Jurnal
Teknologi

Full Paper

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

Willyanto Anggono[a*], Muhamad Mat Noor[b], Shiyong Liao[c], Kevin Sanka[a], Gabriel Jeremy Gotama[d], Sutrisno[a], Fandi D Suprianto[a]

[a]Department of Mechanical Engineering Petra Christian University, Indonesia
[b]Faculty of Mechanical & Automotive Engineering Technology, Universiti Malaysia Pahang, Malaysia
[c]College of Traffic & Transportation, Chongqing Jiaotong University, China
[d]School of Mechanical and Aerospace Engineering, Nanyang Technological University Department of Aerospace and Geodesy Technical, Singapore

Article history
Received
4 June 2020
Received in revised form
18 March 2022
Accepted
18 March 2022
Published Online
20 June 2022

*Corresponding author
willy@petra.ac.id

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 mengunakan 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

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].

(a) (b) (c)

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).

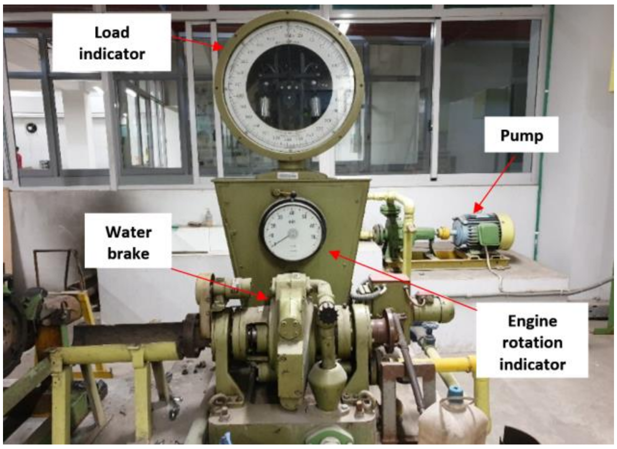

Figure 2 Zollner-Kiel water brake dynamometer

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 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 × 92
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

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

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).

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

Where T denotes the torque.

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

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.

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

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 fuel characteristics investigation compared methyl ester of *Jatropha curcas* soxhlet (JCBs) with methyl ester of *Jatropha curcas* cold-press (JCBp). Fuel 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 0.9027 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].

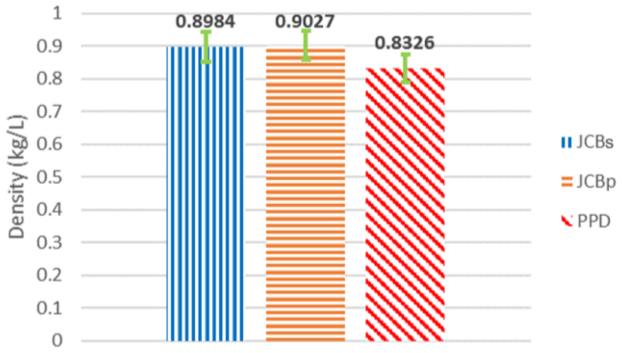

Figure 3 Density of JCBs, JCBp, and PPD

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.

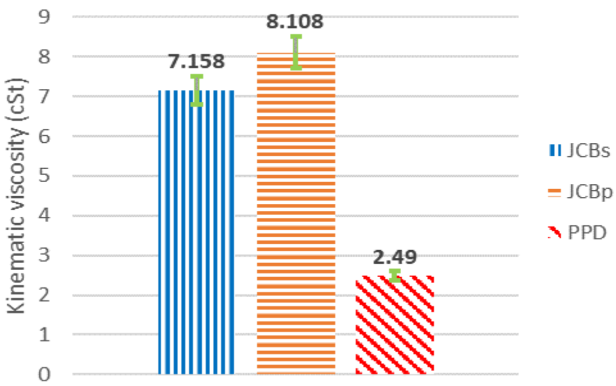

Figure 4 Kinematic viscosity of JCBs, JCBp, and PPD

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 for 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.

