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Experimental Study on A Diesel Engine Fueled with Soybean Biodiesel

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Abstract: Biodiesel is a renewable and environmentally friendly alternative fuel derived from natural fats or vegetable oils and it is considered as an attractive alternative to replace diesel fuels. To optimize the application of biodiesel on vehicle diesel engines, the power and fuel economies performances of a diesel fueled with soybean biodiesel were investigated under different engine loads and speeds. Experimental results show that, compared with diesel fuel, with increase in the biodiesel in the blends, the brake power and torque and the brake specific energy consumption increase, the smoke density under free acceleration decreases except B10, the NO_X emissions increase. The trade-off relationship is clear between the NO_X and smoke density when the diesel engine fueled with different biodiesel percentage in the blends. From the trade-off relationship between NO_X and smoke density, the optimum blend ratio is B20 in the experimental study.

Keywords: Biodiesel-diesel blends, emissions, engine experiment, performance, soybean oil methyl ester

INTRODUCTION

Diesel engines are efficient power machinery for automotive applications due to their better fuel economy compared to gasoline engines. However, stringent emission regulations and future depletion of petroleum reserves force us to explore new technologies to develop alternative fuel as well as reduce pollutant emissions (Wu *et al*., 2009).

Alternative fuels such as biodiesel and ethanol can satisfy the demand for renewable energy sources with low environmental impacts. While ethanol has been used as a total or partial substitute fuel for gasoline in countries like Brazil and USA, vegetable oil or animal fat derived biodiesel has largely grown as a substitute for diesel oil (Randazzo and José, 2011).

Biodiesel is produced by transesterification of oil, where one mole of oil is chemically reacted with three moles of an alcohol in presence of a catalyst. In this reversible reaction, the glycerol moiety of the triglyceride molecule is replaced with an alkali radical of the alcohol used, giving alkyl based monoesters (Kanitkar *et al*., 2011).

Biodiesel is now mainly being produced from soybean and rapeseed oils. Soybean oil is of primary interest as biodiesel source in the United States, while many European countries are concerned with rapeseed oil and countries with tropical climate prefer to utilize coconut oil or palm oil. However, any vegetable oil-corn, cottonseed, peanut, sunflower or palm-could be used to produce biodiesel (Ayhan, 2007). Furthermore, other sources of biodiesel studied include animal fats and used or waste cooking oils. Researchers are also developing algae that produce oils, which can be converted to biodiesel.

Although biodiesel has many advantages when it comes to fuel properties, it still has several properties that need to be improved, such as its comparatively higher emission of nitrogen oxides (Gokalp *et al*., 2011). The purpose of this experimental study was to determine the effects of fuelling a diesel engine with soybean oil methyl ester and diesel fuel blends on performance and smoke density and NO_X emissions. Based on the trade-off relationship between NO_X and smoke density, the optimum blend ratio was determined.

TEST PROCEDURE

The biodiesel used in the investigation was soybean oil methyl ester. The main physical and chemical properties are listed in Table 1.

The experimental engine is a water cooling, 4-cylinder, 4-stroke, supercharged, direct injection diesel engine. The capacity is 2.499 L and the compression ratio is 18.5. The rated power is 76 kW at 3800 r/min and the fuel injection timing is 4.5±0.5 ºCA BTDC. In order to compare and analyze comprehensively the power and fuel economies performances, smoke density and NO_X emissions of soybean biodiesel with different blending ratios, engine tests were carried out at the rated torque speed of 2000 r/min and a high speed of 3000 r/min under 30, 60 and 100% of full load, respectively. The engine power was kept the same

