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Engine Performance Characteristics of a Compression Ignition Engine Fuelled by Traditional Diesel and Waste Cooking Oil

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Abstract. This research presents a comparison of the test engine's performance characteristics fuelled by diesel and waste cooking oil synthetic diesel (WCOSD). Commercial diesel (CD) fuel used in this research was commercial diesel in the market; meanwhile, WCO was manufactured from cooking waste product using Catalytic Cracking Method. The synthesizing process known as Catalytic Cracking Method at pilot scale level using non-food oil such as waste cooking oil to manufacture biodiesel fuel oil in place of diesel with a stable energy output. The results of this research showed that it can be concluded that the engine torque with WCO drop from 1.9 Nm to 5.4 Nm at all speed while the BSFCs drop at almost speed at full load condition compared to that of CD. The BTEs of the engine fuelled with WCOSD are higher than that of the engine fuelled with CD at almost engine speed at full load. The result of this research is the foundation for using WCO in worldwide application.

1. Introduction

Recently, environmental pollution and energy crisis has been one of the most serious problems facing humanity and other life forms on our planet today. And thus, it is necessary to find out the solution to replace the traditional energy sources as mentioned in [1-5]. Biodiesel is a fuel that is produced from renewable biological sources and equivalent to diesel. Biodiesel is the common name for all kinds of ester-based oxygenated fuels derived from renewable biological sources. It can be produced from animal fats and organic oils [6]. Chemically, biodiesel refers to mixtures of mono alkyl-esters of long chain fatty acids produced from animal fats or vegetable oils. It is normally manufactured by trans-esterification of an animal fat or vegetable oil with a monohydric alcohol, such as ethanol or methanol in the presence of catalyst to produce glycerin and esters (biodiesel). Generally, methanol is favored for trans-esterification [6-7]. The purpose of the trans-esterification process is to reduce the viscosity of the animal fat or vegetable oil. Trans-esterification is basically a sequential reaction. Firstly, triglycerides are reacted to di-glycerides, then di-glycerides are subsequently reacted to mono-glycerides and finally mono-glycerides are reacted to fatty acid esters. Reaction environment such as reaction temperature and time, catalysts, free fatty acid and water content in animal fats or vegetable oils and the molar ratio of alcohol to glycerides are the main factors affecting trans-esterification [6]. Most of the biodiesel made today is produced with the base catalyzed reaction for some reasons: It get high efficiency (98%) with minimal reaction time and side reactions; Pressure and temperature are low; Construction materials are simple.

The combustion process of engine can be improved as the engine is fuelled with biodiesel because of their oxygen content. The oxygen content of biodiesel also reduces its oxidation potential. The combustion efficiency of biodiesel increases in comparison to that of petroleum-based diesel. Biodiesel involves average 11% oxygen by weight and biodiesel usually contains no sulfur. When CI engine is used with biodiesel its life can be extended since biodiesel is more lubricating than petroleum-based diesel. Lubricant properties of biodiesel are better than those of petroleum-based diesel.

A. Abu-Jrai et al [14] has tested blends of treated waste cooking oil and commercial diesel on a naturally aspirated, water-cooled, four stroke, direct-injection, compression-ignition engine to investigate exhaust emission characteristics and combustion characteristics of the engine. They observed that the total combustion duration of B50 was expanded in comparison with that of commercial diesel fuel. They also saw that the combustion was advanced at the all examined engine loads and BSFC for B50 slightly increases in comparison with conventional diesel. In terms of emissions, they also showed that the NOx emissions concentration of the engine fuelled with B50 were increased by 37%, 29%, and 22%, but the smoke emission was dropped by 42%, 31%, and 30% in comparison with conventional diesel at 25%, 50%, and 75% loads respectively. CO2 emissions increased nearly linearly as the load increases.

In 2012, S. Padalkar [9] analyzed effects of waste fried oil methyl esters on exhaust emission and performance of an engine. They observed that the emission characteristics of engine fuelled with different waste fried oil methyl ester blend improved significantly. For example, CO emissions were decreased with different blends of 21–45% of fried oil methyl esters; for blend B50, CO concentration was lower by 21% than that of conventional diesel. Particulate matter percentage was dropped by 23–47% as fried oil methyl esters quantity in the blends increase. Sulfur dioxide emission was dropped by 50% to 100% for different waste fried oil methyl ester blend. However, NOx emission concentration was increased by 4–10% as fried oil methyl esters concentration in the blend increase. In another research, H. An et al [10] investigated effects of biodiesel derived from waste cooking oils on emission characteristics, combustion characteristics and performance of the test engine. They concluded that the use of biodiesel/blend fuels lead to a higher BSFC, particularly at partial load conditions and low engine speed. For instance, the BSFC of the engine running with biodiesel increased by 34.4% and 42% in comparison with conventional diesel at 1200 rpm and 800 rpm respectively and at 25% engine load and the opposite trend was found at 50% and 100% load. For emission characteristics, the major emissions such as HC and NO_x slightly reduced for biodiesel in comparison with conventional diesel. With respect to combustion process, ignition delay is slightly shorter and peak heat release rate is lower with the use of biodiesel. But at low engine speed trend was opposite, disclosing that the low engine speed affect significantly on the emission formation and combustion processes in the engine.

