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Effect of Biodiesel/Diesel Blend and Temperature on 1-Cylinder Diesel Fuel Injection Pump Performance and Spray Pattern

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Abstract

Biodiesel as a renewable alternative energy produced from vegetable and animal oils can be used as a fuel for diesel engines. However, biodiesel has a high viscosity that affects the performance of the pump, thereby reducing diesel engine performance. One of the ways to overcome this problem is by preheating the fuel. The purpose of this study is to investigate fuel spray pattern and pump performance including capacity, head, and efficiency at various biodiesel/diesel blends (B0-B30) and preheating temperatures of B30 (30°C-70°C) at constant injection pressure. The results showed that pump performance decreased with increasing percentage of biodiesel. The weakest pump performance occurred at B30. Fuel spray pattern did not change too much, except for B30 where the spray angle decreased significantly. Better results were obtained when biodiesel blend of B30 was heated. The highest pump capacity and efficiency occurred at 50°C, while the highest pump head was at 70°C. At 60°C and 70°C, pump experienced an excessive vibration. Fuel spray angle also increased as the preheating temperature rises. The widest spray angle occurred at fuel preheating temperature of 70°C.

INTRODUCTION

The increase in population and needs over time have led to higher energy demands, including in Indonesia. Energy supplies, especially non-renewable energy, are depleting, it will run out over time. Based on data from the Agency for the Assessment and Application of Technology (2016), in 2014 Indonesia's energy consumption reached 962 million barrels. Of this amount, 48% was consumed by the industrial sector, 35% by the transportation sector, 11% by the household sector, 4% by the commercial sector, and 4% other. Energy consumption is dominated by fuel oils such as gasoline, diesel, kerosene, fuel oil, avtur and avgas.

In order to reduce dependence on fossil energy resources that are increasingly depleted, it is necessary to use renewable alternative energy. In Indonesia, there are abundant renewable energy sources, one of which is biofuel. Biofuel can be produced directly from plants or indirectly from industrial, commercial, domestic or agricultural wastes (Nugroho, 2010). Biodiesel for diesel substitution can be produced from Jatropha curcas, palm oil and soybeans, while bioethanol for gasoline substitution can be produced from sugar cane and corn.

Biodiesel produced from oil or fat through transesterification process is a liquid that has composition rather similar to diesel (Nugroho, 2010). Besides being produced from plants, biodiesel can also be produced from wastes, such as waste cooking oil or commonly called used cooking oil. Biodiesel has a lower heating value than diesel, but has a higher cetane number (Sitorus, 2004). Biodiesel is commonly used as a mixture or

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substitution of diesel fuel. More than 15% biodiesel in the fuel leads to higher fuel consumption and reduces engine performance. The higher the concentration of vegetable oil in the mixture, the lower the performance of diesel engines (Sudik, 2013).

Biodiesel has a higher viscosity than diesel. If diesel fuel is mixed with biodiesel, there will be an increment of viscosity. If it used in a diesel engine, the fuel will not easily flow to the pump and injection system (Sudik, 2013). The higher the viscosity of the fluid, the lower the pump performance. To overcome this, it is necessary to treat the fuel supply system, one of which is by preheating the fuel to be injected. When the biodiesel-diesel fuel blend is heated, the viscosity will decrease. Preheating of biodiesel to a temperature of 60°C on a 4-cylinder 4-stroke diesel engine can produce better engine efficiency and reduce fuel consumption (Sahbana & Fuhaid, 2012).

So far, research on the use of biodiesel blend only discussed the overall engine performance. Research that focuses on one part of the engine such as fuel injection pump needs to be done in order to know the effects of using biodiesel. The use of two types of fluid in the pump can affect pump performance. It was found that a mixture of water and crude oil in a centrifugal pump decreases the capacity, head, and pump efficiency, while the pump power increases with the increase in the percentage of crude oil (Ardhelas, 2012).

