Experimental Studies on the Performance and Emission Characteristics of an Ethanol Fumigated Diesel Engine

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ABSTRACT:

An experimental investigation was carried out to evaluate the performance and emission characteristics of an ethanol fumigated diesel engine. Tests were conducted in a suitably instrumented, four stroke, single cylinder, water cooled diesel engine at five different loads (0, 25, 50, 75 and 85% of rated load) for four ethanol fumigation rates (0.4, 0.6, 0.8 and 1 kg/hr) each at five ethanol air mixture temperatures (70, 85, 100, 115 and 130°C) in the inlet manifold. The substitution capability of fumigated ethanol for diesel was also evaluated. While the performance of the engine was evaluated using brake thermal efficiency, the emission levels of NO_X, HC, CO, CO_2 and O_2 were used for emission characteristics. The investigation indicates that the ethanol fumigation can result in diesel substitution as high as 92.64% through increasing ethanol air mixture temperature. At all loads the brake thermal efficiency with fumigation run is lower compared to diesel run. While CO and HC levels rise, fumigation helps lowering NO_X levels.

Keywords – **Diesel Engine, Emissions, Ethanol, Fumigation, Performance**

I. INTRODUCTION

Depleting world petroleum reserves, increase in petroleum fuel prices and restrictions on exhaust emissions from internal combustion engines triggered by environmental concerns had accelerated the interest in exploring the use of alternate and renewable fuels in internal combustion engines. Use of oxygenated fuels in diesel engines is aimed at achieving high thermal efficiencies without exceeding the limits imposed by the emission regulations on exhaust emissions. Alcohols that were once considered as the best substitute for petrol are now used as an alternate fuel in diesel engines too by using fumigation, blending, emulsion and duel injection techniques. While biodegradability, low toxicity, regeneration capability and clean burning characteristics are the attractions, immiscibility with diesel in the presence of moisture, low cetane number, poor auto ignition capability, poor lubrication property and lower thermal efficiencies due to high latent heat of vaporization are the constraints for the use of alcohol in diesel engines.

Fumigation is a method by which alcohol is introduced into the engine by carburizing, vaporizing or injecting into the intake air stream. The use of fumigation technique in a diesel engine (i) requires minimum modification or retrofitting in the inlet manifold (ii) enables operation of the engine both in dual and diesel modes (iii) reduces smoke and (iv) permits partial substitution of diesel by alcohol.

Eugene Ecklund et al [1], in their study, ordered the methods of using alcohol fuel in diesel engines (as per increasing diesel fuel displacement) as solutions, emulsions, fumigation and dual injection.

J.B.Heisey and S.S. Lestz [2] conducted tests in a single cylinder DI diesel engine by fumigating ethanol and methanol in amounts up to 55% of the total fuel energy. They concluded that while alcohol fumigation increased ignition delay and CO, it decreased NO_X and thermal efficiency at heavy loads.

Broukhiyan and Lestz [3] conducted tests on an ethanol fumigated V-8, light duty, indirect injection diesel engine to evaluate the performance and emission characteristics of the engine[ ]. Their test results indicated that ethanol fumigation resulted with reductions in brake specific NOx concentration and particulate emission with modest gains in thermal efficiency.

K.R.Houser et al [4] conducted tests on an Oldsmobile 5.7l V-8 Diesel fumigated with methanol in amounts up to 40% of fuel energy. They found that methanol fumigation decreased NO_X emissions and beneficial effect on fuel efficiency at high loads.

L.D.Savage et al [5] conducted tests on a four stroke turbo charged engine using multipoint port injection alcohol fumigation by different injection cycles. They concluded the multipoint dual cycle fumigation of alcohol as a viable approach to dual fueling of diesel engine.

Tests were conducted by Rodica A.Baranescu [6] in a turbocharged single cylinder DI Diesel engine fumigated with methanol, ethanol and aqueous ethanol to address the impact of alcohol fumigation on rates of pressure rise, peak cylinder pressure, specific energy consumption and gaseous emissions of CO, HC and NO_X.

T.K.Hayes et al [7] conducted tests on a turbocharged diesel engine with different proofs of alcohol fumigation. The results indicated that while HC and CO emissions increased, the NO_X emissions decreased compared to diesel and that the lower proofs provided optimum performance with a multipoint ethanol injection system.

K.D.Barnes et al [8] conducted tests on a high speed six cylinder turbocharged diesel engine. Alcohol significantly reduced smoke and inlet manifold temperature. However, the efficiency and HC emissions were unchanged.

Qiqing Jiang et al [9] conducted performance and emissions tests on a four cylinder turbocharged diesel engine. They suggested that fumigation may have a potential as an emission control technique in diesel engines to reduce NO_X

A.R.Schroeder et al [10] conducted tests on a multi cylinder, turbocharged diesel engine fumigated with methanol by changing the diesel injection timing. Tests results indicated that advancing the injection timing decreased CO and HC levels in the exhaust and that the increase in NO levels due to advances in diesel timing was offset by the decrease in NO due to ethanol addition.

In the present experimental work, an attempt was made to evaluate the performance and emission characteristics of an ethanol fumigated diesel engine. The performance of the engine was evaluated rating brake thermal efficiency and the emission characteristics using the emission levels of NOx, HC, CO, CO_2 and O_2. Tests were also conducted to ascertain the effects of ethanol–air mixture temperature on performance and emission characteristics of the engine and on the percentage substitution of diesel by fumigated ethanol.

II. DESCRIPTION OF THE EXPERIMENTAL FACILITY

A single cylinder, four stroke, water cooled diesel engine manufactured by Kirloskar, India was used in this study. The schematic representation of the experimental setup is as shown in Fig . 1.

