# SOME EXPERIMENTAL INVESTIGATIONS ON TERNARY BLENDS OF DIETHYL ETHER IN COMPRESSION IGNITION ENGINE

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**MASTER OF TECHNOLOGY**

**IN**

**THERMAL ENGINEERING**

Submitted by

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# CANDIDATE'S DECLARATION

I ABHINAV MALAIYA, 2K16/THE/002 student of M Tech. (THERMAL ENGINEERING) hereby declare that the project Dissertation titled **"Some Experimental Investigation On Ternary Blends of Di-ethyl Ether in Compression Ignition engine"** which is submitted by me to the Department of Mechanical, Production and Industrial Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement of the degree of Master of Technology is original and not copied from any source without any citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate-ship, Fellowship and other similar title and recognition.

Place: Delhi

**Abhinav Malaiya**

M.Tech. (Thermal Engineering)

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# CERTIFICATE

I hereby certify that the project Dissertation titled **"SOME EXPERIMENTAL INVESTIGATIONS ON TERNARY BLENDS OF DIETHYL ETHER IN COMPRESSION IGNITION ENGINE"** which is submitted by **Abhinav Malaiya (2K16/THE/02)** to Department of Mechanical, Production and Industrial Engineering, Delhi Technological University, Delhi in partial fulfilment for the award of Master of Technology in Renewable Energy Technology, is a record of the project work carried by him under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

**Prof. Naveen Kumar**
Mechanical Engineering Department
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# ABSTRACT

Due to huge reduction in crude oil resources as result of excessive utilization of oil products soon there will be a scarcity of transportation fuels in the world. The scarcity has to be remunerated by exploring some substitute fuels. This work deals with finding a diesel alternative as consumption of diesel is roughly four times the consumption of gasoline as per the annual report of Ministry of Petroleum and Natural Gas, so, it is quite effectual to replace diesel with a suitable alternative viz alcohols, ethers, biodiesel etc. Ethers have shown some promising properties as a diesel fuel alternative, out of which dimethyl ether and diethyl ethers are most trending and booming alternatives among research fraternity most recently. So, in this work, ternary blends of diethyl ether and jatropha biodiesel in diesel are examined on various standards so as to proclaim that diethyl ether is the prospect substitute fuel for compression ignition engine. In this work, ternary blends of diethyl ether and jatropha biodiesel in diesel are prepared in different proportions and named as DEExBy where "x" is the % of DEE in blends and "y" is the % of biodiesel in blends. These blends are firstly monitored for a month after being prepared to check their stability. Once it is found that the blends are stable, physic-chemical properties of these blends are measured and compared with that of neat diesel. Spray characteristics of these blends are established using Malvern Spraytec Optical Spray Analyzer and these characteristics are compared with that of diesel, as spray characteristics are quite significant in estimating quality of combustion of a fuel in combustion chamber. Lastly, when the blends passed every prerequisite test to be used for engine trials, they are tested in unmodified Single Cylinder Air Cooled Diesel Engine. Various performance parameters of engine are measured with these blends at different loads viz no load, 20% load, 40% load, 60% load, 80% load and at full load. Emission

characteristics are also examined using AVL gas and smoke analyzer. Emission characteristics or variation of amounts of gases emitted by engine at different loads are estimated and examined including smoke opacity and plotted against BMEP (brake mean effective pressure).

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# NOMENCLATURE

| | |
|---|---|
| BSFC | Brake specific fuel consumption |
| BTE | Brake thermal efficiency |
| BMEP | Brake mean effective pressure |
| BP | Brake power |
| CO | Carbon Monoxide |
| EGR | Exhaust Gas Recirculation |
| HC | Hydrocarbon |
| DEE | Di-ethyl Ether |
| NO | Nitric oxide |
| NOx | Oxides of nitrogen |
| PPM | Part per million |
| RPM | Revolution per minute |
| PM | Particulate matter |
| $SO_2$ | Sulfur dioxide |
| DEExBy | "x% by volume" DEE and "y% by volume" biodiesel in blend |
| EGR | Exhaust Gas Recirculation |
| ETBE | Ethyl-Tert-Butyl-Ether |
| KME | Karanja Methyl Ester |
| ASTM | American Standards of Testing and Measurement |
| PCCI-DI | Premixed Charge Compression Ignition- Direct Injection |
| BSEC | Brake Specific Energy Consumption |
| CN | Cetane Number |
| D100 | Diesel |
| $\Delta p$ | Pressure Difference |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

A global crisis of crude oil and increasing threat to environment due to emissions from prime movers like I.C. engines, gas turbines etc. have inhibited the attention of researcher fraternity towards the promising domain of alternative transportation fuels. As compression ignition engine has been used as a commercial prime mover in Indian economy since number of decades, so, the researchers are adhering to the field of alternative fuels for this stallion of Indian economy. This report refers to the various researches done using DME and DEE on Compression Ignition engines.

Energy sources and alternative transportation fuels are a concern of utmost significance - not only among the scientific and engineering area, but also in framing economic and public policy. Alternatives need to be compared on scientific and economic terms which has not done fine in the media.

Elective energizes and vitality sources give a superb chance to presenting an assortment of science points, and expanding understudy enthusiasm for those themes. Science and designing fields are progressively disciplinary - exercises on biodiesel can exhibit that unmistakably, by demonstrating the covering of science, science, and material science in concentrate this and other elective powers. It can likewise show to understudies that science isn't free of financial aspects, and headways in science can yield significant advantage to the overall population (i.e. moving from oil powers to locally delivered biofuels would make a huge number of employments, enhance our economy, lessen contamination colossally, and dispose of a key worry for all nations - the reliance on remote fuels)Some of the promising elective energizes are:

### 1.1.1 BIODIESEL

Biodiesel is a liquid fuel obtained by esterification or trans-esterification of vegetable oils or animal fats and an alcohol that can be used in diesel engines, alone or blended with diesel oil. ASTM International (originally known as the American Society for Testing and Materials) defines biodiesel as a mixture of long-chain mono-alkylic esters from fatty acids obtained from renewable resources, to be used in diesel engines. Blends with diesel are indicated as ‘‘BX’’, where ‘‘X’’ is the percentage of diesel replaced in the blend. For instance, ‘‘B7’’ indicates a blend with 7% biodiesel and 93% diesel fuel; in consequence, B100 indicates pure biodiesel.

### 1.1.2 ALCOHOLS

Alcohols have been used as a fuel. The first four aliphatic alcohols (methanol, ethanol, propanol, and butanol) are of interest as fuels because they can be synthesized chemically or biologically, and they have characteristics which allow them to be used in internal combustion engines. One advantage shared by the four major alcohol fuels is their high octane rating. This tends to increase their fuel efficiency and largely offsets the lower energy density of vehicular alcohol fuels (as compared to petrol/gasoline and diesel fuels), thus resulting in comparable "fuel economy" in terms of distance per volume metrics, such as kilometers per liter, or miles per gallon.

### 1.1.3 FUEL BLENDS

Fuel blends are combinations of different types of liquid fuels. An example is E85, which is a blend of 85% ethanol and 15% gasoline. While most vehicles may require unblended gasoline, Flex-fuel vehicles (FFVs) can operate on any mixture of ethanol and gasoline.

### 1.1.4 ETHERS

**a. Diethyl Ether (DEE)**

DEE has favorable properties to be used in diesel engines, such as higher cetane number (>125), prolonged flammability, moderate energy density for bulk storage, lower auto-ignition temperature, good miscibility with diesel [1]. Diethyl ether when blended with diesel obtains a excellent fuel blend for CI engines.

Cylinder pressure and peak pressure rise were higher for EBD-5DEE. Highest HRR is observed for neat EBD without additives. Lowest NOx and BSFC were recorded for

MBD-5DEE. DEE addition in EBD reduces the ignition delay, EGO, PM and smoke emissions. DEE addition in MBD lowers the combustion duration, HC and NOx emissions. [2]DEE injection improves the efficiency and reduces the emission. [4] The low-temperature performance of fuel blends significantly improved as the diethyl ether content increased in the fuel. [5] The ether fuels show high level of cavitation compared to that of conventional diesel fuel due to their low viscosity. The spray characteristics like spray tip penetration and sauter mean diameter for DME and DEE fuels have been found to be shorter and smaller compared to that of diesel fuel. However, DME and DEE exhibit excellent atomization behavior compared to that of diesel fuel because the ether fuels are characterized by high Reynolds number.

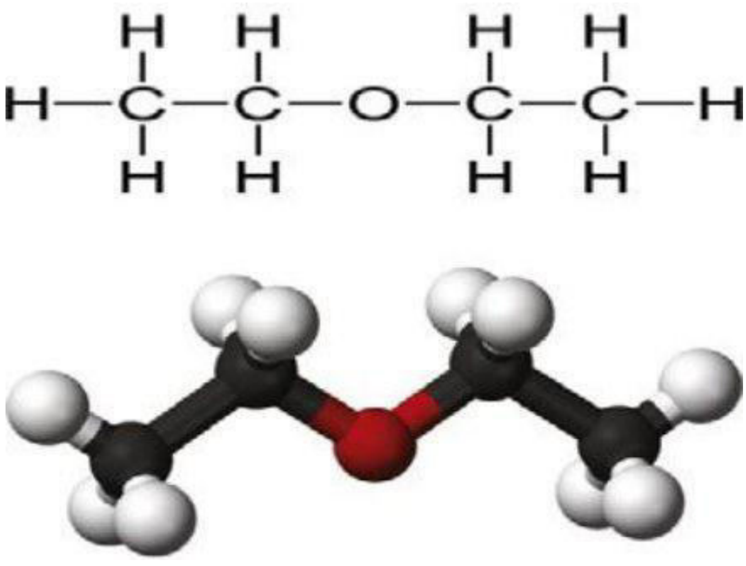


**Figure 1: Structure of Di-Ethyl Ether**

**Table 1: Properties of Di-Ethyl Ether**

| PROPERTIES | DIETHYL ETHER |
|---|---|
| Molecular Weight | 74.1216 |
| No. of Atoms | 15 |
| Critical Temp. | 367±2K |
| Critical Pressure | 36±1bar |

| | |
|---|---|
| **Boiling Point** | **307.7±0.2K** |

The fuel properties, viz. density, cetane number and auto ignition temperature are seen improved with the addition of DEE [7]. Significant reduction in NOx, HC and CO emission is seen for fuels blended with diethyl ether. Break specific fuel consumption is found on the higher side with diethyl ether blend. Break thermal efficiency was incresed as the diethyl ether proportion increases. [8]Higher heat release rates are observed with DEE blend but combustion duration and engine stability was reduced.

Above all the constraints diethyl ether have found to be a comprehensive research topic with loads of opportunities.

