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Experimental Investigation of Novel Methanol Fumigation on Single Cylinder Constant Speed Diesel Engine

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Abstract - Bio fuels play an important role as alternate fuel in diesel engines. In this paper, methanol fumigation on a constant speed single cylinder diesel engine is experimentally investigated. Fumigation is a method by which volatile fuels are injected into the intake manifold. Previously Carburetion and injection arrangements are used for fumigation. In this work, computer control injection using LabVIEW software is attempted for methanol fumigation and common rail is used to inject at same pressure always. Methanol at different rates is used as fumigation fuels. The performance and emission characteristics are studied with and without fumigation. Fumigation increases specific fuel consumption, carbon monoxide emission, and hydrocarbon emission. Fumigation decreases brake thermal efficiency at low load, carbon di-oxide and smoke. Fumigation increases specific fuel consumption at medium and high load conditions. The results show that fumigation replaces diesel up to certain percentage and reduces both nitrogen oxides as well as smoke.

Index words - Fumigation, Methanol, Electronic injection, LabVIEW.

I. INTRODUCTION

The world energy demand witnessed fears in two dimensions for the last two decades (Nwafor 2004). Firstly, the price of conventional fossil fuel is too high and has added burden on the economy of the importing nations. Secondly, combustion of fossil fuels is the main culprit in increasing the global carbon dioxide (CO_2) level, a consequence of global warming. The scarcity and depletion of conventional sources are also cases of concern and have prompted research world-wide into alternative energy sources for internal combustion (IC) engines. Compression ignition (CI) engine is in the pace of increasing popularity due to its higher thermal efficiency. It powers much of our land and sea transport, provides electrical power, and is used in farming, construction and industrial activities. Despite its significant advantages, the tailpipe emissions from CI engines, especially particulate matter (PM) and NOx, are still a matter of great concern.

The necessities for the search fuels are to ensure that when the shortfall in crude oil occurs, there can be a smooth transition to other fuels, to provide long-term security of supply because well over half of the world's crude oil is in the Middle East, to improve air quality because the alternative fuel may give cleaner exhaust gases, and to overcome the absence of an indigenous crude oil supply together with an adverse balance of payments situation. (Tiruvenkadam 2015) The selection criteria of alternative fuels are, it must be cheap and should be available everywhere, it must burn and produce less emission, it must have high calorific value, it must be easy and cheaper to produce, it should need less modification in existing engines, it should increase the engine life, it should require less engine maintenance, and it should be easy for handling and storage.

Out of available bio-fuels such as biogas, bio-methanol and biodiesel, methanol is very much striking and capable alternative fuel due to its storage facility and handling (Ganesan, 2002). Biogas requires high pressure for storage and leakage is also a problem. Biodiesel is produced from edible and non edible sources. Edible sources are not having very much potential for IC engines, since they are the suppliers of food for the population. Non edible source cultivation indirectly reduces the sources of edible source.

The alcohol is the fuel of the family of oxygenates. The alcohol molecule has one or more oxygen, which contributes to the combustion. The alcohols are named accordingly to the basic molecules of hydrocarbon which derives from them: Methanol (CH_3OH); Ethanol (C_2H_5OH); Propanol (C_3H_7OH); Butanol (C_4H_9OH). Theoretically, any of the organic molecules of the alcohol family can be used as a fuel. Two of the alcohols which are having simplest molecular structure are technically and economically suitable as fuels for internal combustion engines and they are methanol and ethanol. Methanol is produced by a variety of processes, i.e., distillation of wood; distillation of coal; natural gas and petroleum gas. Ethanol is produced mainly from biomass transformation, or bioconversion. It can also be produced by synthesis from petroleum or mineral coal. The advantages of methanol include they can be made out of organic material such as biomass and municipal waste; methanol combustion produces higher combustion pressures inside the combustion chamber of the IC engines; methanols have better combustion characteristics and performance due to the increased volumetric efficiency of methanol fuel; better safety for fire, leakage and spillages; methanols have a lower evaporative emission; carbon content in methanol is very small, and methanols do not require special transportation.

The methods of using methanol in diesel engine are methanol fumigation, methanol-diesel blend, methanol-diesel emulsification and dual injection.

II. LITERATURE SURVEY

The literatures in the areas of fumigations are collected and are reviewed here.

