Environmental Aspects of Using Alternative Fuels in Diesel Engines

Şehmus ALTUN
*Technology Faculty, Department of Automotive Engineering Batman University, Turkey

Abstract:

Much research has been conducted on alternative fuels for using in diesel engines due to increasing environmental concerns and depletion of fossil fuels. Alternative fuels represent a valuable contribution to conserve energy and protect the environment as they have potential to reduce emissions from engines in comparison to conventional fuels derived from fossil fuels. In this study, petroleum based diesel, neat biodiesel obtained from waste cooking oil, their blend known as B20 and two blended fuels consisting of diesel, biodiesel and ethanol or methanol were tested in a direct injection diesel engine to investigate exhaust emissions. The experimental results indicated that NO_x emissions for biodiesel and B20 were higher than for diesel, while ternary fuel blends could lead to reduction of NO_x emissions. In addition, CO emissions of all the oxygenated fuels are lower than those of diesel, while brake specific fuel consumption is higher.

Key words: alternative fuels, biodiesel, emissions, diesel engines.

1. Introduction

Biodiesel is produced from vegetable oils or animal fats by transesterification process using methanol and a base catalyst, and it has many advantages over the petroleum diesel fuels as renewable, oxygenated, non-toxic, sulfur-free and biodegradable. Biodiesel have been investigated in diesel engines as pure or blended with diesel fuel by researchers [1-3], and it has been shown that there is a substantial reduction of carbon monoxide (CO), unburned hydrocarbons (HCs) and particulate matter (PM) emission whereas increase nitrogen oxides (NOx) [4-6]. Its high production cost and poor cold-flow properties are other problems; the first one is due to biodiesel feedstock, which is about 80% of the total operating cost [7]. The price of biodiesel is competitive with that of petroleum based diesel fuel when using waste cooking or frying oils as a feedstock [8]. Alcohol fuels have also been considered as oxygenated alternative fuels for diesel engines as the blended fuels for a long time. In alcohols, methanol and ethanol are used most often as fuels and fuel additives in diesel engines [9]. Ethanol is regarded as one of the promising alternative fuels or oxygen additives for diesel engines, with its advantages of renewable energy and high oxygen content. However, its limited miscibility with petroleum diesel limits its use in diesel engines [10]. Methanol also reduces NO_x and PM in diesel engines when it is mixed with diesel fuel. Because of the miscibility problems and the decrease of the cetane number, the ratio of methanol/diesel is not so high but the combustion changes a lot, even with relatively small additions of methanol [11]. Thus they could be used in diesel engines as fuel additive, e.g. Rakopoulos et al. [12] and Sayın [13] tested methanol–diesel and/or ethanol–diesel fuel blends. Zhu et al. [14], Qi et al. [15], Shi et al. [16] and Lapuerta et al. [17] tested alcohol-biodiesel-diesel blends in diesel engines. In these studies, it was reported that the blended fuels (ethanol or methanol-diesel) could lead to reduction of both NO_x and PM of a diesel engine when

*Corresponding author: Address: Technology Faculty, Department of Automotive Engineering Batman University, 72100, Batman TURKEY. E-mail address: sehmus.altun@batman.edu.tr, Phone: +904882173500 Fax: +904882173601

compared with diesel fuel, and the diesel-biodiesel–alcohol blends show excellent ability to eliminate smoke emissions. As seen in the literature review, methanol or ethanol and biodiesel blending with diesel fuel influence the diesel engine performance and emissions. Therefore, this study focused on the influences of diesel-biodiesel-methanol and diesel-biodiesel-ethanol blended fuels on the engine performance and exhaust emissions of a direct-injection diesel engine.

