International Journal of Marine Engineering Innovation and Research, Vol. 8(2), Jun. 2023. 213-221
(pISSN: 2541-5972, eISSN: 2548-1479)

Biodiesel Potentials of Waste Cooking Oil (WCO): Production, Content of Fuel Properties, and Effects on Engine Performance

Suardi[1], Doddy Suanggana[2], Basri Said[3]

(Received: 03 May 2023 / Revised: 03 May 2023 /Accepted: 09 May 2023)

Abstract*-The potential for biodiesel to become the main fuel in the future seems to be getting brighter with the enactment of government policies related to the implementation of the Euro 4 standard. In addition, the government has also launched de-carbonization to reduce the greenhouse effect by referring to the International Maritime Organization (IMO) plan which sets a target of reducing world carbon emissions by 40% by 2030 and 70% by 2050. To answer this challenge, this research aims to find out the bio-diesel production process by utilizing waste cooking oil (WCO), the next step is whether the bio-diesel produced has content properties that are following the quality standards set by the government, the final step is that the bio-diesel is tested on a test engine to know the value of the engine performance produced. In this research two types of methods are used to solve the problem, the first is the transesterification method, which is a method commonly used in the process of making biodiesel, this method utilizes a catalyst to separate pure biodiesel from glycerol, in this research using methanol and NaOH catalysts. The second method is the experimental method, which is testing biodiesel directly on the engine so that the resulting engine performance values including power, torque, and SFC can be known. The test obtained results in the form of content of fuel properties still included in government standards which include Density, Viscosity, Flash Point, Pour Point, and Cetane Number. The best torque value is in the B15 fuel variation at engine speeds of 1400 RPM and 1600 RPM, for the best effective power value results in the B15 fuel variation using engine speed of 1600 RPM, and the best specific fuel consumption value in the B15 fuel variation at 1000 RPM engine speed. So it can be concluded that mixing coconut cooking oil with pure cooking oil into biodiesel can be used as an alternative fuel and has a good impact on diesel engine performance.

Keywords- Biodiesel, Waste Cooking Oil (WCO), Transesterification, Content of Fuel Properties, Engine Performance

I. INTRODUCTION

Many factors make the Indonesian government promote the use of environmentally friendly fuels today. These factors include the ambition of the International Maritime Organization (IMO) which will reduce exhaust emissions from ships in 2030 by 40% and is targeted by 2050 to reduce emissions by 70% [1], the second factor is Indonesia's ambitious target to go net zero emissions in 2060 with the big Indonesia Decarbonization plan [2], This plan has been seen since Indonesia officially joined the International Energy Agency (IEA) in 2015, which is a body of developed countries with a mission to form a community of countries that can create future energy that is environmentally friendly and renewable [3], decarbonization steps have also been launched by China which is also ambitious to reduce emissions by 2060 [4][5]. The third factor is that currently, the demand for fossil fuels in the country is very increasing and not proportional to the rate of oil production, this forces the government to increase the amount of oil imports from outside which greatly burdens the government's financial balance with a daily deficit of -677,363 barrels per day and ranks globally 14th in the world in terms of fuel consumption [6].

On the other hand, Indonesia is the largest palm oil-producing country in the world, with 45,500 (in million metric tons) [7] is one of the good enough capital to be used as raw material for diesel, especially now that the European Union through the Renewable Energy Directive (RED II) has placed restrictions on imports of CPO raw materials from Indonesia because it considers that the production of palm oil derivatives has damaged the environment (forest destruction) [8], [9]. With the abundant supply of domestic palm oil, it is an opportunity and challenge for the government to convert hydrocarbon fuels to biodiesel. Currently, the government has implemented a combination of hydrocarbon and biodiesel fuels through the launch of biodiesel fuel (B35), and has been implemented as of 1 February 2023 [10]. This fuel has been distributed in almost all provinces in Indonesia. With the enactment of this policy, the amount of use of hydrocarbon fuels can slowly be reduced and suppressed a little bit.

Many research articles discuss the potential of biodiesel to be used as a new fuel source. Some of them are testing the potential of biodiesel from corn oil against the effects it has on the engine, from the test the performance value of the test engine is obtained with low oil consumption of 15% compared to the test results when the engine uses diesel fuel (Pertamina Dex), this is of course very positive considering that it can provide quite high savings on the engine, but in terms of power and

Suardi is with Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail :suardi@lecturer.itk.ac.id
Doddy Suanggana is with Department of Mechanical Engineering, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia.
e-mail : doddy.suanggana@lecturer.itk.ac.id
Basri Said is with Department of Mechanical Engineering, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail : 03171014@itk.ac.id

thermal efficiency it is lower by 7% and 8% compared to using pure diesel oil fuel [11]. Another article is about the use of palm oil bunch waste (POME) to make bio-diesel, the results found are by utilizing this waste, it can be made into biodiesel with the transesterification method, separating the methyl ester from glycerol (water) using the chemical catalyst methanol and NaOH or KOH, until it finally becomes a bio-diesel. At the end of the study, the biodiesel properties value (B5) for its viscosity was included in the fuel quality standard of 5.8 cSt, but the density value was not 810 kg/m^3, for (B10) the viscosity was higher than the fuel quality standard of 6.3 cSt, and the density is sufficient, namely 860 kg/m^3 [12]. Another article was also found which tested the effect of the temperature difference in biodiesel on the combustion effect, the result was that the higher the temperature of the fuel being tested, the greater the detonation of the engine which affected the ignition of the engine [13].