In alcohol fumigation, the alcohol fuel is introduced into the intake air up stream of the manifold by spraying or carbureting (Abu-Qudais et al ., 2000; Bhupendra Singh Chauhan et al., 2011). In ethanol–diesel blend, ethanol and diesel fuels are premixed uniformly and then injected into cylinder directly through the fuel injector (Bilgin et al., 2002; Chaplin and Janius 1987). In methanol–diesel emulsification, an emulsifier is used to mix the fuels to prevent separation (Cheng et al.,, 2008). In dual injection, separate injection systems are used for fuels injection (Goldsworthy 2013).

The direct-injection diesel engine operation in a duel fuel mode using pongamia methyl ester injection and methanol carburetion on performance and emission characteristics is experimentally investigated (Haribabu et al. 2010). It is noted that exhaust gas temperatures are moderate and there is a better reduction of NOx, HC, CO and CO2 at a methanol mass flow rate of 16.2 mg/s. Smoke level is observed to be low and comparable. Improved thermal efficiency of the engine is also observed.

The effect of applying biodiesel with either 10% blended methanol or 10% fumigation methanol in 4-cylinder diesel engine at 1800rev/min with 5 different loads is compared (Cheng et al. 2008). Blended mode has lower CO, HC and NO2 and particulate emissions and however, the fumigation mode gives higher brake thermal efficiency at medium and high engine loads. The experiment clearly shows two different conditions with their effects over exhaust gas and engine performance.

The fumigation of methanol is tested in 4-cylinder direct injection diesel engine which influences engine combustion and particulate emissions (Zhang et al. 2013). It reduces diesel fuel consumed and increases the heat release rate in premixed mode. With the application of fumigation methanol, the minimum in-cylinder pressure decreases from low to medium engine load, but increases at high engine load. It also increases the ignition delay, but has no significant influence on the combustion duration. It effectively reduces particulate mass and number of concentrations and increases the fraction of nucleation mode particles, and thus decreases the Geometric Mean Diameter (GMD) from medium-to-high engine loads.

The inferences obtained from the above discussions are as follows:

- Methanol is used as fumigation fuels.
- Fumigation is applied for common rail diesel engine, turbo charged engine, indirect injection engines and multi cylinder engines.
- Biodiesel is combined with methanol fumigations.
- Emulsifier method is comparable with fumigation method and fumigation gives better results.
- Fumigation improves performance, combustion and emission characteristics of diesel engines.

The objective of this paper is to investigate a constant speed single cylinder diesel engine using methanol fumigation for performance and emission. Methanol is used as a fumigation fuel with three different fumigation ratios of 10%, 20% and 30% on energy basis. Performance and emission characteristics are compared for methanol fumigation with diesel fuel.

III. MATERIALS AND METHODS

The engine selected for this experimental work is a single cylinder, constant speed diesel engine. The specification of the engine and testing equipments are given in Table 1.

Table 1. Specification of engine

Parameter	Details
Make	Kirloskar AV1
Number of cylinders, strokes	Single cylinder, four stroke
Bore and Stroke	80mm and 110mm
Power	3.75kW @ 1500rpm
Compression ratio	18:01
Type of cooling	Water cooling

Cubic capacity	0.553 ltr
Loading	Eddy current water cooled dynamometer
Measurement of CO, HC, No_x, Co_2	AVL 444 gas analyzer
Measurement of smoke opacity	AVL 437 smoke meter

The alcohol selected for this experiment is methanol, which is readily available in India. The fuel properties of methanol and diesel are tabulated in Table 2.

Table 2. Fuel Properties

Fuel / property	Methanol	Diesel
Chemical formula	CH_3OH	$C_{10}H_{22}$
Density (kg/m^3)	792	856
Boiling temperature at 1.013 bar (^{o}C)	64	188-343
Cetane number	4	40-55
Viscosity at 20^{o}C (mPa S)	0.59	2.8
Lower heating value (MJ/kg)	19.7	43.8
Heat of vaporization (kJ/kg)	1178	270
Oxygen content (weight %)	50	0
Ignition temperature (^{o}C)	470	316
Stoichiometric fuel / air ratio	0.12	0.15

Methanol possesses high self ignition temperature, high latent heat of vaporization and low cetane number. Methanol contains 50% oxygen. Hence it allows the engine to completely combust the fuel and yielding low emissions. Methanol have lower energy density compared to diesel and lower stoichiometric Air / Fuel Ratio (AFR) which increases the fuel mass that must be injected per cycle to achieve the same fuel equivalence ratio. Cetane number determines the ignition characteristics of fuel in diesel engines. If the cetane number is higher, its ignition properties are better. Cetane numbers of methanol is 4. Lower cetane numbers indicated longer ignition delays, allowing more time for the fuel to vaporize before combustion starts. Methanol has lower calorific value compared to diesel by 75.6% respectively. Therefore more methanols are to be replaced for getting the same power from the engine.

