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Pankajkumar G. Patel

L.D.College Of Engg-ahmedabad, pan2005in@rediffmail.com

Kintuben R. Patel

L.D.College Of Engg-ahmedabad, kintupatel@rediffmail.com

Hirenkumar B. Parikh

L.D.College Of Engg-ahmedabad, hiren_1812@yahoo.co.in

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Investigation of the performance and emission of bus engine using blends of diesel fuel with bio-diesel of sunflower

¹Pankajkumar G Patel, ²Kintuben R Patel, ³Hirenkumar B Parikh

L.D.College Of Engg-ahmedabad

E-mail : pan2005in@rediffmail.com, kintupatel@rediffmail.com, hiren_1812@yahoo.co.in

Abstract- An experiment investigation is conducted to evaluate the use of sunflower oil methyl esters (bio-diesels) of Greek origin as supplements in the diesel fuel at blend ratios of 10/90 and 20/80, in a fully instrumented, six-cylinder, turbocharged and after-cooled, direct injection (DI), Mercedes –Benz, mini-bus diesel engine installed at the author's laboratory. The tests are conducted using each of the above fuel blends, with the engine working at two speeds and three loads. Fuel consumption, exhaust smokiness and exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide and total unburned hydrocarbons are measured. The diesel fuel and two bio-diesels are determined and compared.

Keywords: Bio-diesel; Sunflower oil; Emissions; Bus diesel engine

I. INTRODUCTION

Engine manufacture worldwide have achieved to develop diesel engines with high thermal efficiency and specific power output, always trying to keep inside the frame of imposed emission regulations that every day becomes more stringent. Significant achievements for the development of cleaner diesel engines have been made, by following various engine –related techniques, such as for example the use of common-rail systems, fuel injection control strategies, exhaust gas recirculation, exhaust gas after –treatment, etc.[1,2].furthermore , especially for the reduction of pollutant emissions, researchers have focused their interest on the domain of fuel-related techniques, such as for example the use of alternative fuels often in fumigation form [3,4],or gaseous fuels of renewable nature that are friendly to the environment [5,6], or oxygenated fuels that show the ability to reduce particulate emissions[7], usually with an increase of the emitted nitrogen oxides.

Another aspect of the problem concerns the use not only of diesel fuel (and gasoline), but also the use of alternative fuels of renewable nature. Favorable fuels of the last category are bio-fuels made from agricultural products [8, 9] furthermore, concerning the environmental aspect, rational and efficient end-use technologies are identified as key options for the achievement of the Kyoto targets of greenhouse gas emissions reduction.

Replacement (partial) of fossil fuels with renewable bio-fuels has been set as a target worldwide to reduce greenhouse effect and energy dependence as well as to improve agricultural economy. Emissions from transportation engines are considered to greatly contribute to greenhouse gases (carbon dioxide) release. The European union has set as target in its state members, the use of bio-fuels of at least 2% by the end of 2005 and 5.75% by the end of 2010 in the transportation fuels. Each country should produce bio-fuels from local raw materials, which may vary from place to place due, at least, to the different weather conditions and soil quality [10-12].

Among the bio-fuels, bio-ethanol, vegetable oils and especially their derived bio-diesels (methyl or ethyl esters) are recently considered as most promising ones (oxygenated by nature); they are derived from biological sources showing an ad hoc advantage in emitted carbon dioxide reduction. Because of its high octane number, bio-ethanol is a good spark-ignition engine fuel [2], although it is tried recently also as a diesel fuel supplement despite its poor miscibility with the diesel fuel [13-15]. On the contrary, vegetable oils and especially their bio-diesels are very good diesel engine fuels due to their reasonably high acetone number [16-22].

The main disadvantages of vegetable oils, as diesel fuels, are associated with the highly increased viscosity, 10-20 times greater than the normal diesel fuel. Thus, although short-term tests using neat vegetable oils showed promising results, problems appeared after the engine had been operated for longer periods. To solve the problem of the very high viscosity of neat vegetable oils, the following usual methods are adopted: blending in small blend ratios with normal diesel fuel, micro-emulsification with methanol or ethanol, cracking, and their conversion into bio-diesels [23-25]. The latter ones are manufactured from their corresponding vegetable oils, in batch or continuous systems, mainly through the transesterification process, where one ester is converted into another. The more widely used vegetable oils, for this purpose, are rapeseed methyl

ester (RME) in Europe and soybean methyl ester (SME) in the USA, collectively known as fatty acid methyl esters (FAME).

