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Studies on Emission Characteristics of Diesel Engine Run Using Diesel Di Methoxy Ethane Blend Fuel

K.Balasubramaniyan [1], P.Balashanmugam [2], A.Raghupathy [3],G.Balasubramanian[4]

Abstract— **The diesel engines are widely used in variety of vehicles due to its fuel efficiency and low cost compared to petrol engines. Even though they produce low carbon monoxide and hydrocarbon emission than gasoline engine, the major problem with the diesel engines is the presence of particulate matter that is present in the exhaust emission. During last five decades, these emissions have been regulated through legislation. This research aims to reduce the exhaust emission from the diesel engines using fuel additives. The additives used in this work are 1-2 Di methoxy ethane. It was mixed with diesel in the concentration of 1%, 3%, &5% by volume and this was used to conduct experiments in Kirloskar TV-I single cylinder diesel engine. The result showed that by using the above said fuel additives the percentage of smoke, NOx and particulate matter (PM) in the engine exhaust was reduced. One of the major sources of air pollution is constituents emitted from CI engines. Therefore, the emissions from CI engines are serious concern on the ecological environment. It has occurred problems such as the ozone layer destruction, enhancement of the greenhouse effect and acid rain etc. It is mainly because of the obvious fuel-oil constituent effects on engine emission characteristics. The addition of oxygenated additives into fuel oil is one of the possible approaches for reducing this problem. Diesel engines are the major contributors of various types of air polluting gases like carbon monoxide, oxides of nitrogen, smoke, etc. Improvement of fuel properties is essential for suppression of Diesel pollutant emissions along with the optimization of design factors and after treatment equipment.**

Index Terms— **Diesel engine, Diesel particulate matter, Fuel modification, Exhaust pipe**

I. INTRODUCTION

The trend toward low emission diesel fuels is growing worldwide. In the United States, **Clean Air Act** legislation will mandate reduced particulates in 1994 and lower NOx emissions in 1998. Emission reductions beyond these targets will require a combination of new engine technology, additives, and reformulated diesel fuels. The production of economically viable low emission diesel fuels will remain a substantial challenge into the years to come. Oxygenated diesel fuel may offer one possible solution. Oxygenate utilization to produce "cleaner burning" diesel fuels has been known for over fifty years. Oxygenates are well known to reduce particulate emissions. Low molecular weight alcohols, such as methanol, ethanol, and t-butyl alcohol, have been reported to reduce emissions (2). Higher alcohols (3), carbonates, diethers, such as diglyme, and various glycol ethers have also been reported. Particularly attractive are P-series glycol ethers, which contain both ether and a propylene glycol end-group. This paper deals with oxygenate selection criterion and emission reductions in modern diesel engines. Various application strategies to reduce emissions and enhance diesel fuel performance are discussed.

Diesel engine exhaust emissions (commonly known as 'diesel fumes') are a mixture of gases, vapours, liquid aerosols, and substances made up of particles. They contain the products of combustion including:

- carbon (soot);
- nitrogen;
- water;
- carbon monoxide;
- aldehydes;
- oxides of nitrogen;
- oxides of sulphur;
- Polycyclic aromatic hydrocarbons.

The carbon particle or soot content varies from 60% to 80% depending on the fuel used and the type of engine. Most of the contaminants are adsorbed onto the soot. Petrol engines produce more carbon monoxide but much less soot than diesel engines.

The quantity and composition of diesel fumes in your workplace may vary depending on:

(i) the quality of diesel fuel used;
(ii) the type of engine, eg standard, turbo or injector;
(iii) the state of engine tuning;
(iv) the fuel pump setting;
(v) the workload demand on the engine;
(vi) the engine temperature;
Whether the engine has been regularly maintained.

Smoke is the product of combustion. Vehicles at your workplace may produce three kinds of smoke, two of which indicate engine problems. The three types are:

- blue smoke (mainly oil and unburnt fuel) which indicates a poorly serviced and/or tuned engine;
- black smoke (soot, oil and unburnt fuel) which indicates a mechanical fault with the engine;

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K.Balasubramaniyan, *Mechanical Engineering, As salam college of Engineering and Technology, Thanjavur..*

P.Balashanmugam, *Mechanical Engineering, Annamalai University Chidambaram,India,*

A.Raghupathy,*Mechanical Engineering, Annamalai University Chidambaram, India.*

G.Balasubramanian, *Mechanical Engineering, Annamalai University Chidambaram, India,*

- white smoke (water droplets and unburnt fuel) which is produced when the engine is started from cold and disappears when the engine warms up.

