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Full Length Research Paper

Performance of tobacco oil-based bio-diesel fuel in a single cylinder direct injection engine

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In the present investigation, the high viscosity tobacco oil, which has been considered as non-edible oil as a potential alternative fuel for the Compression Ignition Engine (C. I.). Tobacco Methyl Ester (TME) was prepared by transesterification of raw tobacco oil. A two stage transestirification process was developed since tobacco is having higher acidic value. Transesterification was done using NaOH in the presence of sulphuric acid as catalyst and both acid transesterification and base transestirification was performed. Since TME has higher kinematic viscosity, its viscosity has been reduced by blending with neat diesel. The bio-diesel was blended with neat diesel at various volumetric proportions of B_2, B_5 (denoting 2, 5%) .The performance of this alternate fuel was tested by conducting a series of tests on 4 stroke single cylinder 5.2 kW direct injection diesel engine. The engine was run at different loads like full load, $^3/_4$, $^1/_2$, $^1/_4$ and no load at various speeds and also at constant speed .The tests were conducted by using neat diesel and also diesel fuel blended with TME The combustion characteristics and exhaust emissions like hydrocarbon (HC), carbon (II) oxide (CO) and nitric oxides (NO) were measured. Torque, brake power, specific fuel consumption was also measured and the test was plotted in the graphs. The physical and chemical specifications like flash point, fire point, density, kinematic viscosity and acid number of TME were established. Significant improvement in engine performance was observed. The specific fuel consumption and the exhaust gas temperature reduced due to the decrease in viscosity of TME. From the properties and engine test results it has been established that at lower percentage of blending, TME has improved the engine performance but at higher percentages of blending, the performance and engine emissions were drastically effected. The results show that the TME can be used as an alternate fuel in diesel engines without any engine modifications.

Key words: TME (Tobacco Methyl Ester), transesterification, diesel blend $B_{xx.}$

INTRODUCTION

Due to the gradual depletion of world petroleum reserves and the impact of environmental pollution of increasing exhaust emissions, there is an urgent need for suitable alternative fuels for use in Compression Ignition (I.C) engines. To face this challenge in terms of long term energy security there is an urgent need to develop alternative fuels, whose properties are comparable to petroleum, based fuels and can be directly used in the I.C.engines with little or no engine modifications. Vegetable oils provide an alternate source for diesel engines but the major limitation of vegetable oil is its higher viscosity than that of diesel fuel. Hence, only a partial replacement of diesel fuel is possible. Vegetable oil and diesel fuel blending (dilution) is one of the methods to reduce their viscosity (Herchel et al., 2001; Silvo et al., 2002; Murat and Fikret, 2007; Nwafor, 2004; Agarwal and Agarwal, 2007). Vegetable oils have almost similar energy density, octane number, heat of vaporization and stoichometric air/fuel ratio compared to mineral diesel fuel (Agarwal and Das, 2001). Obviously, the use of non-edible vegetable oils compared to edible oils is very significant because of the tremendous demand for edible oils as food and they are far too expensive to be used as fuel at present. The results (Larry et al., 1984) show that because of the long chain hydrocarbon structure, vegetable oils have good ignition characteristics, however they cause serious problems as carbon deposits buildup, they have poor durability and also poor thermal efficiency. While short term tests were encouraging, longer-term endurance tests revealed problems generally attributable to inefficient combustion (Marvin,1987 Tadashi et al.,1984). These problems of incomplete combustion are more relevant with direct injection engines than with pre chamber types. With vegetable oils, emissions of hydrocarbon (HC) and nitric oxides $(NO)_x$ could be higher too. But nitric oxides - particulate matter (NO_X–PM) trade-off is always associated with most of the emission reduction techniques. Very low emissions from engines can be achieved with exhaust gas after treatment and optimized combustion processes (Eichlseder and Wimmer, 2003). However, these might be overcome by injectors designed specifically for the fuel or the use of antioxidant, detergent and other additives (Garrett, 1994). It has been reported that transesterification is an effective process to overcome all these problems associated with vegetable oils (Saka and Kusdiana, 2001; Murayama et al., 2000) Additional research, in the U.S and abroad demonstrated that the methyl esters derived from vegetable oils create fewer difficulties than the use of vegetable oil in heavy-duty diesel engines. It was therefore suggested that on-road vehicles be tested using vegetable oil methyl esters (Bio diesel) (Gerhard et al., 1997). It is a clean-burning, renewable, nontoxic, biodegradable and environmentally friendly transportation fuel that can be used in neat form or in blends with petroleum-derived diesel in diesel engines. It is the only environmental protection agency (EPA) approved alternative fuel for diesel engines. Bio diesel can be blended at any level with petroleum diesel to create a bio diesel blend. It can be used in compression-ignition (diesel) engines with little or no modifications. Bio diesel not only has proper viscosity, boiling point and high octane number (Ryan et al., 1984) but also is simple to use, biodegradable, nontoxic and essentially free of sulfur and aromatics (Srivastava and Prasad, 2000; Akasaka et al., 1997; Marshall et al.,1995).

