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Research article

Experimental study on characteristics of the test engine fueled by biodiesel based Jatropha oil and traditional diesel

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Abstract: In this study, oil was converted to biodiesel via transesterification reaction under the presence of CaO at the laboratory. This aims to evaluate and compare the influence of Jatropha oil with commercial diesel (CD) fuel on the engine operating characteristics. Secondly, this study is to compare engine performance and temperature characteristics of cooling water and lubricant oil under various engine operating conditions of the test engine fueled by Jatropha oil and CD. The results indicated that the engine torque of the engine running with Jatropha oil dropped from 0.2 kW to 0.3 kW at all speeds and its brake specific fuel consumption (BSFC) increased at almost every speed due to the low heating value and high viscosity of the Jatropha fuel. The BTEs of the engines fuelled with Jatropha oil was 0.3%, 1.0%, 0.6%, 0.7%, 1.1%, 1.6%, and 1.0% smaller than the BTEs of the engine when varied speed from 1000 rpm to 2200 rpm. However, the difference was trivial. Also, Jatropha oil contributed to reducing the oil temperature of lubricant and cooling water.

Keywords: feedstock; waste cooking oil; engine characteristics; exhaust emissions; specific energy consumption; fuel consumption

1. Introduction

Diesel engines have been used as the major power source for the agricultural machine, heavy truck, bus, and industrial sector. Thus, the demand for petroleum-based diesel has been booming since the last several decades [1–5]. However, there are big challenges with the traditional fuel due to the limitation on petroleum reserves and issues related to environmental pollution [4–9]. As a result, many researchers have performed to find out the solution to solve the above-mentioned problem [10–15].

Biodiesel produced from various feedstocks, such as rapeseed, soybean, cottonseed oil, palm oil, Jatropha oil is the potential solution [16–22]. Jatropha has been expected to be the best energy source of oilseeds and their oil content as mentioned in [23,24]. It can be planted and developed well throughout the world, especially in tropical and subtropical countries such as South America and Southeast Asia. Jatropha originates from central America and was planed in Africa, Mexico, Nicaragua, Thailand, and Vietnam. In some countries such as Brazil, Nepal, and Zimbabwe, Jatropha was chosen as one of the prime plant oil species [25].

Jatropha oil can minimize CO_2 emissions to the environment along with the utilization of traditional diesel fuel [26]. Therefore, many scientists have conducted the study to extract oil from Jatropha seeds to use as fuel for internal combustion engines. However, the viscosity of jatropha oil is high due to glycerol in the backbone of its chemical structure; thus, it limits the application of Jatropha oil for engines [27]. Preheating could improve the consumption process of jatropha oil in a diesel engine as mentioned in [28]. This research concluded that Jatropha blends less than 20% could be directly used as straight vegetable oil as a partial replacement of traditional diesel without any requirement of engine modification. However, the engine efficiency of Jatropha oil was slightly lower than that of diesel [29].

In the same research topic, Arridina et al. experimented with the engine characteristics of a turbocharged diesel engine fuelled with Jatropha curcas biodiesel-diesel blends [30–32]. They concluded that the engine performance parameters of the test engine fueled by every Jatropha blends were higher than those fueled by diesel fuel at 2000 rpm. The fuel consumption was lowest for the 10% Jatropha blend (JCB10). Moreover, the heat release was highest for the JCB10 blend. Sayon Sidibe et al. performed the comparative study of three ways of using Jatropha curcas vegetable oil in a direct injection diesel engine corresponding to blends of 20, 40, 50, and 75% Jatropha oil in diesel, called JB20, JB40, JB50, and JB75, respectively. The results illustrated that fuel consumption, thermal efficiency, and the engine exhaust temperature for Jatropha oil and diesel, depending on the increase in load rate. The fuel consumption of the engine reduced with a load increase with all the fuels corresponding to 11% on average with preheated Jatropha oil and 13% with non-preheated Jatropha oil in comparison with that of traditional diesel engines.

In addition to the research projects that have been discussed above, several other studies have investigated the use of JB100 (100% Jatropha) fuel on CI engines such as mentioned in [33–35]. Regardless, no study has investigated the impacts of Jatropha oil on the cooling and lubricant temperature of the conventional CI engines. Consequently, this research aims to discuss the technology that is used to produce biodiesel derived from Jatropha oil and evaluate its characteristics in conventional CI engines. To achieve these aims, the experimental processes were conducted to produce Jatropha. Besides, experimental procedures were performed to measure the characteristics of test engines fuelled by either diesel or Jatropha oil. The results of this research are the foundation for using Jatropha in the worldwide application.

