
B20	20%	80%
B35	35%	65%
B100	100%	0%

III. RESULTS AND DISCUSSION

A. Analysis of multi-feedstock biodiesel characteristics

The test data of HSD and multi-feedstock biodiesel characteristics with variations of B20, B35, and B100 are presented in Table 5 below:

TABLE 5. Biodiesel Characteristics Data

Fuel	Flash Point (° C)	Density (kg/m3)	Viscosity (cSt)	Cetane Number	Calorific Value (cal/g)
Pertamina Dex	55	820 - 860	2,0 - 4,5	51 (min)	10.401
Biodiesel	52	815 - 880	2,0 - 5,0	49 (min)	-
B20	58	844	1,84286	>62.5	10,675
B35	65	864	1,83298	>62.5	10,473
B100	131	884	2,38445	>62.5	9,520

Based on the data table from table 5 shows that the flash point value of HSD is lower than that of B20, B35, and B100. The higher the concentration of multi-feedstock biodiesel, the higher the density, which affects the mass injected into the combustion chamber, the greater the density, the greater the mass injected. On the other hand, viscosity has an influence

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

on fuel atomization. A high viscosity value affects the lower atomization and the combustion process slows down and the viscosity value increases as the biodiesel content increases. The cetane number values in the table above measure the delay of the fuel combustion process in diesel engines. The higher the cetane value, the faster the combustion process. In Table 5, the cetane number of B100 with palm oil, used cooking oil and sunflower coconut oil are qualified or meet the SNI of biodiesel quality standards. SNI stipulates that the minimum biodiesel cetane number is 51, while B100 has a value of >62.5, it can be concluded that B100 has exceeded the standard value.

B. Test Results of Exhaust Gas Emissions (CO) using HSD

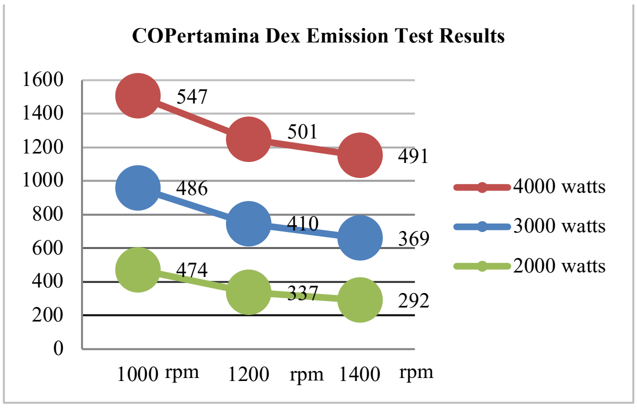


Fig 4. Exhaust gas emission graph of CO

From the graph, it can be concluded that exhaust emissions (CO) decrease with an increase in lamp load and RPM, proving that good combustion can reduce CO levels produced by the engine. The following is a table for exhaust emission tests using the *Carbonmonoxide* Meter tool with B20, B35, and B100 biodiesel fuels.

C. Test Results of Exhaust Gas Emissions (CO) using B20, B35, and B100

TABLE 5. Multi-feedstock Biodiesel Exhaust Gas Emission Test Table with CO Meter

	RPM	CO (ppm)	CO (mg/Nm³)
Biodiesel B20	2000 Watt Load		
	1000	598	747.5
	1200	534	667.5
	1400	473	591.25
	3000 Watt Load		
	1000	725	906.25
	1200	627	783.75
	1400	506	632.5
	4000 Watt Load		
	1000	802	1002.5
	1200	595	743.75
	1400	449	561.25
Biodiesel B35	RPM	CO (ppm)	CO (mg/Nm³)
	2000 Watt Load		
	1000	521	651.25
	1200	400	500.0
	1400	384	480.0
	3000 Watt Load		
	1000	541	676.25
	1200	421	526.25
	1400	390	487.5
	4000 Watt Load		
	1000	653	816.25
	1200	501	626.25
	1400	438	547.5
Biodiesel B100	RPM	CO (ppm)	CO (mg/Nm³)
	2000 Watt Load		
	1000	474	592.5
	1200	371	463.75
	1400	367	458.75
	3000 Watt Load		
	1000	510	637.5
	1200	377	471.25
	1400	347	433.75
	4000 Watt Load		
	1000	474	592.5
	1200	358	447.5
	1400	348	435.0