In this experiment, fumigation method is selected for using methanols in diesel engines. Carburetion technique is widely used for fumigating fuel into the air. Instead of carburetion, electronic injection is considered for fumigating methanol in this work. The block diagram of the injection system developed is shown in Figure 1.

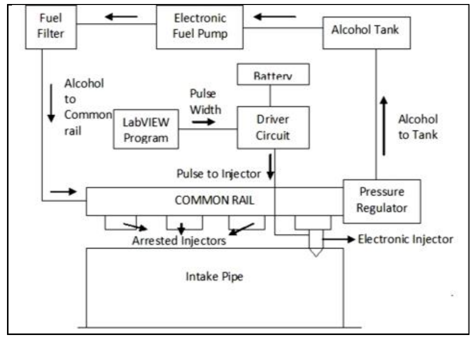


Fig. 1Fumigation Arrangement

Methanol is injected into the manifold by using electronic injector. Electronic injector is getting methanol from the common rail tube. Fuel pulse widths are generated by LabVIEW programs and are given to the injector through driver circuit. Fuel pulse widths are calculated for various loads using base fuel diesel. Common rail is getting methanol through the electronic pump and fuel filter. The pressure regulator maintains the pressure at the common rail. When the pressure is more than the set value the regulator opens and send the methanol to the tank. The pressure set on the common rail is 300 kilo Pascal, which is always constant. The common rail fitted in the intake pipe is shown in
Figure 2.

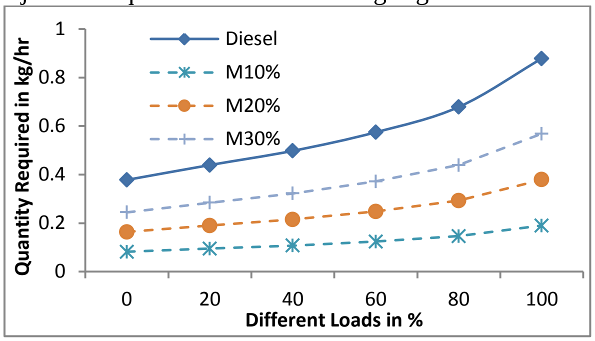
Fig 2. Common rail fitted in intake pipe

Common rail is mainly used to maintain the pressure constant at all loading conditions and when there is excess pressure created, it is released to the tank through pressure regulator. At this pressure methanol is injected in atomized and vaporized form which is required to mix with inlet air.

The Fuel map is the graph which shows the amount of fuel required for operating the engine at different operating conditions. In this experiment fuel map is required for operating the engine at different fumigation ratios. Using this fuel map only the quantity of methanol required for different load condition is calculated. The fuel map is shown in Figure 3.

Using base diesel reading the quantity of fumigation fuel required is calculated on the basis of energy. Methanol is injected at the ratio of 10%, 20% and 30% on energy basis. For instance the energy requirement for full loading of the engine when operating in diesel only is 37350 kJ/hr which is calculated by using diesel fuel consumption rate of

0.8788 kg/hr. And 10% methanol fumigation ratio is replacing 10% energy at full load i.e., 3735 kJ/hr and the amount of methanol injection required is 0.1895 kg/hr. Similarly for all loads and for all fumigation ratios, the injection requirement is found using Figure 3.



Fuel pulse widths are required for operating the methanol injector with different fumigation rates. In this experiment, fuel pulse width can be obtained by LabVIEW software, data acquisition hardware and driver circuit. In LabVIEW software, square pulses are created with different frequency and duty cycle. The program developed is shown in Figure 4. Through data acquisition hardware, square pulses are given to the driver circuit. Analog output card NI 9263 and USB method data acquisition chassis NI 9472 are used as data acquisition hardware. The data acquisition hardware is shown in Figure 5. The L293D electronic chip is used as a driver circuit. This electronic chip circuit is connected across the data acquisition hardware, battery and methanol injector. This driver circuit is used for injecting the fuel, according to pulse width given by the software. The driver circuit connection is shown in Figure 6.