Table 1: Specifications of the engine

Engine	**Kirloskar AVI engine**
Type	**Single cylinder, vertical, four stroke, water cooled, Diesel engine**
Bore	**80mm**
Stroke	**110mm**
Max power	**3.7kW**
Speed	**1500rpm**
Injection timing	**23^o before TDC**
Injection pressure	**215.82bar**
Compression Ratio	**16.5:1**

The specification of the diesel engine used in the present work is given in Table 1. A custom made tank and flow metering system were used for the measurement of the

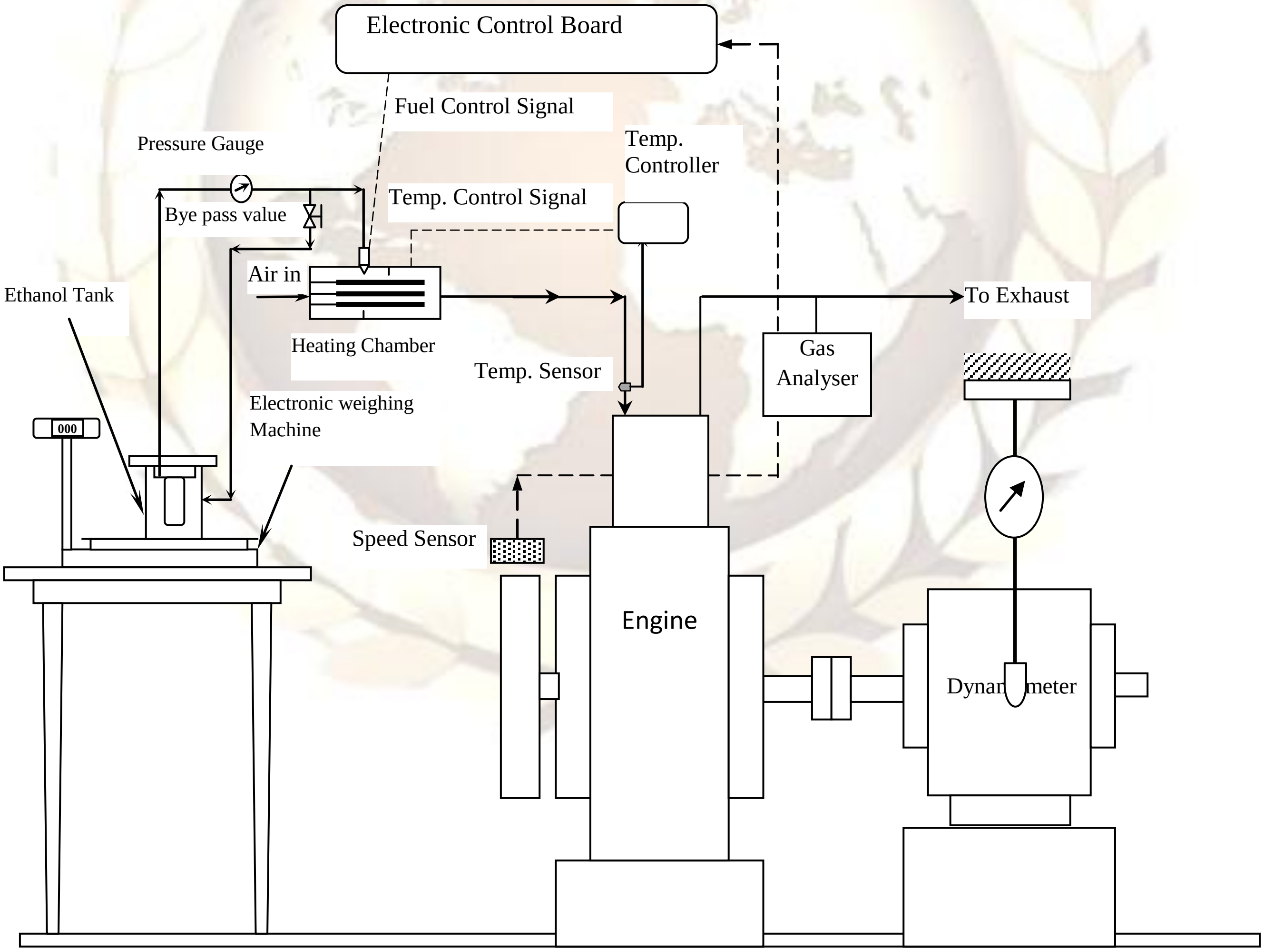


Fig. 1: Schematic representation of the experimental setup

diesel fuel consumption. The flow metering system consists of a glass burette and a stop watch to calculate the volume flow rate of diesel. To assist the fumigation of ethanol, a separate fumigation circuit consisting of ethanol storage tank, pump, electronic weighing machine, solenoid valve, pressure gauge, control valve (with a bypass return line to tank) electronic control system and injector was designed and incorporated. While baffles were employed to promote intake air-ethanol mixing, electric heating elements with temperature controller were used for heating fumigated ethanol and maintaining ethanol-air mixture temperatures. An eddy current dynamometer coupled to the engine was used to load the engine. The constituents of the engine emission were measured using a Horiba make gas analyser. The physical and chemical properties of diesel and ethanol are tabulated as shown in Table 2.

Table 2: Physical and Chemical properties of diesel, and ethanol.

	Diesel	Ethanol
Density at 20°C (kg/m^3)	0.829	0.789
Boiling point (°C)	180-360	78.4
Pour point (°C)	-1 to 3	-117.3
Mole weight	190-220	46.07
Flash point (°C)	65-88	13-14
Viscosity at 30°C (MPa s)	3.35	1.20
Cetane number	45-50	5-8
Appearance	Mild brown liquid	Colorless clear liquid
Other names	Petro diesel, diesel oil	Ethyl alcohol, hydroxyethane
Calorific value (kJ/kg)	41000	26800

III. EXPERIMENTAL PROCEDURE

Tests were conducted by running the engine with diesel at its rated speed and at five torque levels corresponding to 0, 25, 50, 75 and 85 % of rated load. In each test the volume flow rate of diesel and the constituents of exhaust emission such as NO_x , HC , CO , CO_2 and O_2 were measured at steady states. Each test was repeated thrice and the average of the measured values was taken for evaluation of engine performance and emission characteristics. The above procedure was repeated by running the engine with ethanol fumigation at various flow rates of ethanol and ethanol-air mixture temperatures. Tests to evaluate the influence of fumigation rate on the engine characteristics and on the substitution capabilities were also carried out.

