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Diesel Engine Emission Characteristics Study using Algae Biofuel

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The purpose of this study is to determine the benefits of using algal biodiesel blends in motorized vehicles, as well as knowing the extent to which the biodiesel mixture can reduce its emissions to suppress the impact on the environment. The engine employed was coupled to a dynamometer and evaluated at a speed of 1500 rpm at various degrees of load. FTIR spectrum of the oil and biodiesel was studied. Various emission parameters such as carbon monoxide, unburnt hydrocarbon, nitrogen oxides and smoke opacity were analyzed using AVL emission analyzer. The results of this study have indicated a mixture of quality effects of biodiesel against diesel. In various scenarios the biodiesel blends showed a significant reduction in environmental impact.

Keywords: *Chlorella vulgaris*, Biodiesel, Blending, Injection, Emission

Introduction

Pollution currently occurs due to emissions from stationary and mobile sources, which are operated by internal combustion engines. The conventional diesel is associated with harmful emissions. Nitrogen oxides (NO_X) are considered to be the most harmful among engine emissions consisting mainly of nitric oxide (90%) and nitrogen dioxide (NO_2). Its emissions increases with the amount of pilot fuel, with low and high engine loads, and with diesel injection advancement.[1] Liu *et al*.[2] observed that this is due to the consumption of pilot fuel at low premix conditions which led to a lower local temperature. Lower NOx emissions are possible by use of small amounts of pilot fuel, to ignite the homogeneous mixture (natural gas/air). Thereby, the results showed a greater reduction of NOx, for an engine load ranging from 40% to 53%. Carbon monoxide (CO) is also classified as another harmful emissions. Its formation is associated with incomplete combustion of the fuel, and the temperature in the cylinder. These two parameters control the speed of fuel decomposition, as well as its oxidation.[3] A significant amount of CO is generally generated in the richer fuel regions, due to lack of oxygen.[4] However, a large amount of CO, can also be produced in the fuel-poor region, when the combustion temperature is less than 1450 K. According to Cheenkachorn *et al*.[5], the rotation speed (varying from 1100 rpm to 2000 rpm) of the heavy vehicle diesel engine, operating in dual-fuel mode, affects emissions of CO. Egusquiza *et al.* [6], found that there is no significant effect of the varying engine speed (1600 rpm to 2600 rpm) on CO emissions.

Due to the incomplete combustion of hydrocarbons, the other emission that results is unburnt hydrocarbons (HC). Complete oxidation of HC takes place at low temperatures. The increase in HC emissions can also be produced by the effect of variation in engine speed.

At this juncture, since biodiesel has emerged as an alternate fuel, to test its effect on emission parameters is thought of. Biodiesel is revolutionizing the use of different blends with commercial diesel. Pure biodiesel or mixtures can be used on all types of diesel engines. The advantages of biodiesel compared to diesel oil are environmental friendly, non-toxic, and sulfur-free. The biodiesel are high in cetane number which shortens the ignition time after fuel spraying is done. This matter will slow the temperature rise in the combustion chamber and reduce the noise. There are several studies on engine application of second generation biodiesel however, few reports based on diesel mixed with *Chlorella vulgaris* biodiesel could be found. Based on these facts and also considering the same as a major research gap, the present investigation has centered on the utilization of various blends of algal biodiesel and diesel. An experimental study has been drawn up to identify the effects of this alternative fuel on pollutant emissions from engines operating in dual-fuel mode.

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Materials and Methods

Lipid extraction and biodiesel production

The methods used to extract lipids from oilseeds can be applied for the extraction of oil from microalgae. Hexane is less efficient than chloroform, but it is also substantially less toxic, less expensive, and, presents high selectivity for neutral lipid fractions.[7] For these reasons, hexane has been the solvent for lipid extraction[8] and soxhlet method was employed for the same.

