

The Effect of Biodiesel Blends Made from *Carica papaya* L. Seeds on the Performance of Diesel Engine

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Abstract. Fuel oil is one of the important parts to support daily activities. The demand for fuel oil is increasing every year. Therefore, the search for the latest energy source is continuously conducted. *Carica papaya* L. seed oil is investigated as a renewable energy source replacement part of petroleum diesel fuel. *C. papaya* seed oil obtained through the extraction process using soxhlet method with n-hexane solvent. Then produce methyl ester by means of transesterification using 1 % NaOH catalyst and 20 % methanol of the weight of the oil and stirred at 400 rpm for 1 h. A mixture consisting of 10 % *C. papaya* seed biodiesel and 90 % petroleum diesel fuel, called CPSB-10, produces fuel properties that meet the specified standards by the Indonesian Directorate General of Oil and Gas. From the result of the performance test in a diesel test engine, the maximum brake power and brake thermal are consecutively 30.6 kW and 140.23 N m, the lowest sfc is 268 g kW⁻¹ h⁻¹, and the highest brake thermal efficiency is 32 %.

Keywords: Power, renewable fuel, sustainable energy, thermal efficiency.

1 Introduction

The increasing number of world population and the increasing need of human beings over time resulted in an increase in global energy demand. This fact leads to a decrease in energy supplies, especially for the types of energy coming from non-renewable sources, and even from time to time, this energy sources will eventually run out. Aware of this matter, the study of sustainable energy has been carried out by many researchers using many sources of waste material that can be found in their surroundings such as biogas [1–3], waste leaves [4, 5], waste twigs [6], and non-edible seeds [7, 8].

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The largest portion of oil consumption is in the transportation sector [9], and transportation is also the most affected sector with increasing population due to the increasing mobility of people and goods. The number of motor vehicles continues to increase in line with the increase in population and therefore will also increase the amount of fuel consumption and as a result, the amount of oil reserve will decline rapidly. At present, a lot of research has been done to find alternative fuel sources that can effectively reduce or even replace conventional fossil fuels that are commonly used today. These studies are conducted to find alternative fuels for both gasoline and diesel engines. In Indonesia, the biodiesel production process as an alternative fuel for diesel engines is still quite expensive because it uses palm oil as the raw material. Palm oil still has a high economic value because palm oil and its derivatives can be used in the food, cosmetics, and other industries, so in the long term it is less suitable and less viable if used as an alternative to biodiesel because of the demand competition with various crude palm oil (CPO) industry users [10].

The selection of papaya seeds (*Carica papaya* L.) as the raw material for sustainable biodiesel is due to papaya seed is considered as waste product and classified as non-edible material. Figure 1 shows the world production of papaya fruit in 2014. Indonesia is among the top 10 countries that produce the largest number of papaya fruit each year. For example: in 2014, this country produced 840 121 t of papaya fruit. With a seed content of about 15 % [11], it can be said that Indonesia produced more than 120 000 t of papaya seeds that year, with an oil content of about 30 % [12], means that Indonesia has the potential to produce around 30 000 t of papaya seed oil annually.

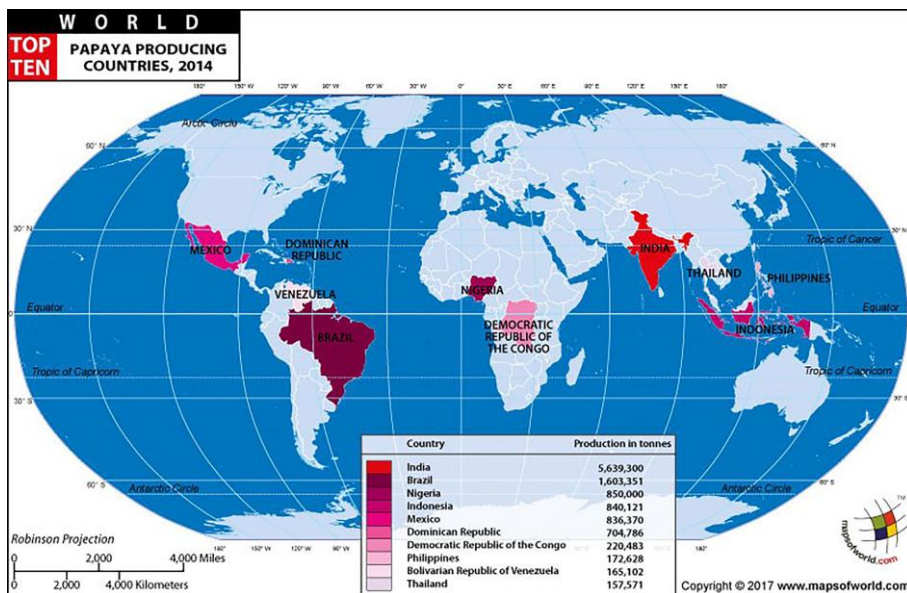


Fig. 1. World map of top ten papaya producing countries in 2014 [13].