2. Experimental apparatus and procedures

2.1. *Characteristics of commercial diesel and biodiesel fuel*

This research compared the characteristics of test engines that were fuelled by CD and biodiesel. The CD fuel was bought at a fuel station in Vietnam and was used as the reference fuel for this study.

The characteristics of CD and biodiesel are listed in Table 1.

Table 1. Chemical and physical properties of tested fuels.

Property	Biodiesel based Jatropha oil	Diesel fuel	Method test
Cetane number	51	49.2	ASTM D613
Density at 15 °C, kg/m^3	880.12	827.485	ASTM D1298
Viscosity at 40°, cSt	4.8	3.74	ASTM D445
Flashpoint, °C	135	81.5	ASTM D92
Ash content, wt %	0.012	0.099	ASTM D2415
Carbon residue, wt %	0.2	0.1	ASTM D4530
Total sulfur, ppm	<3	<3	ASTM D5453
Heating value, MJ/kg	39.73	44.564	ASTM 04-5865

Jatropha seeds were collected from some provinces located in Vietnam. Jatropha oil was manufactured by pressing oil from Jatropha seeds with a yield of 20%. Biodiesel from Jatropha oil was obtained via transesterification reaction with the presence of CaO as the catalyst. Because Jatropha oil has a high acid value (17 mg KOH per g), so it should be pre-treated with methanol via esterification reaction using sulfuric acid as the catalyst to reduce the acid value (lower than 4 mg KOH per g), which is suitable for transesterification using basic catalysts.

2.2. Esterification process

A total of 500 mL of Jatropha oil was introduced into a three-necked flask and heated to the temperature of 65 °C. 50 mL of methanol and 5 mL of concentrated H_2SO_4 were carefully added to the mixture, then refluxed for 3 hours at a temperature around 65 °C while stirring. After completion of the reaction, the mixture was cooled, washed 4 times with deionized water, and separated in a separating funnel. The treated Jatropha oil was collected from the top layer in separating funnel and was dehydrated in an oven at 105 °C for 3 h.

2.3. Transesterification reactions

Treated Jatropha oil was converted to biodiesel via transesterification reaction under the presence of CaO. CaO powder was activated by calcined for 2 hours at a temperature of 700 °C. A total of 500 g treated Jatropha oil was introduced into a three-necked flask and heated to the temperature of 65 °C. Then appropriate concentrations of 5% CaO and methanol with the mole oil ratio: methanol 1:18 was carefully added. The mixture was kept at 65 °C for 3 h under stirring with a mechanical stirrer at 300 rpm. After completion of the reaction, the mixture was poured into the separating funnel and left for 12 hours. The biodiesel was collected in the top layer from the glycerol on the bottom layer. Biodiesel was then washed with warm water until neutral pH to remove residual catalyst and glycerol. Finally, biodiesel was heated at a temperature of 105 °C in over for 3 h to remove water leftover laundry.

The fuel properties of the biodiesel product were evaluated to compare to regular diesel fuel using ASTM methods. Cetane number, density, kinematic viscosity, flash point, carbon residue, ash, sulfur, and the calorific value of biodiesel were characterized. Cetane number was determined by comparing its combustion characteristics in a test engine with those for blends of reference fuels of known cetane number under standard operating conditions (ASTM D-613). A digital density analyzer was used to measure the sample at 25 °C temperature. Meanwhile, Viscosity was determined using a U-tube viscometer (ASTM D-445) at 40 °C. Flashpoint of Jatropha was determined by filling the test cup with Jatropha to the filling mark inside of the test cup, and the lighted test flame was passed along the circumference of the cup (ASTM D-92). The heating value of the test fuel was determined using a bomb calorimeter. Carbon residue was calculated through the amount of carbon residue left after evaporation and pyrolysis of the sample (ASTM D-189). Ash was calculated by igniting and burning samples until only ash and carbon remain (ASTM D-482). The sulfur content was determined using an energy-dispersive X-ray fluorescence analyzer (ASTM D-4294).