The raw material for biodiesel, especially from WCO, is obtained from used cooking oil and becomes environmental waste. Data shows that in Indonesia, in 14 days, it takes a supply of cooking oil of more than 78,200 tons for the community [14]. The high consumption of cooking oil also has an impact on the high waste (WCO) generated both from households and the food processing industry. The data obtained shows that around 6.46 - 9.72 million Kilo liters of WCO are produced every year in Indonesia [15]. WCO is a problem in itself because if it is consumed it will have an impact on health in the future but if it is disposed of in the environment it will pollute the environment. So the potential to be used as a raw material for the manufacture of bio-diesel is very appropriate.

By looking at the trend of petroleum being increasingly expensive and scarce, in the future, the use of bio-diesel will grow and even be able to replace the role of hydrocarbon fuels. Studies on the potential of biodiesel will become the main reference in future policy processes.

II. Method

To solve the problem according to the previous background, this article uses two methods. The method applied is the transesterification method to convert WCO into biodiesel. the process of this method is to change triglycerides from WCO into methyl esters or biodiesel [16]. The stages of this method can be seen in Figure 1.

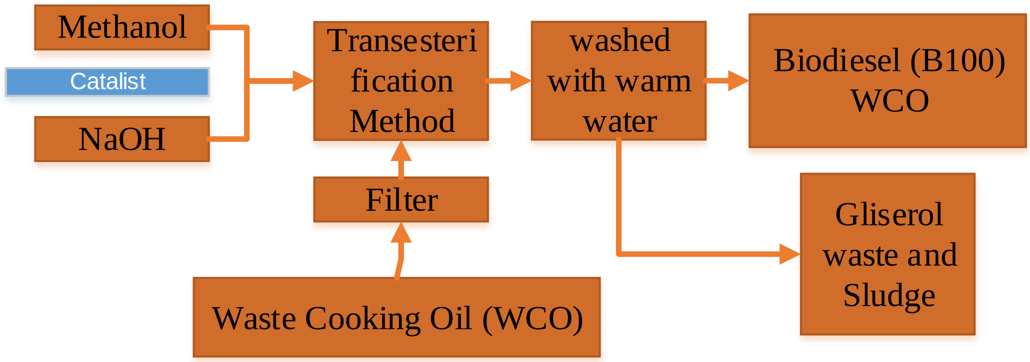

Figure 1. Stages in The Transesterification of WCO Into Biodiesel

After making biodiesel, the next step is testing the properties of biodiesel. The reference parameter is that the quality of bio-diesel must have properties similar to the quality set by the government. For testing the quality of the properties of biodiesel carried out in a laboratory belonging to a private national company, namely Petrolab, Balikpapan branch stages of this method can be seen in Figure 1 [17]. The properties of biodiesel parameters tested in the laboratory can be seen in Table 1.

TABLE 1.
PARAMETERS OF THE TESTED BIODIESEL PROPERTIES

No	Parameter	Unit	Typical	Method
1	Density at 15^0 C	Kg/m^3	815-880	ASTM D1298-12b
2	Flash Point PMCC	^{0}C	min 52	ASTM D93-12e1
3	Viscosity Kin@ 40^{0}C	cSt	2.0 - 5	ASTM D7279-20
4	Pour Point	^{0}C	Max 18	ASTM D97-12
5	CetaneIndex	-	Min 45	ASTM D1976-11

The specifications for the type of machine running the test can be seen in Table 2. As well as the testing scheme on the machine can be seen in Figure 2.

TABLE 2.
TEST ENGINE SPECS [18]

Name of Engine	Yanmar TF Series
Variety	TF 85 MH
Character of Cylinder	1 Cylinder 4 Stroke
Displacement	493 cc
Range of Power/rpm	7,5 Hp/2200 rpm
Compression Ratio	1:18
Fuel Consump (SFC)	171 gr/HP h

Figure 2. Biodiesel Testing Scheme on The Engine

When testing the engine, the data to be collected includes fuel consumption time data, the amount of generator current generated for each fuel variation and load variation, as well as the generated electric voltage. By obtaining this data, the calculation process to obtain the value of power, torque, SFC and thermal efficiency of the engine can be carried out.

III. Results and Discussion

There are three main studies of this research, the contents of the article begin with the manufacture of biodiesel from WCO materials that have been collected. The next study is that the biodiesel produced is tested in a laboratory to determine the quality of the fuel. And the last study is to test biodiesel on the engine directly so that a comparison of the resulting performance is known. The complete stages of the contents of this article will be presented below.

A. Methanolysis Process to Make WCO Biodiesel

It is called process methanolysis because in the process it is made using methanol and NaOH catalyst which is mixed into WCO. This process is also more commonly known as the transesterification process (separating the methyl esters and triglycerides in WCO to become biodiesel. In its manufacture, it takes about 2x24 hours starting from the filtering stage to precipitation and obtaining biodiesel. The methanol mixed in WCO has detergency properties (descaling) that are in the engine cylinder [19] while glycerol in WCO must be removed and minimized because of the effect it causes on precipitation [20]. The stages in the production of biodiesel from WCO using the transesterification method can be seen in Figure 3 [21].

