Experimental Study of the Use of Rubber Seeds as Biodiesel Feedstocks; Production Optimization, Characterization and Performance Testing

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Abstract

This study's objective was to create and characterize biodiesel from rubber seeds. Rubber seeds collected from smallholder plantations in the northern Sumatra region of Indonesia are peeled to separate the shell from the kernel. The rubber seed kernels are boiled for 4 hours to boiled to release the sap. The boiled kernels are drained and dried in the sun for two days in sunny weather. Furthermore kernels boiled and dried are pressed with a screw press machine, and RSO (rubber seed oil) is obtained. This RSO is produced into RSB (Rubber Seed Biodiesel) using a double jacket reactor through degumming, esterification, and trans-esterification stages. Biodiesel production is carried out with variations in the ratio of catalysts, temperature, and reaction time. For each of these variables, the yield of biodiesel produced is calculated. Then the biodiesel produced was characterized through psycho-chemical property testing, including calorific value, cetane number, oxidation stability, density, viscosity, acid content, pour point, and flash point. Furthermore, the biodiesel was tested on a diesel engine at several engine speeds to observe its performance and emissions. In biodiesel production, the maximum yield is the catalyst/crude oil ratio = 0.75, the oil/methanol molar ratio = 1:1.25, the reaction temperature is 60 oC and the reaction time is 100 minutes, but the yield increase from 90 minutes to 100 minutes is not significant. RSB meets ASTM biodiesel standards except for oxidation stability, which is 1.2 hours instead of 3 hours. RSB engine performance and exhaust emissions are comparable to biodiesel in general.

Keywords: rubber seed, biodiesel, properties, engine performance

Abstrak

Tujuan penelitian ini adalah untuk memproduksi dan mengkarakterisasi biodiesel dari biji karet. Biji karet yang dikumpulkan dari perkebunan rakyat di wilayah Sumatera Utara, Indonesia dikupas untuk memisahkan kulit dari bijinya. Biji karet direbus selama 4 jam untuk mengeluarkan getahnya. Biji karet yang telah direbus ditiriskan dan dikeringkan di bawah sinar matahari selama dua hari dalam cuaca cerah. Selanjutnya biji karet yang telah direbus dan dikeringkan tersebut dipres dengan mesin pengepres sekrup, dan diperoleh RSO (minyak biji karet). RSO ini diproduksi menjadi RSB (Biodiesel Biji Karet) menggunakan reaktor *Double jacket* melalui tahap degumming, esterifikasi, dan trans-esterifikasi. Produksi biodiesel dilakukan dengan variasi rasio katalis, suhu, dan waktu reaksi. Untuk masing-masing variabel tersebut, rendemen biodiesel yang dihasilkan dihitung. Kemudian biodiesel yang dihasilkan dikarakterisasi melalui pengujian sifat psikakimia, meliputi nilai kalor, angka setana, stabilitas oksidasi, densitas, viskositas, kadar asam, titik tuang, dan titik nyala. Selanjutnya, biodiesel diuji pada mesin diesel pada beberapa putaran mesin untuk mengamati kinerja dan emisinya. Dalam produksi biodiesel, yield maksimum adalah rasio katalis/minyak mentah = 0,75, rasio molar minyak/metanol = 1:1,25, suhu reaksi 60 ^{o}C dan waktu reaksi 100 menit, tetapi peningkatan yield dari 90 menit menjadi 100 menit tidak signifikan. RSB memenuhi standar biodiesel ASTM kecuali untuk stabilitas oksidasi, yaitu 1,2 jam, bukan 3 jam. Kinerja mesin RSB dan emisi gas buang sebanding dengan biodiesel pada umumnya.

