Effect of biodiesel and alkyl ether on diesel engine emissions and performances

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Abstract

Over the last years numerous attempts have been made to minimize the amount of toxic and harmful exhaust gases from diesel powered vehicles. The rapidly exhausted fossil sources coupled with increasing price of petroleum together with the public awareness concerning the environmental protection, are the main reasons that have made many scientists to search for alternative and renewable energy sources.

According to the recent EU regulations starting with 1st of January 2010, 5.75wt% of classical diesel fuel must be replaced with more environmental friendly fuels. The most used biofuel is biodiesel (fatty acid methyl esters), mainly synthesized by catalytic transesterification of fatty glycerides. Roughly 10 wt% of glycerol is obtained as by-product in catalytic transesterification of fatty glycerides and there are many researching directions in order to find new applications for the increasing availability of glycerol as a low-cost feedstock.

In our study we have tested the energetic and ecologic performances (the exhaust emissions as CO, CO_2 and NO_x) of biodiesel or alkyl ether-diesel blends by testing the fuels on a Diesel engine 392-L4-DT/104 at different engine speeds. The emission tests were measured by using a FTIR SESAM 1.4 equipment.

Engine tests were run on the same engine in the same day in order to have the same atmospheric conditions (96 kPa pressure and 29°C) within the three repetitions of each test and average of measured values were taken.

The measured CO emissions of biodiesel and alkyl ether-diesel blends were found to be 15% and 37% lower than that of diesel fuel, respectively.
Keywords: biodiesel, alkyl ether, diesel engine, emissions.

WIT Transactions on Ecology and the Environment, Vol 147, © 2011 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AIR110311

1 Introduction

In the past century, fuels derived from fossil resources, were the global source of energy. The rapidly depletion of the petroleum, the oscillating increase in the oil price per barrel together with the worldwide effort to protect the environment, are the main reasons that have made many scientists to concentrate their efforts to search for alternative and renewable energy sources in order to reduce harmful emissions. Concerning diesel fuel, the newest regulations related to the environmental protection are more restrictive.

In order to fulfill these requirements it is obviously essential to control the injection and combustion processes or to find alternative fuels that may offer an approach to reduce harmful emissions without drastically modifications of the engine power and fuel consumption.

In our study we try to find alternative fuels as biodiesel and alkyl ether in order to reduce the dangerous emissions. It is well known that biodiesel is a very interesting alternative fuel because does not contain carcinogens such poly aromatic hydrocarbons and nitrous poly aromatic hydrocarbons. More than this, when burned, produces pollutants which are less aggressive to human health. The emissions of carbon monoxide and particulate matter are much lower than corresponding to classic diesel fuel, although a slightly increase in emissions of nitrogen oxides (NO_x) was observed by using biodiesel. The increasing of nitrogen oxides emissions could be attributed to the lowered in-cylinder soot levels thus lower radiation heat transfer resulting in higher in-cylinder temperatures.

By using biodiesel, it is important to improve the calorific value, the horsepower output and to reduce the emission of nitrogen oxides (NO_x).

The objective of the present study is to investigate the effects of biodiesel and alkyl ether addition in diesel fuel over diesel engine emissions and performances. The fatty acid methyl esters are produced by catalytic transesterification of the fatty glycerides existing into sunflower oil in the presence of methanol. The glycerol is the main by-product obtained in the transesterification reaction and its production is equivalent to approximately 10 wt% of the total fatty acid methyl esters (biodiesel), therefore the glycerol was etherified with isobutene and the main product – the alkyl ether was also used for diesel fuel blending.

The fatty acid methyl ester or alkyl ether-diesel fuel blends were tested in a diesel injection engine in order to measure the engine power, specific fuel consumption, smoke density and the amount of CO, CO_2 and NO_x from the gases from the exhaust pipe of the car.

2 Experimental

The experimental study was focused on two researching routes; the first one was carried on synthesis and characterization of fatty acid methyl esters and alkyl ethers, while the second route consisted of engine performances of fatty acid methyl ester or alkyl ether-diesel blends and comparison to classic diesel fuel.

