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Experimental investigation of the effect of *Nephelium Lappaceum* seed biodiesel to the automotive diesel engine performance

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Abstract. To decrease the reliance of fossil fuel and at the same time utilizing organic waste, an investigation regarding the viability of *Nephelium lappaceum* (rambutan fruit) seed oil as biodiesel has been conducted. The investigation was carried out by comparing the fuel characteristics of *Nephelium lappaceum* seed biodiesel with pure petro-diesel produced in Indonesia. The outcome of this investigation suggested that *Nephelium lappaceum* seed biodiesel has comparable fuel characteristics as that of commercial diesel fuel. Further comparison was also conducted by testing these fuels in diesel engine. The series of tests compared these fuels in terms of fuel consumption, brake mean effective pressure, thermal efficiency, torque, and power. The result indicates that *Nephelium lappaceum* seed biodiesel has better engine performance than pure petro-diesel. Overall, the output of this study proves the feasibility of *Nephelium lappaceum* seed biodiesel as environmentally friendly substitute for pure petro-diesel fuel in Indonesia.

1. Introduction

The economic growth is strongly affected by many factors, including the availability of energy resources. The demand of fossil fuel raises while the supply for it are limited [1-3]. The most prominent hurdle faced by society in terms of energy are the scarcity of fossil fuel and its damage to environment from utilizing it [4,5]. One solution to resolve this crisis comes by developing alternative source of energy, mainly known as renewable energy [6].

One of many examples of renewable energy which may solve the energy problem is biodiesel [7,8]. Biodiesel is composed of long-chain of fatty acids with alcohol attached to them [9,10]. Biodiesel is a type of biofuel, and as a biofuel, it is an intriguing object of research around the world [11]. Biodiesel requires organic substances as raw material and they are easily obtained from vegetation crops and natural wastes found around society [12]. Because of the abundant resources of its materials (350 crops) [13-15], biodiesel production is highly supported [16]. Most of these materials are easily found in rural area and may benefit the community of those area [17]. To obtain biodiesel, transesterification technique is known to be the most common and most important technique to be utilized [18,19].

Compared to fossil fuel, biodiesel prevails in term of renewability, ease of utilization, lower emission, and energy efficacy. The environmentally friendly and biodegradable characteristics of biodiesel support biodiesel viability as solution for energy crisis problem [3,20]. Another strong advantage offered by biodiesel is its capability to be blended with common fuels, regardless of the ratio between them. Utilization of biodiesel only demand small to no further upgrade and adjustments in the engine [21-23]. Combining biodiesel with diesel was discovered to add some numbers of advantages to diesel engine such as lower brake specific fuel consumption, higher power and torque, and higher brake thermal efficiency [7,24]. Renewable energy like biodiesel also helps in resolving the rise of energy consumption and hydrocarbon price in developing countries by offering a low-cost alternative [25].

While the advantages of biodiesel seem prominent, it has its drawback. Since biodiesel uses organic materials including food crops, it may diminish the stock for food supply and deemed as wasting food resources. Solution to this problem includes the use of non-edible raw material for biodiesel like animal tallow and shrubs [26,27]. Other non-edible raw material includes *Nicotiana tabacum, Cerbera manghas, Calophyllumin ophyllum, Jatropha curcas,* and *Hevea brasiliensis* which require additional process because of their elevated free unsaturated fat content [28-30].

The diversity of flora and abundant number of organic matters in Indonesia provide favorable condition for biodiesel development. Rambutan fruit with its scientific name *Nephelium lappaceum* is commonly found in Indonesia. Studies have suggested the viability of producing biodiesel from *Nephelium lappaceum* seed oil [31]. The extraction of oil from *Nephelium lappaceum* was found to be 40% by Wong et al, 41.3% by Wanayanuwattikun et al and 42 % by Nguyen et al [31-33]. Wanayanuwattikun et al discovered the cetane index of *Nephelium lappaceum* seed oil to be 61.12 [33]. Albeit all these studies, engine testing for biodiesel derived from *Nephelium lappaceum* seed oil has not been conducted before. By conducting an engine testing, the potential of *Nephelium lappaceum* seed oil as an alternative fuel for diesel engine can be determined further.