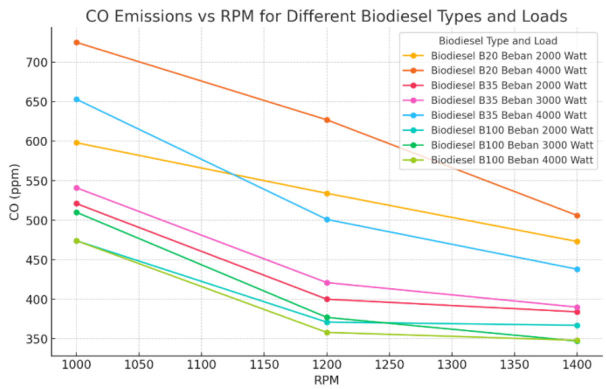


Fig 5. Trend Chart of CO Value of *Multi-feedstock* Biodiesel

Based on the test data, the table and graph above show the trend of CO emissions (in ppm) versus RPM for various raw materials and types of biodiesel. The highest CO value was achieved in Biodiesel B20 with a load of 4,000 watts with a value of 725 ppm at 1,000 rpm. While the lowest CO value achieved was Biodiesel B100 with a load of 4,000 watts with a value of 348 ppm at 1,400 rpm. The line with the highest CO value was Biodiesel B20 Charge 4000 Watt, while the line with the lowest CO value was Biodiesel B100 Charge 4000 Watt. Overall, the trend showed a decrease in CO emissions as engine rpm increased for all biodiesel types and loads tested.

From the test results, it can be seen that the CO levels produced under various load and speed conditions far exceed the maximum limits specified in the quality standards. For example, for generators with a capacity of 101 to 500 KW using oil, the maximum limit is 170 mg/Nm^3, while the test results show figures above 500 mg/Nm³ for all loading conditions and modes. It can be concluded that the carbon monoxide (CO) emission data generated from the multi-

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

feedstock biodiesel test does not meet the quality standards set by the Ministry of Environment and Forestry of the Republic of Indonesia in 2021. The CO produced exceeds the maximum allowable limit in all tested generator capacities.

This proves that the emissions produced by pure Biodiesel (B100) are better than HSD. These results also prove that the combustion process in the engine is more complete when using pure Biodiesel (B100), but Biodiesel still has the disadvantage that it easily settles and causes deposits on the cylinder walls. This is what motivates commercial companies to continue blending pure biodiesel with petroleum, to improve engine performance and reduce emissions to ensure better environmental sustainability.

D. Four-Stroke Diesel Engine Performance Test Results

- *Power*

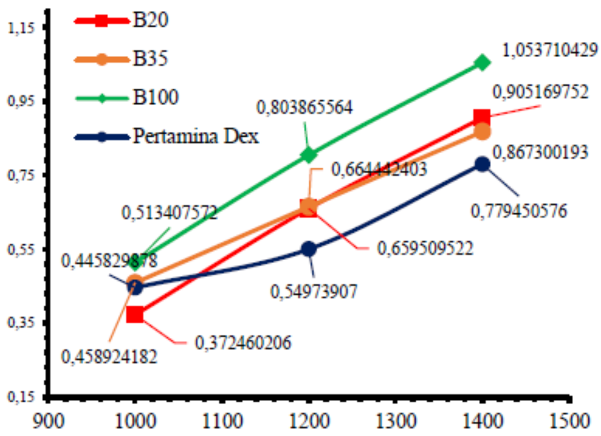


Fig 6. Generator power for 2000 Watt load

Figure 6 shows the power graph at 2000 watts load for the four fuel types. At 1000, 1200, and 1400 rpm, the B100 biodiesel blend produced the highest power of 1.053 kW at 1400 rpm. The B20 blend produced more power (0.905 kW) than B35 (0.867 kW) at 1400 rpm. HSD produced the lowest power at 1400 rpm, 0.779 kW.