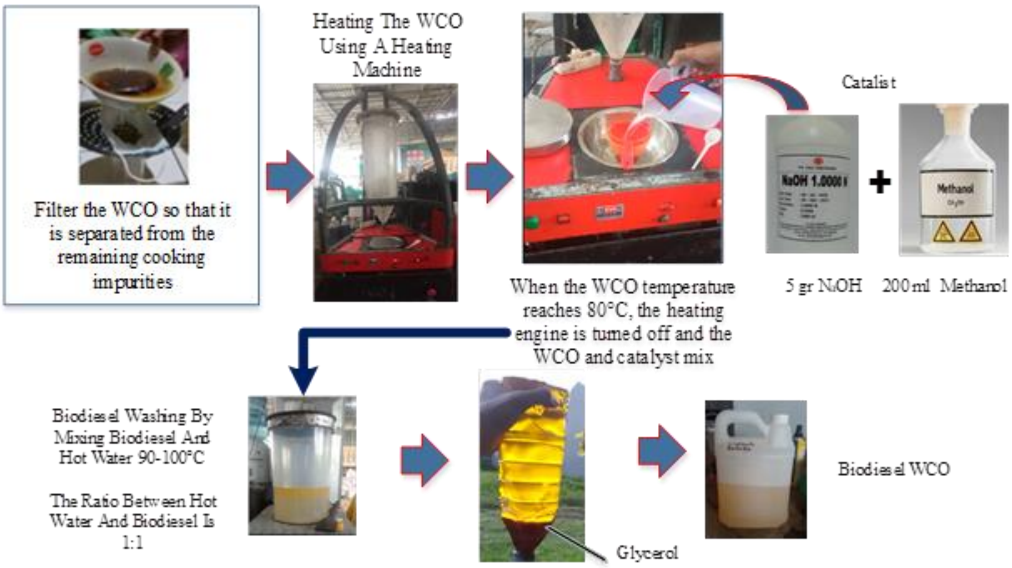

Figure 3. Methanolisis / Transesterification WCO Procces

B. WCO Biodiesel Properties Test

The biodiesel sample is then tested in a laboratory to determine the quality of the biodiesel. There are five parameters tested, namely Density, Flash Point, Viscosity, Pour point, and Cetane index. The laboratory test results can be seen in Table 3.

TABLE 3.
LABORATORY TEST RESULTS FOR WCO BIODIESEL QUALITY

No	Parameter	Unit	Typical	Method	Result		
					B10	B15	B20
1	Density at 15^0 C	Kg/m^3	815-880	ASTM D1298-12b	830.3	834.3	838.7
2	Flash Point PMCC	^{0}C	min 52	ASTM D93-12e1	71	72	73
3	Viscosity Kin@ 40^0C	cSt	2.0 - 5	ASTM D7279-20	3.34	3.76	4.24
4	Pour Point	^{0}C	Max 18	ASTM D97-12	-12	-9	-6
5	Cetane Index		Min 45	ASTM D1976-11	56	55.5	54.5

From the test results, it was found that the biodiesel properties were still within the standards set by the government, however, with more and more biodiesel mixed in the fuel, the Density, Flash Points, Viscosity, Pour Point, and Cetane Index also increased.

C. Engine Running (Biodiesel WCO test)

The engine must be checked before testing the biodiesel, the engine is heated using pure diesel fuel for 10 minutes. Engine oil must also be sufficient, as well as engine cooling water. Supporting equipment must also be checked such as AVO meters, clamp meters, light boards (loads), and Rpm gauges, and of course safety equipment must be available such as fire extinguishers. After it was felt that it was ready for data collection, the engine fuel was diverted to using samples of B10, B15, B20, and pure diesel (Pertamina Dex without biodiesel mixture).

Each sample was tested under load conditions of 1000 watts, 2000 watts, 3000 watts, and 4000 watts. While the speed variations used are 1000 rpm and 1200 rpm, 1400 rpm, and 1600 rpm. For reference, the amount of biodiesel used is 10 ml for all types of fuel variations. The results of running the engine for each fuel variation can be seen in Table 4. The data obtained from the results of machine testing, it is then entered into table 4 above to make it easier to process the data. The data is very important to be used in the process of calculating engine performance values.

TABLE 4.
THE RESULTS OF TESTING THE VARIATION OF FUEL ON THE ENGINE

RPM	Load (Watt)	Fuel (ml)	**B10**			**B15**			**B20**			**B0 (Pertadex)**		
			Current(A)	Voltage (V)	Time (s)	Current(A)	Voltage (V)	Time (s)	Current(A)	Voltage (V)	Time (s)	Current(A)	Voltage (V)	Time (s)
1000	1000	10	2.94	114	131	2.98	116	140	3.03	121	123	3.03	121	123
	2000		5.77	111	94	5.77	110	107	5.86	114	95	5.86	114	95
	3000		8.21	100	83	8.37	103	95	8.39	104	83	8.39	104	83
	4000		10.2	89.1	81	10.2	90,1	88	10.3	91,0	72	10.3	91,0	72
1200	1000	10	3.42	151	93	3.42	150	110	3.46	153	88	3.46	153	88
	2000		6.53	139	76	6.58	140	85	6.64	143	73	6.64	143	73
	3000		8.94	118	68	8.99	118	75	8.93	117	69	8.93	117	69
	4000		10.6	95.9	66	10.5	94,6	76	10.4	92,4	67	10.4	92,4	67
1400	1000	10	3.82	184	68	3.85	187	74	3.81	185	76	3.81	185	76
	2000		7.21	165	60	7.26	168	52	7.17	166	58	7.17	166	58
	3000		9.32	126	60	9.26	125	46	9.17	124	49	9.17	124	49
	4000		10	86.7	56	10.6	95,7	49	10.3	90,8	57	10.3	90,8	57
1600	1000	10	4.18	217	61	4.18	218	62	4.18	219	60	4.18	219	60
	2000		7.79	191	48	7.81	192	48	7.69	188	48	7.69	188	48
	3000		9.74	137	47	9.79	138	46	9.48	131	52	9.48	131	52
	4000		10.4	92.2	49	10.9	99,8	42	10.2	89,0	44	10.2	89,0	44

1. Comparative analysis of Power, Torque, and Fuel Consumption vs. Power

The main parameters in engine performance are the amount of power and torque produced, this is the most important benchmark for each machine because with large power it will be able to provide good work performance on that machine. Furthermore, the second parameter is how much fuel consumption occurs in the machine. a good engine that has great power and torque and relatively lower fuel consumption. This is what will be used as a reference in calculating engine performance values using fuel variations B0 (pertamina dex), B10, B15, and B20.