2. Materials and Method

2.1. Fuels tested

Petroleum diesel fuel was obtained from a commercial supplier, and used as the baseline fuel for the present experimental study. Biodiesel used in this study was produced from waste cooking oil by a commercial producer, located in İstanbul, Turkey. Methanol and ethanol with purity of 99.8 and 99.5%, respectively, were used for preparing ternary fuel blends. Five kinds of fuels were prepared and tested: pure diesel and biodiesel (B100), 20% biodiesel blending with 80% diesel (indicated as B20), 10% methanol blending with 20% biodiesel and 70% diesel (indicated as DBM10) and 10% ethanol blending with 20% biodiesel and 70% diesel (indicated as DBE10). The fuel properties were determined at Fuel Analysis Laboratory of Automotive Engineering in Çukurova University, Adana, Turkey and presented in Table 1. Compared with petroleum diesel fuel, all the oxygenated fuels have lower heating value by about 13–19%. The viscosity and density of biodiesel is evidently higher than that of other fuels used. An important property of diesel engine fuel is cetane number, and that of diesel is slightly higher than that of biodiesel. Methanol, ethanol and biodiesel contain molecular oxygen by roughly 50, 35 and 11% (wt.), respectively. Therefore, the fuels having highest oxygen content, in descending order, are: B100, DBM10, DBE10 and B20, it was taken into consideration that petroleum diesel fuel does not contain molecular oxygen. The heat of evaporation of diesel, biodiesel, ethanol and methanol are 290, 300, 840 and 1178 kJ/kg, respectively [19]. The ternary fuel blends (biodiesel-diesel-methanol or ethanol) for engine tests were prepared just before starting the experiment to provide that the fuel mixture is homogenous. As a matter of fact, ethanol-biodiesel-diesel (EB-diesel) fuel blend microemulsions are stable well below sub-zero temperatures, and biodiesel can be used as an amphiphile (a surface-active agent) to stabilize ethanol and diesel, as reported by Fernando and Hanna [18].

Table 1. The properties of fuels used.

Properties	Diesel	Biodiesel	BD	BDM	BDE
Density (kg/m^3) (at 15 °C)	833	878	842	840	841
Viscosity (mm^2/s) (at 40 °C)	2.95	4.43	3.21	3.57	3.63
Heating Value (MJ/kg)	45.65	36.6	39.6	38	36.9
Cetane Number (CN)	54.63	53.57	54.4	42.6	43.7

2.2. Test engine and experimental procedure

The performance and exhaust emission tests were conducted on a four-cylinder, four-stroke, naturally aspired, water-cooled and direct-injection diesel engine which has a 3.9 liter displacement and develops 89 kW @ 3200 rpm. The experimental set-up is installed in Automotive Engineering Laboratory of Faculty of Engineering in Çukurova University, Adana, Turkey. A hydraulic dynamometer (Netfren brand) is connected to test engine to provide brake load. A Magnetic pick-up sensor was used to measure the speed of the engine. The load on the dynamometer was measured using a Load Cell. Fuel consumption was measured with a gravimetric fuel consumption meter. A data acquisition system was used to collect the data and store it in a personal computer. The exhaust emissions were measured by an exhaust analyzer (Testo 350-XL), which was calibrated before each test. A schematic diagram of the experimental setup is shown in Fig. 1. The engine was started with petroleum diesel fuel and warmed up for a sufficient time in order to reach steady state operational conditions for each fuel. The warm up period ends when the cooling water temperature is stabilized. The results evaluated here were obtained at full-load conditions at the engine speeds between 1000 and 2500 rpm with intervals of 500 rpm.