Domestically it can be produced from a variety of feedstocks, including biogas from organic waste. Because of its lack of carbon-to-carbon bonds, using Diethyl ether as an alternative to diesel can virtually eliminate particulate emissions and potentially negate the need for costly diesel particulate filters. Diethyl ether has a high cetane number of 85-96 and is used as a starting fluid, in combination with petroleum distillates for gasoline and Diesel engines because of its high volatility and low flash point.

It is used extensively in the chemical industry and as an aerosol propellant. Diethyl ether was formerly used as a general anaesthetic, until non-flammable drugs were developed, such as halothane. It has been used as a recreational drug to cause intoxication.

Diethyl ether can be prepared both in laboratories and on an industrial scale by the process called acid ether synthesis.

Ethanol is mixed with a strong acid like sulfuric acid ($H_2SO_4$).This strong acid dissociates in the aqueous environment producing $H_3O^+$(hydronium ions).

Later a hydrogen ion protonates the electronegative oxygen atom of the ethanol, giving the ethanol molecule a positive charge.

$$C_2H_5OH + H_3O^+ \rightarrow C_2H_5OH_2^+ + H_2O$$

A nucleophilic oxygen atom of unprotonated ethanol displaces a water molecule from the protonated (electrophilic) ethanol molecule, producing water, a hydrogen ion and diethyl ether.

$$C_2H_5OH_2^+ + CH_3CH_2OH \rightarrow H_2O + H^+ + C_2H_5OC_2H_5$$

This reaction must be carried out at temperatures lower than 150°C in order to ensure that an elimination product (ethylene) is not a product of the reaction. At higher temperatures, ethanol will dehydrate to form ethylene.

The reaction to make diethyl ether is reversible, so eventually, an equilibrium between reactants and products is achieved. Getting a good yield of ether, which in turn requires that ether is distilled out of the reaction mixture before it reverts to ethanol.

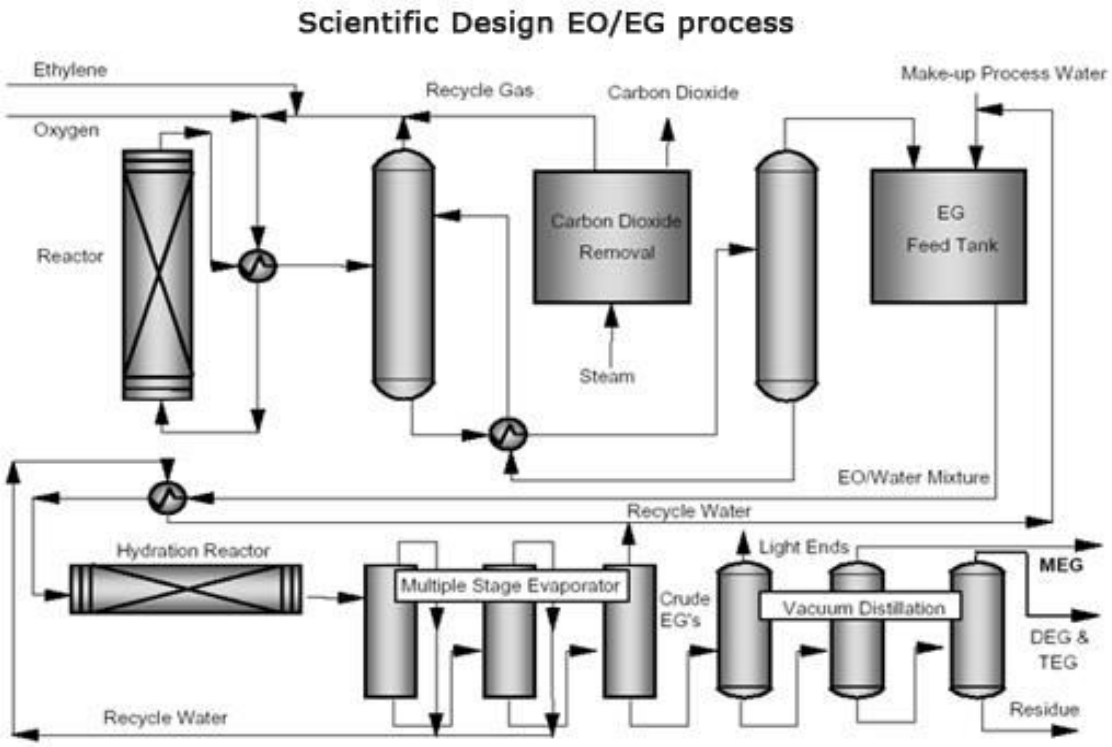



**Figure 2: Block diagram of EO/EG process for Di-Ethyl Ether production**

## 1.2 FUEL SCENARIO IN INDIA

Energy plays a vital role in the socio-economic development of a nation. In 2011- 12 the majority share of energy consumption was by the Industrial sector with 47% Transport sector accounted for 6.9%. Retail selling prices of only 3 products i.e. Diesel (retail sales), PDS Kerosene and Subsidized Domestic LPG are regulated by the Government. The prices of Petrol are market determined. The Refinery Gate Price of Diesel is based on Trade Parity Price (TPP) consisting 80% of Import Parity Price (IPP) and 20% of Export Parity Price (EPP).

Subsidies are provided for three petroleum products- PDS kerosene, domestic LPG and diesel. Subsidies covers only a part of the difference between the cost price (including marketing costs) and the selling price of these three petroleum products, thereby resulting in "under-recoveries" for the Oil Marketing Companies (OMCs). The difference between the desired price of a petroleum product for supply to OMCs' dealers/distributors and the government-controlled price of that product is referred to as the gross under-recovery per unit of the product.[22]

| **Fiscal Subsidy(crores)** | | **Under recoveries to oil companies(crores)** | |
|---|---|---|---|
| PDS Kerosene | 741 | PDS Kerosene | 29410 |
| Domestic LPG | 1989 | Domestic LPG | 39558 |
| - | - | Diesel | 92061 |
| Total | 2730 | **Total** | **161029** |

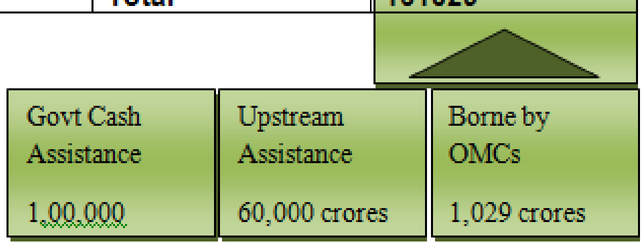



**Figure 3: Fiscal Subsidies and Underrecovery datas**

- Total consumption of petroleum products:

Diesel constitutes 44%

Petrol constitutes 10%

- Transport sector consumes:

Diesel- 70%

Petrol- 99.6%

The total under recovery on Diesel during 2017-18 was Rs. 92,061 crores (57.2% ) Based on the sector-wise consumption pattern of diesel the total under recovery of Rs. 92,061 crores went to:

- Owners of private cars and utility vehicles (UV) -Rs. 12,100 crores
- Commercial cars and UV-Rs. 8,200 crores
- HCV/LCV-Rs. 26,000 crores
- Buses-Rs. 8,800 crores
- Agriculture sector-Rs. 12,000 crores
- Other sector- Rs. 15,600 crores

This clearly indicates how the well off are also benefitting from the subsidies and there is no economic or social reason to provide subsidy on diesel to these consumers. Increase in price gap between petrol and diesel has led to the to shift from the petrol cars and increased usage of diesel passenger cars. Dieselization taking place with consequent adverse affects on the environment.

The average of the projections of the different scenarios shows that by 2040 increase in: Number of Vehicles - 18 times Fuel consumption - 19 times. In India approximately 140,000 people die of traffic accidents every year. Increased number of vehicles will lead to increased pressure on roads, apparent that the rate of road accidents will only increase. With increasing number of vehicles the concomitant emissions will also rise thus deteriorating the air quality. Imperative that increased vehicular emissions and high rate of accidents due to rise in number of vehicles and the increased pressure on roads be addressed.[22]

Being largely dependent on imports, India needs to be prepared to meet its future petroleum requirements. Cannot be met by domestic production as at the present pace the reserves will last only for another 17.5 years With the GDP growth, the transport sector will flourish and the resultant petroleum requirements will be considerable. With the rise in number of vehicles, concomitant emissions and traffic accidents are bound to increase. To enhance energy security, to reduce the number of vehicle on road, to improve road safety and cut down on vehicular emissions, the A-S-I (Avoid-Shift-Improve) approach can be used.

Reducing or avoiding the need to travel using motorized modes. This can be achieved through transit orient development, integrated land use planning, making use of information technology and thereby reducing the need to make trips. Maintaining a share of more environmentally friendly options i.e. a modal shift from transport modes that consume considerable amount of energy and emit GHGs to more environmental friendly options like Non Motorised Transport (NMT), and public transport. Improving the energy efficiency of transport modes and vehicle technology. It can be pursued by improving energy efficiency of transport modes, fuel quality, and vehicle emission standards and introduction of alternative energy.

Deteriorating air quality is a pressing issue that most Indian cities face today. India heavily lags behind in its vehicle emission standards and need to establish a roadmap for vehicle emission and fuel quality standards. Rapid adoption of ultra-low sulphur fuels and BS VI vehicle emission standards would dramatically improve India's air quality to the benefit of public health. Alternative transport fuels have to be promoted and brought into the mainstream to tackle the twin objectives of reducing vehicular emissions and import dependence Diversifying fuel basket with the introduction alternative fuels will provide the much needed energy security with the environment being considered.[21]

The crude oil production for the year 2016-17 is at 36.01 Million Metric Tonnes (MMT) as against production of 36.94 MMT in 2015-16, showing a decrease of about 2.53%. 70.8% of crude oil production is by ONGC and OIL from nomination regime and remaining 29.2% of crude production is by Private/JVs companies from PSC regime. The projected crude oil production in 2017-18 is 37.37 MMT.[21] Crude oil production during April-November, 2017 was at 23.94 MMT which was lower by 0.2% against 23.99 MMT during April-November, 2016. Shortfall in production by ONGC was mainly due to delay in deployment of MOPU-Sagar Samrat, delay in implementation of development of Western Periphery of MHS (ZC) project and natural decline in matured fields of Western Offshore. Production by OIL is mainly from matured fields where decline rate encountered was more than expected, contribution from work-over and new well drilling was not commensurate with fall in production as well as bandhs, blockades, miscreant activities contributed to direct loss of production. Shortfall in production under PSC Regime was mainly due to shutdown at Mangala Processing Terminal (MPT), Panna platform and poor reservoir performance of Bhagyam field. Underperformance of CY-ONN-2002/2 & CB-ONN-2004/2, natural decline in CB-OS/2 and closure of 1 well in MA field in KG-DWN-98/3 also affected the production.

