Effect of Waste Cooking Oil Methyl Ester, Engine Speed and Engine load on CO and NO_x Emissions of a Diesel Engine

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Abstract: In This study, the effects of percentage of waste cooking oil methyl ester (biodiesel) in fuel mixture (biodiesel and diesel fuel No.2), engine speed and engine load as engine operation parameters on changes in emission characteristics CO and NO_x emissions. The experiments were conducted on a four cylinder direct-injection diesel engine. The usage of biodiesel resulted in lower emissions of CO and increased emissions of NO_x.
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1. Introduction

Today, because of the rapid development of certain growing economies, the request for energy has grown very quickly Biofuels such as alcohols and biodiesel have been proposed as alternatives for diesel engines (Agarwal, 2007; Demirbas, 2007; Ribeiro et al., 2007). Especially, the environmental issues concerned with the exhaust gases emission by the usage of fossil fuels also encourage the usage of biodiesel, which has proved to be ecofriendly far more than fossil fuels. In particular, biodiesel has received wide attention as a replacement for diesel fuel because it is biodegradable, nontoxic and can significantly reduce toxic emissions and overall life cycle emission of CO_2 from the engine when burned as a fuel (Cvengroš and Považanec, 1996; USEPA, 2002).

The carbon present in the exhaust supply deficit will have serious implications for many non-oil producing countries which are dependent on oil imports. Furthermore, the extensive use of fossil fuels has increased the production of greenhouse gases, especially carbon dioxide (CO_2), thus exacerbating the greenhouse effect. Biodiesel is known as a carbon neutral fuel because the carbon present in the exhaust was originally fixed from the atmosphere (Srivathsan, 2008). The potential to both reduce fossil fuel reliance and the release of CO_2 to the atmosphere.

Kulkarni and Dalai (2006) concluded that the engine performance of biodiesel obtained from waste frying oil is better than that of diesel fuel while the emissions produced by the use of biodiesel are less than those using diesel fuels except that there is an increase in NO_x, so biodiesel from waste cooking oil is a more economical source of the fuel.

Lapuerta et al. (2008) tested two different biodiesel fuels obtained from waste cooking oils with different previous uses on diesel particulate emissions. They found no important differences in emissions between the two tested biodiesel fuels.

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 CO, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons and PM than conventional diesel emissions (Cherng and Lin, 2007; Demirbas, 2005). The NOx 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 waste cooking oil 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 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 waste cooking oil origin, showed that the smoke reduction was about 60% for B100 and approximately 25% for B20 (Çetinkaya and Karaosmano_lu, 2005). Dorado et al. (2003) used waste olive oil in a four-stroke, three-cylinder, and 2.5 L direct injection engine with a power rating of 34 kW through an eight mode test. They achieved 58.9% reduction in CO, 8.6% reduction in CO_2 and 57.7% reduction in SO2 emissions. On the other hand, increases of 32 and 8.5% in the NOx 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 waste cooking oil 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 waste cooking oil was tested by Meng et al. (2008) on an unmodified diesel engine, and the results showed that under all conditions, the dynamical performance remained normal. Moreover, B20 and B50 blend fuels created unsatisfactory emissions, while the B20 blend fuel reduced PM, CO emissions significantly. In another study, wasted cooking oil from restaurants was used to produce neat 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 research the effects of biodiesel percentage of in fuel mixture (biodiesel and diesel fuel No.2) as fuel parameter and engine speed and engine load as engine operation parameters on changes in emission characteristics of a diesel engine was investigated. The relationships between biodiesel fuel blends, engine speed and engine load and CO and NO_x exhaust emissions was studied. In addition, using diagrams, the interaction effects of process parameters on the responses are analyzed and discussed.

2. Material and Methods

2.1 Biodiesel preparation and fuel properties

In the present investigation, biodiesel was produced from waste vegetable cooking oil. Biodiesel from waste cooking oil is a more economical source of the fuel. Kulkarni and Dalai (2006) concluded that the engine performance of biodiesel obtained from waste cooking oil is better than that of diesel fuel while the emissions produced by the use of biodiesel are less than those using diesel fuels except that there is an increase in NO_x.