Kata kunci: biji karet, biodiesel, sifat, kinerja mesin

1. Introduction

Energy is essential for human life and is the driving factor behind societal growth. As energy consumption increases in many nations and areas, energy security is crucial for all governments' national security [1]. The International Energy Outlook 2016 (IEO2016) estimates that global total energy consumption will increase 48% between 2012 and 2040 [2]. The energy crisis, climate change, and environmental pollution are critical world problems

[3]. It is thought that the peak of standard oil production has been reached and that the peak of natural gas and coal output will be reached soon [4]. The energy crisis has become a serious topic recently and is a concern of research in many nations throughout the globe [5].

At the same time, practically all nations rely on fossil fuels. It was reported by the World Bank (2018) that in 2014, 81% of global energy consumption came from fossil fuels [6]. In the field of transportation and industry, diesel is the most often used fuel [7], because in this industrial era, the usage of high-speed diesel (HSD) in the electrical industry is quickly growing, transportation, agriculture, and other commercial sectors [8], included in the fossil energy group whose reserves are dwindling.

Nearly all nations have enacted particular policies in anticipation of this fossil energy crisis. In Indonesia, for instance, the Indonesian National Energy Policy has begun to convert at least 23% of primary energy consumption to a new and renewable energy blend by 2025 and 31% by 2050 [9]. Converting fossil energy to bioenergy necessitates using fuels with unique physicochemical qualities acceptable for engine operation [10]. Biodiesel is a kind of renewable energy used to replace diesel fuel owing to its physical and chemical features being comparable to diesel fuel [11]. An alternative fuel that is more eco-friendly than diesel is biodiesel. Biodiesel is non-toxic, biodegradable, has lower carbon content, more excellent lubricity, and a higher flash point than diesel. Because of these characteristics, biodiesel is an excellent diesel alternative [5].

Biodiesel from various raw materials has been researched and produced, and its properties are similar to diesel [8]. The new technology in biodiesel production and its superior nature in replacing diesel fuel will allow it to replace 100% fossil fuels in the future [12]. The two biggest obstacles to the manufacture of biodiesel on a wide scale are: (1) deciding on readily available, high-oil non-edible feedstocks; and (2) synthesis methods (chemical or enzymatic) [13], [14].

Different forms of biodiesel feedstock are available in varying amounts in different places; this feedstock will be used to fulfill the growing demand for biodiesel production [15]. However, the qualities of the biodiesel fuel generated are heavily reliant on the feedstock's physicochemical attributes and fatty acid makeup. Each raw material has its benefits and drawbacks [16].

Given the rising awareness and sensitivity to green energy, this condition is a fantastic chance to promote rubber trees as a resource choice for clean manufacturing and sustainable development. The rubber tree's only function recently has been gathering sap. One of the most underutilized but abundant leftovers is the seed of the rubber tree [1].

Rubber seed oil may be used to produce biodiesel [2]. Rubber seed, or Hevea brasiliensis, is a low-cost, non-edible raw material that grows in large numbers in the Amazon. Up to 89.4% of rubber seeds are made up of oil, and about 80.5% of that oil comprises unsaturated fatty acids [3]. Indonesia boasts the world's biggest rubber plantation area [4]. According to the Directorate General of Indonesian Plantations, the size of Indonesian rubber plantations will exceed 3.6 million hectares by 2021 [5].

Table 1. Potential of Vegetable Oil and Biodiesel from Rubber Seed [5], [6], [7].

Region	**Area (hectare)**	**Seed production (tons/year)**	**Crudge oil (tons/year)**	**Biodiesel (tons/year)**
Southeast Asia	7,5 million	11,6 million	5,8 million	5,2 million
Indonesia	3,6 million	5,5 million	2,75 million	2,4 million
Sub-sahara Afrika	717 thousand	107 thousand	17 thousand	16 thousand

As shown in table 1, 77% of the world's natural rubber is produced in Southeast Asian countries, where rubber tree seeds are currently disposed of as biomass waste. Based on the 7.5 million hectares of rubber plantation cultivation in this region, rubber seeds are predicted to yield more than 11.6 million tonnes yearly [6]. It is predicted that 717,750ha of rubber trees in Sub-Saharan Africa/SSA nations can generate 251 million trees each year, 107,662 tonnes of rubber seeds, 17,947,339 tonnes of rubber seed oil, and the equivalent of 16,691,025 tonnes of biodiesel [8].