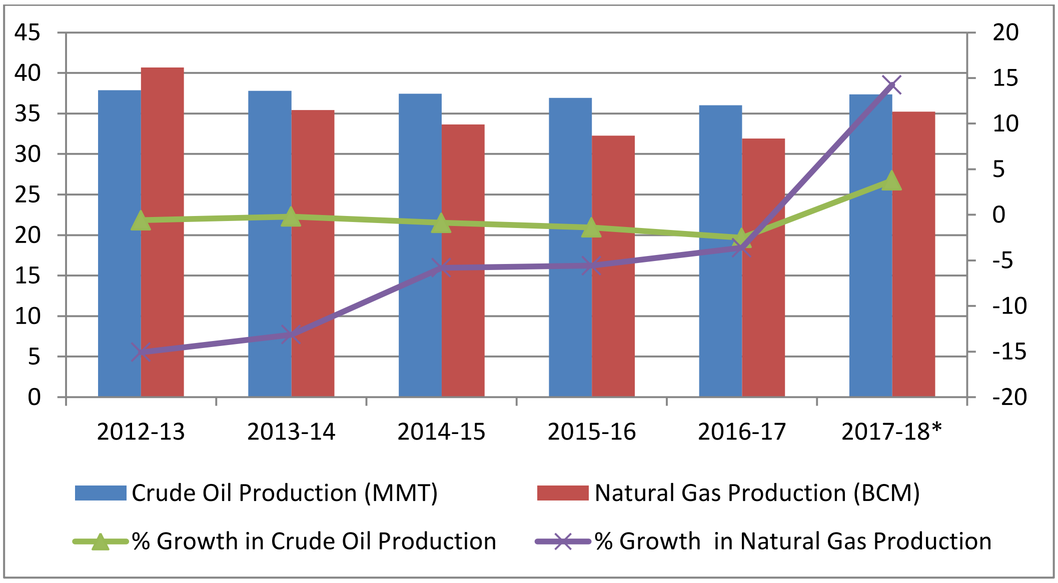



**Figure 4: Crude Oil Production and Growth Data[21]**

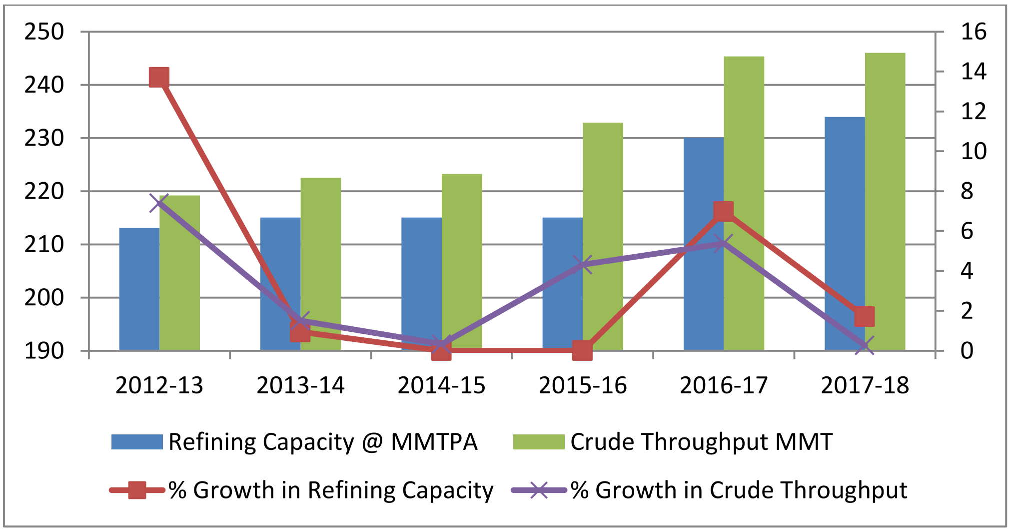



**Figure 5: Refining Capacity and Crude Throughput Data[21]**

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

In today's scenario increasing demand of petroleum products and decreasing resources of petroleum has lead the human race to go for some alternatives for these products. An integral part of this endeavor is to be assure about proposed alternative fuels to be compatible with petroleum-derived materials present in fuel blends. Exploring the available alternatives researchers came across two of a very promising options of fuels which could be used as CI engine fuels either in pure form or in blends with diesel and bio-diesel: dimethyl ether and diethyl ether. Till now diethyl ether has been used by number of researchers in blends with different proportions and with different additives but the research carried out using dimethyl ether has not been done by many, which creates an opportunity for everyone to work in this promising field.

## 2.2 LITERATURE REVIEW

Low cetane number fuels generally have a tendency to exhibit longer ignition delay due to their ignition quality. The ignition quality can be improved by adding small quantities of ignition improvers or cetane number improvers. Examples of ignition improvers are organic peroxides, nitrates, nitrites and various sulphur compounds. Earlier, alkyl nitrates (isopropyl nitrate, primary amyl nitrates, primary hexyl nitrates, octyl nitrate) were commercially used. By adding these improvers, the ignition characteristics of poorer quality diesel fuel, particularly alcohols, will be improved when they are used in CI engines. The use of ignition improvers or cetane improvers offers two advantages when they are used with alcohols: firstly, alcohols can be used in CI engines without any major engine modification; and secondly, they offer total replacement of diesel fuel in diesel engines. An ignition improver of up to 15% by volume would normally be required to enable the ignition of alcohol fuels in CI engines. The cost of these additives is high, and hence, they are not largely used. In addition to these improvers, some cetane improvers produced from biomass can be used. Examples of these are Diethyl ether (DEE) and Dimethyl ether (DME).

Some of the literatures taken into consideration for the purpose of this thesis are discussed below:

Venu et. al The present work focuses on improving the performance of ternary blends (alcohol-biodiesel-diesel) by using DEE (diethyl ether) as ignition enhancer. The test fuels used are diesel, a blend of ethanol (20%)- biodiesel (40%)-diesel (40%) (denoted as EBD), blend of methanol (20%)-biodiesel (40%)-diesel (40%) (denoted as MBD), a blend of EBD with 5% Diethyl ether (denoted as EBD-5DEE), a blend of EBD with 10% Diethyl ether (denoted as EBD-10DEE) and a blend of MBD with 5% Diethyl ether (denoted as MBD-5DEE). MBD-10DEE blend was very viscous and the engine stopped working at higher engine loads. EBD-5DEE and MBD-5DEE results in better engine performance with minimal emissions and can be directly used as a potential alternative feedstock for diesel engine without any modifications.[1]

Debabrata Barik, S. Murugan Despite of simultaneous reduction of the nitric oxide (NO) and smoke emissions in a biogas–KME (Karanja methyl ester) fueled dual fuel engine, there seems to be lower efficiency, higher fuel consumption, and longer ignition delay period. In this study, an attempt has been made to increase the thermal efficiency, reduce the brake specific fuel consumption (BSFC) and reduce the ignition delay as much as close to that of diesel, in biogas–KME run dual fuel diesel engine, applying DEE port injection strategy. The injection of different percentages of DEE as an ignition improver in a biogas–KME run DI diesel engine was investigated. The DEE injection quantity was varied to get the optimum result in terms of combustion, performance and emission characteristics of the engine.[2]

Obed M. Ali, Rizalman Mamat In this study, the effect of adding small portions of a diethyl ether additive to biodiesel–diesel blended fuel (B30) was investigated. This study includes an evaluation of the fuel properties and a combustion analysis, specifically, an analysis of the cyclic variations in diesel engines. The amount of additive used with B30 is 2%, 4%, 6% and 8% (by volume). The experimental engine test was conducted at 2500 rpm which produce maximum torque, and the in-cylinder pressure data were collected over 200 consecutive engine cycles for each test. The same test can be performed at different loads and for different proportions of ethers.[4]

Balaji Mohan et. al. In this work, the spray characteristics of ether fuels such as dimethyl ether (DME) and diethyl ether (DEE) have been numerically investigated using KIVA-4 CFD code. A new hybrid spray model developed by coupling the standard KHRT model to cavitation sub model was used. The detailed thermo-physical properties of ether fuels have been predicted and validated with experimental results available from literature. [5]

Chunhua Bai, Yue Wang The knowledge of the vapor liquid two-phase diethyl ether (DEE)/air mixtures (mist) on the explosion parameters was an important basis of accident prevention. Two sets of vapor liquid two-phase DEE/air. mixtures of various concentrations were obtained with Sauter mean diameters of 12.89 and 22.90 mm. Experiments were conducted on vaporeliquid two-phase DEE/air mixtures of various concentrations at an ignition energy of 40.32 J and at an initial room temperature and pressure of 21 _C and 0.10 MPa, respectively.[6]

Srihari et. al.  This work evaluated the effect of diethyl ether in biodiesel-diesel blends on the performance and emission characteristics in a Premixed Charge Compression Ignition-Direct Injection (PCCI-DI) engine. Biodiesel obtained from cotton seed oil is used for this study. PCCI-DI engine is operated with main injection and pilot injections with varying percentages of DEE along with 20% biodiesel blended with neat diesel. The experiment is performed on a single cylinder, four stroke direct injection diesel engine coupled with an eddy current dynamometer.[7]

Amr Ibrahim This study was to experimentally investigate the effect of blending the DEE with the diesel fuel in different proportions up to 15% by volume on diesel engine performance, combustion characteristics, and engine stability. All the tests were conducted using a single-cylinder direct-injection diesel engine without modification at a fixed engine speed of 1500 rpm and variable load conditions. It was found that using the DEE as a fuel additive improved the engine performance significantly for the most of engine load conditions.[8]

Mohammed AlAbbad et. al. Ignition delay times of four different primary reference fuels (PRF), mixtures of n-heptane and iso-octane, were measured behind reflected shock waves in a high-pressure shock tube facility. The PRFs were for- mulated to match the RON of two high-octane gasolines (RON 95 and 91) and two prospective low-octane naphtha fuels (RON 80 and 70). Experiments were carried out over a wide range of temperatures (700–1200 K), pressures (10, 20, and 40 bar) and equivalence ratios (0.5 and 1).[16] Pressure appears to have a significant effect on the ignition delay times and this effect is amplified in the NTC region compared to the high and low temperatures. The effect of equivalence ratio and composition on the ignition delay time is also larger in the NTC region.[9]

Yasuyuki et.al. In the present study, the potential energy surfaces for the unimolec- ular reactions of OOQOOH isomers and 1- and 2-ethoxyethyl radicals were determined with a CBSQB3 composite method. In the presence of an OOH group, the reaction barrier of the hydrogen shift from the β site (terminal carbon atom) decreases as it does in alkane oxidation but there is no effect on the hydrogen shift from the α site (next to the ether oxygen atom). Therefore, the reaction barriers of OOQOOH isomers have the same trend as the corresponding ROO radical and rate constants for the reactions of OOQOOH isomers were determined.[9] It was con- firmed that the model reproduces well the experimental data at 500–1300 K and 1–40 bar, except shock-tube experiments at 40 bar.

