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Performance and Emission characteristics of Medium Capacity Diesel Engine fuelled with Isopropyl alcohol-Diesel Blends

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ABSTRACT

The increasing industrialization and motorization of the world has led to a sudden rise for the demand of petroleum products. Researchers all around the world after examining the performance related problems of diesel fuel such as poor combustion, injection nozzle plugging, engine deposits, pump fouling etc. have started exploring the various alternate fuels to substitute the diesel fuels. At present, renewable resources prove to be a sustainable solution to the worldwide energy problem and the potential of alcohols for use in internal combustion engines is being explored. In the present investigation 10%, 20%, 30%, 40 % (v/v) of diesel was substituted by the isopropyl alcohol. The various blends named as IPA10D90 (10% isopropyl alcohol with 90% Diesel), IPA20D80, IPA30D70 and IPA40D60 were found to be homogenous and stable. Blends were tested in a single cylinder unmodified diesel engine. The NO_X emissions were found to decrease significantly. At no load, the NO_X emissions from various blends were similar to diesel fuel. However, at peak load, 5.8% reduction in NO_X emissions was observed with 40% blend and 13.4% reduction was observed with 10% blend. The break thermal efficiency increased slightly for 30% and 40% blend. At lower loads, an increase in BSFC and BSEC was observed. However, at peak loads, variation in BSFC and BSEC was insignificant. The UBHC emissions were higher. At peak load, CO emission increased. 40 % blend showed lower smoke intensity at peak load.

Keywords: Diesel Engine, Blends, Isopropyl Alcohol, Performances and Emissions.

I INTRODUCTION

The current global energy sector being driven by demand, supply, and effects on the environment are set to undergo significant changes while facing an era of revolutionary transitions and considerable turbulence. Developing nations such as India is entering its most energy-intensive phase of economic growth as they industrialise, build infrastructure, and increase their use of transportation. Demand pressures will stimulate alternative supply and more efficiency in energy use but these alone may not be enough to offset growing demand tensions completely. The Internal combustion engines have revolutionized the world in last hundred years but also contributed significantly towards environmental degradation. Post Kyoto Protocol; there have been considerable efforts to reduce GHG emissions and more emphasis is now given on using clean source of energy. Though, majority of fuels used in IC engines are still petroleum derived fuels, interest in alternative fuels gained momentum ever since first oil embargo took place followed by stringent emission norms [1-3].

India is among the fastest growing economy of world and use energy extensively to sustain its growth. Together, coal and oil represent about two-thirds of total energy use. Natural gas accounts for a seven percent share, which is expected to grow with the discovery of new gas deposits. Combustible renewable and waste constitute about one fourth of Indian energy use. This share includes traditional biomass sources such as firewood and cow dung, which are used by more than 800 million Indian households for cooking [4]. India does not have huge reserves of crude petroleum and imported crude petroleum worth 533,907 crores INR in 2012-13 [5]. The likely demand of crude petroleum shall be around 115 million barrels per day in 2040 [6]. Global energy-related carbon dioxide emissions may rise from 31.1 billion metric tons in 2010 to 45.4 billion metric tons in 2040 with much of the increase in developing nations of the world, and India is expected to overtake U.S. as major CO_2 emitter [7].

Diesel Engines due to its higher efficiency and ruggedness play a very significant role in Indian economy as these are used in agriculture, transport and industrial sectors. However, diesel engines also emit harmful emissions and pollute environment [8]. From the point of view of protecting the global environment and the concern for long-term supplies of conventional diesel fuel, it becomes necessary to develop alternative fuels that give engine performance at par with diesel [9].

The search for alternative fuels for leasing a new life to IC engines has been a serious domain of scientific and intellectual activity worldwide. In this context many promising alternatives such as biofuels have been evaluated [10]. Amongst these fuels, trans-esterified vegetable oil, known as biodiesel, are practically implemented in many countries as a partial substitute of mineral diesel without any changes in the engine hardware [11-15]. Alcohol is one of the bio-fuel which has gained the importance as a fuel for IC engines since their invention. 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. The properties of methyl, ethyl, propyl and butyl alcohol are compared with octane (high quality gasoline) and hexadecane (high quality diesel fuel) and it was found these alcohols can be used for blending in fuel in internal combustion engine showing promising results. Octane and hexadecane (petroleum fuels) have higher boiling points, lower latent heats and are insoluble in water. The alcohols become more like petroleum fuels as their chemical weights increase [18].