The viscosity of biodiesel makes better lubrication at the injection pump. However, to some extent, higher viscosity inhibits the performance of the injection pump. Good lubrication can reduce wear rates because of direct contact between metal surfaces that are constantly moving. The use of 20% biodiesel causes better lubrication at the injection pump and fuel system, while the use of less than 5% biodiesel has little effect on lubrication (Schumacher & Howell, 1994). The use of biodiesel blend at the fuel injection pump causes the increase of peak frequency and low frequency vibration along with the increase in the percentage of biodiesel because of the increase of viscosity, density and fuel bulk modulus. This shows an increase in dynamic load on pump components (Abruss, 2014).

Researches on the fuel spray pattern as the effect of biodiesel blends heating have been carried out. In this study, besides fuel spray pattern, the performance of the pump was also investigated. This research was conducted to analyze the optimal conditions of the use of biodiesel blends at various temperatures in terms of atomization and fuel capacity.

MATERIALS AND METHODS

Materials

The materials used in this study were diesel fuel, and biodiesel-diesel blends namely B10, B20 and B30. Diesel fuel was obtained from the PT Pertamina gas station. The biodiesel used was biodiesel from used cooking oil produced by CV. Klaten Energy. Table 1 shows the density and kinematic viscosity of the fuel.

Table 1. Fuel properties

Fuel	Density (kg/m^3) at 15°C	Kinematic viscosity (mm^2/s) at 40°C
Diesel (B0)	845.70	2.92
Biodiesel (B100)	862.13	5.27

Research Procedure

This research was carried out in three stages. The first stage was the preparation of equipment and materials by mixing biodiesel with diesel using a stirrer. The following stage was study on spray patterns and pump performance at various biodiesel blends (B0, B10, B20 and B30). The last stage was study on spray patterns and pump performance for B30 at various preheating temperatures (30°C, 40°C, 50°C, 60°C, and 70°C). Pump head and efficiency were calculated based on pump capacity and the difference of discharge and suction pressures.

Experimental Setup

The schematic of the experimental setup is shown in Figure 1. The fuels was filled and mixed in the tank using a mechanical stirrer, then filtered with a fuel filter. After that, the fuel was flowed into the injector using an in-line 1-cylinder fuel injection pump driven by a 1-phase electric motor of 0.5 HP at 2500 rpm. Injection pressure was set at 120 kg_f/cm^2. The injector used is a single hole pintle type injector. The fuel was heated at predetermined temperature using a 350 W heater. Fuel temperature was measured using a thermocouple connected to the temperature controller.

