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# EFFECTS OF EXTRACTION METHODS ON THE FUEL CHARACTERISTICS AND DIESEL ENGINE PERFORMANCES OF *JATROPHA CURCAS* BIODIESEL

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## Graphical abstract



## Abstract

The development of high-quality biodiesel fuel has become more relevant due to the limited reserve and environmental effects of fossil fuel. In this study, oils derived from *Jatropha curcas* seeds through two extraction methods (soxhlet and cold-press) were compared. The fuel characteristics investigation suggested that methyl ester derived from oil extracted with the soxhlet method has lower viscosity, higher calculated cetane index, and slightly higher sulphur content. Comparison on the fuel characteristics with biodiesel standards showed that the methyl esters still had substantial amount of methanol and water due to low temperature during transesterification. The oils were also compared for their engine performances in a diesel engine under engine rotation of 1800 to 3000 RPM by blending derived methyl ester with pure petro-diesel to create B20 biodiesel. On average, B20 from soxhlet extraction has 3.86% higher power output, 3.55% higher torque, 3.4% higher BMEP, and 5.89% lower BSFC compared to cold-press. The extraction method affects the fuel characteristics of the methyl ester and the engine performances of the B20 biodiesel.

**Keywords:** Extraction, *Jatropha curcas*, biodiesel, engine performance, fuel characteristic

## Abstrak

Proses pembangunan bahanapi biodiesel yang berkualiti tinggi menjadi kritikal kerana rizab bahanapi yang terhad dan kesan dari bahanapi fosil ke atas alam sekitar. Dalam kajian ini, perbandingan dilakukan keatas bahanapi yang berasal dari biji *Jatropha Curcas* melalui dua kaedah pengekstrakan iaitu soxhlet dan tekanan sejuk. Ciri-ciri bahanapi menunjukkan bahawa methyl ester dari minyak yang diekstrak dengan kaedah soxhlet mempunyai kelikatan yang lebih rendah, indeks cetane yang dikira lebih tinggi, dan kandungan sulfur yang sedikit lebih tinggi. Perbandingan ciri bahan bakar biodiesel menunjukkan bahawa methyl ester masih mempunyai sejumlah besar metanol dan air kerana transesterifikasi dilakukan semasa suhu rendah. Prestasi minyak ini juga diuji dengan menggunakan enjin diesel untuk 1800 hingga 3000 RPM dengan mencampurkan methyl ester dari minyak dengan petro-diesel tulen dan menjadi biodiesel B20. Secara purata, biodiesel B20 dari pengekstrakan dengan kaedah soxhlet mempunyai output kuasa 3.86% lebih tinggi, tork 3.55% lebih tinggi, BMEP 3.4% lebih tinggi, dan BSFC 5.89% lebih rendah.

berbanding kaedah tekanan sejuk. Kaedah pengekstrakan mempengaruhi ciri-ciri bahanapi dari methyl ester dan prestasi enjin biodiesel dari biodiesel B20.

**Kata kunci:** Pengekstrakan, *Jatropha curcas*, biodiesel, prestasi enjin, ciri-ciri bahanapi

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## 1.0 INTRODUCTION

The importance of energy and its demand have become intergovernmental issues [1]. The high demand occurred due to rapid economic development from big countries, including Indonesia [2]. Energy is an essential factor in economic growth [3], and its demand through non-renewable fuel has been increasing with time [4]. The scarcity of fossil fuel and its harmful emissions have become significant issues in the energy sector [5-8]. In order to solve these issues, new resources of renewable energy need to be investigated further [9-11], such as biogas [12, 13] and biodiesel [14]. Biodiesel is an oxygenated fuel mainly formed of methyl ester fatty acids often derived from natural sources [15-17]. Biodiesel may decrease fossil fuels' overutilisation and the adverse environmental effects of non-renewable fuels [18-21].

The change from conventional diesel fuel to biodiesel will have dramatic effects as it is widely used in many parts of the industries [22]. The feedstocks for biodiesel production can be obtained by utilising crops and wastes produced by humans, including sources inedible for consumption [19, 23]. Some of the positive features of using biodiesel in comparison with petroleum-based diesel include renewable raw material [24], higher energy efficiency [24, 25], and lower emissions produced [24, 26]. Bio-based fuel can be blended directly with petroleum-based fuel at almost any mixing level without further upgrades or significant engine adjustments [18, 24, 25]. The development of renewable energy such as biodiesel fuel [27] and solar energy [28] may also improve rural areas' economy.

Even with biodiesel fuel's advantages, biodiesel derived from edible sources causes issues, such as the possibility of decreasing the food supplies [28-31]. Therefore, vegetable oils derived from non-food crops are promising alternatives for biodiesel based on edible feedstocks [32]. Many studies have been conducted to decrease the dependency on fossil fuel by utilising non-edible fuel sources. Notable examples of non-consumable vegetable feedstocks are *Cerbera manghas* [33] and *Jatropha curcas* [23, 34].