Preparation of tobacco methyl ester

Bio diesel has been produced by transesterification of triglyceride (VOs) to methyl esters with methanol using sodium hydroxide dissolved in methanol as catalyst, as represented in the following equations:

CH_2OCOR'''		CH_2OH	R'COOR
|		| Catalyst	
CH_2OCOR'' + 3ROH		CH_2OH +	R''COOR
|		|	
CH_2OCOR^1		CH_2OH	R'''COOR
|			
Oil or fat	Alcohol	Glycerin	Biodiesel

A two stage transesterification consisting of both acid and base treatment was performed to convert free fatty acids into triglycerides. Hence this involves making the triglycerides of tobacco oil to react with methyl alcohol in the presence of a catalyst (NaOH) to produce glycerol and fatty acid ester. When a base catalyzed trans-esterification process is directly applied to the mixture, this high free fatty acid content causes fairly high soap formation, which diminishes the ester yield (Diasakou et al., 1998; Alcantara et al., 2000; Antolin et al., 2002). Therefore, it was necessary to reduce the free fatty acid contents. 100 ml of tobacco raw oil was taken and heated around 100°C to remove any presence of water. Then 10 g of NaOH was added to methanol (6% by volume of tobacco oil) to prepare sodium methoxide. Half of this sodium methoxide was added to the tobacco oil, 1 ml of 95% pure sulphuric acid was added and the mixture was heated to around 45 °C for about 1 h and allowed to settle at night. To this mixture, the remaining amount of sodium methoxide was added and stirred continuously for a period of 5 min. Then the mixture was heated continuously to about 65°C for about 120 min .The mixture was allowed to form two layers overnight. The bottom layer was glycerine, while the upper layer was the ester. The glycerine was removed at the end of the settling. The ester was washed with pure water three times. A small amount of phosphoric acid (2.5 ml per liter of the oil) was used in the first washing. At the end of the process, the oil was heated to 100°C to remove any water from the oil left in the ester. The pH value of the final methyl ester was measured as 6.2.The experiment was conducted at different molar ratio of tobacco oil to methanol (1:6 to 1:8 by volume) and the mixture temperature was also varied from 45 to 70°C and the stirring is continued for about 90 min at different speeds. From the results it has been found that the yield increased from 75 to 90% when the temperature varied from 45 to 65°C and the best molar ratio found to be 6:1 by volume considering the soap content. At lower molar ratios the tendency of soap formation was too high and at higher molar ratios the yield started decreasing. Keeping these two results, it has been recommended that 6:1 is the best molar ratio for the tobacco methyl esterification at a temperature of 65°C. The Production potential of major oil seeds in india is given in Table 1. Table 2 gives the fuel properties of tobacco methyl ester when compared to the diesel. The Free fatty acid composition of the TME with respect to the other oils is given in Table 3. The chemical properties of the oils are given in Table 4. From all the tables it was clear that the properties of tobacco methyl ester were highly comparable with that of the other bio-fuels.

ENGINE TESTS-EXPERIMENTAL METHODOLOGY

A four stroke, direct injection, naturally aspirated single cylinder diesel engine is employed for the present study. The detailed specifications of the engine used are given in Table 5. Exhaust gas analyzer was used to measure the concentration of gaseous emissions such as unburnt HC, carbon monoxide (CO) and carbon

Table1. Production potential of major oil seeds in India (Ramadhas et al., 2005).

Oil seed group	Yield (kg/ha)	Oil content (%)	Oil yield(kg/ha)
Ground nut	936	40	374.4
Mustard	845	33	278.9
Soybean	872	17	148.2
Sunflower	753	35	263.6
Sesamum	284	45	127.8
Castor	806	42	338.5
Safflower	1000	30	300.0
Cotton seed	550	12	66.0
Chewing tobacco	1171	37	433.3

Table 2. Properties of diesel, tobacco oil and methyl ester of tobacco oil.

Properties	Diesel	Tobacco oil	Methyl ester of Tobacco oil
Density (kgm^{-3})	840	954.8	910
Viscosity (cst)	4.59	64.94	6.65
Flash point (℃)	50	290	210
Carbon residue (%)	0.1	0.78	0.65

Table 3. Fatty acid distribution of jatropha oil, rapeseed oil, soyabean oil and tobacco oil (% by wt).