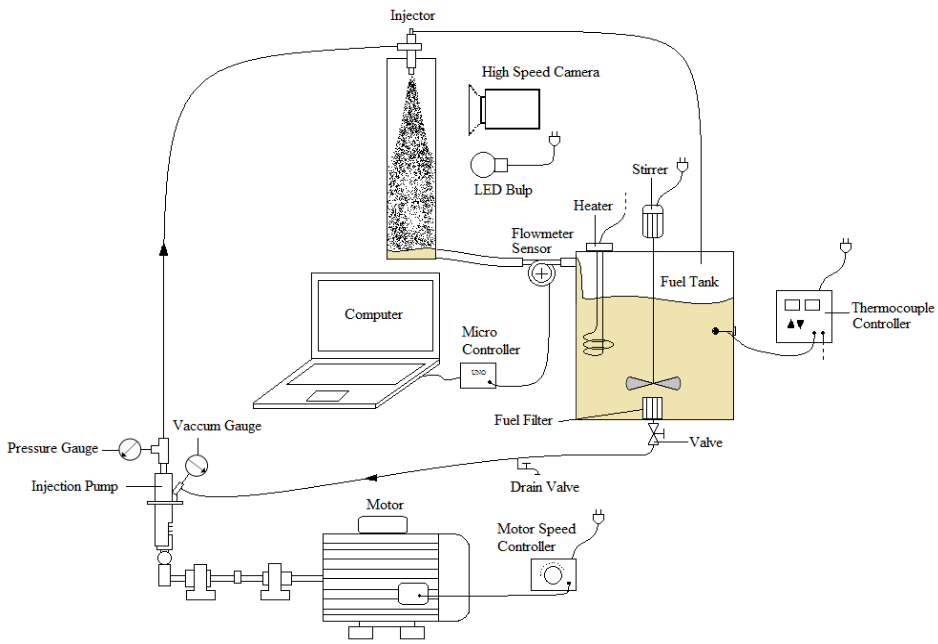

Figure 1. Schematic of the experimental setup

Pump pressure at the suction side was measured using a compound gauge with a range of -1–3 bar and at the discharge side using a pressure gauge with a range of 0–250 kg_f/cm^2. The sprayed fuel on the injector was collected in a transparent tube made of acrylic with an inner diameter of 10 cm and a pipe length of 70 cm. The collected fuel was then flowed back into the tank through a flow meter sensor equipped with a microcontroller to measure fuel capacity. The fuel spray pattern was taken using a high-speed camera with a frame rate of 30 fps (1280x720 pixels) and with the help of a white LED lighting bulb of 9W.

RESULTS AND DISCUSSION

Results and discussion are divided into two parts. The first part discussed the effect of biodiesel-diesel blend on pump capacity, head, efficiency, and spray pattern. While the second part discussed the effect of B30 fuel preheating temperature on the pump capacity, head, efficiency, and spray pattern.

Effect of Biodiesel-Diesel Blend

Effect of biodiesel-diesel blends on pump capacity is shown in Figure 2. The average capacity that can be pumped decreased as the percentage of biodiesel increases. Based on Figure 2, it can be seen that B30 had the lowest pump discharge of 360.333 ml/min, while B0 (diesel) provided the highest pump discharge of 378 ml/min. Pump capacity resulting from the use of B10 decreased by 0.79% or by 3 ml/min compared that of B0. While for B20 and B30, the pump capacities decreased by 2.82% and 4.67%, which were 10.667 ml/min and 17.667 ml/min, respectively. This is due to the different viscosity of each fuel blend.

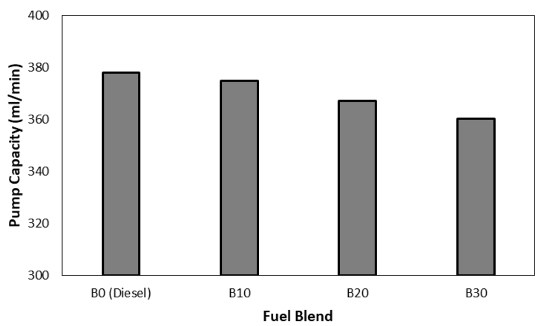

Figure 2. Effect of biodiesel-diesel blend on pump capacity.

Biodiesel has a higher viscosity than diesel, so when biodiesel and diesel are mixed, the viscosity of the mixture will rise. Viscosity is a fluid property that shows the ability of a fluid to flow. Liquid fluids with high viscosity (dense) will be more difficult to flow compared to fluids with low viscosity (dilute) because the flow resistance becomes greater (Anis & Karnowo, 2008). This is also confirmed by Sudik (2013) that the use of high viscosity fuels would cause the fuel not to flow easily along the pump and injection system.

Effect of biodiesel-diesel blends on total pump head is shown in Figure 3. Addition of biodiesel to diesel fuel causes a decrease in the total pump head. Based on Figure 3, it can be seen that B30 had the lowest pump head of 933.316 m, while B0 (diesel) provided the highest pump head of 947.756 m. Pump head resulting from the use of B10 decreased by 0.5% or by 4.767 m compared that of B0. While for B20 and B30, the pump heads decreased by 1.02% and 1.52%, which were 9.639 m and 14.440 m, respectively. This is due to the different density of each fuel blend.