The oil was then transesterified for biodiesel production. Transesterification requires 3 moles of alcohol for each mole of triglycerides to produce 1 mole of glycerol and 3 moles of methyl esters. For the reaction to take place to a great extent and the balance is shifted towards the production of esters, that is, biodiesel, 6 moles of methanol for each mole of triglycerides was used, The excess alcohol was recovered at the end. The yield in methyl esters exceeds 98% of the weight of the original oil.[9]

In this study, Shimadzu FT-IR instrument was used. It contains of interferometer chamber with KBr and Mylar beam splitters. The apparatus is capable of covering the complete IR region (450-4000 cm^{-1}) with a resolution of 1.0 cm^{-1}. This device can identify the various functional groups such as alkenes, alkanes, alkynes, alcohols, alkyl halides, aldehydes, ethers, carboxylic acid, ketones, esters, anhydrides, amides, acid chlorides, benzenes and amines.

The fatty acid composition was carried by GCMS manufactured by Shimadzu Analytical India Pvt. Ltd. The GCMS analysis details, which consist of polysiloxane glycol Column, 30 metre 0.25 BPX70, 0.25 µ film; oven temperature with time programming 180°C (3 min) - 4°C/min - 220°C (15 min); Injector temperature, 240°C; Detector, 260°C; Carrier gas Flow (N_2), 1 ml/min; Split Ratio, 1:60 and sample for analysis 0.2 µl.

Test bench

It was composed of a single-cylinder engine, designed to operate at speeds between 0–2500 rpm, where 5.2 kW power is developed. It also includes a dynamometric brake, a particle analyzer, an exhaust gas analysis bay, and the engine was operating in dual-fuel mode. The running conditions of the engine had been kept constant with fuel to be injected at a fixed 23°angle before TDC in the pressure level of 220 bar. An AVL 365C type angle encoder is installed on the crankshaft, allowing reach a resolution of 0.1° CA, with an accuracy of ± 3 rpm. Also, this mode acquisition consists of recording an average of 100 consecutive cycles. Each press is measured according to the type of sensor. This sensor is cooled by water circulation. It is noted that these parameters are controlled by the Lab View software. To measure polluting emissions, an analysis bay is installed on the line exhaust gas outlet for analyzing the leading polluting gases like CO, HC, NO, CO_2, NOx, and particles. The exhaust gas is dehydrated before analysis. Pollutant emissions have been analyzed by using AVL's five gas analyzer.

Results and Discussion

Characterization of FTIR&GC-MS

To determine the functional groups contained in algae oil and biodiesel characterization by FTIR (Fourier Transform Infra-Red) is used. FTIR characterization was carried out at 4000-400cm^{-1} wave numbers. Sharp absorption with strong intensity appears in the range of ± 1700 cm^{-1}, wide absorption with strong intensity appears at ± 3400 cm^{-1}, are the vibrations of a typical group arising from castor oil and a methyl ester. All methyl esters, fatty acids, and triglycerides have the characteristics of the vibrations of the C = O (carbonyl) group that appear in the absorption region of 1700 cm^{-1}. Uptake that appears in the range of 2923.12 and 2856.94 cm^{-1} can be stretching vibrations possible from CH (sp3) where the structure of the methyl ester has two possible locations -CH_3 namely in the methyl group bound to the carbonyl group and the methyl group located in the tail chain framework methyl ester. To find out the absorption of Csp2-H (-CH = CH-) group vibrations in the obtained methyl ester structure, the infrared spectra data showed absorption in the region of 3368.8 cm^{-1} with a weak and sharp absorption intensity. Vibration group - CH = CH - strengthened by the absorption of 1742.35 cm^{-1} which shows the vibration of the group - C = C - and a sharp absorption in the fingerprint region of 721.16 cm^{-1} which is the vibration of CH -alkene bending out of the field In the range of 3400 cm^{-1}, which in this absorption band is typical of the -OH group vibrations. The vibration of the -OH group in castor oil did not show a significant difference compared to the vibration of the -OH group in the methyl ester product. The sharpness of the -OH group produced in the photocatalytic reaction increases than without the photocatalyst methyl ester and when compared to the methyl ester from transesterification reaction. The functional groups that appear are mainly unchanged, because they are characteristic of the bonds that may be produced by oil or methyl esters.[10]

The fatty acid composition of the purified oil is identified through GC-MS tests. The fatty acid profile shows that the *Chlorella vulgaris* algae oil contains about 72.57% of unsaturated fatty esters. It has 22.03% of poly unsaturated fatty acids, which are very active species and much readily undergo auto and photo oxidation. It also has minor proportion of unsaturated components with C is bond and very active when compared to normal unsaturated acids. It is seen in the Table .1 that the unsaturated ester present in the *Chlorella vulgaris* is lower.