The alcohols have received importance as they can be used as either blends with the conventional fuels in the existing engines or as a reactant in biodiesel production [16]. Due to their higher octane number and high oxygen content, use of alcohol in SI engine shows promising results as compared to gasoline [17]. In context to Compression ignition engines, some difficulties were faced by the researchers with the use of alcohols in compression ignition (CI) engines owing to mainly their low cetane number, high latent heat of vaporization and

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long ignition delay. However, the use of alcohols in diesel engines provides significant improvement in exhaust emissions [20].

II PROPERTIES OF FUELS

The properties of isopropyl alcohol [19] and diesel fuel are shown in Table1. Isopropyl alcohol can be produced from three different pathways: indirect hydration of propylene, direct hydration of propylene, and catalytic hydrogenation of acetone.

TABLE1: Properties of Isopropyl alcohol and diesel fuel

Properties	ASTM Method	Diesel	Isopropyl Alcohol
***Density (Kg/m3,at15ºC)**	D-4052	823	**793**
Boiling Point Temperature (ºC)	D-5399	215-376 [39]	**82.5**
***Flash Point (ºC)**	D-93	53	**12**
Cetane Number	D-613	49 [40]	**13**
***Viscosity (cSt at 40 ºC)**	D-445	3.71	**1.84**
***Calorific Value (KJ/kg)**	D-4809	4584	**3011**
***Specific gravity**	**D-4052**	**85**	**0.79**

An exhaustive review of literature on the potential use of alcohols in internal combustion engines applications has been made and some of these works have been summarized below.

Karabektas et. al. conducted experiment on a single cylinder, direct injection (DI) diesel engine and tested blends of isobutanol in diesel fuel. They replaced upto 20% (v/v) of diesel fuel with isobutanol and found that isobutanol can be used as blend with diesel fuel in CI engine without any modification and found 10% isobutanol blend to be an optimum blend in terms of performance and exhaust emissions [20].

Krishanan et. al. conducted experiments with ASTM-CFR engine, in duel fuel injection by carburetion method to determine optimum proportions between ethanol and diesel fuels for the higher output and higher efficiency and also used some additives to increase the ignition quality. [21]

Fernández et. al. conducted experiment on using ethanol butanol and pentanol diesel blends in three-cylinder, four- stroke, water-cooled, 18.5:1 compression ratio, direct injection diesel engine and found that 30% butanol/diesel fuel blend and 25% pentanol/diesel fuel blend may replace the use of 100% diesel fuel on diesel engines without any modification and without significant loss of performance. [22].

Sathiyagnanam et. al. conducted experiment on DI Kirloskar TV1 diesel engine to study the performance and emission of hexanol, ethanol and diesel blends on diesel engine. They found that hexanol can be used to increase the stability of ethanol in diesel fuel and 20 % ethanol blend shows higher brake thermal efficiency than the other blends and diesel and the brake thermal efficiency improves by 1.89%.[23].

Jilin Lei et. al. conducted experiment on 3.298L, direct injection, turbocharged diesel engine and studied performance and emission characteristics of engine using diesel ethanol blends by varying the pressure. They found that HC and CO emission increase with decrease in speed and load while NOX and smoke decreased at 81 kPa pressure and increasing pressure have a slight effect on engine performance. [24].

Deep et. al. studied the Performance and Emission Characteristics of 1-Octanol/Diesel Fuel Blends in a Water Cooled Compression Ignition Engine. They found that the Brake thermal efficiency was decreasing with increasing in alcohol concentration in diesel fuel and he also found that the brake specific fuel consumption is inversely proportional to the brake thermal efficiency. The emissions (NO_X, smoke opacity and CO) were decreased by significant amount while HC were increased substantially by about 22%.[25].