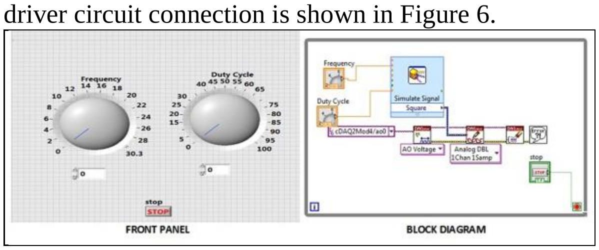


Fig 4. LabVIEW Program

Fig 5. Data Acquisition Hardware

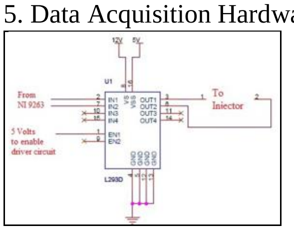


Fig 6. Driver Circuit

IV. EXPERIMENTAL SETUP AND TESTING

The schematic of the experimental setup is shown in Figure 7. The photographic view of the experimental setup is shown in Figure 8. Smoke meter was used to measure smoke and exhaust gas analyzer was used to measure the emission values. Range and accuracy of different instruments used was shown in Table 3. Burettes were used to measure the volumetric fuel consumption rates of diesel and methanols. The exhaust gas temperature and cooling water outlet temperature were measured online by a K-type iron constant thermocouple.

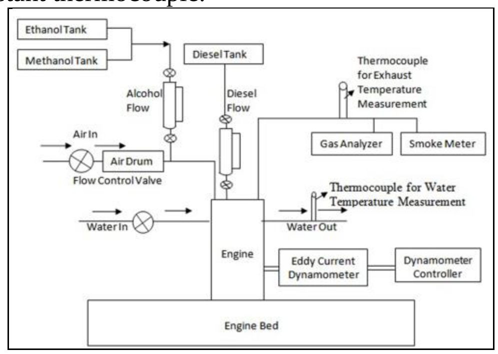


Fig 7. Schematic of the Experimental Setup

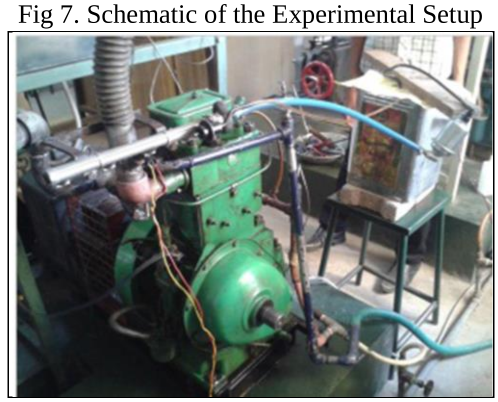


Fig 8. Experimental Setup

Table 3. Range and Accuracy of Instruments

Instruments	Range	Accuracy
Gas analyzer	CO 0-10%, CO_2 0-20%, HC 0-10000 ppm NO_x 0-5000 ppm	+0.02% to -0.02% +0.03% to -0.03% +20 ppm to -20 ppm +10 ppm to -10 ppm
Exhaust gas temperature indicator	0-900°C	+1°C to -1°C
Speed measuring unit	0-1000 rpm	+10 rpm to -10 rpm

The experiments were carried out for different loads on the engine. The engine was run for 20 minutes to warm up. The quantities of fuel consumed at different loads of the engine were measured. The intensity of smoke is measured by the light obscuration method in which the intensity of the light beam is reduced by smoke, which is a measure of smoke intensity. The carbon monoxide, hydrocarbons (UBHC) emissions were measured by Non-Dispersive Infra Red (NDIR) analyzer. The exhaust gases are allowed to pass through a water trap immersed in an ice bath to separate the condensed water so that only dry exhaust gas is allowed into the exhaust analyzer. The AVL five gas analyzer and smoke meter were used for the measurement of exhaust gas emissions and smoke. The readings are taken for diesel and methanol with three fumigation rates.