Papaya plants include the main commodity fruit group that received priority research and development from the national horticulture research center in Indonesia. In dry weight, papaya seeds contain up to 30 % oil [12]. Compared with 19.63 % soybean, sunflower seeds 22.23 % and coconut 54.74 %, the oil content in papaya seed is relatively high [14], so it is very prospective to be developed into alternative fuel. In addition, papaya fruit is not produced seasonally so that the harvest time can be done anytime.

Similar to other vegetable oils processing, papaya seed oil can be converted into biodiesel through conventional processes. Conventional processes for producing biodiesel/FAME involve drying, oil extraction, refining, and transesterification. *C. papaya* seed biodiesel production has been done in a previous study [15] but has never been tested on a diesel engine with variable engine speed.

The research process will be done by drying the *C. papaya* seed first, then extracting the oil, then converting triglycerides and fatty acids into biodiesel through the transesterification process. *C. papaya* seed biodiesel will be blended with pure petroleum diesel fuel with 10 % and 20 % biodiesel.

The fuel property test of these biodiesel and petroleum diesel blend will be conducted in accordance with the specifications set by the Indonesian Directorate General of Oil and Gas for diesel engine fuel oil, where the reference properties are: density, kinematic viscosity, calculated cetane index, flash point, pour point, distillation temperature, sulfur content, water content, ASTM color, and heating value. Only the mixtures whose properties meet the specification standards that will be tested on diesel engines to know their effect on the performance of diesel engines.

2 Experimental method

The research process was conducted in fuel laboratory at Petra Christian University. The first step that needs to be done is the preparation of tools and materials for the process of extracting oil from papaya seeds. The tools include soxhlet apparatus, scales, volumetric flask, electric stove, water pump, filter paper, and a small hose. Materials needed are papaya seeds oil and n-hexane.

The obtained papaya seeds were dried under the sun for 3 d and then heated in 100 °C ambient for 30 min. After the drying process, then the process of grinding papaya seeds by blender and stored in a closed container. The process of extracting papaya seed oil is done by a Soxhlet apparatus. The extracting process runs about 1 h to 2 h, the amount of papaya seeds used for one time the process of extracting is 40 g and using 125 mL of n-hexane. After the oil obtained from papaya seed oil extraction must be purified first so that no liquid n-hexane in papaya seed oil. The purification process is done using a Rotary Evaporator tool. Purification process lasts for 1 h with temperature 60 °C with enough rotation. After the Rotary process is complete it will be obtained purified oil and n-hexane which can be reused for another extraction process.

After getting pure papaya oil, the transesterification process is done. The required tools are magnetic hotplate stirrer, thermometer, and aluminum foil. The materials used are methanol with 99.9 % purity, NaOH, and papaya seed oil. In the process of transesterification, papaya seed oil used NaOH as much as 1 % of the weight of oil and methanol 20 % of the weight of oil. The amount of oil used in the transesterification process is 250 mL. The main thing to do is dissolve the first NaOH together with methanol using a magnetic stirrer and then also done heating papaya seeds oil up to 60 °C. When all NaOH is dissolved, then mixture between methanol and NaOH mixed into papaya seed oil and stirring process. After the transesterification process is complete the resulted papaya seed oil is sterilized for 24 h for the separation process between methyl ester and glycerol. After that will get two layers of the top layer called methyl ester and the bottom layer called glycerol.

The mixing of methyl ester with diesel is done with percentage of methyl ester volume of 10 % and 20 % and then tested the characteristic of the mixture at UPPS Laboratory of Pertamina Surabaya and the performance test of the machine was done in Automotive Laboratory at Petra Christian University by using water brake dynamometer and a diesel test engine.