Although there have been many studies as listed above that investigated the use ability of waste cooking oil on compression-ignition engine; however, these studies used biodiesel produced from waste cooking oil throughout the transesterification reaction directly waste cooking oil to fuel for the engine. In addition, these studies only focused on testing at some operating engine points, such as speed characteristic at full load or load characteristic at rated engine speed. For these reasons, the objective of this study is to produce biodiesel from waste cooking oil and investigate the compression-ignition engine performance and its combustion characteristics fueled by WCO corresponding to all main operating engine points.

2. Testing equipment, experiment setup and test procedure

In this study, waste cooking oil synthetic diesel produced from waste cooking oil successfully manufactured in this research was used and compared with conventional diesel fuel when they were used run on internal combustion engine. The physical and chemical properties of WCOSD and CD fuels are shown in Table 1. The test engine is a four stroke, single-cylinder, water-cooled, naturally aspirated, direct injection diesel engine, a KUBOTA model RT140.

To conduct the specific engine speed, the experiments were conducted with the single cylinder diesel engine corresponding to various engine speeds. In the experiment, the engine was coupled with a 40-kW regenerative dynamometer. The cylinder pressures were recorded by a high-speed data acquisition system including two high accuracy AVL piezoelectric pressure transducers, a Crank Angle Encoder model Kistler 2613B - GU12P and a combustion analyzer model DEWE-5000-CA-SE. The fuel consumption was determined by FC2210 Advanced Fuel Measurement Device. In order to measure the air flow rate, TH01-40 air consumption meter was set up on the intake manifold. In addition, six different digital thermocouples were set up to measure the exhaust gas, engine oil, coolant inlet and outlet, fuel, and air inlet temperature.

Table 1. Chemical and physical properties of tested fuels.

Properties		WCO	CD
Composition (%)	C, H, N	77.14, 14.6, 0.078	81.17, 15.29, 0.067
Density (kg/m³)		820.289	827.485
Heating Value (MJ/kg)		44.245	44.864
Flash Point (˚C)		93.5	81.5
Viscosity (mm^2/s)		2.92	3.74