The example calculation below uses a diesel engine test sample with 1000 RPM rotation, 1000 Watt Load, 10 ml Fuel Volume, 2.94 Amperes Current, 114 Volt Voltage, 335.8 kW Power, and 131 seconds.

$$P = 2\ (\pi \times n / 60)\ T \quad (1)$$

Where:

P = Engine Power (W)
n = Engine Rotation (Rpm)
T = Engine Torque (N.m)

Meanwhile, when the machine is running, the component data that is taken is the value of current and voltage

P = (Current x voltage x 0,001) / Load Factor
= (2,94 x 114 x 0,001) / 0,8
= 0,419 kW

So to get the torque value, the equation is:

$$T = (P \times 60) / (2\pi \times n) \quad (2)$$

Until finally the torque can be calculated based on the previous equation:

T = (419 x 60) / (2 x 3,14 x 1000)
T = 3.99 N.m

The next step is to calculate the engine SFC value based on the data obtained when the engine is running:

$$SFC = (mf \times 10^3) / P \quad (3)$$

Where:

SFC = Specific Fuel Consumption (gr/kWh)
mf = Fuel Consumption (kg/jam)
= ((ρ x vf) / tf) x 3600
P = Power (kW)
Sgf = Fuel Specific Grafity (kg/L)
vf = Fuel Volume (L)
tf = Fuel Consumption Time (s)

With the above equation, the SFC calculation can be performed as follows:

mf = ((*Sgf* x vf) / tf) x 3600
= ((0.8303 x 0.01)/131) x 3600
= 0.228 kg/h

SFC = (0.228 x 10^3) / 0.419
= 544.63 gr / kW.h

Overall, the value of the results of calculating engine performance which includes Torque, Power, and SFC from three variations of fuel samples at four variations of the load is presented in more detail in Table 5.

TABLE 5.
DATA RESULTS OF THE CALCULATION OF POWER, TORQUE, AND SFC IN TOTAL.

Load (watt)	Rpm	Ne (kW)	Torque (N.m)	SFC (gr/kWh)	Ne (kW)	Torque (N.m)	SFC (gr/kWh)	Ne (kW)	Torque (N.m)	SFC (gr/kWh)	Ne (kW)	Torque (N.m)	SFC (gr/kWh)
		Fuel variation (B10)			Fuel variation (B15)			Fuel variation (B20)			Pertamina Dex		
1000	1000	0.42	4.00	544.63	0.35	3.32	617.19	0.37	3.52	665.06	0.33	3.14	790.30
2000		0.80	7.64	397.19	0.63	6.05	443.23	0.67	6.38	475.14	0.63	5.97	475.93
3000		1.03	9.80	350.92	0.86	8.23	366.64	0.88	8.38	414.23	0.86	8.18	420.17
4000		1.14	10.84	324.84	0.93	8.83	368.98	0.94	8.93	448.36	0.96	9.16	403.08
1000	1200	0.65	5.13	497.90	0.51	4.08	532.25	0.53	4.21	647.98	0.50	4.01	626.95
2000		1.13	9.03	346.65	0.92	7.33	383.49	0.95	7.58	434.28	0.92	7.29	444.29
3000		1.32	10.49	333.35	1.06	8.45	377.08	1.05	8.34	417.54	1.06	8.46	428.31
4000		1.27	10.11	356.42	1.00	7.93	396.30	0.96	7.63	469.67	1.01	8.05	449.90
1000	1400	0.88	5.99	500.31	0.72	4.93	561.84	0.71	4.82	562.56	0.70	4.76	598.71
2000		1.49	10.14	335.01	1.22	8.30	474.60	1.19	8.10	438.19	1.21	8.24	420.15
3000		1.47	10.01	339.38	1.16	7.88	565.31	1.14	7.74	542.90	1.21	8.27	440.06
4000		1.08	7.39	492.52	1.02	6.92	603.90	0.94	6.38	566.41	1.00	6.83	552.30
1000	1600	1.13	6.76	432.18	0.91	5.43	532.17	0.91	5.45	551.17	0.91	5.43	566.97
2000		1.86	11.10	334.82	1.50	8.92	418.55	1.15	6.83	549.37	1.43	8.53	433.31
3000		1.67	9.95	381.29	1.35	8.05	483.65	1.24	7.41	467.50	1.22	7.25	499.64
4000		1.20	7.15	508.94	1.08	6.47	659.70	0.91	5.42	754.82	0.83	4.95	691.68

2. Comparative analysis between Torque vs Load

The first parameter for performance that is measured is the comparison between engine torque based on the variation of fuel used. The torque value will be measured based on variations in load and engine Rpm so that it can be known which sample composition gives good results. This can be seen in Figure 4.