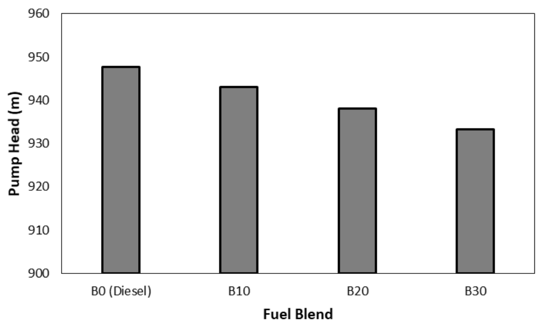

Figure 3. Effect of biodiesel-diesel blend on pump head.

The density of biodiesel is higher than that of diesel, so the higher the percentage of biodiesel in the fuel mixture, the greater the density, and vice versa. This is also revealed by Alptekin (2008) that the density of a fuel mixture decreases as the biodiesel content decreases in the fuel mixture. The total pump head reduction is mostly due to the increase in density of each fuel mixture. Fluid density affects the pressure head produced. Pump pressure head according to Sularso & Tahara (2000) can be calculated by the following equation (1).

$$H_p = \frac{\Delta P}{\gamma} = \frac{P_d - P_s}{\rho g} \ (m) \quad (1)$$

Pump pressure head (H_p) is the pressure difference between suction side (P_s) and discharge side (P_d) divided by the density (ρ). When the density increases, the pressure head decreases, so that the total pump head will also decrease. Total pump head (H) is the sum of the pressure head (H_p), velocity head (H_v), elevation head (Z) and head loss (H_L) as shown in the equation (2).

$$H = H_p + H_v + Z + H_L \quad (2)$$

or

$$H = \frac{\Delta P}{\gamma} + \frac{v^2}{2.g} + Z + H_L \ (m) \quad (3)$$

Effect of biodiesel-diesel blends on pump efficiency is shown in Figure 4. Pump efficiency is the comparison between water horsepower (WHP) and brake horsepower (BHP) or the comparison between fluid power and shaft power (Anis & Karnowo, 2008). Pump efficiency can be calculated by using equation (4).

$$\eta_{pump} = \frac{WHP}{BHP} \times 100\% \quad (4)$$

Pump efficiency decreased as the percentage of biodiesel increases. Based on Figure 4, it can be seen that B30 had the lowest pump efficiency of 18%, while B0 (diesel) provided the highest pump efficiency of 18.856%. The decrease of pump efficiency resulting from the use of B10, B20, and B30 is due to the decrease of pump capacity of each mixture. Pump capacity affects the produced pump power. When the pump capacity decreases, the pump efficiency will also decrease.

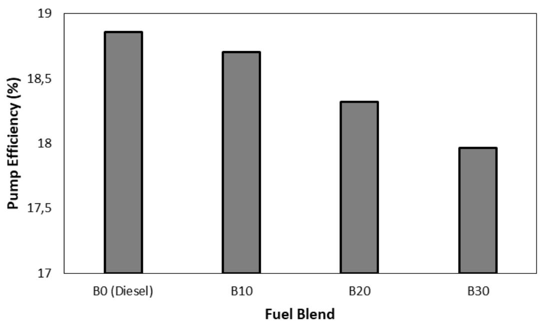

Figure 4. Effect of biodiesel-diesel blend on pump efficiency.

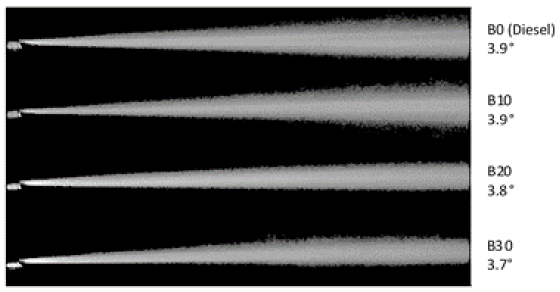

Figure 5. Effect of biodiesel-diesel blend on fuel spray pattern

Effect of biodiesel-diesel blends on fuel spray pattern is shown in Figure 5. Nozzle spray angle was taken at a pressure of 120 kg/cm^2 using a high-speed camera. It can be observed from the figure that the spray pattern of diesel fuel produced smaller/finer mist particles and wider fuel spray. Fuel mist spray spreads the light of the lamp used as

