Study on the utilization of essential oil as an additive for pure plant oil in single cylinder diesel engine

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Abstract. This paper discusses an effect of rhodinol and turpentine-based bio-additives to improve pure plant oil characteristics. Rhodinol and turpentine were added to PPO at 1% by volume. Testing was conducted on single cylinder diesel engine for agriculture application referring to SNI 0119:2012. The results of fuel characteristics show that bio-additive+PPO could fulfill the quality standards of SNI 7431:2015. Both rhodinol and turpentine showed capability to reduce water and particle content in PPO. Engine test results showed that at engine speed of 1800 rpm, turpentine+PPO could reach a maximum power of 4.53 kW, maximum torque of 24.06 Nm, smoke opacity of 6.87 FSN, and specific fuel consumption of 145.62 g/kWh; while the PPO had maximum power of 4.39 kW, maximum torque of 23.31 Nm, smoke opacity of 7.56 FSN, and specific fuel consumption of 150.12 g/kWh. Here, rhodinol+PPO were also slightly higher on power, torque and lower on smoke emission, and specific fuel consumption compared with PPO without additive. In general, rhodinol and turpentine were slightly higher on engine power and torque with lower specific fuel consumption and lower smoke emission. However, reduction of water and particle content must be further investigated to have better understanding on its effect on engine components lifetime.

1. Introduction

The use of vegetable oil as an alternative fuel to substitute fossil fuels is part of the government’s national energy policy as mandated by the Ministry of Energy and Mineral Resources Regulation No. 12/2015 [1] on an acceleration of utilization biofuel such as Biodiesel, Bioethanol, and Vegetable Oil (Bio-Oil). The regulation states that bio-oil with minimum ratio of 20% by volume to conventional fuel oil will be implemented on low and medium speed diesel application at industry, transportation, and power generation starting from 2020. This will reduce utilization of fossil fuel oil significantly while bring other advantages as environmentally friendly fuel. The use of bio-oil as an energy source has been studied in various forms such as pure bio-oil without modification (Pure Plant Oil), esterification process to form Fatty Acid Methyl Ester (FAME), and with hydrogenation vegetable oil (HVO). The study showed that FAME and HVO have similar fuel characteristics including density, viscosity, final boiling point (FBT). Moreover, they have been superior on cetane number which influences to better combustion characteristics with ordinary diesel fuel. Furthermore, FAME and HVO have resulted in lower emission compared to diesel fuel, and especially HVO has identical power due to its comparable of heating value with diesel fuel [2]. However, FAME and HVO are more
expensive than diesel fuel due to its fuel processing. Thus, bio-oil shows an advantage as it has potential to reduce the fuel process price significantly.

Indonesia has abundant sources of raw material for biofuels including coconut oil, palm oil, castor oil (*Jatropha curcas*), soybean oil, canola oil, and so on [3]. Although almost all of sources available in Indonesia are classified as edible oil, palm oil, due to its abundant supply which is around 25 million tons per year, can be considered a promising supply amount for biofuel application. Bio-oil in form of straight vegetable oil (SVO) or pure plant oil (PPO) has a high viscosity of 30 to 50 cSt at 40 °C compared to diesel oil which has a viscosity of 2 to 5 cSt. This high difference in viscosity will negatively affect the atomization of fuel from vegetable oils [4]. Application of PPO as an alternative fuel in diesel engine can be done in various methods such as modifying an engine by providing heating system at fuel lines, blending with conventional fuel at certain ratios and heating at around 80 °C to lower its viscosity. Kadarohman et al. [5] reported direct utilization of PPO with solvents or additives and modified them using a heater or heat exchanger in the fuel line to improve its fuel characteristics. Here, an additive from essential oil was introduced to improve combustion efficiency and to promote fuel reactivity internally. Additive from essential oil is classified as promising bio-additive as it is originally from renewable natural resources available in Indonesia.

