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Research article

Some Experimental Investigation on use of Methanol and Diesel Blends in a Single Cylinder Diesel Engine

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ABSTRACT

In view of increasing pressure on crude oil reserves and environmental degradation as an outcome, fuels like methanol may present a sustainable solution as it can be produced from a wide range of carbon based feedstock. The present investigation evaluates methanol as a diesel engine fuel. Methanol and diesel are immiscible at room temperature and formulation of micro-emulsion using surfactants has been a prescribed technique for diesel engine applications. However, preparation of micro-emulsion requires technical expertise. Therefore, macro-emulsion using a simple on board stirrer with predetermined rpm is a promising solution.The test fuels were prepared with 5% and 10% (v/v) of methanol in the emulsion and experiments were conducted on a single cylinder diesel engine. The results showed that for 5% methanol in the emulsion, full load brake thermal efficiency was reduced by nearly 10 % and for 10% methanol, 28% reduction was observed as compared to diesel baseline. Consequently, brake specific fuel consumption was increased with increase in methanol percentage in the emulsion. Emission of carbon monoxide was insignificant at part loads but at higher loads these emissions were reduced with rising percentage of methanol in the emulsion. For 10% emulsion, emission of hydrocarbons was reduced by nearly 20% at full load, but a little variation was observed for neat diesel and 5% emulsion.Variation in nitrogen oxides emission was not significant for all test fuels at part load. However, at full load emissions for 10% substitution was found to be nearly 11% higher and for 5% substitution nearly same as neat diesel

Key Words: Diesel engine, methanol, emulsions, brake thermal efficiency, emission etc.

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1. INTRODUCTION

Since the inception of industrial revolution in eighteenth century, the search for portable prime movers to run machines for both industrial and transportation purpose became intense. Steam engines took a lead role in the beginning, but could not pass the test of time as they were bulky, less efficient and required huge quantity of low energy density solid fuels like coal. In the later part of nineteenth century, diesel engine was invented. Since then these engines have become an integral part of modern human civilization and mostly replaced the steam engines which became obsolete. These engines are extensively used worldwide for transportation, decentralized power generation, agricultural applications and industrial sectors because of their high fuel conversion efficiency, ruggedness and relatively easy operation [1,2]. These wide fields of global usage of diesel engines lead to ever increasing demand of petroleum derived fuels. Petroleum fuels are exhaustible sources of energy and hence an over reliability on these fuels is not sustainable in long run. Besides, the rising crude oil prices and increasing pollution due to excessive use of these engines is another grey area. The exhaust emissions of diesel engines, particularly soot, oxides of nitrogen and carbon monoxide are extremely harmful to natural environment and living beings [3].Projections for the 30-year period from 1990 to 2020 indicate that vehicle travel, and consequently fossil-fuel demand, will almost triple worldwide and the resulting emissions will pose a serious problem [4].

Therefore on a nutshell it can be stated that concerns about long-term avail-ability of petroleum diesel, stringent environmental norms and environmental impacts due to extensive use of diesel engines, have mandated the search for a renewable alternative of diesel fuel [5]. In these context alcoholic fuels as a partial or complete substitute of diesel is an area of interest. Reports on the use of alcohol as a motor fuel were published in 1907 and detailed research was conducted in the 1920s and 1930s. Historically, the level of interest in using alcohol as a motor fuel has followed cycles of fuel shortages and/or low feed-grain prices [6].

Among the alcohols, methanol has the lowest combustion energy. However, it also has the lowest stoichiometric or chemically correct air-fuel ratio. Therefore, an engine burning methanol would produce the maximum power. A lot of research has been done on the prospect of methanol as an alternative fuel. Methanol, CH_3OH, is the simplest of alcohol and originally produced by the destructive distillation of wood. However, methanol can be produced from many fossil and renewable sources which include coal, petroleum, natural gas, biomass, wood landfills and even the ocean [7].

Today it is produced in very large quantities from natural gas by the reformation of the gas into carbon monoxide and hydrogen followed by passing these gases over a suitable catalyst under appropriate conditions of pressure and temperature [8].

In energy deficit countries like India, Methanol can provide a sustainable solution against petroleum crisis due to the following reasons.

- ✓ Methanol can be manufactured from a variety of carbon-based feedstock such as natural gas, coal, and biomass (e.g., wood). As India is rich in all these sources, use of methanol would diversify country’s fuel supply and reduce its dependence on imported petroleum.

- ✓ Methanol is much less flammable than gasoline and results in less severe fires when it does ignite. So for fire safety purpose it is better than petroleum.
- ✓ Methanol has a higher laminar flame propagation speed, which may make combustion process finish earlier and thus may improve engine thermal efficiency [9].
- ✓ Methanol is a high-octane fuel that offers excellent acceleration and vehicle power. Though the latent heat of methanol is higher, measures are not necessary for the mixture preparation due to lower fraction, while it may increase engine volumetric efficiency and thus increase engine power [10].
- ✓ With economies of scale, methanol could be produced, distributed, and sold to consumers at prices competitive with petroleum.