2.1 Fatty acid methyl ester synthesis

Transesterification of the fatty glycerides existing into sunflower oil was realized in a batch reactor using potassium hydroxide as catalyst via a method given elsewhere [1–3]. The reaction was carried out at 60°C, atmospheric pressure, for 2 hours, under vigorous agitation in order to achieve the maximum conversion. In order to obtain the fatty methyl ester by transesterification we used 100 wt% excess methanol, keeping the molar ratio sunflower oil to methanol at 1:6 and the catalyst concentration of 1%.

The crude methyl ester was separated by glycerol by gravity and the catalyst was eliminated by hot water washing. The residual water in biodiesel was removed by distillation at 100°C and reduced pressure for 30 min. The properties of the sunflower oil and fatty acid methyl ester such acid value, density, viscosity, lubricity, and pour point were determinate according to ASTM standards and are given in table 1.

Table 1: Properties of vegetable oil, methyl ester, glycerol and alkyl ether.

	Results				Methods
	Sun flower oil	Methyl ester	Glycerol	Alkyl ether	
Density [25°C, kg/m^3]	918	857	975.1	831.0	ASTM D-1298
Viscosity [40°C, cSt]	31.86	4.38	6.3	-	ASTM D-455
Lubricity WS1.4, [μm]	123	210	300	180	ASTM D-6079
Acid value [mgKOH/g]	0.12	0.30	0.16	-	ASTM D-1980
Pour point, [°C]	-13	-5	-22.0	-20.0	ASTM D-2500

2.2 Alkyl ether synthesis

Roughly 10 wt% of glycerol is obtained as by-product in catalytic transesterification of fatty glycerides and there are many researching directions in order to find new applications for the increasing availability of glycerol as a low-cost feedstock. In our present contribution the alkyl ether was synthesized by catalytic etherification of glycerol with isobutene in a stainless steel Berghoff autoclave. The reaction was carried out at 80°C, for 5 hours under vigorous agitation, with 1.5:1 isobutene:glycerol molar ratio [4].

The properties of the glycerol and alkyl ether such acid value, density, viscosity, lubricity, and pour point were determinate according to ASTM standards and are given in table 1.

2.3 Materials

Diesel fuel used for our investigations was obtained by hydrodesulfurization of diesel fuel from atmospheric distillation plant and it was delivered by Petrotel-Lukoil Refinery. Its properties, especially the sulfur content and lubricity, are depicted in table 2.

The sunflower oil, methanol and potassium hydroxide used in our investigation are of analytical grade and were provided by Sigma-Aldrich.

Table 2: Properties of diesel fuel.

Characteristics	Diesel Fuel	Methods
Density [25°C, kg/m^3]	838.0	ASTM D-1298
Sulfur [wt%]	0.0076	ASTM D-2622
Viscosity at 40°C, cSt	2.29	ASTM D-455
Cetane number	51.9	ASTM D-613
Pour point, °C	-17	ASTM D-2500
Copper corrosion	1a	ASTM D-130
Distillation	°C	ASTM D-86
T 90%	334.7	
T 95%	354.9	
Hydrocarbon type	% vol	ASTM D-1319
Aromatics	22.1	
Polyaromatics	6.2	
Lubricity WS1.4, μm	535	ASTM-D6079

2.4 Engine tests

The energetic and ecologic performances of diesel fuel, fatty acid methyl ester or alkyl ether-diesel blends were investigated by testing the fuels on a Diesel engine 392-L4-DT/104 at different engine speeds. The parameters of diesel engine are given in table 3.

The emission tests are measured by using FTIR SESAM 1.4 equipment. Engine tests were done according to internal combustion engines examine and test standards (RO 6635/87). Engine performances and exhaust emission tests were carried out at 1600, 1800 and 2000 RPM.

Engine tests were run on the same engine in the same day in order to have the same atmospheric conditions (96 kPa pressure and 29^{o}C) within the three repetitions of each test and average of measured values were taken [5–12].

Table 3: Nameplate parameters of the diesel engine.