The advantages of bio-diesels as diesel fuel are the minimum sulfur and aromatic content, and higher flash point, lubricity, cetane number, biodegradability and non-toxicity. On the other hand, their disadvantages include the higher viscosity and pour point, and the lower calorific value and volatility. Furthermore, their oxidation stability (chemical stability for prolonged oxidation in air) is lower, they are hygroscopic, and as solvents may cause corrosion of components attacking some plastic materials used for seals, hoses, paints and coatings. For all the above reasons, it is generally accepted that blends of standard diesel fuel with 10% or up to 20% bio-diesels (and possibly vegetable oils or bio-ethanol) can be used in existing diesel engines without any modifications.

II. Description of the engine experimental facilities

Facilities to monitor and control engine variables were installed on a test-bed, 'Tata truck', 1210, six-cylinder, direct injection, four stroke, water cooled, diesel engine located at the first author's laboratory. The engine is turbocharged with a 'Garrett' turbocharger and a water after-cooler after the turbocharger compressor. It is coupled in the laboratory to a 'Schenck' U1-40 hydraulic brake (dynamometer). These engines power the mini-buses of the Athens Urban Transport Organization fleet.

The engine has a total displacement volume of 5958 cm³, a cylinder bore of 97.5 mm, a piston stroke of 133mm, a rod length of 230 mm and a compression ratio of 18:1. The firing order of the six-cylinders is 1-5-3-6-2-4. It delivers a maximum power of 177kw at 2600 rpm and a maximum torque of 840Nm at 1250-1500 rpm.



Figure 1 schematic arrangement of the engine test bench

The engine is fitted with a 'Bosch', in-line, six-cylinder fuel injection pump coupled to a variable-speed mechanical governor. The static injection timing is fixed at $5 \pm 1^\circ$ CA before top dead center (TDC) within the engine speed range of 800-2600 rpm. The injector nozzle has five holes having an opening pressure of 250 bars, with the fuel jets issuing into the offset bowl-in-piston combustion chamber.

A custom made tank and flow metering system is used for fuel consumption measurements of the various blend samples as follows. A glass burette of known volume was used with the time measured for its complete evacuation of the fuel sample feeding the engine. A system of pipes and valves was constructed in order to have a quick drain of a fuel sample, including the return-fuel from the pump and injector, and the refill of metering system with the new fuel sample.

Standard instruments measuring speed, pressures, temperatures etc, were used. For measuring the pressure in the cylinder, a 'Kistler' miniature piezoelectric transducer is used, mounted to the cylinder head and connected to a 'Kistler' charge amplifier. Also, a 'Kistler' piezoelectric transducer is connected on the injector side of the pipe linking the injection pump and injector, in order to provide the fuel pressure signal. The signal from a 'Tektronix'

TDC magnetic pick-up marker is used for reference and speed measurements.

The exhaust gas analysis system consists of a group of analyzers for measuring soot (smoke), nitrogen oxides (NO_x), carbon monoxide (CO) and total unburned hydrocarbons (HC), the smoke level in the exhaust gas was measured with a 'Bosch' RTT-100 opacimeter, the reading of which are provided as Hartridge units (% opacity) or equivalent smoke (soot) density.

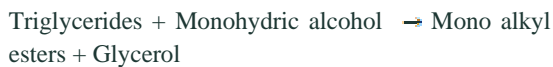
Fig.1 shows a full schematic arrangement of the engine test bed, instrumentation and data logging system.

III. Bio-diesel production - properties of fuels

The conventional diesel fuel was supplied by the Aspropyrgos refineries of the 'Hellenic Petroleum SA' and represents the typical, Greek road (automotive), low sulphur (0.035% by weight) diesel fuel (gas oil); it formed the baseline fuel of the present today. Bio-diesels (methyl esters, ME) of sunflower in blends ratios of 10/90 and 20/80 (by vol.) were mixed with the conventional diesel fuel. The two fuels, after being measured in graduated glass tubes, were mixed and stirred thoroughly; as known, these blends do not separate after mixing.