Due to high octane rating and similarities with gasoline, methanol has always considered as a good SI engine fuel. But bulk of the transport fuel consumed worldwide is diesel. Ironically countries like India hugely subsidize diesel fuel to regulate inflation which in turn reduces Government's ability to fund welfare schemes. Above all the major contribution to pollution also comes from diesel engines. Therefore, substitution of diesel by potential fuels like methanol (which can be produced from locally available raw materials) by any method has more impact on economy and environment than substitution of gasoline by the same fuel. This paper will carry out further study on the effects of methanol, and its fraction on CI engine performance.

2. METHANOL AS A SUPPLEMENTARY CI ENGINE FUEL.

Methanol, also known as methyl alcohol, wood alcohol, wood naphtha or wood spirits, is a chemical with the formula CH_3OH (often abbreviated MeOH). It is the lowest alcohol with just one carbon atom, four hydrogen atoms and one oxygen atom. Fig.1 shows the atoms of methanol in spatial arrangements.

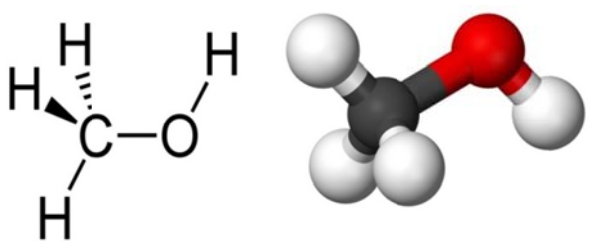

Figure 1: Atoms of methanol in spatial arrangement.

Methanol is an oxygenated fuel with just one carbon atom. It provides a clean combustion with negligible carbon footprints. In order to envisage methanol as a supplementary diesel engine fuel, it is essential that the physico-chemical properties of the fuel is to be determined and then analyzed. Table1 provides a comparative chart of various properties of methanol, ethanol, petrol and diesel [11].

Table 1: (Comparison of fuel properties)

Property	Methanol	Ethanol	Petrol	Diesel
Chemical formula	CH3OH	C2H5OH	C-C mix	C-C mix

Molecular weight	32	46	--	--
Boiling point (^{0}C)	64.5	78	--	--
Density at 20^{0}C (Kg/m^3)	796.6	788.9	740	824.2
Stoic. Air fuel ratio	6.4:1	9:1	14.7:1	--
Cetane number	3	8	10	50-55
Octane number	92	90	80-90	--
Calorific value (MJ/Kg)	23.8	--	43.6	44.5
Flash point (^{0}C)	11	--	43	52

Table1 shows that methanol has a minimal stoichiometric air fuel ratio of 6.4:1 as compared to other fuels. Therefore, in heterogeneous combustion processes like that of diesel engine combustion it may be proved to be very effective as it requires less oxygen to completely burn. However, low cetane number, extremely low calorific value, and lower flash pointare its disadvantages for direct diesel engine application. Table 2 provides a comparative assessment of methanol as a diesel engine fuel [12].

Table2: Comparative study of methanol as a diesel engine fuel

Sl No.	Methanol as CI engine fuel advantages	Methanol as CI engine fuel shortcomings
1	High stoichiometric fuel air ratio.	Longer ignition delay.
2	High oxygen content, high hydrogen to carbon ratio and low sulfur content.	More corrosive.
3	High latent heat of vaporization.	Lower energy content.
4	Reduced soot and smoke.	Lower flash point.
5	Higher cooling, hence less compression work.	Poor combustion characteristics.

As a definitive conclusion from table 2, it may be suggested that methanol can be used as a partial substitute of diesel such that its advantages can be well exploited and shortcomings to be minimized. This is possible by operating diesel engines with dual fuel mode with methanol and diesel. A good range of research has been carried out so far for to develop possible ways to use methanol in diesel engines. A brief review of some important research outcomes is discussed below.

Murat et al. [12] has experimentally investigated the effects of methanol and diesel fuel blends on performance and exhausts emissions ofa four cylinders, four stroke, direct injection, and turbocharged diesel engine.Results indicated that brake specific fuel consumption and nitrogen oxide emissions increased while brake thermal efficiency, carbon monoxide and hydrocarbons decreased relative to single diesel fuel operation with increasing amount of methanol in the fuel mixture.