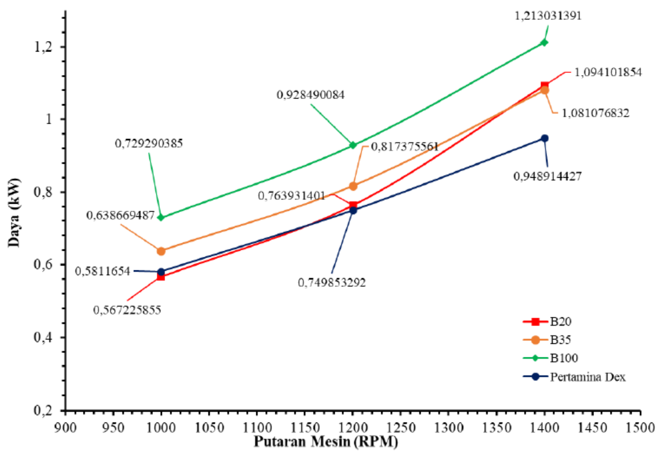


Fig 7. Generator power for 3000 Watt load

Figure 7 shows the power graph at 3000 watts load for the four types of fuel tested. At 1000 rpm, 1200 rpm, and 1400 rpm, the B100 biodiesel blend produced the highest power of 1.213031391 kW at 1400 rpm engine speed variation. Meanwhile, the B20 biodiesel blend produced more power than B35 at 1400 rpm. B20 produces 1.094101854 kW while B35 only produces 1.081076832 kW. The fuel that produces the lowest power at 1400 rpm is HSD, which only produces 0.948914427 kW.

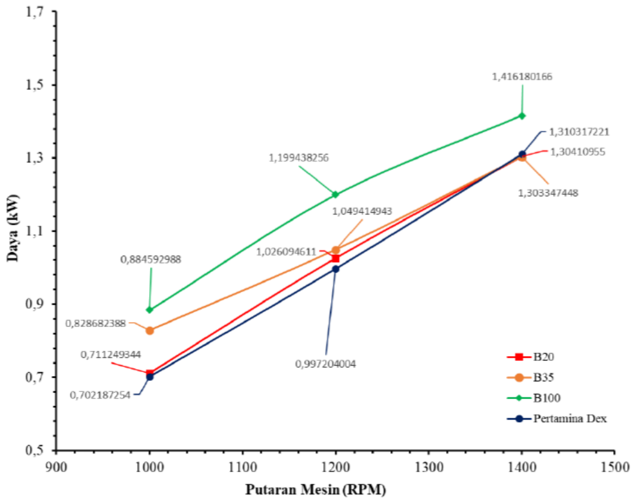


Fig 8. Generator power for 4000 Watt load

Figure 8 shows the power graph at 4000 watts load for the four types of fuel tested. At 1000 rpm, 1200 rpm, and 1400 rpm, here the B100 biodiesel mixture is still constant to produce the highest power, which is 1.416180166 kW at 1400 rpm engine speed variation. At the time of the 1400 rpm rotation variation with a load of 4000 watts, HSD experienced an increase in power compared to the previous load, HSD produced a power of 1.310317221 kW. While the B20 biodiesel mixture produces more power than B35 at 1400 engine speed. B20 produces 1.30410955 kW of power while B35 only produces 1.303347448 kW of power.

Based on the description above, it can be concluded that the B100 multi-feedstock is the most optimal fuel by providing the maximum power from the generator compared to other fuels.