With older engines, the white smoke produced has a sharp smell which may cause irritation to your upper respiratory system.

1.1. Major Pollutants from Petrol and Diesel Engines

a. Carbon Monoxide (CO)

Produced when the fuel in the engine does not burn properly. In the UK road traffic produces 91% of all CO emissions. Problems caused when inhaled reduce the oxygen carrying capacity of blood and causes headaches, fatigue, stress, respiratory problems and at high levels - death.

b. Nitrogen Oxides (NOx)

Produced from the burning of fuel in the engine. In the UK road, traffic is responsible for 49% of all NOx emissions. Problems caused**:** NOx emissions help make 'acid rain'. Also combines with hydrocarbons forming low-level ozone pollution and may contribute to lung disease.

c. Hydrocarbons (HC)

Compounds of hydrogen and carbon are present in petrol and diesel e.g. Benzene. UK petrol contains about 2% benzene. In the UK road, traffic is responsible for about 35% of all HC emissions.

Problems caused**:** HC's react with nitrogen oxides producing a number of pollutants, including ozone. Benzene can cause some forms of cancer.

d. Smoke (particulate matter or PM)

Made of fine particles of carbon coated with organic chemicals, produced when fuel is only partly burnt in the engine.

Problems caused**:** Increases in smoke levels associated with increases in death from heart and lung disease and may cause lung cancer.

e. Ozone

Made when some pollutants from vehicles combine in the sunlight. This happens some time later and can be much further away from any vehicles, so 'hot spots' of ozone pollution do not usually occur. Problems caused**:** Ozone can affect human health and causes plant damage.

Typical gaseous emission values of these pollutants from diesel engine and petrol engine are given in the table 1 and 2 respectively.

Table 1 Toxic components produced by I.C.Engines

Components	Diesel Engine	Petrol Engine
Carbon monoxide in %	0.20	6.00
Oxides of nitrogen in %	0.35	0.46
Hydrocarbon in %	0.04	0.46
Hydrogen sulphide in%	0.04	0.007
Soot in mg/c	0.30	0.05

1.2. Compound in Particulate matter

The exact composition of particulates generated by an diesel engine was studied using gas chromatography-mass spectroscopy (GC-MS) techniques. Column chromatography was used to separate the extract into aliphatic and five other fractions before analysis. Thirty-five hydrocarbons are identified including alkanes, Polynuclear aromatic hydrocarbons and six oxygenate compounds primarily of the phenolic type.Tenty nine additional hydrocarbons and oxygenated compounds were tentatively identified. Normal alkanes of carbon number 14 to 20 found to constitute approximately half of the total aliphatic fraction. Compounds extracted from diesel particulate matter are given in the table3.

Table 2 Concentration of exhaust gas constituent (Diesel Vs Petrol engine)

Driving condition	Carbon monoxide vol. in %		Oxides of nitrogen in ppm		Hydrocarbon in ppm	
	Diesel engine	Petrol engine	Diesel engine	Petrol engine	Diesel engine	Petrol engine
Idle	0.0	11.7	59	33	390	4830
Acceleration	0.05	3.0	849	1347	210	960
Cruise	0.0	3.4	237	563	90	320
Deceleration	0.0	5.5	30	18	330	16750

Table 3 Compounds extracted from diesel Particulate matter

Acidic Compounds	Paraffinic Compounds	Aromatic Compounds
Phenol	Pentane	Benzene
Cresol	Hexane	Tolune
Dinitor-o-cresol	Octane	Diphenyl
Benzonic acid	n-Tetradecane	Antharacane
O,m,p-Phenols	n-Hexadecane	Styrene
	n-Octadecane	Xylene
	n-Nonadecane	Pyrene
	n-Eicosane	Chrysene
	n-heneicosane	Benzo(a)pyrene

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2. ADDITIVES AND THEIR FORMULATION

Additives are chemicals that are added in relatively small quantities either to enhance fuel performance and or to correct deficiency. The selection of additives depends on the base fuels in which they are blended. Mainly consists of a single chemical compounds or more compounds. Wide range of fuel additives is available. Critical skill is required to ascertain the correct additive formulation to be stable over a full range of ambient storage condition. If not the component separation, degradation makes the additives inactive.