Murray et al.[13]investigated the performance of methanol-coconut oil blends in diesel engines, using coconut oil biodiesel (CME) as a co-solvent. Six fuels were tested in a diesel engine test unit; diesel, neat CME, neat coconut oil, a coconut oil-CME blend, a blend containing 10% methanol by volume and another containing 30% methanol by volume. It was found that the methanol blends had better engine performance, when compared to neat coconut oil operation. Further, it was found that the methanol blends exhibited similar and even better engine performance than diesel operation, with a BTE of 28.6% for the 30% methanol blend as compared to 22.9% for diesel operation. [22].

Najafi et al.[14]in his study tested the four stroke, four cylinder, direct injection diesel engine using methanol blended diesel at certain mixing ratio of 10:90, 20:80 and 30:70 of methanol to diesel respectively. Experimental results showed that the output power and torque for diesel fuel was lower compared to methanol-diesel blended fuel at any ratio. The best mixing ratio that produced the lowest exhaust temperature was at 10% of Methanol in 90% of Diesel fuel. The exhaust temperature for diesel fuel was higher compared to any mixing of the blended fuel.

Turkcan et al.[15] studied the influence of methanol/diesel and ethanol/diesel fuel blends on the combustion characteristic of an IDI diesel engineat different injection timings by using five different fuel blends (diesel, M5, M10, E5 and E10). The tests were conducted at three different start of injection {25^o, 20^o (original injection timing) and 15^o CA before top dead center (BTDC)} under the same operating condition. The experimental results showed that maximum cylinder gas pressure (P_{max}) and maximum heat release rate $(dQ/d\theta)_{max}$ increased with advanced fuel delivery timing for all test fuels. Although the values of P_{max} and $(dQ/d\theta)_{max}$ of E10 and M10 type fuels were observed at original injection and retarded injection (15^o CA BTDC) timings, those of the diesel fuel were obtained at advanced injection (25^o CA BTDC) timing. From the combustion characteristics of the test fuels, it was observed that ignition delay (ID), total combustion duration (TCD) and maximum pressure rise rate $(dP/d\theta)_{max}$ increased with advanced fuel delivery timing. The ID increased at original and advanced injection timings for ethanol/diesel and methanol/diesel fuel blends when compared to the diesel fuel.

Suresh et al.[16] modified a single cylinder vertical air cooled diesel engine to use methanol dual fuelmode and to study the performance, emission, and combustion characteristics. The primary fuel, methanol with air, compressed, and ignited by asmall pilot spray of diesel. Dual fuel engine showed a reduction inoxides of Nitrogen and smoke in the entire load range. However,it suffers from the problem of poor brake thermal efficiency andhigh hydrocarbon and carbon monoxide emissions, particularlyat lower loads due to poor ignition. In order to improve theperformance at lower loads, a glow plug was introduced insidethe combustion chamber. The brake thermal efficiency improvedby 3% in the glow plug assisted dual fuel mode, especially at lowload, and also reduced the hydrocarbon, carbon monoxide, andsmoke emissions by 69%, 50% & 9% respectively. The presenceof glow plug had no effect on oxides of nitrogen.

Chu Weitao[17]investigated the influence of M0, M5and M15 methanol / diesel fuel mixture on diesel engine performance in a single-engine ZS195. Test results show that with adding of methanol, the driving force of the engine was weaker; fuel economy was improved; diesel smokeand CO emissions are significantly reduced; NOxemissions are more at M5, but were reduced about 8% atM15; HC emissions were increased when the dieselengine parameters remained unchanged.

Jikar et al. [18]carried out a comprehensive research on methanol as an alternative fuel.In this study,the diesel engine was tested using methanol blended with diesel atcertain mixing ratio of 10:90, 20:80 and 30:70 of methanol to dieselrespectively.Experimental results showed that the output power and torque for diesel fuel was lower compared to methanol-diesel blended fuel at anyratio. The best mixing ratio that produced the lowest exhausttemperature was at 10% of Methanol in 90% of Diesel fuel. Theexhaust temperature for diesel fuel was higher compared to anymixing of the blended fuel. The brake specific fuel consumption forthe three mixing ratios was not varying significantly but the lowestwas for 30% Methanol and 70% Diesel.

The specific fuelconsumption for diesel fuel was much lower compared to any mixingratio. It was noticed that brake thermal efficiency was thus improvedin almost all operation conditions with the methanol and diesel blended fuels.

Literature review stated two basic methods accepted by researchers worldwide for methanol application in diesel engines.They include blending methanol with diesel and injecting methanol with charge air. The later is also known as fumigation [19].Fumigation of methanol has been a very effective technique to use high percentage of methanol in diesel engines, but it requires engine modification to accommodate low pressure methanol injector and metering device to inject methanol into air intake system. Therefore, it can not be carried out in unmodified engines. Using methanol as a minor blend in diesel fuel is another method. The most important problem associated with methanol diesel blend is the separation of phases as diesel and methanol are completely immiscible with each other at room temperature. The standard method followed worldwide to prepare a stable diesel methanol mixture is the preparation of micro-emulsion using some surfactants. The standard surfactants are dodecanol, isobutane, bio-diesel, sodium salt of dibutyl ester of sulphosuccinic acid etc. [12,13]. Some ignition improvers like diethyl ether can also be added to compensate for the low cetane number of methanol in the emulsion [12].