3 Results and discussion

3.1 Fuel characteristics

The result of fuel property test obtained is the result of testing at Pertamina UPPS Laboratories. The results of the data obtained are in accordance with the specifications set by the Indonesian Directorate General of Oil and Gas. 978.K/10/DJM.S/2006 dated November 19, 2013, and these specifications serve as a standard benchmark of biodiesel properties allowed as diesel engine fuel oil.

Results from the fuel property test of B-10 mixture (CPSB-10) have met the specifications of fuel use in diesel engines. While the B-20 mixture (CPSB-20) does not meet the specifications because its flash point is only 51 °C which is lower than the requirement by 1 °C. For this reason, CPSB-20 is not used on diesel engine performance testing. The engine performance tests in this research were done in Automotive laboratory at Petra Christian University and the specification of diesel engine used are provided in Table 1. The comparison of fuel property test results between Pure Petroleum Diesel (PPD) and CPSB-10 are given in Figure 2.

Table 1. Diesel Engine Specification.

| Items | Description |
|-----------------------|-----------------------------------|
| Type | ISUZU Diesel Engine 4JA - I. OHV |
| Cylinder | 4 - in line |
| Combustion type | Direct injection |
| Bore x Stroke | 93 mm × 92 mm |
| Cylinder volume | 2 499 cm ³ |
| Compression ratio | 18.4 |
| Compression pressure | 31 kg cm ⁻² |
| Maximum output | 86 ps per 3 900 rpm ^{*)} |
| Idling speed | 750 rpm |
| Number of nozzle hole | 4 |
| Injection pressure | 182 kg cm ⁻² |
| Injection timing | 12° before TDC |

^{*)}SI: 1rpm= 1/60 Hz

Figure 2a shows the density test result using ASTM D-1298 standard. PPD density is 0.832 6 while the density of CPSB-10 is 0.835 kg/L. The higher the density value will adversely affect the performance of the injectors due to the greater loading and filling load and may affect the fuel atomization efficiency for the combustion system. From the test results, CPSB-10 has a higher density than PPD, thus potentially reducing injector performance.

Figure 2b shows kinematic viscosity at 40 °C test result using ASTM D-445 standard. PPD kinematic viscosity is 2.49 cSt while the kinematic viscosity of CPSB-10 is 2.6 cSt. It is observed that the increase in kinematic viscosity value is due to the high cyclopropene fatty acid and palmitic acid [16]. The higher the value of kinematic viscosity leads to a larger droplet size resulting in injector resistance and forming the engine deposit due to inadequate fuel atomization. And usually, the higher the value of kinematic viscosity, the flash point value is lower. From the test results, CPSB-10 has a higher kinematic viscosity than PPD, thus giving the same impact with higher density that is potentially reducing injector performance.