Table 4.Properties of Additives (1, 2 Dimethoxyethane)

Melting point	-58°C
Boiling Point	85°C
Flash Point	-6°C
Comments	Clear colourless liquid
Specific gravity	0.8683
Vapour density	3.1

2.1. Types of Additives

a. Peroxides based ketene improvement additives
b. Cleaning additives
c. Barium based additives
d. Copper fuel additives

2.2. Peroxides based cetane improvement additives

- ❖ Increasing the cetane number of the fuel can be achieved,
- ❖ By lowering the aromatic content of the fuel
- ❖ By addition of chemical cetane improvers

Aromatic reduction is the low cost alternative to obtain higher natural catane.2-Ethyl-Hexyl-Nitrate is a chemical cetane enhancer commercially available. For the commercial use of peroxides, Di-t-butyl-peroxide is used as a cetane improvement additive.

2.3. Oxygenated fuel additives

Oxygenated fuel is nothing more than fuel that has a chemical compound containing oxygen. It is used to help fuel burn more efficiently and cut down on some types of atmospheric pollution. In many cases, it is credited with reducing the smog problem in major urban centers. It can also reduce deadly carbon monoxide emissions.

Oxygenated fuel works by allowing the gasoline in vehicles to burn more completely. Because more of the fuel is burning, there are fewer harmful chemicals released into the atmosphere. In addition to being cleaner burning, oxygenated fuel also helps cut down on the amount of non-renewable fossil fuels consumed. Various additives used for oxygen enrichment of fuel are as below.

Dimethyl carbonate, often-abbreviated DMC, is a flammable clear liquid boiling at 90 °C. It is a carbonate ester, which has recently found use as a methylating reagent. It was also classified as an exempt compound under the definition of volatile organic compounds by the U.S. EPA in 2009. Its main benefit over other methylating reagents such as iodomethane and dimethyl sulfate is its much lower toxicity and its biodegradability. In addition, it is now prepared from catalytic oxidative carbonylation of methanol with carbon monoxide and oxygen, instead of from phosgene. This allows dimethyl carbonate to be considered a green reagent.

2.4. Types of Oxygenate Fuel Additives

Dimethoxylene (DME) is clear, colorless, aprotic, and liquid ether that is used as a solvent. DME is miscible with water and is often used as a higher boiling alternative to diethyl ether and THF.

2-Ethylhexyl Acrylate is water white liquid with a characteristic odor. It is a stable product, with only negligible solubility in water. It is readily polymerized and displays a range of properties dependent upon the selection of the monomer and reaction conditions. 2-ethylhexyl acrylate is used in the production of homo-polymers. It is also used in the production of co-polymers, for example acrylic acid and its salts, esters, amides, methacrylates, acrylonitrile, maleates, vinyl acetate, vinyl chloride, vinylidene chloride, styrene, butadiene, and unsaturated polyesters. 2-ethylhexyl acrylate is also used in pressure sensitive adhesives.

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It was found that soot concentration is maximum when pure diesel was burned, followed by emulsified fuels and the lease concentration was obtained when bio-fuel was burned. Further, methanol has the most significant effect on the reduction of soot once added to each fuel, while acetone has the lease effect on soot reduction. The results gave good indication of the effect for oxygenated additives in reduction the soot formation.