Several methods have been devised to produce biodiesel from renewable resources. The general concept of the process is to extract the natural oil available in the feedstock and apply treatment to it, such as transesterification [35, 36] to produce biodiesel. For vegetable-based feedstock, the two most common methods to extract the oil are the

solvent extraction method and the cold-press method [37]. The solvent extraction method uses a solvent such as n-hexane to bind and remove the feedstock's natural oil. The blend is then separated by evaporating the solvent, leaving natural oil as the remaining substance. Soxhlet method with n-hexane solvent is one of the most used types of solvent extraction method. According to Achten et al. (2008), the soxhlet method with n-hexane yields 95-99% extraction of *Jatropha curcas* oil [37].

On the other hand, the cold-press method pushes the oil out of the feedstock by pressing the feedstock using specific mechanisms [38]. The extracted oil ranges from 60 – 80% of the total available oil, depending on the mechanism used [37, 39-42]. The feedstocks' pre-treatment may increase the extracted oil yield up to 91 % [37, 43]. Extraction with the cold-press method, while it seems less complicated than the solvent extraction method, has its disadvantages; the mechanism used is usually only appropriate for certain feedstocks. The extracted oil also requires additional treatment, filtering, and degumming processes [44].

Several studies have suggested that various methods used to extract the feedstocks' natural oil may contribute to its final characteristics. Özcan et al. (2019) [45] conducted a study to compare the effects of extracting *M. oleifera* and *M. peregrina* oils with cold pressing and soxhlet methods. They reported a larger content of fatty acids and tocopherol in the oil extracted with the cold-press method due to the oil's additional impurities from the said method. Ahmed et al. (2019) [46] found smaller density, acid value, unsaponifiable matter, and peroxide value in walnut kernels oils extracted using the soxhlet method instead of the cold-press method. However, they also found higher iodine, saponification value, and a refractive index in oils from soxhlet extraction.

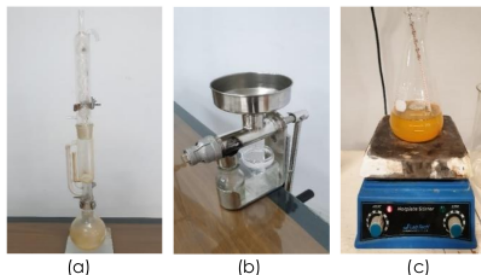
Vieira et al. (2015) [47] extracted oil from *Vitis vinifera* and *Vitis labrusca* using both the cold-press and soxhlet method. They found differences in the moisture content and fatty acids between oils from two extraction methods. They also found that oil extracted using the soxhlet method has a large residual of solvent. They suggested that additional pre-treatment of drying the feedstock at high temperature may reduce the solvent's remnant in the oil. Ibrahim et al. (2017) [48] suggested that various extraction methods affect *jatropha* oil characteristics as fuel for various degrees. Those characteristics include density, viscosity, flash point, cetane number, and calorific value.

As previously discussed, several studies have compared the effect of various extraction methods on biodiesel's fuel characteristics. However, since biodiesel's eventual use is in an engine application, a good understanding of its engine performance is necessary. Unfortunately, not many studies have examined biodiesel's engine performances derived from different oil extraction methods. The difference in the oils' fuel characteristics from various extraction methods suggests that the biodiesel's engine performance will differ depending on the oil extraction method used. By understanding this effect, a proper extraction method can be employed to maximize the engine output. Therefore, this study aims to clarify further the effect of soxhlet and cold-press extraction methods on biodiesel's fuel characteristics and engine performances. *Jatropha curcas* seed was chosen as the feedstock studied because of its abundance in Indonesia and its inedible property.

## 2.0 METHODOLOGY

*Jatropha curcas* seeds have 20-60 %wt of crude *Jatropha curcas* oil (CJCO) [23, 45, 49]. *Jatropha curcas* fruits collected from the trees were cut open and had their seeds taken. The seeds' water content was reduced using an oven; a similar method is employed by Izzatie et al. (2019) for their feedstock [50]. Afterwards, the seeds were pulverised into small size (60 mesh, 0.25 mm) to help extract the oil using the soxhlet method. The seeds were not pulverised for the cold-press method as it can be directly processed. For soxhlet extraction, n-hexane was used as a solvent since it is the most common solvent used and easy to obtain [48, 51]. After soxhlet extraction, the solvent was evaporated using a rotary evaporator and conventional heating method. Soxhlet and cold-press instruments used in this study are shown in Figure 1(a) and Figure 1(b), respectively.