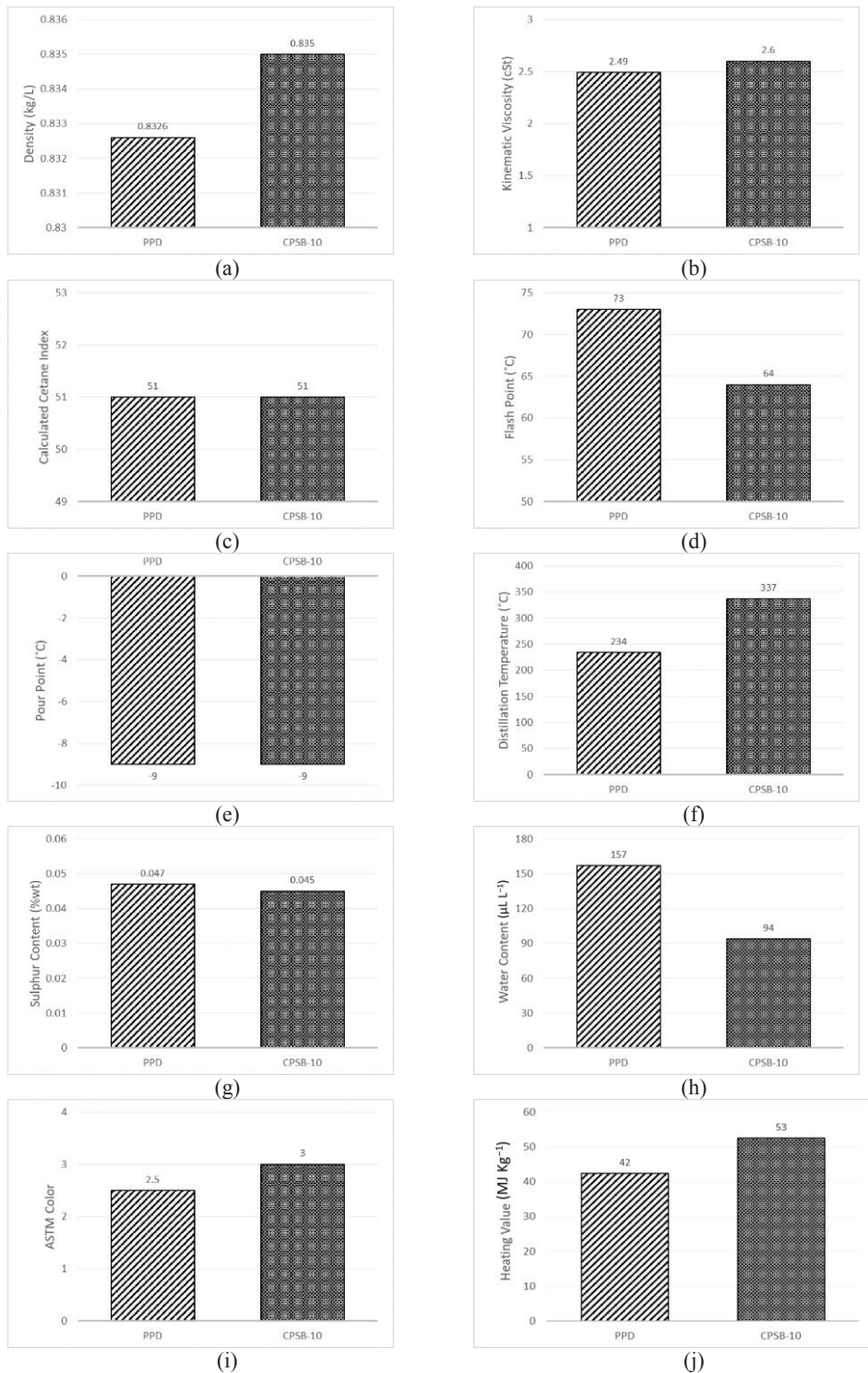


Fig. 2. PPD and CPSB-10 properties comparison (a) density, (b) kinematic viscosity, (c) calculated cetane index, (d) flash point, (e) pour point, (f) distillation temperature, (g) sulphur content, (h) water content, (i) ASTM colour, and (j) heating value.

Figure 2c shows the Calculated Cetane Index (CCI) test result using ASTM D-4737 standard. CCI of CPSB-10 is the same as the CCI of PPD which is 51. CCI number is obtained by calculation using distillation measurement data and density measurement at 15 °C. The magnitude of CCI affects the combustion quality. High CCI number in fuel will shorten the combustion time resulting in complete combustion, improving cold ignition, reducing exhaust emissions as well as engine deposits, and preventing engine knock. Both PPD and CPSB-10 have the same CCI number so it can be said that they will produce the same combustion quality under the same conditions.

Figure 2d shows the flash point test result using ASTM D-93 standard. The flash points of PPD and CPSB-10 are 73 °C and 64 °C respectively. The lower the flash point value accelerates the burning speed of the fuel. In addition, fuel storage must be at a temperature lower than the flash point value in order to avoid the explosion. From the test results, CPSB-10 has a lower flash point than PPD, thus its burning speed is higher than PPD.

Figure 2e shows the pour point test result using ASTM D-97 standard. The pour point of PPD and CPSB-10 are the same at -9 °C. Pour point is the temperature when the liquid starts to gel (or no longer viscous), so this property indicates the ability of the fuel to flow at low temperatures. The lower the pour point value the fuel is not easy to freeze and does not cause difficulties in cold start conditions. Both PPD and CPSB-10 have the same pour point temperatures so it can be said that they will have the same cold starting ability.

Figure 2f shows the distillation temperature test result using ASTM D-86 standard. PPD distillation temperature is 234 °C while the distillation temperature of CPSB-10 is 337 °C. There is a correlation between distillation temperature and kinematic viscosity of fuel where the increase of distillation temperature is affected by the increase in kinematic viscosity. CPSB-10 has a higher distillation temperature than PPD, this is proportional to the results of CPSB-10 kinematic viscosity test which is also higher than the PPD.