Ethyl tert-butyl ether (ETBE) can be synthesized by reacting bio-ethanol (47% v/v) and isobutene (53% v/v) with heat over a catalyst, It can be considered a "bio-fuel", therefore ETBE helps to reduce the vehicle-out carbon dioxide (a green house gas) introduced to the atmosphere. As an additive to gasoline, ETBE has been extensively examined with regard to its impact on exhaust emissions, exhaust gas after treatment systems, evaporative emissions, and cold storability, materials used in the fueling systems and others in spark ignition engine-powered vehicles. The fundamental characteristics regarding to ignition and combustion of both the pure ETBE and ETBE blended fuels have been studied as well. ETBE has the properties of low auto-ignitability, low boiling point, oxygenated, and infinite solubility in diesel fuel. Therefore, ETBE, as an additive to diesel fuel, has the potentials for suppression of the smoke emissions increasing with EGR and extending smokeless and low NOx diesel combustion to higher loads by promoting fuel-air mixing as well as by its oxygenated property. Nevertheless, some concerns should be addressed when using ETBE as an additive to diesel fuel. For instance, the lowered fuel cetane number due to addition of ETBE causes a too high rate of in-cylinder pressure rise and deteriorates thermal efficiency or fuel economy. In addition, it is concerned that addition of ETBE to diesel fuel, like ethanol addition to diesel fuel, might cause some increases in unregulated toxic emissions such as carbonyl or aldehyde emissions.

Ethylene Glycol Mon acetate (EGM), and its effects on the characteristics of performance and emission of a compression ignition engine. The results show that the engine power outputs decrease and the BSFC increase when the diesel engine fueled with blends, but the diesel equivalent BSFC decrease. The results also indicate that all oxygenated fuels tested in this study show a beneficial effect on reducing smoke emissions at the operation conditions compared with diesel fuel. With the EGM15, an average smoke reduction of 49.9% and a maximal smoke reduction of 71% are obtained. The blends have little effects on the NOx emissions at most loads. The CO emissions of the EGM diesel blends decrease obviously at high load. All these results indicate the potential of EGM-diesel blend for clean combustion in diesel engine.

2.5. Oxygenate selection

The selection of oxygenates was guided by several considerations. The oxygenate boiling point was required to be in the range of temperatures commonly observed for diesel fuel components and the flash point to meet commonly adopted diesel fuel fire safety requirements ,Necessary requirements, concerning fire safety and combustion properties of the pure substances defined the elimination criteria for the first selection.

Boiling point > 60 0 °C,
Flashpoint > 55 0 °C,
Ignition temperature < 350 °C,
Kinematic viscosity < 4 mm^2 /s.

In addition, other criteria (e.g. oxygen content, density, lower heating value ...) were set to choose the more suitable oxygenated additives in reducing the exhaust opacity of automotive diesel engines.

Key oxygen selection criterion includes cost, toxicity, environmental impact, fuel blending properties, and engine performance. Critical fuel blending properties, which were used to screen and identify viable oxygenate candidates, included: high oxygen content, diesel fuel solubility, flashpoint, viscosity, water solubility in the resultant fuel blend, oxygenate extractability from the fuel, and minimal impact on the natural diesel fuel cetane number. The oxygenate should be soluble in diesel fuel from 1.0 to 5.0% to achieve maximum emissions reduction and improved engine performance. Above 5.0%, oxygenate cost per gallon of fuel treated is prohibitive. A number of high oxygen containing materials, such as ethylene and propylene carbonate, and most **E -** series glycol ethers, which are based on ethylene glycol, were eliminated from consideration due to poor diesel fuel solubility. As aromatic content in future reformulated diesel fuels is reduced from 35% to 10 - 20%, oxygenate solubility in the less polar hydrocarbon fuels will become acute.

2.6. Requirements of good oxygenate properties

Oxygenates that are to be blended with diesel fuel must have fuel properties appropriate for motor fuel. In particular

- ❖The blend must exhibit an adequate water tolerance.
- ❖The oxygenate must be miscible with various diesel fuels over the range of environmental temperature seen in vehicle operation.
- ❖The blend must have an adequate cetane number and preferably allow the blend to show an increased cetane number.
- ❖The oxygenate blend must not exhibit excessive volatility when mixed with various diesel fuel base.