IV. RESULTS AND DISCUSSION

Tests were conducted to determine the influence of ethanol fumigation rate and ethanol-air mixture temperature (also termed as "fumigation temperature") on the diesel substitution, performance and emission characteristics of a diesel engine. At ambient temperature of 34°C, the test engine permitted a maximum fumigation rate of 0.4 kg/hr and the mixture temperature was found to be 30°C due to evaporation of ethanol. Under these conditions the economic load on the engine was found to be 75% of the rated load. A slight increase in the fumigation rate above 0.4 kg/hr resulted in further cooling of the inlet ethanol air mixture and ended up with misfiring, fluctuations in speed and dense black smoke emissions due to incomplete combustion. The working of the engine, at economic load, was found to be normal when the fumigation temperature was in the range of 30°C to 130°C at a constant fumigation rate of 0.4 kg/hr. To make ethanol fumigation more effective, the minimum fumigation temperature was selected as 70°C, based on boiling point of ethanol (78.4°C), so that at this temperature ethanol exists in liquid form in the inlet manifold. Severe audible knock conditions and abnormal combustion imposed restrictions on the higher value of ethanol–air mixture temperature, in the temperature range. Further an increase in fumigation temperature from 130°C to 150°C resulted in a steep drop in volumetric efficiency of the engine confirming lower mass flow rate of air into the cylinder.

At the fumigation rate of 0.4 kg/hr, the fumigation temperature was varied from 70°C to 130°C, in steps of 15°C, and its effect on (i) Brake thermal efficiency, (ii) the constituents of emission such as NO_X, HC, CO, CO_2 and O_2 and (iii) the percentage substitution of diesel by ethanol, at economic load conditions, are represented in figure 2.

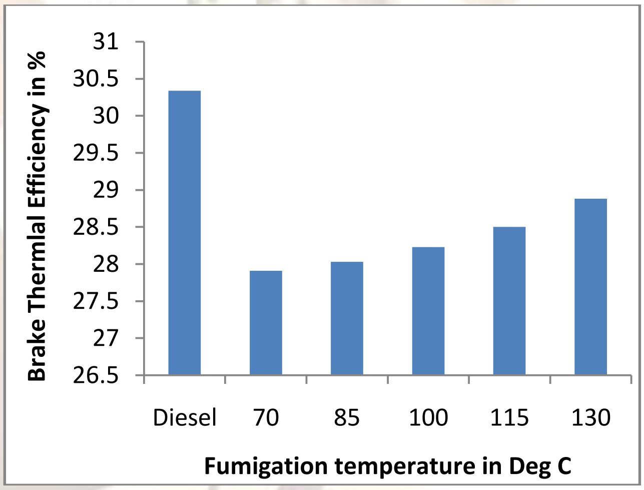


Fig 2a

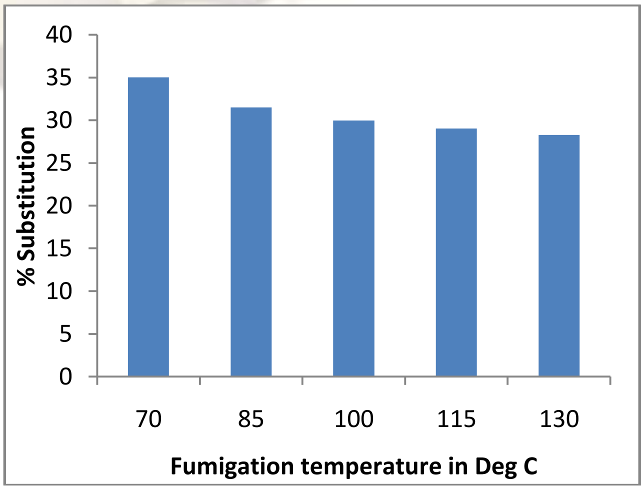
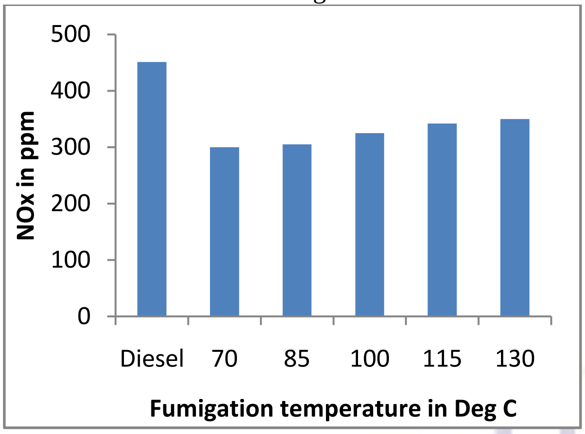


Fig 2b



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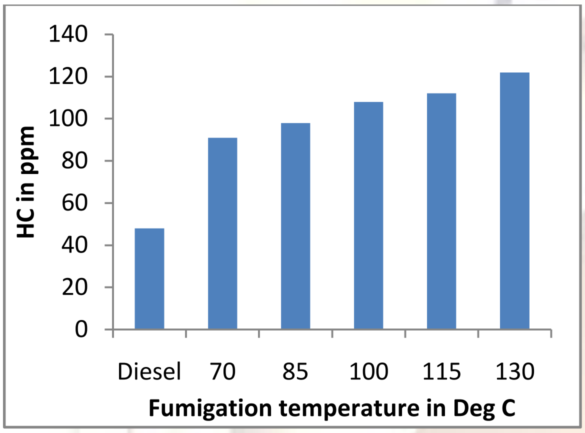
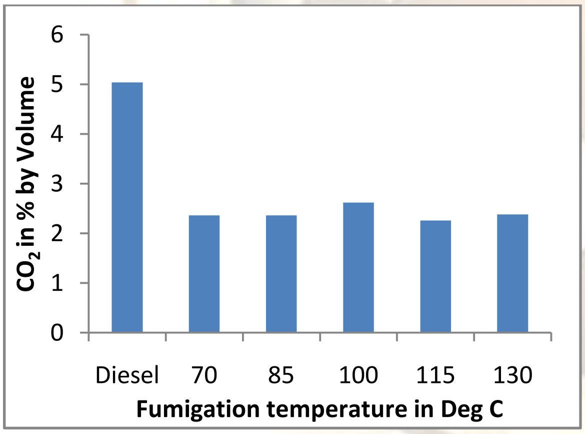


Fig 2d



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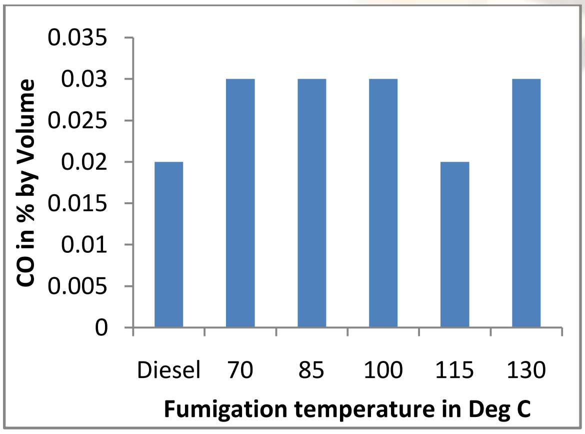