Choongsik Bae, Jaeheun Kim This review paper covers potential alternative fuels for automotive engine application for both spark ignition (SI) and compression ignition (CI) engines. It also includes applications of alternative fuels in advanced combustion research applications.[11] Gradual penetration of low-carbon fuels, such as biofuels and natural gas, is expected to con- tribute to lowering greenhouse gas (GHG) emis- sion in the long term. Advanced technologies in the manufacturing process of biofuels has the potential to decrease GHG emission compared to conven- tional fuels on a well-to-wheel (WTW) basis. GHG emission is expected to increase short term, due to the increased demand for energy consumption.[10]

Carder et. al. As emission standards continue to evolve, it is clear that future engine control strategies will involve the integration of combustion optimization, fuel refinement and advanced exhaust after-treatment technologies. The West Virginia

University (WVU) Center for Alternative Fuels Engines and Emissions (CAFEE) continues to engage the challenge of future regulation in a multi-pronged approach, investigating advanced combustion regimes, alternative fuels, and next-generation emissions control technology. Results presented herein summarize recent regulatory challenges for compression ignition engines and discuss future pathways [12]. In order to achieve high pollutant reduction efficiencies exhaust gas temperatures are being raised via thermal management strategies that in most cases adversely affect fuel consumption which stands in direct contrast to increasingly stringent fuel economy requirements by the U.S. Environmental Protection Agency. Additionally, projected improvements in thermal engine efficiencies will further escalate this problem by reducing exhaust gas temperatures.[11]

Pragyan P The present investigation is motivated to compare the performance of the engine when run with diesel alone and when it is run with additives like ferric chloride ($FeCl_3$) and diethyl ether. The experiments in the laboratory establish lowering emissions of CO, HC and smoke (excluding NO) with diesel and DEE additives compared to that with diesel and $FeCl_3$ additives and diesel alone [10]. Diesel with $FeCl_3$ combinations as a fuel mixture in the CI engine resulted an improvement of BTE by 8%, reduced the BSFC up to 9% as compared to diesel mode, with highest cylinder peak pressure and temperature observed.[12]

Lyford-Pike et al. operated a 14 litre, six cylinder, diesel engine with an ignition-improved ethanol. Hydrated ethanol (95% v/v) was used together with additives for ignition improvement, lubrication and protection against corrosion. The composition of the fuel was developed by Mercedes-Benz with the following additives:

(a) Alicolita (4.5% v/v)-this is a Tri Ethyl Glycol Di - Nitrate (TEGN) based additive; it promotes self - ignition in ethanol and mixes with hydrated ethanol.

(b) Castor oil (1 % v/v) - used to improve the lubricating properties of ethanol.

(c) Max lub 8027 (0.025% v/v) - used for protection against corrosion.

They modified the engine by operating it at different higher compression ratios, with the inclusion of a turbocharger, change of injectors, injection timing and duration and calibration of the fuel pump. They reported that by doing all this, the engine attained high in-cylinder temperatures and pressures necessary to promote self-ignition and to sustain combustion. They changed the compression ratios to evaluate their effect on ignition delay for the ethanol operation. They concluded that, an overall decrease of 5 oCA in ignition delay was observed with an increase in compression ratio from 15.8:1 to 16.5:1. The engine attained a peak cycle pressure of 114 bar and achieved the same power output as that of diesel operation in the same engine. At rated load, the brake thermal efficiency of the alcohol engine was 38%, better than that of the corresponding diesel engine. The opposite was true at part load conditions.[23]

Hodgson evaluated the performance and emissions of a Perkins based naturally aspirated, 4 cylinder, DI diesel engine, running on ignition improved ethanol and methanol at a compression ratio of 16:1, which was the same as that for a diesel fueled engine. They changed the fuel pump and injectors to allow for expected larger fuel deliveries with the alcohol fuels. Higher brake thermal efficiency was reported when running on ignition improved ethanol than with gasoil on the corresponding standard engine.[24]

Ren et al.studied the combustion and emission characteristics of a DI diesel engine, fueled with the diesel-ethanol blends (E5, E10, E15 and E20) and an ignition improver. They have added 0.2 vol% CN improver (isoamyl nitrite) with 5, 10, 15 and 20 vol% ethanol fraction in diesel. The ignition delay and premixed combustion duration of fuel blends with E10 and additives were found to be similar to those of diesel. They reported that the maximum rate of heat release increased with the increase in the ethanol mass fraction in the blends compared to that of diesel. The diesel equivalent BSFC was found to be lower, with an increase in the ethanol fraction at full load. Also, there was a simultaneous reduction of NOx and smoke compared to that of diesel.[25]

Can et al. added an unsaturated fatty acid-based solvent as an additive and isooctyl nitrate as an ignition improver to the ethanol (10–30 vol%) -diesel blend in a single cylinder engine. The physicochemical properties and stability of the blend was observed to be improved. Also, they concluded engine emissions varied with changes in engine operating conditions, ethanol content, additives and ignition improver.[26]

Ashok added DME, DEE and $H_2O_2$ as additives with the diesel-ethanol emulsified fuel, and studied the performance, combustion and emissions of a diesel engine using these emulsified fuel. He showed that the higher cetane number of DME and DEE has led to a better performance, combustion and emission of a diesel engine. The oxygen enriched DME and DEE provided a lesser fuel consumption than $H_2O_2$ added ethanol diesel emulsion fuel. The presence of oxygen in the fuel reduces self-ignition temperature and increases cetane number. As a result, the emulsified fuels with DME and DEE start burning early but release a lesser amount of heat with the improvement of premixed combustion phase. He stated that more the oxygen-enriched additive in fuel, higher is the value for cetane number of emulsified fuels and lower is the NO emission. Also, he concluded that the addition of DME and DEE with 50:50 ethanol-diesel emulsion have shown to improve BTE.[27]

Ashok extended the investigated to study effect of using emulsified ethanol-diesel fuel with 5% water and 6% H2O2 with the presence of hydrophilic surfactant TWEEN80. He concluded that the emulsified fuel without water showed a better performance than same with water. The presence of water reduces the quantity of free oxygen in the emulsion and hence the cetane number of the same.[28]

## 2.3 LITERATURE SUMMARY

It is clear from the survey of various papers that DEE possesses properties which are appropriate for using it as a fuel in CI engines. DEE being an oxygenated fuel is likely to reduce $NO_x$ and HCs. Density and viscosity of DEE is less as compared to diesel, so its addition to diesel fuel will reduce the density of blends resulting in enhanced combustion and spray characteristics. Droplet size estimated to be decreasing due reduced density of blends which may reduce the knocking combustion if DEE is added in appropriate qu

antities. After going through various literatures it can be deduced that DEE is a potential fuel for diesel engine in future.

### 2.3.1 GAPS IDENTIFIED

In the above review of numerous researches done, after meticulously analyzing them certain gaps are found on which further research could be done. So identified gaps are:

- Physical properties of fuel blends with DEE are not investigated experimentally.
- The effect of varying quantity of DEE as fuel is not investigated in ternary blends with jatropha biodiesel.
- The knock limiting quantity for fuel blends with DEE is an untouched issue till date.
- Performance of particular fuel blend with DEE at different engine parameters like compression ratio, speed, a/f ratio is not performed till now.
- Spray characteristics for both the fuels are analyzed numerically but no experimental validation is present.
- Emission characteristics of ternary blends of DEE with jatropha biodiesel and diesel are not revealed.

So, above given are some of the identified gaps on which the future works will be based.

### 2.3.2 OBJECTIVE

The objective of the present work is:

- Comprehensive literature survey.
- Determination of physico-chemical properties of ternary blends of DEE with jatropha biodiesel in diesel.
- Investigation of spray characteristics of different blends using Malvern Spraytec.
- Study of performance of single cylinder air cooled engine when used with ternary blends.
- Studying the emission characteristics of single cylinder air cooled engine using blends of DEE.
- Analysis of results.

# CHAPTER 3

# SYSTEM DEVELOPMENT AND EXPERIMENTAL PROCEDURE

## 3.1 PHYSICO-CHEMICAL PROPERTIES TESTING

Different physico-chemical properties of prepared ternary blends of $C_4H_{10}O$ (DEE), jatropha biodiesel in diesel are measured using respective lab apparatus. Properties measured are density, specific gravity, kinematic viscosity and calorific values are measured. Physico-chemical properties gives the pre-requisite estimation of fuels performance in a particular engine. These properties governs processes such as fuel injection, engine lubrication etc. The word physico-chemical is a combination of physical and chemical which takes into consideration both the aspects of a fuel blend. In the course of investigating the physico-chemical properties both ternary blends and binary blends of DEE and jatropha biodiesel in diesel are experimentally investigated.

### 3.1.1 DENSITY AND SPECIFIC GRAVITY

Density and specific gravity of the fuel are one of the most important physical properties in context of fuels for compression ignition engine. Density and specific gravity are relevant for fuel injection operation. Higher the density and specific gravity of fuel more average pressure differrence across the nozzle will be required for fuel injection hence more power will be required to pump the fuel into the chamber.

Power required to introduce the fuel in to the cylinder, $P=\Delta p \times Q_i$

where, $\Delta p= p_{injection}-p_{atm}$ (Pa)

$Q_i$= flow rate of fuel ($m^3/s$)

where, V= velocity of fuel trough nozzle

$\theta$= angular displacement of crank during fuel injection

$N_i$= N for 2-stroke engine

N/2 for 4-stroke engine

Density and specific gravity are measured by Anton Par DMA-4500 density meter. Both properties are measured at 15˚C standard condition for which the apparatus was calliberated.


**Figure 6: Automatic Density meter Anton Par DMA 4500**

## THE OSCILLATING U-TUBE METHOD

The sample is introduced into a U-shaped borosilicate glass tube that is being excited to vibrate at its characteristic frequency. The characteristic frequency changes depending on the density of the sample. Through a precise determination of the characteristic frequency and a mathematical conversion, the density of the sample can be measured. The density is calculated from the quotient of the period of oscillations of the U-tube and the reference oscillator" Density and specific gravity of our ternary and binary blends are measured and values are displayed in tables below:

**Table 2: Specific Gravity and Density of different Blends**

| BLENDS | Specific Gravity | Density ($g/cm^3$) |
|---|---|---|
| DEE2.5B2.5 | 0.8253 | 0.82456 |
| DEE5B5 | 0.824 | 0.8235 |
| DEE7.5B7.5 | 0.8252 | 0.82444 |
| DEE10B10 | 0.8274 | 0.82667 |
| Diesel | 0.8242 | 0.825 |
| DEE | 0.7134 | 0.7117 |

### 3.1.2 KINEMATIC VISCOSITY

In this thesis, kinematic viscosity is measured using Automatic Viscosity Meter (Viscobath). Viscobath measures viscosity interms of seconds. Viscosity is measured at 40˚C according to the standards. Sample whose viscosity is to be measured is filled into the capillary and then the capillary is placed into the viscobath. Start the stopwatch when meniscus reaches the upper mark then stop the stopwatch when meniscus reaches lower mark. The recorded time in seconds is multiplied with constant of capillary tube.

$$\upsilon = k \times t$$

k= 0.02702 $mm^2/s^2$, constant of capillary tube

t= time recorded by stopwatch (sec)


**Figure 7: Automatic Viscosity Meter (Viscobath)**

The most common technique used to measure kinematic viscosity is the capillary action due to gravity. It is temperature controlled at 40 ºC for single grade oils and both 40 and 100 ºC for multi-grade oils. The relation between viscosity and time determine the measurements using capillary viscometers. If the oil is more viscous then it will take more time to flow through the capillary under the influence of gravity alone. a number of standardized capillaries are used today. Most lab instruments use tubes or capillaries which is made of glass.