Fatty acid	Jatropha oil	Rapeseed oil	Soya bean oil	Tobacco oil
Myristic acid	0.1	1	0.1	--
Palmitic acid	14.1 - 15.3	3.5	11.4	15.2
Stearic acid	3.7 - 9.8	0.9	3.2	4.8
Arachidic acid	0.3	0.4 - 2.4	0.2	--
Behenic acid	0.2	0.6 - 2.5	0.3 - 2.4	--
Palmitoleic acid	1.3	0 - 0.1	0.1 - 1	--
Oleic acid	34.3 - 45.8	64.1	21.8	13.2
Linoleic acid	29 - 44.2	12 - 22	54.9	66.7
Linolenic acid	0.3	7 - 9	8.3	1.0

Table 4. Chemical properties of certain edible oils in comparison with Tobacco seed oil.

Chemical properties	Ground nut oil	Mustard oil	Sun flower oil	Safflower oil	Tobacco oil
Saponification value	188 - 195	172 - 200	188 - 200	186 - 194	199
Iodine value	82 - 106	87 - 122	101- 135	130 -150	135
Acid Value (Oleic acid %)	0.02 - 0.6	0.26 - 2.53	1 - 25	0.15 -10	3.20

dioxide (CO_2) Performance and emission tests were carried out on the C.I engine, using various blends of diesel fuels. The tests were conducted at the rated speed of 1500 rpm at 0.461, 1.357, 2.27, 3.13 and 3.67 kW loads. With fuel injection pressure of 200 bars, the engine was started with diesel fuel and data was collected after attaining steady state. Then the experiment was switched over to blends of TEM and diesel fuel. The engine was sufficiently warmedup and stabilized before taking all readings. The engine was run with neat diesel and then blends of 5 and 10% TME respectively. For each test sample the engine was run for 10 h and for each load the readings were taken by running the engine for nearly about 2 h. Engine tests were run on the same engine and on same day for both diesel and TME blend for each load, in order to have almost the same atmospheric conditions. The cooling water temperature was maintained constant (60 to 65℃).All observations recorded was replicated three times to get a reasonable value. The performance characteristics of the engine are evaluated in terms of brake thermal efficiency, Brake Specific Fuel Consumption (BSFC), Brake Specific Energy Consumption (BSEC) and emission characteristics in terms of smoke. The experimental data generated are documented and presented here using appropriate graphs. These tests aimed at optimizing the concentration of ester to be

Table 5. Engine specifications.

Parameter	Value
Diameter of the brake drum	0.285 m
Dia of the orifice	0.02 m
Brake power	5 H.P.
Speed	1500 rpm
Bore diameter	0.08 m
Stroke length	0.11 m

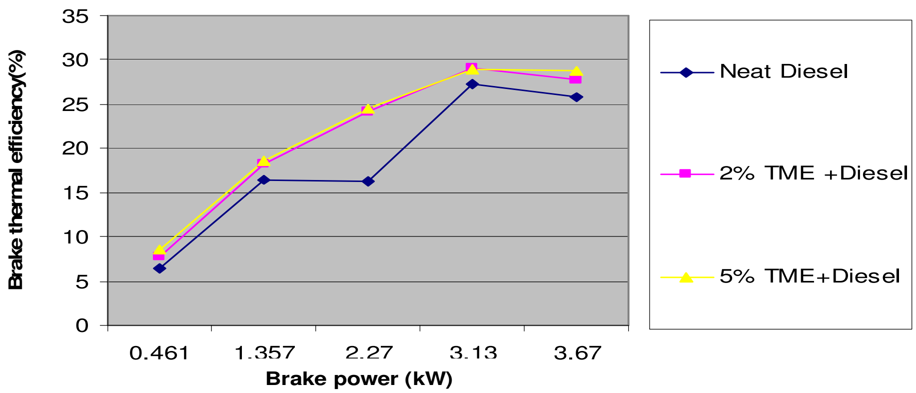

Figure 1. Brake thermal efficiency versus brake power.

