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Research Article

The Potential of Waste Cooking Oil B20 Biodiesel Fuel with Lemon Essential Oil Bioadditive: Physicochemical Properties, Molecular Bonding, and Fuel Consumption

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Abstract

This study is motivated by the depletion of fossil fuels in nature, which is inversely proportional to the higher level of fuel oil consumption, so the need for alternative fuels, namely biodiesel. Biodiesel can be made using waste cooking oil because of its abundant quantity, low price, and not being reused. One of the efforts to achieve energy conservation and improve fuel quality is using bioadditives. A lemon essential oil can be used as a bio-additive because it is easily soluble in fuel and its oxygen-rich content can reduce the rate of fuel consumption. The process in this study is to produce biodiesel with waste cooking oil (WCO) using a transesterification process. Biodiesel samples containing the bioadditive lemon essential oil on B20 biodiesel with varying volume fraction (0%; 0.1%; 0.15%; 0.2%). In general, this research can be done in three steps. The first step is the characterization of the compound composition (GCMS) and functional group (FTIR) of diesel fuel, biodiesel, and lemon essential oil bioadditive. The second step is the characterization of the physicochemical properties (density, viscosity, flash point, calorific value) of B20 biodiesel with various concentrations of lemon essential oil bioadditive, then compared with SNI 7182:2015. The third step is determining the rate of fuel consumption in diesel engines. The results show that Biodiesel B20 with a volume fraction of 2% lemon essential oil bioadditive has a high ability to reduce the rate of fuel consumption.

Keywords: Biodiesel; Waste Cooking Oil; Lemon Essential Oil; Physicochemical Properties; Specific Fuel Consumption

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1. Introduction

In recent years, renewable energy sources have to be initiated and developed. Serious threats can arise if dependence on fossil energy is unavoidable, namely depletion of petroleum reserves, prices due to greater demand from oil production, and an increase in global warming due to air pollution resulting from burning fossil fuels [1]. The government has imposed strict regulations on exhaust emission regulations and

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encouraged researchers to seek renewable fuel sources. There are several renewable alternative fuels that were slightly selected in this research topic, namely biodiesel [2]. Biodiesel can be used as an alternative fuel, because it has a physical and chemical composition that is not too different from diesel fuel, and also has a high level of environmental friendliness compared to fossil fuels [3,4]. Biodiesel is a methyl ester fatty acid, where the biodiesel used comes from vegetable oil or animal fat which is made through esterification and transesterification processes [5,6]. Palm oil biodiesel has a high viscosity value, low heating value with a higher amount than essential oils [7].

The abundance of palm oil production in Indonesia has enticed researchers to convert it into biodiesel, a diesel oil substitute. The disadvantage of using biodiesel is that it meets the government's B20 standard, which means that fuel consumption and emissions are still high. One of the efforts made to reduce exhaust gas emissions or pollution produced by petroleum-fueled engines is by making the combustion reaction more complete by enriching the amount of oxygen in the fuel by adding oxygen-rich additives that can be dispersed in the fuel [9]. One good and environmentally friendly alternative to additives is to use essential oils [10].

Essential oil is a renewable resource that is still rarely researched. This oil is made from natural ingredients used in fragrance production [11]. Because it is volatile and has a low boiling point, this essential oil can be used as a raw material for biodiesel bioadditive. Furthermore, essential oils are highly content in oxygen and have the same chemical properties as gasoline, namely carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). The primary goal of using bioaditive essential oils is to increase the oxygen content in the gasoline, as essential oils contain a large number of oxygen atoms capable of perfecting combustion in the combustion engine [12,13]. The purpose of this study is to see whether lemon essential oil can be used as a bioadditive in biodiesel fuel (B20) to minimize exhaust emissions from the combustion process. The purpose of this study is focused on investigating the potential of lemon essential oil as a bioadditive for biodiesel fuel (B20) to reduce the rate of fuel consumption in diesel engines [14,15].

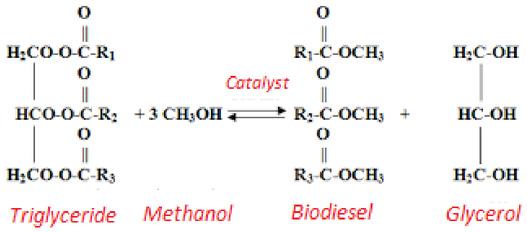
2. Materials and Methods

2.1 Biodiesel Production Process

The material used in this study is B20 biodiesel with a variation of lemon essential oil bio additive as much as 0%, 0.1%, 0.15%, and 0.2%. Esterification and trans esterification are two chemical reactions used in the production of biodiesel. To minimize the amount of FFA in waste cooking oil (WCO), esterification was used. Waste cooking oil (WCO) is reacted with methanol at a ratio of 1:6 at 60 °C with a 1% wt H_2SO_4 catalyst, and then stirred for 120 minutes with a magnetic stirrer. The conversion of fatty acids to esters is called esterification. It is a popular method for producing biodiesel from oil that contains a lot of free fatty acids (acid content more than 2%).The esterification reaction is shown in Equation (1) [26]:

$$\underset{\text{Fatty Acid}}{RCOOR} + \underset{\text{Alcohol}}{ROH} \rightarrow \underset{\text{Ester}}{RCOOR} + \underset{\text{Water}}{H_2O} \qquad (1)$$

The transesterification process for making biodiesel is continued after the FFA level is reduced to less than 2%. With the aid of a KOH catalyst 1.5 wt% at 60 °C for 120 minutes, a reaction between waste cooking oil (WCO) and methanol (1: 6) occurs during the trans esterification process. After that, a 24-hour precipitation process is used to isolate biodiesel from glycerol, which is the end product of the process. Furthermore, biodiesel was washed with distilled water three times or more until the distilled water was clear. Biodiesel was then heated at about 100 °C to remove water content [16]. Furthermore, biodiesel is washed three or more times with distilled water until the distilled water was clear. The biodiesel is then heated to around 100 °C to eliminate any remaining water [16]. Transesterification is the process of converting triglycerides (vegetable oils) into alkyl esters and glycerol by reacting them with an alcohol. The trans esterification reaction is shown in Equation (2) [28].