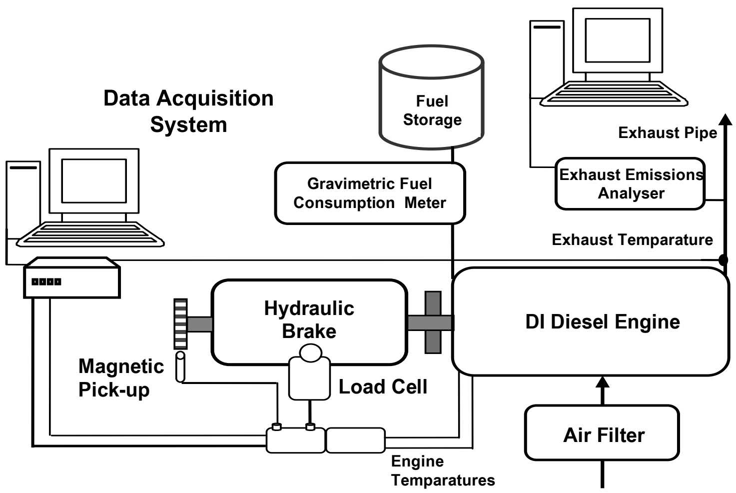

Figure 1. Schematic diagram of the experimental setup

3. Results

A comparison of brake specific fuel consumption (BSFC) for fuels tested is shown in Figure 2. For biodiesel and blended fuels, the BSFC are higher than that of the diesel fuel. The BSFC of different oxygenated fuels was increased up to 8% on average, compared with the pure diesel. Figure 3 compares the CO emissions of diesel fuel and different oxygenated fuels at engine speed of 1000-2500 rpm. Compared with diesel fuel, as shown in Fig. 3, CO emissions for biodiesel and biodiesel-diesel blend are lower. Many researchers agree that biodiesel, derived from various sources, causes a decrease of CO emissions [19] and [20]. For the blended fuels with 10% alcohol, compared with the diesel fuel, CO emissions are lower. However, DBM10 and DBE10 showed slightly higher CO emissions in comparison to biodiesel. Compared to pure diesel, the average CO emissions of the oxygenated fuels were reduced up to 18%.