Biodiesel was produced by using a transesterification process which was catalyzed by KOH (as Alkali catalyst) and methanol (as alcohol) in the TMU bio energy research laboratories. Then, biodiesel was analyzed by an established research institution following the ASTM D6751 standard. The important properties of waste vegetable cooking oil and No. 2 diesel are shown in Table 1.

Table 1. Properties of diesel and biodiesel fuels

Property	Method	Units	Biodiesel	Diesel
Flash point	ASTM-D92	°C	150	61
Pour point	ASTM-D97	°C	-5	0
Cloud point	ASTM-D2500	°C	-1	3
Kinematical viscosity, 40°C	ASTM-D445	mm^2/s	4.3	4.15
Density	---------	Kg/m^3	875	830

2.2 Test engine, experimental setup and procedure

Engine tests were carried out on a 4-cylinders, four-stroke, turbocharged, water cooled DI diesel engine. The diesel engine fuelled with waste vegetable cooking oil, its blends and No. 2 diesel fuel were at the different engine speeds and engine loads. In each speed, the maximum engine torque was reached for each fuel. Engine speed was measured by a digital tachometer with a resolution of 1 rpm. The engine was coupled to a hydraulic dynamometer to provide brake load and a gas analyzer was used to measure CO and NO_x emissions in the exhaust gas.

3. Analysis and Results

3.1. Statistical analysis

The experiment matrix (Table 2) was performed and the experimental data for CO and NO_x exhaust emissions of the diesel engine are shown in Table 2.

Table 2. The experimental and predicted data for the three responses

Experiment number	Experimental data	
	CO (%)	NO_x(ppm)
	Y_2	Y_3
1	0.081	248
2	0.056	293
3	0.054	206
4	0.029	246
5	0.061	432
6	0.043	511
7	0.039	356
8	0.023	430
9	0.061	301
10	0.026	400
11	0.071	415
12	0.031	312
13	0.06	154
14	0.037	464
15	0.041	359

3.2. CO emissions

Figures (1-4) show the CO traces for different fuels. It was observed that the CO emission decreased with the increase in engine speed. This decrease may be due to the oxygen content of the blends and pure biodiesel. Poor atomization and uneven distribution of small portions of fuel across the combustion chamber, along with a low gas temperature, may cause local oxygen deficiency and incomplete combustion (Roskilly et al., 2008). The CO emissions are shown to decrease more rapidly for all fuels from 1000 rpm to 2000 rpm. Reduced CO emissions were maintained, probably, thanks to the oxygen inherently present in the biodiesel, which makes it easier to be burnt at higher temperature in the cylinder. Similar results can be found in other studies (Roskilly et al., 2008; Raheman and Phadatare 2004).