- *Generator Specific Fuel Consumption (GSFC)*

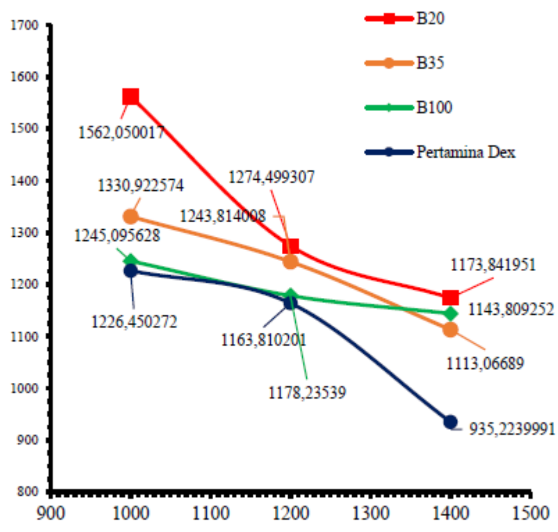


Fig 9. GSFC for 2000 watt load

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

In Figure 9 there is a graph of gsfc at 2000 watts load for the four types of fuel tested. At 1000 rpm, 1200 rpm, and 1400 rpm, HSD produces the lowest *gsfc*, which is 935.2239991 gr/kWh at 1400 rpm engine speed variation. Meanwhile, the B35 biodiesel blend produced a lower *gsfc* than B100 at 1400 engine speed. B35 produces a *gsfc* value of 1113.06689 gr/kWh while B100 produces a *gsfc* value of 1143.809252 gr/kWh. For fuel that produces the highest *gsfc* value at 1400 rpm engine speed is B20 which produces a *gsfc* value of 1173.841951 gr/kWh.

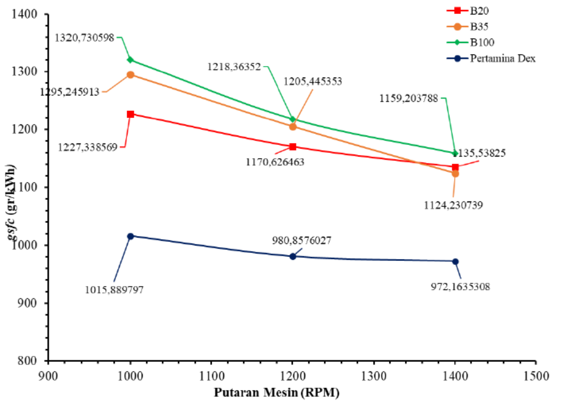


Fig 10. GSFC for 3000 watt load

In Figure 10 there is a graph of *gsfc* tested. At 1000 rpm, 1200 rpm, and 1400 rpm, HSD produces the lowest *gsfc*, which is 972.1635308 gr/kWh at 1400 rpm engine speed variation. Meanwhile, the B35 biodiesel blend produced a lower *gsfc* than B20 at 1400 engine speed. B35 produces a *gsfc* value of 1124.230739 gr/kWh while B20 produces a *gsfc* value of 1135.53825 gr/kWh. For fuel that produces the highest *gsfc* value at 1400 rpm engine speed is B100 which produces a *gsfc* value of 1159.203788 gr/kWh.

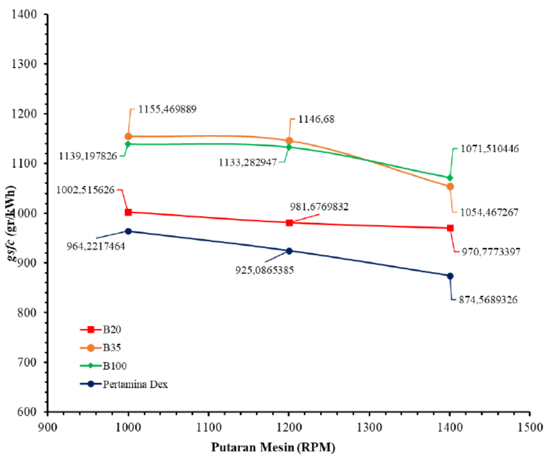


Fig 11. SFC for 4000 watt load

In Figure 11 there is a graph of *gsfc* at 4000 watts load for the four types of fuel tested. At 1000 rpm, 1200 rpm, and 1400 rpm, HSD produces the lowest *gsfc*, which is 874.5689326 gr/kWh at 1400 rpm engine speed variation. Meanwhile, the B20 biodiesel blend produced a lower *gsfc* than B35 at 1400 engine speed. B20 produces a *gsfc* value of 970.7773397 gr/kWh while B35 produces a *gsfc* value of 1054.467267 gr/kWh. For fuel that produces the highest *gsfc* value at 1400 rpm engine speed is B100 which produces a *gsfc* value of 1071.510446 gr/kWh.