Fig 2f

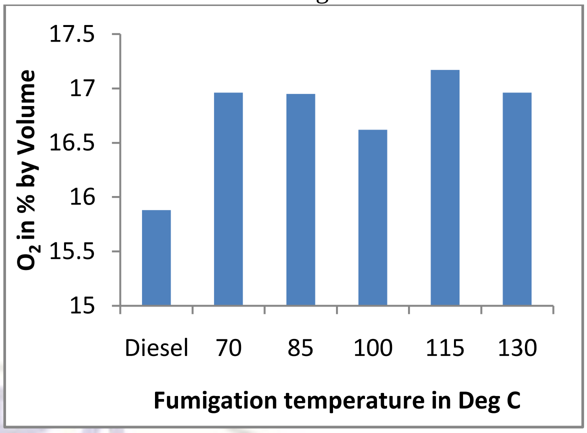


Fig 2g

Fig 2 – Effect of Fumigation Temperature on (a)on Brake Thermal Efficiency, (b) % Substitution, (c) NO_X, (d) HC, (e) CO_2, (f) CO and (g) O_2 at a Fumigation Rate of 0.4kg/hr at 75% of rated load in comparison with Diesel

Under these conditions, an increase in fumigation temperature resulted in an increase in brake thermal efficiency. With fumigation the brake thermal efficiency was maximum at a fumigation temperature of 130^{o}C which is slightly less than that obtained for neat diesel run. The percentage substitution of diesel by alcohol decreased with an increase in fumigation temperature from 70^{o}C to 130^{o}C. An increase in fumigation temperature ended up with an increase in NO_X emissions, but these emissions were less when compared with that of neat diesel. The HC emissions increased with increase in fumigation temperature and these were higher than that obtained for neat diesel. The CO_2 emissions were slightly lower when compared with neat diesel. The O_2 emissions are higher than that of neat diesel run confirming excess O_2 at all fumigation temperatures.

Increasing the fumigation temperature permitted higher rates of fumigation. Within the temperature range of 70^{o}C to 130^{o}C, the test engine permitted a maximum fumigation rate of 1 kg/hr at all loads. Increase in flow rate above 1 kg/hr resulted fluctuations in speed of the engine, and dense smoke emissions at part loads up to 50% of rated load.

The results of tests conducted on the diesel engine with ethanol fumigation in the range of 0.4 kg/hr to 1 kg/hr, in steps of 0.2 kg/hr, with the fumigation temperature varying from 70^{o}C to 130^{o}C, in steps of 15^{o}C, and discussion on the same follow in the succeeding paragraphs.

Brake thermal efficiency plots corresponding to five different fumigation temperatures (70, 85, 100, 115 and 130^{o}C) are shown in figure 3a to 3d for four ethanol fumigation rates (0.4, 0.6, 0.8 and 1 kg/hr). It is observed that ethanol fumigation results in lower thermal efficiencies compared to the base line neat diesel run. Lower calorific value and higher latent heat of evaporation of ethanol are the causes for lower thermal efficiencies. Higher the fumigation rate, higher is the decrease (from the base line value) in brake thermal efficiency. Decrease in thermal efficiency is pronounced at lower loads compared to higher loads and the decrease is the least at the economic load, these being true for all fumigation rates. Increase in fumigation temperature resulted in increase in efficiency, this effect being significant with lower fumigation rates and at higher loads of operation. Fumigation lowered the economic load compared to neat diesel run. Neither the fumigation rate nor the fumigation temperature greatly influences the economic load.

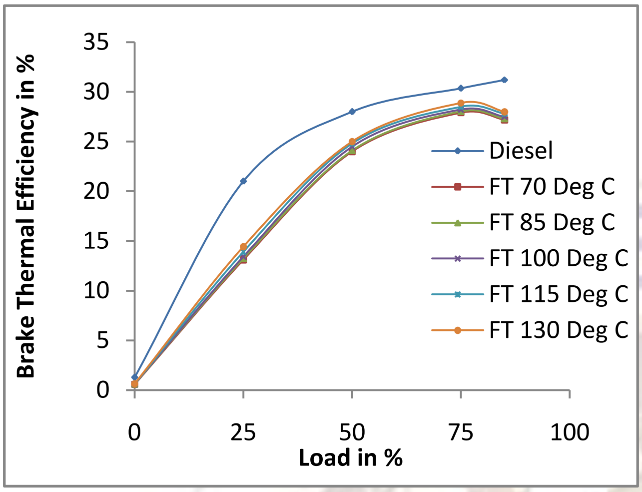
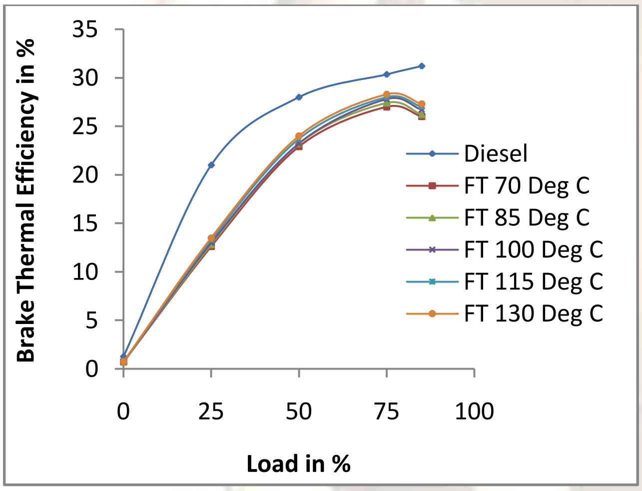


Fig 3a



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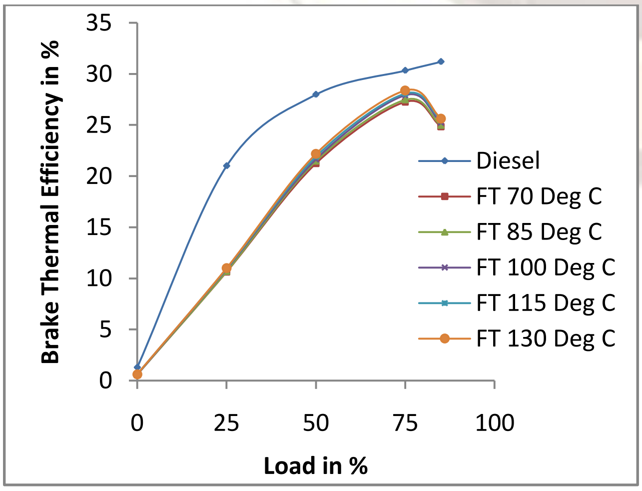