After obtaining the oil, the transesterification process was carried out using a heated magnetic stirrer shown in Figure 1(c). Methanol and KOH catalyst were mixed with the oil to produce methyl ester. Specification of the heated magnetic stirrer is given in Table 1. The stirrer was set for 60 °C and operated for 60 minutes with a speed of 600 RPM. 50 mL of methanol for every 250 mL of CJCO (20 %vol) was used in the process. The amount of KOH catalyst used in the transesterification process is 1 gram for every 250 mL of CJCO (0.2 %wt). During the mixing, the top of the mixing container was covered with aluminium foil to prevent methanol evaporation. After mixing the oil with methanol and catalyst, the mixture was left for 24 hours under room temperature to separate the methyl ester from the glycerine, KOH catalyst, and methanol. The portion of the methyl ester was then water washed with distilled water and underwent reheating with a temperature of 75-80 °C to further refine it from the remaining methanol and n-hexane. The transesterification method was chosen to treat the oils as it is the most common method used that does not require substantial resources to perform [35, 36].



**Figure 1** Experimental apparatuses used to extract and process the *Jatropha curcas* oil, including (a) soxhlet, (b) manual cold presser, and (c) heated magnetic stirrer

**Table 1** Specifications of the heated magnetic stirrer

No.	Items	Description
1	Brand	Daihan Labtech
2	Model	LMS-1003
3	Overall dimensions for length x width x height (mm)	200 x 250 x 110
4	Temperature Range (°C)	Room temperature + 5 to 380
5	Rotation Range (RPM)	60 to 1500
6	Controller	Electronic solid-state controller
7	Voltage (V)	220

After transesterification, a series of tests were carried to obtain the fuel characteristics and the biodiesel engine performances. Fuel characteristics tests were conducted in a testing laboratory under ASTM standards with a maximum uncertainty of 5% in the measurements. The tests examined methyl esters obtained from both the soxhlet and cold-press method and pure petro-diesel (PPD) for comparison. For the engine performance tests, the methyl esters were blended with PPD to get 20 %wt of biodiesel (B20) in the fuel's total composition. This blending was done to reduce the methyl esters' viscosity, which is too viscous for engine testing [52]. 20 %wt of blending was chosen to abide by the regulation set by the Ministry of Energy and Mineral Resources, Republic of Indonesia, to utilise B20 fuel within the year of 2016 to 2019 [53, 54].

The engine performance tests were carried in the automotive laboratory of Petra Christian University using a diesel engine. Similar engine performance tests have been conducted previously [3]. The tests were conducted for two repetitions for each type of fuels, and the obtained data were then averaged. The experiments were performed under engine rotation of 1800 to 3000 RPM with increments of 400 RPM. The investigation also utilised a water brake dynamometer, as shown in Figure 2, with its specifications in Table 2. The specifications of the diesel engine are given in Table 3. The engine rotation was initially adjusted at 3000 RPM when the brake load was set at 0%. The dynamometer brake load was then increased gradually, and the engine rotation decreased with decrements of 400 RPM until reaching 1800 RPM while maintaining the indicated pressure of 2 bar in the water brake dynamometer. The load of the engine was



measured for every 50 mL of fuel consumed for each engine rotation. The data recorded include engine rotation, engine load, and time required for 50 mL of fuel to be consumed. Those data were used to calculate the engine power (Eq. 1), torque (Eq. 2), brake mean effective pressure (BMEP, Eq. 3), and brake specific fuel consumption (BSFC, Eq. 4).

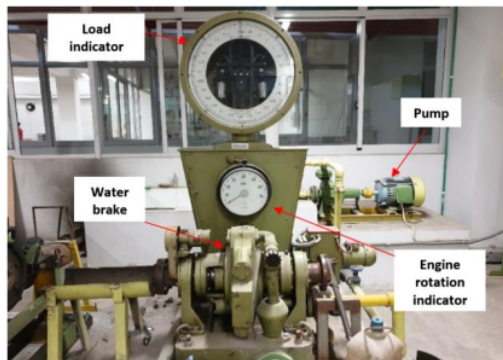


Figure 2 Zollner-Kiel water brake dynamometer

Table 2 Specifications of the water brake dynamometer

No.	Items	Description
1	Type	Zollner-Kiel 3n19A
2	Power (kW)	120
3	Voltage (V)	220
4	Current (A)	13.6
5	Rotation (RPM)	7500 (max)
6	Ev Volt (V)	42
7	Ex Curr (A)	2

Table 2 Specifications of the water brake dynamometer

No.	Items	Description
1	Type	Zollner-Kiel 3n19A
2	Power (kW)	120
3	Rotation (RPM)	7500 (max)
4	Rotation direction	One direction
5	Type of weight balance	Sluice gate
6	Number of impellers	One