3. Testing equipment, experimental setup, and test procedure

The test engine that this study used was a single-cylinder, four strokes, naturally aspirated and air-cooled D12 engine with the specifications are summarized in Table 2.

Table 2. Specifications of the D12 engine.

Name of the engine	D12
Type of the engine	Single-cylinder, 4 strokes, diesel engine
Number of cylinders	1
Displacement	566 cm^3
Continuous rated power output	9 kW/2000
Compression ratio	17
Starting system	Electric system
Air cleaner type	Wet/dry type
Lubricating system	Forced lubrication with a pump
Combustion system	Direct injection
Max. torque	49 N.m/1600 rpm
Compression ratio	18.1

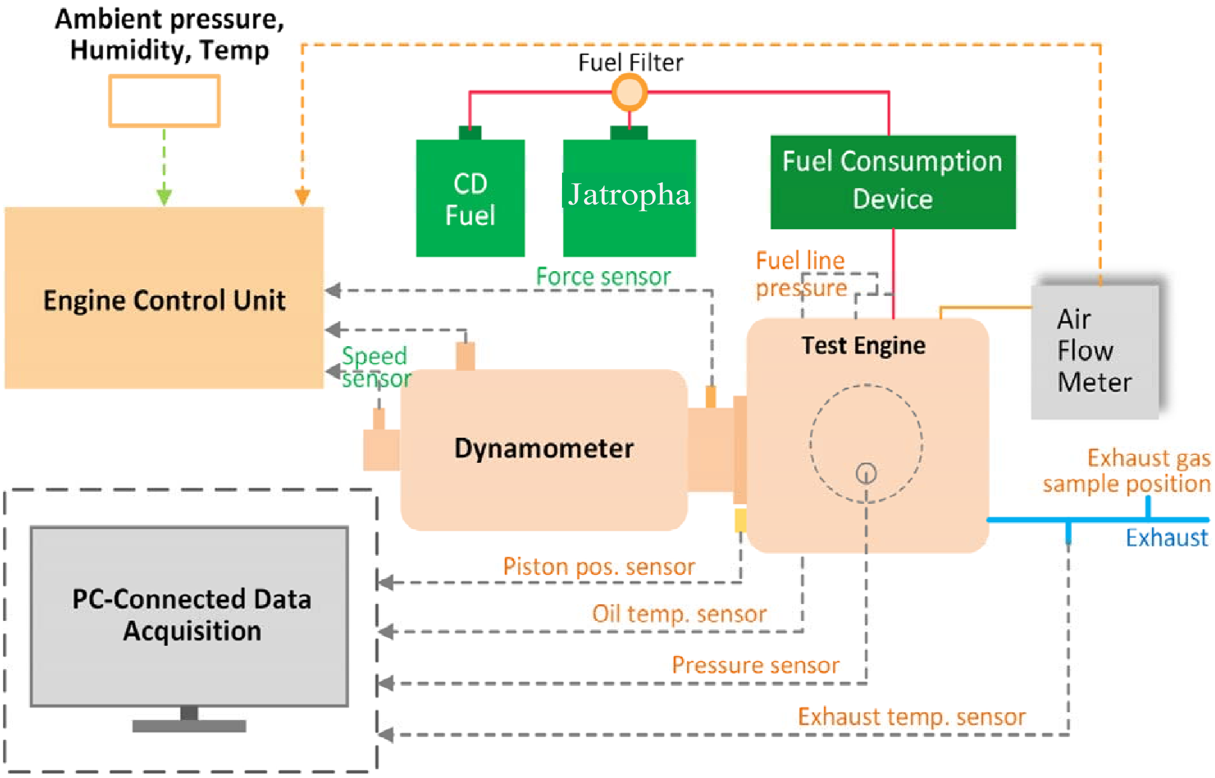

Figure 1. Schematic diagram of engine test in the experiment.