Because the seed kernel contains 40-50% of the oil, rubber seed oil is A possible feedstock for environmentally friendly manufacturing of biodiesel fuel. Using rubber seed oil (RSO) as raw material for biodiesel production can also reduce biodiesel prices due to bringing down the cost of raw materials If the cost exceeds 80% of total manufacturing costs [6]. Rubber seed oil (RSO) has recently gained much interest since it has not been explicitly utilized and is plentiful in most Asian nations [9]. Among other vegetable oils, rubber seed oil (RSO) has emerged as a feedstock for biodiesel production and, based on several studies, has properties comparable to fossil diesel [10]. Degumming can be used to clean up crude rubber seed oil, and the bleaching process decreases the oil's peroxide value. The dose of bleaching the earth is crucial in cleaning up the oil. The reaction time and phosphoric acid dosage are then given. This technique may reduce the quantity of peroxide in the oil, making it more oxidation-resistant [11]. In Bangladesh, research has been done on rubber seed oil (RSO) as a possible source of biodiesel. Rubber seeds from nearby farms were extracted to make rubber seed oil. Cold percolation and mechanical pressing with and without solvent have been used as oil extraction methods. Mechanically crushing the seeds and regularly using solvents revealed the highest oil concentration at 49% [12].

Table 2. Physico-chemical properties of Rubber seed oil from various references

References	**Density ($g\ cm^{-3}$)**	**Viscosity (cSt)**	**Moisture content (wt%)**	**Acid value (mg KOH/g)**	**Iodine Value (grI_2/100 gr)**	**FFA value (%)**	**Flash Point (ºC)**	**Cloud Point (ºC)**	**Pour point (ºC)**
[13]	0.894	7,54	0.013	10,60	-	5,25	-	-	-
[14]	-	-	-	18,19	142,20	9,648	-	-	-
[15]	0,839	42.91	-	70	118,3		278	16	12
[16]	0,91	13,13	0,27	24	113		273	3	2
[17]	0.886-0.910	40.18-66.20	-	18.20-83.76	118.8-137.02	-	198-240.3	-	-
[18]	0,91	40,86	0,30	83,76	118,8	41,64	-	-	-
[19]	0,869	34	0,23	13,2	72	-	-	-	-
[12]	0,88	33	0,93		132,6	45	-	-	-
[2]	0,885	38,9	-	0,42	-	-	-	-	-
[20]	0,91	40,86	0,37	83,76	118,8	41	-	-	-

With contributions from Indonesia, Malaysia, Thailand, and India, Brazil is the world's top producer of rubber seeds. Brown oil makes up 40–50% of the weight of rubber seed kernels compared to 50–60% of the weight of seeds. When heated to 40 °C, rubber seed oil has a viscosity of 42.54 mm2/s, a density of 917 kg/m3, and a calorific value of 38.64 MJ/kg. [24]. Rubber seed oil is abundant in unsaturated fatty acids such as linolenic acid (16.3%), linoleic acid (39.6%), and oleic acid (24.6%) [21]. The physicochemical properties of rubber seed oil from several references shown in table 2 indicate that the oil can be considered a potential raw material for biodiesel production.

Esterification is one of the most crucial organic synthesis processes. Esters may be found in both natural and manufactured organic molecules. Biofuels such as biodiesel are prime examples of esterification products [22]. In general, biodiesel (mono-alkyl ester) may be made from various oils (edible or inedible) by esterification or transesterification processes with alcohol (methanol, ethanol, or any other alcohol). The raw ingredients for the esterification process are mainly acidic oils, while the transesterification reaction uses base oils. Both reactions occur concurrently in acidic and basic oils-containing feed materials [23]. Transesterification (alcoholysis) is the chemical process that produces mono-esters by combining triglycerides and alcohol in the presence of a catalyst. The transesterification process is made up of three sequential reversible processes. That is, triglycerides are converted to diglycerides, which are then converted to monoglycerides. The glycerides are transformed into glycerol in each step, giving one ester molecule. These esters' characteristics are akin to those of diesel.