2. Experimental methods

Nephelium lappaceum seeds were dried and crushed. Afterward, the process of extracting the oil from these seeds were done by using soxhlet instrument. After obtaining the seed oil, the oil was purified by using rotary evaporator to separate the remnant of n-hexane in the oil. After purified seed oil was obtained, the transesterification process was commenced using magnetic hotplate stirrer.

After completing the transesterification process, the oil was idled for 24 hours to separate the glycerol and methyl esters. Subsequently, the methyl ester was heated to evaporate methanol and n-hexane. The obtained methyl ester was combined with petro-diesel to obtain biodiesel. Since the methyl ester is obtained from *Nephelium lappaceum* seed, the biodiesel is named *Nephelium lappaceum* seed biodiesel. The methyl ester and pure petro-diesel were mixed under 10:90 ratio.

Figure 1. Photographic view of combustion engine laboratory in Petra Christian University.

The obtained *Nephelium lappaceum* seed biodiesel was tested for its fuel characteristics and engine performances. The fuel characteristics tests were carried under ASTM (American Society for Testing and Materials) standards in UPPS (*Unit Produksi Pelumas Surabaya*, Surabaya Lubricant Production Unit) laboratory in Pertamina. The engine performance test of *Nephelium lappaceum* seed biodiesel was performed using diesel engine and water brake dynamometer. The engine performance test was carried in combustion engine laboratory under management of Petra Christian University. The condition of combustion engine laboratory is shown in figure 1. The specification of diesel engine and water brake dynamometer are provided in table 1 and table 2, respectively.

Table 1. Diesel engine specification.

Items	Description
Brand and type	Automotive diesel engine ISUZU (4JA - I. OHV)
Type of combustion	Direct injection
Ratio of compression	18.4
Volume of the cylinder	2499 cm^3
Pressure of compression	31 kg/cm^2
Bore	93 mm
Stroke	92 mm
Peak output	86 ps / 3900 RPM (Rotation per minute)
Number of cylinder and arrangement	4 - in line
Speed during idle	750 RPM
Number of holes in nozzle	4
Pressure during injection	182 kg/cm^2
Timing of injection	12° before TDC (Top dead center)
Type of pump injection	Bosch Distributor
Type of nozzle	Hole

Table 2. Water brake dynamometer specification.

Items	Description
Brand and type	Zollner (3n19A)
Balancer of weight	Sluice gate
Impeller number	1
Direction of rotation	1 direction
Peak speed	7500 RPM
Peak performance	120 kW

The engine performance and fuel characteristics tests were also carried on pure petro-diesel produced by local fuel company in Indonesia. The fuels were tested in order to compare their result with *Nephelium lappaceum* seed biodiesel. The comparison is used to determine the performance of *Nephelium lappaceum* seed biodiesel and its viability as a substitute for pure petro-diesel.

3. Results and discussion

3.1. Fuel characteristics

The characteristics of fuels were tested using ASTM standards. The results of the fuel characteristics tests are displayed in table 3. In this table, pure petro-diesel is abbreviated to PPD and *Nephelium lappaceum* seed biodiesel is abbreviated to NLSB. The test result of density testing under ASTM D-1298 standard suggested that *Nephelium lappaceum* seed biodiesel has higher density of 0.8331 Kg/L compared to pure petro-diesel with density of 0.8326 Kg/L. The test results of kinematic viscosity under ASTM D-445 standard suggested that *Nephelium lappaceum* seed biodiesel has higher kinematic viscosity level of 2.55 cSt compared to pure petro-diesel with kinematic viscosity level of 2.49 cSt.

The test result of flash point testing under ASTM D-93 standard suggested that pure petro-diesel has higher flash point with value of 73 °C compared to *Nephelium lappaceum* seed biodiesel with flash point of 58 °C. The test result of pour point testing under ASTM D-97 standard suggested that *Nephelium lappaceum* seed biodiesel has higher pour point of -4 °C compared to pure petro-diesel with pour point of -9 °C. The test result of Sulphur content testing under ASTM D-4294 standard suggested that pure petro-diesel has higher sulfur content of 0.047 %wt compared to *Nephelium lappaceum* seed biodiesel with sulfur content of 0.041 %wt. The test result of color testing under ASTM D-4294 standard suggested that pure petro-diesel and *Nephelium lappaceum* seed biodiesel has similar color point of 2.

Table 3. Summary of fuel characteristics for pure petro-diesel (PPD) and *Nephelium lappaceum* seed biodiesel (NLSB).