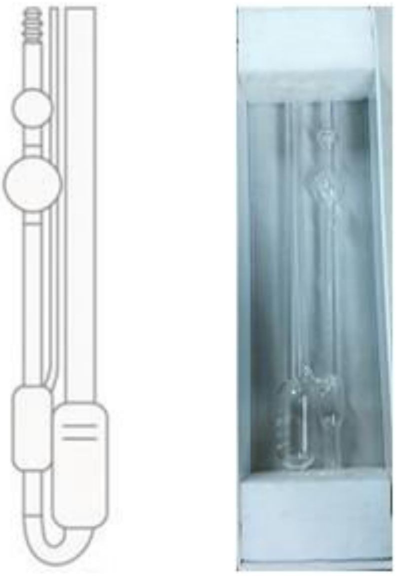


**Figure 8: Capillary used in Viscosity Measurement**

**Table 3: Kinematic Viscosity of Different blends**

| BLENDS | Kinematic Viscosity ($m^2/s$) |
|---|---|
| DEE | $2.224\times10^{-6}$ |
| DEE2.5B2.5 | $2.6925\times10^{-6}$ |
| DEE5B5 | $2.6835\times10^{-6}$ |
| DEE7.5B7.5 | $2.62094\times10^{-6}$ |
| DEE10B10 | $2.6177\times10^{-6}$ |
| Diesel | $2.702\times10^{-6}$ |

### 3.1.3 CALORIFIC VALUE

Calorific value of prepared samples were measured using Parr 6100 Automatic calorimeter. Sample is firstly placed in a cupola and a Nichrome wire is dipped into the sample. Then the cupola is placed into the bomb. Now oxygen is filled into the bomb for combustion process to occur. Now test run is started, after 15 min. calorimeter automatically displays reading of calorific value in terms of Cal/kg.

Density of DEE-diesel with jatropha biodiesel were measured using an Automatic Microprocessor controlled Calorimeter 6100 Calorimeter Operation as shown in figure 9


**Figure 9: Parr 6100 Automatic Calorimeter**

**Table 4: Measured Calorific Value Of Different blends**

| BLENDS | CALORIFIC VALUE (MJ/kg) |
|---|---|
| DEE | 33.9 |
| DEE2.5B2.5 | 46.57 |
| DEE5B5 | 45.94 |
| DEE7.5B7.5 | 46.2 |
| DEE10B10 | 44.92 |
| Diesel | 45.0 |

## STEPS WHICH ARE INVOLVED IN FINDING OUT THE CV

1. Turn on the calorimeter- The calorimeter will boot up to the main menu.
2. Turn on the Oxygen Supply.
3. Go to the Calorimeter Operation menu.
4. Prepare a Sample- Take (zero the weight of) a combustion capsules. Weigh a sample of the blend to the nearest .0001 mg between .6 to .8 gm
5. Put the sample on the head- Attach a fuse wire. The fuse wire should dip inside the weighted sample
6. Load the head into the bomb cylinder. Turn on the cap as far as it will go. Do not over-tighten or loose fitted.
7. Place the Oxygen Fill Connection on to the bomb cylinder.
8. Touch the O2 Fill tab on the Operation screen. Oxygen will stream into the bomb cylinder. A timer will count down the load time. Pressing the O2 Fill key while the timer is counting down will end the fill process.
9. Fill the bucket with approx 2 liters of distilled water.
10. Place the bucket inside the calorimeter.
11. Using the bomb lifter setting the bomb part way into the bucket.
12. Connect the ignition wires to the terminals on the bomb head. Keep away from getting your fingers damp.

## 3.2 SPRAY CHARACTERISTICS

Atomized particle and drop size estimation are core characteristics for defining fuel performance across numerous applications such as introduction of drugs into human inhalation system through the application of coatings and agro-chemicals. In each application sprays incur unique challenges, in terms of surroundings within which measurements have to be made or transmittance of the event to be characterized. Malvern spray-tec is designed to leap across these challenges and delivers exact and precise spray characteristics analysis.

### 3.2.2 MALVERN SPRAYTEC

Malvern Spraytec is an instrument setup designed to analyze sprays of high concentrations and sprays from a robust, easy to use interface. A real time laser diffraction measurement characterizes both intermittent and continuous events. Data regarding extensive size distribution are generated rapidly and presented in a form that allows for an instant understanding of the evolution of atomization over the time. The system’s versatile design enables it to meet the requirements for routine spray characterization, from fundamental research application through to product QC and batch testing.

**FEATURES POSSESSED BY MALVERN SPRAYTEC ARE:**

- Rapid Measurement: Acquisition rate is 100kHz which delivers the estimation of complete particle size contour every 100µsec resulting in accurate investigation.

- Size Range: It covers the size range 0.1-2000µm using just couple of lenses.

- Simple Operation: SOP record all the important hardware and software parameters associated with a method. System is aligned and configure itself automatically.

- Robustness: Optical design prepared by Malvern allow us to measure over large working ranges.

- High concentration analysis is possible.

- Evocative Data Analysis: Gives unique data charts enables us to change and manipulate particle size.

- Compliance is Regulatory: International standards are met by Malvern Spraytec recommended for laser diffraction measurement ISO13320:2009.

**Figure 10: Malvern Spraytec Laser Diffraction Instrument [29]**

### 3.2.3 PROCEDURE OF ANALYSIS

An exceptionally impressive software interface controls the measurement capabilities access to ensure precise measurements.

Step1-

Setup your Standard Operating Procedure (SOP) using the system's integrated method definition wizard. SOP slock down all aspects of the measurement processs including the hardware configuration, analysis settings, triggering options, result parameter reporting and data averaging. Online help supports method specification for different spray types.

Step 2-

Run the measurement by selecting the desired SOP from the menu system. This automatically configures the system and ensures everything is optimally set to deliver accurate results, including auto-alignment of the optical system. Synchronization of external systems such as extractors, actuators and positioning systems is also supported.

Step 3-

Observe each stage of the measurement via the software's measurement manager. This allows the user to monitor all aspects of the measurement and analysis process. Prompts ensure that the correct sample preparation, handling and disposal procedures are followed.

Step 4-

View the results using the size history window. This displays the recorded particle size distributions along with a size history chart showing how the spray developed over time. Users can playback the spray event and select records for further analysis.

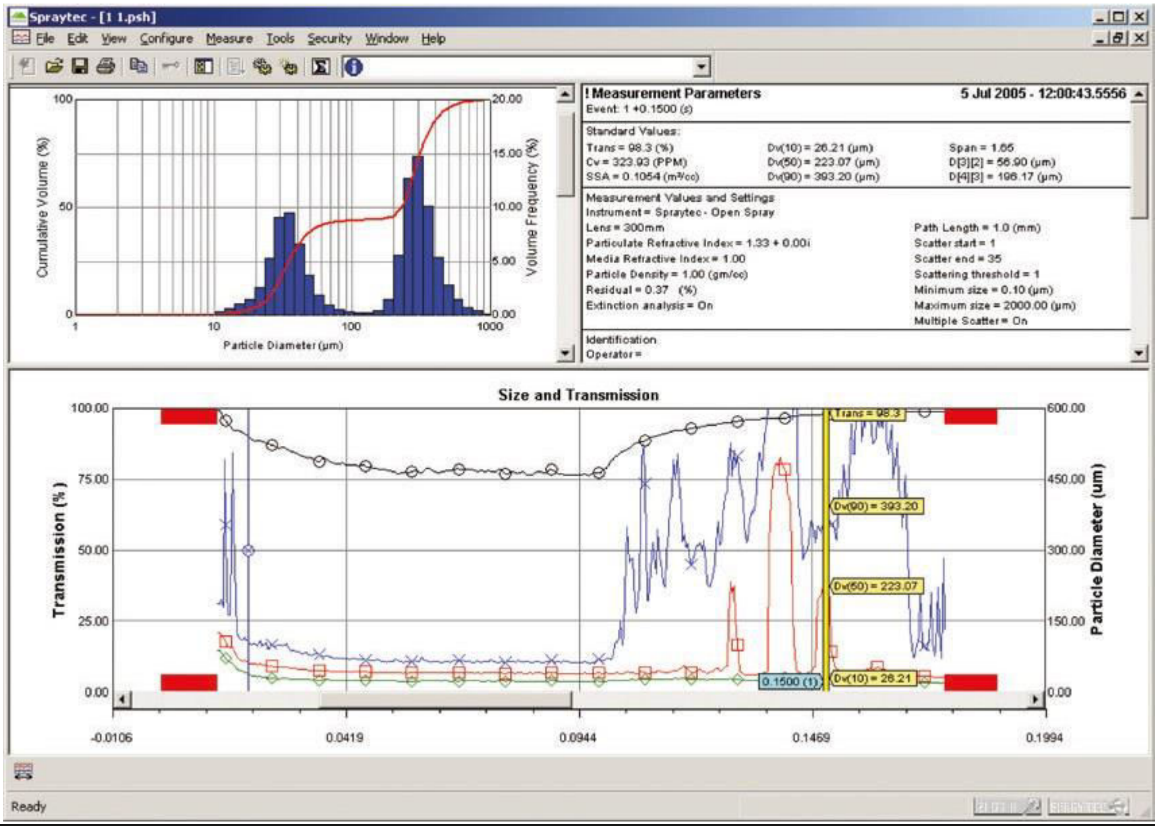



**Figure 11: Malverna Spraytec Manual Operation Window**

## 3.3 ENGINE SELECTION

There is no doubt in the fact that India is going to face a ruthless fuel crisis in coming days because fuel consumption has increased in all the vital sectors particularly in transportation and agricultural region. As diesel engines plays an important role in transportation and agriculture region and as such diesel consumption will increase in the coming time.