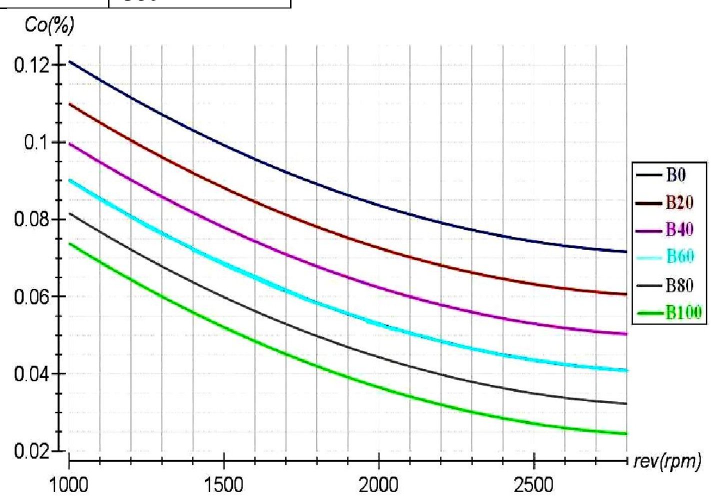

Fig 1. E ne load

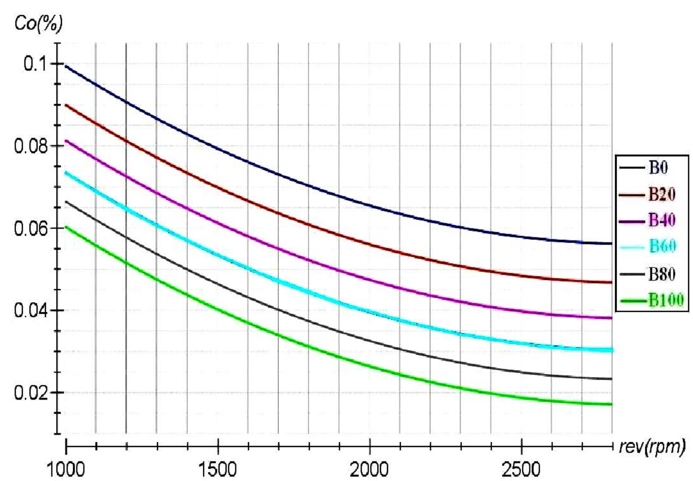

Fig 2. Effect of biodiesel and engine speed on CO emissions at 50% engine load

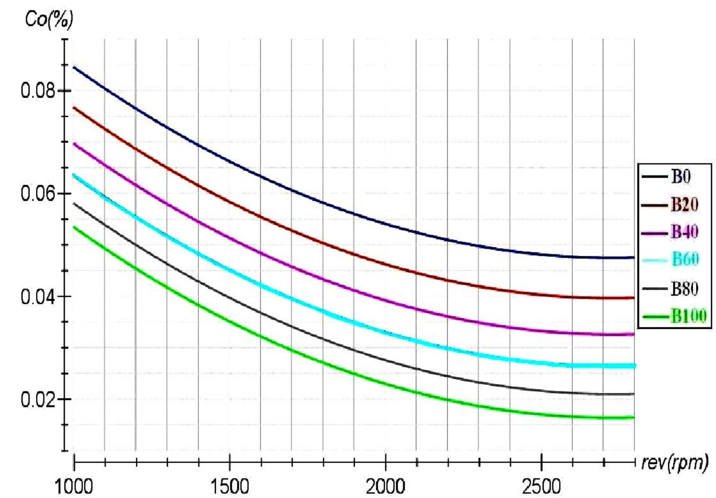

Fig 3. I ne load

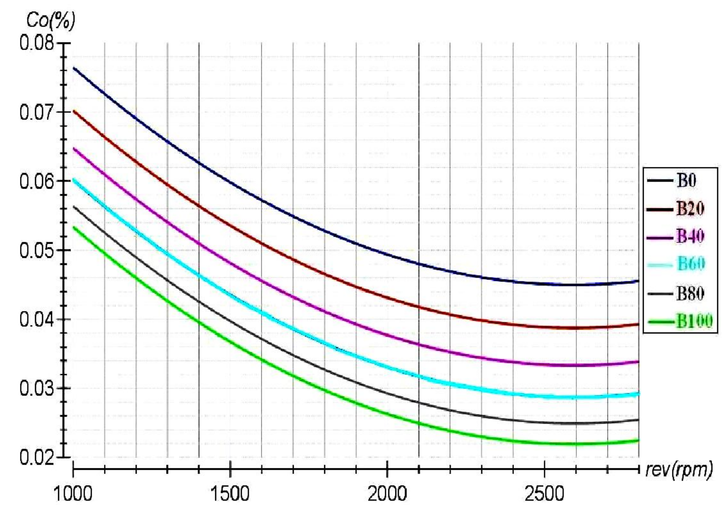

Fig 4. Effect of biodiesel and engine speed on CO emissions at 100% engine load

The CO emissions of the six fuels continuously decrease with increasing engine load. CO emissions are primarily controlled by the local fuel-air equivalence ratio. In general, low local cylinder temperatures and lean fuel-air mixture regions at low engine loads may cause the combustion reactions to be unstable so that CO can't continuously react into CO_2 ,or a temperature is reached at which the carbon monoxide concentration appears to freeze, leading to CO formation. At low engine loads, over-lean mixture areas, low in-cylinder temperatures, and bad atomization conditions influenced by the high viscosity of biodiesel at low temperatures can lead to higher CO emissions when using biodiesel fuel (Mani et al., 2009; Ramadhas et al., 2005). Under high engine loads, the molecular oxygen in biodiesel fuel improves the combustion for local rich mixtures, and the high cetane number of biodiesel fuel leads to less fuel-rich zone formation; consequently, the CO emission decreases (Tan et al., 2012).