Engine Model	392-L4-DT seria 104
Engine type	four stroke, 4 cylinder in line, water cooled
Engine total displacement	3922 cm^3
Compression ratio	17.5:1
Bore/Stroke	102 mm/120 mm
Maximum power	68 kW at 2600 rpm
Injection model	KBEL BOSCH-DLLA 150 P44
Fuel injection pump	RO-PES 4A 90D 410 RS 2240
Maximum power	76 kW@2800 rpm
Maximum toque	255 Nm@1600 rpm
Needle opening pressure	240 bar

3 Results and discussion

3.1 Engine performances

The engine performances such variation of power, specific fuel consumption, variation of smoke density and the exhaust emissions as CO, CO_2 and NO_x of prepared alkyl ether or methyl ester mixed with diesel fuel were studied in comparison with diesel fuel.

3.1.1 Variations of power

The variation of engine power with engine speed for diesel fuel and for mixtures diesel fuel-methyl ester, diesel fuel-alkyl ether is presented in figure 1. From figure 1 it is obviously that the power output of classic diesel fuel is higher than the power developed in the case of blended fuels but, in general, the maximum power values of all three fuels are very close. By addition of methyl ester or alkyl ether in diesel fuel the engine power decreases with about 4% than the engine output when classic diesel fuel is used. The engine power decreases proportional with the rising of the oxygen content from the mixture. Another possible explanation for this decrease could be due to the fuel flow problems, as higher density and higher viscosity [13].

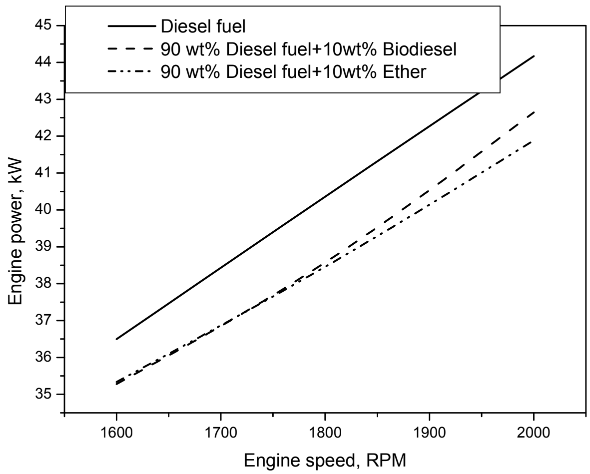

Figure 1: Engine power versus engine speed.

3.1.2 Specific consumption

The evolution of the specific consumption with engine speed for all three fuels is depicted in figure 2. For smallest engine speed 1600 RPM, the highest specific consumption was recorded for classical diesel fuel but for higher engine speeds the specific consumption for diesel fuel decreases while for mixtures diesel fuel-methyl ester and diesel-alkyl ether we observed a high specific consumption. A higher density and viscosity compared to diesel fuel, as well as a lower heating value coupled to a bad fuel injection atomize, could be a possible explanation for this evolution.

3.1.3 Variations of smoke density

The variation of smoke density produced with engine speed during the test for all three fuels is depicted in figure 3. The maximum smoke density was measured at

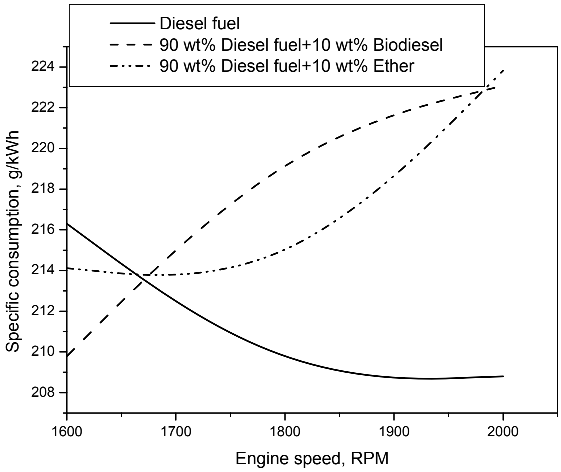

Figure 2: Specific consumption versus engine speed.

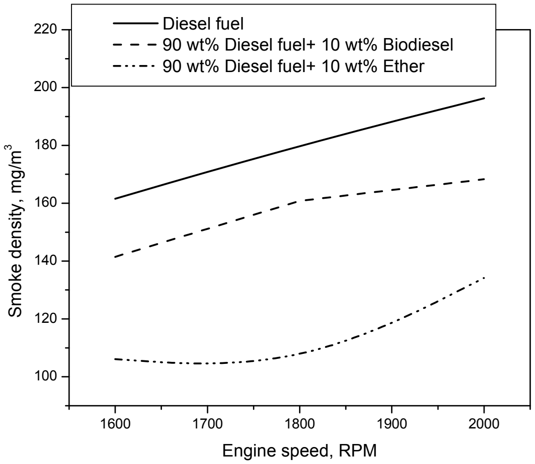

Figure 3: Smoke density versus engine speed.

