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Full Length Research Paper

Emission characteristics of a diesel engine using waste cooking oil as biodiesel fuel

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In this study, the use of waste cooking oil (WCO) methyl ester as an alternative fuel in a four-stroke turbo diesel engine with four cylinders, direct injection and 85 HP was analyzed. A test was applied in which an engine was fueled with diesel and three different blends of diesel/biodiesel (B25, B50 and B75) made from WCO. The test engine was run at 18 different speeds with a full load, and the results were analyzed. The biodiesel fuels produced slightly less smoke than the conventional diesel fuel, which could be attributed to better combustion efficiency. The use of biodiesel resulted in lower emissions of total hydrocarbon (THC) and CO, and increased emissions of NO_x. This study showed that the exhaust emissions of diesel/biodiesel blends were lower than those of the diesel fuels, which indicates that biodiesel has more favorable effects on air quality.

Key words: Alternative fuels, biodiesel.

INTRODUCTION

Extensive research on the use of alternative input products, such as rape, soybean and safflower oils, waste cooking oil (WCO) and tallow oil in the production of biodiesel have been conducted. Based on exhaustive engine tests, it can be concluded that bio-diesel can be adopted as an alternative fuel for existing conventional diesel engines without requiring any major modifications in the mechanical system of the engines. Bio-diesel emissions in a conventional diesel engine contain substantially less unburned HC, CO, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons and PM than conventional diesel emissions (Cherng and Lin, 2007; Demirbas, 2005). The NO_x emissions from bio-diesel blends of various origins are slightly lower than those of conventional diesel, and the difference is greater for blends with higher percentages of bio-diesel (Rakopoulos et al., 2006). Other researchers have observed the same behavior for all vegetable oil blends of various origins (Ulusoy et al., 2004; Kaplan et al., 2006; Çetinkaya et al., 2005).

Various studies have shown that bio-diesel made from WCO can be used in different types of diesel engines with no loss of efficiency (Hamasaki et al., 2001) and significant reductions in PM emissions (Lapuerta et al., 2008; Tat 2003; Çanakçi and VanGerpen 2003; Mittelbach and Tritthart 1988; Payri et al., 2005), CO emissions (Tat 2003; Payri et al., 2005) and total hydrocarbon (THC) emissions (Mittelbach and Tritthart, 1988; Aakko et al., 2002) when compared with emissions from conventional fossil diesel fuel. The performance and smoke results obtained from an engine used for generating electricity, when fueled with bio-diesels of WCO origin, showed that the smoke reduction was about 60% for B100 and approximately 25% for B20 (Çetinkaya and Karaosmanoğlu, 2005). Dorado et al. (2003) used waste olive oil in a four-stroke, three-cylinder, 2.5 L direct injection engine with a power rating of 34 kW through a eight mode test. They achieved 58.9% reduction in CO, 8.6% reduction in CO_2 and 57.7% reduction in SO_2 emissions. On the other hand, increases of 32 and 8.5% in the NO_x emissions and specific fuel consumption were observed in the B100 and B20 mixtures, respectively. Murillo et al. (2007) tested a four-stroke diesel outboard engine running on conventional diesel, conventional diesel blended with certain amounts of WCO bio-diesel (10, 30 and 50%), and pure bio-diesel and proved that the bio-diesel blends are environmentally friendly alternatives to conventional diesel. They found some reduction in power of approximately 5% with B10 and B30, and 8% with B50 and B100 with respect to the power obtained from conventional diesel.

The biodiesel from WCO was tested by Meng et al. (2008) on an unmodified diesel engine, and the results showed that under all conditions, the dynamical perfor-

Table 1. Specification of test engine.

Parameter	Description
Engine	TTF 8000s Engine
Model	85 HP TC
Type	4 Stroke
Cylinder number	4 Cylinder
Combustion chamber	Direct-Injection (DI)
Bore	104 mm
Stroke	115 mm
Volume	3908 cm^3
Compression ratio	18:1
Nominal revolution	2500 rpm
No load high idle speed	2750
Maximum power	62.5 kW (2500 rpm)
Maximum torque	340 Nm (1500 rpm)
Cooling system	Water cooled
Fuel pump	BOSCH Distributor type
Weight	430 kg

mance remained normal. Moreover, B20 and B50 blend fuels (which includes 20 and 50% crude biodiesel, respectively) created unsatisfactory emissions, while the B′20 blend fuel (which includes 20% refined biodiesel) reduced PM, HC and CO emissions significantly. In another study, wasted cooking oil from restaurants was used to produce neat (pure) biodiesel through transesterification, and this converted biodiesel was then used to prepare biodiesel/diesel blends. The authors of the study concluded that B20 and B50 are the optimum fuel blends in terms of emissions (Lin et al., 2007).