In general, additive can be divided into two big groups, namely synthetic and bio-additive. Essential oil is one of the potential materials for bio-additive as it has comparable viscosity with diesel fuel, short until medium carbon chain which is near to diesel fuel, oxygenated materials, low boiling point, and abundant supply in Indonesia. Kadarohman et al. [5] reported that structure of essential oils could decrease the strength of Van der Walls bond in diesel fuel and chain of carbon, so that it could promote better combustion process. Moreover, our previous study also reported that bio-additive from essential oils is one of promising material to suppress formulation of water and particle in blend fuel of diesel fuel and biodiesel with ratio of 80:20 % by volume (B20) due to its capability on decreasing the strength of van der walls bond in diesel fuel. PPO has a hygroscopic characteristic so that it can absorb moisture from the air. An increase on water content can degrade quality of PPO which could raise problem on fuel filter blocking, decreasing engine performance, etc. Sulistia et al. [6] reported that formulation of essential oils as material resources for bio-additive is possible to suppress water content which also could promote an optimization on combustion and improvement of diesel fuel characteristics. An increase in water content in PPO could increase levels of free fatty acid which will accelerate deterioration of PPO characteristics. In the hydrolysis reaction, the oil will be converted into free fatty acids and glycerol. Hydrolysis reaction results in damage to fats and oils [7]. Moreover, storage duration can also be affected by water content in PPO which can lead to an increase on acid number of PPO. Furthermore, if the PPO is stored for a long time, the possibility of an oxidation reaction will also be higher. In this study, essential oil was used as bio-additive for PPO to improve bio-oil in the form of pure plant oil characteristics to meet SNI 7431/2015 [8] quality standards. This study aims to evaluate an effect of bio-additive for PPO on suppression of water and particulate contaminant on medium speed diesel engines and evaluate its performance using two formulas of essential oils.

2. Materials and Methods
2.1. Tested Fuel
Tested fuel was PPO originated from crude palm oil that has been treated with degumming and neutralization, then it was added with bio-additive from essential oil derivatives. There are several types of essential oils derivatives commonly used as component of bio-additive including turpentine, eugenol, eugenol acetate, limonene, terpen clove, citronella and alpha pinene. However, in this study, the types of essential oil used were only variation between rhodinol and turpentine as shown in Table 1.
Both rhodinol and turpentine were used on the previous study as fuel additive for diesel fuel and B20 fuel (blend of diesel and biodiesel FAME with ratio 80:20 by volume). The study reported that bio-additive+B 20 could reduce fuel consumption by 5.14% [8].

2.2. Engine Specification
An experimental investigation was conducted using diesel engine commonly used in a tractor with the specifications shown in Table 2.

| Specifications                      | Value                                      |
|------------------------------------|--------------------------------------------|
| Engine type                        | Diesel Engine, 4 stroke, RD 65 DI-1S       |
| Number of cylinders                | 1 cylinder                                 |
| Bore x stroke                      | 80 x 75 mm                                 |
| Displacement                       | 376 cc                                     |
| Maximum power                      | 6.5/4.8 Hp/kW, 2200 rpm                    |
| Maximum torque                     | 2.36 kg.m, 1600 rpm                        |
| Continuous power                   | 5.4/4.1 Hp/kW 2200 rpm                     |
| Cooling system                     | Water cooling system                       |
| Starting up                        | Crank starter                              |
| Rotation direction                 | counterclockwise viewed from the flywheel  |
| Injection system                   | Direct injection                           |
| Oil capacity                       | 2 L                                        |
| Lubricant system                   | Lubrication pressed with trochoid pump     |

Data Source: ptkubota.co.id/product/

2.3. Engine Test Method
Testing was conducted on engine test bench facilities belong to The Agency for Assessment and Application of Technology at the Laboratory for Thermodynamics, Engine and Propulsion Technology (BT2MP-BPPT). Data of engine performance, exhaust emissions, and fuel consumption test were analyzed with descriptive quantitative methods. Setpoint of the engine performance test was based on ECE R85 engine test method. Preparation work was done prior engine testing which consisted of alignment, instrumentation, and calibration of measuring instruments to ensure the validity of testing data. Figure 1 shows an engine installation in test bench of BT2MP-BPPT.

| No | Formulation | Material     |
|----|-------------|--------------|
| 1  | F1          | Rhodinol     |
| 2  | F2          | Turpentine   |
Engine was tested with a DC dynamometer of 30 kW using three types of fuels including PPO, PPO+bio-additive formula 1 (F1) and PPO+bioadditive formula 2 (F2). Firstly, engine performance, fuel consumption, and emission test were evaluated at various engine speeds and loads. Then, durability test was conducted by using the best fuel from the performance test results to investigate an effect of bio-additive on engine components which will be reported on another study.