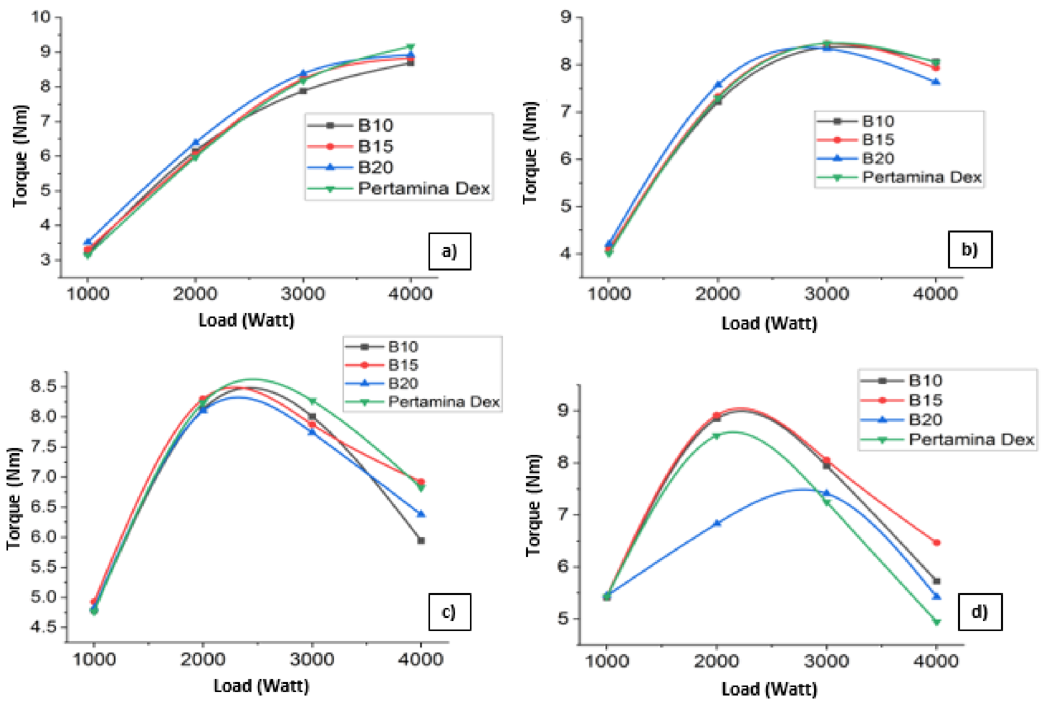

Figure 4. Comparison graph of Torque with load for each Rpm (a) 1000 Rpm, (b) 1200 Rpm, (c) 1400 Rpm, and (d) 1600 Rpm.

Figure 4 presents a graph of the results of the torque-to-load comparison on the B10, B15, B20, and Pertamina Dex fuel variations. Figure 4 (a) above shows a graph of the ratio of torque to load with a rotation of 1000 RPM, the largest torque value is found in the Pertamina Dex fuel graph at a load of 4000 Watt with the largest torque value of 9,165 Nm. Meanwhile, the smallest torque value is found in the Pertamina Dex fuel graph at 1000 Watt load with a torque value of 3,142 Nm. Then, in Figure 4 (b) above, it shows the torque-to-load ratio graph at 1200 RPM rotation, the largest torque value is obtained on the B10 fuel graph at 4000 Watt load with the largest torque value of 8,066 Nm. Meanwhile, the smallest torque value is found in the Pertamina Dex graph at a load of 1000 watts with a torque value of 4,008 Nm. Furthermore, in Figure 4 (c) above, it shows a graph of the ratio of torque to load with a rotation of 1400 RPM, the largest torque value is found in the B15 fuel graph at a load of 2000 Watt with the largest torque value of 8,298 Nm. Meanwhile, the smallest torque value is found in the Pertamina Dex fuel chart at a load of 1000 Watts with a torque value of 4,765 Nm. Also, Figure 4 (d) above shows the torque-to-load ratio graph at 1600 RPM rotation, the largest torque value is obtained on the B15 fuel graph at 2000 Watt load with the largest torque value of 8,919 Nm. Meanwhile, the smallest torque value is found in the Pertamina Dex fuel chart with a load of 4000 Watts, the torque value is 4,946 Nm. Based on the graph in Figure 4.1 it is explained that B15 and Pertamina Dex fuel dominate for the highest and average torque values occurring at 2000-watt and 4000 Watt loads. The highest torque value affects the power produced by diesel engines, so it can be concluded that B15 and Pertamina Dex fuel has very good torque values compared to other fuel variations. The decrease in torque from variations in fuel occurs with increasing engine speed. This happens because the tests were carried out using a variable speed so that with increasing engine speed, the loading mass decreases. This study used variable engine speed, so that the greater the engine speed, the higher the power generated. the higher the engine speed, the torque value will increase. This is because, with high engine speed, more fuel is compressed so that the explosion that occurs during combustion is greater. The big explosion produces a greater thrust on the piston head. This thrust causes the torque to increase. However, at higher engine speed, the effect of the resulting torque will decrease, because the higher the engine speed, the greater the loss of frictional power, so the effective power produced decreases and the torque decreases. The torque value for each fuel mixture which increases at 1000 RPM rotation along with the increase in the amount of load given results in a curve that tends to increase where this event is influenced by the relationship between torque performance and also specific fuel consumption performance which is interrelated where applicable results that are inversely proportional to the value of torque with the value of specific fuel consumption. If the specific fuel consumption value is low, the torque value obtained will be high, so that the performance test results show the highest torque value at the lowest specific fuel consumption value.

3. Comparative analysis between Power vs Load

Power is the main parameter in engine performance, this is a common standard seen by ordinary people related to the engine. large power provides good performance. A comparison chart between power and load can be seen in Figure 5.