Figure 2g shows the sulfur content test result using ASTM D-4294 standard. The amount of Sulphur content in PPD and CPSB-10 are 0.047 %wt and 0.045 %wt respectively. High sulfur content in fuels may cause damage to engine components due to corrosion and may lead to emissions of sulfur dioxide and sulfur trioxide gas, both of which contribute to acid rain and smoke pollution. The sulfur content of PPD and CPSB-10 is much lower than the required sulfur content which must be below 0.25 %wt, so it can be assured that both fuels are not easy to cause corrosion or SO_x pollution.

Figure 2h shows the water content test result using ASTM D-6304 standard. Water content in PPD is 157 μL L⁻¹, and in CPSB-10 is 94 μL L⁻¹. The decrease of water content in biodiesel is due to the presence of ester bonds, thus having a higher polarity than diesel fuel and tends to be stronger to absorb water [17]. The excessively high water content in the fuel can result in incomplete combustion and degrade the performance of the diesel engine. Although both fuels meet the permissible water content limits, the CPSB-10 has a lower water content that can result in better combustion.

Figure 2i shows ASTM color test result using ASTM D-6045 standard. The color test results for PPD and CPSB-10 are 2.5 unit and 3 units respectively. The value of the ASTM color test does not affect the performance of the diesel engine. This number index is only to determine the color category visually, where the greater the index number indicates that the color of the fuel is darker (from a pale straw through to a deep red). CPSB-10 has a greater ASMT color unit than PPD because its color is slightly darker.

Figure 2j shows the heating value test result using an Oxygen Bomb Calorimeter. The heating value of PPD is 42 MJ/kg and the heating value of CPSB-10 is 53 MJ kg⁻¹. The heating value of a fuel affects both the brake thermal efficiency and combustion

characteristics of an engine. Because CPSB-10 has a higher heating value than PPD, it is expected that CPSB-10 will provide higher thermal efficiency than PPD.

3.2 Engine performances

The result of engine performance test obtained is the result of testing performed at Automotive Laboratory in Petra Christian University using a water-brake dynamometer. The tests use pure petroleum diesel fuel (PPD), and 10 % *C. papaya* seed biodiesel blend (CPSB-10). Parameters obtained from the test are brake power (kW), brake torque (N m), specific fuel consumption (fuel g kW⁻¹ h⁻¹), and brake thermal efficiency (%). Engine performance test results using PPD and CPSB-10 are presented below.

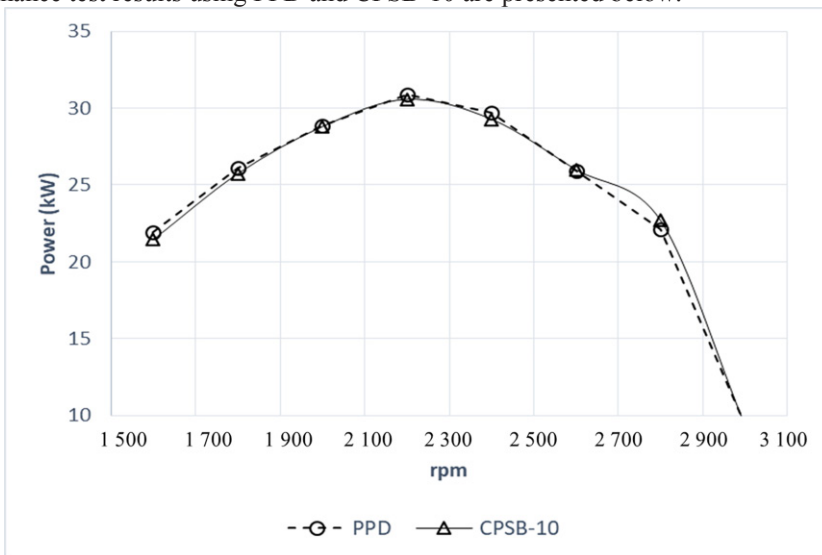


Fig. 3. Comparison of engine brake power vs. rpm test results between PPD and CPSB-10

Figure 3 shows that at 2 200 rpm (1rpm=1/60 Hz) is the peak brake power point of both fuels. PPD has a peak value of 30.9 kW and CPSB-10 has a peak value of 30.6 kW. Although the peak brake power of CPSB-10 is lower than the peak brake power of PPD, it can be seen that the difference is not significant along the range of engine revolution. When compared with PPD, the peak power obtained by CPSB-10 has a slight decrease of around 1 %. It can also be seen from the curves that the brake power produced by CPSB-10 tends to be higher than the brake power produced by PPD at higher engine revolution. Although CPSB-10 has a higher energy value as shown by the heating value test in figure 2j, it does not mean that CPSB-10 will produce higher engine power than PPD. The reason is that in addition to heating value, the performance of a diesel engine is also influenced predominantly by other characteristics in the fuel such as density, kinematic viscosity, distillation temperature, and flash point that affect the atomization process in combustion [18].