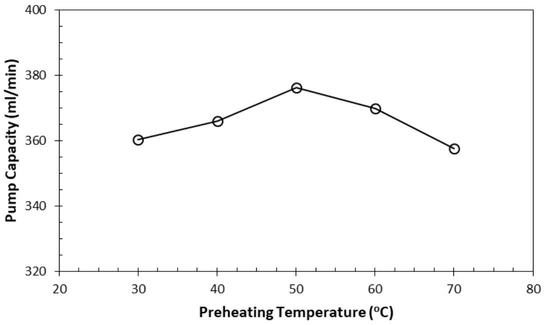

Figure 6. Effect of B30 fuel preheating temperature on pump capacity.

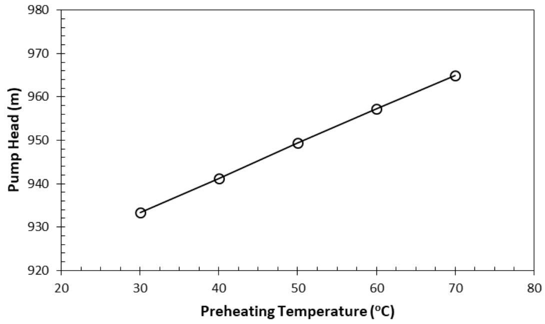

Figure 7. Effect of B30 fuel preheating temperature on pump head.

a source of lighting. The more mist spray will cause more scattered light.

The fuel spray angle is strongly influenced by the viscosity and density of the fuel. At high viscosity and density, the fuel spray angle becomes narrower. In contrast, at low viscosity and density, the fuel spray angle becomes. The higher viscosity and density of biodiesel causes worse atomization than diesel fuel (Agarwal & Chaudhury, 2012). Separation of fuel particles during spraying becomes more difficult, so that only a little air can be mixed in the mist.

The spray pattern and angle of B10 seen similar to diesel fuel with a spray angle of 3.9˚. This value is close to a good fuel spray angle of 4˚ in the injector. The spray pattern of B30 looks to have a narrower spray pattern and angle with a spray angle of 3.7˚. The higher viscosity and density of B30 resulted in poor pump performance. With poor pump performance; the fuel injection process on the injector becomes more difficult. This condition is also revealed by Mohlis (2007) that poor fuel injection process causes detriment in the diesel engines performance including incomplete combustion, low engine power and high fuel consumption.

Effect of Fuel Preheating Temperature

Figure 6 shows the effect of fuel preheating temperature of B30 on pump capacity. The average pump capacity increased as the increase of fuel preheating temperature. Based on the figure, it can be seen that the lowest pump capacity of 357.67 ml/min occurred at 70ºC, while the highest pump capacity of 376.33 ml/min was obtained at 50ºC.

The increase of fuel preheating temperature up to a certain point caused an increase in pump capacity. At temperatures of 40ºC and 50ºC, pump capacities increased by 1.55% or 5.667 ml/min and by 4.25% or 16 ml/min, respectively. This is caused by viscosity factor in which at high temperatures, the viscosity of the fluid becomes smaller (dilute) so that pumping of the fluid becomes lighter. Nevertheless, further increase of fuel preheating temperature caused a reduction of pump performance. Compared to fuel preheating temperature of 50ºC, it was found that at temperatures of 60ºC and 70ºC, the pump discharge decreased by 1.68% or 6.333 ml/min and by 4.96% or 18.666 ml/min, respectively. The reduction of pump capacity at 60ºC and 70ºC is influenced by a significant decrease in viscosity up to 1.801 mm^2/s and 1.107 mm^2/s, respectively. This causes greater friction between the plunger and the cylinder wall in the pumping system due to poor lubrication.