3. PREVIOUS WORK

Diesel engines are widely used for transportation and agriculture applications due to their reliability, durability, and high thermal efficiency. However, there are two major challenges facing the use of Diesel engines. One is related with fossil fuel sustainability and other is related with environmental concern on engine emissions. So far, Diesel engines have adapted many technical breakthroughs for reducing both fuel consumption and pollutant emissions. A number of experimental investigations have been reported with a wide variety of oxygenated additives to improve the fuel properties and engine performance and to reduce emissions. Some of these studies suggested that improvement in particulate emission is directly related to the oxygen content in the blended fuel.

Ren *et al*. investigated the effect of di-methoxy methane (DMM) blended with Diesel fuel on performance and exhaust emissions in a compression ignition engine and found that remarkable reduction in CO and smoke were achieved when operated with Diesel/DMM blends. The 5% addition of DMM with Diesel gives better thermal efficiency and reduced engine emissions.

Yanfeng *et al*. used 2-methoxy ethyl acetate in a direct injection Diesel engine and reported that addition of 15% MEA in Diesel gives 50% - 60% reduction in smoke. The CO and HC emissions also decrease with increase of MEA in the blends. MEA blends produce shorter combustion duration and increased engine thermal efficiency.

Husnawan *et al*. investigated the use of oxygenated and metal-based additive in biodiesel-Diesel blends in a four-stroke Diesel engine and reported that the additive blended fuels produce reduced exhaust emissions as compared with fuels without additive.

Sorenson *et al*. studied the performance and emission characteristics of DI Diesel engine using dimethyl ether (DME) and found that engines produce ultra-low emissions. However, there are some disadvantages in the DME fuel, including reduced viscosity, reduced lubricity, and vapour block for its low low boiling temperature.

Ball *et al*. studied the effect of dimethoxy methane additive on Diesel engine particulate matter emission and found that

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the addition of additive causes a shift in particulate matter size distribution to smaller diameters and substantial particulate matter reduction. The NOx emission does not changed with dimethoxy methane addition.

Liu *et al.* carried out experimental work on the effect of DMM blended with gas-to-liquid s in a CI engine and found that the particulate matter and smoke emissions were reduced with an increase of oxygen content in the fuel. The unburned or partially burned (total) hydrocarbon (THC) emissions, smoke (soot) or particulate matter (PM), nitrogen oxides (NOx), sulfur oxides (SOx) emitted from compression ignition (CI) engines and particularly carbon dioxide (CO_2) create severe environmental problems, which have been tried to be reduced by the stringent emission legislations. The different alternatives such as the investigation of viable alternative fuels and the reformulation of conventional fuels have been evaluated for meeting the emission standards and future energy demand. The reformulation of diesel fuel contains the reduction of the sulfur and aromatic contents or the oxygen addition to diesel fuel. Many works have been performed to show the effects of using alternative diesel fuels and additives including synthetic diesel fuels, biodiesels, alcohols, and ethers.

Many studies have shown that the addition of oxygen to a base diesel fuel will result in a reduction of particulate emissions (**MiSosSaw Kozak *et al.*, 2008 and 2009**). The primary parameter influencing the formation of particles appears to be the amount of oxygen in the fuel, and secondarily, the chemical structure of oxygenate providing the oxygen. The work of **Miyamoto *et al.*, (1998**) demonstrated that it was the oxygen content of the fuel additive that had the primary influence on soot reduction- not its chemical form. **Curren *et at.*, (2001**) done chemical kinetic modeling of selected oxygenates in N- heptanes as a base diesel fuel and demonstrated that the generation of soot precursors decreased with the increasing oxygen content of the fuel mixture.

Andrea bertola *et at.*, (2000) has considered twenty seven oxygenated hydrocarbons as diesel fuel additives and concluded that the butylal offers significant advantages over most other oxygenates in that its physical properties are very close to that of common diesel fuel. Generally, most of the oxygenated compounds when blended with diesel fuel decrease the pollution, but some of them only improve the performance (**Brian *et at.*, 2001).**

Cheng A.S. Ed *et at.*, (2002) tested diglyme and other oxygenates to show that particulate matter reduction is controlled largely by the oxygen content of the blend fuel and the effect of chemical structure was observed to be small. But the results of **Micheal D Boot *et at.*, (2007**) confirms the importance of oxygen mass fraction of the fuel blend, but at the same time illustrates the effect of chemical structure.