CO Emission

The carbon monoxide (CO) emission measurements recorded in the exhaust gases for the different fuels tested are shown in Fig.1. CO emissions increase with increasing engine load, and then stabilize the load. It is observed that CO emissions from B20 Injection fuel are lower than that of diesel fuel due to the higher oxygen content in the blend and complete combustion of the air-fuel mixture. The CO emission of diesel fuel (13.32 g/kwhr) and B20 Blending (12.81 g/kwhr) fuels increased compared to the neat B20 Injection (6.12 g/kW-hr). The drop in CO emission of B20 Injection fuel is enhanced oxidization of CO gas to CO_2. It is also due to the reduced ID and improved combustion of the fuel.[11]

Table 1 — Composition (% by weight) in fatty acids

Fatty acid	Composition (%)
C14:0	0.38
C14:1	Tr
C16:0	15.41
C16: 1n-7	1.17
C18: 0	6.24
C18: 1n-9	33.14
C18: 1n-7	1.13
C18: 2n-6	9.73
C18: 3n-6	Tr
C18: 3n-3	1.93
C18: 3n-3	Tr
C20: 0	0.19
C20: 4n-6	Tr
C20: 5n-3	3.23
C22: 5n-3	3.11
C22: 6n-3	20.94

Tr - trace quantities

HC Emission

The emissions of unburnt hydrocarbons (HC) are caused by incomplete combustion of the fuel. The variation of HC emissions as a function of the engine load is illustrated in Fig.1. The HC emissions recorded in the exhaust gases in dual fuel mode are considerably lower, than those in conventional mode, for all loads. This can be attributed to the improved combustion, which is due to the higher temperatures of the charge admitted into the cylinder, as well as to the richer mixture. It is found that HC emissions are lower for B20 Injection fuel as compared to the diesel fuel as a result of the improved combustion and better cetane number. HC emission of clean diesel fuel (1.52 g/kwhr) and B20 Blending (1.2 g/kwhr) enhanced as compared to B20 Injection (0.73 g/kwhr). This can be due to the diesel reduces the carbon activation temperature and advances the improved combustion. It is also found that HC emissions of the fuel are improved due to the low O_2 found in the fuel results

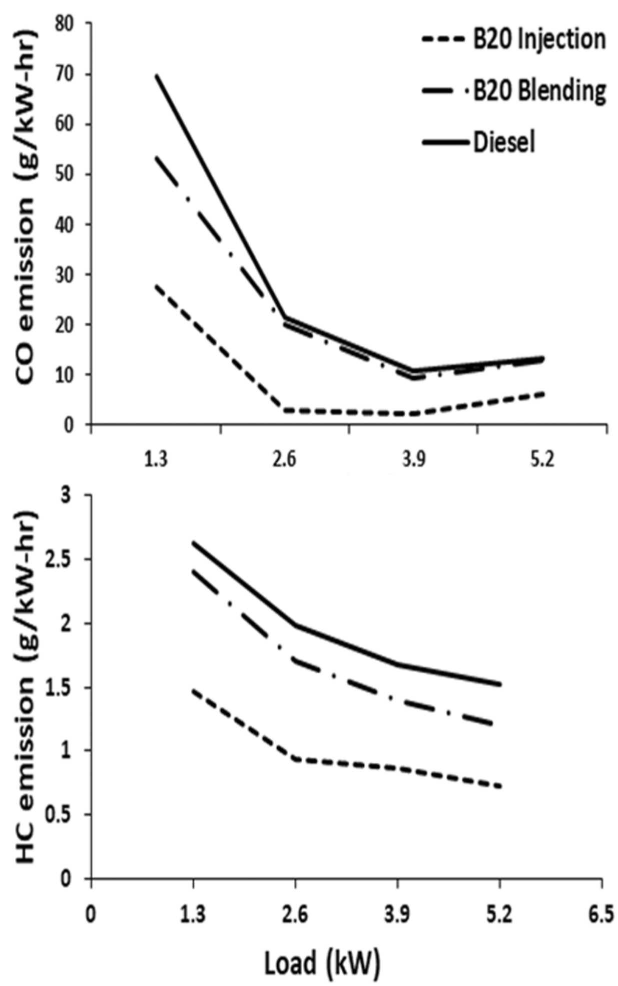

Fig.1 — Variation of CO and HC emission versus Load

in poor combustion, as well as leads to the forming of HC emissions.[12]