In this study, the performance of WCO methyl ester blended with diesel fuel in ratios of 25% (B25), 50% (B50) and 75% (B75) was investigated and compared with that of regular diesel in terms of emissions in a four-stroke four-cylinder direct-injection diesel engine.

MATERIALS AND METHODS

Test and measurement system

The experiments were conducted at the Research and Development Engine Test Laboratory of the Türk Traktör Factory in Turkey. In the tests, WCO from domestic, industrial and service sector sources of the Marmara Region were used. During the test, an engine was fitted to an engine test bench and coupled to an AC electric dynamometer. The specifications of the engine are given in Table 1.

Gaseous emissions including CO, CO_2, O_2, HC and NO_x were measured with a HORIBA MEXA-7100D emissions measuring system. Descriptions of the measuring devices are given in Table 2.

The engine was run for some time until the cooling water and oil temperatures had stabilized. During that time, the gas analyzers were calibrated with the zero-emission gas and span gas. After the warm up, the test conditions were set and the engine was allowed to reach a steady state before any data were taken. In the study, diesel/biodiesel blends (B25, B50 and B75) and regular diesels were used as test fuels; the test engine was loaded with values from 2700 down to 1000 rpm, and the performance results were recorded. To determine the main performance values of the engine, the tests were first conducted with conventional diesel fuel, and subsequent tests were made with blends of WCO methyl ester. The specifications of the WCO methyl ester are shown in Table 3.

Table 2. Measuring systems details.

Parameter	Description
Dynamometer	A/C dynamometer (215 kW)
Torque measurement	Load cell with digital readout
Fuel flow measurement	AVL 733 S Dynamic fuel meter
Smoke	AVL 415 sampling smoke meter
Air meter	Cusson laminar air flowmeter
Pressure	Digital pressure transducers
Temperatures	NiCr-Ni Thermocouples
Gas emissions	HORIBA MEXA-7100D
CO, CO_2	AIA – 721A
O_2	MPA – 722A
HC	FIA – 725A
NOx	CLA – 725 A
Particulate	HORIBA MDLT-1300

RESULTS

Smoke, CO, THC and NO_x emissions

The smoke emission values obtained from the four mentioned fuels are given in Figure 1. As seen in the figure, the smoke emissions of WCO methyl ester were lower than those for diesel fuel at all the engine speeds. All the fuels produced a large amount of smoke at low engine speeds, and the smoke concentration dropped sharply after 1300 rpm. The improved combustion efficiency could be attributed to increased turbulence effects. It is clear that the smoke emissions reduced all the WCO blends under all the operating conditions. Reduction of smoke number for B25 with an average of 23%, for B50, with an average of 52% and for B75, with an average of 59% was obtained.

Smoke emissions progress to low values at and above 1600 rpm. The calorific value of biodiesel was slightly lower than that of diesel, and its flash point was higher than that of diesel. A higher thermal efficiency indicates better and more complete combustion of fuel, which implies that a lesser amount of unburnt hydrocarbons are present in the engine exhaust emissions. Therefore, lower smoke density values are achieved with biodiesel blends than with conventional diesel (Ramadhas et al., 2005).

The CO emissions for all fuels at different engine speeds are given in Figure 2. As shown in the figure, CO emissions decreased with increasing engine speeds for all the fuels. The CO emissions of biodiesel blends and diesel fuel showed similar trends at all the operation con-

Table 3. Specifications of the test fuel.

Properties	Test method	WCO methyl ester
Density at 15℃ (kg/m^3)	ISO 12185	884.8
Kinematic viscosity at 40℃ (mm^2/s)	ISO 3104	5.605
Flash point (℃)	ISO 3679	160.5
Iodine value	EN 14111	54
CFPP, C	EN 116	-1
Phosphorous (mg/kg)	EN 14107	<0.1
Methanol % (m/m)	EN 14110	0.01
Monoglycerides % (m/m)	EN 14105	0.66
Diglycerides % (m/m)	EN 14105	0.62
Triglycerides % (m/m)	EN 14105	0.01
Free glycerol % (m/m)	EN 14105	0.02
Total glycerol % (m/m)	EN 14105	0.28