3. Results and discussion

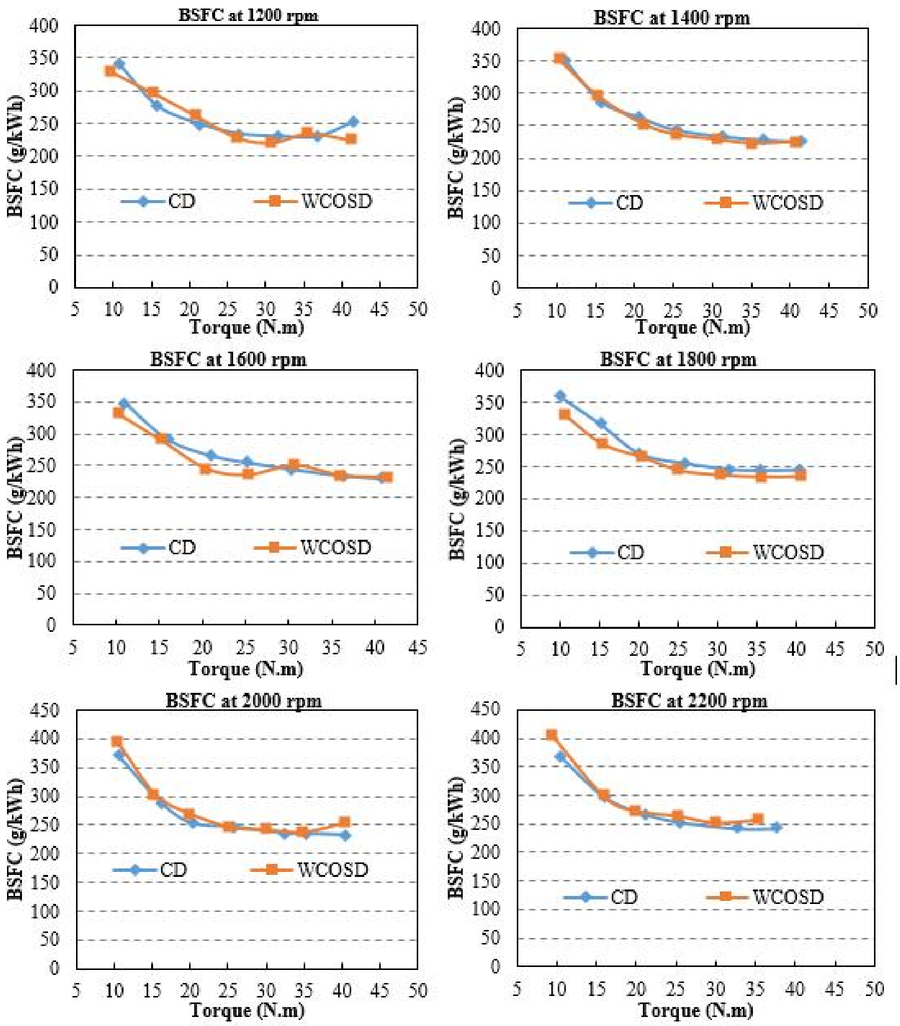

Figure 1. Brake specific consumption at part load different engine speeds.

Figure 1 shows the experiment results of brake specific fuel consumptions (BSFCs) of the test engine fuelled by two different fuels WCO and CD at part load condition and seven different engine speeds.

From the results, it can be seen that the BSFCs of CD is almost higher than that of WCO. At 1200 rpm, when the engine toques are 15 Nm, 20 Nm, and 35 Nm, the BSFCs of the engine running with WCOSD are respectively 19.6 g/kWh, 13.3 g/kWh and 5.6 g/kWh higher than that of the engine running with CD. Whereas at 10 Nm, 25 Nm, 30 Nm and 40 Nm, the BSFCs of the engine running with WCOSD decrease 13.5 g/kWh, 5.5 g/kWh, 8.8 g/kWh and 26.2 g/kWh respectively.

In comparison with CD at 1400 rpm and part load condition, it can observe that, the BSFCs of the engine running with WCOSD drop at 5/7 test point, particularly, 11.7 g/kWh at 20 Nm, 8.0 g/kWh at 25 Nm, 5.3 g/kWh at 30 Nm, 6.9 g/kWh at 35 Nm and 0.5 g/kWh at 40 Nm; and increase at the other points, particularly, 0.7 g/kWh and 7.8 g/kWh. At 1600 rpm, the BSFCs of the engine running with WCOSD drop 17.0 g/kWh, 0.2 g/kWh, 20.6 g/kWh and 18.8 g/kWh at 10, 15, 20 and 25 Nm respectively. Whereas they increase 6.2 g/kWh, 0.9 g/kWh and 2.2 g/kWh at 30, 35 and 40 Nm. The BSFCs of the engine running with WCOSD drop at all test points at 1800 rpm, particularly 31.4, 31.2, 4.6, 10.4, 7.8, 9.0 and 8.9 g/kWh at load from 10 to 40 Nm.

At 1600 rpm, the BSFCs of the engine running with WCOSD drop 17.0 g/kWh, 0.2 g/kWh, 20.6 g/kWh and 18.8 g/kWh at 10, 15, 20 and 25 Nm respectively. Whereas they increase 6.2 g/kWh, 0.9 g/kWh and 2.2 g/kWh at 30, 35 and 40 Nm.

The BSFCs of the engine running with WCOSD drop at all test points at 1800 rpm, particularly 31.4, 31.2, 4.6, 10.4, 7.8, 9.0 and 8.9 g/kWh at load from 10 to 40 Nm. However at 2000 rpm and 2200, the BSFCs of the engine running with WCOSD increase at almost part load conditions, with the increase amount from 1.6 to 35.6 g/kWh.