Fig 3c

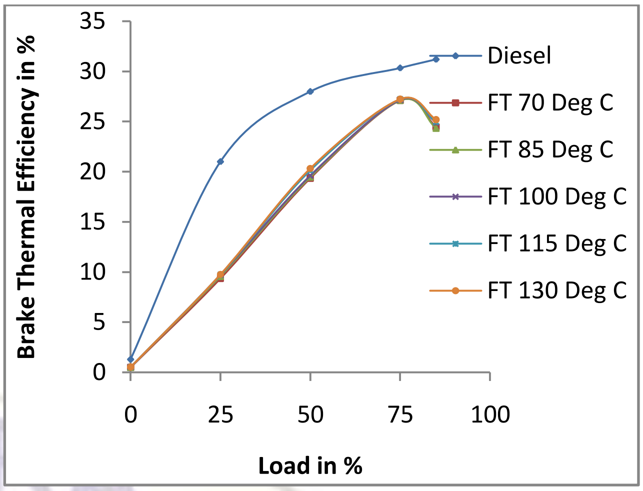


Fig 3d

Fig 3 – Effect of Load and Fumigation Temperature (FT) on Brake Thermal Efficiency at Ethanol Fumigation Rates of (a) 0.4kg/hr, (b) 0.6 kg/hr, (c) 0.8 kg/hr and (d) 1kg/hr

Figure 4a to 4d depicts the variation of NO_X emission against load corresponding to five fumigation temperatures for four ethanol fumigation rates. At all loads, fumigation rates and fumigation temperatures, the NO_X levels were found to be much lower than that of neat diesel. Fumigation results in lower NO_X levels due to cooling effect for reasons similar to those suggested to lower brake thermal efficiencies. Higher the fumigation rate, lower are the NO_X levels and the decrease from base value is pronounced at higher loads. With increasing fumigation temperature, NO_X increased, this effect being significant with higher fumigation rates and at higher loads of operation. Factors that influence NO_X levels include in-cylinder peak temperature and its duration, oxygen concentration of the mixture, and residence time in the high temperature zone.

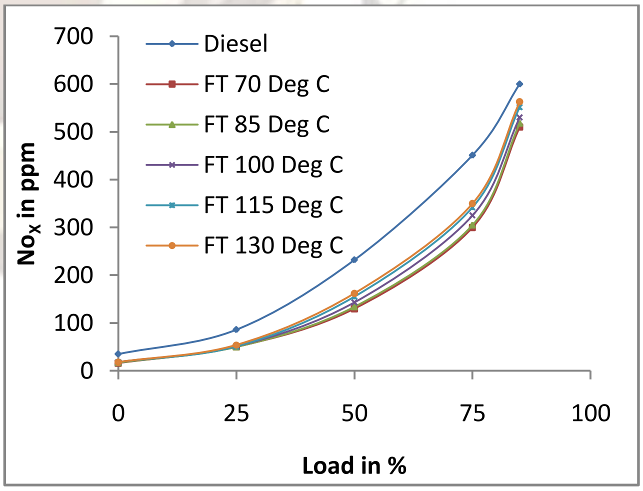


Fig 4a

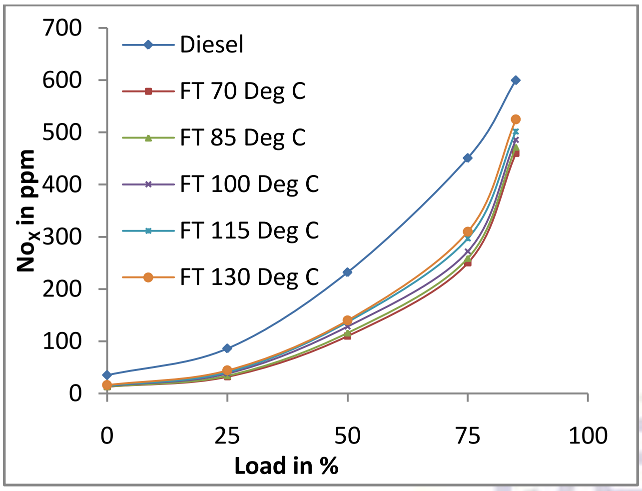


Fig 4b

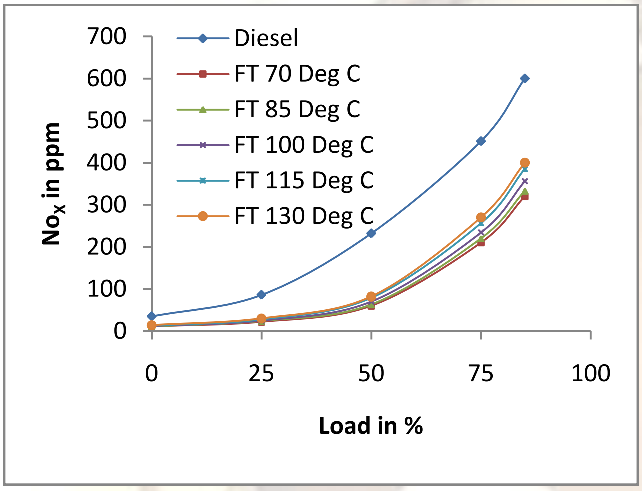


Fig 4c

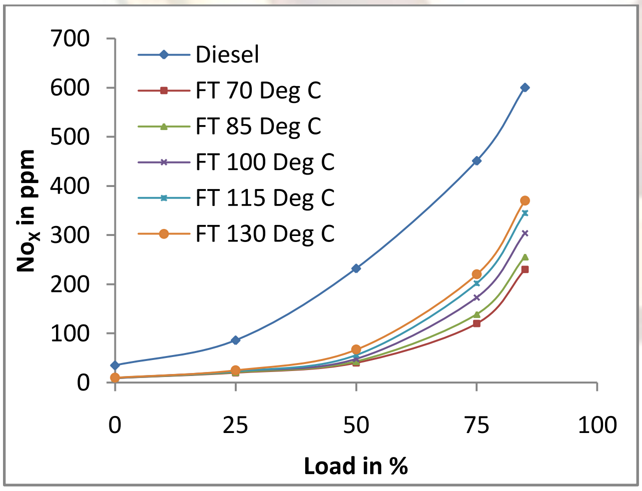


Fig 4d

Fig 4 – Effect of Load and Fumigation Temperature (FT) on NO_X at Ethanol Fumigation Rates of (a) 0.4kg/hr, (b) 0.6 kg/hr, (c) 0.8 kg/hr and (d) 1kg/hr