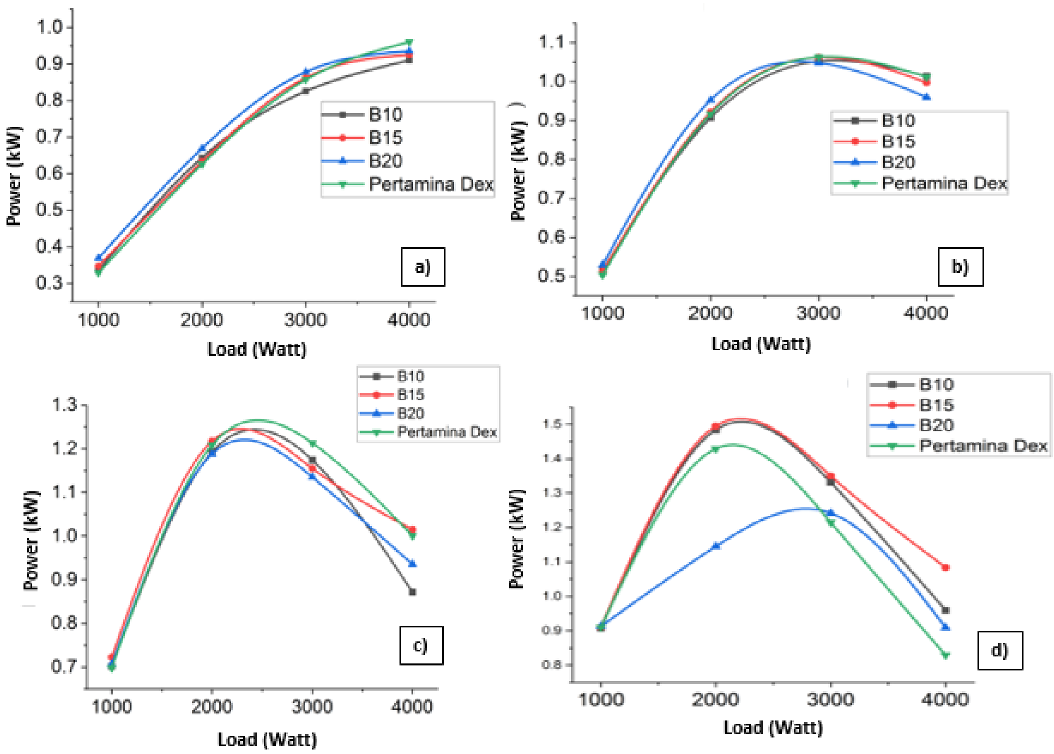

Figure 5. Comparison graph of Power with load for each Rpm (a) 1000 Rpm, (b) 1200 Rpm, (c) 1400 Rpm, and (d) 1600 Rpm.

In Figure 5 there is a comparison graph of adequate power with load on fuel variations B10, B15, B20, and Pertamina Dex. Figure 5 (a) above shows a comparison graph of adequate power against the load at 1000 RPM, the largest effective power value is obtained in the Pertamina Dex fuel graph at a load of 4000 Watts with an effective power value of 0.960 kW. As for the smallest effective power value found in the Pertamina Dex fuel graph at a load of 1000 Watts, 0.329 kW is obtained. Furthermore, Figure 5 (b) above shows a comparison graph of adequate power against the load at 1200 RPM rotation, the largest effective power value is obtained in the Pertamina Dex fuel graph at a load of 3000 Watt with a power value of 1.063 kW. Meanwhile, the smallest effective power value is found in the Pertamina Dex fuel graph at a load of 1000 Watts with an effective power value of 0.504 kW. Then, Figure 5 (c) shows a comparison graph of adequate power against the load at 1400 RPM rotation, the largest effective power value is obtained in the B15 fuel graph at 2000 Watt load with an effective power value of 1.217 kW.

Meanwhile, the smallest effective power value is found in the Pertamina Dex fuel graph at a load of 1000 Watts with an effective power value of 0.699 kW. As well as in Figure 5 (d) above shows a comparison graph of adequate power against the load at 1600 RPM rotation, the largest effective power value is found in the B15 fuel graph at 2000 Watt load with an effective power value of 1.495 kW. Meanwhile, the smallest effective power value is found in the Pertamina Dex fuel graph at a load of 4000 Watts with an effective power value of 0.829 kW.

Based on the graph of effective power analysis results that have been presented, it can be explained that B15 and Pertamina Dex fuels dominate for the highest and average effective power values occurring at 2000-Watt and 4000-watt loads. In the analysis above, the results of the effective power value graph have the same curve as the torque value graph, although the results of the values obtained between the two are different, it can be concluded that the effective power value graph and the torque graph are directly proportional. the more engine speed increases, the effective power value continues to increase, due to the higher engine speed, the consumption of fuel and air entering the combustion chamber is enlarged. So that the mixture of air and fuel entering the combustion chamber approaches the stochiometric mixture which makes the combustion that is happening close to perfect. In perfect combustion, the rotation of the crankshaft also becomes fast and results in the effective power produced by the engine increasing. Effective power is influenced by the rotation of the crankshaft which makes the piston push due to the combustion of fuel with air that occurs in the combustion chamber. if the specific fuel consumption value is low, the torque value obtained will be high, so that in the performance test results the highest torque value is obtained at the lowest specific fuel consumption value. the higher the engine speed, the greater the specific fuel consumption value, and the effective power value can decrease because the engine performance has been increased beyond ideal performance.

4. Comparative analysis between SFC vs Load

The last parameter to be analyzed is a comparison graph between fuel consumption values (SFC) and load variations. The complete results can be seen in Figure 6.