In India, roughly all irrigation pump sets, tractors, mechanized farm machinery and heavy transportation vehicle are powered by direct injection diesel engines. Considering the wide application of a small capacity diesel engine which has got great dominance in Indian agriculture sector, a similar engine has been selected for the present study. The controlling parameters could be changed with suitable arrangement provided in the engines. The single cylinder, vertical, air cooled(radial), four-stroke, diesel engine used for this study is manufactured by Kirloskar. It is commonly used in

India in agriculture, many small and medium scale industries and in residences for emergency power generation. It has a provision of loading electrically since it is coupled with single phase alternator through flexible coupling. The engine can be hand started using decompression lever and is provided with centrifugal speed governor. The engine was started on diesel engine and then it was switched on to the straight vegetable mode where it again run on part load for more than one hour then the real data was taken from zero load to full load.

The cylinder is made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine is of wet sump type, and oil is delivered to the crankshaft and the big end by means of a pump mounted on the front cover of the engine and driven from the crankshaft.

**Figure 12: Test Engine**

**Table 5: Specifications of the Diesel Engine**

| **Make** | **Kirloskar** |
|---|---|
| **Model** | **DAF8** |
| Type | Single cylinder, vertical. DI diesel engine |
| Number of Cylinder | 1 |
| Bore(mm) | 95 |
| Stroke (mm) | 110 |
| Compression Ratio | 17.5 |
| Cooling System | air cooled |
| Cycle | 4-stroke |
| Maximum output power (KW/HP) | 5.9/8.0 |
| Swept volume (cc) | 780 |

## 3.4 SELECTION OF TESTING PARAMETERS

The selection of operating parameters was very important for the accurate monitoring of engine performance and due care was taken to select these parameters. The parameters to be observed are given below.

1. Emission from the exhaust.

2. Power produced by the engines.

3. Fuel consumption.

4. Engine speed (Revolution/min).

5. Temperature.

6. engine speed.

With a view to calculate the parameters mentioned above, it was essential to pick up the following signals from the test bench.

1. RPM of the engine.

2. Current generated by the alternator.

3. Voltage generated by the alternator.

4. Fuel consumption rate.

5. AVL DiTest Gas 1000 BL smoke meter.

Once the parameters were selected, the necessary instruments compulsory for sense these parameters were installed at the suitable points in the investigational set-up.

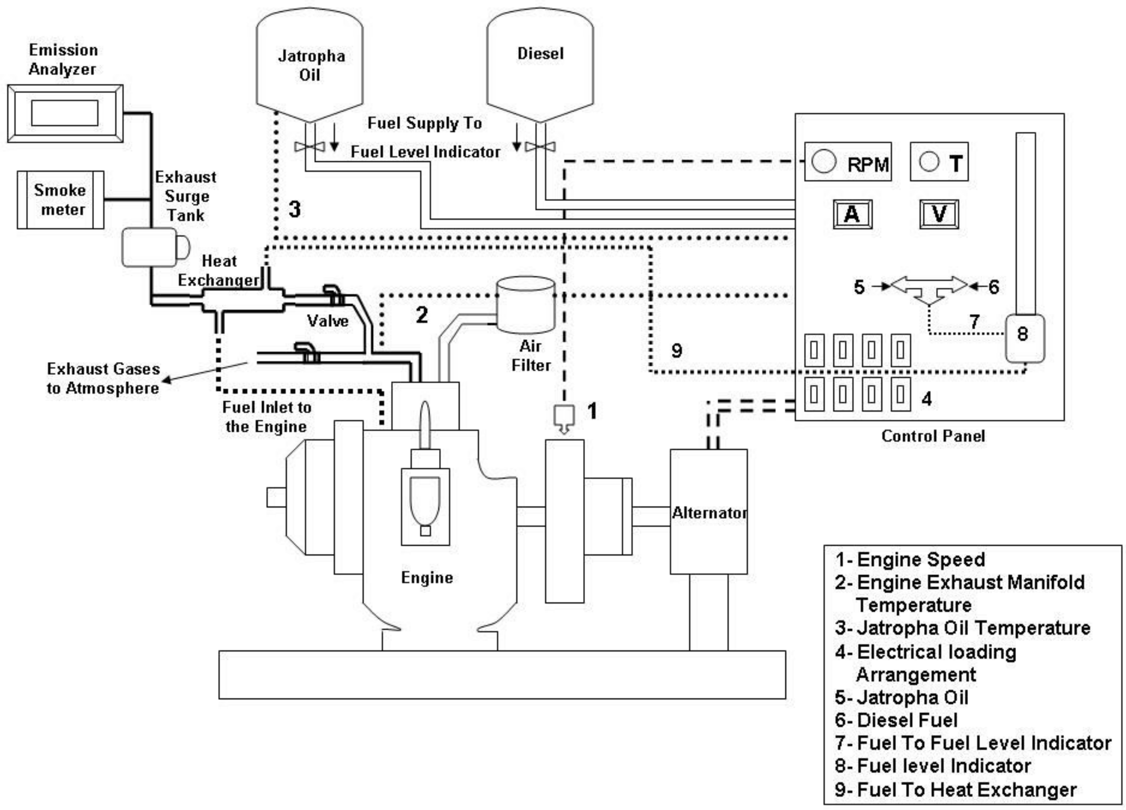



**Figure 13: Schematic Diagram of the Experimental Set Up**

## 3.5 INSTALLATION OF THE INSTRUMENT CONTROL PANEL

After finalizing the procedures for data collection and procurement of the desired instruments, they were put on a panel. A stand was fabricated and a 1020mm×850mm bakelite sheet of 3-mm thickness was mounted on it. Instruments such as voltmeter, ammeter, speed counter, six channels digital temperature display was mounted on the front side of the control panel. Electrical load banks, i.e., 12 bulbs each of 500 watts, were mounted on the rear side of the control panel which is shown in and their switches provided on the front side of the control panel.

One burette with stop cocks and two way valves were also mounted on the front side of the panel for fuel flow measurements and selecting between either diesel fuel or jatropha oil. The two fuel tanks were mounted on the rear side of the panel at highest position as shown in figure 14


**Figure 14: Control Panel**

**Figure 15: Load Bank**

## 3.6 FUEL FLOW MEASURING SYSTEM

The fuel consumption of an engine is measured by determining the time required for consumption of a given volume of fuel. The mass of fuel consumed can be determined by multiplication of the volumetric fuel consumption to its density. In the present set up volumetric fuel consumption was measured using a glass burette. The time taken by the engine to consume a fixed volume was measured using a stopwatch. The volume divided by the time taken for fuel consumption gives the volumetric flow rate. The test facilities were built up for measuring both diesel and jatropha oil consumption rates. For this, two separate tanks, one burette, and a number of valves were provided on the panel as shown in figure 16

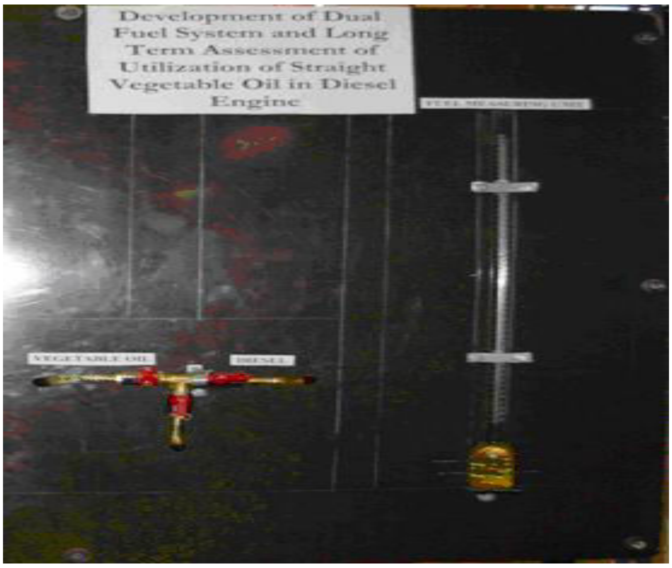



**Figure 16: Fuel Flow Measuring System**

This test was carried out only after the preliminary run. After stable operating conditions were experimentally achieved, the engine was subjected to similar loading conditions. Starting from no load, observations were recorded at 20%, 40%, 60%, 80% and 100% of the rated load.

The brake specific fuel consumption was calculated by using the relationship given below:

$$bsfc = (V_{cc} \times \ell \times 3600) / (hp \times t)$$

Where, bsfc = Brake specific fuel consumption, g/kW-h

$V_{CC}$ = Volume of fuel consumed, cc

ℓ = Density of fuel, g/cc

hp = Brake horsepower, kW

t = Time taken to consume, cc of fuel, sec.

The brake thermal efficiency of the engine on different fuel blends at different operating conditions was determined using the equation as given below:

$$\eta_{th} = Ks / (HV \times bsfc)$$

Where, $\eta_{th}$ = Brake thermal efficiency, %

Ks = Unit constant, 3600

HV = Gross heat of combustion, kJ/kg

bsfc = Brake specific fuel consumption, g/kW-h

**Rpm of the Engine**

An 'MTC' make digital panel tachometer with proximity/photo reflective sensor was used for measurement of RPM. The instrument is capable of functioning in the range of 1 to 9,999 rpm with a sampling time of 1 second. For measurement, a nut was welded on the flywheel face and sensor was mounted on a bracket near the flywheel in such a way that the distance was less than 5 mm. The display unit is digital and mounted on the panel board. The engine speed measurement arrangement is shown in figure 17

**Figure 17: Engine Speed Measurement**

## 3.7 EXPERIMENTAL PROCEDURE

The speed governor adjusted the diesel injection in an attempt to keep the engine speed constant. The engine was started on diesel fuel and 30 minute time is given for steady condition . One by one all the blends were tested. Keeping the butterfly valve fixed in position load on generator was varied and due to this variation blend quantity is increased by governor to make speed constant. Because given blend combustion quantity varied with load. In a particular load emission measurement is taken out and reading is noted. First reading is taken at no load then 50% 75% 100% of load reading is noted down. There is a series of precaution that are to be taken care off while performing the diesel engine test run. In steady state, readings were taken by the engine. Digital rpm sensor and indicator were used though it was constant speed diesel engine, in order to check the variation in speed from no load to full load and its effect on various other parameters. The load was varied by changing the power output from the alternator side which was connected to the load bank. Digital ammeter, voltmeter were used for performing the test. Thermocouples were used to measure the temperature at the salient point of the diesel engine at running conditions. The output of the thermocouple was fed to the digital temperature indicator with variable junction to indicate the temperature readings. Optimization of the diesel engine hardware is necessary to avoid leakage of energy in order to obtain the results with best of accuracy.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

In this section of the thesis, results from the tests performed in the preceding sections are displayed and discussed. Various tests are performed to determine properties and performance with ternary blends of DEE and biodiesel in diesel. These tests include determination of physico-chemical properties, spray characteristics and engine trials for performance evaluation and emission analysis.