Table 3 Specifications of the diesel engine

No.	Items	Description
1	Model	Isuzu 4JA1
2	Working machines	Four cylinders, four strokes
3	Cooling method	Water-cooled
4	Engine cooling system	Radiator
5	Combustion system	Direct injection
6	Injection timing	14° before TDC
7	Bore × stroke (mm)	93 × 12
8	Cylinder volume (cc)	2499
9	Compression ratio	18.4:1
10	Fuel pump	Bosch
11	Lubrication system	Forced lubrication
12	Engine dimensions for length x width x height (mm)	805 x 625 x 729
13	Maximum Power (HP)	86
14	Maximum Torque (Nm)	172

$$P = 2 \pi n F_D R \quad (1)$$

Where  $P$  denotes the engine power,  $n$  denotes the engine speed,  $F_D$  denotes the acting force in the water brake dynamometer, and  $R$  denotes the theoretical arm length of the water brake dynamometer (0.9549 m).

$$T = F_D R \quad (2)$$

Where  $T$  denotes the torque.

$$BMEP = \frac{P r_c}{A S c n} \quad (3)$$

Where  $BMEP$  denotes the brake mean effective pressure,  $r_c$  denotes the number of crankshaft revolution for one engine work cycle,  $A$  denotes the effective area of the piston,  $S$  denotes the length of the stroke, and  $c$  denotes the number of cylinders.

$$BSFC = \frac{m_f}{P t} \quad (4)$$

Where  $BSFC$  denotes the brake specific fuel consumption,  $m_f$  denotes the mass of the consumed fuel, and  $t$  denotes the time required to consume the fuel.

A measurement cup was used to assess the sum of the fuel burned when operating the diesel engine. A timer was used to determine the time needed by the diesel engine to consume 50 mL of fuel in each cycle. An electric fan was also used to cool down the engine through the radiator. Some measuring tools, such as voltmeter, thermometer, and tachometer, were used to ensure good testing condition. All instruments used in this study had been calibrated beforehand.

### 3.0 RESULTS AND DISCUSSION

The characteristics investigation compared the results of *Jatropha curcas* soxhlet (JCBs) with the results of *Jatropha curcas* cold-press (JCBp). The characteristics of PPD were included in the comparison for a benchmark to analyse the feasibility of JCBs and JCBp as a substitute for conventional fuel. The fuel characteristics results are presented as bar charts with error bars that correspond to the maximum uncertainty of 5%.

Density indicates the mass of fuel related to the occupied volume of the fuel in a tank. The density examination was performed under the ASTM D-1298 method. A similar ASTM standard to measure the density was used previously by Mohiddin et al. (2018) [15]. The results of the density test are displayed in Figure 3. JCBs reached 0.8984 kg/L of density, JCBp reached 0.8327 kg/L of density and PPD reached 0.8326 kg/L. PPD has the least density value of 0.8326 kg/L, while JCBp has the largest density value of 0.9027 kg/L. The difference in the density between JCBs and JCBp is minuscule. This small difference can be attributed to the remaining n-hexane in JCBs, which has a smaller density value of 0.66051 kg/L [55] at the atmospheric condition. It slightly reduced the overall density of JCBs. The density of the methyl esters is higher compared to results by Maina (2014) but close to the results from Chauhan et al. (2012) [56, 57]. The density of JCBs and JCBp fulfil the biodiesel standard of ASTM D6751 (at least 880 kg/L) [58], close to the upper limit of standard EN 14214 (860-900 kg/L) [58], and exceeded the Indonesian standard SNI 7182:2015 (850-890 kg/L) [59].

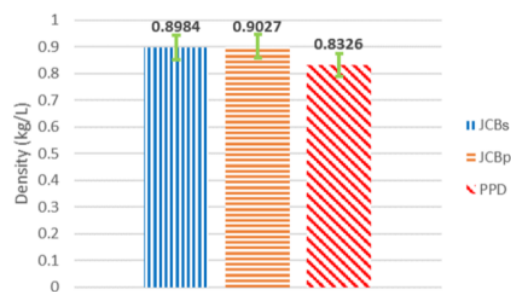


Figure 3 Density of JCBs, JCBp, and PPD

Kinematic viscosity indicates the resistance of the fluid towards the weight of gravity. Higher viscosity value suggests that the fluid is more viscous and thus harder to flow; however, it also gives better lubrication capability. The kinematic viscosity was examined using the ASTM D-445 method. A similar ASTM standard to measure the kinematic viscosity was used previously by Mohiddin *et al.* (2018) [15]. The results of the kinematic test are displayed in Figure 4. It was found that JCBs reached 7.158 cSt of kinematic viscosity, JCBp reached 8.108 cSt, and PPD reached 2.49 cSt of kinematic viscosity. PPD has the lowest viscosity of 2.49 cSt, while JCBp methyl ester has the largest viscosity of 8.108 cSt.