$$\underset{\text{Triglyceride}}{\begin{array}{l} H_2CO\text{-}O\text{-}\overset{O}{\overset{\|}{C}}\text{-}R_1 \\ HCO\text{-}O\text{-}\overset{O}{\overset{\|}{C}}\text{-}R_2 \\ H_2CO\text{-}O\text{-}\overset{O}{\overset{\|}{C}}\text{-}R_3 \end{array}} + \underset{\text{Methanol}}{3\,CH_3OH} \xrightleftharpoons{\text{Catalyst}} \underset{\text{Biodiesel}}{\begin{array}{l} R_1\text{-}\overset{O}{\overset{\|}{C}}\text{-}OCH_3 \\ R_2\text{-}\overset{O}{\overset{\|}{C}}\text{-}OCH_3 \\ R_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}OCH_3 \end{array}} + \underset{\text{Glycerol}}{\begin{array}{l} H_2C\text{-}OH \\ HC\text{-}OH \\ H_2C\text{-}OH \end{array}} \qquad (2)$$

Mixing biodiesel and diesel fuel is the next step. A magnetic stirrer is used to mix a 20% waste cooking oil (WCO) biodiesel and an 80 percent diesel fuel mixture for 30 minutes, after which the finished B20 is added with bio additive essential oil. To avoid hazards to the chemical properties of the fuel and fuel components, the process of adding B20 to essential oil uses an Ultrasonic Homogenizer (KG-MT-UPDHM-3N) set at a 50% amplitude and 0.5 cycles for 2 minutes. The mixing phase should take no longer than two minutes to prevent harmful chemical properties and components. To preserve chemic balance, the temperature is kept between 30 °C and 32 °C.

2.2 Biodiesel Analysis

The working parameters, density, viscosity, flash point, heating value, GC-MS and FTIR analyses were all determined as physicochemical properties [18,19]. Shimadzu's QP-2010 Plus was used for the GC-MS analysis. Fourier-transform infrared spectroscopy (FTIR) (FTIR model, IRPrestige-21, Shimadzu) at a wavelength of 500–4000 cm was used to find the functional groups and bonds. Density tests were carried out by weighing up to 50 mL of biodiesel in an analytical balance at a temperature of 40 °C. The mass that has been obtained is substituted into Equation (3) [20].

$$\rho = \frac{m}{V} \quad \left({}^{kg}\!/_{L} \right) \tag{3}$$

The NDJ-8S viscometer was used in the ASTM D2196 viscosity test. At a temperature of 40 °C, the samples were poured into a 300 ml beaker glass. The data obtained in the form of dynamic viscosity is then converted to kinematic viscosity using Equation (4) [21].

$$\nu = \frac{\mu}{\rho} \quad \left({}^{cP}\!/_{kg/L} \right) \tag{4}$$

Meanwhile, the flash point test used the Flash Point Tester SYD-3536 using the ASTM D93 method. The HHV value was obtained by using the XRY-1A Bomb Calorimeter using the ASTM D240 method. After the HHV value was obtained, it is substituted in Equation (5) with the latent heat of water vaporization value of 3.052 MJ/kg [22].

$$LHV\,(\frac{MJ}{kg}) = HHV - 3.052 \tag{5}$$

Table 1. The composition of fatty acid methyl ester (FAME) in biodiesel from WCO.

Component	Composition (%)
Oleic acid methyl ester	42.6
Palmitic acid methyl ester	42.25
Linoleic acid methyl ester	7.12
Stearic acid methyl ester	6.12
Myristic acid methyl ester	0.99

Testing on a diesel engine (compression-ignition engine) requires 3 liters of each fuel to be tested. The Mazda R2 4 Cylinder 2184 cc diesel engine is used to test the rate of fuel consumption with variations in engine speed (1700; 1900; 2100 and 2300 rpm).

3. Results and Discussion

3.1 GC-MS Analysis

Gas chromatography-mass spectrometry is used to examine the composition of the WCO biodiesel sample (GC-MS). Figure 1 shows the total ion chromatogram portion of WCO biodiesel. Table 1 shows the results of the GC-MS study of WCO biodiesel components, where only the composition presented is greater than 1%. The components used in biodiesel are made of five free fatty acid methyl esters, with oleic acid methyl esters having the highest composition, according to GC-MS analysis. Biodiesel consists of 97% methyl ester consisting of palmitic acid methyl ester, linoleic acid methyl ester, oleic acid methyl ester, stearic acid methyl ester, and myristic acid methyl ester. It can be inferred that the fatty acid methyl ester composition of WCO biodiesel is nearly identical to the fatty acid methyl ester composition of palm oil, which is WCO's main ingredient. The emissions of CO and HC from oleic acid methyl ester are smaller than those from diesel [17].

D-Limonene has the highest peak area of 37.21 percent in the lemon essential oil sample shown in Figure 1, followed by I-Beta-Pinene with a peak area of 16.06%, Terpinene with a peak area of 10.79%, Triacetin with a peak area of 10.32%, Alpha-Pinene with a peak area of 3.76%, Beta-Phellandrene with a peak area of 3.45%, and other. One of the causes of total combustion is the presence of oxygen in the compound. The specific fuel consumption will decrease after complete combustion [18].