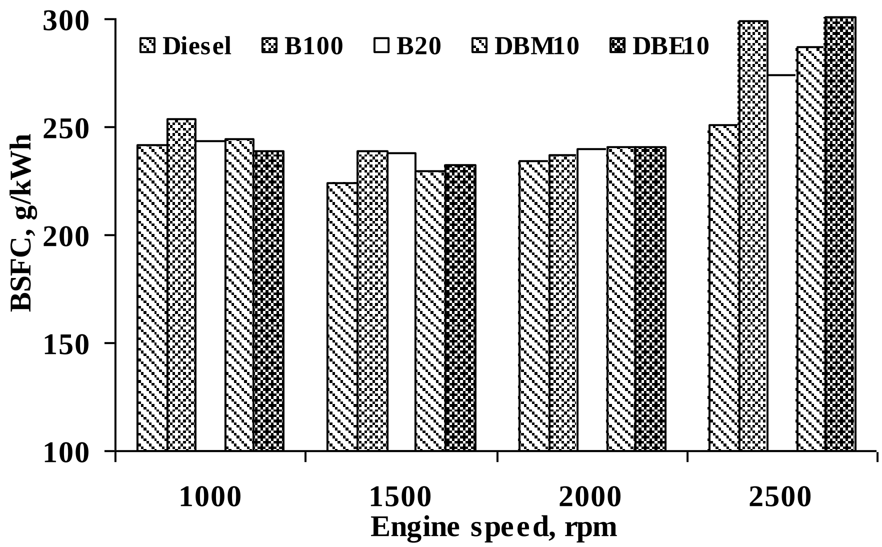

Figure 2. Variation of BSFC with engine speed for different fuels

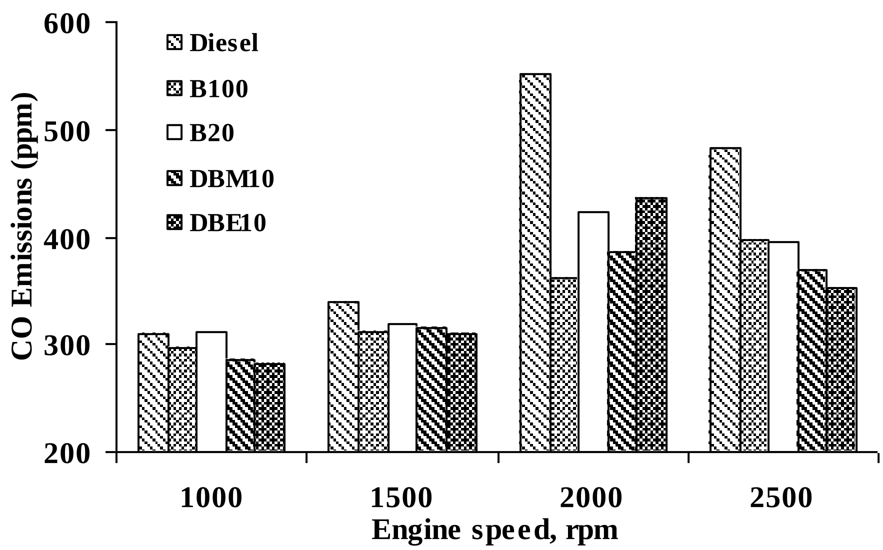

Figure 3. Comparison of CO emissions

NO_x emissions for diesel and different oxygenated fuels are shown in Figure 4. Fig. 4 shows the NO_x emissions for the fuels used decreases with increase in engine speed. This variation should be attributed to the engine operation conditions rather than the fuel type as all the fuels tested have the same tendency. Figure 4 also shows that NO_x emissions are increased with respect to pure diesel when the engine is fueled with B100 and B20 and the increase in NO_x is up to 10%, on average. B100 produced the highest NO_x for engine speeds of 1500, 2000 and 2500 rpm while B20 gave the highest NO_x at engine speeds of 1000 rpm. For the ternary blends (DBM10 and DBE10), lower NO_x emissions were obtained at all engine speeds compared with B100 and B20. Compared with pure diesel, the reduction in NO_x emissions was obtained between engine speeds of 1500-2500 rpm, while pure diesel produced the lower NO_x emissions at an engine speed of 1000 rpm. On the average, the results showed that when DBM10 and DBE10 were used, a reduction in NO_x emissions was obtained compared with those of pure diesel, B100 and B20 up to 11-12% respectively.

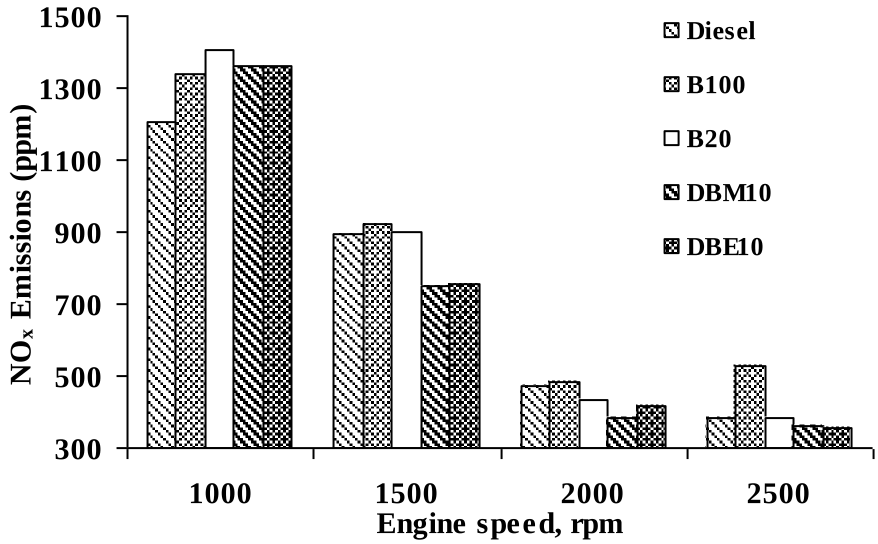

Figure 4. Comparison of NO_x emission

When the engine experiments were carried out, there was no smoke meter in the laboratory, and it was a deficiency of this study. Smoke emissions are main concern in diesel engines, however the highest consensus in oxygenated fuels such as biodiesel and ethanol is found in the sharp reduction in particulate emissions, as reported by Lapuerta et al. [21].