As stated above fumigation needs engine modification and a stable methanol diesel blend needs surfactants, ignition improvers and preparation of emulsions which in turn needs sophisticated equipment set up and technical knowledge.Therefore, it is suggested that a third alternative must be tried in which diesel methanol mixture is to be stirred inside the engine tank with a predetermined rpm so that temporary single phase and stability can be established in the blend for engine application. Various proposed stirring methods for the same includes mechanical stirring [20], electromagnetic stirring [21], homogenizing machine [22] and mixer stirring [23].

In the present investigation an exhaustive engine trial was carried out using diesel methanol blend with on board mixer stirring facility. To minimize the poor combustion characteristics of methanol, the composition of methanol in the test fuels were confined within 10% on (v/v%) basis.

3. SYSTEM DEVELOPMENT AND EXPERIMENTAL PROCEDURE.

3.1 Methanol diesel blends development.

During the course of present study, two blends of methanol and diesel were prepared which include 5% methanol blended with 95% diesel (v/v %), called as M5 and 10% methanol blended with 90% diesel (v/v %) which was termed as M10 .The nomenclature of neat diesel was D100. The methanol sample was of standard quality with less than 1% impurities. Fig. 3.1 shows methanol sample.

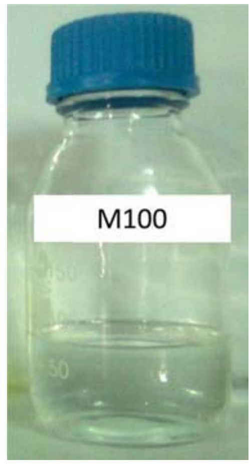

Figure 2: Neat methanol (M100) sample**.**

3.2 Design and development of customized stirrer.

As discussed earlier a mixer stirrer is to be used to prepare a single phase methanol diesel blend for engine application. The stirrer was developed from an electric motor with a 7” shaft. The shaft end was locked with a Teflon agitator. Fig.3 shows the stirrer. A motor speed regulator was added to the circuit for the purpose of speed regulation.

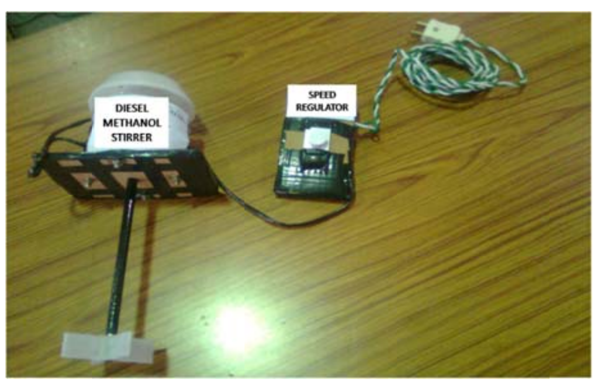

Figure 3: Stirrer with motor and speed regulator.

Once the stirrer was developed it became important to make the speed fixed such that while stirring it would not make either excessive turbulence or extremely slow mixing causing phase separation. For the purpose the stirrer was inserted in a sample test fuel and was allowed to rotate so that the rotation should not lead to excessive turbulence.

Motor specification	Single phase, 50 Hz,230V,45Watt230V,45Watt 1400 rpm Serial No. RDU-0004 Make- Crompton Greaves
Speed regulator specification	Quality standards- IS:11037-1984 Make- CONA

The respective rpm was measured by an infrared rpm sensor. All three samples were used one after one to fix the optimum rpm. It was found that 150 rpm was suitable for all two blends. The stirrer developed was to be mounted on the fuel tank in the diesel engine test rig. It was to be connected to the power source and allowed to rotate at the predetermined speed of 150 rpm. Table 4 shows the stirrer specification.

Table 4: Stirrer specifications.

It may be suggested here that the rpm of the stirrer was chosen on the basis of minimum turbulence concept and no work have been carried out to determine the effect of stirrer rpm on engine performance. This may be subjected to further investigation.

3.3 Development of engine test rig.

The experimental test setup (Fig.4) consisted of the CI engine, the fuel supply and measurement system, load variation and measurement system, emission measurement system, digital data acquisition system and computer.