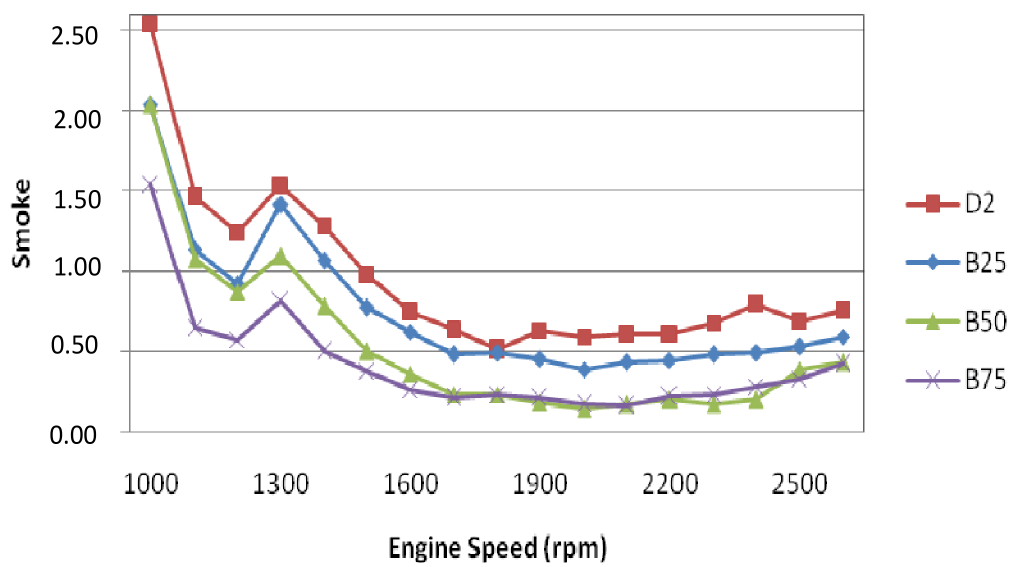

Figure 1. Smoke emissions of the biodiesel and diesel fuels.

ditions. In particular, all fuels showed similar CO emissions characteristics after 1300 rpm. The variations of CO emission with respect to fuels and engine speeds are shown in Figure 2. The test results showed that B25 and B75 reduced CO emissions by an average of about 2 and 13%. On the other hand with the B50, CO emissions increased by an average of 2%. CO emissions increased markedly at lower engine speed then showed a significant reduction after 1500 rpm for up to 18%. This is typical with all internal combustion engines because the air-fuel ratio decreases with increasing load, and CO emissions increase as the fuel-air ratio becomes greater than the stoichiometric value. The CO concentration in the exhaust is negligibly small when a homogeneous mixture is burned at a stoichiometric air-fuel ratio or on the lean side of the stoichiometric value (Ramadhas et al., 2005).

The variation of THC emissions with engine speed for the different fuels can be seen in Figure 3. As shown in the figure, THC emissions were lower when WCO methyl ester was added to the diesel fuel. The results demonstrated that THC emissions decreased when the diesel engine was run with B25, B50 and B75 and the reduction rates were about an average in the order of 9, 5 and 7% at all operation conditions. The presence of peroxides due to the biodiesel oxidation process may result in lower THC emissions (Lapuerta et al., 2008).

The variation of NO_x emissions with engine speed for the different fuels can be seen in Figure 4. As shown in the figure, it is clear that the NO_x emissions varied considerably with the test fuels at all the engine speeds. All the fuel blends produced higher NO_x emissions relative

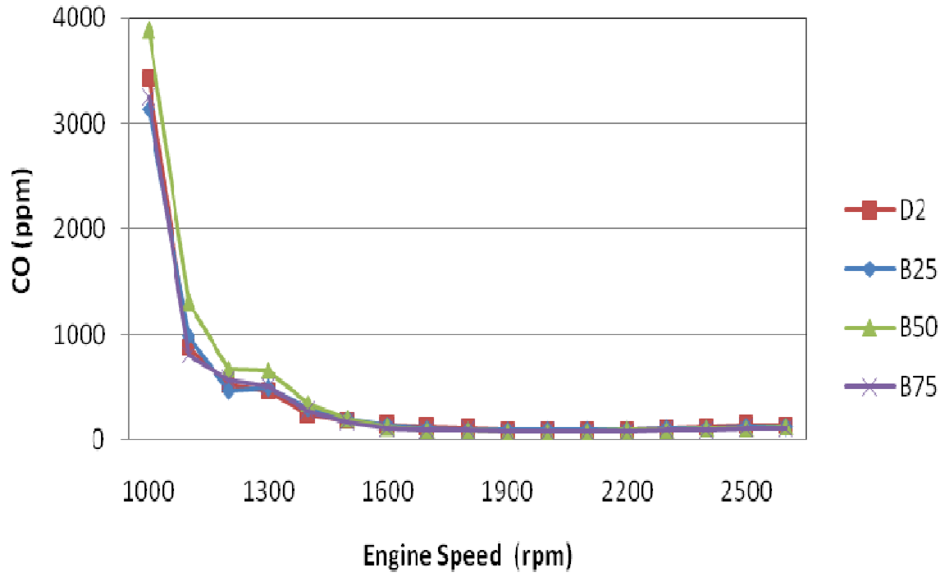

Figure 2. CO emissions of the biodiesel and diesel fuels.