V. RESULTS AND DISCUSSION

In this experiment, performance and emission were evaluated using diesel and diesel with methanol fumigation. Three fumigation ratios are used and they are 10%, 20% and 30%. These ratios are obtained by using fuel map and electronic injection. The results on engine performance and emission are discussed here.

Specific Fuel Consumption (SFC) is calculated by following equation.

$$SFC = (q_{m,d} + q_{m,a})/P_b$$

Here $q_{m,d}$ and $q_{m,a}$ are mass consumption rated of diesel and methanol and P_b is brake power. The variation of SFC with loads of diesel and fumigation fuels was shown in Figure 9.

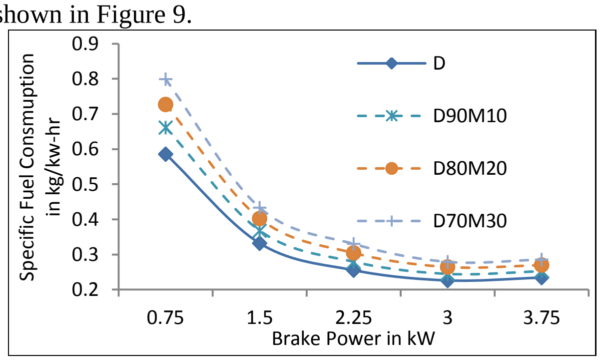


Fig 9. SFC Vs BP

The results showed that SFC was higher than that of diesel fuel for any percentage of fumigated fuel and increased with the level of fumigation. It showed 0.662 kg/kW-hr, 0.727 kg/kW-hr and 0.799 kg/kW-hr SFC at 20% load for methanol fumigation, which is 12.9%, 24.1% and 36.3% higher than operating on diesel fuel. The methanol fumigation has higher SFC for all ratios at all loads. The lower calorific value of methanol is the reason for the increase of SFC in methanol fumigation. And also due to methanol fumigation, more cooling is happening inside the cylinder. Because of cooling effect more amount of fuel is needed to support the complete combustion and to provide the required amount of power.

Brake Thermal Efficiency (BTE) is calculated by following equation.

$$BTE = \{ Pb / [(q_{m,d} \times Q_{LHV,d}) + (q_{m,a} \times Q_{LHV,m})] \} \times 100\ \%$$

Here $q_{m,d}$ and $q_{m,a}$ are mass consumption rate of diesel and methanol, $Q_{LHV,d}$ and and $Q_{LHV,m}$ are lower heating value of diesel and methanol and P_b is brake power. The variation of BTE with loads of diesel and fumigation fuels was shown in Figure 10. The result showed that methanol fumigation decreases the BTE at low load and increases the BTE at medium and higher engine loads. The decrease in efficiency is up to about 11% for 30% methanol fumigation at 20% load condition. The results indicate that the combustion efficiency decreases at low loads, but could be improved at high loads, with an increase in the level of fumigation methanols. At low loads, the fumigation methanol and the intake air to form a mixture which might be too lean to support combustion, resulting in deterioration in the combustion efficiency. At medium to high loads, the mixture might be rich enough to support combustion, resulting in better combustion. The enhanced rate of heat release due to the combustion of the homogeneous air/methanol mixture should help to improve the brake thermal efficiency.

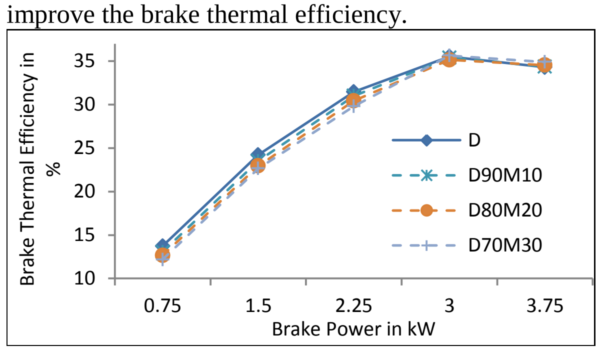


Fig 10. BTE Vs BP

The variation of Oxides of nitrogen (NO_x) with loads of diesel and fumigation fuels was shown in Figure 11.