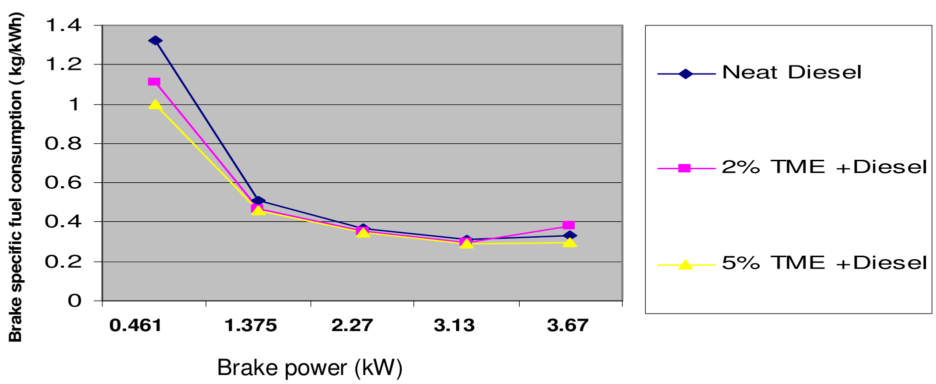

Figure 2. Break specific fuel consumption versus brake power.

used in the bio diesel–diesel mixture for long-term engine operation. In each experiment, engine parameters related to thermal performance of the engine such as fuel consumption and applied load were measured. In addition to that, the engine emission parameters such as CO, CO_2, oxygen (O_2), NOx were also measured. The results were compared with the characteristics of 100% neat diesel oil fueled engines as well as diesel oil blended with different percentages of TEM. Bxx represents the percentage of ester (xx %) used in the mixture, that is, 5% ester in the blend is represented by B5.

RESULTS AND DISCUSSION

The variation of brake thermal efficiency with brake power of neat diesel and diesel blended with TEM are shown in Figure 1. Brake thermal efficiency of B2 blend is very close to 5%TME diesel blend (B5) for entire range of operation. Maximum brake thermal efficiency of B5 blend is 29% against 27.31% of neat diesel which is lower by 1.69%. For B10 rubber seed oil the maximum brake thermal efficiency was only 28% and for unrefined rubber seed oil it is still lesser (Ramadhas et al., 2005) . Figure 2 shows the variation of BSFC with brake power for diesel and its blends. At part loads BSFC of B2 and B5 are 0.46 and 0.48 but whereas for neat diesel it is 0.51 which is higher than B2 and B5. But where as full loads the BSFC of 2% blend (B2) is higher than that of B5 and neat diesel

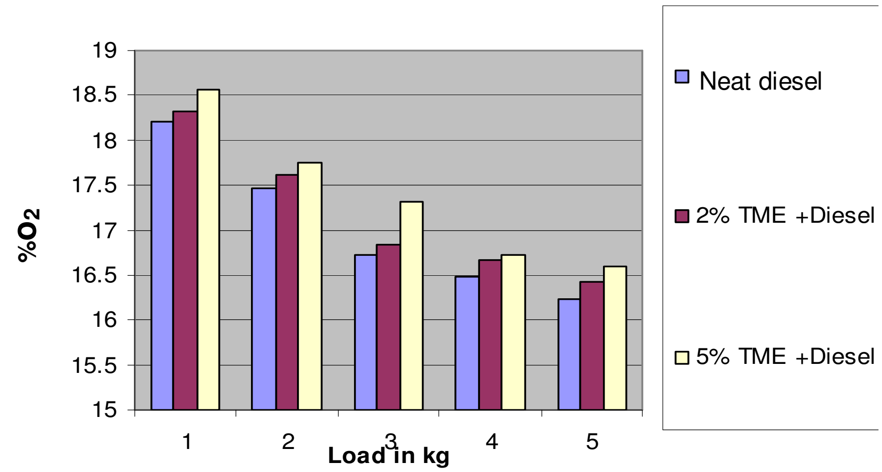

Figure 3. Load versus % o_2.