The experimental tests were performed to evaluate the test engine characteristics fueled by CD and Jatropha oil. They were carried out for a range of engine speeds from 1000 to 2200 rpm with 200 rpm increments under full-load conditions. The operating parameters of the test engine, including the output power, fuel consumption, and lubricant temperature, cooling water temperature, were recorded for the comparison. The schematic of the experimental test is described in Figure 1 including a dynamometer to measure the engine power, fuel consumption measurement, and temperature measurement devices. All of the test devices were controlled directly by a server computer using dedicated software with high accuracy and to be carefully calibrated before testing. The dynamometer composes of an absorption unit and the means to measure the torques and rotational speeds of the test engine corresponding to the accuracy ratings of ±0.25%. It was controlled using an installed particular computer to collect signals from sensors equipped on the dynamometer and the test engine. For increasing the accuracy of the experimental results, the test dynamometer was retrofitted into an external cooling system to control the cooling temperature. The fuel consumption was measured by a fuel balance device operating based on the gravimetric method enabling a high-precision measurement even at low consumption and short measuring times. Furthermore, a high precision temperature measurement system based on a thermocouple sensor was used in this experiment to measure cooling water and lubricant temperatures. The accuracy of any empirical result is a direct consequence of the quality of the experimental setup and the strict control over testing conditions. Therefore, the instrumentation of any engine now incorporates a wide range of sensors and actuators, with varying signal types and communication protocols.

4. Results and discussions

4.1. Comparison of engine performance characteristics

In the performance test, the performance characteristics of the test engine fueled by CD and biodiesel were measured and compared at full and partial load conditions and corresponding to the engine speeds varying from 1000 to 2200 rpm. The engine performance of the test engine at the full load regime is described in Figure 2.

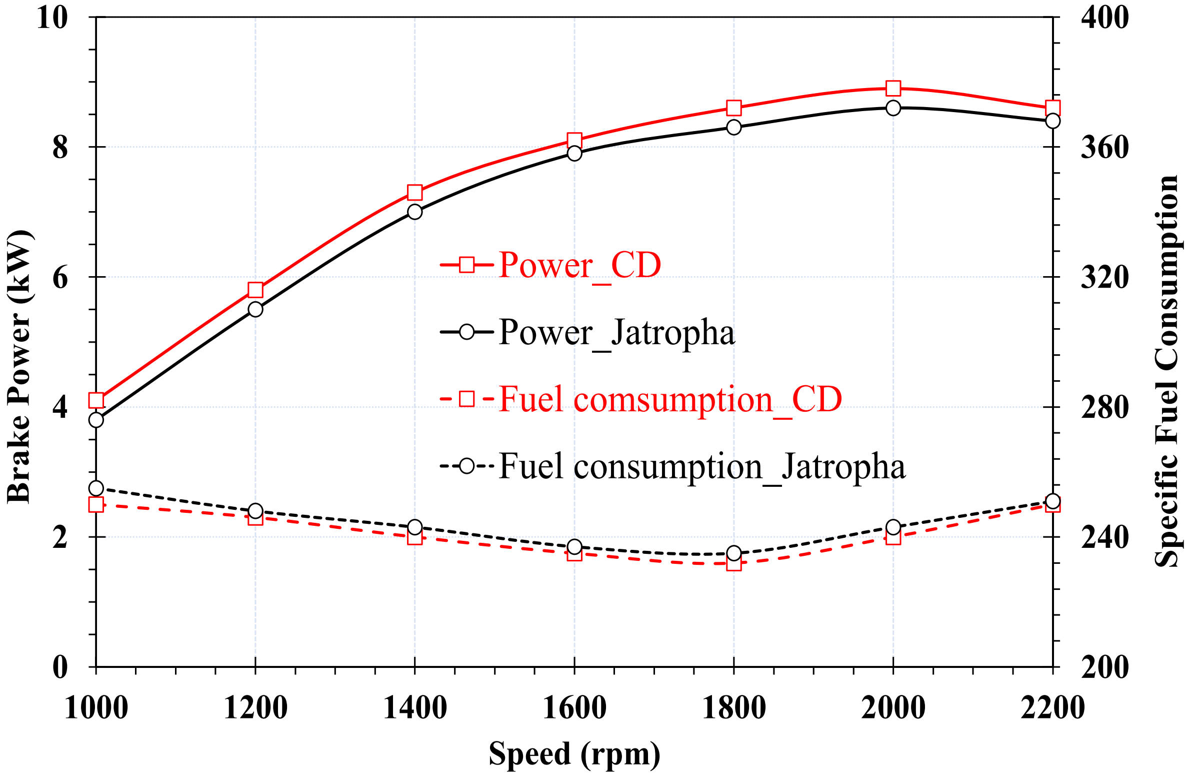

Figure 2. Engine performance of the test engine fueled by CD and Jatropha oil.