Figure 5a to 5d show the variation of HC emission against load corresponding to fumigation temperatures for four ethanol fumigation rates. Fumigation results in higher levels of HC emission compared to those with diesel run. HC emissions were much higher at lower loads, decreased to a minimum at the economic load and increased beyond, this trend being true with both neat diesel run and with the fumigation rates. Increase in fumigation rate and increase in fumigation temperature both resulted in higher HC emissions. The influence of fumigation temperature is pronounced at lower loads. With increasing fumigation rate, the HC plots tend to be linear and less steep.

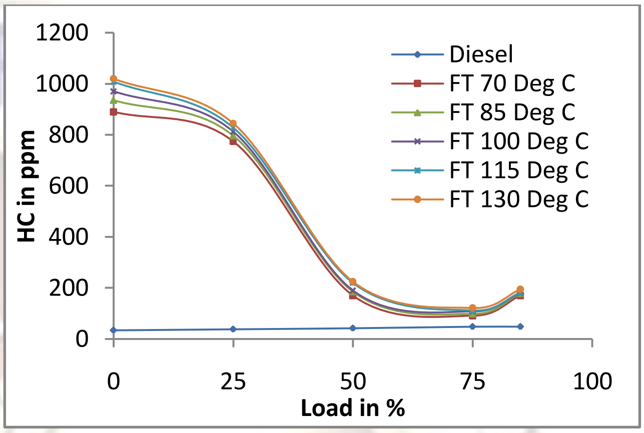


Fig 5a

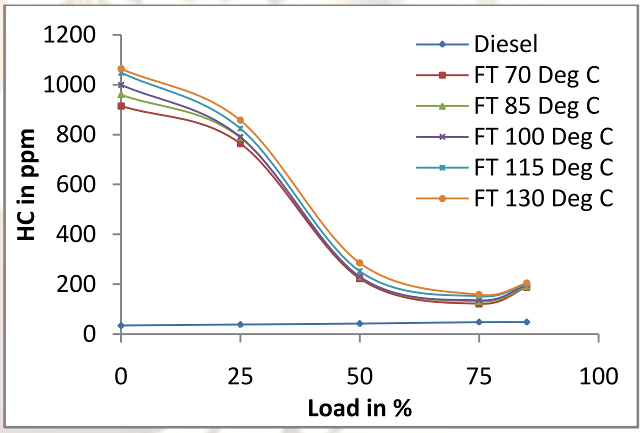
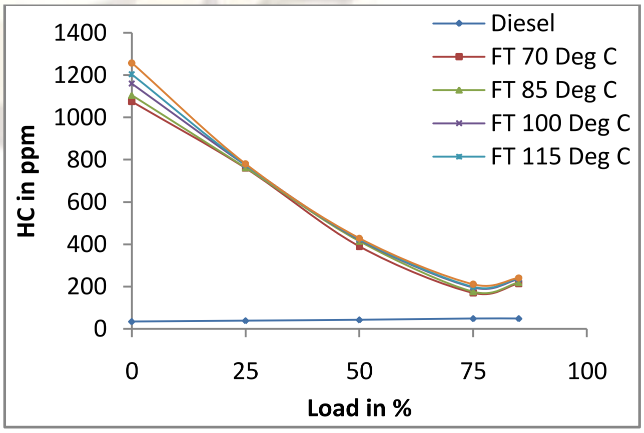


Fig 5b



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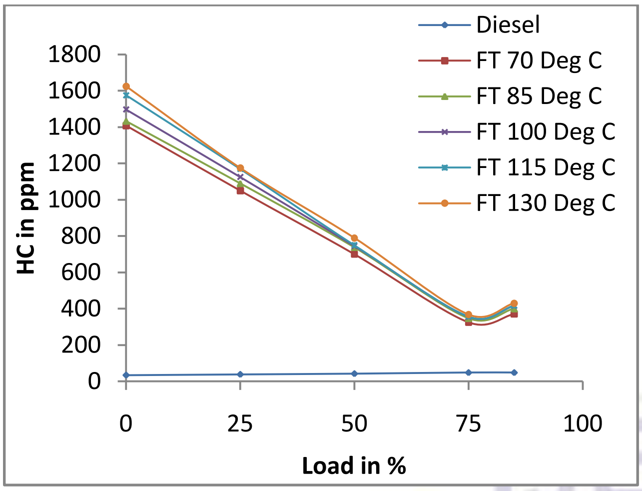

Fig 5d

Fig 5 – Effect of Load and Fumigation Temperature (FT) on HC at Ethanol Fumigation Rates of (a) 0.4kg/hr, (b) 0.6 kg/hr, (c) 0.8 kg/hr and (d) 1kg/hr

Figures 6 and 7 depict respectively the variation of CO and CO_2 levels against load. CO level tends to increase with increasing load both in the lower load region (0 to 20%) and in the higher load region (80 to 85%). In the mid ranges (20 to 80% load) CO level drops with the increase in load. These trends are followed for both the neat diesel run and the fumigation runs. Fumigation results in higher CO levels than base line values. Increase in fumigation rate or increase in fumigation temperature or both results in an increase of CO level. Fumigation results in lower CO_2 compared to that with neat diesel run.CO_2 level tend to increase with increasing load.