The use of the synthetic additives is a more advantageous way of oxygenizing diesel fuels. Such groups of chemical compounds as ethers, acetals, carbonates, esters and higher alcohols, should be taken into consideration (**Irshad Ahmed *et at.*, 2001).** Some compounds of the mentioned groups have physical and chemical properties very similar to that of diesel fuel. Moreover, they are characterized with a very high cetane number (often above 100) and very high oxygen content (often above 50% m/m). All this shows that these compounds should be effective even if a small amount is added to the base fuel (**K. B. Spreen *et at.*, 1995**).

Mani **Natarajan *et at.***, and **Manuel A *et at.*, (2001**) have suggested the screening and selection methodologies for oxygenates based on a set of physical and chemical properties, that will be eligible for diesel engine testing.

4. XPERIMENTAL SET UP

A vertical, water cooled, single cylinder, four stroke direct injection diesel engine was used for this work. The engine was coupled to a eddy current dynamometer for power measurement. The smoke intensity was sampled in a filter paper and evaluated using a hart ridge smoke meter. Experiments were carried out on four different phases. In the first phase bases reading were obtained using neat diesel. In the other three phases the engine performance was studied using 1%, 3% and 5% of additives mixed with diesel. The engine specifications are given below. The smoke density and various gases were measured by using AVL smoke meter and AVL di-gas analyser.Photographic view of test engine was shown in figure 1**.**

4.1. Engine Specification

Brand	: Kirloskar TV-I
Type	: Single cylinder, vertical, water –cooled and four stroke diesel engine
Stroke	: 110 mm
Bore	: 87.5 mm
Cylinder diameter	: 0.0875 m
Stroke length	: 0.11 m
Compression ratio	: 17.5:1
Orifice diameter	: 0.02 m
Dynamometer arm length	: 0.195 m
Power	: 5.2 kW (7 H.P)
Speed	: 1500 rpm
Loading device	: Eddy current dynamometer

Figure 1 Photographic view of test engine

4.2. Fuel preparation

The preparation of 1% 1-2 Dimethoxy ethane (by volume) contains the following steps

- ❖One litre of diesel was taken in a container

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❖ One ml of diesel was taken out from the container by using a pipette

❖ One ml of additive was added with the fuel in the container

❖ The mixure was stirred for about 15-30 minutes with the help of magnetic stirrer.

The above procedure was followed for the preparation of 3 &5 % 1-2 Dimethoxy ethane (by volume)

4.3. Test Carried out

4.3.1. Load test

❖ Initial temperature readings and room temperature were noted

❖ The engine was started by cranking after ensuring no load condition

❖ The engine was allowed to run at rated speed (1500 rpm) for a period of 20 minutes to reach the steady state.

❖ A stopwatch noted the time taken for a fuel consumption of 10 cc.

❖ Smoke readings were taken using the hart ridge Smoke meter in the exhaust outlet

❖ The exhaust gas temperature was noted using a thermometer.

❖ Then the load was applied using the dynamometer. The readings were taken at 20 %, 40%, 60% and 80percentage loads.

❖ Experiments were conducted using neat diesel and oxygenated diesel as the fuel.

4.3.2. Measurement of smoke

It was done by hartridge smoke meter. It works on the principle of light extinction. Exhaust sample was passed through a tube of about 46 cm diameter, which has light source at one end and photocell at the other end. The amount of light passed through this tube was used as indication and meter was calibrated.

5. RESULTS AND DISCUSSION

The following observations were arrived from the experimental investigation. From the figure 2, it is clear that for all the concentrations of the additives (1%, 3% and 5 %) particulate matter content in the exhaust initially decreses and then increases with increasing load. The presence of particulate matter is minimum for 1% fuel additive. Addition of fuel additive first increases the NOx content in emission and then decreases. NOx content is minimum for 5% fuel additive. However, at peak load the NOx content is minimum for 1 % fuel additive. For all the trails, the NOx level increases with increasing load. It is clear from figure 3 .Like NOx the smoke also increases with increasing load. It is evident from figure 4.But smoke in the exhaust is minimum for 15 fuel additive which quite opposite to the NOx content in the exhaust. From figure 5 it is concluded that the addition of additives does not have any drastic effect on the engine performance i.e., brake thermal efficiency. There is a slight increase in brake thermal efficiency as the percentage of additive in the fuel increases.