The bio diesels used were supplied from and produced at the chemical process laboratory of the school of chemical engineering, of the national technical university of Athens (NTUA), via transesterification with methanol of the corresponding feed stock raw material at a pilot plant using KOH as catalyst; they were tested according to the EN 14214 standard [26]. The original vegetable oils were produced from Greek feedstock and obtained from Greek commercial processing facilities.

With the transesterification process, one ester is converted into another .the reaction proceeds with catalyst (base or acid) or without catalyst by using primary or secondary monohydric aliphatic alcohols, where the glycerol based trimesters (or triacyl glycerides) that make up oils (or fats) are converted into monoesters yielding free glycerol as a by-product.



It is evident from the above reaction that bio-diesel fuels consist of a mixture of transesterified free fatty acids of high molecular weight. Typical chemical syntheses of bio-fuels are reported in the literature based on the distribution of the fatty acids in their corresponding vegetable oils [12, 19].

The vegetable oils were neutralized (acid value less than 1mgkoh/gr oil and water content less than .1% by weight) and freed of gums. The quality of the

methanol (CH₃ OH) used for the transesterification reaction was of industrial grade (with water content less than 0.06% by weight). flakes of industrial grade (91%by weight) potassium hydroxide (KOH) were used as catalyst. The production process was based on the basic homogeneous catalysis technology. The main parts of the pilot unit comprised the following: (a) the preparation and measuring, (b) The reactor, (c) the washing vessel, and (d) the product tanks. Details can be found in [26].

Table 1
Properties of diesel fuel and methyl esters (ME) of sunflower oils

Fuel properties	Diesel fuel	Sunflower ME
Density at 15°C (kg/m ³)	837	880
Lower calorific value (kj/kg)	42700	37500
Kinematic viscosity at 40°C (mm ² /s)	3	4.4
Surface tension at 20°C (N/m)	0.023	0.026
Cetane number	50	50
Stoichiometric air-fuel ratio	15	12.5
Bulk modulus of elasticity (bar)	16000	17500
Sulfur content (ppm)	320	40

Table 2
Fatty acid composition (% by weight) of sunflower oil.

Acid (structure)	Sunflower oil
Palmitic (16:0)	6
Stearic (18:0)	3
Oleic (18:1)	17
Linoleic (18:2)	74

The properties of the diesel fuel and the sunflower are summarized in Table 1, while table 2 shows typical values of the fatty acid composition for the vegetable oils used taken from the literature [25]. With the exception of the density and lower calorific values that were used in the computations, all the other cited properties were not used; they are only referred to here for comparative purposes, in order to explain qualitatively the relative performance and emissions behavior of the different fuel blends.

IV. Conditions and parameters tested

The series of tests are conducted using each of the above fuel blends, with the engine working at speeds of 1200 and 1500rpm , and at three loads of 20%, 40% and 60% of the full load, corresponding to mean effective pressures of 3.56, 7.04 and 10.52 bar, respectively.owing to the differences among the calorific values and oxygen contents of the fuels tested, the comparison must be effected at the same engine brake mean effective pressure(load) and not the same injected fuel mass or air fuel ratio.

In each test, volumetric fuel consumption, exhaust smokiness and exhaust regulated gas emissions such as nitrogen oxides (NOX), carbon monoxide (CO) and total unburned hydrocarbons (HC) are measured. From the first measurement, brake specific fuel

consumption and brake thermal efficiency are computed using the sample density and lower calorific value. Table 3 shows the accuracy of the measurements and the uncertainty of the computed results of the various parameters. It is stated that the emissions, measured by the 'standard' analyzers described.

Table 3
Accuracy of measurements and uncertainty of computed results

Measurements	Accuracy
Soot density (mg/m ³)	±1
NO _x	±5 ppm
CO	±2 ppm
HC	±0.5 ppm
Time	±0.5%
Speed (rpm)	±2
Torque (Nm)	±0.5
Computed results	Uncertainty (%)
Fuel volumetric rate	±1
Power	±1
Specific fuel consumption	±1.5
Efficiency	±1.5

V. Comparison of experimental results.

A. theoretical aspects of blends combustion in the engine

Before proceeding to the discussion of the experimental results, it is constructive to precede some fundamental aspects of fuel blends combustion in a diesel engine, taking also into account the properties of the fuels and operating conditions in the engine cylinder [20, 34, 35].