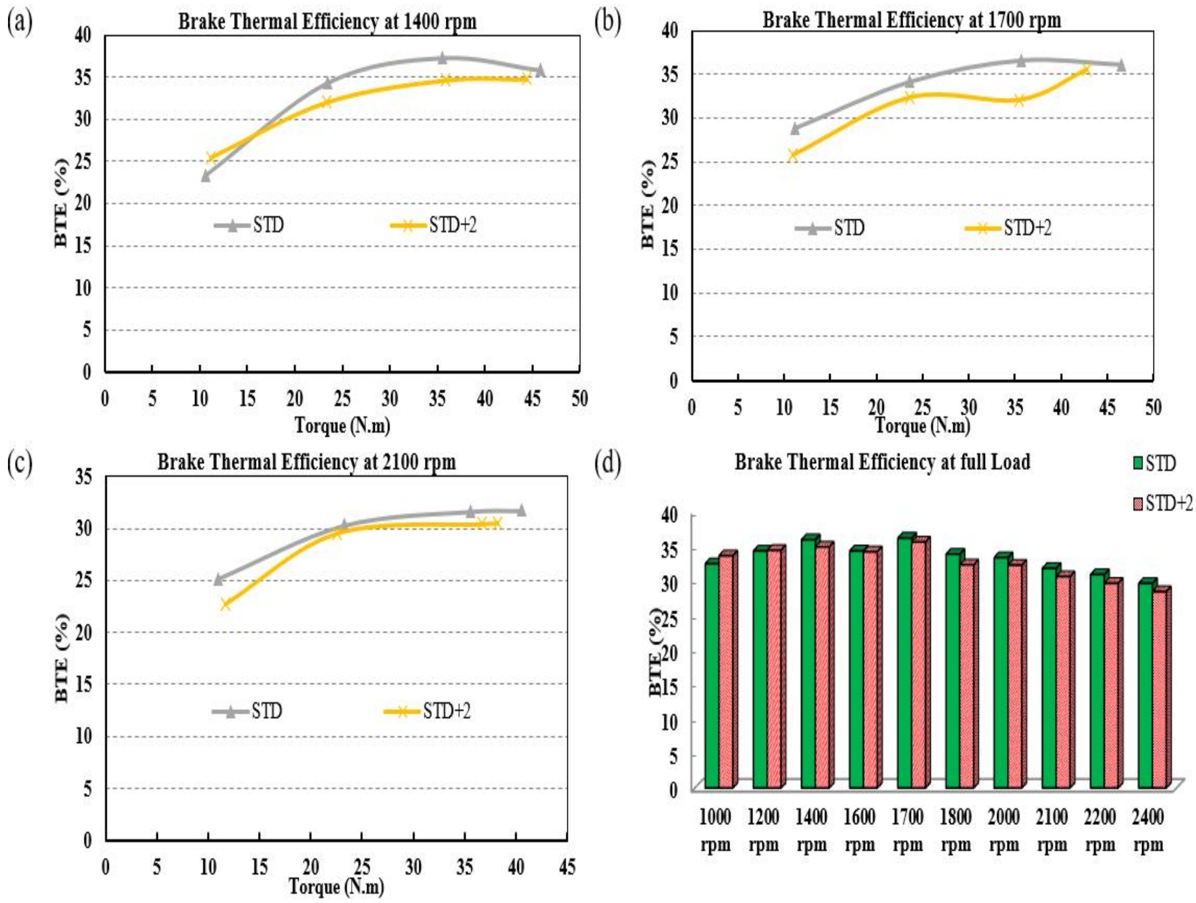

Figure 2. Brake Thermal Efficiency of the engine running with WCOSD for standard (STD) and retard injection timings (STD+2) at (a) 1400 rpm, (b) 1700 rpm, (c) 2100 rpm and (d) full load.

The results referring to the brake thermal efficiency (BTE) of the engine running with WCOSD for standard and retard injection timings, at 1400 rpm, 1700 rpm and 200 rpm constant speeds and full load, are shown in Figure 2.

It may be readily seen that the BTEs of the engine run by WCOSD drop than at almost of all engine operating conditions when injection timing is retarded 2^{o}CA.

It can be seen from the experiment results that when injection timing is retarded 2^{0}CA, the BTEs of the engine running with WCOSD at 1400 rpm decrease 2.3% and 2.7% at 23 Nm, 35 Nm respectively. The BTEs drop 3.1%, 1.8% and 4.5% at 11 Nm, 23 Nm and 35 Nm and 1700 rpm as well. At 2100 rpm the BTEs of the engine with standard injection timing is 2.4%, 0.8% and 1.2% higher than that of the engine with 2CA retarded injection timing at 11 Nm, 23 Nm and 35 Nm respectively as shown in Figure c.

It can be seen from Figure 2d that the BTEs drop at almost all speeds at full load condition when the injection timing of the engine is changed from STD to STD+2. The BTEs drop 1.1%, 0.1%, 0.6%, 1.5%, 1.1%, 1.2%, 1.3% and 1.2% at 1400 rpm,1600 rpm, 1700 rpm, 1800 rpm, 2000 rpm, 2100 rpm, 2200 rpm, and 2400 rpm respectively. However The BTEs increase at 1000 rpm and 1200 rpm.

4. Conclusion

In this paper, catalyst cracking biodiesel from waste cooking oil was used. The first target of this study is to evaluate the influence of using WCOSD on the performance and emissions of a conventional direct-injection single cylinder compression-ignition engine, a KUBOTA model RT140, comparing with commercial diesel fuel as base line. The results indicate that in comparison with CD at full load condition the engine torque of the engine running with WCOSD drops from 1.9 Nm to 5.4 Nm at all speeds while the BSFCs drop at almost speeds, thus the BTEs of the engine fuelled with WCOSD are higher at almost engine speed.

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