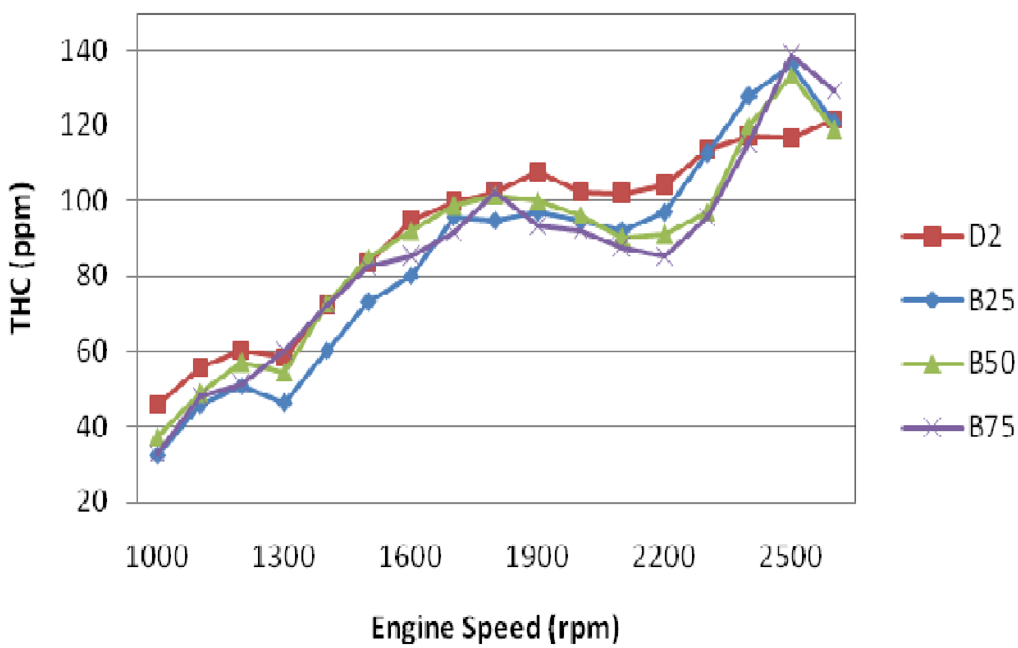

Figure 3. THC emissions of the biodiesel and diesel fuels.

to diesel fuel. Among the tested fuels, B75 produced the highest NO_x emission at an engine speed of 1800 rpm.

NO_x emissions with B25, B50 and B75 increased about an average of 12, 15 and 18% at all the operating conditions when compared with diesel fuel. Increasing NO_x emissions is an indicator of higher heat release and it can be explained by the decrease of the cetane number with the addition of the oxygenates (Shi et al., 2005).

Conclusion

The obtained results are consistent with their counterparts in the literature. The emission characteristics of the biodiesel blends indicate that the blends provided a good alternative to conventional diesel. The results of this study showed that WCO methyl esters have similar properties with diesel fuel, and they support the statement

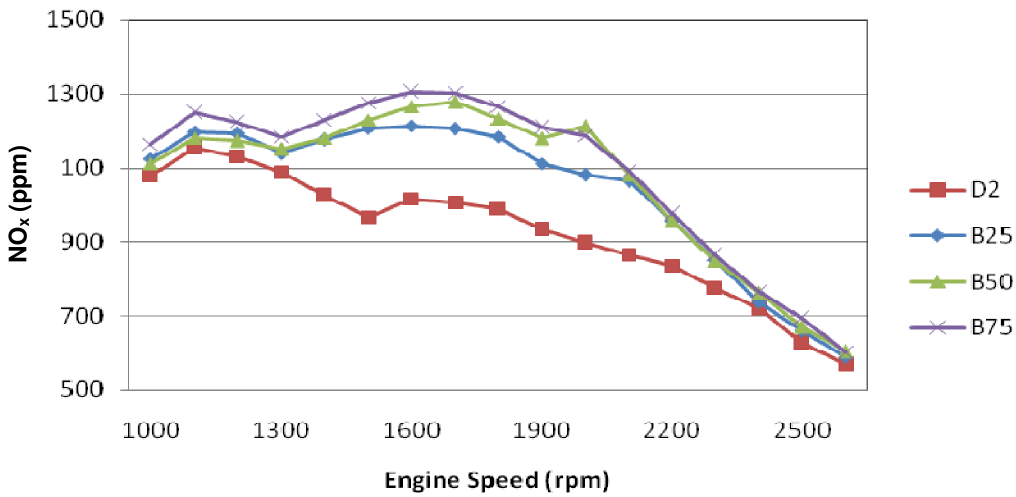

Figure 4. NO_x emissions of the biodiesel and diesel fuels.

that exhaust emissions from biodiesel fuels are lower than those of fossil diesel fuels, which may indicate that biodiesel has better effects on air quality.

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