Carbon (C), hydrogen (H), and oxygen (O) are the most common elements found in essential oils (O). Resins and waxes, which are non-volatile elements, are found in limited quantities in essential oils. The chemical structure and elements of lemon essential oil are shown in Table 2. Hydrocarbons (oxygenated terpenes) and oxygenated hydrocarbons (oxygenated terpenes) make up lemon essential oil. In general, essential oils containing oxygenated terpenes are more soluble than those containing terpenes, for example triacetin, citral, linalool, alpha terpineol, *etc*. The higher the terpene content, the lower the solubility or the more difficult it is to dissolve, because non-

Table 2. The test result of GCMS of Lemon Essential Oil.

Peak No	Retention Time	Compound Name	Molecular Formula	Molecular Weight	Peak Area (%)
1	3.161	Methyl Isobutyl Ketone	$C_6H_{12}O$	100	0.04
2	3.308	4-Penten-2-one, 4-methyl	$C_6H_{10}O$	98	0.02
3	3.475	Heptane, 2-methyl	C_8H_{18}	114	0.02
4	3.556	Toluene	C_7H_8	92	1.15
5	3.714	Cyclohexane, 1,3-dimethyl	C_8H_{16}	112	0.03
6	4.026	3-Penten-2-one, 4-methyl	$C_6H_{10}O$	98	1.19
7	4.819	2-Pentanone, 4-hydroxy-4-methyl	$C_6H_{12}O_2$	116	0.35
8	6.609	Alpha-Phellandrene	$C_{10}H_{16}$	136	0.16
9	6.772	Alpha-Pinene	$C_{10}H_{16}$	136	3.76
10	7.113	Camphene	$C_{10}H_{16}$	136	0.08
11	7.656	Beta-Phellandrene	$C_{10}H_{16}$	136	3.45
12	7.746	I-Beta-Pinene	$C_{10}H_{16}$	136	16.06
13	8.007	Beta-Myrcene	$C_{10}H_{16}$	136	1.55
14	8.277	Octanal	$C_8H_{16}O$	128	0.08
15	8.338	Alpha-Phellandrene	$C_{10}H_{16}$	136	0.33
16	8.476	3-Carene	$C_{10}H_{16}$	136	0.11
17	8.612	1,3-Cyclohexadiene, 1- methyl-4-(1-methylethyl)	$C_{10}H_{16}$	136	0.28
18	8.793	o-Cymene	$C_{10}H_{14}$	134	1.79
19	8.923	D-Limonene	$C_{10}H_{16}$	136	37.21
20	9.048	Alpha-Pinene	$C_{10}H_{16}$	136	0.04
21	9.285	Beta-Ocimene	$C_{10}H_{16}$	136	0.09
22	9.559	Gamma-Terpinene	$C_{10}H_{16}$	136	10.79
23	9.764	Octyl chloroformate	$C_9H_{17}ClO_2$	192	0.04
24	9.870	6-Nonynoic acid, mehyl ester	$C_{10}H_{16}O_2$	168	0.02
25	10.216	Cyclohexene, 3-methyl-6-(1-methylethylidene)	$C_{10}H_{16}$	136	0.59
26	10.418	Linalool	$C_{10}H_{18}O$	154	0.32
27	10.525	Acetic acid, trichloro-, heptyl ester	$C_9H_{15}Cl_3O_2$	260	0.03
28	11.208	Limonene oxide, trans	$C_{10}H_{16}O$	152	0.13
29	11.300	Limonene oxide, trans	$C_{10}H_{16}O$	152	0.08
30	11.461	Oxirane, 2-(hexyn-1-yl)-3-methoxymethylene	$C_{10}H_{14}O_2$	166	0.04
31	11.892	(3E,5E)-2,3-Dimethylocta-3,5,7-trien-2-ol	$C_{10}H_{16}O$	152	0.03
32	12.158	Terpinen-4-ol	$C_{10}H_{18}O$	154	0.05
33	12.426	Alpha-Terpineol	$C_{10}H_{18}O$	154	0.05
34	13.422	Neral	$C_{10}H_{16}O$	152	1.31
35	13.533	Carvone	$C_{10}H_{14}O$	150	0.01
36	13.665	Butanoic acid, 3-methyl-, 1-ethenyl-1,5-dimethyl-4- hexenyl ester	$C_{15}H_{26}O_2$	238	0.04
37	14.003	Citral	$C_{10}H_{16}O$	152	1.88
38	15.501	Triacetin	$C_9H_{14}O_6$	218	10.32
39	15.772	(Z)-3,7-Dimethyl-2,6-octadienyl heptanoate	$C_{17}H_{30}O_2$	266	0.43
40	16.125	4-Hexen-1-ol, 5-methyl-2- (1-methylethenyl)-, acetate	$C_{12}H_{20}O_2$	196	0.33
41	17.037	Caryophyllene	$C_{15}H_{24}$	204	0.34
42	17.267	Trans-Alpha-Bergamotene	$C_{15}H_{24}$	204	0.09
43	17.627	(E)-Beta-Famesene	$C_{15}H_{24}$	204	0.02
44	18.792	Spiro[2,4]heptane, 1,5-dimethyl-6-methylene	$C10H_{16}$	136	0.01
45	18.967	Beta-Bisabolene	$C_{15}H_{24}$	204	0.15
46	19.784	Beta-Ocimene	$C_{10}H_{16}$	136	0.06
47	28.200	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	270	1.38
48	31.453	9,12-Octadecadienoic acid (Z,Z)-methyl ester	$C_{19}H_{34}O_2$	294	0.36
49	31.561	9-Octadeccnoic acid, methyl ester, (E)	$C_{19}H_{36}O_2$	296	3.00
50	32.024	Methyl stearate	$C_{19}H_{38}O_2$	298	0.30