Owing to the small blend ratios used (10% and 20% by vol.) the injecting on rate or the macroscopic behavior of the spray is almost identical for the neat diesel fuel and blended fuels used in this study, of course for the same engine operating conditions of injection timing, speed and load (brake mean effective pressure). The increased values of compressibility of the bio-diesel compared to the diesel fuel one which causes an earlier injection of fuel into the engine cylinder is not expected to play important role as this injection advance difference is at most of 1° crank angle the same remark is expected to hold little higher for the bio-diesel compared to the diesel fuel. The premixed combustion, by decreasing its duration (decreased ignition delay) the higher the cetane number [1].

The only marked difference occurs in the atomization process, given that the mean droplet size (as for example expressed in Sauter mean diameter) is larger when bio-diesel is used against the diesel fuel. This is mainly due to the bio-diesel having a higher kinematic viscosity than that of the neat diesel fuel. The little higher cetane number of the bio-diesel, as compared to the neat diesel fuel case, can decrease the NO_x emissions due to the relatively lower ignition delay and shorter premixed combustion during which NO_x is mainly formed

B. Discussion of the experimental results

Fig. 2 show, for the speeds of 1200 and 1500 rpm, respectively, the emitted smoke (soot) density for the neat diesel fuel and bio-diesel blends of sunflower oil at the three loads considered one can observe that the soot emitted by all bio-diesel blends is lower than the ones for the corresponding neat diesel fuel case, with this reduction being higher the higher the percentage of the bio-diesel in the blend.

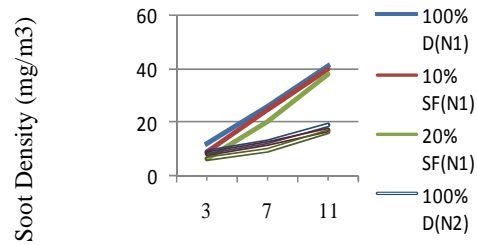


Figure 2 Emitted soot density for the diesel fuel and blends of sunflower. Brake mean effective pressure (bar) 200 rpm and 1500 rpm

Fig 3 show, for the speeds of 1200 and 1500 rpm, respectively, the nitrogen oxides (NO_x) exhaust emissions for the neat diesel fuel and bio-diesel blends of sunflower at the three load considered. One can observe that the NO_x emitted by all bio-diesel blends are slightly higher than the ones for the corresponding diesel fuel case, with this increase being higher the higher the percentage of the bio-diesel in the blend. Although the little higher cetane number and absence of aromatics tend to contribute to less NO_x production.

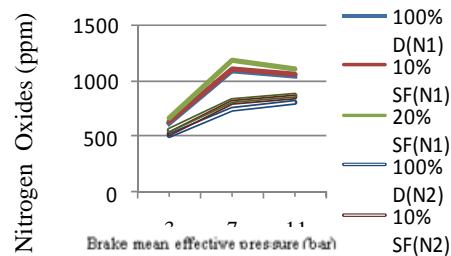


Figure 3 Emitted NO_x for the diesel fuel and blends of sunflower at three loads, for the speeds of 1200 rpm and 1500 rpm

Fig 4 show, for the speeds of 1200 and 1500 rpm, respectively, the carbon monoxide (CO) exhaust emissions for the neat diesel fuel and bio-diesel blends of sunflower at the three load considered. One can observe that the CO emitted by all bio-diesel

Carbon Monoxide (ppm)

Carbon Monoxide (ppm)

blends are lower than the ones for the corresponding diesel fuel case, with this reduction being higher the higher the percentage of the bio-diesel in the blend.

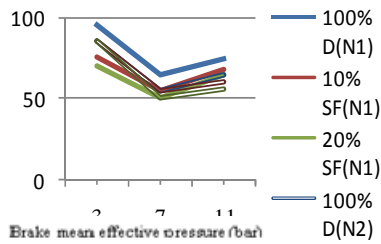


Figure 4 Emitted carbon monoxide for the diesel fuel and blends of sunflower at three loads for the speeds of 1200 rpm and 1500 rpm

Fig 5 show, for the speeds of 1200 and 1500 rpm, respectively, the total unburned hydrocarbons (HC) exhaust emissions for the neat diesel fuel and bio-diesel blends of sunflower at the three load considered. One can observe that the HC emitted by all bio-diesel blends are higher than the ones for the corresponding diesel fuel case, with this increase being higher the higher the percentage of the bio-diesel in the blend.