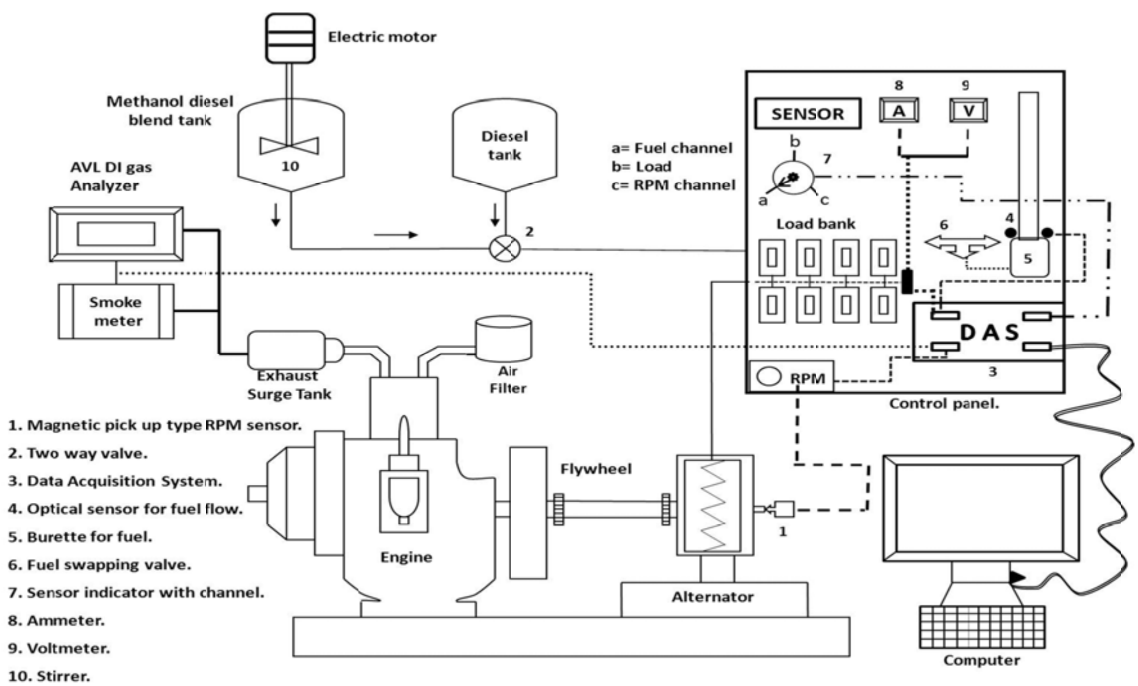

Figure 4: Lay out of experimental test rig**.**

Fuel consumption rate was measured in terms of time in minutes per centimeter cube fuel consumption. Various loads applied to the engine were 0%, 20%, 40%, 60%, 80% and 100% load throughthe electrical load bank on control panelcomprising of ten tungsten electrode bulbs of 500 W each. Various engine emission parameters like HC, NOx and CO were recorded using AVL Di gas analyzer and the smoke opacity was determined using AVL 437 smoke meter. The following parameters were fed into the computer: liquid fuel flow rate data, engine speed etc. The acquisition card could collect data at the rate of 250 kB/s. All instruments and the methods selected were of standard quality and the error was within the permissible range. The details of the test rig instrumentation are provided in table 5.

Table 5: Test set up instrumentation details

Sl No.	Instrument name	Range	Accuracy	Measurement technique	Percentage uncertainty
1	Alternator	0-1500 VA	±0.25 VA	Resistive load	±0.2
2	Fuel flow sensor	0-50 cc	±0.1 cc	Volumetric type.	±0.1
3	Speed measuring unit	0–10,000 rpm	±10 rpm	Magnetic pick up type.	±0.1
4	Pressure sensor	0-200 bar	$\leq 0.1^0$	Transmission light principle	±0.25
	Exhaust gas analyzer				
5	Carbon Monoxide	0-9.99% vol.	±1%	NDIR principle (non dispersive infra-red sensor).	±0.20
6	Hydrocarbons	0-10,000 ppm	±2 ppm	Flame ionization detector-FID.	±0.20
7	Oxides of Nitrogen	0-10,000 ppm	±10 ppm	Chemiluminescence principle.	±0.20
8	Opacity	0 - 100% capacity in %0 - ∞ absorption m-1	± 1% full scale reading	Selenium photocell Detector	±0.1

3.3 Experimental procedure.

The engine trial was conducted as specified in IS: 10,000. The engine was started using neat diesel and allowed to run for at least 30 minutes before taking observations. After engine conditions stabilized and reached to steady state, the base line data were taken. Load was varied using the alternator load bank and the same was recorded. Gaseous emissions, fuel consumption were also recorded from the respective sensor. In case of different methanol and diesel blends, the engine was started on diesel and when engine became sufficiently heated; the supply of diesel was substituted by different methanol and diesel blends (which are consistently stirred) for which a two way valve was used. All the data at different loads and blends were recorded only when engine reached to steady state.