Based on the results of the above research, it shows that HSD is the most optimal fuel in gsfc. The smaller the gsfc value indicates that the engine is more efficient in using fuel. This can be interpreted that in every unit of energy produced the engine requires less fuel.

E. Analysis of Emission Test Results of Biodiesel B35 and Biodiesel B35 against Quality Standard Standards

Emission tests were conducted on a four-stroke diesel engine using commercial biodiesel fuel compared to a B35 multi-fuel engine, with several variables including RPM and lamp load. The tests were conducted in the PPNS workshop using a gas analyzer brought by PT Kualitas Prima Nusantara technicians. The total emission test conducted by the company is 18 points, several products have been produced including oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitric oxide (NO), and nitrogen oxides (NOx).The levels produced from the emission test can be guaranteed to be accurate for the CO meter tested by the author, because the gas analyzer is operated by certified technicians and the results have been verified by PT.Qualita Prima Nusantara accredited by KAN (National Accreditation Commission). The following table shows the results of the emission comparison test between commercial biodiesel and B35 multi-feedstock biodiesel.

TABLE 6. Commercial Biodiesel Emission Testing Results with *Gas Analyzer*

Load	Parameters	1000 rpm	1200 rpm	1400 rpm	Unit
2000	CO	575	659	554	ppm
	NOx	337	521	778	mg/m³
3000	CO	440	431	430	ppm
	NOx	729	902	1046	mg/m³
4000	CO	352	407	454	ppm
	NOx	1040	1241	1468	mg/m³

TABLE 7. Emission Test Results of Multi-feedstock Biodiesel B35 with Gas Analyzer

Load	Parameters	1000 rpm	1200 rpm	1400 rpm	Unit
2000	CO	1047	731	695	ppm
	NOx	485	645	931	mg/m³
3000	CO	525	483	509	ppm
	NOx	832	1012	1308	mg/m³
4000	CO	323	408	456	ppm
	NOx	1022	1242	1396	mg/m³

In the table above, the CO emissions show a different pattern: biodiesel typically produces higher CO emissions at lower loads, but significantly lower CO emissions at higher loads than biodiesel. At 2000 rpm, CO_2 emissions for biodiesel range from 575 ppm to 554 ppm, while for biodiesel, CO_2 emissions drop sharply from 1047 ppm to 695 ppm. At 3,000 rpm, biodiesel had CO emissions of about 440 to 430 ppm, while biodiesel CO emissions ranged from 525 ppm to

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

509 ppm. At 4,000 rpm, biodiesel CO_2 emissions ranged from 352 ppm to 454 ppm, while biodiesel emissions were much lower at 323 ppm to 520 ppm. Biodiesel showed a more significant decrease in CO_2 emissions at higher loads.

On the other hand, NOx emission values increased with higher rpm for both fuels. For biodiesel, NOx emissions at 2000 rpm increased from 337 mg/m^3 to 778 mg/m^3, at 3000 rpm from 729 mg/m^3 to 1046 mg/m^3 and at 4000 rpm from 1040 mg/m^3 to 1468 mg/m^3. Biodiesel has higher overall NOx emissions, with values at 2000 rpm ranging from 485 mg/m^3 to 931 mg/m^3, at 3000 rpm from 832 mg/m^3 to 1308 mg/m^3 and at 4000 rpm from 1022 mg/m^3 to 1396mg/m^3. Biodiesel always produces higher NOx emissions than biodiesel, especially at lower RPMs.