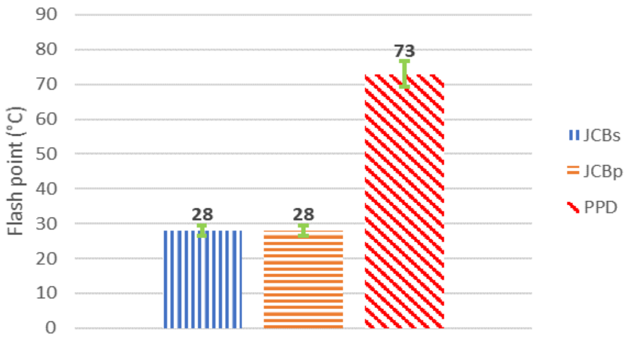

Figure 5 Flash point of JCBs, JCBp, and PPD

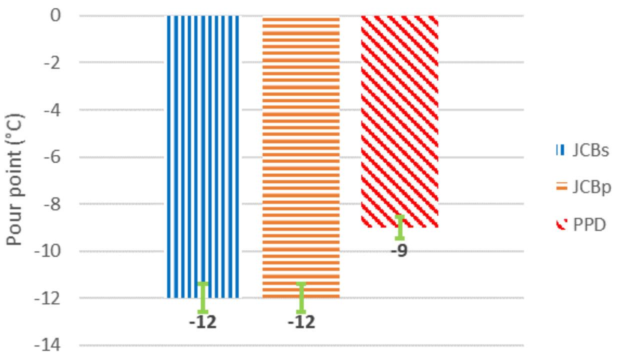

Figure 6 Pour point of JCBs, JCBp, and PPD

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.

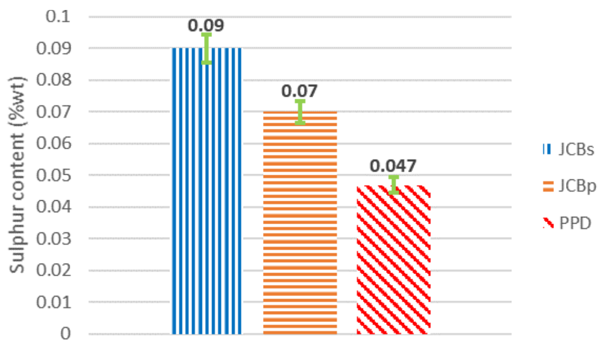

Figure 7 Sulphur content of JCBs, JCBp, and PPD

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.

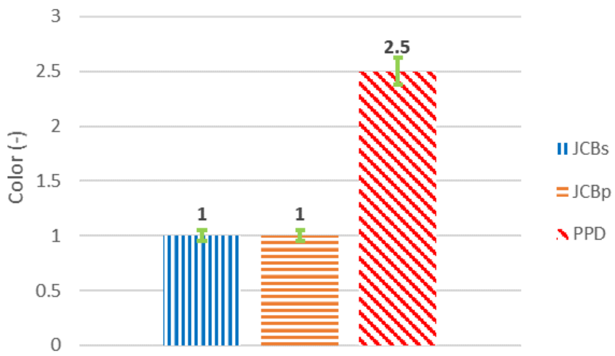

Figure 8 Colour point of JCBs, JCBp, and PPD

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.

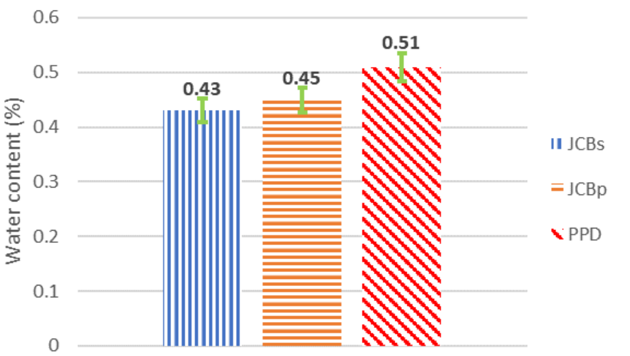

Figure 9 Water content of JCBs, JCBp, and PPD

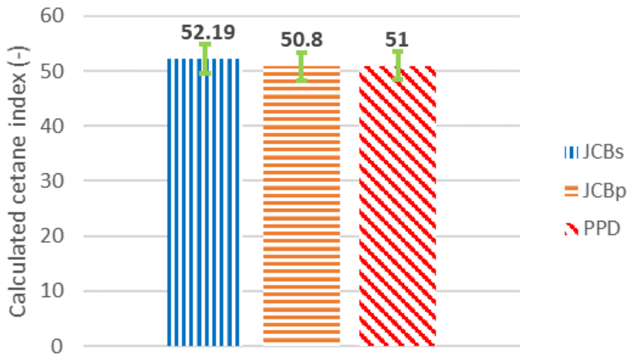

Figure 10 Calculated Cetane Index (CCI) of JCBs, JCBp, and PPD

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.

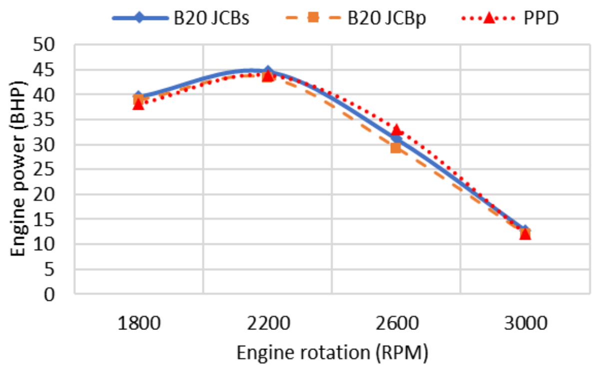

Figure 11 Engine power of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

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.