Figure 7 shows the effect of fuel preheating temperature of B30 on total pump head. The total head produced increased with the increase of B30 preheating temperature. It can be observed that the lowest pump head of 933.316 m occurred at fuel preheating temperature of 30ºC, while the highest pump head of 964.952 m was obtained at 70ºC. In general, the pump head increased sequentially by 0.84% or 7.894 m at 40ºC, 1.69% or 16.088 m at 50ºC, 2.49% or 23.888 m at 60ºC, and 3.28% or 31.636 m at 70ºC.

An increase in the preheating temperature of B30 resulted in an increase in the total pump head. This is caused by changes in fuel density where the density of biodiesel blends decrease with increasing temperature (Tesfa et al., 2010). As previously discussed that the pressure head is the difference of pressure between the suction (P_s) and discharge (P_d) sides divided by the density (ρ). When the density decreases, the resulting pressure head will increase so that the total pump head will also increase.

Effect of fuel preheating temperature of B30 on pump efficiency is shown in Figure 8. The increase of fuel preheating temperature up to 50ºC

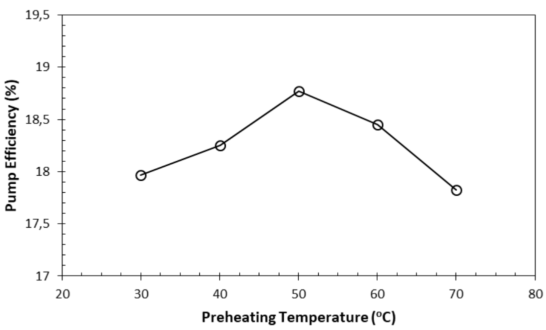

Figure 8. Effect of B30 fuel preheating temperature on pump efficiency

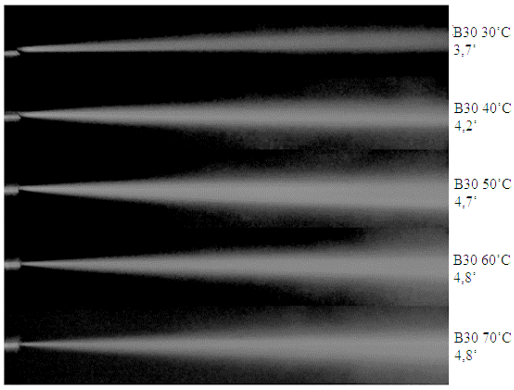

Figure 9. Effect of B30 fuel preheating temperature on spray pattern

caused an increase in pump efficiency. Above that temperature, pump efficiency decreases. It can be seen that the lowest pump efficiency of 17.83% occurred at a temperature of 70°C, while the highest pump efficiency of 18.77% was obtained at a fuel preheating temperature of 50°C.

The low pump efficiency at temperatures of 60°C and 70°C is due to a decrease of pump capacity produced. The viscosity of B30 at temperatures of 60°C and 70°C decreased significantly to 1.801 mm^2/s and 1.107 mm^2/s, respectively, making the friction in the pumping system larger. In addition, at the temperature range of 50°C to 70°C, there is a phenomenon of excessive vibration at the pump. This happens because the B30 fuel viscosity is too dilute which is close to the water viscosity of 1.0 mm^2/s at 20°C. If the pump is operated for a long period under this condition, it is possible that the plunger and the pump cylinder will be damaged in the form of scratches thereby leakage will occur.

Effect of fuel preheating temperature of B30 on spray pattern is shown in Figure 9. As the fuel preheating temperature of B30 increases, the mist particles get smaller and the spray angle gets bigger. This is because the lower viscosity and density of the fuel with increasing fuel preheating temperature.

At a fuel preheating temperature of 30°C, the fuel volume and spray angle are smaller, while at temperatures of 50°C to 70°C produces larger fuel volume and wider spray angle of 4.7° to 4.8°. The resulting spray angle exceeds a good spray angle of 4°. The lower fuel viscosity and density cause the mist particles to be smaller, so that the separation of fluid particles is easier and much air can be mixed in the mist. If the mist particles are smaller, fuel combustion will be easier so that diesel engine performance will be better.