Dattatray et. al. conducted experiments on multicylinder direct injection diesel engine using diesel-ethanol-biodiesel blends of high ethanol content. They studied the feasibility of using higher percentage of ethanol in ethanol-diesel blends with biodiesel as co solvent and found that brake specific fuel consumption increased considerably, thermal efficiency improved slightly, smoke opacity reduced remarkably at high loads. NOX variation depends on operating conditions while CO emissions drastically increased at low loads. Blend which replaced 50% diesel gave satisfactory performance. [26].

Liu et. al. prepared emulsion of methanol and diesel using a rotating packed bed. The method was suitable to overcome the homogeneity concerns while making diesel methanol blend. The viscosity of the emulsified fuel appeared similar to Newton fluids. A reduction in surface tension was noticed with increase in surfactant concentration in the emulsion where as the stability of the fuel was found to be high with higher rate of agitation, additive amount and higher liquid flow rate [27].

The ethanol biodiesel blend can reduce the particulate matter by 30 % with slight increase in NO_X emissions [28, 29]. The fuel composition and the air/fuel equivalence ratio also have a significant impact on the exhaust emissions of organic acids from the spark ignition engine. Exhaust formic acid is slightly enhanced from aromatics and oxygenated compounds; acetic acid is slightly enhanced from the oxygenated fuel components; propionic acid comes from fuel aromatic compounds. Air/fuel equivalence ratio increases the exhaust concentration of formic, acetic acid (for the fuels without oxygenated compounds), and acrylic acid and decreases the concentration of isovaleric acid. The emissions of all HC generally decrease with the addition of oxygenated compounds, except sometimes in the case of methane, ethane and cyclohexane. Under rich conditions, the relative increase of exhaust methane and benzene is more important than the other saturated HC. Some HC are correlated with the physical properties of the fuel and other exhaust pollutants [30-33]

Many researchers have investigated the applications of alcohols in diesel fuel engines [34-44]. The literature survey as enumerated above shows that much work has been done on methanol, ethanol, butanol and higher alcohols but the comprehensive investigation on the potential of isopropyl alcohol for use in direct injection diesel engine is not being done and it is in this context this study was undertaken.

TABLE2: Technical specifications of the diesel engine

Make	**Kirloskar**
Rated Output	5.0 kVA@1500 rpm
Model	CAF 8
Rated Brake Power (bp/kW)	8 / 5.9
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 x 110
Compression Ratio	17.5:1
Cooling System	Air Cooled (Radial Cooled)
Lubrication System	Forced Feed

Cubic Capacity	0.78 Lit
Inlet Valve Open (Degree)	4.5 BTDC
Inlet Valve Closed (Degree)	35.5 ABDC
Exhaust Valve Open (Degree)	35.5 BBDC
Exhaust Valve Closed (Degree)	4.5 ATDC
Fuel Injection Timing (Degree)	26 BTDC

Four Blends were prepared (by volume) by directly mixing iso-propyl alcohol in diesel fuel. The blends were kept undisturbed for a month and it was found that the blends formed were homogenous and stable. Visual inspection and centrifuge test were carried for evaluation of homogeneity and stability. The properties of various blends formed used diesel engine is as shown in Table 4. The various blends were tested on a single cylinder diesel engine. All the tests were conducted three times and the average value of the experimental data was taken as reference. All the tests were performed under steady state conditions. Tests were first conducted with diesel fuel to obtain the base data of the engine. All the tests were performed at 0% load, 20 % load, 40% load, 60 % load, 80 % load and full load. This is in accordance to IS:10000 which is an Indian Standard for testing of engines The engine set up used in the tests is shown in Fig, 1. Two tanks were used for two different fuels. In one of the tanks, neat diesel was taken and in another tank blended fuel was taken and the feeding of the fuel from the respective tanks was controlled with the help of valves. The fuel consumption rate of the engine was determined with a burette arrangement and time taken for consumption of 20 c.c. of fuel blend was noted with the help of a stop watch. The HC, CO, NOX and CO2 emissions were measured with the help of AVL DI Gas analyzer. The smoke opacity was measured with the help of AVL Smoke meter. The specification of the diesel engine is shown in Table2. The specifications of AVL DI Gas analyzer and AVL Smoke meter is shown in Table 3.