4. RESULTS AND DISCUSSIONS.

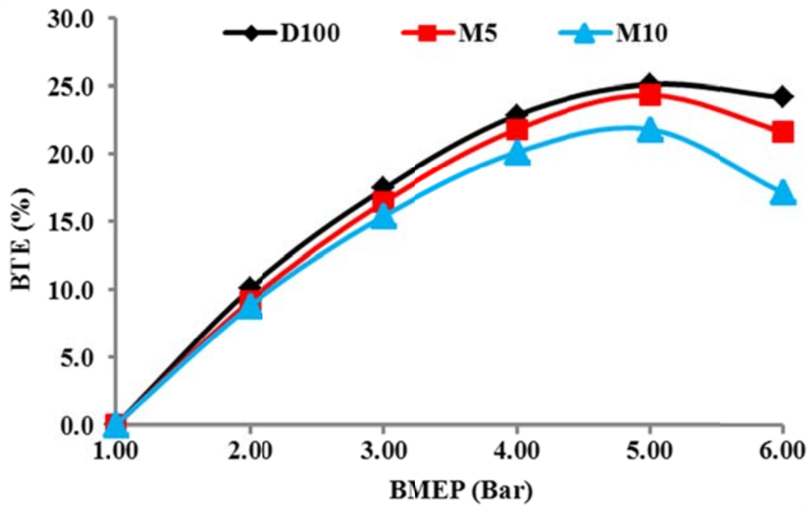

Figure 5: Variation of BTE.

BTE indicates the ability of the combustion system to accept the experimental fuel and provides comparable means of assessing how efficiently the energy in the fuel was converted to mechanical output [23]. Variation of BTE with respect to engine BMEP for various test fuels is shown in Fig.5. Results indicated that M5 showed lower BTE at all loads as compared to neat diesel operation. More specifically BTE exhibited by M5 was 3.2% and 10 % lower at 80% and 100% loads as compared to the same for diesel baseline. This reduction in thermal efficiency for M5 may be attributed by the fact that despite of being an oxygenated fuel with very low stoichiometric air fuel ratio requirement to burn completely, it has very low calorific value and therefore in an unmodified diesel engine thermal efficiency got reduced. M10 shows further decline in BTE as compared to M5. This reduction in BTE is attributed by the low calorific value of the fuel and low cetane rating with higher ignition delay which made the combustion erratic at higher loads reducing its thermal efficiency. Besides, the inferior cetane rating makes the combustion erratic and engine operation noisy beyond 60% load for M10. Engine virtually stopped at 120% load.

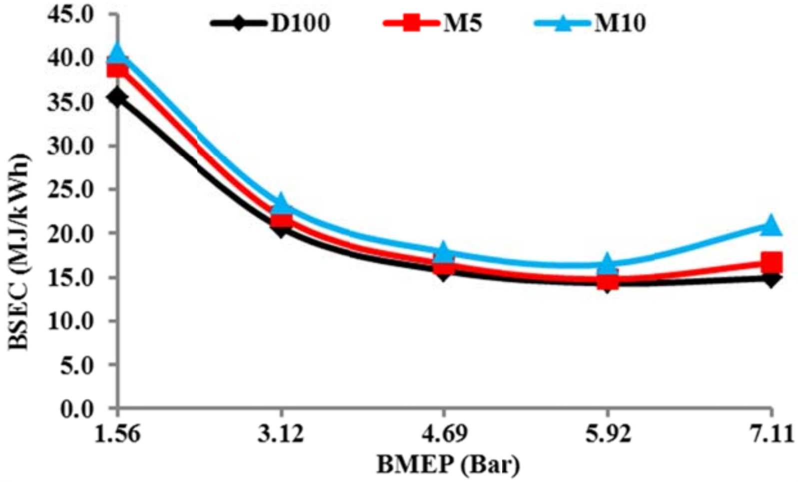

Figure 6: Variation of BSEC.

BSEC and BTE are complementary results; however, BSEC provides a quantitative picture about the amount of thermal energy consumed to generate one unit of work, hence important for performance analysis. Fig.6 shows the variation of BSEC with engine BMEP for various test fuels. The full load BSEC exhibited by M5 was 16.6 MJ/kWh as compared to 14.9 MJ/kWh as exhibited by diesel baseline. M10 showed further reduction in BSEC and full load BSEC reported was 21.0 MJ/kWh.