Figure 4 shows that the peak brake torque produced by both fuels is reached at 2 000 rpm. PPD has a peak brake torque of 141.2 N m and CPSB-10 has a peak brake torque of 140.2 N m. Although the peak brake torque of CPSB-10 is lower than the peak brake torque of PPD, it can be seen that the difference is not significant along the range of engine revolution. When compared with PPD, the peak torque obtained by CPSB-10 has a slight decrease of around 0.7 %. Similar to the trend seen in engine brake power charts, the torque curves produced by CPSB-10 also tends to be higher than the torque produced by PPD at

higher engine revolution. Overall it can be concluded that CPSB-10 produces engine power and torque characteristics that are not much different from PPD.

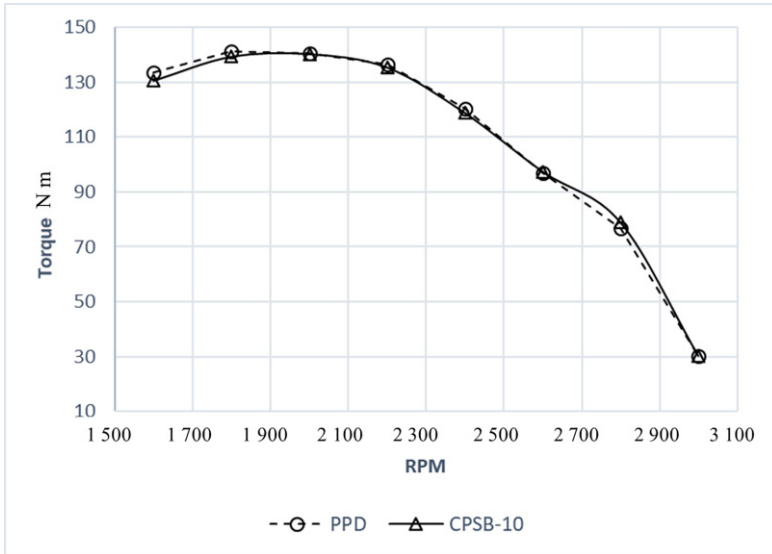


Fig. 4. Comparison of engine brake torque vs. rpm test results between PPD and CPSB-10.

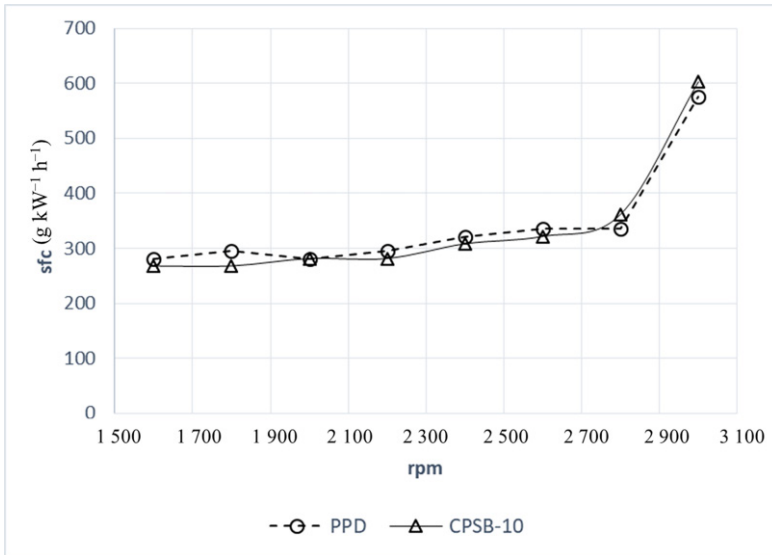


Fig. 5. Comparison of engine sfc vs. rpm test results between PPD and CPSB-10.