The difference in both methyl esters' kinematic viscosity can be attributed to the remnant of n-hexane in JCBs and impurities in JCBp. n-hexane has a kinematic viscosity of 0.455 cSt at 25 °C [60], much smaller than JCBs and JCBp's viscosity. Therefore, it reduces the kinematic viscosity of JCBs. On the other hand, the impurities in the JCBp, which usually needs to be treated [44], may increase the fuel's viscosity. Another notable finding in the kinematic viscosity results is the large viscosity of the JCBs and JCBp in this study compared to previous studies [56, 57]. However, previous results still show that *Jatropha curcas* methyl ester has a higher viscosity than PPD. The viscosity of the methyl esters in this study exceeds the standards ASTM D6751 (1.90–6.00 cSt) [58], EN 14214 (3.40–5.00 cSt) [58], and SNI 7182:2015 (2.3–6.0 cSt) [59]. The high viscosity value with previous studies may be attributed to the feedstock's origin and quality [43, 44], and the methyl esters' purity.

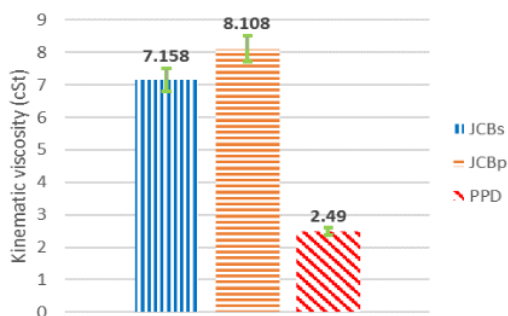


Figure 4 Kinematic viscosity of JCBs, JCBp, and PPD

Flash point indicates the bottom limit of the temperature where a fuel becomes combustible when ignited [61]. A lower flash point indicates that it is easier for the fuel to be ignited. Pensky Martens Closed Cup (PMCC) Flash point analysis has been performed in a laboratory under ASTM D-93 standard. A similar ASTM standard to measure the flash point was used previously by Candeia *et al.* (2009) [61]. The results of the flash point test are displayed in Figure 5. Both JCBs and JCBp have the same flash point value of 28 °C, while PPD reached 73 °C. The methyl esters' flash point is significantly lower than the standard ASTM D6751 (100–170 °C), EN 14214 (at least 120 °C), and the SNI 7182:2015 (at least 100 °C). The flash point of the methyl esters is exceptionally low compared to results from previous studies [56, 57, 62, 63]. It suggests that a considerable amount of methanol from the transesterification process remained in the methyl esters. The temperature during the transesterification was 60 °C during stirring and 75–80 °C when reheating. The temperature was low and led to substantial methanol remaining that significantly reduced the flash point of the methyl ester. This is considered a limitation in this study, and it is recommended for future studies to conduct the heating at a higher temperature.

Pour point is a temperature where the fuel loses its flow characteristics to move freely by its weight [64]. The loss of flow characteristics is caused by the fuel turning into a gel and blocking its movement. Pour point analysis was conducted within the laboratory using the ASTM D-97 standard. A similar ASTM standard to measure the pour point was used previously by Mohiddin *et al.* (2018) [15]. The results of the pour point test are displayed in Figure 6. Both methyl esters have a similar value for pour point, that is -12 °C while PPD reached -9 °C. The pour point of the methyl esters' is within the standard ASTM D6751 (-15 to 16 °C). The lower pour point of the methyl esters compared to PPD is unusual. However, previous studies have reported a large scatter of pour point measurement for *Jatropha curcas* methyl ester. Results from Prodhan *et al.* (2020) [62] is in line with the present study. They reported a pour point of -10.01 °C, which is lower than the PPD's pour point found in this study. On the other hand, Khethiwe *et al.* (2020) [65] reported a pour point of 1 °C while Shama Dugala *et al.* (2020) [66] reported -3 °C and -6.3 °C, depending on the amount of methanol used during transesterification. The large scatter or reported pour point value suggests that this study's low pour point results are within the expected inconsistency. The methyl esters' impurities in this study (as discussed in the previous paragraph) may also contribute to the low pour point.