Parameters	PPD	NLSB
Density (kg/L)	0.8326	0.8331
Kinematic viscosity (cSt)	2.49	2.55
Flash point (°C)	73	58
Pour point (°C)	-9	-6
Sulfur content (%wt)	0.047	0.041
Color characteristic	2.5	2.5
Water content (ppm)	157	117
Cetane index	51	51
Distillation point (°C)	234	337

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The test result of water content testing under ASTM D-6304 standard suggested that pure petro-diesel has higher water content with value of 157 ppm compared to *Nephelium lappaceum* seed biodiesel with water content of 117 ppm. The water content follows the standard of EN 14214 which is below 500 mg/kg or 500 ppm [31]. The test result of cetane index testing under ASTM D-4737 standard suggested that pure petro-diesel and *Nephelium lappaceum* seed biodiesel has similar cetane index of 51. This value of cetane number is acceptable under standard of ASTM D6751 which requires the cetane index of diesel fuel to be higher than 47 [31]. The test result of distillation point testing under ASTM D-86 standard suggested that *Nephelium lappaceum* seed biodiesel has higher distillation point of 337 °C compared to pure petro-diesel with distillation point of 234 °C.

3.2. Engine performances

The results of the engine performance tests are displayed from figure 2 to figure 6. Similar with fuel characteristics test results, pure petro-diesel is abbreviated to PPD and *Nephelium lappaceum* seed biodiesel is abbreviated to NLSB.

Power parameter shows the capability of engine in performing movement under certain load. Engine testing result for power value under various range of RPM is presented in figure 2. The result suggested that *Nephelium lappaceum* seed biodiesel has higher average power value of 11.98 HP (horse power) compared to pure petro-diesel with average power value of 11.25 HP. *Nephelium lappaceum* seed biodiesel has higher average power of 6.1 % than pure petro-diesel.

Torque level indicates the capability of an engine to produce movement. Engine testing result for torque value under various range of RPM is presented in figure 3. The result suggested that *Nephelium lappaceum* seed biodiesel has higher average torque value of 34.78 Nm compared to pure petro-diesel with average torque value of 32.65 Nm. *Nephelium lappaceum* seed biodiesel has higher average torque of 6.14 % than pure petro-diesel.

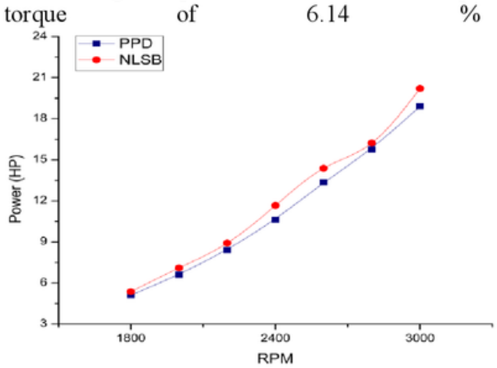

Figure 2. Power engine test results of various diesel fuels with respond to RPM changes.

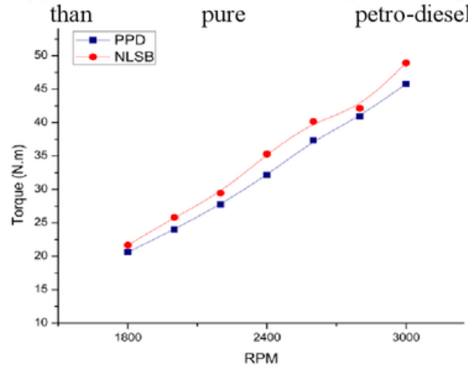

Figure 3. Torque engine test results of various diesel fuels with respond to RPM changes.

Break mean effective pressure (BMEP) is one of many parameters used to assess the engine performance of fuel. Engine testing result for BMEP value under various range of RPM is presented in figure 4. The result suggested that *Nephelium lappaceum* seed biodiesel has higher average BMEP value of $1.72x10^{-6}$ kg/cm^2 compared to pure petro-diesel with average BMEP value of $1.62x10^{-6}$ kg/cm^2. *Nephelium lappaceum* seed biodiesel has higher average BMEP of 6.13 % than pure petro-diesel.