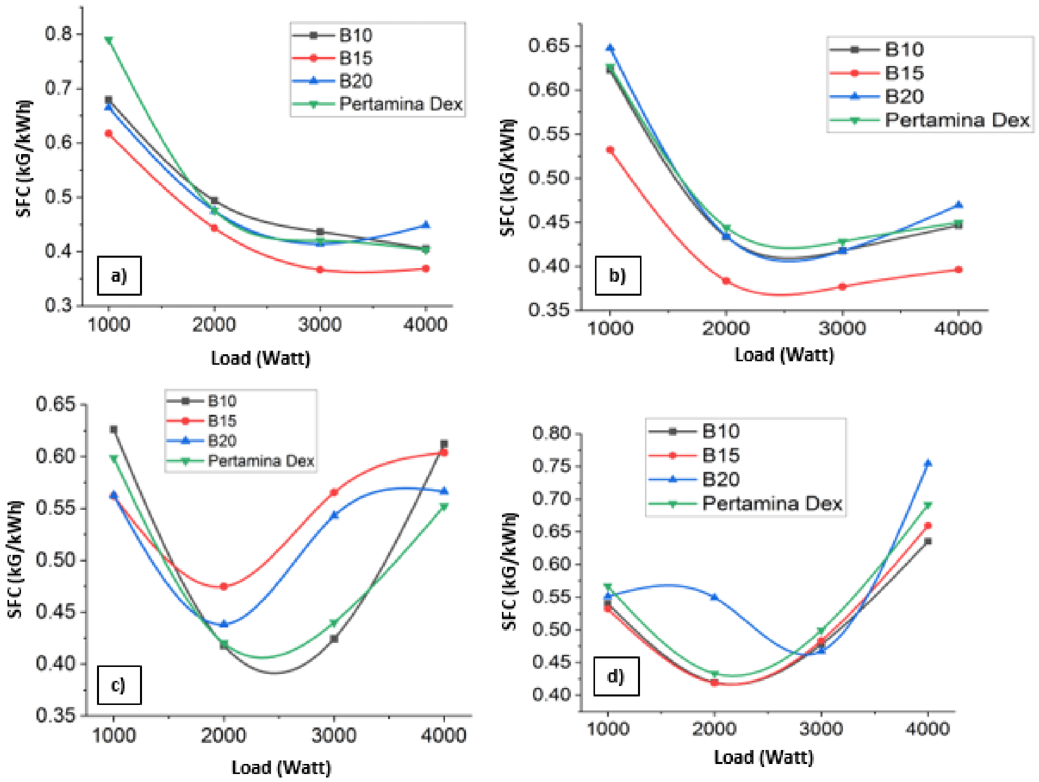

Figure 6. Comparison graph of SFC with load for each Rpm (a) 1000 Rpm, (b) 1200 Rpm, (c) 1400 Rpm, and (d) 1600 Rpm.

Figure 6 there are the results of the comparison of SFC (Specific Fuel Consumption) against load on fuel variations B10, B15, B20, and Pertamina Dex. Figure 6 (a) above shows the comparison graph of SFC (Specific Fuel Consumption) against the load with a rotation of 1000 RPM, the largest value is obtained in the Pertamina Dex fuel graph at a load of 1000 Watt with the largest SFC value of 0.790 gr/kWh. Meanwhile, the smallest value is found in the B15 fuel graph with a load of 3000 watts with the smallest SFC value of 0.367 gr/kWh. Then, Figure 6 (b) shows a comparison graph of SFC against load with a rotation of 1200 RPM, the largest value is obtained in the B20 fuel graph at a load of 1000 Watts with the largest SFC value of 0.648 gr/kWh. As for the smallest value found in the B15 fuel graph with a load of 3000 watts, the smallest SFC value is 0.378 gr/kWh. Furthermore, Figure 6 (c) shows a comparison graph of SFC against load with a rotation of 1400 RPM, the largest value is obtained in the B10 fuel graph at a load of 1000 Watts with the largest SFC value of 0.6273 gr/kWh. As for the smallest value on the B10 fuel graph with a load of 2000 watts, the smallest SFC value is 0.418 gr/kWh. Also, Figure 6 (d) shows the comparison graph of SFC against the load with a rotation of 1600 RPM, the largest value is obtained in the B20 fuel graph at a load of 4000 Watt with the largest SFC value of 0.754 gr/kWh. As for the smallest value on the B15 fuel graph with a load of 2000 watts, the smallest SFC value is 0.419 gr/kWh.

Based on the results of the graph analysis that has been presented, it can be concluded that the highest SFC value is dominated by the B20 fuel variation and the lowest SFC value is the average for the B15 fuel variation. The decrease in SFC value will change along with the decrease in fuel consumption rate and the increase in the value of the load used, and vice versa. the level of fuel saving can be seen from the SFC value. A good SFC value is if the SFC value is low which results in fuel consumption that is not wasteful. Meanwhile, the increasing SFC indicates that the engine is increasingly wasteful in using fuel. the more engine speed increases, the value of specific fuel consumption decreases. Near-perfect combustion makes fuel consumption better because all fuel is almost completely burned so that it becomes effective power.

IV. CONCLUSION

The result that can be concluded from this research is that the best fuel mixture variation is the B15 fuel variation. However, with the increasing amount of biodiesel mixed in the fuel, the Density, Flash Point, Viscosity, Pour Point, and Cetane Index also increase. for the best engine performance value in the B15 fuel variation. The best variation is in the B15 fuel variation. In B15 fuel, the highest torque value is at 1600 RPM with a load of 2000 watts, and the highest torque value is 8.919 Nm. In the variation of the B15 fuel mixture, the highest torque value is obtained and greatly affects the power produced and fuel consumption in diesel engines. for the best effective power at 1600 RPM with a load of 2000 watts, the best effective power value is 1.495 kW. In the variation of the B15 fuel mixture, the best effective power value is obtained and it is very influential on engine speed which results in increased engine power and results in near perfect combustion so that fuel consumption becomes better because all fuel is almost completely burned to become effective power. while the best Specific Fuel Consumption value is B15 fuel. In B15 fuel, the best SFC value is at 1000 Watt RPM with a 3000 Watt load, the best SFC value is 0.367 gr/kWh. Near-perfect combustion makes fuel consumption better because all fuel is almost completely burned so that it becomes effective power. By looking at these results, Biodiesel can be made even only with simple tools and can produce good fuel for the engine.

REFERENCES

[1] “IMO’s work to cut GHG emissions from ships,” 2023. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx (accessed Apr. 18, 2023).

[2] A. Rahman, R. Richards, P. Dargusch, and D. Wadley, “Pathways to reduce Indonesia’s dependence on oil and achieve longer-term decarbonization,” *Renew. Energy*, vol. 202, no. November 2022, pp. 1305–1323, 2023, doi: 10.1016/j.renene.2022.11.051.