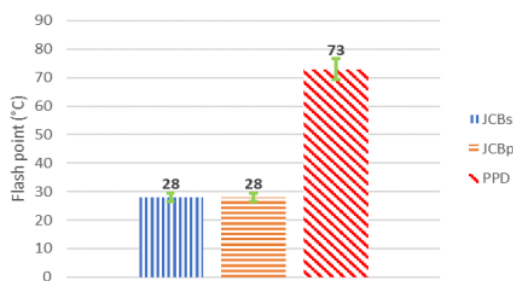


Figure 5 Flash point of JCBs, JCBp, and PPD

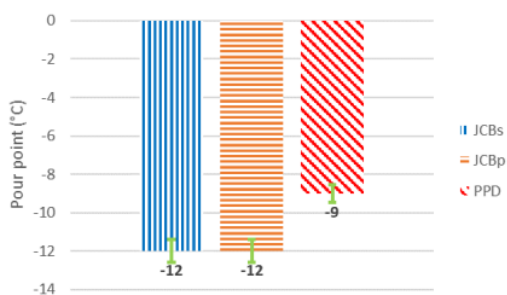


Figure 6 Pour point of JCBs, JCBp, and PPD

Sulphur content inside the fuel is very harmful to the engine as sulphur is highly corrosive. The analysis for the sulphur content in fuels has been performed under the ASTM D-129 standard. A similar ASTM standard to measure the sulphur content was used previously by De and Bahttacharyya [67]. The results of the sulphur content test are displayed in Figure 7. JCBs reached 0.09 %wt of sulphur content, JCBp reached as much as 0.07 %wt, and PPD has 0.047 %wt of sulphur. PPD has the least sulphur content of 0.047 %wt, while JCBs has the largest sulphur content of 0.09 %wt. The sulphur content of the methyl esters exceeds the maximum limit of ASTM D6751 (150 ppm or 0.015 %wt) [58] and SNI 7182:2015 (50 mg/kg or 0.005 %wt) [59]. The difference between JCBs and JCBp sulphur content may be attributed to the different level of oil purities between the cold-press method and the soxhlet method [44, 68]. The sulphur content of biodiesels found in this study is higher than the sulphur content measured by Sarin *et al.* (2007) [26]. This differing results from Sarin *et al.* (2007) [26] may be attributed to the diverse origin and quality of the feedstock [43, 44] and the purity of the methyl esters.

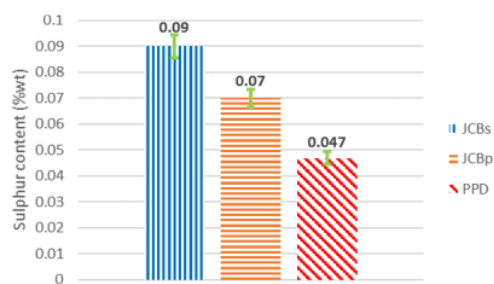


Figure 7 Sulphur content of JCBs, JCBp, and PPD

Colour analysis is a parameter that indicates the colour level of the fuel. The higher the colour point, the darker the colour of the fuel. Colour analysis has been performed under ASTM D-1500 standard. A similar ASTM standard to measure the colour point was used previously by Vu and Lim (2019) [69]. The results of the colour test are displayed in Figure 8. It was found that JCBs reached 1.0 point of colour point, JCBp reached 1.0 point of colour point, and PPD has 2.5 colour point. Both JCBs and JCBp have the same colour point value at 1.0 point. The colour analysis showed that both JCBs and JCBp have the same light colour characteristic while the PPD has a darker colour characteristic.

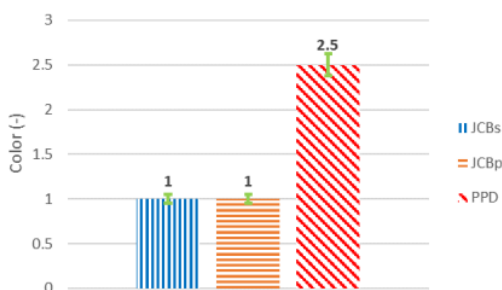


Figure 8 Colour point of JCBs, JCBp, and PPD

Water content analysis shows the percentage of water in the fuel, and it is one of the most fundamental analysis to determine the diesel fuel quality. Water may cause lower combustion temperature and react together with sulphur, leading to corrosive acid production. Water content analysis has been performed under the ASTM D-4377 standard. A similar ASTM standard to measure the water content was used previously by Canesin *et al.* (2014) [70]. The results of the water content test are displayed in Figure 9. It was found that JCBs has 0.43% of water content, JCBp has 0.45% water content, and PPD has 0.51% water content. JCBs has the least water content, while PPD has the largest water content. The difference in water content between JCBs and JCBp is minuscule. The methyl esters' water content exceeds the limit of EN 14214 and SNI 7182:2015 (500 ppm or 0.05%) [58,59]. A large amount of water in the methyl esters is due to the low temperature used during transesterification. In the transesterification process, the separated methyl ester underwent water washing using distilled water. It was then reheated with a temperature of 75-80 °C, which is less than the water boiling temperature. It resulted in a large portion of water remaining in the methyl esters.

Calculated Cetane Index (CCI) is the quality to measure diesel fuel derived by testing the fuel parameters. The index is measured based on volatility and the density of the fuel. CCI has been performed under ASTM D-4737 standard. A similar ASTM standard to measure the CCI was used previously by Candeia *et al.* (2009) [61]. The results of the CCI test are displayed in Figure 10. It was found that JCBs reached 52.19 CCI, JCBp reached 50.8 CCI, and PPD reached 51 CCI. JCBp has the



least CCI of 50.8, whereas JCBs has the largest CCI of 52.19. Previous studies reported mixed results with higher CCI [56, 62], lower CCI [57], or close to the present results [63]. The difference from previously reported results may be attributed to the different quality and origin of feedstocks used [43, 44] and the level of methyl esters' purity. The differing CCI between JCBs and JCBp may come from the impurities of the cold pressing method [44] that reduce the overall quality of the fuel. The reported CCI in this study fulfils the ASTM D6751 standard [58] (minimum 47.00), and close to the requirement of EN 14124 [58] and SNI 7182:2015 [59] standards (at least 51.00) for JCBp.