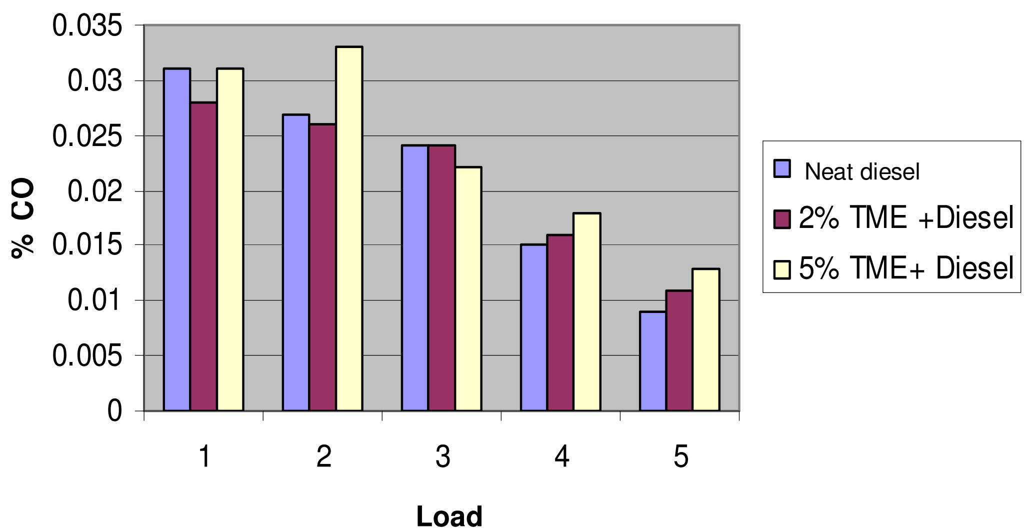

Figure 4. Load versus % Co.

It is note worthy that BSFC of neat diesel is higher than that of B2 and B5 over a wide range of loads applied. This drop in thermal efficiency and increase in BSFC for neat diesel can be attributed to poorer combustion. Whereas for B2 and B5 the higher thermal efficiency and lower BSFC can be attributed to better combustion due to the availability of excess oxygen the same which is reflected in oxygen graphs.

Emission characteristics

Figure 3 shows that there is an increase in the percentage of O_2 due to the increase of TME in the diesel. This is due to the higher oxygen content of TME in the diesel because TME is an oxygenated fuel. The emission of CO decreases with increase in percentage of TEM in diesel as shown in Figure 4. But comparatively in the case of rice bran oil the emission of CO increases with increase in load whenever there is an increase in the percentage of rice bran oil in the diesel blend (Venkanna et al., 2009).But in our TME diesel blend B2 is giving less percentage of CO when compared to B5 blends with increase of load. However the percentage of CO is higher than B2 blend and lower than B5 blends. It is interesting to note that, the engine emits more CO using diesel as compared to that of bio diesel blends under all loading conditions. With increasing bio diesel percentage, CO emission level decreases. Bio diesel itself has about 11% oxygen content in it. This helps for the complete combustion. Hence, CO emission level decreases with increasing bio diesel percentage in the fuel.

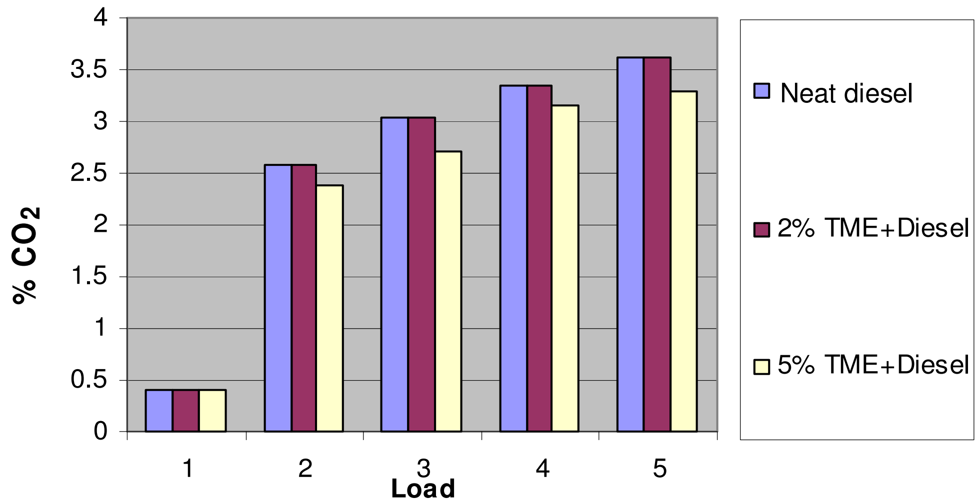

Figure 5. Load versus CO_2.