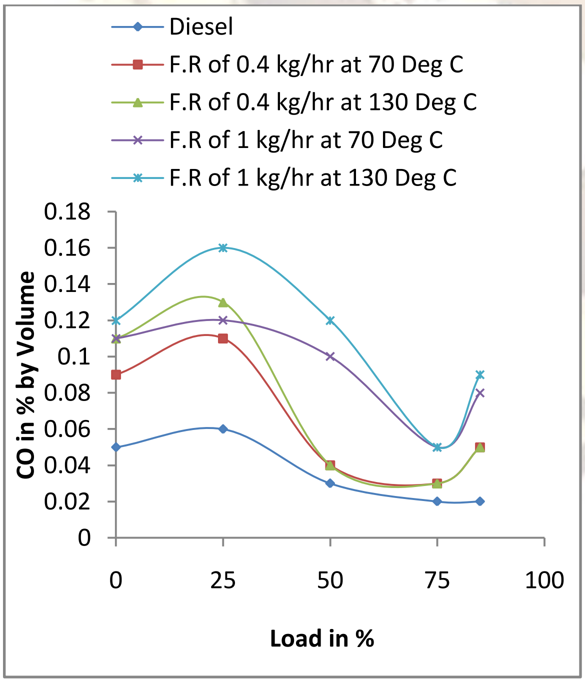

Fig 6 – Effect of Load, Fumigation Rate and Fumigation Temperature on CO Emissions in comparison with Diesel

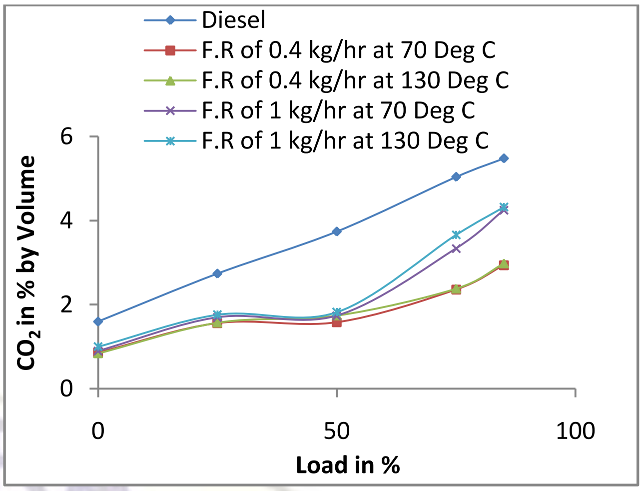

Fig 7 – Effect of Load, Fumigation Rate and Fumigation Temperature on CO_2 Emissions in comparison with Diesel

Figure 8 show that fumigation results in higher excess oxygen, which may be due to the presence of more oxygen molecules in ethanol.

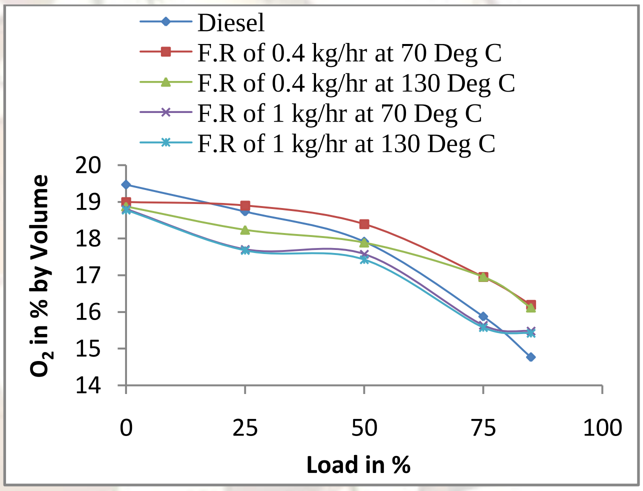

Fig 8 – Effect of Load, Fumigation Rate and Fumigation Temperature on O_2 Emissions in comparison with Diesel

Influence of ethanol fumigation rate and fumigation temperature on percentage of diesel substitution is shown in figure 9. As obvious, increase in fumigation rate resulted in an increase in substitution at all loads of operation. Generally, substitution also increased with increasing fumigation temperature. The highest substitution of 84.36 percent was possible with 75% load at a fumigation rate of 1 kg/hr at fumigation temperature of 130°C. An attempt to further increase the percentage substitution at 75% load resulted in substitution of 91.13% and 92.64% at fumigation rates of 1.2 kg/hr and 1.32 kg/hr respectively at fumigation temperature of 130°C with the corresponding brake thermal efficiencies lowered to 25.62% and 23.73%. The variations in brake thermal efficiency, percentage substitution and the constituents of emission for fumigation rates of 1kg/hr,1.2kg/hr and 1.32kg/hr at a fumigation temperature of 130°C are shown in Fig.10.

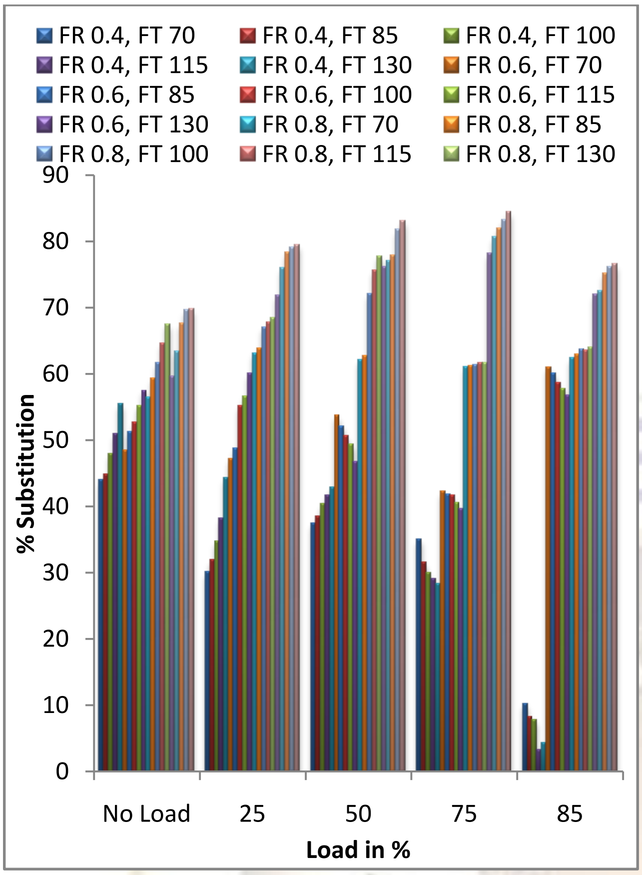

Fig 9 – Effect of load, Fumigation Rate (FR in kg/hr) and Fumigation Temperature (FT in °C) on percentage Substitution of Diesel by Ethanol