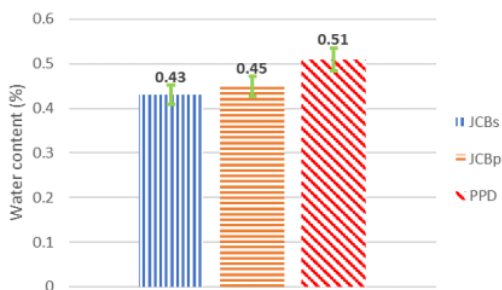


Figure 9 Water content of JCBs, JCBp, and PPD

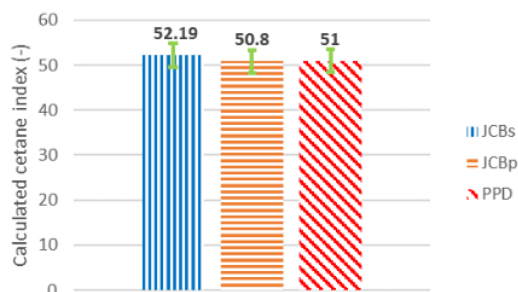


Figure 10 Calculated Cetane Index (CCI) of JCBs, JCBp, and PPD

Based on the fuel characteristics results, it can be concluded that JCBs and JCBp have differing fuel characteristics. For specific parameters such as density, flash point, pour point, colour point, and water content, there are small or no differences between JCBs and JCBp. The parameters that show notable differences are viscosity, sulphur content, and CCI. Explanations regarding these differences have been previously provided. Compared with PPD, the density, and particularly the flash point and viscosity [18] of both JCBs and JCBp are not practical to be used in an engine. Therefore, both methyl esters were blended with PPD to create B20 JCBs and B20 JCBp (20 %wt of methyl ester) in the engine performance tests.

The engine performance tests included the measurement of power, torque, BMEP, and BSFC. Engine power is defined as the power generated to cope with the given load by the engine. Test results for power as a function of the engine rotation are

displayed in Figure 11. The engine power was calculated using Eq. 1, and it is dependent on the acting force and theoretical arm length of the water brake dynamometer, and the engine speed. It was found that B20 JCBs reached as high as 44.68 BHP while B20 JCBp reached as high as 43.35 BHP. The results show that B20 JCBs, on average, produces 3.86% more power compared to B20 JCBp. The largest and average standard deviation for the power performance test with two replications are 0.89 BHP and 0.27 BHP, respectively.

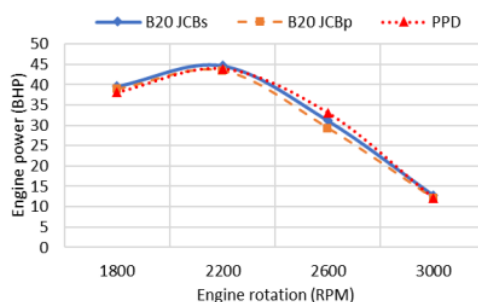


Figure 11 Engine power of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

Torque represents the ability of the engine to generate movement for the vehicle/machine. Torque is the result of the tangential force and length that is described in Nm unit. The higher the torque, the more obstacles can be overcome by the vehicle/machine. Test results for torque as a function of the engine rotation are displayed in Figure 12. The torque was obtained through Eq. 2, and it is dependent on the acting force and theoretical arm length of the water brake dynamometer. B20 JCBs reached as high as 159.7 Nm while B20 JCBp reached as high as 156.7 Nm. B20 JCBs has, on average, 3.55% more torque compared to B20 JCBp. The largest and average standard deviation for the torque performance test with two replications are 2.8 Nm and 0.85 Nm, respectively.