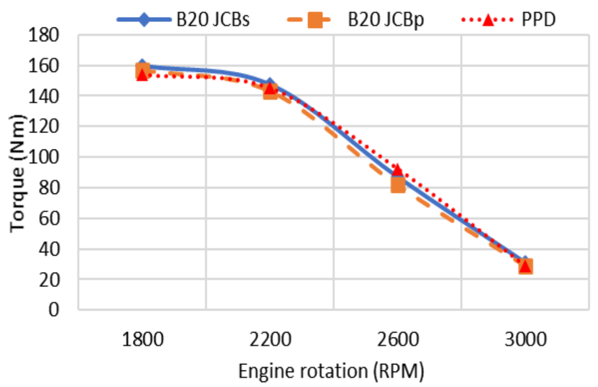

Figure 12 Torque of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

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 1.48×10^{-5} kg/cm^2 while B20 JCBp reached as high as 1.46×10^{-5} kg/cm^2. 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 2.72×10^{-7} kg/cm^2 and 8.19×10^{-8} kg/cm^2, 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.

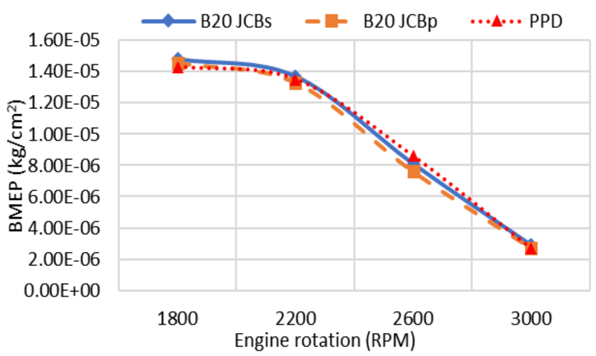

Figure 13 BMEP of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

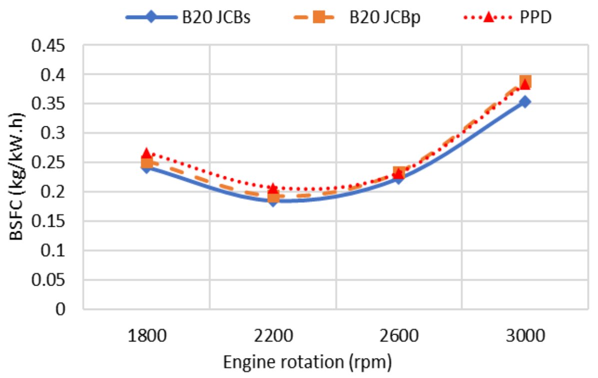

Figure 14 BSFC of B20 JCBs, B20 JCBp, and PPD as a function of the engine rotation

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.

Acknowledgement

Authors would like to express their gratitude to Petra Christian University, Indonesia (Research Grant: 04/HB-Penelitian/LPPM-UKP/I/19), Directorate General of Higher Education, Ministry of Research, Technology and Higher Education of the Republic of Indonesia (Penelitian Produk Terapan 2016-2017: SP DIPA-042.06.1.401516/2017), Universiti Malaysia Pahang, Malaysia through the research project RDU190386.

References

[1] Aziz, N. N. F. A. N., Said, M., Malik, M. S. A., Ja'afar, M. N. M., Othman, N., Ariffin, M. K. and Hassan, M. F. 2020. Combustion Study of Waste Cooking Oil Biodiesel in an Oil Burner. *Jurnal Teknologi (Sciences & Engineering)*. 82(4): 93-98. DOI: http://doi.org/10.11113/jt.v82.13908.

[2] Kusworo, A., Kumoro, A. C., Yaqin, M. A., Fatiyah, N. and Utomo, D. P. 2020. Modification of Nano Hybrid PES-ZnO Membrane Using UV Irradiation for Biodiesel Purification. *Jurnal Teknologi (Sciences & Engineering)*. 82(5): 147-156. DOI: https://doi.org/10.11113/jt.v82.14682.

[3] Anggono, W., Sutrisno, Suprianto, F. D., Setiyo, M., Wibisono, R. and Gotama, G. J. 2019, January. Experimental Investigation of The Effect of *Nephelium Lappaceum* Seed Biodiesel to The Automotive Diesel Engine Performance. *9th International Conference on Future Environment and Energy*. *IOP Conf. Series: Earth and Environmental Science*. 257: 012039. DOI: http://doi.org/10.1088/1755-1315/257/1/012039.

[4] Noor, M., Wandel, A. P., & Yusaf, T. 2014. MILD Combustion: The Future for Lean and Clean Combustion Technology. *International Review of Mechanical Engineering*. 8(1): 251-257. DOI: https://doi.org/10.15866/ireme.v8i1.1267.