[3] “Mission - About - IEA.” https://www.iea.org/about/mission (accessed Apr. 18, 2023).

[4] X. Chen *et al.*, “Pathway toward carbon-neutral electrical systems in China by mid-century with negative CO2 abatement costs informed by high-resolution modeling,” *Joule*, vol. 5, no. 10, pp. 2715–2741, 2021, doi: 10.1016/j.joule.2021.10.006.

[5] L. L. Sun, H. J. Cui, and Q. S. Ge, “Will China achieve its 2060 carbon neutral commitment from the provincial perspective?,” *Adv. Clim. Chang. Res.*, vol. 13, no. 2, pp. 169–178, 2022, doi: 10.1016/j.accre.2022.02.002.

[6] “Indonesia Oil Reserves, Production and Consumption Statistics - Worldometer.” https://www.worldometers.info/oil/indonesia-oil/ (accessed Apr. 18, 2023).

[7] “Palm Oil Production by Country in 1000 MT - Country Rankings.”https://www.indexmundi.com/agriculture/?commodity=palm-oil (accessed Apr. 18, 2023).

[8] A. Rifin, Feryanto, Herawati, and Harianto,“Assessing the impact of limiting Indonesian palm oil exports to the European Union,” *J. Econ. Struct.*, vol. 9, no. 1, 2020, doi: 10.1186/s40008-020-00202-8.

[9] I. A. Rum, A. Tukker, A. de Koning, and A. A. Yusuf, “Impact assessment of the EU import ban on Indonesian palm oil: Using environmental extended multi-scale MRIO,” *Sci. Total Environ.*, vol. 853, no. September, p. 158695, 2022, doi: 10.1016/j.scitotenv.2022.158695.

[10] “The Biodiesel Program of Indonesia; B35 Scheduled to Be Imposed on 1 February 2023 | Indonesia Investments.” https://www.indonesia-investments.com/news/todays-headlines/the-biodiesel-program-of-indonesia-b35-scheduled-to-be-imposed-on-1-february-2023/item9591 (accessed Apr. 18, 2023).

[11] S. S. Suardi, “Analisa Penggunaan Biodiesel Minyak Jagung Sebagai Campuran Bahan Bakar Alternatif Mesin Diesel,” *Inovtek Polbeng*, vol. 9, no. 2, p. 280, 2019, doi: 10.35314/ip.v9i2.1041.

[12] Suardi, M. Purwanto, A. Y. Kyaw, W. Setiawan, and M. U. Pawara, “Biodiesel Production from POME (Palm Oil Mill Effluent) and Effects on Diesel Engine Perfor- mance,” *Int. J. Mar. Eng. Innov. Res.*, vol. 7, no. 4, pp. 292–299, 2022, doi: 10.12962/j25481479.v7i4.14492.

[13] S. Semin, B. Cahyono, F. M. Muhammad, and B. Barokah, “The Effect of Heating of B20 Fuel to Combustion Characteristic on the Diesel Engine Based on Experiment,” *Int. J. Mar. Eng. Innov. Res.*, vol. 5, no. 1, 2020, doi: 10.12962/j25481479.v4i4.5654.

[14] “Kemenperin: Rata-rata Penyaluran Minyak Goreng Curah Bertambah Sebesar 800 Ton/Hari di Maret – April 2022,” 2022. https://kemenperin.go.id/artikel/23239/Rata-rata-Penyaluran-Minyak-Goreng-Curah-Bertambah-Sebesar-800-TonHari-di-Maret-—-April-2022 (accessed Apr. 18, 2023).

[15] Humas EBTKE, “Direktorat Jenderal EBTKE - Kementerian ESDM,”2022.https://ebtke.esdm.go.id/post/2020/12/07/2725/minyak.jelantah.sebuah.potensi.bisnis.energi.yang.menjanjikan?lang=en (accessed Apr. 18, 2023).

[16] “Transesterification - SRS BiodieselSRS Biodiesel.” https://www.srsbiodiesel.com/technologies/transesterification/ (accessed Apr. 18, 2023).

[17] P. Balikpapan, “Petrolab - laboratory independent,” 2023. https://petrolab.co.id/about-us/ (accessed Apr. 19, 2023).

[18] W. S. Suardi, Muhdar Tasrief, Samsu Dlukha Nurcholik, Amalia Ika Wulandari, “Testing the Inclination of an Industrial Diesel Engine Under Static Conditions According to the International Convention for the Safety of Life at,” *Int. J. Mar. Eng. Innov. Res.*, vol. 8, no. 1, pp. 8–15, 2023, doi: http://dx.doi.org/10.12962/j25481479.v8i1.15749.

[19] V. S., J. E., A. E. Kabeel, B. R., R. Sathyamurthy, and B. Madhu, “Multi-intractable analysis for alternative Diesel–Ethanol–Canola methyl ester ternary blend,” *Energy Reports*, vol. 8, pp. 455–462, 2022, doi: 10.1016/j.egyr.2021.11.051.

[20] A. Z. Abdullah, N. Ghazali, P. Y. Hoo, and N. I. Basir, “Selective glycerol esterification to monolaurate over ZrO2/MCM-41 catalysts prepared using impregnation and precipitation methods,” *Chem. Eng. Commun.*, vol. 209, no. 5, pp. 607–622, 2022, doi: 10.1080/00986445.2021.1881778.

[21] Suardi, Wira Setiawan, Andi Mursid Nugraha Arifuddin, Alamsyah, Rodlian jamal Ikhwani “Evaluation of Diesel Engine Performance Using Biodiesel from Cooking Oil Waste (WCO),” *J. Ris. Teknol. Pencegah. Pencemaran Ind.*, vol. 14, no. 1, pp. 29–39, 2023, doi: https://doi.org/10.21771/jrtppi.2023.v14.no1.p29-39.