These results revealed that the power of the test engine fueled by Jatropha fuel was lower than that of CD at all engine speeds. Consequently, It dropped sequentially from 0.2 kW to 0.3 kW due to the low heating value as mentioned in Table 2. However, Jatropha oil's density is higher than that of CD, and thus Jatropha oil's mass supply was higher than CD's fuel mass supply with the same supply system. It contributes to reducing the effect of the low heating value. Furthermore, higher viscosity is the most challenge in the use of biodiesel as a fuel for engines. It could be solved through the transesterification process. At 40 °C, the viscosity of Jatropha biodiesel is 4.8 cSt and approximately 28% higher than that of CD. The higher viscosity level causes longer liquid penetration times and worse atomization , especially in cold weather. With the rise of the operating temperature, the viscosity is reduced; as a result, it can be observed that the power of the test engine with Jatropha fuel was enhanced dramatically at the high speed conditions corresponding to the high temperature of the test engine.

The brake thermal efficiency (BTE) evaluates how efficiently an engine can transform the chemical energy of a fuel into useful work. It is determined by dividing the brake power of an engine by the amount of energy input to the system. The BTE can be determined by dividing the useful work by the lower heating value of the fuel. Jatropha oil exhibited a little smaller thermal efficiency than CD at all speeds. The BTEs of the engines fuelled with Jatropha oil was 0.3%, 1.0%, 0.6%, 0.7%, 1.1%, 1.6%, and 1.0% smaller than the BTEs of the engine when varied speed from 1000 rpm to 2200 rpm. However, the difference was trivial. In other words, the conversion of the fuel's chemical energy into the engine's mechanical energy is less efficient when the engine is fuelled by Jatropha oil because the density and kinematic viscosity of CD is lower than the density and kinematic viscosity of Jatropha oil.

4.2. Comparison of engine experimental operation conditions on performance tests

4.2.1. Lubricant temperature and cooling water temperature at full load

Figure 3 shows the variations in the lubricant oil temperatures for the two fuels. The lubricant oil temperature increased as the engine speed increased, reaching a maximum speed of 2000 rpm. Jatropha's lubricant oil temperature was lower than CD's lubricant oil temperature at all speeds. For example, Jatropha's lubricant oil temperatures were 4 °C, 3.3 °C, 2.8 °C, 2.7 °C, 3.3 °C, 4.7 °C, and 2.9 °C lower than CD's lubricant oil temperatures at engine speeds of 1000 rpm, 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm, 2000 rpm, and 2200 rpm, respectively. At 2000 rpm, the differences between the two fuels' lubricant oil temperatures reached a peak value of 4.7 °C.

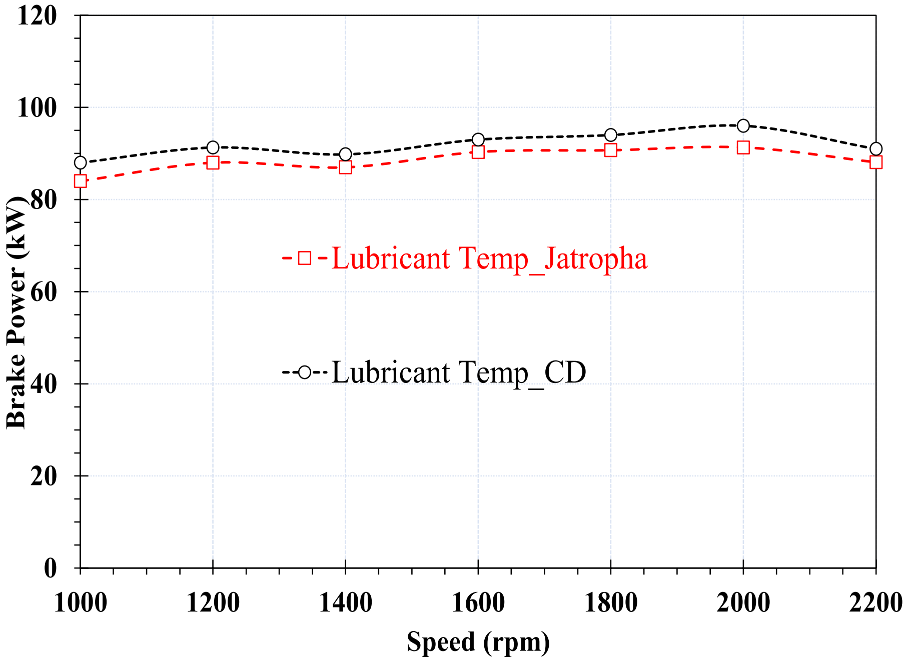

Figure 3. Lubricant oil temperature at full load condition.