[5] Sahu, S. K., Beig, G. and Parkhi, N. 2014. Critical Emissions from the Largest On-road Transport Network in South Asia. *Aerosol and Air Quality Research*. 14: 135-144. DOI: http://doi.org/10.4209/aaqr.2013.04.0137.

[6] Hamada, K. I., Rahman, M. M., Ramasamy, D., Noor, M. M. and Kadirgama, K. 2016. Numerical Investigation of In-Cylinder Flow Characteristics of Hydrogen-fueled Internal Combustion Engine. *Journal of Mechanical Engineering and Sciences*. 10(1): 1792-1802. DOI: http://doi.org/10.15282/jmes.10.1.2016.4.0172.

[7] Noor, M. M., Wandel, A. P. and Yusaf, T. 2014. Effect of Air-Fuel Ratio on Temperature Distribution and Pollutants for Biogas Mild Combustion. *International Journal of Automotive and Mechanical Engineering*. 10(15): 1980-1992. DOI: http://doi.org/10.15282/ijame.10.2014.15.0166.

[8] Liao, S. Y., Jiang, D. M., Cheng, Q., Huang, Z. H. and Wei, Q. 2005. Investigation of the Cold-start Combustion Characteristics of Ethanol-gasoline Blends in a Constant-volume Chamber. *Energy & Fuels*.19: 813-819. DOI: http://doi.org/10.1021/ef049733l.

[9] Kumarasamy, S., Mazlan, N. M., Abidin, M. S. Z. and Anjang, A. 2020. Influence of Biodiesel and Blended Fuels on the Tensile and Compressive Properties of Glass Fibre Reinforced Epoxy Composites. *Jurnal Teknologi (Sciences & Engineering)*. 82(1): 41-47. DOI: https://doi.org/10.11113/jt.v82.13812.

[10] Hu, G., Liao, S. Y., Zuo, Z., Wang, K. and Zhu, Z. 2018. Kinetic Effects of Methanol Addition on The Formation and Consumption of Formaldehyde and Benzene in Premixed N-Heptane/Air Flames. *Journal of Energy Resources Technology*. 140(7): 072205. DOI: http://doi.org/10.1115/1.4039612.

[11] Anggono, W., Suprianto, F. D., Gotama, G. J., Sutrisno and Evander, J. 2018. Combustion Characteristics Behavior of Pterocarpus Indicus Leaves Waste Briquette at Various Particle Size and Pressure. *5th International Conference on Mechanics and Mechatronics Research. IOP Conf. Series: Materials Science and Engineering*. 417: 012007. DOI: http://doi.org/10.1088/1757-899X/417/1/012007.

[12] Anggono, W. 2017. Behaviour of Biogas Containing Nitrogen on Flammability Limits and Laminar Burning Velocities. *International Journal of Renewable Energy Research*. 7(1): 304-310.

[13] Anggono, W., Hayakawa, A., Okafor, E. C., Gotama, G. J. and Wongso, S. 2020. Laminar Burning Velocity and Markstein Length of CH_4/CO_2/Air Premixed Flames at Various Equivalence Ratios and CO_2 Concentrations Under Elevated Pressure. *Combustion Science and Technology*. In-Press. DOI: http://doi.org/10.1080/00102202.2020.1737032.

[14] Arizal, M. A. A, Azman, A. H., Jaafar, M. N. M, Wan Omar, W. Z. 2015. Combustion Performance of Jatropha Biodiesel in an Oil Burner System. *Jurnal Teknologi (Sciences & Engineering)*. 77(8): 47-51. DOI: http://doi.org/10.11113/jt.v77.6153.

[15] Mohiddin, M. N., Saleh, A. A., Reddy, A. N. R. and Hamdan, S. 2018. A Study on Chicken Fat as An Alternative Feedstock: Biodiesel Production, Fuel Characterisation, and Diesel Engine Performance Analysis. *International Journal of Automotive and Mechanical Engineering*. 15(3): 5535-5546. DOI: http://doi.org/10.15282/ijame.15.3.2018.10.0425.

[16] Said, N. H., Ani, F. N. and Said, M. F. M. 2015. Review of the Production of Biodiesel from Waste Cooking Oil Using Solid Catalysts. *Journal of Mechanical Engineering and Sciences*. 8: 1302-1311. DOI: http://doi.org/10.15282/jmes.8.2015.5.0127.

[17] Rajesh Kumar, S., and Sai Chaitanya, P. 2019. Role of Nanoadditive Blended Biodiesel Emulsion Fuel on the Performance and Emission Characteristics of Diesel Engine. *Journal of Mechanical Engineering and Sciences*. 13(2): 4869-4879. DOI: http://doi.org/10.15282/jmes.13.2.2019.08.0405.