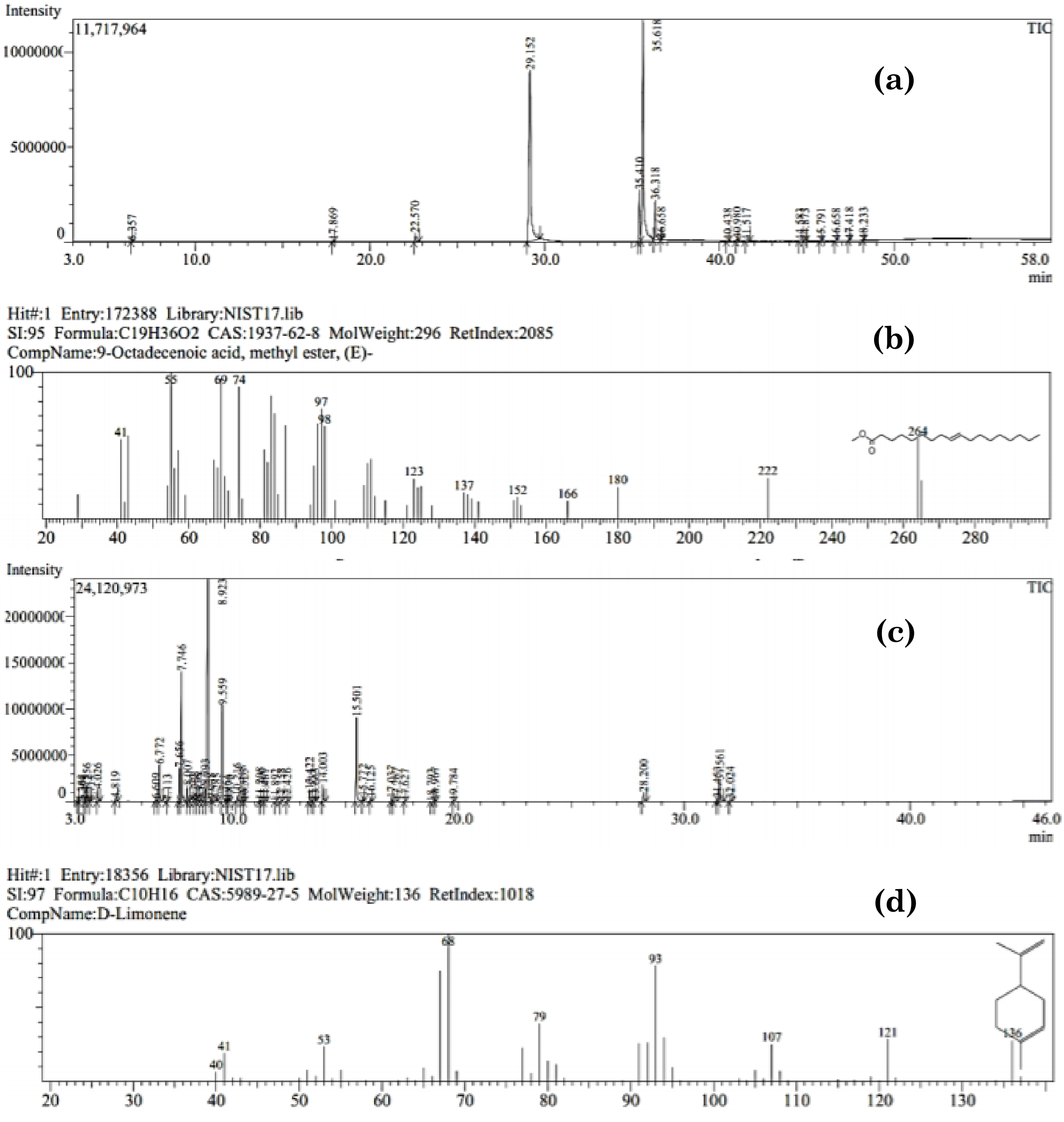


Figure 1. (a) Chromatogram result of Biodiesel WCO, (b) mass spectrum of Biodiesel WCO, (c) Chromatogram result of Lemon Essential Oil and (d) mass spectrum of Lemon Essential Oil.

Table 3. Physicochemical properties of biodiesel compared with diesel oil.

Properties	SNI 7182:2015	Diesel Oil	B100	B20	B20+0.1%	B20+0.15%	B20+0.20%
Density (kg/L)	850-890	0.830	0.893	0.839	0.838	0.837	0.836
Flash Point (°C)	130	72	176	104	102.33	102	98.33
Low Heating Value (MJ/kg)	-	47.108	42.835	38.280	38.949	40.149	40.592
Viscosity (cSt)	2.3-6	5.720	5.648	5.565	5.525	5.453	5.418

oxygenated terpenes are nonpolar compounds that do not have a functional group.

3.2 Density

Table 3 shows the comparison of the physicochemical values of biodiesel properties (B100) with diesel oil. Figure 2 shows the density in each sample. The highest density was in the B20 sample of 0.8392 kg/L and the lowest was the B20 biodiesel sample with 0.2% additive of 0.8367 kg/L. Density decreases as the concentration of lemon essential oil increases because the density of lemon essential oil is lower than B20, the mixture will have a lower density [15]. Density decreases with increasing concentration of lemon essential oil. The decrease in density was caused by the lower density of lemon essential oil compared to biodiesel B20. Density is related to heating value. The lower the density, the higher the heating value. Density affects fuel injection in the combustion chamber, including affecting the initial injection, injection pressure, and fuel injection characteristics related to combustion and exhaust gas emissions. Lower density causes better fuel injection. The better the fuel injection system, the more powerful the diesel engine and the lower the fuel consumption [19].