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Table 1: Fuel properties

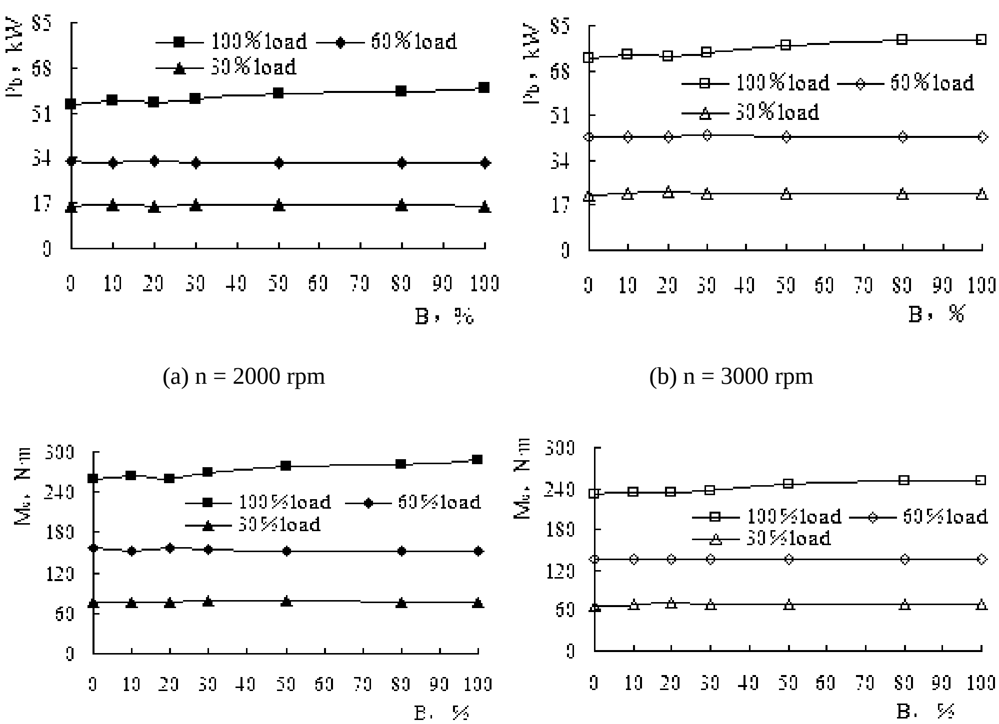
Property	B0	B100
Cold filter plugging point (°C)	3	1
Solidifying point (°C)	-6	-1
Distillation temperature at 50% (°C)	260	330
Distillation temperature at 90% (°C)	350	340
Distillation temperature at 95% (°C)	354	345
Flash point (°C)	64	140
Kinematic viscosity at 20°C (mm^2/s)	4.8100	9.6100
Kinematic viscosity at 40°C (mm^2/s)	2.8400	5.0600
Specific gravity at 20°C (g/mL)	0.8360	0.8750
Specific gravity at 30°C (g/mL)	0.8070	0.8660
Gelatine content (mg/100 mL)	0.2870	2.2
Carbon residue (%)	0.1780	0.2440
Sulphur content (wt%)	0.0274	0.0102
Acidity (mg/g)	0.0600	1.7600
Copper corrosion	<1	1a
Ash (%)	0.0055	0.0225

under 30 and 60% of full load and the accelerator rod of the engine was kept maximum at full load, the smoke density under free acceleration was measured according to the standard GB17691-2001 of China.

The test bed included an eddy current absorption dynamometer which was used to provide loading to the engine and to maintain engine speed. Smoke density and NO_X emissions were measured by AVL Digas 4000 Light and AVL Dismoke 4000. Instruments were available to measure the flow rate of the fuel inlet.

RESULTS AND DISCUSSION

Brake power and torque: The power performance of engines is usually characterized by the brake power and torque. The variation in brake power and torque with the biodiesel content in the blends is presented in Fig. 1. With increase in biodiesel percentage in the blends, at partial loads there is no obvious difference in the engine brake power and torque, but they increase markedly at full load. This is because the engine power was kept the same under 30 and 60% full load while the accelerator rod of the engine was kept maximum at full load. Biodiesel contains a small amount of oxygen which was believed to accelerate the combustion actively and rapidly, although the heating value of the biodiesel was lower than that of diesel (Kyunghyun, 2010). The higher viscosity and surface tension of biodiesel prevent sufficient breaking of the biodiesel during injection process. Various reasons, most of them related to viscosity, have been reported in the literature to explain the torque and power recovery (with respect to the loss of heating value) at full load with respect to



(a) n = 2000 rpm (b) n = 3000 rpm

(c) n = 2000 rpm (d) n = 3000 rpm

Fig. 1: Brake power and torques

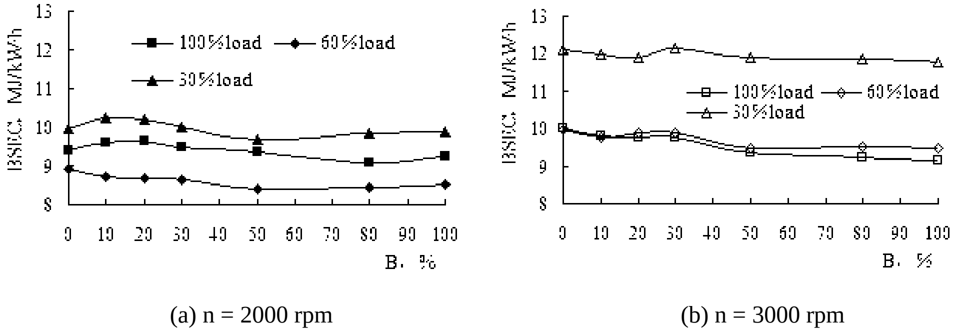
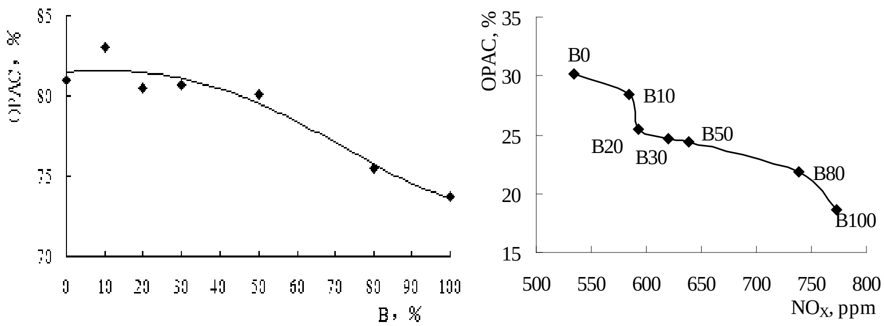
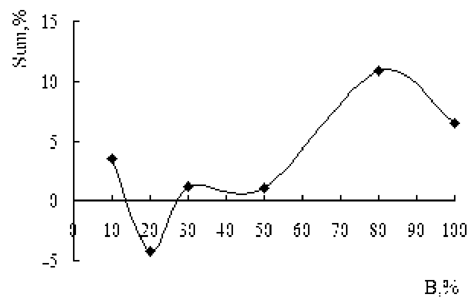