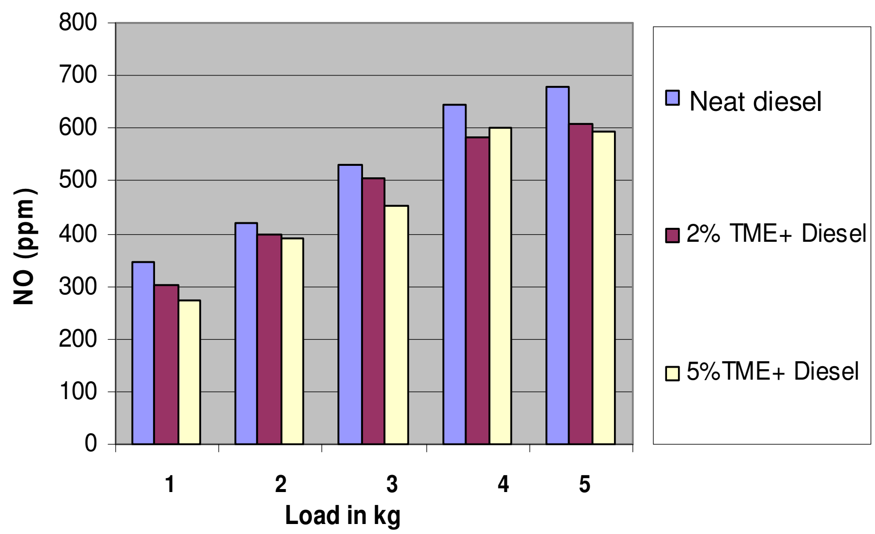

Figure 6. Load versus NO.

Figure 5 compares the CO_2 emissions of various fuels used in the diesel engine. The lower percentage of diesel blends emits very low amount of CO_2 in comparison with diesel. B5 emits very low level of CO_2 emissions as compared to that of diesel operation. More amount of CO_2 in the exhaust is an indication of complete combustion of fuel. This supports the higher value of exhaust gas temperature. The CO_2 emission using tobacco seed oil as fuel is lower because of the incomplete combustion. The combustion of fossil fuels produces carbon dioxide, which are getting accumulated in the atmosphere and it leads to many environmental problems. The combustion of bio fuels also produces CO_2 but crops are readily absorbing these and hence CO_2 levels are kept in balance.

Nitric oxides emissions

Diesel engine combustion generates large amounts of NOx because of high flame temperatures in presence of abundant oxygen and nitrogen in the combustion chamber. Figure 6 indicates that B2 and B5 blends show lower NO emission as compared to a standard diesel operation (Masjuki et al., 2000). But with the increase percentage of oxygen and load, the NO emissions should increase. A possible explanation for the reduction of NO concentration observed, is that less intense premixed burning rate and slower combustion may be the reason for this. There is always a trade-off between the NO emissions and HC (Brecqand and Le Corre, 2005). One can observe the same trend by observing the graphs of

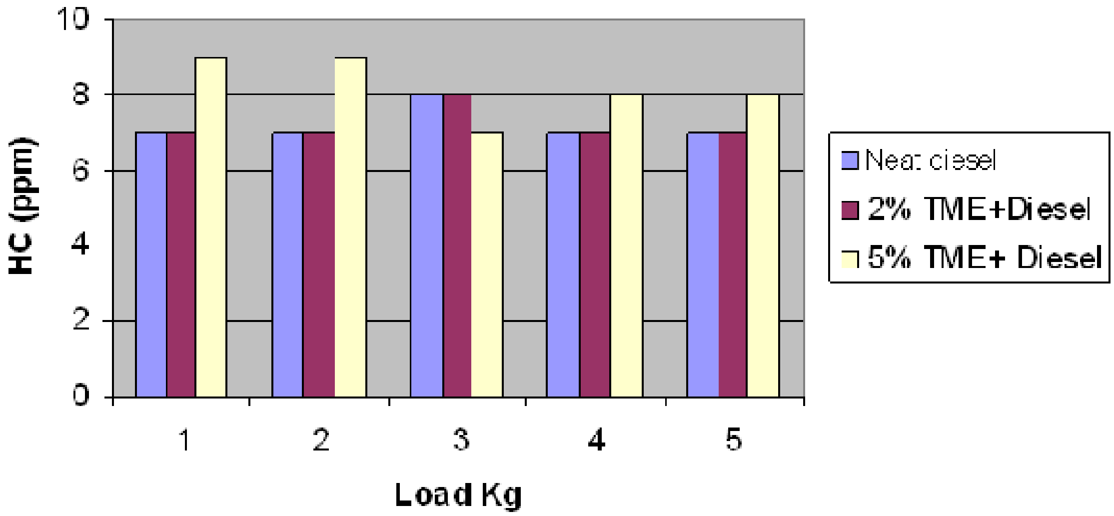

Figure7. Load versus HC.