From our investigation, there are no researchers who have comprehensively explained the use of rubber seeds as raw material for biodiesel, starting from the methods and procedures for producing crude oil from rubber seeds, followed by the production of biodiesel from crude oil, investigating the properties of biodiesel from rubber seeds to testing the performance of diesel engines using biodiesel. This condition needs to be explained so residents around the rubber plantations can utilize rubber seeds as raw material for biodiesel.

In this paper, we present the work that we have done, starting from collecting rubber seeds from people's gardens, stripping rubber seeds, producing crude oil from rubber seeds using a press that we built ourselves, producing biodiesel from crude oil, and investigating its properties, then testing it in a diesel engine testing installation that we assemble ourselves.

Some of the methods and tools we use will be adopted by researchers and public members who wish to turn rubber seeds into biodiesel.

2. Material and methode

3. 1 Chemicals

All ingredients (dry methanol 99.9%, H3PO4 pellets 85%, sulfuric acid 99.9%) were acquired from a chemical importer business in Medan, North Sumatra, Indonesia, under the Merck Germany brand Emsure.

3. 2 Feedstock treatment

Smallholder farms in Indonesia's Northern Sumatra area are where rubber seeds are harvested (Figure 1a). Additionally, the shell and kernel of the rubber seeds are broken and separated before being peeled. Then the kernel is boiled for 4 hours to release the sap. The boiled kernels are drained and then dried in the sun for two days in sunny weather conditions (figure 1b).

(a) (b)

Figure 1. Rubber seeds (a) before peeling (b) after peeling (kernel)

3. 3 Crude Oil Production

Kernels that have been boiled and dried in the sun are pressed using a screw press machine (figure 2) repeatedly for four cycles to obtain rubber RSO. The crude oil obtained was filtered through a 200 mesh sieve, then deposited for one day to separate the water and latex content. After the sediment is visible at the bottom of the container, the sediment is removed to obtain rubber seed crude oil ready to be produced into biodiesel.

Figure 2. Screw press to extract crude oil from rubber seeds kernel

Picture description
1. Hopper
2. Screw press tube
3. Oil duct gap
4. Dregs channel
5. Electro motor

3. 4 Rubber Seeds Biodiesel (RSB) Production

3. 4.1 Degumming

Degumming, or removing gummy or mucilaginous particles from vegetable oils, is essential for using crude vegetable oils as a feedstock for biodiesel generation [24]. These gums slow transesterification processes by deactivating the catalyst and preventing the glycerol phase from being separated from the biodiesel. They also create carbon particle accumulation inside engine equipment, reducing performance. To address these concerns, gums must be removed from oils before the oils may be used as fuel. Rubber seed crude oil is processed in a double jacket reactor (figure 3) and added H_3PO_4, the temperature of 60 ^oC, stirred at 1000 rpm for 30 minutes, then precipitated for 2 hours.

Figure 3. Double Jacket reactor

3. 4.2 Esterification and Trans-esterification

Several esterification and transesterification reactions were carried out to find the maximum ester yield. These reactions were to investigate the effect of the catalyst ratio, methanol ratio, temperature, and reaction time on the resulting biodiesel yield.

The esterification reaction was carried out at a ratio of catalyst H_2SO_4/oil (%v/v) 0.25%, 0.5%, 0.75%, and 1%. The trans-esterification reaction was carried out at a ratio of methanol KOH (w/v) 1: 1.25, 1:1.5, 1:1.75, and 1:2 (g/ml). The effect of reaction temperature was investigated at temperatures of 50 ºC, 60 ºC, 70 ºC, and 80 ºC. At the same time, the effect of reaction time was investigated at 70, 80, 90, and 100 minutes.