## 4.1 BLENDS PREPARED

**Table 6: Matrrix of Blends Prepared**

| S.no | BLENDS | DEE(% v/v) | BIODIESEL(%v/v) | DIESEL(%v/v) |
|---|---|---|---|---|
| 1 | D100 | 0 | 0 | 100 |
| 2 | DEE2.5B2.5 | 2.5 | 2.5 | 95 |
| 3 | DEE5B5 | 5.0 | 5.0 | 90 |
| 4 | DEE7.5B7.5 | 7.5 | 7.5 | 85 |
| 5 | DEE10B10 | 10 | 10 | 80 |

## 4.2 PHYSICO-CHEMICAL PROPERTIES

Results of tests conducted to measure various physico-chemical properties viz density, specific gravity, kinematic viscosity and calorific value are plotted and displayed below:

Figure 18 shows the variation of specific gravity with percentage replacement of diesel with DEE and jatropha biodiesel.

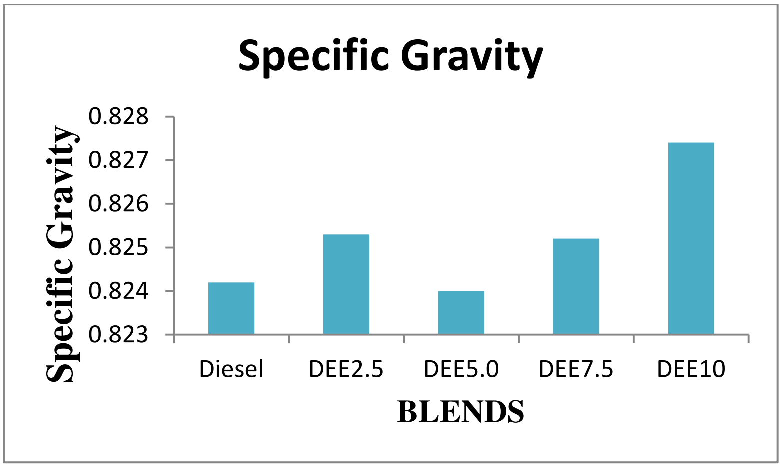



**Figure 18: Variation of Specific Gravity with Percentage of DEE**

Lower specific gravity values are desired for fuel in compression ignition engine. The minimum of specific gravity is witnessed for DEE5B5 (0.824) blend. More than 5% replacement of each DEE and biodiesel results in an increase in specific gravity.

Figure 19 shows the variation of density with percentage replacement of diesel with DEE and jatropha biodiesel.

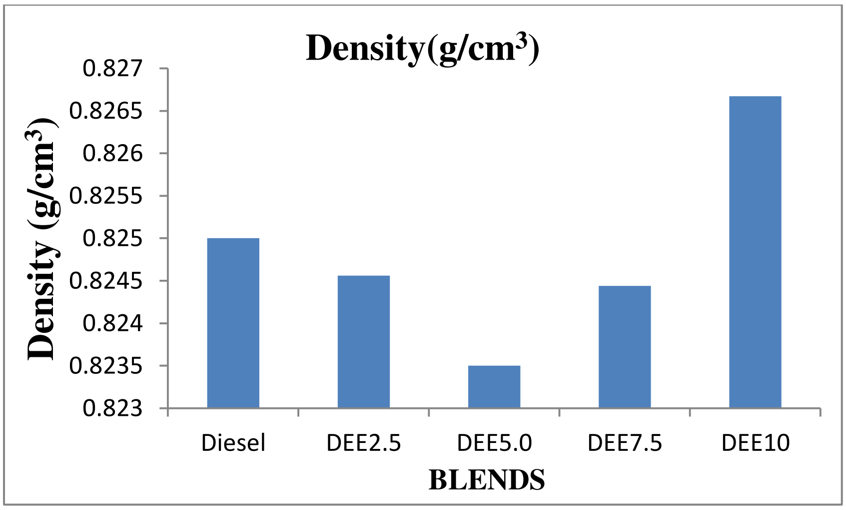



**Figure 19: Variation of Density with Percentage of DEE**

Similar trends for specific gravity and density are witnessed which implies minimum density at DEE5B5 and then increasing trends after the one.

Figure 20 shows the variation of kinematic viscosity with percentage replacement of diesel with DEE and jatropha biodiesel. Kinematic viscosity decreases sharply when replacement exceeds 5%.

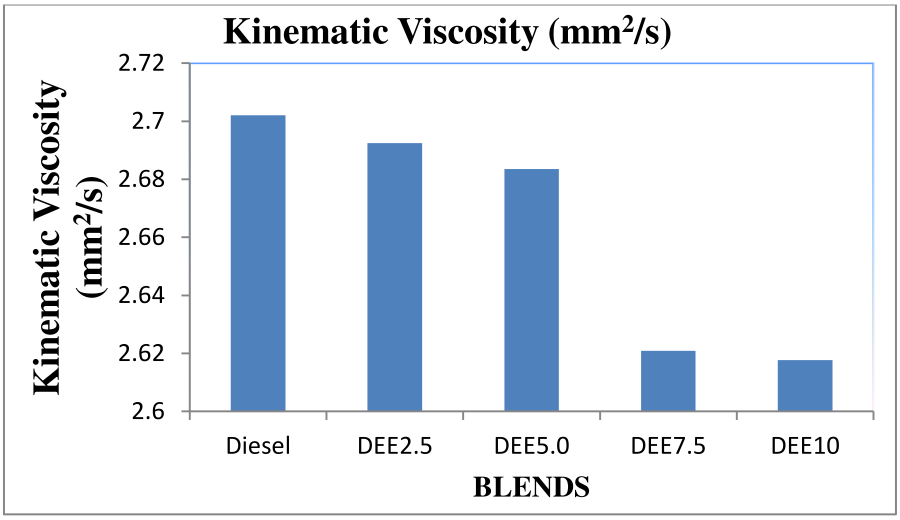



**Figure 20: Variation of Kinematic Viscosity (mm2/s) with Percentage of DEE**

Kinematic viscosity is an important physic-chemical property as far as the engine lubrication and spray characteristics are concerned. Kinematic viscosity drips sharply after DEE5B5 and then shows nearly a constant trend after that.

Figure 21 shows the variation of Calorific Value with percentage replacement of diesel with DEE and jatropha biodiesel.

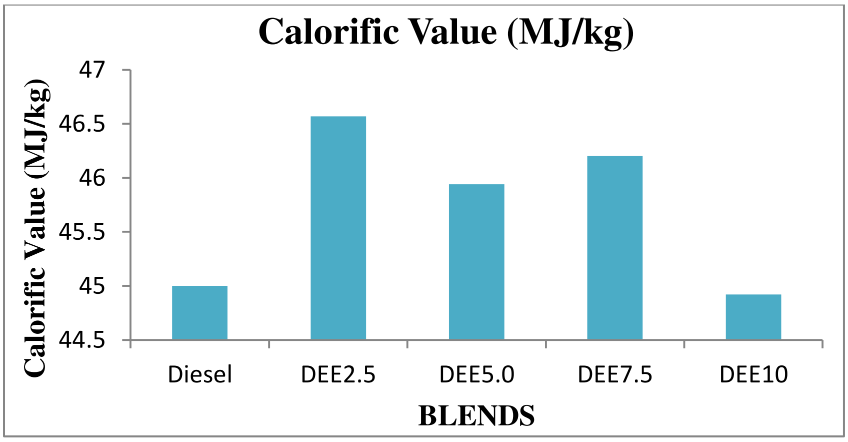



**Figure 21: Variation of Calorific Value (MJ/kg) with Percentage of DEE**

Calorific value of a fuel is the most significant physic-chemical property because it gives an idea about how much energy is supplied to the prime mover in terms of heat. It is said that higher the heating value of the fuel higher will the efficiencies. The blends prepared in this, thesis possesses higher calorific value than diesel except for DEE10B10.

After whole of our discussion about physico-chemical properties it is seen that DEE5B5 possesses quite satisfactory properties for compression ignition engine fuel.

## 4.3 RESULTS AND DISCUSSIONS FOR SPRAYTEC

In fluid dynamics, **Sauter mean diameter** (**SMD**, $d_{32}$ or $D[3, 2]$) is an average of particle size. It was originally developed by German scientist Josef Sauter in the late 1920s. It is defined as the diameter of a sphere that has the same volume/surface area ratio as a particle of interest. Several methods have been devised to obtain a good estimate of the SMD.

SMD is typically defined in terms of the surface diameter, $d_s$:

$$d_s = \sqrt{\frac{A_p}{\pi}}$$

and volume diameter, $d_v$:

$$d_v = \left(\frac{6V_p}{\pi}\right)^{1/3},$$

where $A_p$ and $V_p$ are the surface area and volume of the particle, respectively. If $d_s$ and $d_v$ are measured directly by other means without knowledge of $A_p$ or $V_p$, Sauter diameter for a given particle is

$$SD = D[3,2] = d_{32} = \frac{d_v^3}{d_s^2}.$$

If the actual surface area, $A_p$ and volume, $V_p$ of the particle are known the equation simplifies further:

$$\frac{V_p}{A_p} = \frac{\frac{4}{3}\pi(d_v/2)^3}{4\pi(d_s/2)^2} = \frac{(d_v/2)^3}{3(d_s/2)^2} = \frac{d_{32}}{6}$$

$$d_{32} = 6\frac{V_p}{A_p}.$$

This is usually taken as the mean of several measurements, to obtain the Sauter mean diameter, SMD: This provides intrinsic data that help determine the particle size for fluid problems.

For neat diesel, spray parameters that are recorded during the spray characteristics estimation through Malvern Spraytec are span, path length, cumulative volume, SSA (Specific Surface Area), transmittance and mean sauter diameter.

Span= 1.939

Path Length= 100.00 mm

Cumulative Volume= 1535 ppm

Specific Surface Area= 0.0213 $m^2$/cc

Transmittance= 19.0 %

Sauter Mean Diameter= 281.5 µm

Particle size distribution curve obtained during the spray characteristics test with Spraytec software is given below as Figure 22 for neat diesel.

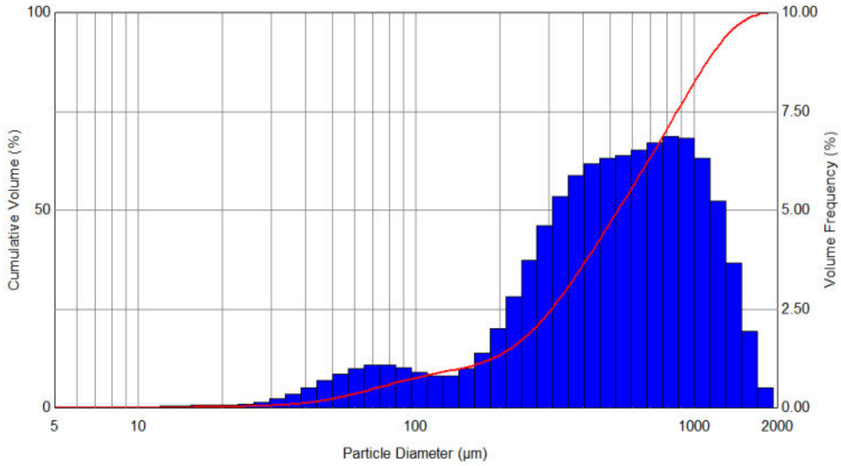



**Figure 22: Particle Size Distribution for Neat Diesel**

For DEE2.5B2.5, spray parameters that are recorded during the spray characteristics estimation through Malvern Spraytec are span, path length, cumulative volume, SSA (Specific Surface Area), transmittance and mean sauter diameter.