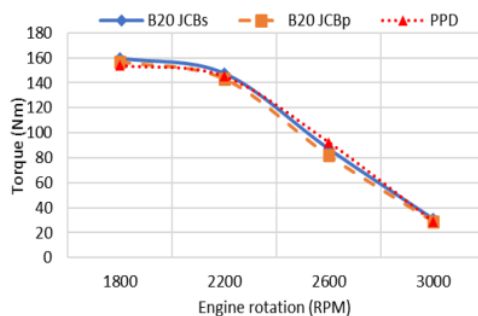


Figure 12 Torque of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation



BMEP (brake mean effective pressure) indicates an engine's output measured from the average effective pressure of the cycles. Test results of BMEP as a function of the engine rotation are displayed in Figure 13. The BMEP was calculated using Eq. 3, and it is dependent on various parameters, including the engine power (Eq. 1). It may be observed that the BMEP value for B20 JCBs is higher compared to B20 JCBp. B20 JCBs reached as high as  $1.48 \times 10^{-5}$  kg/cm<sup>2</sup> while B20 JCBp reached as high as  $1.46 \times 10^{-5}$  kg/cm<sup>2</sup>. The data showed that B20 JCBs has, on average, 3.40% more BMEP than B20 JCBp. The largest and average standard deviation for the BMEP performance test with two replications are  $2.72 \times 10^{-7}$  kg/cm<sup>2</sup> and  $8.19 \times 10^{-8}$  kg/cm<sup>2</sup>, respectively.

Brake specific fuel consumption (BSFC) is the quantity of fuel consumed to create net power for a particular time. The BSFC of both blended JCBs and JCBp as a function of the engine rotation is displayed in Figure 14. The BSFC was calculated using Eq. 4, and it is dependent on the mass of fuel consumed, the time required for fuel consumption, and the engine power (Eq. 1). The data showed that BSFC for B20 JCBs reaches as high as 0.354 kg/kW.h while B20 JCBp reaches as high as 0.388 kg/kW.h. The results show that B20 JCBs is, on average, 5.89% more economical compared to B20 JCBp. The largest and average standard deviation for the BSFC performance test with two replications are 0.023 kg/kW.h and 0.0076 kg/kW.h, respectively.

The results of the engine performance tests corroborate the fuel characteristics test results. A higher cetane index in JCBs compared to JCBp means that the combustion quality is better in JCBs [60, 61] and therefore leads to higher in-cylinder pressure (power), higher torque, higher BMEP and lower BSFC [61, 71–73]. All engine performance tests showed good agreement of trends between biodiesel and PPD, supporting the use of B20 biodiesel from *Jatropha curcas* as a potential substitute for PPD.

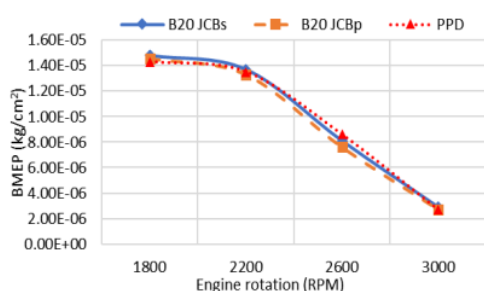


Figure 13 BMEP of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

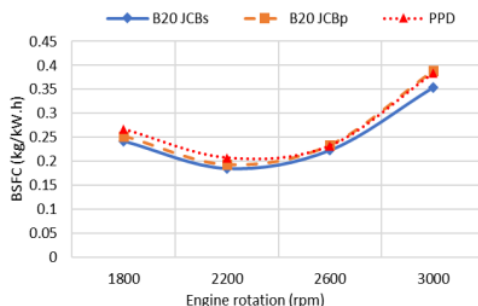


Figure 14 BSFC of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

## 4.0 CONCLUSION

The fuel characteristics test results indicate that *Jatropha curcas* oil extracted with the soxhlet method has different properties than *Jatropha curcas* oil extracted with the cold-press method. Methyl ester produced from oil extracted with the soxhlet method has a slightly lower density and water content (0.8984 Kg/L and 0.43%, respectively) than the one extracted with the cold-press method (0.9027 Kg/L and 0.45%, respectively). Methyl esters from both extraction methods have similar characteristics of flash point, pour point, and colour point (28 °C, -12 °C, and 1, respectively). Methyl ester from the soxhlet method has a higher calculated cetane index value, higher sulphur content, and lower kinematic viscosity (52.19, 0.09 %wt, and 7.158 cSt, respectively) than the one extracted with the cold-press method (50.8, 0.07 %wt, and 8.108 cSt, respectively). Some of the methyl esters' fuel characteristics reported in this study do not fulfil the biodiesel standards. It suggests that a substantial amount of methanol and water remain after the transesterification process. Higher temperature during transesterification is recommended in future studies.

It was found from the engine performance tests that biodiesel B20 from the soxhlet method has, on average, 3.86% higher power output, 3.55% higher torque, 3.4% higher BMEP, and 5.89% lower BSFC compared to biodiesel B20 from the cold-press method. These results suggest that biodiesel B20 derived from *Jatropha curcas* oil extracted with the soxhlet method gives better engine performance over the cold-press method. The higher calculated cetane index of the methyl esters originated from the soxhlet method corroborate the engine performance test results.

Overall, the study found that the extraction methods of *Jatropha curcas* seed oil affect the methyl ester and biodiesel B20 quality produced in terms of fuel characteristics and engine performances.

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