Each variation of the catalyst ratio, temperature, and reaction time is calculated as the yield of biodiesel produced, and biodiesel yield was calculated using the following formula (Eq. (1)), the results are shown in figure 5.

$$Yield\ (\%) = \frac{volume\ of\ biodiesel\ (l)}{volume\ of\ Crude\ oil\ (l)}\ x\ 100\% \qquad (1)$$

3. 5 Biodiesel Psychochemical Properties Test

The biodiesel that has been produced is then tested for its physicochemical properties using standard ASTM procedures. Kinematic viscosity test using ASTM D7042, density testing using ASTM D4052, oxidation stability test using ASTM D7525, acid number testing using ASTM D664, Iodine number test using ASTM D664, Flash point testing using ASTM D93-20.

3. 6 Diesel Engine Performance and Emission

As shown in figure 4, a trial tool for testing diesel engines has been created to do this study. This tool is made up of a small CI engine unit, a Synchronous Generators Single Phase AC 3 KW, a series of lamps/200 watts as a load, a measuring pipette used as a fuel container so that fuel consumption can be measured, a tacho meter NJK-5002C for measuring engine speed and a Flue Gas Analyzer E-4500 S for measuring exhaust emissions.

It is a single-cylinder, four-stroke diesel CI engine. The CI machine's maximum output power and weight are 4.86 W and 65 kg, respectively. Local farmers in Indonesia often utilize this kind of CI equipment for agricultural jobs like running micro tractors or maize seed shellers.

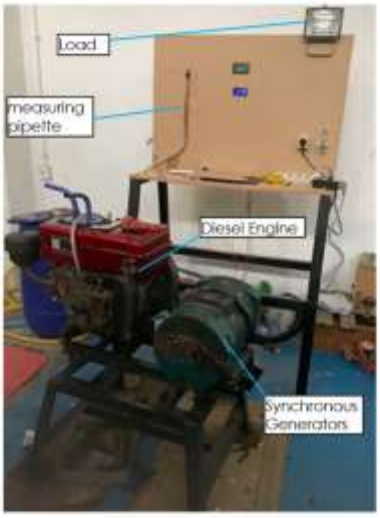

Figure 4. Engine Performance Testing Scheme

The engine was tested in two modes of operation: diesel fuel and diesel-biodiesel mixed fuel. The CI engine is connected to a single-phase synchronous generator using pulleys and a belt. The following are the generator specs. The maximum power, rating frequency, and voltage are 50/60 Hz, 115-230 V, and three kVA, respectively. The generator's energy will power bulbs that can function at 200 W and multiple loads. The CI engine is tested at various speeds in each fuel mode, evaluating fuel consumption, torque, power output, and exhaust pollutants.

Table 3. Specification of the CI engine

No.	Parameter	Value
1	Commercial name/model	Dong Feng Diesel Engine R 175 A
2	Number of cylinder/stroke	Single-cylinder/4 strokes and Horizontal
3	Cooling system	Water cooled
4	Bore × Stroke	75 mm × 80 mm
5	Maximum output	4.86 kW
6	Rated output	4.41 kW
7	Rated speed	2600 rpm
8	Engine weight	65 kg
9	Compression ratio	23:1

3. Results and discussion

3.1 Biodiesel Yield

One mole triglyceride and three moles of methyl alcohol are required for the typical stoichiometric transesterification process [25]. This results in three moles of fatty acid methyl esters and one mole of glycerol. However, achieving an ideal transesterification, i.e., a 3:1 ratio, is only sometimes attainable since glycerol and soap production yield vary with the quantity of FFAs, and conversion is only sometimes flawless [26]. Figure 5 results from several experiments to get the most significant RSB yield from 1 liter of RSO use equation 1. It is found in figure 5 (a) that the maximum yield (85%) is obtained when using a catalyst/crude oil of 0.75. Figure 5 (b) explains that the greater the molar ratio of oil: to methanol, the more significant the yield. However, this experiment needs to be continued to find a point optimally. The maximum yield (85%) is also achieved at a reaction temperature of 60 oC, the yield also increases with increasing reaction time, but from 90 minutes to 100 minutes, the increase gets smaller.