3.3. NO_x emissions

The formation of nitrogen oxides (NOx) is affected by the peak flame temperature, the residence time of the high burning gas temperature, ignition delay, and the content of nitrogen and oxygen available in the reacting mixture (Lin C and Lin H, 2007). NOx emissions appeared to lessen with an increase in engine speed, as shown in figures (5-8). Although the increased engine speed caused an increase in the temperature and pressure of the burning gas, the period of the ignition delay was reduced at the mean time. This then resulted in a reduction of the residence time of the peak burning gas temperature. Decreased NOx emissions were therefore observed, as can be seen in figures (5-8). Figures (5-8) show the increase in NOx emissions was proportional to the amount of biodiesel. Hess et al. (2005) inferred that the ignition timing of biodiesel may be advanced because of its higher isentropic bulk modulus, which incurs a higher level of NOx emissions. In addition, the NOx formation was enhanced and became significant in the presence of the chemically bound oxygen content in the biodiesels, thus resulting in their higher level of NOx emissions compared with the diesel fuel No.2. This result agrees well with previous studies (Knothe et al., 2006; Ozsezen et al., 2008).

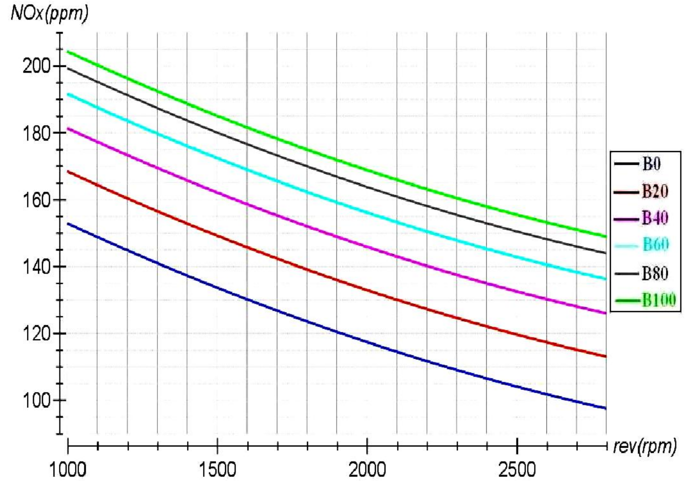

Fig 5. E ne load

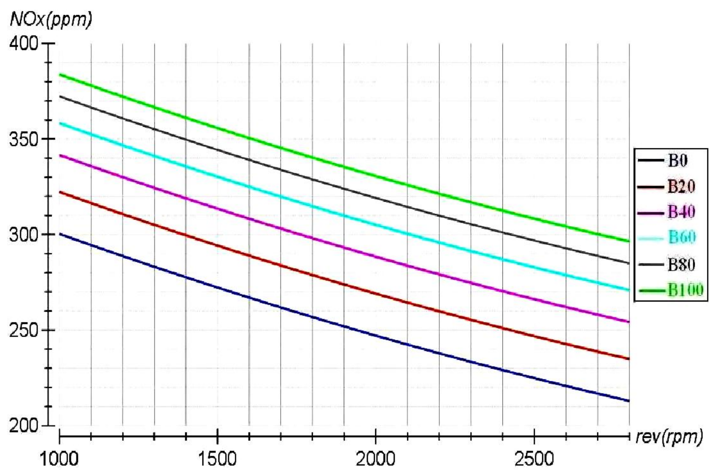

Fig 6. E ne load

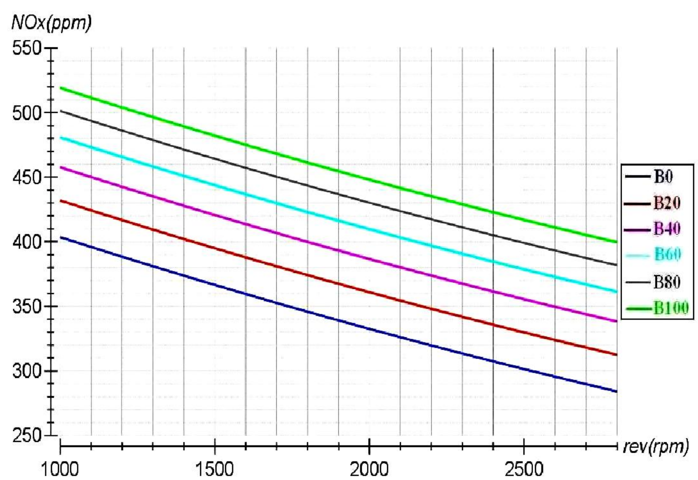

Fig 7. Effect of biodiesel and engine speed on NO_x emissions at 75% engine load

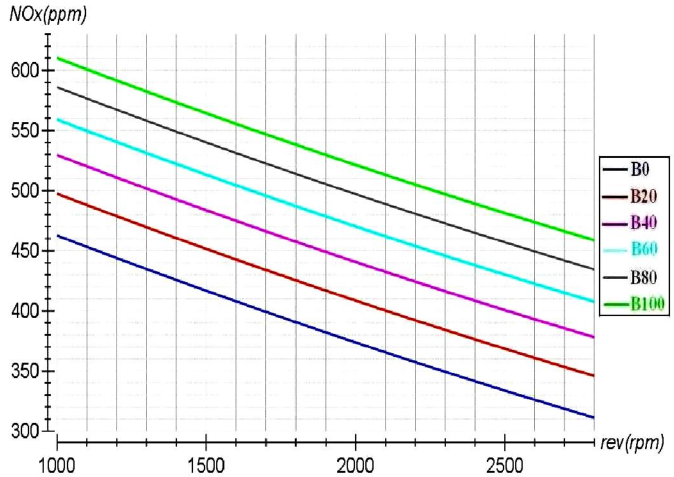

Fig 8. Effect of biodiesel and engine speed on NO_x emissions at 100% engine load