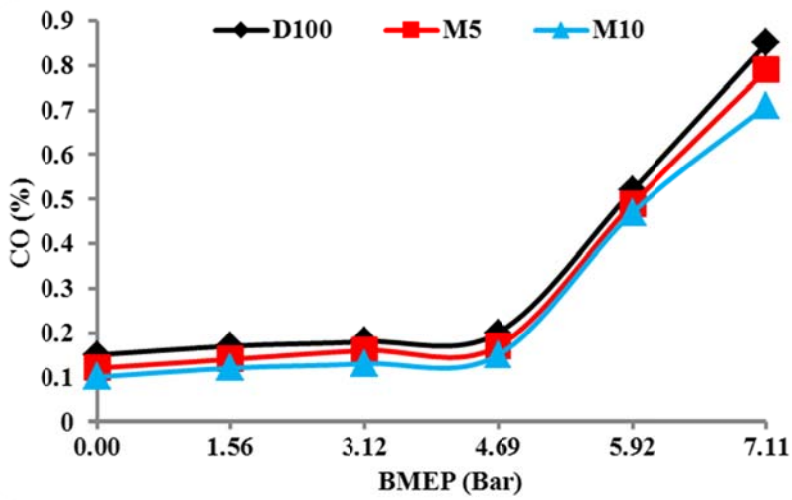

Figure 7: Variation of CO emissions.

The formation of CO takes place when the oxygen present during the combustion is insufficient to form CO2 [24]. Variation of CO emission with respect to engine BMEP for various test fuels is shown in Fig.7. It was found from the experiment that CO emission reduced with increase in methanol percentage in the test fuel. Full load CO emission exhibited by M5 was found to be 7% less and that of M10 was 16% less than full load neat diesel operation. This may be due to the fact that methanol is itself an oxygenated fuel and needs less amount of air to burn completely. Again the stoichiometric air fuel ratio of methanol is 6.5:1 making it a clean burning fuel.

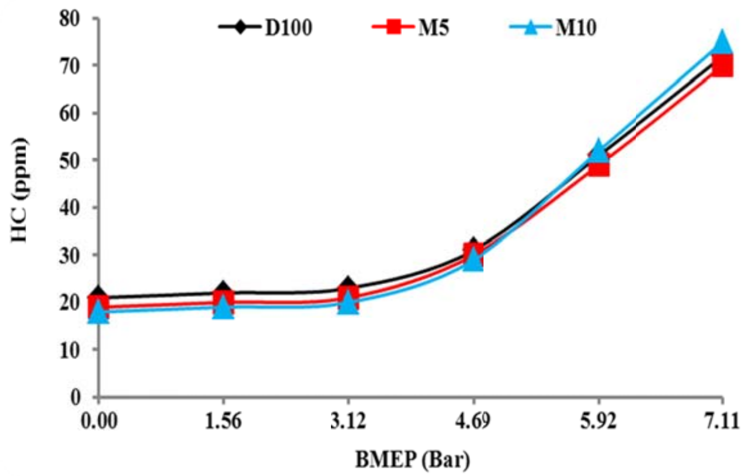

Figure 8: Variation of HC emissions.

Most of the unburnt hydrocarbons are caused by unburnt fuel air mixture; where as the other sources are the engine lubricant and incomplete combustion. Variation of HC emission with respect to engine BMEP for various tests fuels is shown in Fig. 8. When methanol is added diesel it provides more oxygen for the combustion process. Again methanol needs less air for complete burning; hence excess air is made available for the combustion process. Besides methanol molecules are polar and can not be absorbed easily by non-polar lubricating oil, hence methanol can lower the possibility of production of organic compounds in the gaseous state by lubricating oils. The same was evident from the experiment which indicated that full load HC emission was reduced by 7% for M5. However, a marginal increase in emission of HC was observed for M10 due to erratic combustion at full load impinging proper combustion.