4. Discussion

The increase of BSFC can be attributed to the lower heating values of biodiesel, methanol and ethanol compared with diesel fuel. Lapuerta et al. [22] reported that according to the loss of heating value, the brake specific fuel consumption (BSFC) increases while using ethanol-diesel with respect to that obtained with the reference fuel. Moreover, the BSFC of biodiesel is higher than that of blended fuels, while the BSFC of DBM10 and DBE10 is close to each other. The results obtained in this work are in agreement with that observed by other authors [23] and [24].

Biodiesel has molecular oxygen rather than the diesel fuel, which could improve the combustion and lead to lower CO emissions. In other words, the additional oxygen in combustion chamber improves the fuel oxidation during combustion, thus leading to lower CO emissions in comparison to pure diesel. However, DBM10 and DBE10 showed slightly higher CO emissions in comparison to biodiesel. It is possible that ethanol and methanol could reduce the in-cylinder temperature, which could lead to increase in CO emissions in comparison to pure biodiesel. Furthermore, as carbon monoxide is product of incomplete combustion, the lower cetane number of DBM10 and DBE10 results in lower tendency to form ignitable mixture, and thus, higher carbon monoxide. Increases in NO_x emissions with the use of biodiesel and biodiesel-diesel blend relative to diesel are clearly reported and this is attributed to the oxygen content or advanced injection timing by researchers [25-27]. A comprehensive analysis of biodiesel impacts on exhaust emissions performed by the EPA has shown that there is 2% NO_x increase for B20 and 10% NO_x increase for neat biodiesel in diesel engines, on average [28]. In the same way, researchers have reported that there is generally an increase in NO_x emissions when using biodiesel [29]. Fuel injection timing and oxygen content play the dominant role in the NO_x increase for biodiesel. The timing advance attributable to the elevated bulk modulus of biodiesel is likely responsible for the increase in NO_x [30]. The increase in oxygen supply in biodiesel and B20 fuels also favors NO_x formation. The presence of more oxygen in the combustion chamber affects the NO formation from two aspects; one is that it leads to the more complete combustion, and hence higher combustion temperature; the other is that the higher content of oxygen reacts with the nitrogen component in the surrounding air [31].

For the ternary fuel blends (DBM10 and DBE10), NO_x emissions were lower than those of diesel fuel, B100 and B20. Although the oxygen content and the lower cetane number, as shown in Table 1, (because of alcohol content) favour NO_x formation, the results show a slight decrease in NO_x emission. This can be explained because the gas temperature in combustion chamber is much lower for blended fuels with 10% alcohol and because the heat of evaporation of methanol and ethanol is much higher, and leading to reductions of NO_x emissions with respect to those from diesel fuel or biodiesel. Fernando et al. [32] reported that thermal nitrogen oxide formation is the main contributor to emission of nitrogen oxide in a diesel engine. Therefore, to reduce the rate of thermal nitrogen oxide formation, the temperature inside the combustion chamber must be reduced. The results observed in this study agree well with statement above. As a matter fact, as reported in the section 2.1, the heat of evaporation of methanol (1178 kj/kg) is higher than ethanol (840 kj/kg). Thus, it can be said that because of alcohol content, the higher heat of evaporation of BDM and BDE could lead to reduction of NO_x emissions due to the cooling effect of them, namely it might lower the combustion temperature and hence reduce NO_x formation, as commonly reported by researchers [33-34]. The cooling effect of methanol or ethanol in blended fuels has been found to be effective factor rather than oxygen content and lower cetane number.