In the biodiesel fuel, CO emissions at 2000, 3000 and 4000 watt loads were 1047 ppm (1308.75 mg/Nm^3), 640 ppm (800 mg/Nm^3) and 408 ppm (510 mg/Nm^3), all of which exceeded the limit set at 168 mg/Nm^3. NOx emissions at the same load were 485 mg/Nm^3, 1012 mg/Nm^3 and 1242 mg/Nm^3 respectively, all of which were below the standard limit of 2300 mg/Nm^3. Thus, CO emissions from BioDiesel did not meet the standard, while NOx emissions did.

On biodiesel fuel, CO emissions at 2000, 3000 and 4000 watt loads were 575 ppm (718.75 mg/Nm^3), 440 ppm (550 mg/Nm^3) and 352 ppm (440 mg/Nm^3) respectively, exceeding the standard limit of 168 mg/Nm^3. NOx emissions at the same load were 337 mg/Nm^3, 729 mg/Nm^3 and 1,040 mg/Nm^3, respectively, all below the standard limit of 2300 mg/Nm^3. BioDiesel's CO emissions did not meet the standard, while NOx emissions met the standard. Overall, BioDiesel and BioSolar met the NOx emission quality standard but not the CO emission standard.

F. Multi-Feedstock Comparison of B35 Biodiesel with Conventional Biodiesel

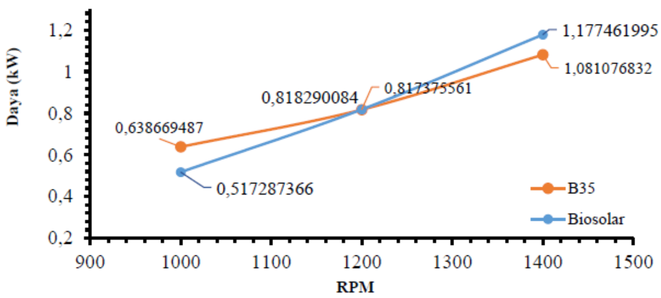


Fig 12. Comparison graph of generator power using B35 and Biosolar fuel

In Figure 11 there is a comparison graph of the generator power value at a load of 3000 watts for the type of fuel Biodiesel B35, Biosolar at 1000 rpm, 1200 rpm, and 1400 rpm. It can be seen on the graph that B35 excels only when the engine speed variation is 1000 rpm. At 1200 rpm, and 1400 rpm. Biodiesel B35 has a decreased power value compared to Biosolar.

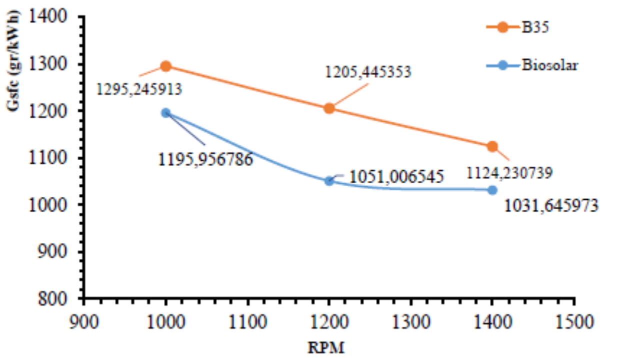


Fig 13. Comparison graph of gsfc values using B35 and Biosolar fuels.

In Figure 12, the gsfc value at 3000 watts load for Biodiesel B35 and Biosolar fuel types at 1000 rpm, 1200 rpm, and 1400 rpm, B35 has a gsfc value that is too high compared to Biosolar. Looking at these results, it can be concluded that the materials for making *multi-feedstock* B35 biodiesel (palm oil, used cooking oil, sunflower oil) are still less superior than fossil fuels. However, these feedstocks are still worth considering for biodiesel production because at one rpm variation, B35 biodiesel performed better than the other fuels.

IV. Conclusion

The conclusion that can be drawn is that B100 *multi-feedstock* biodiesel is the most optimal and most environmentally friendly fuel as shown by CO meter testing conducted at 3 different speed variations. This test produces the lowest carbon monoxide (CO) levels, namely in the maximum test condition of 474 ppm with the maximum load and the highest engine speed at 1400 RPM. Compare the highest variation of carbon monoxide levels using HSD fuel with CO levels of 547 ppm. The conclusion from testing using a CO meter is that the combustion of B100 *multi-feedstock* biodiesel is more efficient compared to HSD because better combustion results in lower carbon monoxide levels. On the other hand, the power generated from B100 has the highest value at each load, but the lowest GSFC value is obtained from HSD at all three loads.