Figure 5 shows that sfc increases with increasing engine rpm for both fuels. At the peak brake power at 2 200 rpm, an engine with CPSB-10 fuel produces work with sfc of 281.5 g kW⁻¹ h⁻¹ or 4.5 % lower than PPD fuel. The sfc increases gradually from the lowest rpm to 2 800 rpm where the value does not change much and then rises steeply when the rpm is above 2 800. The increase in sfc at higher rpm is due to the decrease in volumetric efficiency because less time is available for suction strokes when a reciprocating engine is running at high speed. Besides, flow and mechanical friction loss also increases significantly at high engine rpm. Overall it can be concluded that within the

normal rpm working range, CPSB-10 fueled engine gives a slightly better sfc than PPD fueled engine.

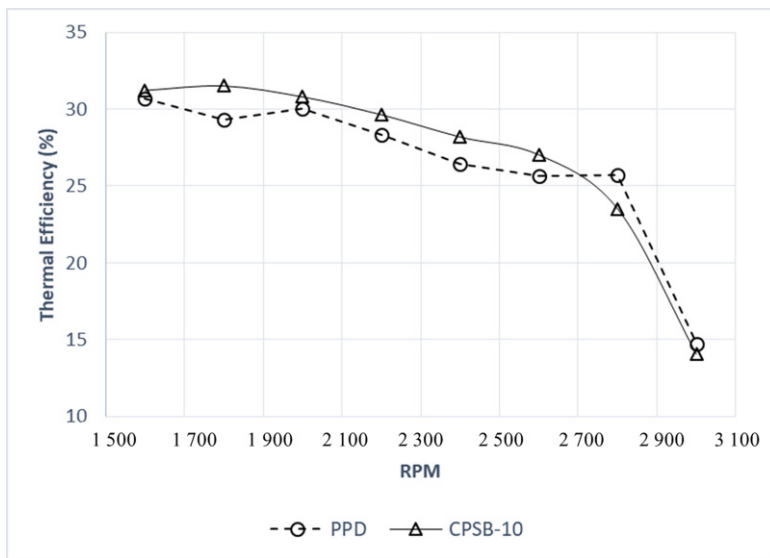


Fig. 6. Comparison of engine brake thermal efficiency vs. rpm test results between PPD and CPSB-10.

Figure 6 shows that the brake thermal efficiency decreases with increasing engine rpm for both fuels. At the peak brake power at 2 200 rpm, an engine with CPSB-10 fuel produces work with 29.6 % of brake thermal efficiency or 4.6 % higher than PPD fuel. Brake thermal efficiency decreases gradually from the lowest rpm to 2 700 rpm where the value does not change much and then falls steeply when the rpm is above 2 700. The decrease in thermal efficiency at higher rpm is due to the pumping and mechanical frictional losses, and the shorter period within which combustion has to take place. Overall it can be concluded that within the normal rpm working range, CPSB-10 fueled engine gives a slightly better thermal efficiency than PPD fueled engine as expected from the test results of a higher CPSB-10 heating value than the PPD.

The fuel characteristics test result shows that although there are differences in some CPSB-10 properties when compared with PPD, the values of CPSB-10 properties are still within the allowable range of standard diesel fuel oil specification set by the Indonesian Directorate General of Oil and Gas. Testing of diesel engine performance has been carried out using a water brake dynamometer and gives approximately the same results between CPSB-10 and PPD. The value and character of the engine power and torque produced by both fuels are not much different, but there is a slight difference in the sfc value and thermal efficiency between CPSB-10 and PPD. CPSB-10 has a better sfc and thermal efficiency than PPD which is mainly due to its higher heating value.

4 Conclusion

The non-edible *C. papaya* seeds which are classified as waste materials can be used as alternative energy sources to become biodiesel after going through the transesterification process. A mixture consisting of 10 % *C. papaya* seed biodiesel and 90 % petroleum diesel fuel, called CPSB-10, produces fuel properties that meet the specified standards by the Indonesian Directorate General of Oil and Gas for the use of such fuel in diesel engine

vehicles. From the result of the performance test in a diesel test engine, the maximum brake power and brake torque are consecutively 30.6 kW and 140.23 N m, the lowest sfc is 281.5 g kW⁻¹ h⁻¹, and the highest brake thermal efficiency is 32 %. The value and character of the engine power and torque produced by CPSB-10 are not much different when compared to pure petroleum diesel fuel (PPD), but there is a slight difference in the sfc value and thermal efficiency between CPSB-10 and PPD. CPSB-10 has a better sfc and thermal efficiency than PPD within the normal rpm working range.

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