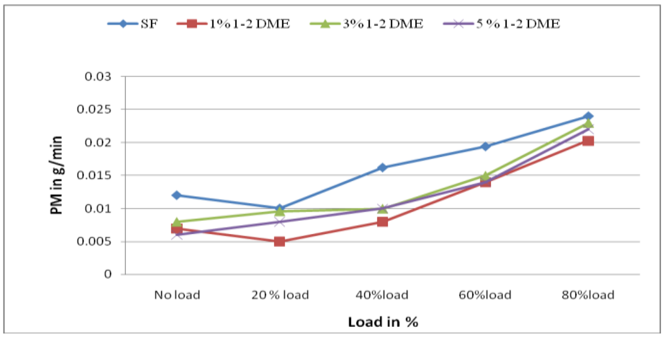

Figure 2 Effect on fuel additive on PM

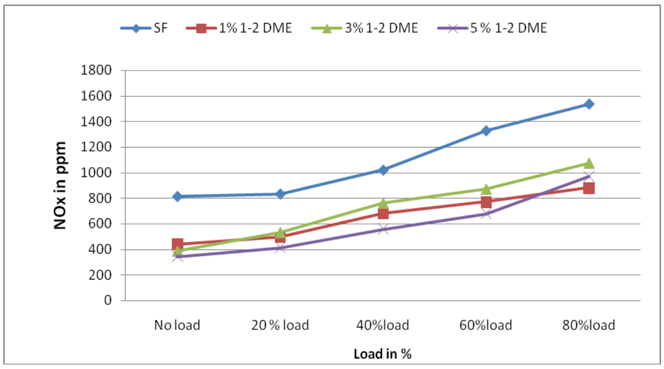

Figure 3 Effect of fuel additive on NOx

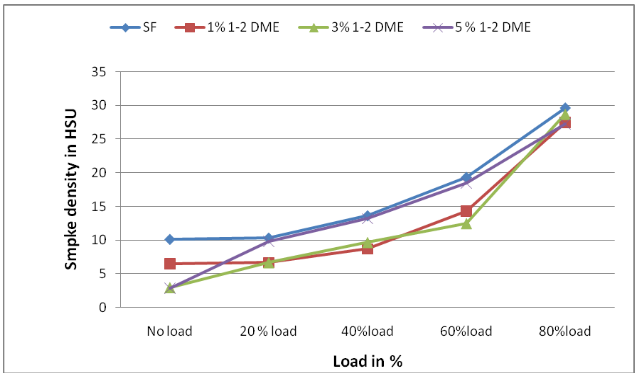

Figure 4 Effect of fuel additive on Smoke density

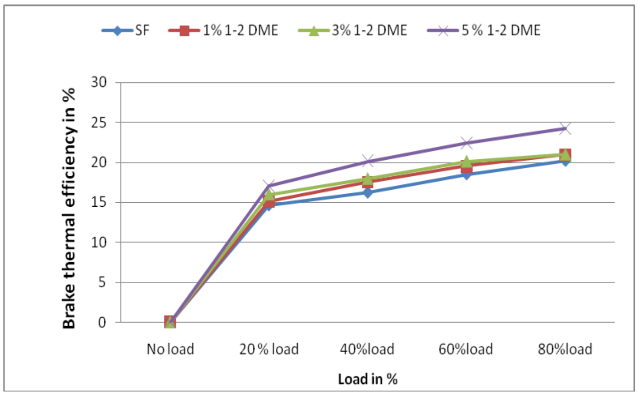

Figure 5 Effect of fuel additive on brake thermal efficiency

CONCLUSION

The following conclusions were obtained from this work.

❖ The addition of additives (1-2 dimethoxy ethane) to the fuel improves the engine performance marginally

❖ NOx particulate matter and smoke density in the diesel engine exhaust reduces considerably with the addition of additives with the fuel

❖ As the smoke density is more for 5 % additive where the NOx level is minimum, a compromise should be made between these two.

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