Cooling water temperature illustrates the operating state of the engine. As described in Figure 4, the cooling water temperature of the CD-fuelled engine was higher than the cooling water temperature of the Jatropha engine. The highest difference in cooling water temperature was 4.1 °C at an engine speed of 2000 rpm. The cooling water temperature differences at each test point changed from 1.7 °C to 4.1 °C. The cooling water temperature of the engine fuelled with Jatropha oil was 2.9 °C, 1.7 °C, 4.6 °C, and 3.2 °C, 4.1 °C, and 3 °C lower than the cooling water temperature of the engine fuelled by CD at engine speeds respectively from 1200 to 1800 rpm. By comparison, the Jatropha oil-fuelled engine's cooling water temperature was 3 °C lower than the CD-fuelled engine's cooling water temperature at 2200 rpm. At 1000 rpm and 2000 rpm, the differences in the cooling water temperatures were insignificant for both engines.

As illustrated above, at a full load, the same speed, and when fuelled by CD or Jatropha oil, there was a less than 4 °C difference in the engines' lubricant and cooling water temperatures. This could be explained by the differences in the heat values of between CD and Jatropha fuel. Indeed, the heat value of CD is higher than the heat value of Jatropha fuel; as a result, the higher heat release of CD leads to higher cooling water and lubricant temperatures.

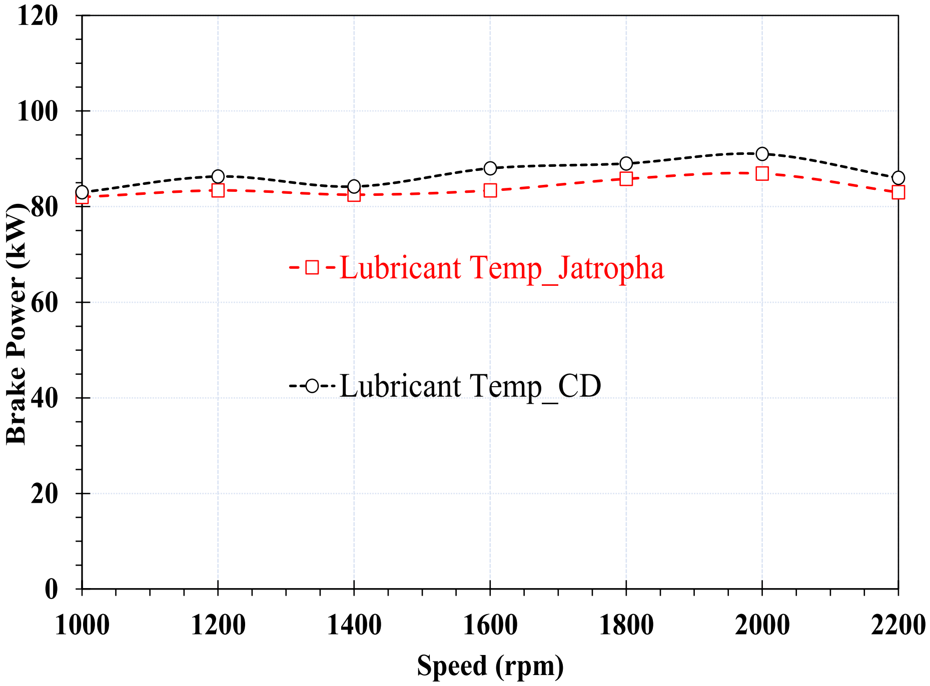

Figure 4. Cooling water temperature at the full load condition.

4.2.2. Lubricant temperature, cooling water temperature, and partial load conditions

Figure 5 shows the oil lubricant temperature with partial load conditions corresponding to the output torque of respectively 5, 19, 15, 20, 25, 30, and 35 N.m. Generally, the oil lubricant temperatures of the engine fuelled with CD were higher than the oil lubricant temperatures of the engine fuelled with Jatropha oil. At engine speeds of 1200 rpm, 1400 rpm, 1800 rpm, 2000 rpm, this difference was higher at low and high loads and smaller at medium loads. When the engine load was low, the CD-fuelled engine's oil lubricant temperature was lower than the Jatropha-fuelled engine's oil lubricant temperature. However, for high engine loads, this trend shifted in the opposite direction. At 1800 rpm, the differences in lubricant temperature were higher at low loads and lower at high loads.