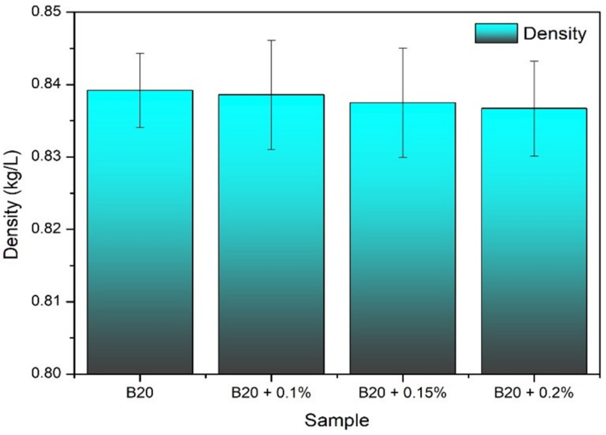


Figure 2. Density of each biodiesel sample.

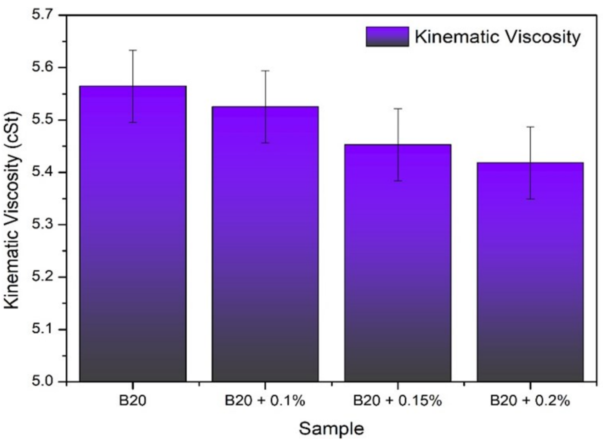


Figure 3. Kinematic viscosity of each biodiesel sample.

3.3 Viscosity

Figure 3 shows the viscosity of each sample. The highest viscosity was in the B20 sample of 5.565 cSt and the lowest was the B20 sample with 0.2% additive of 5.418 cSt. The viscosity decreases because lemon essential oil has a lower viscosity of 1.06 cSt. The mixture of biodiesel and lemon essential oil has a lower kinematic viscosity [23]. The viscosity of each sample is depicted in Figure 3. The B20 sample has the highest viscosity of 5.565 cSt, while the B20 sample with 0.2% additive has the lowest viscosity of 5.418 cSt. Since lemon essential oil has a lower viscosity of 1.06 cSt, the viscosity decreases. The mixture of biodiesel and lemon essential oil has a lower kinematic viscosity [23].

3.4 Flash Point

Figure 4 shows the flash point in each sample. The highest flash point is 104 °C in the B20 sample, and the lowest is 98.33 °C in the B20 sample with a 0.2% additive. With rising concentrations of lemon essential oil, the flash point drops. The flash point of lemon essential oil is 48 °C [24]. The flash point of a mixture of biodiesel and lemon essential oil is lower [6]. The bioadditive's catalytic cracking effect causes the fuel hydrocarbon molecules to break down into smaller particles, lowering the flash point. The flash point rises in proportion to the density. The viscosity of a substance affects its flash point. The lower the viscosity, the lower the flash point, and the lower the viscosity and flash point values, the simpler it is to burn the fuel, resulting in stronger combustion in the

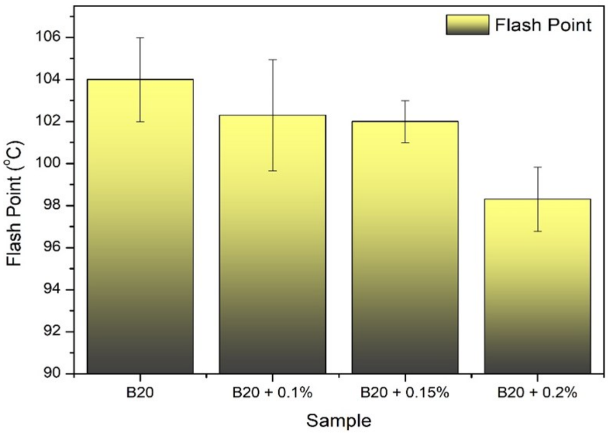


Figure 4. Flash point of each biodiesel sample.

combustion chamber. As a result, it can improve the performance of the diesel engine. The low flash point value causes a decrease in ignition delay and an increase in combustion characteristics [24].

3.5 Heating Value

The heating value in each sample is shown in Figure 5. The highest Lower Heating Value (LHV) was 40.594 MJ/kg in the B20 sample with 0.2% lemon essential oil additive, and the lowest was 38.276 MJ/kg in the B20 sample. With increasing concentrations of lemon essential oil, the heating value increases [6]. The heating value is proportional to the sample density. The heating value is higher due to the sample's low density [25]. The heating value is proportional to the sample density. The calorific value is higher due to the sample's low density. Higher energy density is caused by a higher calorific value. The higher the energy density, the more propulsion energy is produced (propulsion). The higher the calorific value, the better the diesel engine's output and the less fuel it consumes. Transportation, fuel storage, and engine power are all affected by calorific value. A diesel engine's power can be increased by using fuel with a high heating value. Fuel spray and atomization are caused by low fuel calorific value [25].

3.6 Fourier Transform Infrared Spectrometry Analysis (FTIR)

The functional groups of compounds in the samples of Biodiesel B100, diesel D100, and lemon essential oil are known after the FTIR or Fourier Transform Infrared test as shown in Figure 6. FTIR is an analytical method that can be used to determine the functional groups of a compound by recording the residue spectrum with energy absorption by organic molecules in the infrared [26,27]. Biodiesel B100 which has been transesterified was analyzed using the FTIR instrument to prove that a methyl ester functional group will be formed [28].