[18] Kywe, T. T. and Oo, M. M. 2009. Production of Biodiesel from Jatropha Oil (*Jatropha curcas*) in Pilot Plant. *World Academy of Science, Engineering and Technology*. 50: 477-483.

[19] Ofori-Boateng, C. and Teong, L. K. 2011. Feasibility of Jatropha Oil for Biodiesel: Economic Analysis. In *World Renewable Energy Congress 2011*. DOI: http://doi.org/10.3384/ecp11057463.

[20] Harreh, D., Saleh, A. A., Reddy, A. N. R., Hamdan, S. and Charyulu, K. 2018. Production of Karanja Methyl Ester from Crude Karanja Oil Using *Meretrix lyrata* Synthesised Active Cao Catalyst. *International Journal of Automotive and Mechanical Engineering*. 15(3): 5683-5694. DOI: http://doi.org/10.15282/ijame.15.3.2018.21.0436.

[21] Gashaw, A., Getachew, T. and Teshita, A. 2015. A Review on Biodiesel Production as Alternative Fuel. *Journal of Forest Products & Industries*. 4(2): 80-85.

[22] Anggono, W., Ikoma, W., Chen, H., Liu, Z., Ichiyanagi, M., Suzuki, T., Gotama, G. J. 2019. Investigation of Intake Pressure and Fuel Injection Timing Effect on Performance Characteristics of Diesel Engine. *9th International Conference on Future Environment and Energy*. *IOP Conf. Series: Earth and Environmental Science*. 257: 012037. DOI: http://doi.org/10.1088/1755-1315/257/1/012037.

[23] Parawira, W. 2010. Biodiesel Production from *Jatropha Curcas*: A Review. *Scientific Research and Essays*. 5(14): 1796-1808.

[24] Salvi, B. L. and Panwar, N. L. 2012. Biodiesel Resources and Production Technologies - A Review. *Renewable and Sustainable Energy Reviews*. 16: 3680-3689. DOI: http://doi.org/10.1016/j.rser.2012.03.050.

[25] Azad, A. K., Ameer Uddin, S. M. and Alam, M. M. 2012. A Comprehensive Study of DI Diesel Engine Performance with Vegetable Oil: An Alternative Bio-fuel Source of Energy. *International Journal of Automotive and Mechanical Engineering*. 5: 576-586. DOI: http://doi.org/10.15282/ijame.5.2012.4.0045.

[26] Sarin, R., Sharma, M., Sinharay, S. and Malhotra, R. K. 2007. Jatropha-Palm Biodiesel Blends: An Optimum Mix for Asia. *Fuel*. 86: 1365-1371.