CONCLUSIONS

Based on the results of the study, it can be concluded that addition of biodiesel in diesel fuel affects the performance of one cylinder injection pump and injector. This is indicated by a decrease in pump performance including pump capacity, head, and efficiency along with the increase of biodiesel-diesel blends ratio. The lowest pump performance occurred at 30% biodiesel fraction (B30). Fuel spray pattern changes slightly, especially for B0, B10, and B20. The narrowest fuel spray angle was obtained at B30. The performance of one cylinder fuel injection pump and injector was also influenced by fuel preheating temperature. This is indicated by the increase of pump capacity and efficiency up to a certain temperature. For B30, the best condition was obtained at 50°C. Fuel spray angle of B30 increased with the increase of fuel preheating temperature. The widest spray angle occurred at 60°C and 70°C.

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REFERENCES

Abruss, A., Guo, Y., Wang, T., Gu, F., Ball, A. D., Brown, D. 2014. Investigation of The Effect of Biodiesel Blends on Fuel Injection Pumps based on Vibration and Pressure Measurements. Vibration Engineering and Technology of Machinery. 23:535-546.

Agarwal, A. K., Chaudhury, V. H. 2012. Spray Characteristics of Biodiesel/blends in a High Pressure Constant Volume Spray Chamber. Experimental Thermal and Fluid Science. 42: 212-218.

Alpatekin, E., Canakci, M. 2008. Determination of The Density and The Viscosities of Biodiesel – Diesel Fuel Blends. Renewable Energy. 33: 2623-2630.

Anis, S., Karnowo, .2008. Dasar Pompa. Semarang: Universitas Negeri Semarang. Indonesia.

Ardhelas, K. A. 2012. Pengaruh Aliran Dua Fase Crude Oil-Water pada Performansi Pompa Sentrifugal yang Didesain untuk Aliran Satu Fase. Final Year Project. Department of Mechanical Engineering. Semarang. Indonesia.

BPPT. 2016. Outlook Energi Indonesia 2016. Jakarta: BPPT.

Mohlis, M. 2007. Pengaruh Pemanasan Bahan Bakar Solar melalui Upper Tank Radiator terhadap Konsumsi Bahan Bakar dan Kepekatan Asap Gas Buang pada Mesin Isuzu Panter. Final Year Project. Department of Mechanical Engineering. Universitas Negeri Semarang.

Nugroho, T. 2010. Peluang Besar Usaha Membuat Bensin dan Solar dari Bahan Nabati. Yogyakarta: Pustaka Mahardika. Indonesia.

Sitorus, T. B. 2004. Kaji Eksperimental Performansi Motor Diesel dengan Bahan Bakar Biodiesel dari Minyak Goreng Bekas. Jurnal Teknik SIMETRIKA. 3(3): 243-248.

Sudik, S. 2013. Perbandingan Performa dan Konsumsi Bahan Bakar Motor Diesel Satu Silinder dengan Variasi Tekanan Injeksi Bahan Bakar dan Variasi Campuran Bahan Bakar Solar, Minyak Kelapa dan Minyak Kemiri. Final Year Project. Department of Mechanical Engineering. Universitas Negeri Semarang.

Sularso, Tahara, H. 2000. Pompa dan Kompresor. Jakarta: Pradnya Paramita. Indonesia.

Sahbana, M. A., Fuhaid, N. 2012. Pengaruh Variasi Temperatur Pemanasan Awal Biodiesel terhadap Konsumsi Bahan Bakar dan Daya pada Motor Diesel 4 Tak 4 Silinder. Jurnal PROTON. 4(1): 6-11.

Schumacher, L. G., Howell, S. A. 1994. Lubricating Qualities of Biodiesel and Biodiesel Blends. presented at the Sixth National Bioenergy Conference. Nevada. 2-6 Oktober 1994.

Tesfa, B., Mishra, R., Gu, F., Powless, N. 2010. Prediction Models for Density and Viscosity of Biodiesel and their Effects on Fuel Supply System in CI Engines. Renewable Energy. 35: 2752-2760.