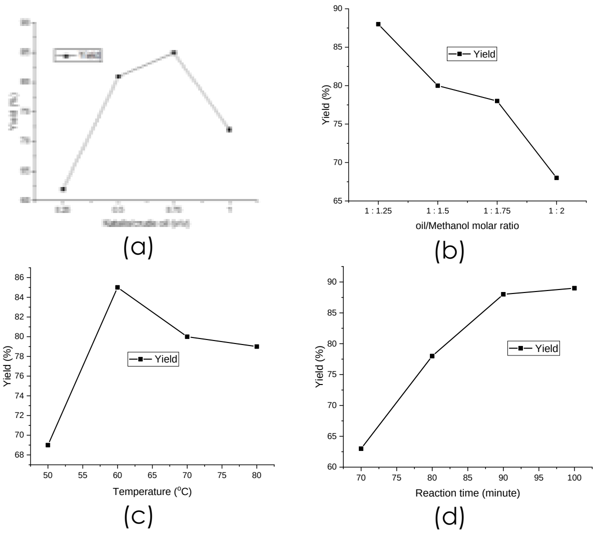

Figure 5. Effect of (a) catalyst amount, (b) oil/methanol molar ratio, (c) reaction temperature, and (d) reaction time on biodiesel yield

3. 2 Psychochemical Properties of Biodiesel

The qualities of biodiesel generated from rubber seeds have been tested; the ASTM protocol performed all experiments. The results of testing the properties of biodiesel seed rubber are compared with the properties of ASTM standard biodiesel and diesel oil (table 4). Almost all of the properties meet ASTM standards, except for the acid value of 0.53 mg KOH/g, which is 0.03 mg KOH/g higher, whereas according to [27] in the ASTM D6751-D 664 standard, the maximum acid value is 0.5 mg KOH/g.

Table 4. Psychochemical properties Rubber seed biodiesel, biodiesel ASTM and Petroleum diesel

Psychochemical properties	**Test method**	**RSB in this work**	**Biodiesel ASTM** (16), (27,28)	**Diesel** (29), (16)
Heating value (J/g)	ASTM D-4809-06	39,953	37,270	45,620 to 46,480
Cethane Index	ASTM D-976/D-2699	56.9	47 min	42 to 43
Kinematic viscosity (mm^2/s) at 40 °C	ASTM D-445	4.9	1.9 to 6	1.9 to 4.1
Density (kg/m^3) at 40 °C	ASTM D-2638-10	887	860 to 900	846
Flashpoint (°C)	ASTM D-93	148	130 min	38 to 56
Cloud point (°C)	ASTM D-97	10	–3 to 12	–15 to 5
Pour point (°C)	ASTM D-97	6	–15 to 10	–20
Oxidation stability (h at 110 °C)	ASTM D-7525	1.2	3	
Acid value (mg KOH/g oil)	ASTM D-664	0.53	0.5	0.35
Iodine Value (g-I_2/100 g)	ASTM D-664	112		

3. 3 Engine Performance

3. 1 Output Power and Torsion

For the three types of fuel, in Figure 6 (a), the higher the engine speed, the higher the power output. A diesel engine's speed at a certain speed is related to the number of combustion cycles that occur at one time [30]. At higher engine speed, a diesel engine can perform more combustion cycles in one minute, producing a higher power output. At an engine speed of 1000 rpm, the power output of B10 is higher than that of B0; likewise, at an engine speed of 1300 rpm, biodiesel tends to have better combustion performance at low engine speeds. Therefore, blending with biodiesel may result in better combustion at lower engine speeds, which can increase torque and higher power output. At high engine speeds, the mixture with biodiesel can experience a decrease in output power because biodiesel has a higher viscosity and a longer burning time[30]. This condition can reduce combustion efficiency and hinder increased power output at high engine speed. It can be seen in Figure 2 that, in general, the B10 produces good performance at low engine speed.