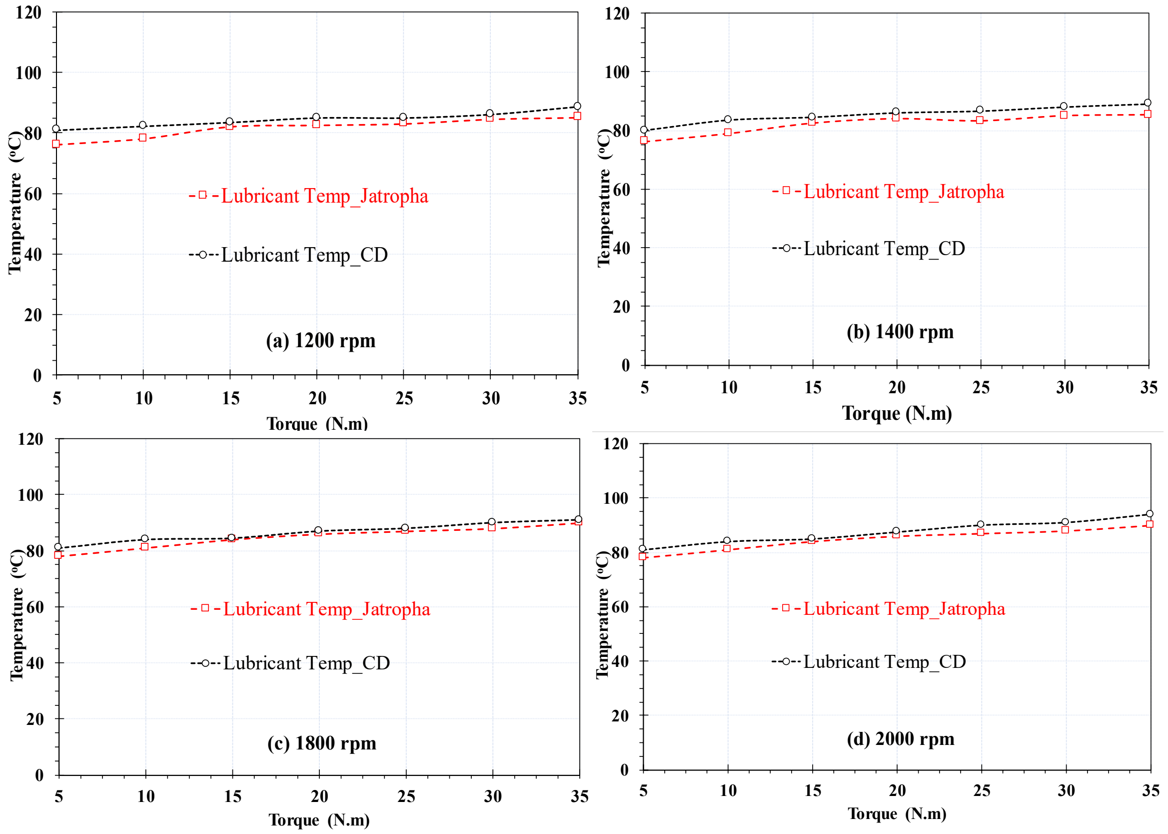

Figure 5. Lubricant oil temperatures at different load.

Figure 6 presents the examination of torque and the cooling water temperatures at seven different engine speeds. According to the experiment results, the cooling water temperatures of the Jatropha-fuelled engines were higher than the cooling water temperatures of the CD-fuelled engines at low and medium load conditions. In contrast, the cooling water temperatures of the Jatropha-fuelled engines were lower than the cooling water temperatures of the CD-fuelled engines at high load conditions. For most test conditions that used the same engine speeds and load conditions, the differences between the lubricant temperatures and cooling temperatures were inadequate. Also, when the engines were tested with both fuels, the parameters of each test point were recorded when the engines reached a steady state. Thus, the parameters for the performance of the engines at the same speeds and load conditions could be fully compared and analyzed.