Acknowledgment

Authors would like to express the deepest gratitude to Mr. Widodo, A. Md. as an K3 Examiner on duty at the Surabaya City Environmental Service, for his support and assistance for the smooth running of the emission test.

References

[1] Prasetyo, A.W. and Windarta, J. (2022) 'Utilization of Carbon Capture Storage (CCS) Technology to Support Sustainable Energy Production', Journal of New and Renewable Energy, 3(3), pp. 231-238.

[2] Fahmi, I., Soelistyo, T., Maulani, M., Sasongko, N. A., & Yoesgiantoro, D. (2022). Biofuels as a substitute for fossil fuels (Biofuels: Biodiesel, Bioethanol, BioAvtur, Green Diesel, Green Gasoline, Green Avtur). Journal of Patriot Biru Quarterly, 1(3), 51-58.

[3] A. Dahiya, Biofuels economics, sustainability, environment and policy, Second Edi. Elsevier, 2020. doi: 10.1016/B978-0-12-815497-7.02007-8.

[4] Ministry of Energy and Mineral Resources, "Performance Achievement of the Energy and Mineral Resources Sector in 2021 and Plan for 2022," Ministry of Energy and Mineral Resources Website. ESDM, p. 43, 2022,

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)

[Online].

[5] I. Nurhadi, "The Effect of Biodiesel Use on Performance and Main Components in the Main Motor of Kri Weling-822," Thesis-Me 14251, 2015.

[6] A. Wijono, "Impact of vehicle emission reduction on the use of 20% biodiesel blend," J. Nas. Science and Technol. no. November, pp. 1-12, 2017.

[7] Minister of Environment and Forestry of the Republic of Indonesia. (2021). Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 11 of 2021 concerning Emission Quality Standards for Engines with Internal Combustion. Ministry of Environment, 1-32.

[8] Rahmat, A. (2019). Dissecting Policies and Pluses and Minuses of Biodiesel Use in Indonesia. https://coaction.id/membedah-kebijakan-dan-plus-minus-penggunaan-biodiesel-di-indonesia/

[9] EBTKE, H. (2021). Opportunities and Challenges of Utilizing Used Cooking Oil-Based Biodiesel. https://ebtke.esdm.go.id/post/2021/03/09/2824/peluang.dan.tantangan.pemanfaatan.biodiesel.berbasis.minyak.jelantah.

[10] Utami, T. (2019). Biodiesel from Sunflower Seed Oil Utilization as an Alternative Energy to Replace Petroleum. https://iatekunsri.com/biodiesel-dari-pemanfaatan-minyak sunflower-seed-as-an-alternative-energy-to-replace-petroleum/#:~:text=Sunflower-seed-is-also-used-to-replace-petroleum.

[11] Haryono, E., & Witjonarko, R. D. E. (2017). Performance Analysis of Two Stroke Marine Diesel Engine Fueled by a Mixture of Solar Oil (Hsd) and Used Cooking Oil Biodiesel at Full Load Simulator Load. Inovtek Polbeng, 7(2), 179-187. http://ejournal.polbeng.ac.id/index.php/IP/article/view/220

[12] S. Semin, A. Iswantoro, and F. Faris, "Performance and NOx Investigation on Diesel Engine using Cold EGR Spiral Tube: A Review," 2017. doi: 10.12962/j25481479.v1i3.2372.

[13] EBTKE. 2024. FAQ : Program Mandatori Biodiesel 30% (B30). https://ebtke.esdm.go.id/post/2019/12/19/2434/faq.program.mandatori.biodiesel.30.b30. Accessed on August 22, 2024.

https://jurnal.polines.ac.id/index.php/eksergi

ISSN 0216-8685 (print); 2528-6889 (online)