Also Figures 5-8 show the variation of NOx emission with engine load. The NOx concentration increases with increase of engine load for all the fuels. The NOx emissions of the six fuels continuously increased with the engine load and are relatively low at 25% engine load and high at 75% and 100% engine load. One possible reason for the increase of NOx emissions with increasing concentrations of biodiesel is the exhaust gas temperature increases with increase in load for all tested fuels. The nitrogen oxides emission is directly related to the engine combustion chamber temperatures, which in turn indicated by the prevailing exhaust gas temperature. With increase in the value of exhaust gas temperature, NOx emission also increases (Ramadhas et al., 2005).

4. Conclusion

In this study, the mathematical models was developed using response surface methodology to estimate the CO and NO_x exhaust emissions of the diesel engine. It was concluded that the statistical models as fitted can be effectively used to predict the emission characteristics. Also the effect of biodiesel produced from waste cooking oil blends and diesel No.2 fuel on engine exhaust emissions was investigated.

The CO emissions decreased with biodiesel usage. Reduced CO emissions were maintained, probably, thanks to the oxygen inherently present in biodiesel. At the same time, it should be noted that higher NOx formation occurred in biodiesel use due to the presence of the chemically bound oxygen content in the biodiesels and an unexpected advance of fuel injection timing caused by biodiesel because of its higher isentropic bulk modulus.

An increase in engine speed appeared to cause a decrease in the emission of CO and NOx.

On the emissions, in general, CO emissions are higher at low engine loads, and lower at high engine loads while NOx, increase with engine loads.

These results are similar to those found in the literature and support that waste cooking oil methyl esters have similar properties with diesel fuel. Also the results of the study show that use of biodiesel blends with diesel fuel can help in controlling air pollution to a great extent.

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