DOI : http://doi.org/10.1016/j.fuel.2006.11.040.
[27] Farouk, H., Jaafar, M. N. M. and Atabani, A. E. 2014. A Study of Biodiesel Production from Crude Jatropha Oil (CJO) with High Level of Free Fatty Acids. *Jurnal Teknologi (Sciences & Engineering)*. 69(3): 65-72. DOI: http://doi.org/10.11113/jt.v69.3145.
[28] Farhana, K., Kadirgama, K., Rahman, M. M., Ramasamy, D., Noor, M. M., Najafi, G., Samykano, M. and Mahamude, A. S. F. 2019. Improvement in the Performance of Solar Collectors with Nanofluids - A State of the Art Review. *Nano Structures and Nano-objects*. 18: 100276. DOI: http://doi.org/10.1016/j.nanoso.2019.100276.
[29] Takase, M., Zhao, T., Zhang, M., Chen, Y., Liu, H., Yang, L. and Wu, X. 2015. An Expatiate Review of Neem, Jatropha, Rubber and Karanja as Multipurpose Non-edible Biodiesel Resources and Comparison of Their Fuel, Engine and Emission Properties. *Renewable and Sustainable Energy Reviews*. 43: 495-520. DOI: http://doi.org/10.1016/j.rser.2014.11.049.
[30] Babazadeh, R. 2017. Optimal Design and Planning of Biodiesel Supply Chain Considering Non-edible Feedstock. *Renewable and Sustainable Energy Reviews*. 75: 1089-1100. DOI: http://doi.org/10.1016/j.rser.2016.11.088.
[31] Zamberi, M. M., Ani, F. N. and Abdollah, M. F. 2016. Heterogeneous Transesterification of Rubber Seed Oil Biodiesel Production. *Jurnal Teknologi (Sciences & Engineering*. 78(6-10): 105-110. DOI: http://doi.org/10.11113/jt.v78.9196.
[32] Bhaskar, K., Sendilvelan, S., Muthu, V. and Aravindraj, S. 2016. Performance and Emission Characteristics of Compression Ignition Engine Using Methyl Ester Blends of Jatropha and Fish Oil. *Journal of Mechanical Engineering and* Sciences. 10(2): 1994-2007. DOI: http://doi.org/10.15282/jmes.10.2.2016.4.0188.
[33] Anggono, W., Noor, M. M., Suprianto, F. D., Lesmana, L. A., Gotama, G. J. and Setiyawan, A. 2018. Effect of *Cerbera manghas* Biodiesel on Diesel Engine Performance. *International Journal of Automotive and Mechanical Engineering*. 15(3): 5667-5682. DOI: http://doi.org/10.15282/ijame.15.3.2018.20.0435.
[34] Zahari, M. S. M., Ismail, S. B., Ibrahim, M. Z., Lam, S. S. and Mat, R. 2015. Ultrasonicated Jatropha Curcas Seed Residual as Potential Biofuel Feedstock. *Jurnal Teknologi (Sciences & Engineering)*. 77(1): 133-138. DOI: http://doi.org/10.11113/jt.v77.4340.
[35] Hoang, A. T., Noor, M. M. and Pham, X. D. 2018. Comparative Analysis on Performance and Emission Characteristic of Diesel Engine Fueled with Heated Coconut Oil and Diesel Fuel. *International Journal of Automotive and Mechanical Engineering.* 15(1): 5110-5125. DOI: http://doi.org/10.15282/ijame.15.1.2018.16.0395.
[36] Jain, S. and Sharma, M. P. 2010. Prospects of Biodiesel from Jatropha in India: A Review. *Renewable and Sustainable Energy Reviews*.14: 763-771. DOI: http://doi.org/10.1016/j.rser.2009.10.005.
[37] Achten, W. M. J., Verchot, L., Franken, Y. J., Mathijs, E., Singh, V. P., Aerts, R. and Muys, B. 2008. Jatropha Bio-Diesel Production and Use. *Biomass and Bioenergy*. 32(12): 1063-1084. DOI: http://doi.org/10.1016/j.biombioe.2008.03.003.
[38] Raja, S. A., Robinson smart, D. S., Lee, C. L. R. 2011. Biodiesel Production from Jatropha Oil and Its Characterization. *Research Journal of Chemical Sciences.* 1(1): 81-87.
[39] Beerens, P. 2007. Screw-Pressing of Jatropha Seeds for Fueling Purposes in Less Developed Countries. *Eindhoven University of Technology*. Student Thesis: Master.
[40] Forson, F. K., Oduro, E. K. and Hammond-Donkoh, E. 2004. Performance of Jatropha Oil Blends in A Diesel Engine. *Renewable Energy*. 29(7): 1135-1145. DOI: http://doi.org/10.1016/j.renene.2003.11.002.
[41] Rabé, E. L. M. 2006. Jatropha Oil in Compression Ignition Engines: Effects on the Engine, Environment and Tanzania as Supplying Country. Eindhoven University of Technology. Student Thesis: Master.
[42] Ahmad, K. A., Abdullah, M. E., Hassan, N. A., Ambak, K. B., Musbah, A., Usman, N., Bakar, S. K. B. A. 2016. Extraction Techniques and Industrial Applications of Jatropha Curcas. *Jurnal Teknologi (Sciences & Engineering*). 78(7-3): 53-60. DOI: http://doi.org/10.11113/jt.v78.9483.
[43] Atabani, A. E., Silitonga, A. S., Irfan Anjum Badruddin, Mahlia, T. M. I., Masjuki, H. H. and Mekhilef, S. 2012. A Comprehensive Review on Biodiesel as An Alternative Energy Resource and Its Characteristics. *Renewable and Sustainable Energy Reviews.* 16(4): 2070-2093. DOI: http://doi.org/10.1016/j.rser.2012.01.003.
[44] Atabani, A. E., Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., Irfan Anjum Badruddin and Fayaz, H. 2013. Non-Edible Vegetable Oils: A Critical Evaluation of Oil Extraction, Fatty Acid Compositions, Biodiesel Production, Characteristics, Engine Performance and Emissions Production. *Renewable and Sustainable Energy Reviews*. 18: 211-245. DOI: http://doi.org/10.1016/j.rser.2012.10.013.
[45] Özcan, M. M., Ghafoor, K., Al Juhaimi, F., Ahmed, I. A. M. and Babiker, E. E. 2019. Effect of Cold-Press and Soxhlet Extraction on Fatty Acids, Tocopherols and Sterol Contents of The *Moringa* Seed Oils. *South African Journal of Botany*. 124: 333-337 DOI: http://doi.org/10.1016/j.sajb.2019.05.010.
[46] Ahmed, I. A. M., Al-Juhaimi, F. Y., Özcan, M. M., Osman, M. A., Gassem, M. A., Salih, H. A. A. 2019. Effects of Cold-Press and Soxhlet Extraction Systems on Antioxidant Activity, Total Phenol Contents, Fatty Acids, and Tocopherol Contents of Walnut Kernel Oils. *Journal of Oleo Science*. 68(2): 167-173. DOI: http://doi.org/10.5650/jos.ess18141.
[47] Vieira, D. S., Menezes, M., Gonçalves, G., Mukai, H., Lenzi, E. K., Pereira, N. C. and Fernandes, P. R. G. 2015. Temperature Dependence of Refractive Index and of Electrical Impedance of Grape Seed (*Vitis Viniferam Vitis Labrusca*) Oils Extracted by Soxhlet and Mechanical Pressing. *Grasas Y Aceites*. 66(3). DOI: http://doi.org/10.3989/gya.0954142.
[48] Ibrahim, S. M. A., Abed, K. A., Gad, M. S. and Abu Hashish, H. M. 2017. Comparison of Different Methods for Producing Bio Oil from Egyptian Jatropha Seeds. *Biofuels*. DOI: http://doi.org/10.1080/17597269.2017.1387748.
[49] Nzikou, J.M., Matos, L., Mbemba, F., Ndangui, C.B., Pambou-Tobi, N.P.G., Kimbonguila, A., Silou, T., Linder, M. and Desobry, S. 2009. Characteristics and Composition of *Jatropha Curcas* Oils, Variety Congo-Brazzavile. *Research Journal of Applied Sciences, Engineering and Technology*. 1(3): 154-159.
[50] Izzatie, N.I., Basha, M.H., Uemura, Y., Hashim, M.S.M., Afendi, M. and Mazlan, M.A.F. 2019. Co-Pyrolysis of Rubberwood Sawdust (RWS) and Polypropylene (PP) in A Fixed Bed Pyrolyzer. *Journal of Mechanical Engineering and Sciences*. 13(1): 4636-4647. DOI: http://doi.org/10.15282/jmes.13.1.2019.20.0390.
[51] Kaisan, M. U., Pam, G. Y., Kulla, D. M. and Kehinde, A. J. 2014. Effects of Oil Extraction Methods on Bio-Diesel Production from Wild Grape Seeds: A Case Study of Soxhlet Extraction and Mechanical Press Engine Driven Expeller Methods. *Journal of Alternate Energy Sources and Technologies.* 6(1): 35-40. DOI: http://doi.org/10.37591/joaest.v6i1.2101.
[52] Pramanik, K. 2003. Properties and Use of *Jatropha Curcas* Oil and Diesel Fuel Blends in Compression Ignition Engine. *Renewable Energy*. 28: 239-248. DOI: http://doi.org/10.1016/S0960-1481(02)00027-7.
[53] Naimah, D. and Morgunova, M. 2018. Analysis of Palm-Oil-Based Biodiesel in Indonesia Using Technological Innovation System Approach. In *ASTECHNOVA 2017*. E3S Web of Conferences. 43: 01007. DOI: http://doi.org/10.1051/e3sconf/20184301007.
[54] Mayasari, F. and Dalimi, R. 2019. Fuel Oil Supply Demand Projection and Planning in Indonesia Using System Dynamics Modeling. *International Journal of Smart Grid and Clean Energy*. 8(1): 11-21. DOI: http://doi.org/10.12720/sgce.8.1.11-21.
[55] Tahery, R. 2017. Surface Tension and Density of Mixture of m-xylene + n-alkane at 293.15 K: Analysis Under the