Specific fuel consumption (SFC) indicates the number of fuel utilized in providing the engine with power in an hour. Engine testing result for SFC value under various range of RPM is presented in figure 5. The result suggested that *Nephelium lappaceum* seed biodiesel has higher average SFC value of 0.3757 kg/HP.hour compared to pure petro-diesel with average SFC value of 0.4014 kg/HP.hour. *Nephelium lappaceum* seed biodiesel has lower average SFC of 6.85 % than pure petro-diesel.

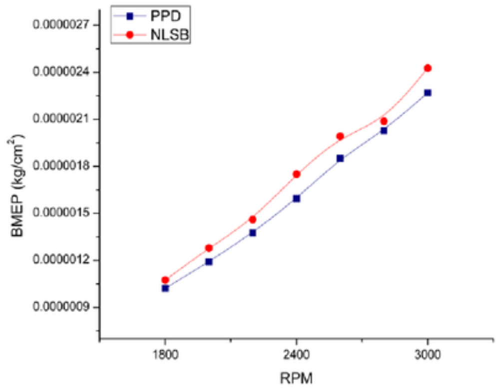

Figure 4. BMEP engine test results of various diesel fuels with respond to RPM changes.

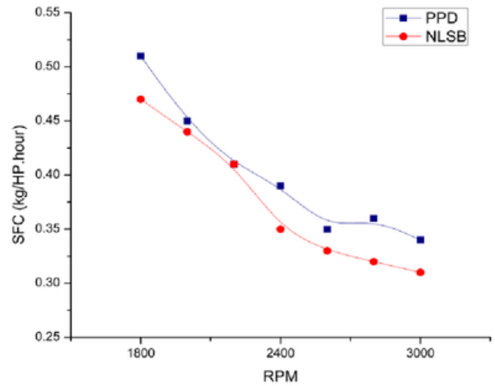

Figure 5. SFC engine test results of various diesel fuels with respond to RPM changes.

Thermal efficiency is parameter used to indicate the economical advantage of an engine when operating using certain fuel. Engine testing result for thermal efficiency value under various range of RPM is presented in figure 6. The result suggested that *Nephelium lappaceum* seed biodiesel has higher average thermal efficiency value of 17.38 % compared to pure petro-diesel with average thermal efficiency value of 16.12 %. *Nephelium lappaceum* seed biodiesel has higher average thermal efficiency of 7.26 % than pure petro-diesel.
The engine performance tests in *Nephelium lappaceum* seed biodiesel bolster the fuel characteristics investigation of *Nephelium lappaceum* seed biodiesel. Lower fuel flow caused by the low viscosity of *Nephelium lappaceum* seed biodiesel explains its higher power value compared to pure petro-diesel [34]. The higher power, thermal efficiency and lower specific fuel consumption in *Nephelium lappaceum* seed biodiesel compared to pure petro-diesel may be instigated from the lower water content of *Nephelium lappaceum* seed biodiesel [35].

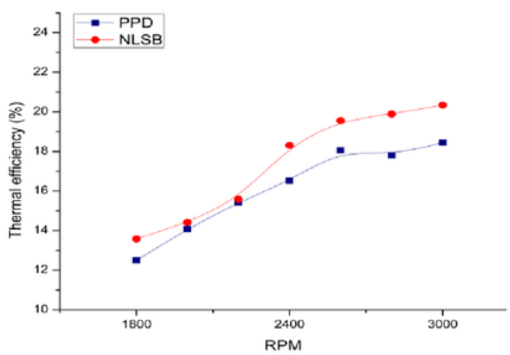

Figure 6. Thermal efficiency engine test results of various diesel fuels with respond to RPM changes.

4. Conclusion

Based on the investigations, it can be concluded that *Nephelium lappaceum* seed biodiesel is a viable substitute for pure petro-diesel. The fuel characteristics of *Nephelium lappaceum* seed biodiesel is comparable with pure petro-diesel which means it meets the standard of an engine fuel. From the engine performance test, the *Nephelium lappaceum* seed biodiesel displays better performance compared to pure petro-diesel. In term of power, torque, BMEP, SFC, and thermal efficiency, *Nephelium lappaceum* seed biodiesel is better compared to that of pure petro-diesel. Another advantage of *Nephelium lappaceum* seed biodiesel is found in its low sulfur content. The low sulfur content may reduce the SOx emission in the exhaust. The lower SFC and higher thermal efficiency in *Nephelium lappaceum* seed biodiesel may help the effort to solve the energy crisis faced by society today.

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