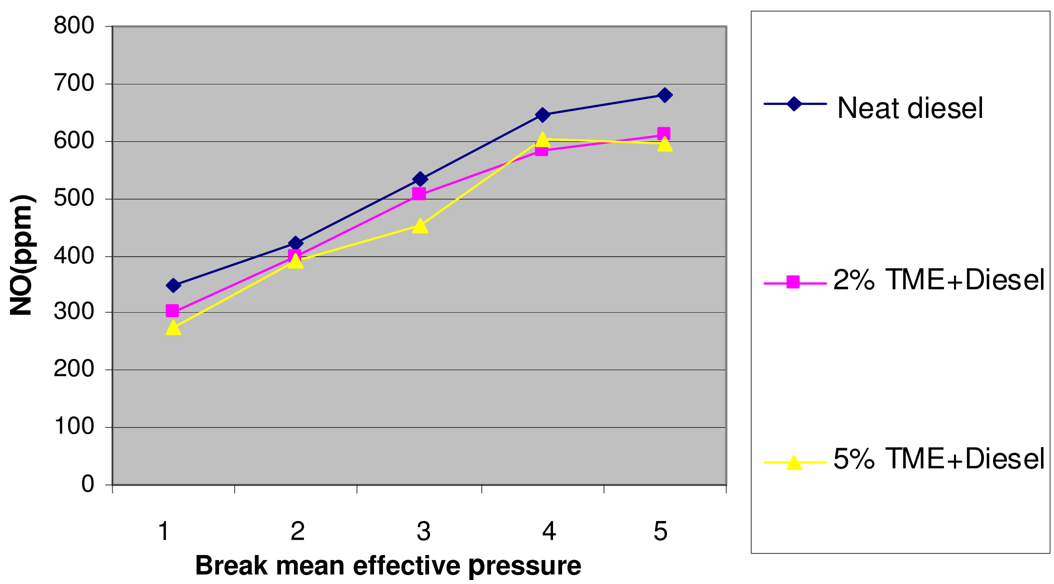

Figure 8. Break means effective pressure versus NO.

Figures 6 and 7. Hence it can be concluded that increase in percentage of TEM in diesel blend reduces NO emissions. In Figure 7 at lower percentages of TME blend, the unburnt HC is similar to that of the diesel but with increase in percentages of TME diesel blend, the unburnt HC is higher than that of the diesel (Senthil Kumar et al ., 2003).

Conclusion

In this study, it was shown that TME is an alternative to diesel fuel. It has been observed that a two stage trans-esterification improved the rate of reaction and also molar ratio of 6:1 and temperature of 65°C has proven to be the best values in terms of yield. The properties of TEM has been tested and established which are in permissible limits. According to the tests, the torque, power and specific fuel consumption for TME operation are within the permissible levels as when operating with pure diesel fuel (Figures 8 to 12). CO emissions decrease while HC emissions increased with increase in TEM in diesel fuel. But remarkable decrease in NO emissions has been observed due to the blending of diesel fuel with TME.

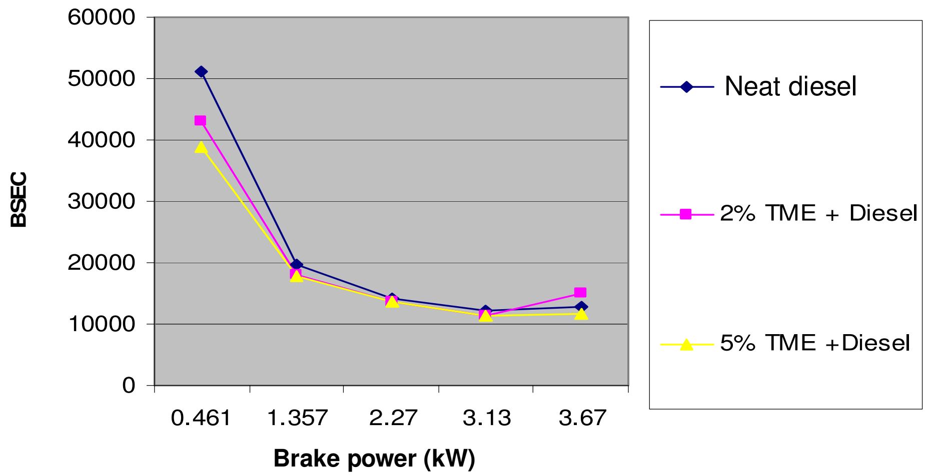

Figure 9. Brake specific energy consumption (BSEC) versus Brake power.