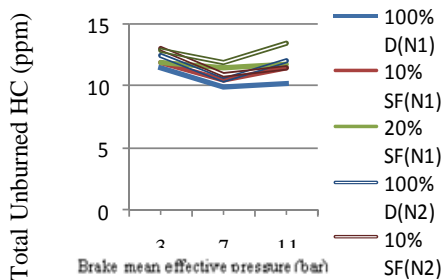


Figure 5 Emitted total UBHC for the diesel fuel and blends of sunflower at three loads, for speeds of 1200 rpm and 1500 rpm

Fig 6 show, for the speeds of 1200 and 1500 rpm, respectively, the brake specific fuel consumption expressed in g/kWh (gram per kilowatt and hour) for the neat diesel fuel and bio-diesel blends of sunflower at the three load considered. The fuel blend mass flow rate is calculated from the respectively measured volume flow rate value and the blend density, since the comparison is made at the same load (brake mean effective pressure) and speed, which is translated into the same engine power, then these values effectively are directly proportional to the fuel mass flow rate:

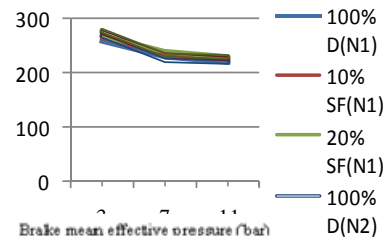


Figure 6 BSFC for the net diesel fuel and blends of sunflower at the three loads for the speeds of 1200 rpm and 1500 rpm

Lastly, Fig 7 show, for the speeds of 1200 and 1500 rpm, respectively, the brake thermal efficiency for the neat diesel fuel and bio-diesel blends of sunflower at the three load considered. It can be observed that, practically, there are no differences in the brake thermal efficiency for all fuels and blends concerned, by taking also into account the small uncertainty in the measurements of the fuels lower calorific values and consumption rates.

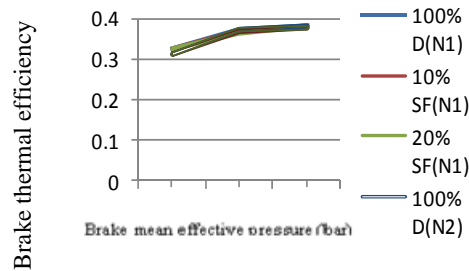


Figure 7 Brake thermal efficiency for the diesel fuel and blends of sunflower at three loads, for the speeds of 1200 rpm and 1500 rpm

VI. Summary and conclusions

An experimental investigation is conducted to evaluate and compare the performance and exhaust emission levels of sunflower oil methyl esters (bio-diesels) of greek origin as supplements in the diesel fuel at blend ratios of 10/90 and 20/80, in a fully instrumented, six-cylinder, turbocharged and after-cooled, direct injection (DI), Tata truck, mini-bus diesel engine installed at the author's laboratory. The series of tests are conducted using each of the above fuel blends, with the engine working at two speeds and three loads. In each test, exhaust smokiness and exhaust regulated gas emissions such as NO_x , CO and total unburned HC_s are measured. Brake specific fuel consumption and thermal efficiency are computed from the measured fuel volumetric flow rate and calorific values.

The smoke density was reduced with the use of all bio diesel blends with respect to that of the neat diesel fuel, with this reduction being higher the higher the percentage of bio-diesel in the blend.

The NO_x emissions were slightly increased with the use of all bio-diesel blends with respect to those of the neat diesel fuel, with this increase being higher the higher the percentage of bio-diesel in the blend.

The CO emissions were reduced with the use of all bio-diesel blends with respect to those of the neat diesel fuel, with this reduction being higher the higher the percentage of bio-diesel in the blend.

The HC emissions were slightly increased with the use of all bio-diesel blends with respect to those of the neat diesel fuel, with this increase being higher the higher the percentage of bio-diesel in the blend.

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