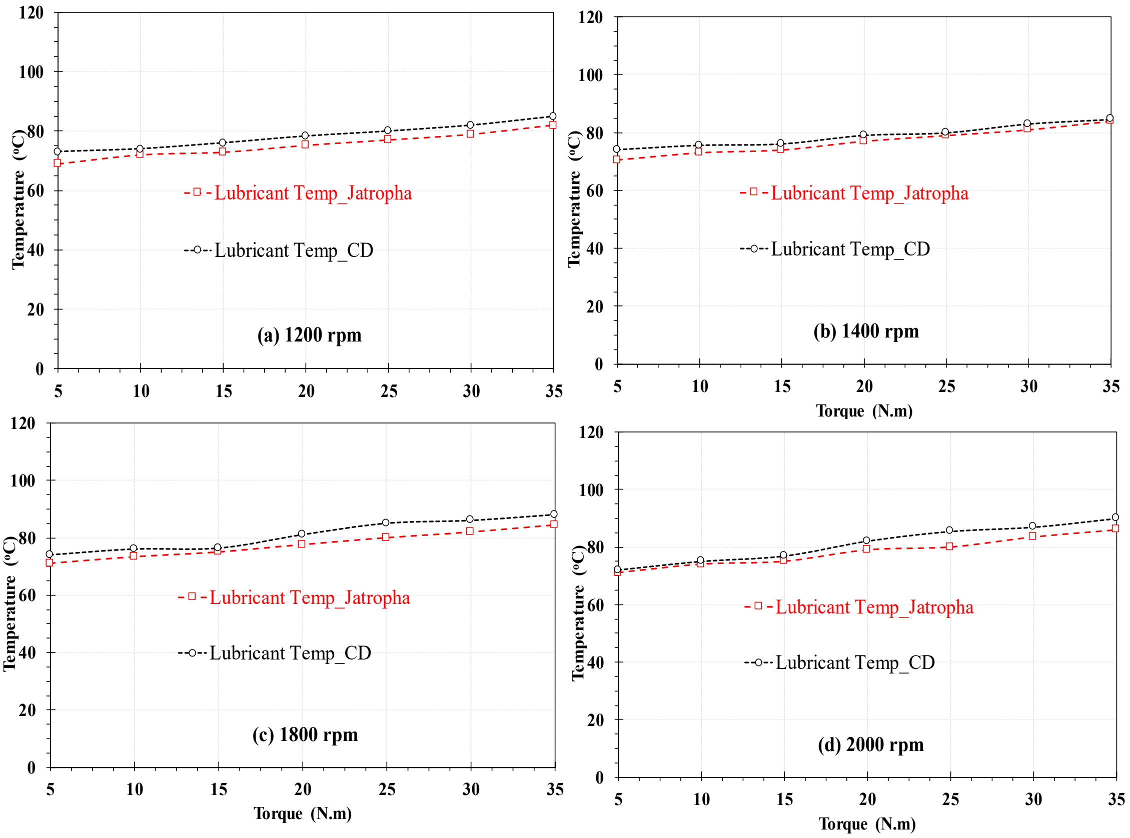

Figure 6. Cooling water temperatures at partial loads and different load.

In general, when the test engine was at a full load condition, CD's higher heating value resulted in higher cooling water and lubricant temperatures. At low load conditions, CD's higher viscosity negatively affected the quality of the injection and air-fuel mixture. As a result, the CD's output power was lower than Jatropha's output power. In summary, CD fuel produced lower cooling water and lubricant temperatures at lower load conditions due to the lower released heat.

5. Conclusions

This research was conducted to evaluate the effect of Jatropha oil on engine characteristics including engine performance, fuel consumption, lubricant, and cooling temperature. Consequently, treated Jatropha oil was converted to biodiesel via transesterification reaction under the presence of CaO and evaluated to compare to regular diesel fuel using ASTM methods. The BTEs of the Jatropha-fuelled engine was similar to the BTEs of the CD-fuelled engine at almost engine speeds. Also, the lubricant oil temperature and the cooling water temperature of that engine were dramatically lower than that of CD fuel due to their lower heating value and higher viscosity. In general, Jatropha oil can be used to fuel conventional CI engines because it allows the engine to work well and to operate smoothly at all operation conditions, its engine performance at a full load is comparable to the engine performance of CD and its engine performance at a partial load is comparable to or slightly better than the engine performance of CD at certain points.

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Conflict of interest

The authors declare no conflict of interest.

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