NOx Emission

The analysis of NOx emissions, in exhaust gases at different loads, for the diesel engine and the dual-fuel mode is shown in Fig.2. It can be seen that the curves describe the same speed whatever the fuel studied. Likewise, the concentration of NOx emissions increases with increasing load. This figure shows us that the concentration of NOx emissions in the flue gases of the diesel engine is much higher than those recorded in the engine operating in dual-fuel mode. As the load on the engine increases the temperature after combustion increases and hence leads to the formation of NOx, Maximum NOxemission occurred at peak power output for diesel fuel when the fuel is at an average temperature. The maximum reduction in NOx emission is obtained with diesel fuel (6.5 g/kwhr), which is 2.2 g/kwhr lower, as compared to B20 Injection. It could be found that NOx emissions significantly reduced diesel fuel. This is as a result of the reduced EGT which reduces the forming of NO emission for diesel fuel.[13]

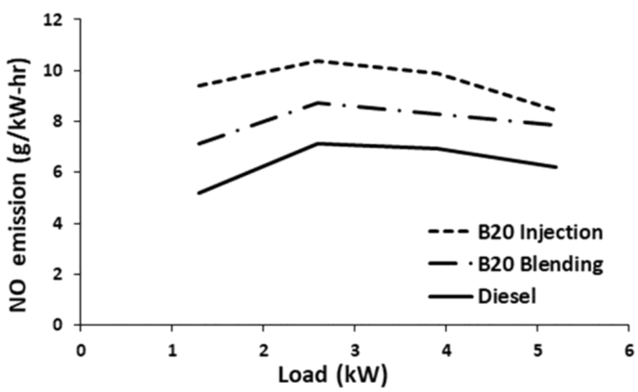

Fig. 2 — Variation of NOx emission versus Load

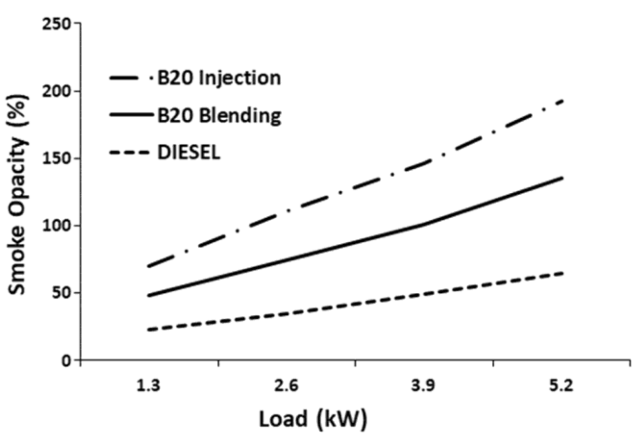

Fig. 3 — Variation of smoke opacity versus load

Smoke opacity

The variation of smoke opacity with the load for all of the fuel samples is shown in Fig.3. It is found that the smoke opacity of B20 Injection had been lower than the diesel and B20 Blending fuels. The decrease in smoke density is a result of the original O_2 content, as well as a higher cetane index of diesel fuel results of improved fuel formation and makes better combustion. It is also due to the better air-fuel mixing along with the diesel fuel leads to better combustion as well as decreased smoke opacity. The smoke emission of diesel fuel (70.13%) and B20 Blending (65%) increased compared to the B20 Injection (57.15%).[14]

Conclusions

An effort was made to come out with the use of a whole new biofuel produced from *Chlorella vulgaris*. The transformation of algae oil into biodiesel was confirmed from FT-IR and GC analysis. A significant decrease in polluting gases of CO, HC, and smoke has-been found from the experimental result. Injection of B20 blend behaves as an oxygen booster which increases combustion properties and therefore some considerable decrease in smoke takes place.

Acknowledgement

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