2.4. Analysis of Fuel Characteristics Test
Physical and chemical characteristics were tested in accordance with Decree of the Director General of Oil and Gas Indonesia No. 933.K/10/DJM.S/2003. Here, the value of PPO quality standard referred to SNI number 7431: 2015, concerning the Quality and Test Method of Pure Vegetable Oil for Medium-Round Diesel Motor Fuel as shown in Table 3. Mixing of additives to the PPO was carried out at concentration of 1% by volume. Here, we also clarified for fuel cleanliness to ensure that all tested fuel could also fulfill engine manufacture requirement. Particle content is one of requirement of fuel cleanliness. It is important parameter especially for advance diesel technology with common rail system which require high injection pressure with precision and tight gap among its component. Particle content in fuel can erode injectors and clog injector hole, so that it is possible to lead inefficient combustion. Data analysis of the characteristics test result was used statistical calculation variance of 2 bio-additive types with different parameters and 2 replications.

Table 3. Specification of Pure Plant Oil

| No | Test Parameter | Unit          | Requirement (min/max) | Test Method (ASTM/Others) |
|----|----------------|---------------|-----------------------|---------------------------|
| 1  | Density 50 °C  | kg/m³         | 870-910               | ASTM D 4052               |
| 2  | Acid Value     | mg KOH/g      | Max 4.0               | ASTM D 664-11a            |
| 3  | Water Content and Sediment Kinematics | % Volume | Max 0.1 | ASTM D 6079 |
| 4  | Viscosity 50 °C | cSt           | Max 36                | ASTM D 445-06            |
| 5  | Iodine Value   | g-I2/100 g    | Max 115               | AOCS Cd 1-25             |
| 6  | Heating Value  | Min 39        | ASTM D 613-10         |
| 7  | Sulfur Content | % Mass        | Max 0.01              | SNI 136591               |
| 8  | Flashpoint     | °C            | Min 100               | SNI 7431                 |

Data Source: SNI 7431 (2015)

3. Test Result
3.1. Fuel Characteristics Test
Table 4 shows fuel characteristics for PPO, F1, and F2 with addition of particle content of 14 micron and heating value which indicates fuel cleanliness and capability to produce energy during combustion. Density was similar for all fuels, while acid value for F1 was lower than both of PPO and F2 as shown...
in Table 4. Therefore, F1 tended to suppress oil oxidation and minimize corrosion on engine components compared with PPO and F2. Furthermore, F1 also was more superior than F2 in reducing water content in PPO by volume, and F2 was lower than PPO especially for F1 which could decreased water content at around 30% and 23%, respectively. Capability of bio-additive to reduce water can be considered due to strength reduction of van der walls bond PPO and trapped water so that it could be separated.

| No | Data                          | Limit          | PPO            | F1             | F2             |
|----|-------------------------------|----------------|----------------|----------------|----------------|
| 1  | Density 50 °C                 | 870-910        | 891± 0.141     | 891± 0.141     | 890± 0.282     |
| 2  | Acid Value                    | Max 4.0        | 0.22 ± 0.332   | 0.14 ± 0.033   | 0.24 ± 0.005   |
| 3  | Water Content                 | -              | 1755± 67.17    | 1362 ± 9.19    | 1495 ± 8.48    |
| 4  | Viscosity 50 °C(cSt)          | Max 36         | 23.9± 0.091    | 22.9± 0.056    | 22.5 ± 0.077   |
| 5  | Iodine Value (g/l2/100g)      | Max 115        | 42.9 ± 0.346   | 56.4± 1.442    | 49.7± 1.039    |
| 6  | Heating Value (kJ/g)          | -              | 39.2 ± 0.021   | 39.4± 0.141    | 39.4 ± 0.007   |
| 7  | Particle Content 14 Micron    | -              | 1592           | 1132           | 456            |
| 8  | Flashpoint (°C)               | Min 100        | 147 ± 1.141    | 175 ± 2.828    | 133            |