The FTIR spectrum of the B100 biodiesel sample showed the highest peak in the absorption area of 2924.09 cm^{-1}. The absorption areas 2924.09 and 2854.65 cm^{-1} are the C−H (Alkane) functional groups. Alkanes are a source of fuel compounds because alkanes can only occur in two reactions, namely combustion and halogenation. Alkanes are related to the quality of combustion, alkanes will be degraded to CO_2 and H_2O when complete combustion occurs. Alkanes become CO or soot due to lack of oxygen so that incomplete combustion occurs [29]. In addition to alkanes, alkenes are also components that can be found in petroleum [30]. The absorption area of 1743.65 cm^{-1} is the C=O (Carbonyl) functional group. The absorption area of 1463.97−1435.04 cm^{-1} is a C=C (Aromatic) functional group. The absorption area of 1361.74 cm^{-1} is the C−H (Alkane) functional group. The absorption area 1246.02−1170.79 cm^{-1} is the C−O (Ether) functional group. Biodiesel B100 has typical functional groups of methyl esters, namely C−O, C=O, and C=C. Esters are one of the carbonyl compounds. The functional groups produced include methyl, ester, carbonyl groups, *etc.* [31]. Biodiesel has the same functional groups as diesel D100, namely ether, aromatic, carbonyl, and alkane so that biodiesel can be used as a substitute for diesel fuel.

The FTIR spectrum of the D100 diesel sample showed the highest peak in the

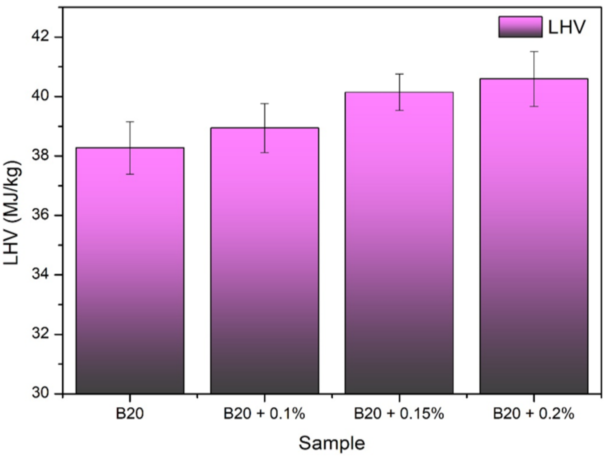


Figure 5. Lower heating value of each sample.

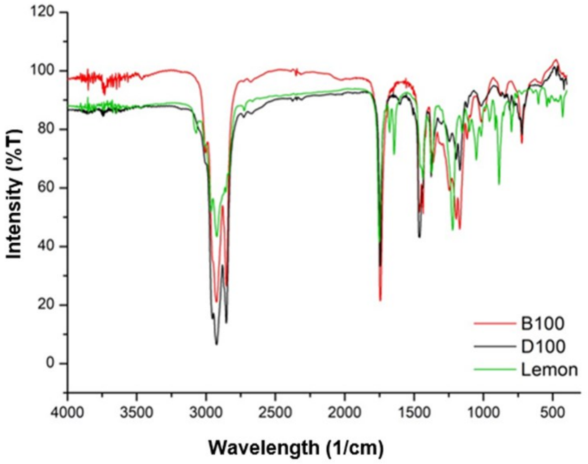


Figure 6. FTIR Spectrometry of Biodiesel, Diesel and Lemon Essential Oil.

absorption area of 2954.95 cm^{-1}. The absorption area is 2954.95−2854.65 cm^{-1} which is the C−H (Alkane) functional group. Alkanes are flammable compounds that are useful as fuels [32]. The absorption area of 1745.58 cm^{-1} is the C=O (Carbonyl) functional group. The absorption area of 1458.18 and 1436.97 cm^{-1} is the C=C (Aromatic) functional group. Aromatic is a functional group that is widely contained in petroleum [30]. The absorption area of 1377.17 cm^{-1} is the −C−H functional group. The absorption regions of 1195.87 and 1170.79 cm^{-1} are C−O (Ether) functional groups. Ethers are similar to alkanes, ether is a functional group found in combustible materials [31].

The FTIR spectrum of the lemon essential oil sample showed the highest peak in the absorption area of 2964.59 cm^{-1}. The absorption area is 2964.59−2835.36 cm^{-1} which is the C−H functional group. The absorption area of 1751.36 cm^{-1} is the C=O functional group. The absorption area of 1436.97 and 1375.25 cm^{-1} is a −C−H functional group. The absorption regions of 1222.87 and 1051.2 cm^{-1} are C−O functional groups. The absorption area of 887.26 cm^{-1} is a =C−H (Alkene) functional group, alkene functional groups can be found in limonene or limonene compounds [32].

3.7 Brake Specific Fuel Consumption

Figure 7 shows each sample's brake-specific fuel consumption. At 2300 rpm, the maximum specific fuel consumption of 0.268 kg/PS.h is achieved using B20. At 2300 rpm, the lowest specific fuel consumption is 0.202 kg/PS.h when using B20 with a 0.2% lemon essential oil additive. The specific fuel consumption rises as the engine speed rises and the concentration of lemon essential oil decreases. Lower heating value, density, and viscosity are all linked to specific fuel consumption [29]. The frictional power increases as the engine speed rises, resulting in a higher amount of fuel consumed [14]. Lower heating value, higher density, and viscosity are all linked to specific fuel consumption. Because of the higher calorific value, the diesel engine's output improves, resulting in lower fuel consumption. Since the fuel has a low calorific value, it sprays and atomizes poorly during combustion, rising fuel consumption. A higher density of the same volume allows for the use of more fuel, while a higher viscosity affects the volumetric fuel injection rate. Because of the combined impact of these factors, real fuel consumption is reduced.