TABLE3: Specifications of AVL Di Gas analyzer and smoke meter

Emission sensor	Measurement range	Resolution
CO	0-10% Vol.	0.01% Vol.
CO_2	0-20% Vol.	0.1% Vol.
NO_X	0-5.000 ppm Vol.	1 ppm
HC	0-20.000 ppm Vol.	1 ppm
AVL Smoke meter	0-100%	+1%

TABLE4: Properties of Various Blends

Blend	Density (Kg/m^3)	Viscosity (mm^2/sec)	Calorific Value (MJ/kg)
D100	823.62	3.71	45.842
IPA100	793	2.74	30.11
IPA10D90	819.88	2.66	45.431
IPA20D80	816.26	2.57	44.104
IPA30D70	815.72	2.49	43.498
IPA40D60	812.56	2.41	42.986

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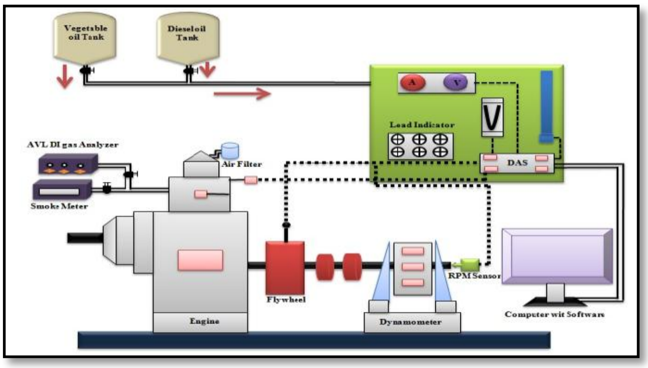

Figure 1.Schematic diagram of experimental test rig setup

III RESULTS AND DISCUSSIONS

Brake Specific Fuel Consumption:

The variation of Brake Specific Fuel Consumption (BSFC) for different fuel samples is shown in Fig2. The BSFC for various fuel blends has increased as compared with diesel fuel due to decrease in the net heating value of the fuel blends. There is an increasing trend in brake specific fuel consumption with increase in the percentage of isopropyl alcohol in the blend. Amongst the different test fuels, the lowest BSFC was observed for diesel fuel because of lower fuel consumption rate and highest BSFC was obtained in case of 40 % blend of isopropyl alcohol (v/v). The increase in BSFC was 6.4 % for 10% isopropyl alcohol blend ranging to 11.4 % increase for 40% isopropyl alcohol blend. The results are consistent with the investigations made by Karebetkas et. al [20], Karthikeyan et. al [25] and Zerves et. al [30,31].