Conclusions

A series of engine tests were performed using diesel, biodiesel obtained from waste cooking oil, a blend of biodiesel-diesel known as B20, and ternary fuel blend of diesel-biodiesel and methanol or ethanol for investigating exhaust emissions. Based on experimental results, the following conclusions can be drawn:

1. For different oxygenated fuels used, the BSFC values were measured to be higher than those of pure diesel.
2. Biodiesel and blended fuels were produced less CO emission than pure diesel fuel.
3. NO_x emissions are increased with respect to pure diesel when the engine is fueled with biodiesel and biodiesel-diesel blend.
4. Lower NO_x emissions were obtained with the use of ternary fuel blends (DBM10 and DBE10) compared with diesel, biodiesel and biodiesel-diesel blend. The comparison of decrease of NO_x emissions between DBM10 and DBE10 fuels indicates that DBM10 is more effective than DBE10.

References

[1] Altun S, Öner C. Gaseous emission comparison of a compression–ignition engine fueled with different biodiesels. Int. J. Environ. Sci. Technol. 2013;10:371–6.
[2] Çetinkaya M, Ulusoy Y, Tekin Y, Karaosmanoğlu F. Engine and winter road test performances of used cooking oil originated biodiesel. Energy Convers Manage 2005;46:1279-1291
[3] Behcet R. A comparative study on anchovy fish oil, anchovy fish oil methyl ester and diesel fuels in a diesel engine. Energy Educ. Sci. Technol. Part A 2011;27(2):313-22.
[4] Karabektas M, Ergen G, Hosoz M. The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine. Appl Therm Eng 2008;28:2136-2143
[5] Gumus M, Kasifoglu S, Performance and emission evaluation of a compression ignition engine using a biodiesel (apricot seed kernel oil methyl ester) and its blends with diesel fuel. Biomass Bioenergy 2010;34:134–139.
[6] Lin C-Y, Li R-J, Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish. Fuel Proces Technol 2009;90:883–888.
[7] Demirbaş A, Progress and recent trends in biodiesel fuels. Energy Convers Manage 2009;50:14-34
[8] Özsezen A.N, Çanakçı M, Sayın C. Effects of Biodiesel from Used Frying Palm Oil on the Performance, Injection, and Combustion Characteristics of an Indirect Injection Diesel Engine. Energ Fuel 2008;22:1297–1305.
[9] Çanakçı M, Sayın C, Özsezen A.N, Türkcan A. Effect of Injection Pressure on the Combustion, Performance, and Emission Characteristics of a Diesel Engine Fueled with Methanol-blended Diesel Fuel. Energ Fuel 2009;23:2908–2920.
[10] Lü X-C, Yang J-G, Zhang W-G, Huang Z. Improving the Combustion and Emissions of Direct Injection Compression Ignition Engines Using Oxygenated Fuel Additives Combined with a Cetane Number Improver. Energ Fuel 2005;19:1879-1888.
[11] Song R. Liu J, Wang L, Liu S. Performance and Emissions of a Diesel Engine Fuelled with Methanol. Energ Fuel 2008;22:3883–3888.
[12] Rakopoulos D.C, Rakopoulos C.D, Kakaras E.C, Giakoumis E.G. Effects of Ethanol–Diesel Fuel blends on the Performance and Exhaust Emissions of Heavy Duty DI Diesel Engine. Energy Convers Manage 2008;49:3155–3162.
[13] Sayın C. Engine Performance and Exhaust Gas Emissions of Methanol and Ethanol–Diesel Blends. Fuel 2010;89:3410-3415.
[14] Zhu L, Cheung C.S, Zhang W.G, Huang Z. Emissions Characteristics of a Diesel Engine Operating on Biodiesel and Biodiesel Blended with Ethanol and Methanol. Sci Total Environ 2010;408:914–921.
[15] Qi D.H, Chen H, Geng L.M, Bian Y.ZH, Ren X.CH. Performance and Combustion Characteristics of Biodiesel–Diesel–Methanol Blend Fuelled Engine. Appl Energy 2010;87:1679-1686
[16] Shi X, Yu Y, He H, Shuai S, Wang J, Li R. Emission characteristics using methyl soyate–ethanol–diesel fuel blends on a diesel engine. Fuel 2005;84:1543–1549.
[17] Lapuerta M, Armas O, Garcıa-Contreras R. Effect of Ethanol on Blending Stability and Diesel Engine Emissions. Energ Fuels 2009;23:4343–4354