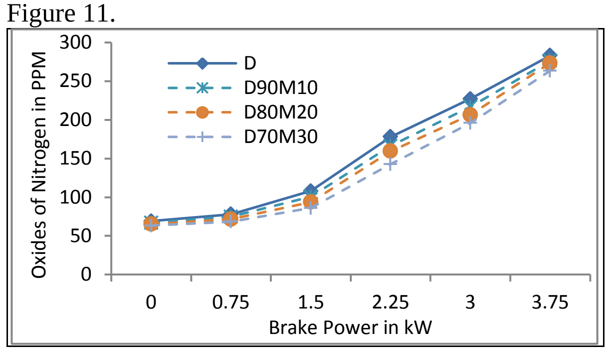


Fig 11. NO_X Vs BP

The results showed that all rates of fumigation gives lower NO_x emission than diesel fuel. However, NO_x emission increases with the rate of fumigation. Depending on engine load, NOx emission is higher at low engine load than medium and higher engine load. The reduction in NO_x is about 9.33% at no load, 12.6% at 20% load, 21% at 40% load, 21.8% at 60%, 14.4% at 80% load and 8.4% at full load for 30% methanol fumigation. The formation of NO_x in a diesel engine strongly depends on the temperature of combustion and along with the concentration of oxygen present in the combustion process. Methanol has a high latent heat of vaporization hence less amount of heat is released during combustion process which reduces the combustion temperature, leading to the reduction of NO_x formation, especially under the lean conditions at lower engine loads.

The variation of carbon monoxide (CO) with loads of diesel and fumigation fuels was shown in Figure 12.

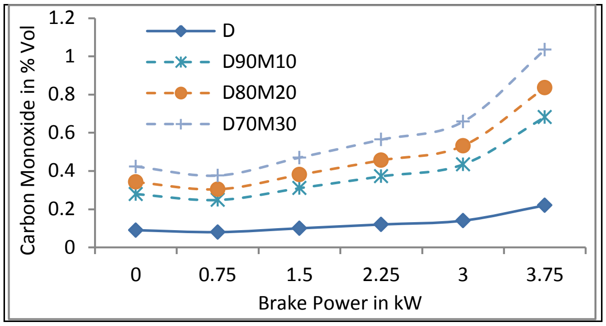


Fig 12. CO Vs BP

The results showed that there is a significant increase in CO emission with methanol fumigation compared to diesel fuel. The results showed that the average CO emission increase was 3.1 times, 3.8 times and 4.7 times of diesel value for 10%, 20% and 30% methanol fumigation ratios. Methanol lowers the in-cylinder gas temperature, which might be not able to ignite the methanol during the expansion stroke. The rapid burning of vaporized methanol and subsequent charge cooling decrease the in-cylinder temperature that might lead to incomplete oxidation of the CO to CO_2 during expansion stroke, resulting and increase in CO emission.

The variation of Hydro Carbon (HC) with loads of diesel and fumigation fuels was shown in Figure 13.

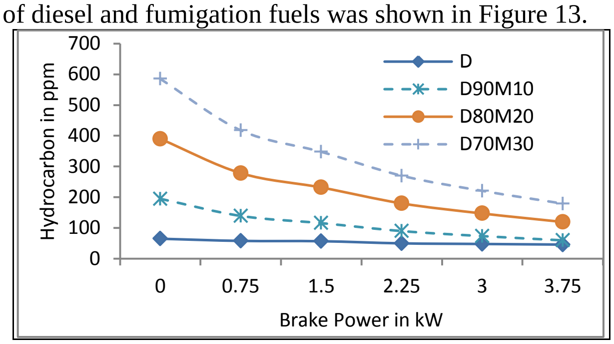


Fig 13. HC Vs BP

From the results, it has been clear that methanol fumigation increases the HC emission compared to diesel fuel. Moreover, the emission increases with the level of fumigation and decreases with increasing engine loads. Their investigation showed that HC emission increases from 65 ppm to 585 ppm at no load while it varies from 46 ppm to 179.4 ppm at full load for 30% methanol fumigation. Since methanol has cooling effect on combustion processes, as a result poor combustion temperature might not be able to ignite the unburned fumigated methanol during the expansion stroke which leads to increase in HC emission. Especially at low engine load condition, due to large amount of excess air, poor fuel distribution and low exhaust temperature, lean fuel–air mixture regions may survive to escape into the exhaust resulting in higher HC emissions.