Fig. 2: Brake specific energy consumption



(a) Smoke density emissions under free acceleration (b) Trade-off between NO_X emissions vs. smoke emissions



(c) Percentage sum of smoke density decreased and NO_X emissions increased

Fig. 3: Smoke density and NO_X emissions

that obtained with diesel fuel (Gokalp *et al*., 2011). Biodiesel viscosity also affects the fuel spray dynamics, increasing spray momentum, tip penetration and velocity. The increase in the spray momentum promoted by biodiesel blending also improves the turbulent kinetic energy available in the fuel jet, which has a significant positive effect in the burning rate during the mixing-controlled combustion (Bueno *et al*., 2011).

Brake specific energy consumption: It is not reliable for brake specific fuel consumption to compare different fuels because of their different calorific values and densities. The brake specific energy consumption, defined as energy consumption for per unit work, is an ideal variable because it is independent of the fuel. Hence, it is easy to compare energy consumption rather than fuel consumption. The smaller brake specific energy consumption is, the higher thermal efficiency is. The variation in brake specific energy consumption produced with the biodiesel content in the blends is presented in Fig. 2. With increase in biodiesel percentage in the blends, the brake specific energy consumption fluctuates and increases slightly. The reason for rise in brake specific energy consumption is that as the combined effect of low heating value and high density of biodiesel (Puhan *et al*., 2005). And the biodiesel with oxygen content has slightly higher thermal efficiency than the diesel fuel, mainly due to more complete combustion (Usta, 2005).

Smoke density under free acceleration: The smoke density emissions under free acceleration variation depending on the biodiesel content in the blends are shown in Fig. 3a. With increase in biodiesel percentage in the blends, the smoke density under free acceleration decreases. Compared with diesel, the decreased percentages for the smoke density emissions under free acceleration of B10, B20, B30, B50, B80, B100 are -2.5, 0.6, 0.4, 1.1, 6.8 and 9%, respectively. The reductions in smoke density emissions are due to penetration and velocity the absence or low sulfur content, low aromatic compounds and the presence of oxygen in biodiesel.

Trade-off between NO_X vs. smoke density: Figure 3b shows the tradeoff relationship between the NO_X and smoke emissions. This is a standard trade-off curve used by engine designers. Usually, anything that decreases NO_X increases the smoke and vice-versa. This is because smoke density emissions are generated under high temperature and lean oxygen while high temperature and rich oxygen contribute to NO_X emissions formation.

With increase in biodiesel percentage in the blends, the smoke density emissions decrease while NO_X emissions increased. Compared with diesel, the decreased percentages for the average smoke density emissions of B10, B20, B30, B50, B80, B100 are 5.8, 15.37, 14.93, 18.57, 27.36 and 38.2%, the increased percentages for the average NO_X emissions are 9.36, 11.14, 16.17, 19.63, 38.26 and 44.69%, respectively. Many studies have reported that biodiesel can result in higher NO_X, but the reason is unknown. Fuel oxygen content is believed to be the main reason, since the fuel oxygen may provide additional oxygen for NO_X formation (Mustafa, 2007). Higher cetane number of biodiesel could reduce ignition delay and fuel consumed in the premixed phase and therefore rise in-cylinder temperature and peak pressure and enhances NO_X formation (Park *et al*., 2009). The impact of the fuel's physical properties on the engine's injection timing may also play a role in the higher NO_X emissions. The difference in compressibility between biodiesel and diesel fuel results in advance of injection timing. Earlier injection timing could make the combustion temperature and pressure higher.

The variation in the percentage sum of smoke density decreased and NO_X emissions increased with the biodiesel content in the blends is presented in Fig. 3c. We can see clearly that the optimum blend ratio is B20.

CONCLUSION

The supercharged vehicle diesel engines with no modification fueled with biodiesel-diesel blends operate perfectly. Compared with diesel fuel, with increase in the biodiesel in the blends, the brake power and torque and the brake specific energy consumption increase, the smoke density decreases while NO_X emissions increase, the decreased percentages for the smoke density under free acceleration of B10, B20, B30, B50, B80, B100 are -2.5, 0.6, 0.4, 1.1, 6.8 and 9%, respectively. The trade-off relationship of diesel engine fueled with different biodiesel content in the blends is confirmed. From the trade-off relationship between NO_X and smoke density, the optimum blend ratio is B20 in the experimental study.

ABBREVIATIONS

CA = Crank angle
BTDC = Before top dead centre
NO_X = Nitrogen oxides
CO = Carbon monoxide
HC = Hydrocarbon
n = Engine speed
OPAC = Opacity
ppm = Parts per million

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