3. 2 Specific Fuel Consumption (SFC)

Generally, an inverse relationship exists between engine engine speed and SFC[30], shown in Figure 6 (a). On average, the higher the engine engine speed, the lower the SFC. At low engine speeds, the thermal efficiency of diesel engines tends to be low. This condition is due to insufficient compaction of the air-fuel mixture in the combustion chamber and low combustion efficiency, resulting in a high SFC. As engine speed increases, thermal efficiency generally increases [31], meaning that a higher power output can be produced with the same amount of fuel. In this work, in each engine speed variation, the higher the percentage of biodiesel in the mixed fuel, the greater the Sfc. Biodiesel tends to have a higher flash point than conventional diesel fuel. This condition can result in longer burning times and lower firing temperatures. As a result, combustion efficiency can decrease, and SFC increases. Biodiesel usually has a higher viscosity than conventional diesel. This increase in viscosity can cause increased friction in the fuel system and reduce fuel flow into the combustion chamber. As a result, the engine speed can be reduced, so the SFC tends to increase. Table 4 shows that the RSB flash point is 148°C higher than diesel fuel, namely 38 to 56°C, and the kinematic viscosity. The calorific value of the fuel also greatly influences the SFC because the calorific value of RSB is lower than that of diesel, so more biodiesel is needed to produce the same calories as diesel.

3. 3 Thermal Efficiency

Thermal efficiency is a parameter that describes the extent to which the engine can use the energy generated from fuel efficiently. How engine speed affects how well the engine uses heat in diesel and biodiesel fuel mixtures can be influenced by factors such as fuel characteristics, operating conditions, and engine design. In Figure 6 (d), the relationship between engine engine speed and thermal efficiency in diesel engines generally follows a general pattern. At low engine speeds, thermal efficiency tends to be lower due to incomplete combustion and loss of heat energy to the exhaust gas channel. However, as the engine speed increases, the thermal efficiency can increase due to more efficient combustion and increased engine mechanical efficiency. It was also found that B10 fuel tends to produce higher thermal efficiency than B0 and B20.

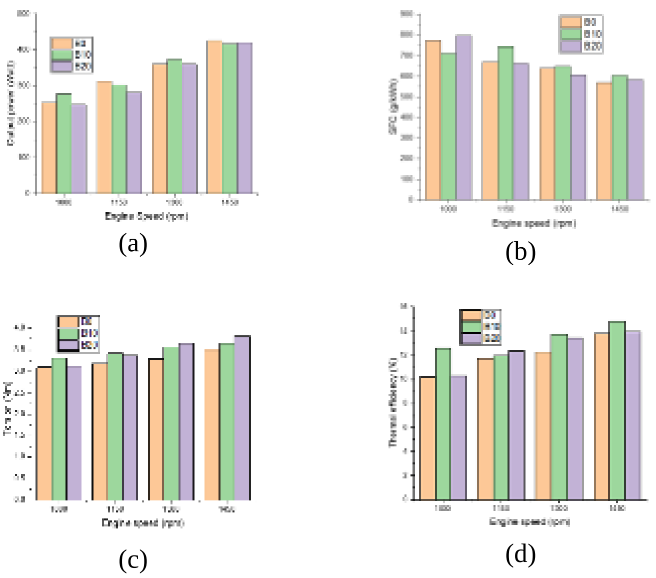

Figure 6. Engine performance on each fuel mixture; (a) output power, (b) sfc, (c) torsion, (d) thermal efficiency

3. 4 Emissions

3. 4.1 CO

Figure 7. (a) shows that the concentration of carbon monoxide in the exhaust gas decreases as the engine engine speed increases, which is consistent with the characteristics of diesel engines in which higher speeds lead to more efficient combustion and lower CO emissions. However, very low or very high engine speed can also affect combustion efficiency and increase CO emissions.