[18] Fernando S, Hanna M. Development of a Novel Biofuel Blend Using Ethanol-Biodiesel-Diesel Microemulsions: EB-Diesel. Energ Fuels 2004;18:1695-1703.
[19] Qi D.H, Chen H, Genga L.M, Bian Y. ZH. Experimental studies on the combustion characteristics and performance of a direct injection engine fueled with biodiesel/diesel blends. Energy Convers Manage 2010;51:2985-2992.
[20] Öner C, Altun Ş. Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine. Appl Energy 2009;86:2114-2120.
[21] Lapuerta M, Armas O. Rodriuez-Fernandez J. Effect of biodiesel fuels on diesel engine emissions. Prog Energy Combust Sci 2008;34:198–223
[22] Lapuerta M, Armas O, Herreros J.M. Emissions from a Diesel–Bioethanol Blend in an Automotive Diesel Engine. Fuel 2008;87:25–31.
[23] Keskin A, Gürü M, Altıparmak D, Aydın K. Using of cotton oil soapstock biodiesel–diesel fuel blends as an alternative diesel fuel. Renew Energy 2008;33:553–557.
[24] Chen H, Wang J, Shuai S, Chen W. Study of Oxygenated Biomass Fuel Blends on a Diesel Engine. Fuel 2008;87:3462–3468.
[25] Tat M.E, Van Gerpen J.H, Wang P.S. Fuel property effects on injection timing, ignition timing, and oxides of nitrogen emissions from biodiesel-fueled engines. Trans ASABE 2007;50(4):1123-1128.
[26] Usta N, Öztürk E, Can Ö, Conkur ES, Nas S, Çon AH, et al. Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a diesel engine. Energy Convers Manage 2005;46:741–55.
[27] Zhu L, Zhang W, Liu W, Huang Z. Experimental study on particulate and NOx emissions of a diesel engine fueled with ultra low sulfur diesel, RME-diesel blends and PME-diesel blends. Sci Total Environ 2010;408:1050–1058.
[28] United States Environmental Protection Agency (EPA), A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions; Air and Radiation, EPA 420-P-02-001, EPA: Washington, DC, 2002.
[29] Boehman AL, Morris D, Szybist J. The Impact of Bulk Modulus of Diesel Fuels on Fuel Injection Timing. Energy Fuels 2004;18:1877-1882.
[30] Szybist J.P, Boehman A.L, Taylor J.D, McCormick R.L. Evaluation of formulation strategies to eliminate the biodiesel NOx effect. Fuel Proces Technol 2005;86:1109– 1126.
[31] Kegl B. NOx and Particulate Matter (PM) Emissions Reduction Potential by Biodiesel Usage. Energ Fuel 2007;21:3310–3316.
[32] Fernando S, Hall C, Jha S. NOx Reduction from Biodiesel Fuels. Energy Fuel 2006;20:376-382.
[33] Di Y, Cheung C.S, Huang Z. Comparison of the effect of biodiesel-diesel and ethanol-diesel on the gaseous emission of a direct-injection diesel engine. Atmos Environ 2009;43:2721–2730.
[34] Huang J, Wang Y, Li S, Roskilly A.P, Yua H, Li H. Experimental investigation on the performance and emissions of a diesel engine fuelled with ethanol–diesel blends. Appl Therm Eng 2009;29:2484-2490.