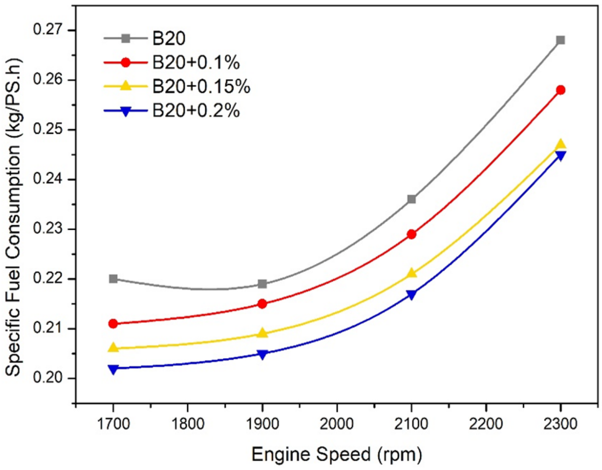


Figure 7. Comparison chart of engine speed and brake specific fuel consumption.

4. Conclusions

The results showed that lemon essential oil had the potential to be used as a bioadditive for biodiesel B20 because all samples met the requirements set by SNI 7431:2015. Biodiesel B20 with 0.2% lemon essential oil bioadditive has better physicochemical properties, where the density, viscosity, flash point, and calorific value of the sample are 0.8367 kg/L; 5.418 cSt; 98.33 °C and 40,594 MJ/kg. Based on testing the rate of fuel consumption on a diesel engine, biodiesel B20 with 0.2% lemon essential oil bioadditive was able to reduce the rate of fuel consumption by 0.201 kg/PS.h at 2300 rpm.

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References

[1] Badan Pengatur Hilir Minyak dan Gas Bumi. (2019). *Citing Internet sources.* URL http://www.bphmigas.go.id/konsumsi-bbm-nasional-per-tahun.

[2] Suharyati, S.H., Pambudi, J.L., Wibowo, N.I., Pratiwi, P. (2019). *Outlook Energi Indonesia 2019.* Jakarta: Sekretaris Jenderal Dewan Energi Nasional.

[3] Lelieveld, J., Klingmüller, K., Pozzer, A., Burnett, R.T., Haines, A., Ramanathan, V. (2019). Effects of fossil fuel and total anthropogenic emission removal on public health and climate. *Proceedings of the National Academy of Sciences of the United States of America*, 116, 7192–7197. DOI: 10.1073/pnas.1819989116.

[4] Huang, Y., Unger, N., Heyes, C. (2020). Global Climate and Human Health Effects of the Gasoline and Diesel Vehicle Fleets. *GeoHealth,* 4, e2019GH000240. DOI: 10.1029/2019GH000240.

[5] Velmurugan, V., Thanikaikarasan, S. (2019). Proceedings Prediction of Exhaust Gas Emission characteristics using Neem oil blended biodiesel in diesel engine. *Materials Today: Proceedings,* 21, 870–875. DOI: 10.1016/j.matpr.2019.07.706.

[6] Rahman, S.M.A., Van, T.C., Hossain, F.M., Jafari, M., Dowell, A., Islam, M.A., Brown, R.J. (2019). Fuel properties and emission characteristics of essential oil blends in a compression ignition engine. *Fuel*, 238, 440–453. DOI: 10.1016/j.fuel.2018.10.136.

[7] De, A., Boxi, S.S. (2020). Application of Cu impregnated TiO2 as a heterogeneous nanocatalyst for the production of biodiesel from palm oil. *Fuel*, 265, 117019. DOI: 10.1016/j.fuel.2020.117019.

[8] Ogunkunle, O., Ahmed, N.A. (2019). A review of global current scenario of biodiesel adoption and combustion in vehicular diesel engines. *Energy Reports*, 5, 1560–1579. DOI: 10.1016/j.egyr.2019.10.028.

[9] Nautiyal, P., Subramanian, K.A., Dastidar, M.G., Kumar, A. (2020). Experimental assessment of performance, combustion and emissions of a compression ignition engine fuelled with Spirulina platensis biodiesel. *Energy*, 193, 116861. DOI: 10.1016/j.energy.2019.116861.

[10] Sun, S., Li, K. (2019). Biodiesel production from phoenix tree seed oil catalyzed by liquid lipozyme TL100L. *Renewable Energy*, 151, 152–160. DOI: 10.1016/j.renene.2019.11.006.

[11] Azahari, D.H. (2018). Sawit Indonesia yang Berkelanjutan, Tantangan dan Kebijakan yang Diperlukan. In Tahlim Sudaryanto (Editor) *Ragam Pemikiran Menjawab Isu Aktual Pertanian.*

[12] Elumalai, P V., Annamalai, K., Dhinesh. B. (2019). Effects of Thermal Barrier Coating on the Performance , Combustion and Emission of DI Diesel Engine Powered by Biofuel Oil – Water Emulsion. *Journal of Thermal Analysis and Calorimetry* 137(2), (2019): 593–605. DOI: 10.1007/s10973-018-7948-6

[13] Venkatesan, H., Sivamani, S., Premkumar, T.M., Tharun, P. (2019). Reduction of exhaust emissions using a nanometallic enriched lemongrass biodiesel blend. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 39 (21), 1-7. DOI: 10.1080/15567036.2017.1395495

[14] Nabi, M.N., Rasul, M.G., Rahman, S.M.A., Dowell, A., Ristovski, Z.D., Brown, R.J. (2019). Study of performance, combustion and emission characteristics of a common rail diesel engine with tea tree oil-diglyme blends. *Energy*, 180, 216–228. DOI: 10.1016/j.energy.2019.05.070.