Extended Langmuir and Shereshefsky Models. *Journal of Chemical Thermodynamics*. 106: 95-103.
DOI: http://dx.doi.org/10.1016/j.jct.2016.11.018.

[56] Maina, P. 2014. Investigation of Fuel Properties and Engine Analysis of Jatropha Biodiesel of Kenyan Origin. *Journal of Energy in Southern Africa*. 25(2): 107-116.
DOI: http://doi.org/10.17159/2413-3051/2014/v25i2a2677.

[57] Chauhan, B.S., Kumar, N. and Cho, H.M. 2012. A Study on The Performance and Emission of a Diesel Engine Fueled with Jatropha Biodiesel Oil and Its Blends. *Energy*. 37: 616-622.
DOI: http://doi.org/10.1016/j.energy.2011.10.043.

[58] Silitonga, A. S., Hassan, M. H., Ong, H. C. and Kusumo, F. 2017. Analysis of the Performance, Emission and Combustion Characteristics of a Turbocharged Diesel Engine Fuelled with *Jatropha curcas* Biodiesel-Diesel Blends using Kernel-Based Extreme Learning Machine. *Environmental Science and Pollution Research*. 24: 25383-25405.
DOI: http://doi.org/10.1007/s11356-017-0141-9.

[59] Badan Standardisasi Nasional Indonesia (National Standardization Agency of Indonesia). 2015. Standar Nasional Indonesia (Indonesian Nasional Standard) Biodiesel SNI 7182:2015.