3. 4.2 CO2

In all fuel mixtures, CO_2 emissions increase as the engine speed increases but tends to decrease at 1450 rpm. At low engine speed, the combustion process in the engine cylinder tends to be incomplete due to the low engine temperature. The addition of biodiesel to diesel fuel produces higher CO_2 emissions. This condition can be explained because biodiesel contains oxygen, so that more carbon will be burned to CO_2.

3. 4.3 NOx

Increasing the engine engine speed can increase the combustion temperature and pressure in the combustion chamber, increasing the formation of nitrogen oxides. Therefore, higher spin speeds tend to lead to increased NOx emissions.

Increased NOx emissions (a mix of nitric, nitrous, and particulate matter) were found in all fuel mixes used to power the test engines. The greater the NOx production, the higher the oxygen concentration of the biodiesel. Biodiesel includes more oxygen due to its biological characteristics. The increase in NOx is generated by the increased heat produced by the fuel burning at high torque when the combustion temperature of the fuel is high, enabling atmospheric nitrogen to burn with oxygen in the exhaust pipe.

3. 4.4 O2

Figure 7 (d) shows that the relationship between the engine speed and the O2 content in the exhaust gas generally follows a general pattern. Because combustion occurs more quickly when the fuel and oxygen are mixed for a more extended period at low engine speeds, the amount of oxygen in the exhaust gas may be reduced. However, the limited combustion time can result in a higher O2 content in the exhaust gas at high engine speed. Using B10 and B20 increases the concentration of O2 in the waste gas. Because biodiesel contains higher oxygen than diesel, which can result in a higher O2 content in the exhaust gas at low and medium engine speeds; however, at high engine speed, the combustion characteristics of biodiesel can reduce the O2 content in the exhaust gas.

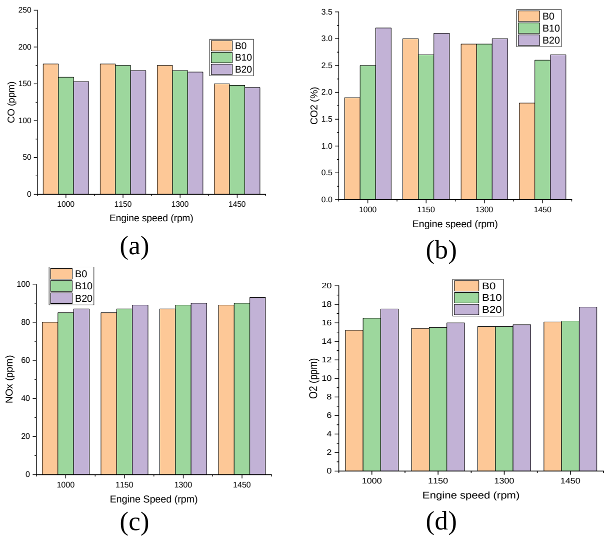

Figure 7. Engine emission on each fuel mixture; (a) CO, (b) CO2, (c) NOx, (d) O2

4. Conclusion

Because rubber seed is a product that has not been used from rubber plantations, the yield of RSB from the highest RSO obtained is 89%, indicating that rubber seed is worthy of consideration as a feedstock for biodiesel.

The maximum yield biodiesel production is the catalyst/crude oil ratio = 0.75, the oil/methanol molar ratio = 1:1.25, the reaction temperature is 60 oC and the reaction time is 100 minutes, but the yield increase from 90 minutes to 100 minutes is not significant.

Overall, the properties of RSB meet the ASTM criteria for biodiesel, except for oxidation stability, which is 1.2 hours, while the ASTM standard is a minimum of 3 hours. Further research is still needed to improve the oxidative stability of RSB.

Engine performance and exhaust emissions using RSB are equivalent to biodiesel in general. However, further research is needed on engine durability to complete the feasibility of rubber seed as biodiesel feedstock.

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