2000 RPM and from figure 3 it is obvious that the smoke density is much lower for mixture diesel fuel-alkyl ether. The smoke density measured for diesel fuel was found to be 161.55 mg/m^3 while for mixture diesel fuel-alkyl ether was 106.09 mg/m^3 at 1600 RPM. The maximum smoke density was measured at 2000 RPM as 196.3 mg/m^3 for diesel fuel, 134.19 mg/m^3 for diesel fuel blended with alkyl ether and 168.31 mg/m^3 for diesel fuel blended with biodiesel. The average amount of smoke density decrease was determined as 33% for diesel fuel blended with alkyl ether and as 13.4% for diesel fuel blended with biodiesel compared to diesel fuel.

3.1.4 CO emission

The variation of CO produced by running the diesel engine using all three fuels is presented in figure 4. By increasing the engine speed we observed a diminish of CO emissions with about 21wt.% for diesel fuel, with 15 wt.% for mixture diesel fuel-biodiesel, but the most spectacular decreasing of 37 wt.% was noticed for the mixture alkyl ether-diesel fuel. The average reduction of CO emissions was 17 wt.% less than diesel fuel.

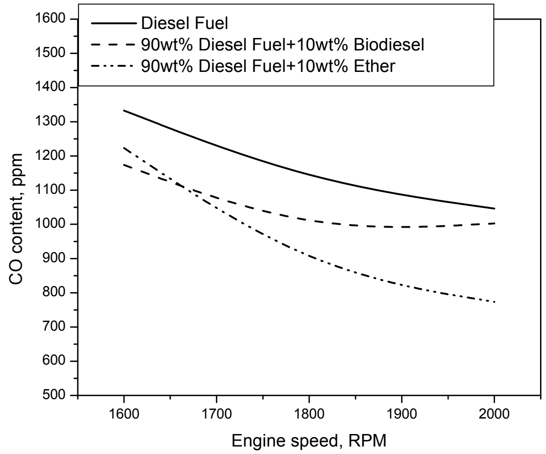

Figure 4: CO emissions versus engine speed.

3.1.5 CO_2 emission

In figure 5 is presented the variation of CO_2 emissions with engine speed using diesel fuel and diesel fuel blended with biodiesel or alkyl ether. The maximum CO_2 was produced for all three fuels at 1800 RPM, respectively 7.6 wt.% when

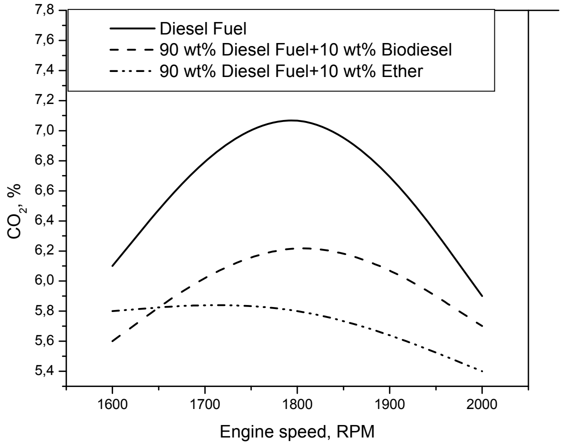

Figure 5: CO_2 emissions versus engine speed.

www.witpress.com, ISSN 1743-3541 (on-line)

diesel fuel was running the diesel engine, 6.5 wt.% when diesel fuel blended with 10 wt.% biodiesel was used and 5.9 wt.% when diesel fuel blended with 10 wt.% alkyl ether. The highest CO_2 emission was obtained from the use of diesel fuel while the lowest CO_2 emission was recorded by using diesel fuel blended with ether.