[60] Kian, K. and Scurto, A.M. 2018. Viscosity of Compressed CO_2-Saturated n-alkanes: CO_2/n-hexane, CO_2/n-decane, and CO_2/n-tetradecane. *The Journal of Supercritical Fluids*. 133: 411-420.
DOI: http://doi.org/10.1016/j.supflu.2017.10.030.

[61] Candeia, R. A., Silva, M. C. D., Carvalho Filho, J. R., Brasilino, M. G. A., Bicudo, T.C., Santos, I. M. G. and Souza, A.G. 2009. Influence of Soybean Biodiesel Content on Basic Properties of Biodiesel-Diesel Blends. *Fuel*. 88: 738-743.
DOI: http://doi.org/10.1016/j.fuel.2008.10.015.

[62] Prodhan A., Hasan, M. I., Sujan, S. M. A., Hossain, M., Quaiyyum, M. A. and Ismail, M. 2020. Production and Characterization of Biodiesel from Jatropha (*Jatropha curcas*) Seed Oil Available in Bangladesh. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. In-Press.
DOI: http://doi.org/10.1080/15567036.2020.1851819.

[63] Rajak, U., Chaurasiya, P.K., Nashine, P., Verma, M., Kota, T. R. and Verma, T. N. 2020. Financial Assessment, Performance and Emission Analysis of Moringaoleifera and Jatropha curcas Methyl Ester Fuel Blends in a Single-Cylinder Diesel Engine. *Energy Conversion and Management*. 224: 113362.
DOI: http://doi.org/10.1016/j.enconman.2020.113362.

[64] Chen, W., Zhao, Z. and Yin, C. 2010. The Interaction of Waxes with Pour Point Depressants. *Fuel*. 89: 1127-1132.
DOI: http://doi.org/10.1016/j.fuel.2009.12.005.

[65] Khethiwe, E., Clever, K. and Jerekias, G. 2020. Effects of Fatty Acids Composition on Fuel Properties of Jatropha Curcas Biodiesel. *Smart Grid and Renewable Energy*. 11: 165-180.
DOI: http://doi.org/10.4236/sgre.2020.1110010.

[66] Sharma Dugala, N., Goindi, G.S. and Sharma, A. 2020. Evaluation of Physicochemical Characteristics of Mahua (*Madhuca indica*) and Jatropha (*Jatropha curcas*) dual Biodiesel Blends with Diesel. *Journal of King Saud University – Engineering Sciences*. In-press.
DOI: http://doi.org/10.1016/j.jksues.2020.05.006.

[67] De, B. K. and Bhattacharyya, D. K. 1999. Biodiesel from Minor Vegetable Oils Like Karanja Oil and Nahor Oil. *Fett/Lipid*. 101(10): 404-406.
DOI: http://doi.org/10.1002/(SICI)1521-4133(199910)101:10%3C404::AID-LIPI404%3E3.0.CO;2-K.

[68] Shivani, P., Khushbu, P., Faldu, N., Thakkar, V. and Shubramanian, R.B. 2011. Extraction and Analysis of *Jatropha curcas* L. Seed Oil. *African Journal of Biotechnology*. 10(79): 18210-18213.
DOI: http://doi.org/10.5897/AJB11.776.

[69] Vu, D. N. and Lim, O. 2019. Ignition and Combustion Characteristics of Gasoline-biodiesel Blend in a Constant Volume Chamber: Effects of the Operation Parameters. *Fuel*. 255: 115764.
DOI: http://doi.org/10.1016/j.fuel.2019.115764.

[70] Canesin, E. A., Oliveira, C. C., Matsushita, M., Dias, L. F., Pedrão, M. R. and Souza, N. E. 2014. Characterization of Residual Oils for Biodiesel Production. *Electronic Journal of Biotechnology*. 17: 39-45.
DOI: http://doi.org/10.1016/j.ejbt.2013.12.007.

[71] Cataluña, R. and Silva, R. 2012. Effect of Cetane Number on Specific Fuel Consumption and Particulate Matter and Unburned Hydrocarbon Emissions from Diesel Engines. *Journal of Combustion*. 738940.
DOI: http://doi.org/10.1155/2012/738940.

[72] Ahmed, S. T. and Chaichan, M. T. 2012. Effect of Fuel Cetane Number on Multi-Cylinders Direct Injection Diesel Engine Performance and Exhaust Emissions. *Al-Khwarizmi Engineering Journal*. 8(1): 65-75.

[73] Rahman, M. M., Hamada, K. I., Noor, M. M., Bakar, R. A., Kadirgama, K. and Maleque, M. 2010. In-Cylinder Heat Transfer Characteristics of Hydrogen Fueled Engine: A Steady State Approach. *American Journal of Environmental Sciences*. 6(2): 124-129.
DOI: http://doi.org/10.3844/ajessp.2010.124.129.