[15] Gad, M. S., Zhixia, H., El-shafay, A.S., and El-seesy, A.I. (2021). Combustion Characteristics of a Diesel Engine Running with Mandarin Essential Oil -Diesel Mixtures and Propanol Additive under Different Exhaust Gas Recirculation: Experimental Investigation and Numerical Simulation. (2021). *Case Studies in Thermal Engineering*, 26, 1-19. DOI: 10.1016/j.csite.2021.101100

[16] Mofijur, M., Masjuki, H.H., Kalam, M.A., Rasul, M.G., Atabani, A.E., Hazrat, M.A (2015). Effect of Biodiesel-Diesel Blending on Physico-Chemical Properties of Biodiesel produced from Moringa oleifera. *Procedia Engineering*, 105(Icte 2014), 665–669. DOI: 10.1016/j.proeng.2015.05.046.

[17] Othman, M.F., Abdullah, A.A., Kamal, K., Asri, S., Azmi, Z. (2019). Improvement of fuel properties for palm oil methyl ester (POME) biodiesel blends using organic germanium as additives Improvement of fuel properties for palm oil methyl ester (POME) biodiesel blends using organic germanium as additives. *Materials Science and Engineering*, 469, 012121. DOI: 10.1088/1757-899X/469/1/012121.

[18] Firlianda, D.A., Permanasari, A.A., Puspitasari, P. (2019). Heat transfer enhancement using nanofluids ($MnFe_2O_4$-ethylene glycol) in mini heat exchanger shell and tube Heat Transfer Enhancement using Nanofluids ($MnFe_2O_4$-Ethylene Glycol) in Mini Heat Exchanger Shell and Tube. AIP *Conference Proceedings*, 2120, 050014. DOI: 10.1063/1.5115690

[19] Permanasari, A.A., Kuncara, B.S., Puspitasari, P. (2019). Convective heat transfer characteristics of TiO_2-EG nanofluid as coolant fluid in heat exchanger Convective Heat Transfer Characteristics of TiO_2-EG Nanofluid as Coolant Fluid in Heat Exchanger. *AIP Conference Proceedings*, 2120, 50015. DOI: 10.1063/1.5115691

[20] Schaschke, C., Fletcher, I., Glen, N. (2013). Density and Viscosity Measurement of Diesel Fuels at Combined High Pressure and Elevated Temperature. *Processes,* 1(2), 30–48. DOI: 10.3390/pr1020030.

[21] Walz, K.A., Britton, S., Crain, J., Cadwell, K., Hoffman, A., Morschauser, P. (2014). Biodiesel Synthesis, Viscosity, and Quality Control for an Introductory Chemistry Lab. *Chem. Educator*, 19, 342–346. DOI: 10.1333/s00897142586a.

[22] Hoang, T.A., Le, V.V. (2017). The Performance of A Diesel Engine Fueled With Diesel Oil, Biodiesel and Preheated Coconut Oil. *Int. Journal of Renewable Energy Development*, 6(1), 1–7. DOI: 10.14710/ijred.6.1.1-7.

[23] Ashok, B., Karuppa, R.T., Nanthagopal, K., Krishnan, R., Subbarao, R. (2017). Lemon peel oil – A novel renewable alternative energy source for diesel engine. *Energy Conversion and Management*, 139, 110–121. DOI: 10.1016/j.enconman.2017.02.049.

[24] Natural Sourcing. (2015). *Lemon Oil CP, Technical Report*, Natural Sourcing Oxford.

[25] Gülüm, M., Bilgin, A. (2015). Density, flash point and heating value variations of corn oil biodiesel–diesel fuel blends. *Fuel Processing Technology*, 134, 456–464. DOI: 10.1016/j.fuproc.2015.02.026.

[26] Tan, Y.H., Abdullah, M.O., Nolasco-hipolito, C., Syuhada, N., Zauzi, A., Wong, G. (2017). Engine performance and emissions characteristics of a diesel engine fueled with diesel-biodiesel-bioethanol emulsions. *Energy Conversion and Management*, 132, 54–64. DOI: 10.1016/j.enconman.2016.11.013.

[27] Balasubramanian, D., Hoang, A.T., Venugopal, I.E., Shanmugam, A., Gao, J., Wongwuttanasatian, T. (2021). Numerical and Experimental Evaluation on the Pooled Effect of Waste Cooking Oil Biodiesel/Diesel Blends and Exhaust Gas Recirculation in a Twin-Cylinder Diesel Engine. *Fuel*, 287, 1-17. DOI: 10.1016/j.fuel.2020.119815

[28] Muhyi, A., Silitonga, D., Alfian, D. (2019). Performance Characterization of Diesel Engine Generator Set with the addition of clove oil as Bio-Additives for Diesel fuel Performance Characterization of Diesel Engine Generator Set with the addition of clove oil as Bio-Additives for Diesel fuel. *Earth and Environmental Science*, 258, 1–6. DOI: 10.1088/1755-1315/258/1/012009.

[29] Wu, G., Ge, J.C., Choi, N.J. (2020). *A* Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines. *Applied Science*, 10(22), 8015. DOI: 10.3390/app10228015.

[30] Sathiyamoorthi, R., Sankaranarayanan, G., Pitchandi, K. (2017). Combined Effect of Nanoemulsion and EGR on Combustion and Emission Characteristics of Neat Lemongrass Oil (LGO)-DEE-Diesel Blend Fuelled Diesel Engine. *Applied Thermal Engineering*, 112, 1421–1432. DOI: 10.1016/j.applthermaleng.2016.10.179

[31] El-din, M.R.N., Mishrif, M.R., Gad, M.S., Keshawy, M. (2019). Performance and exhaust emissions of a diesel engine using diesel nanoemulsions as alternative fuels. *Egyptian Journal of Petroleum*, 28(2), 197–204. DOI: 10.1016/j.ejpe.2019.03.004.

[32] Kumar, A.R.M., Kannan, M., Nataraj, G. (2020). A study on performance, emission and combustion characteristics of diesel engine powered by nano-emulsion of waste orange peel oil biodiesel. *Renewable Energy*, 146, 1781–1795. DOI: 10.1016/j.renene.2019.06.168.

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