3.1.6 Exhaust temperatures

In figure 6 is depicted the variation of exhaust temperature with engine speed. Maximum exhaust temperatures were measured for 1800 RPM. These temperatures were determinate as 510 ^{0}C for diesel fuel, 505 ^{0}C for diesel fuel blended with biodiesel and 495 ^{0}C for diesel fuel blended with alkyl ether. The exhaust temperature for diesel fuel blended with biodiesel is lower as 1% at all test period than diesel fuel and for diesel fuel blended with biodiesel is lower as 3% than diesel fuel. This could be because the methyl ester and alkyl ether have lower heating values than diesel fuel.

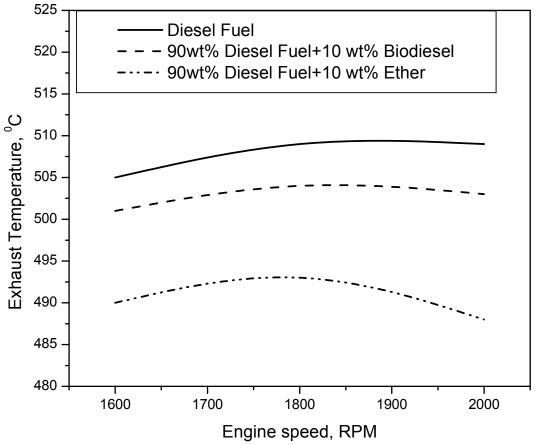

Figure 6: Exhaust temperature versus engine speed.

3.1.7 NO_x changes

The variation of NO_x with engine speed for all three fuels is shown in figure 7. The maximum content of NO_x corresponding to all three fuels was recorded at 1800 RPM. NO_x emitted by biodiesel blend are higher than the one corresponding to diesel fuel, while the NO_x emissions related to ether blend are much lower than the one associated to diesel fuel and biodiesel blend. This tendency can be explained as a consequence of the advanced injection derived from the physical properties of biodiesel (viscosity, density, compressibility).

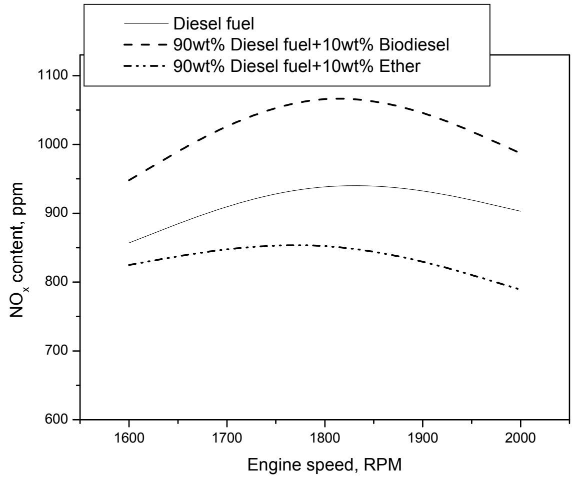

Figure 7: Exchange of NO_x.

4 Conclusions

In recent years investigations have been done in order to fulfill the EU regulations concerning the environmental protection, mainly to reduce harmful diesel fuel emissions. In our experimental study we investigate the effect of addition of two different compounds; methyl ester and alkyl ether in diesel fuel, on diesel engine performances and exhaust emissions.
The following conclusions may be drawn from the result of the present study:

- Fatty acid methyl ester obtained by catalytic transesterification of the fatty glycerides existing into the sunflower oil is a renewable energy resource;
- Alkyl ether is also a renewable energy resource and a low-cost feedstock;
- The maximum power output was observed, for all engine speeds, for diesel fuel while a slightly decreasing of the power output was recorded for diesel fuel blended with alkyl ether or biodiesel;
- The emissions of CO and CO_2 were significantly reduced by blending classic diesel fuel with biodiesel or alkyl ether;
- The NO_x emissions were slightly increased with the use of biodiesel blend with respect to those of the classic diesel fuel, while the emissions recorded for alkyl-diesel fuel blend were lower than for the other two fuels;
- The first results of our investigations on engine performances and exhaust emissions are positive, however, additional tests are necessary to find the optimum biodiesel or alkyl ether percents which must be added to diesel fuel in order to obtain maximum performances of diesel engine.

Acknowledgement

The authors are grateful for financial support to Postdoctoral project CNCSIS-UEFISCSU, project number PN II-RU 6/2010.

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