The variation of Carbon Dioxide (CO_2) with loads of diesel and fumigation fuels was shown in Figure 14.

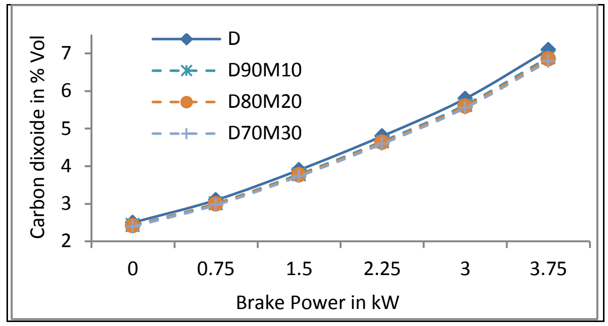
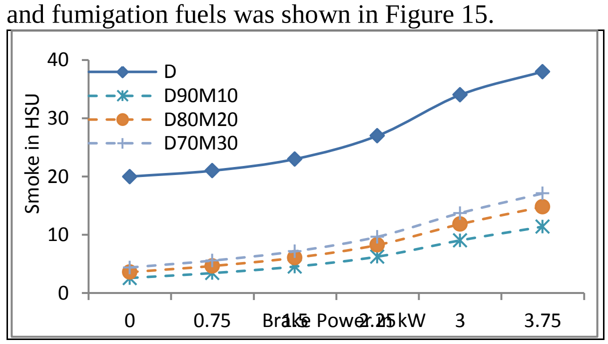


Fig 14. CO_2 Vs BP

The results showed that there is a significant decrease in CO_2 emission with methanol fumigation compared to diesel fuel. At an average reduction of 2.9%, 3.5% and 4.3% is obtained for methanol fumigation at 10%, 20% and 30% fumigation rates respectively. In fumigation mode, brake thermal efficiency decreases, which results in a significant increase in fuel consumption, which reduces the CO_2. CO_2 emission greatly depends on the CO emission. In fumigation mode, due to having a higher heat of vaporization, methanol reduces the in-cylinder temperature, which leads to incomplete oxidation of the CO to CO_2 during the expansion stroke and thus results in an increase in CO emission and decrease in CO_2 emission.

The variation of smoke with loads of diesel and fumigation fuels was shown in Figure 15.



The result showed that methanol fumigation causes low smoke emission than diesel fuel. For methanol fumigation it was 13-30%, 18-39% and 22-45% at 10%, 20% and 30% fumigation. There is less diesel fuel consumed with increasing methanol fumigation since a portion of diesel fuel is replaced by methanol. Therefore, less diesel fuel is burned during combustion and combust together with the methanol/ air mixture which helps to burn faster and with higher availability of oxygen, leading to a reduction in PM emission.

VI. CONCLUSIONS

Biofuels are from renewable and domestically available, which are very much suited as an alternative to conventional fuels. In this experiment fumigation method of using methanol is investigated using electronic injection at the intake manifold. LabVIEW software was used for controlling the fumigation quantity for different loads of single cylinder constant speed diesel engine. Performance and emission characteristics were studied for diesel methanol fumigation at different fumigation rates. The following conclusions are arrived:

1. When fumigation methanol is applied to the diesel engine, SFC increases with the percentage of fumigation methanol at all engine loads. Around 8-36% increase of BSFC in energy basis has been found, which is due to the lower calorific value of methanol.
2. Methanol fumigation decreases BTE at low engine loads, but there is a little increase in BTE at medium and high engine loads. The decrease in BTE has been found in the range of 2–11% and an increase in BTE has been found in the range of 0.2–3%.
3. Methanol fumigation decreases NO_x emission compared to diesel fuel. NO_x emission is significantly affected by engine loads. The maximum reduction has been found to be 22% compared to pure diesel fuel at lower engine load for 30% fumigation.
4. Methanol fumigation increases the CO and HC emission compared to diesel fuel. The increase in CO emission has been found in the range of 2.7- 4.7 times. On the other hand, the increase in HC emission has been found in the range of 2 to 6 times.
5. Methanol fumigation significantly decreases the CO_2 emission which is due to increase in CO.
6. Methanol fumigation can substantially reduce smoke emission compared to diesel fuel. The reductions are mainly associated with the reduction of diesel fuel burned. The reductions have been found between 9–45% of overall engine load conditions.

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