In this testing, viscosity values were measured using an Ostwald viscometer as shown in Table 3. Viscosity values of the PPO, F1, and F2 were 23.91, 22.9 and 22.5 cSt, respectively. The results show that both of F1 and F2 bio-additives could slightly decrease the viscosity of PPO. Moreover, F2 was more effective in reducing viscosity than F1. In general, F1 and F2 have lowered the viscosity value of PPO with percentage around 4.2% and 5.8%, respectively. Here, bio-additive could show capability to decrease the viscosity of PPO but the main reason for decreasing PPO significantly was the heating PPO at 50 °C. However, the whole viscosity test value of PPO, F1, and F2 were fulfilling the standard range of PPO value regulated at SNI 7431: 2015 which is a minimum of 36 cSt at temperature 50 °C. F1 and F2 containing rhodinol and turpentine could increase the Iodine value at around 31.5% and 15.9%, respectively. An increase in the value of the iodine for F1 and F2 indicates the higher unsaturation degree of oil of PPO with additive. Therefore, PPO with additive has potential to have better oxidation stability which is one of important parameter on handling and storage fuel. Heating value of F1 and F2 were slightly higher than PPO. Therefore, both bio-additives of F1 and F2 has potential to increase power of engine as it has high energy for combustion. Measurements of particle content with size of 14 Micron show that F1 and F2 had less particle content compared with PPO. The difference in PPO particle content with bio-additive mixture of F1 and F2 was of 28.9% and 71.4%, respectively.

3.2. Performance Test

Performance test was carried out by implementing a procedure that referred to the modified SNI 0119/2012 Motor for igniting alternating motion compression for general use of specifications, performance, and test method. The measured engine performance parameters were engine speed, torque, power, and Brake Specific Fuel Consumption [10]. Figure 2 shows the results of torque measurement with engine speed was varied from 1400 to 2200 rpm for PPO and PPO+bio-additive. Torque of diesel engines fueled with PPO+bio-additive was comparable with PPO at almost at all engine speed.
The results of the PPO and F1 fuel test show the highest torque value in the engine speed of 1600 rpm with 24.5 Nm, and 1800 rpm is 23.6 different from F2 where the highest torque value is in the engine speed of 2000 rpm. The same trend was also on engine power result as shown in Figure 3, where F1 and F2 additives had comparable result almost at all engine speed condition. Comparable result for both torque and power can be considered due to small different on calorific value.

Figure 4 shows the specific fuel consumption for PPO and PPO+bio-additive at various engine speed. F2 showed slightly better specific fuel consumption compared with both of F1 and PPO without additive. Furthermore, F2 also showed better brake specific fuel consumption at medium engine speed between 1700 rpm until 2000 rpm compared with PPO without additive. Percentage of different specific fuel consumption between F2 and PPO without additive at medium speed was around 1 to 4%. F2 contains solvent turpentine which makes the quality of PPO fuel and combustion better.
Figure 4. Fuel consumption for PPO and PPO+bio-additive

Figure 5 shows the results of smoke emissions for PPO fuels and PPO+bio-additive at low to high engine speed. Smoke emission results show that F2 had a lower smoke value compared with PPO and F1 at almost engine operation speed. It can be considered that in formulation 2, the density, heat, and water content were very influential in producing more complete combustion. Thus, the smoke emission produced was lower than that of PPO and rhodinol formulation.

4. Conclusion
Based on the test results, the addition of essential oils-based bio-additives in biofuels meets the requirements set by SNI 7431 2015. This made all samples were suitable to be used as diesel engine fuel. The engine test results show that PPO+bio-additive has comparable performance and fuel consumption. In addition, further increases in smoke emissions and specific fuel consumption can be achieved with PPO+bio-additive with turpentine components. From the test data, at 1800 rpm engine speed, bio-additive+PPO can reach a maximum power of 4.53 kW, maximum torque of 24.06 Nm, smoke opacity of 6.87 FSN, and specific fuel consumption of 143.8 gr/kWh. Meanwhile, PPO can reach a maximum power of 4.39 kW, maximum torque of 23.31 Nm, smoke opacity of 7.56 FSN and specific fuel consumption of 150.1 gr/kWh. Compared with rhodinol oil test data, the use of turpentine oil is much better. Therefore, turpentine-based bio-additives are promising to be explored as the closest additive to diesel fuel.
Acknowledgments
The author would like to thank Kemenristekdikti 2018 as a funding research so that this research goes well.

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