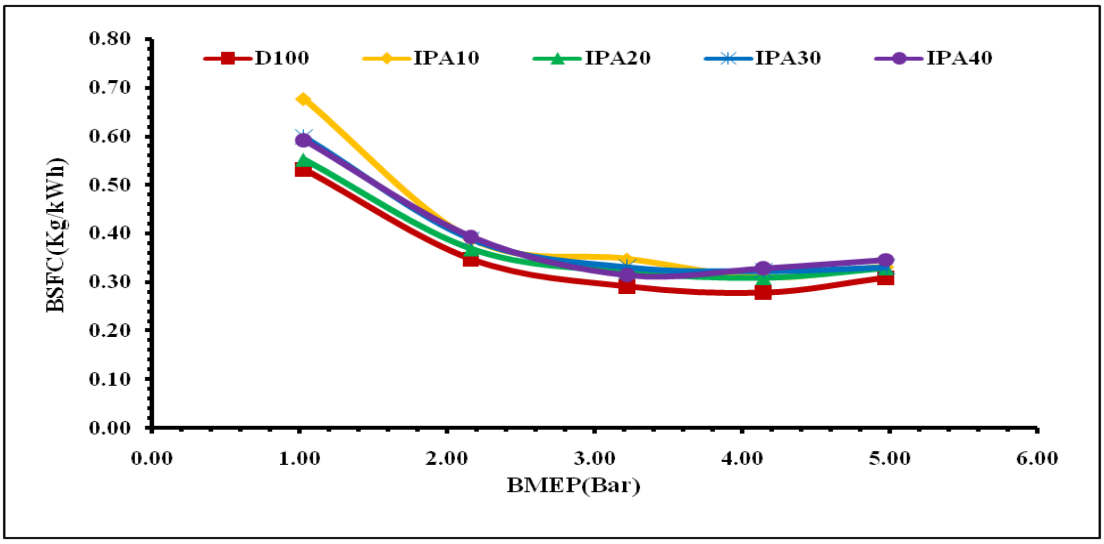

Figure2. Variation of BSFC with respect to BMEP for various blends

Brake Thermal Efficiency:

Fig3 shows the variation in Brake Thermal Efficiency (BTE) of the engine for different test fuels. There is slight decrease in BTE with use of IPA10 blend and IPA20 blend. However, for IPA30 blend and IPA40 blend slight improvement in BTE is observed because oxygen enrichment contained by IPA30 and IPA40 improves fuel evaporation during diffusion combustion the decrease in BTE. With 10% blend and 20% blend was attributed by lower calorific value of isopropyl alcohol as compared to mineral diesel resulting in higher fuel consumption to generate same amount of power. The results are in close consistency with the earlier investigations. [20, 22, 25, 30 and 31].

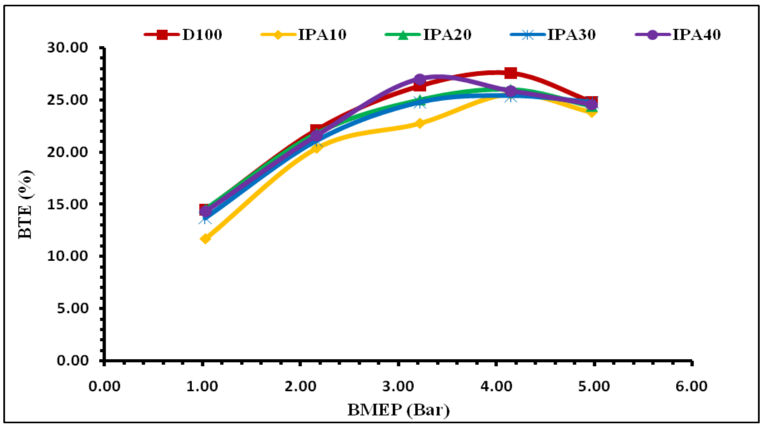

Figure3. Variation of BTE with respect to BMEP for various blends

NOx Emissions:

Fig4 shows the variation in NOx emission of the diesel engine in respect of different test fuels. It can be observed that the NO_X emission has decreased with increase of isopropyl alcohol percentage in the blend. This may be attributed towards low cetane rating of isopropyl alcohol leading to reduced combustion temperature. It was found that emission of NOx at full load was reduced by 5.8% for IPA10 blend and 13.4% for IPA40 blend. These results are in agreement with the results of Karabektas et. al [20], Javier et. al [22] and Zerves et. al [30,31].

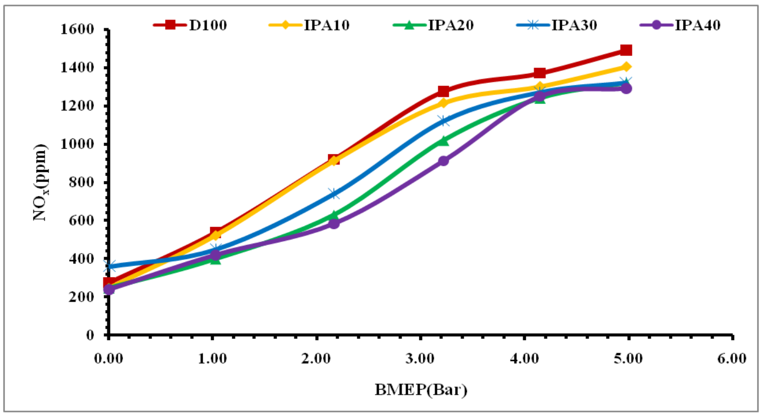

Figure4. Variation of NOX with respect to BMEP for various blends

CO Emissions:

The variation in CO emissions of the engine is shown in Fig5. It is clear that CO emissions are higher for IPA blends as compared to diesel fuel. It was also found that the variation of CO emissions was insignificant for lower loads. However, at peak load the CO emissions increased drastically due to more quantity of fuel injected and lesser availability of oxygen for combustion. The results are in confirmation to the earlier results [22, 25, 30, and 31].