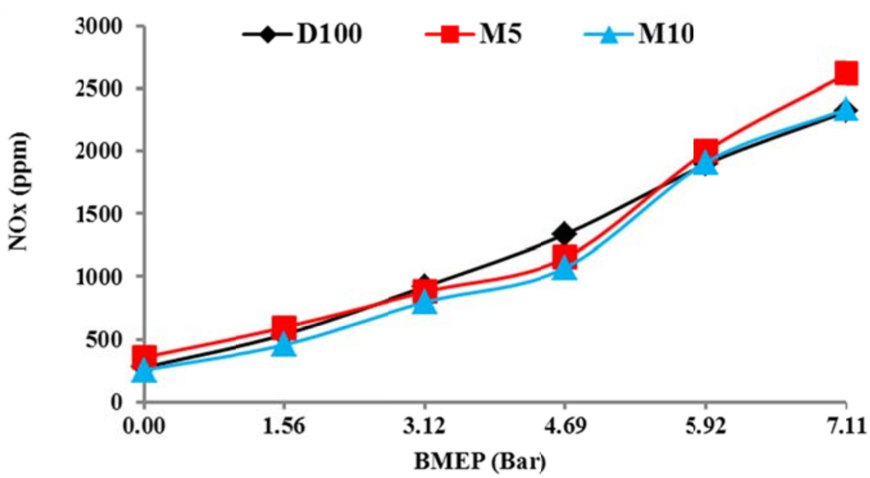

Figure 9: Variation of NOx emissions**.**

The variation of emissions of NOx with respect to engine BMEP is shown in Fig.9. When methanol is added to the diesel, it provides more oxygen for the combustion process. This leads to higher in-cylinder pressure and temperature at lower blends. This can be seen from the results. Results showed that full load NOx emission exhibited by M5 was 13% higher than diesel baseline. However, full NOx emission for M10 was very close to diesel baseline confirming the previous results of poor higher load BTE.

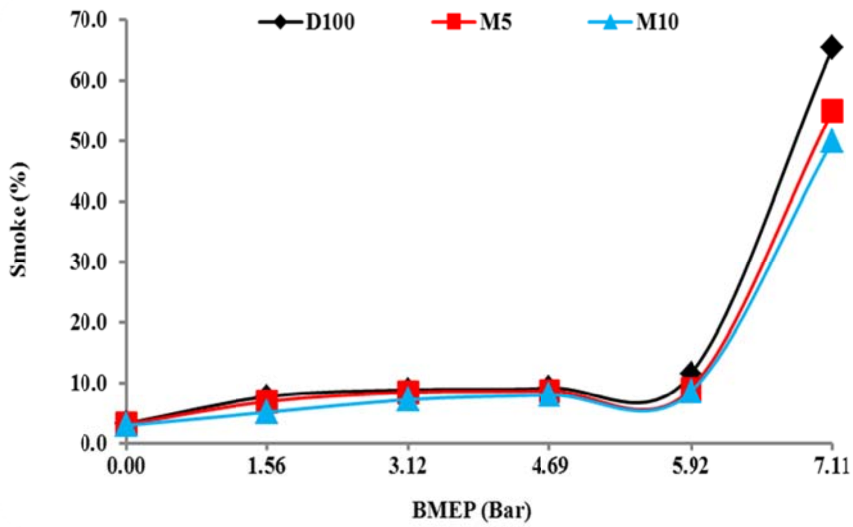

Figure 10: Variation of exhaust smoke**.**

Fig.10 shows the variation of engine exhaust smoke with respect to BMEP for various test fuels. It can be clearly found that full load smoke exhibited by M5 and M10 were significantly lower than diesel baseline. Very less stoichiometric air fuel requirements, better atomization and improved combustion have led to reduced smoke with increasing percentage of methanol in the test fuel.

5. CONCLUSIONS.

In the present study, the effect of using methanol and diesel blends on the performance and emission characteristics of a direct injection diesel engine has been experimentally investigated. A temporary single phase of methanol diesel mixture was established with the help of an onboard stirrer mounted on fuel tank. Summary of the main observations from the engine trail are given below

1. Full load BTE exhibited by M5 was 10% lower than diesel baseline and that of M10 showed a whopping reduction of 28% in full load BTE as compared neat diesel operation.
2. The full load BSEC exhibited by M5 was 16.6 MJ/kWh and that of M10 was 21.0 MJ/kWh compared to diesel baseline.
3. Emission of CO was found to reduce at all loads with increase in methanol composition in the test fuel.
4. M5 showed lower HC emissions at all loads as compared to neat diesel operation. M10 showed a further reduction in HC emission as compared to M5 at part loads, but produced nearly same HC emission as that of D100 at full loads.
5. M5 and M10 produced less NOx emissions at part loads than diesel baseline, however, at full loads M5 showed more NOx emission and M10 exhibited comparable NOx emission as that of diesel baseline.

6. Both the blends of methanol and diesel exhibited a visible reduction in smoke opacity percentage at all loads.

As an outcome of the exhaustive engine trials it can be concluded that 5% direct blending of methanol in diesel with an onboard stirrer exhibited impressive engine emission properties at the penalty of marginal reduction in brake thermal efficiency and increasingly noisy engine operation.

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ABBREVIATIONS

BSEC: brake specific energy consumption

BTE: brake thermal efficiency

M5: blend containing 5% methanol and 95% diesel

M10: blend containing 10% methanol and 90% diesel

D100: neat diesel

M100: neat methanol

CO_2: carbon di-oxide

CO: carbon monoxide

HC: hydro-carbon

UHC: unburned hydro-carbon

PM: particulate matter

NO_x: nitrogen oxides

CI: compression ignition

%: percentage

RPM: revolutions per minute

BMEP: brake means effective pressure

H_2O: water

CA: Crank angles.

BTDC: before top dead center

mm: millimetre