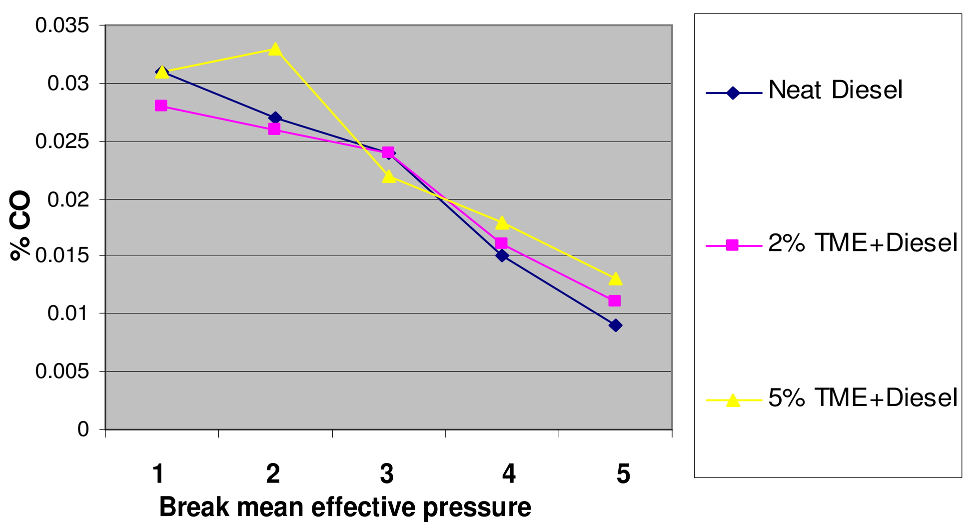

Figure 10. Break mean effective pressure versus % CO.

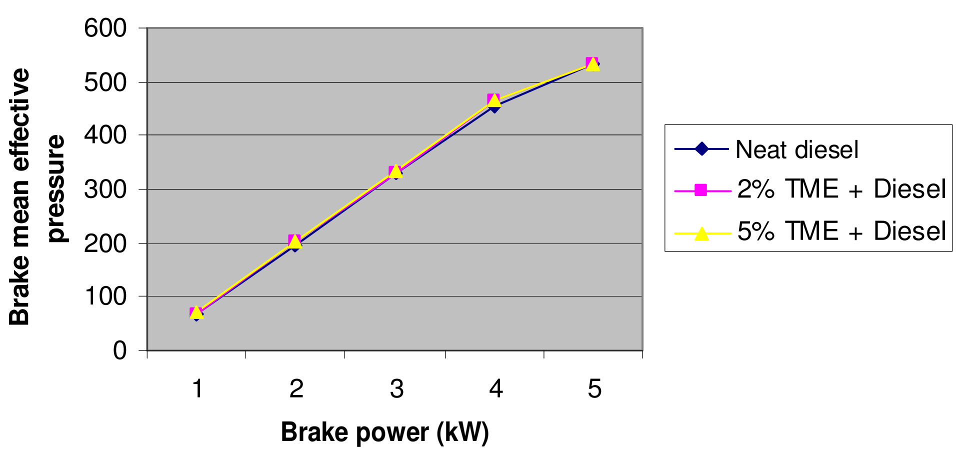

Figure 11. Brake power versus break mean effective pressure.

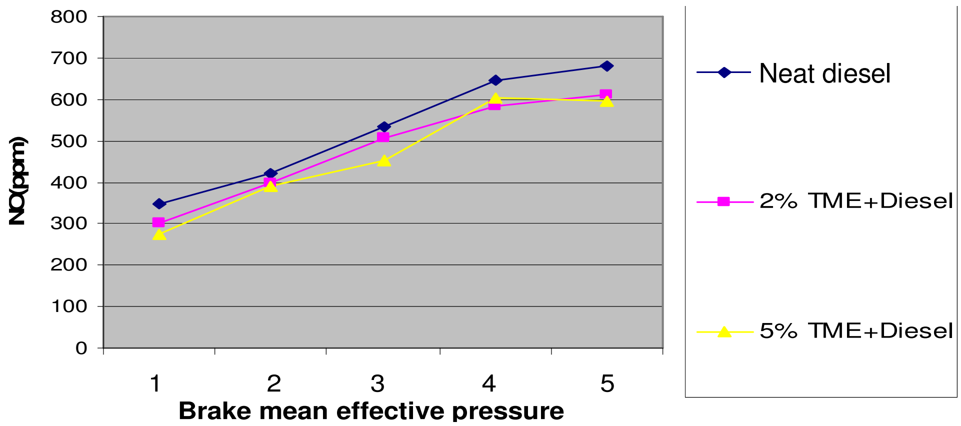

Figure 12. Brake mean effective pressure versus NO.

Emissions decreased slightly when operating with diesel and TME blend. The brake thermal efficiency increased while there is a decrease in brake specific fuel consumption .Although the results of the tests carried out on the test bench seem to be very encouraging, more tests with TME should be carried out to cover all operating conditions, not only full load conditions. Moreover, Increase in percentage of TME in diesel fuel, modifications on engine design and operation parameters such as injection timing, injection pressure and fuel heating should be tested and optimized for TME operation. These second set of tests will be carried out in the next phase of this study and will be presented in upcoming meetings.

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