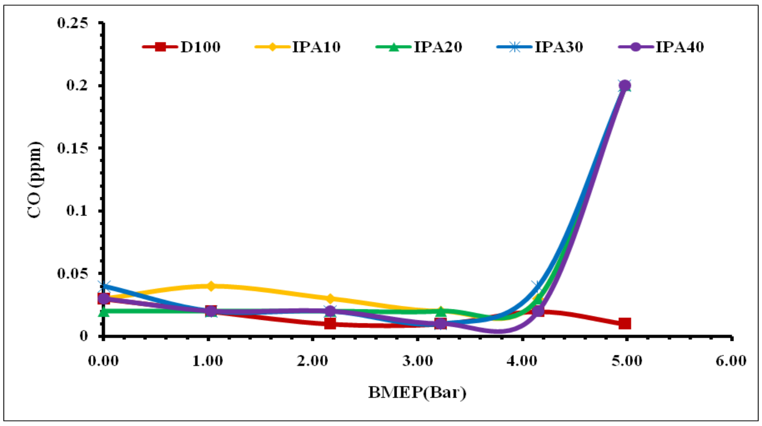

Figure5. Variation of CO with respect to BMEP for various blends

HC Emissions:

Variation in HC emissions with various blends as compared to diesel baseline is shown in fig6. An increase in full load HC emission was observed with increase in IPA concentration in the test fuel. HC emissions are formed as an outcome of incomplete combustion that may occur due to lack of sufficient availability of air, insufficient combustion duration, poor cetane rating of the fuel etc. In the present case, it seems that poor cetane rating of IPA played a detrimental role for HC emissions. Insufficient combustion duration may be a plausible reason subjected to further investigation of combustion phenomena which is out of the scope of the present work. Maximum HC emissions were found with the use of 40 % isopropyl alcohol blend. A 10 % increase in HC emissions was observed for IPA10, IPA20 and IPA30 blends. However for IPA40 blend the HC emissions increased by 15%. Results confirm to the investigations made earlier [22, 25, 30, and 31].

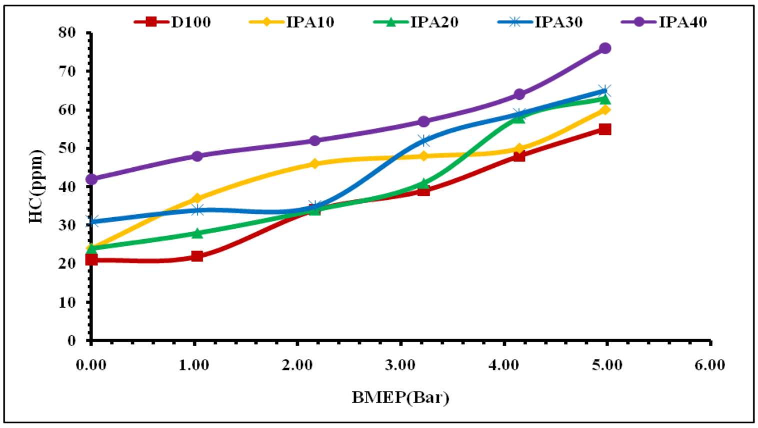

Figure6. Variation of HC with respect to BMEP for various blends

Smoke Opacity:

Fig7 shows the variation of smoke opacity for various test fuels. For all loads smoke opacity of IPA blends are found to be higher than that of diesel. At lower load condition, there is no significant difference in smoke opacity for all IPA blends whereas at higher load IPA30 shows significant increase in smoke opacity. Sathiyagnanam et. al. [23] showed that oxygen enrichment contained by IPA40 improves fuel evaporation during diffusion combustion which subsequently reduces the smoke density.