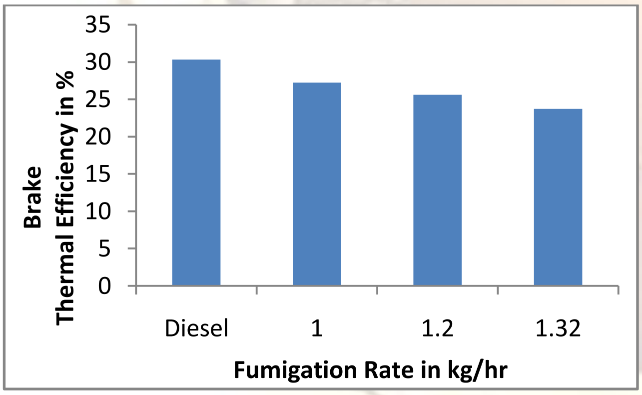

Fig 10a

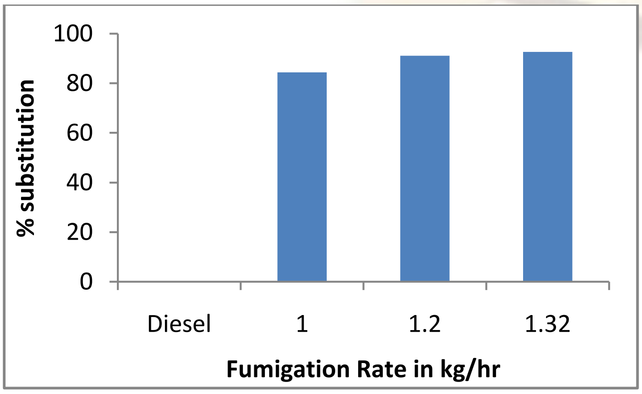

Fig 10b

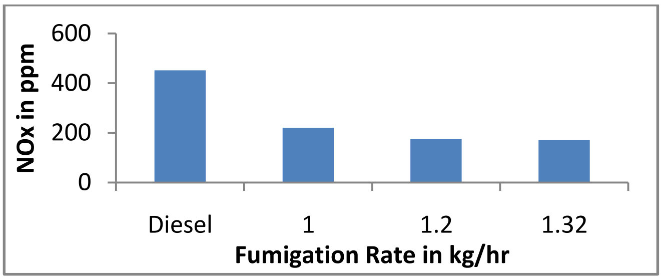

Fig 10c

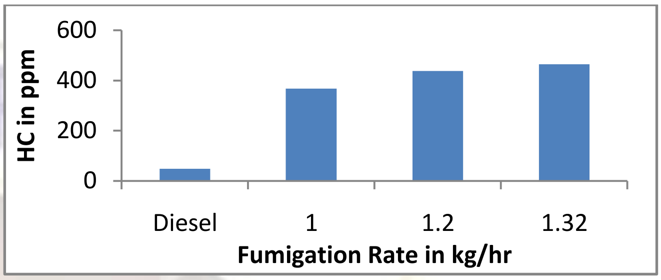

Fig 10d

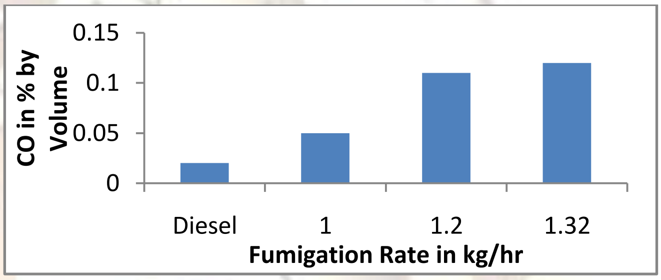

Fig 10e

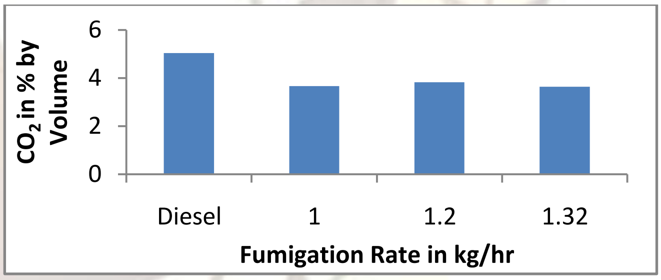

Fig 10f

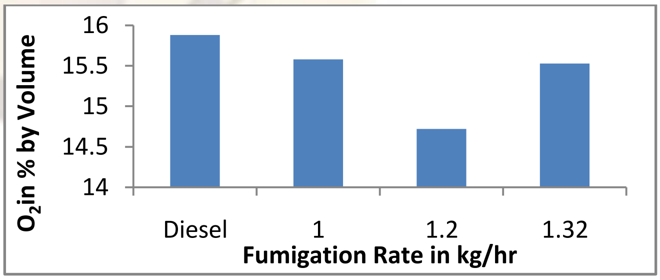

Fig 10g

Fig 10 – Effect of Fumigation Rate on (a) on Brake Thermal Efficiency, (b) % Substitution, (c) NO_X, (d) HC, (e) CO_2, (f) CO and (g) O_2 at a Fumigation Rate of 0.4kg/hr in comparison with Diesel run at 75% of rated Load.

V. CONCLUSIONS

The results of tests conducted in an ethanol fumigated diesel engine at five different loads, five fumigation temperatures for each of four fumigation rates to ascertain the influence of ethanol fumigation on brake thermal efficiency, emission constituents and percentage substitution of diesel by ethanol can be concluded as follows.

- Economic loads for fumigation runs were slightly lower compared to that for diesel run. Neither the fumigation rate nor the fumigation temperature significantly influenced the economic load.
- While increase in the fumigation rate resulted in a decrease in brake thermal efficiency, increase in fumigation temperature ended up with an increase in brake thermal efficiency. In all case, the brake thermal efficiency with fumigation run was lower compared to diesel run.
- The NO_X levels for fumigation run were less than that for neat diesel run. Increase in fumigation rate and fumigation temperature ended up, respectively, with increase and decrease in these levels.
- Increase in either fumigation rate or fumigation temperature or both results in an increase in HC levels.
- Increase in both fumigation rate and fumigation temperature resulted in an increase in percentage substitution of diesel by ethanol. At 75% load, a substitution as high as 92.64% could be achieved at a fumigation rate of 1.32 kg/hr at a fumigation temperature of 130^{o}C.
- Fumigation resulted in slightly higher CO and lower CO_2 levels compared to base line values.

ACKNOWLEDGEMENT

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