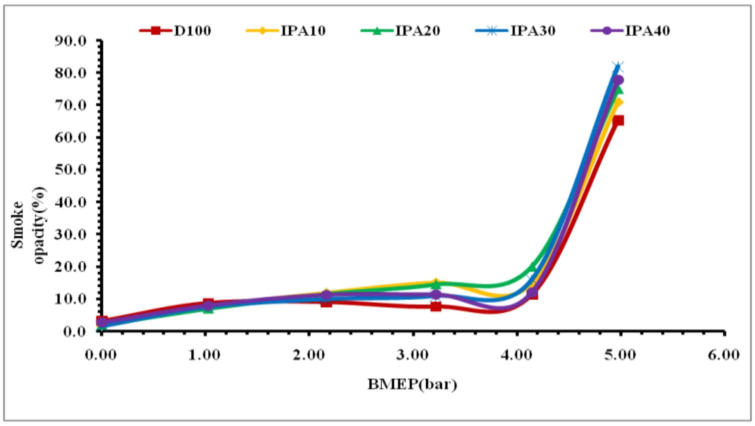

Figure7. Variation of Smoke Opacity with respect to BMEP for various blends

IV CONCLUSIONS

The variation in performance and emission characteristics of the diesel engine when run on various isopropyl alcohol blends with diesel fuel were investigated as compared to neat diesel fuel. During the investigation four blends: (IPA10D90), (IPA20D80), (IPA30D70) and (IPA40D60) were prepared and tested on a single cylinder unmodified direct injection diesel engine and following conclusions were drawn.

- The various blends formed were homogenous and stable leading to the fact that isopropyl alcohol is readily miscible with diesel fuel without phase separation.
- The brake specific fuel consumption of the engine has increased owing to the lower energy content of the various fuel blends. The increase in percentage is in accordance with the blending percentage of isopropyl alcohol.
- The brake thermal efficiency of the diesel engine slightly decreased for 10% and 20% blend. However it increased slightly with 30% and 40% blends due to promoted combustion owing to higher content of oxygen in the fuel.
- The NO_X emissions decreased drastically with all fuel blends and the decrease was in accordance with the blending percentage.
- The HC and CO emissions however increased due to lower cetane number of the blend and incomplete combustion of the diesel fuel. The maximum HC and CO emissions were observed with IPA40D60 blend.
- The IPA40 blend concentration shows better smoke reduction than the other blends and diesel at 80% load. The smoke opacity is nearly similar to diesel fuel at peak loads.

- As an outcome of the exhaustive engine trials, it may be recommended that 40% (v/v) of diesel can be replaced with IPA for direct application in unmodified diesel engines with marginal drop in performance and substantial improvements in the emissions of CO and NOx.

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Definitions/Abbreviations

ABDC	After Bottom Dead Centre	**MJ/Kg**	Mega joules per kilogram
ATDC	After Top Dead Centre	**mm**	Millimeters
BBDC	Before Bottom Dead Centre	**mm^2/sec**	Millimeter square per second
BTDC	Before Top Dead Centre	**NO_X**	Nitrous oxide

bhp	Brake Horse Power
BSEC	Brake Specific Fuel Consumption
BMEP	Brake Mean Effective Pressure
cc	cubic centimetres
CO	Carbon monoxide
°C	Degree centigrade
DI	Direct Injection
GHG	Green House Gases
IPA	Isopropyl alcohol
IPA10D90	10% isopropyl alcohol and 90 % diesel
IPA20D80	20% isopropyl alcohol and 80 % diesel
IPA30D70	30% isopropyl alcohol and 70 % diesel
IPA40D60	40% isopropyl alcohol and 680 % diesel
KJ/g	Kilo joule per gram
Kg/ m^3	Kilo gram per cubic meter
kPa	Kilo pascal
LHR	Low heat rejection
IC	Internal Combustion
ppm	Parts per million
rpm	Revolutions per minute
UBHC	Unburned Hydrocarbon
(v/v)	(Volume/Volume)
CO_2	Carbon dioxide
cSt	centi Stoke
D100	100% diesel blend
°F	Degree Farenhiet
HC	Hydrocarbon