Span= 12.48

Path Length= 100.00 mm

Cumulative Volume= 214.4 ppm

Specific Surface Area= 0.1777 $m^2$/cc

Transmittance= 12.2 %

Sauter Mean Diameter= 33.77 µm

Particle size distribution curve obtained during the spray characteristics test with Spraytec software is given below as figure 3 for DEE2.5B2.5.

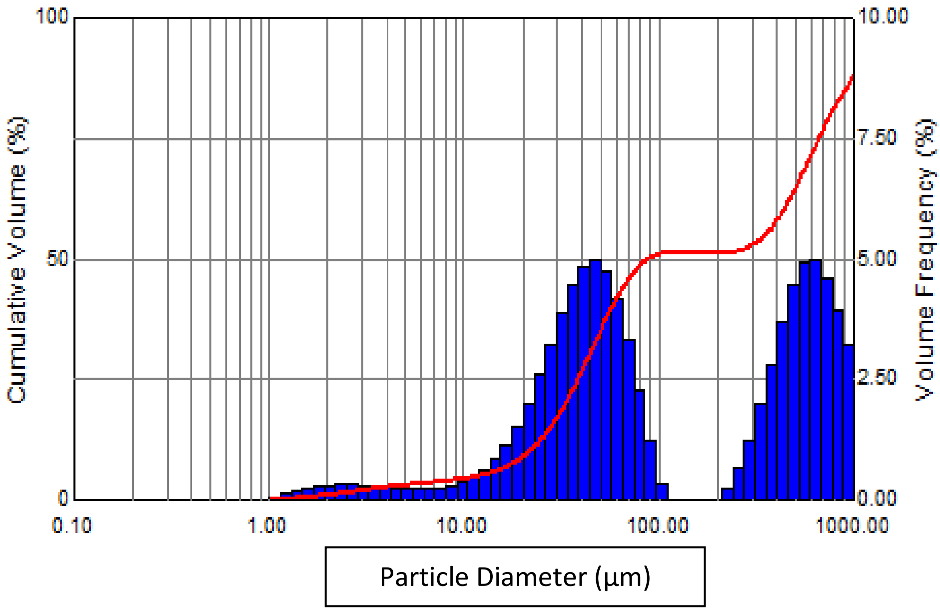



**Figure 23: Particle size distribution For DEE2.5B2.**

For DEE5B5, spray parameters that are recorded during the spray characteristics estimation through Malvern Spraytec are span, path length, cumulative volume, SSA (Specific Surface Area), transmittance and mean sauter diameter.

Span= 24.66

Path Length= 100.00 mm

Cumulative Volume= 59.77 ppm

Specific Surface Area= 0.4138 $m^2$/cc

Transmittance= 24.9 %

Sauter Mean Diameter= 14.5 µm

Particle size distribution curve obtained during the spray characteristics test with Spraytec software is given below as figure 24 for DEE5B5.

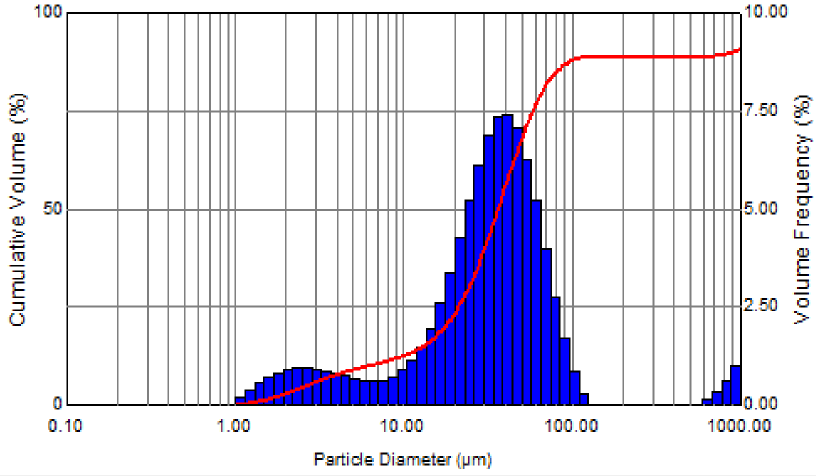



**Figure 24: Particle size distribution for DEE5B5**

For DEE7.5B7.5, spray parameters that are recorded during the spray characteristics estimation through Malvern Spraytec are span, path length, cumulative volume, SSA (Specific Surface Area), transmittance and mean sauter diameter.

Span= 30.67

Path Length= 100.00 mm

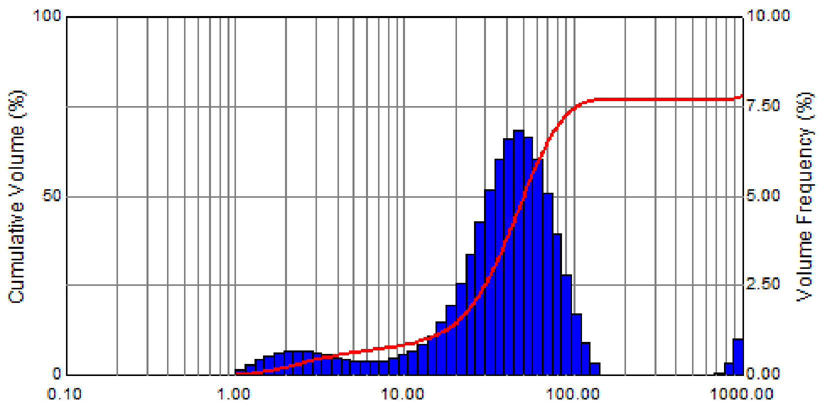
Cumulative Volume= 83.11 ppm

Specific Surface Area= 0.3009 $m^2$/cc

Transmittance= 24.6 %

Sauter Mean Diameter= 19.94 µm

Particle size distribution curve obtained during the spray characteristics test with Spraytec software is given below as figure 25 for DEE7.5B7.5.




Particle Diameter (µm)

**Figure 25: Particle size distribution for DEE7.5B7.5**

For DEE10B10, spray parameters that are recorded during the spray characteristics estimation through Malvern Spraytec are span, path length, cumulative volume, SSA (Specific Surface Area), transmittance and mean sauter diameter.

Span= 1.385

Path Length= 100.00 mm

Cumulative Volume= 1530 ppm

Specific Surface Area= 0.0.0294 $m^2$/cc

Transmittance= 9.2 %

Sauter Mean Diameter= 204.2 µm

Particle size distribution curve obtained during the spray characteristics test with Spraytec software is given below as figure 26 for DEE10B10.

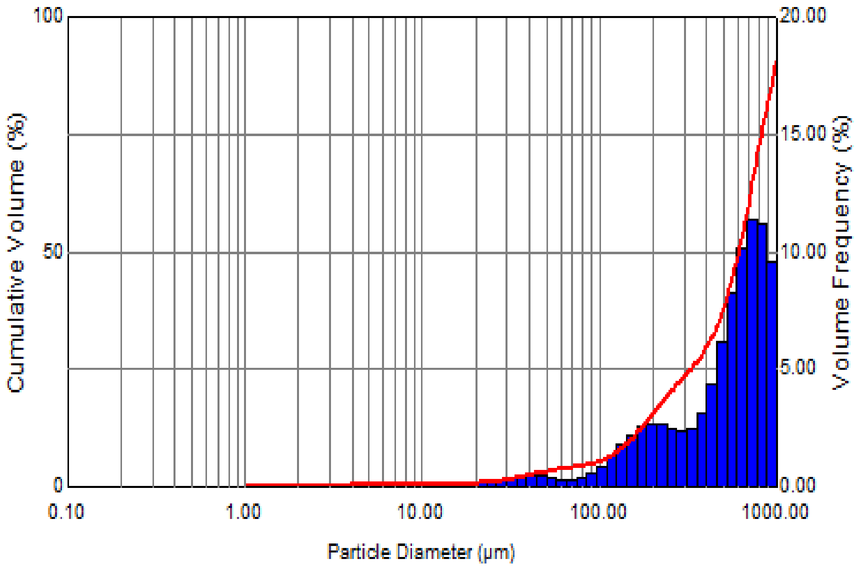



**Figure 26: Particle size distribution for DEE10B10**

Some important patterns are observed for various measurement parameters with varying quantity of DEE and jatropha biodiesel in ternary blends and these patterns are represented in graphical form for different measurement parameters below:

Figure 27 shows the variation of span with percentage replacement of diesel with DEE and jatropha biodiesel.

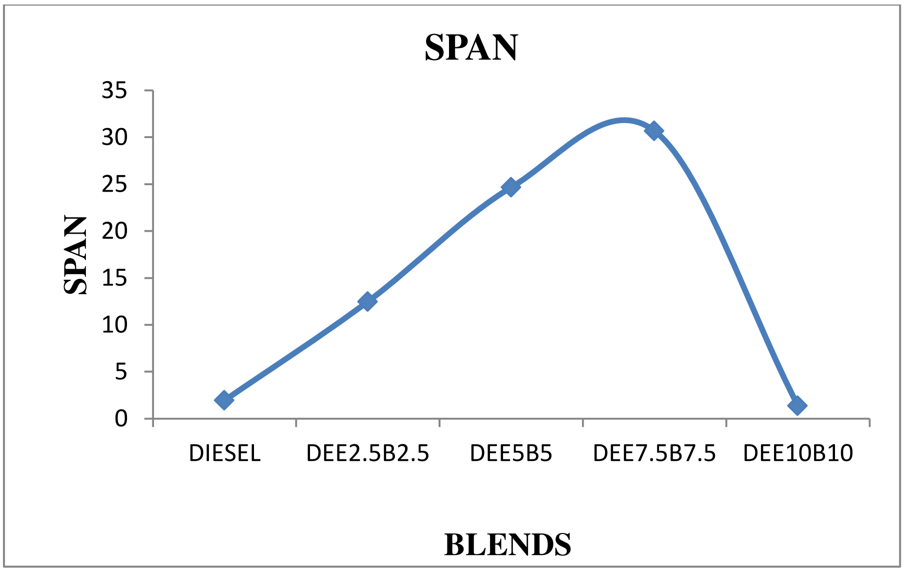



**Figure 27: Variation of Span vs Percentage of DEE**

Span in the test session increases as the percentage of Diethyl ether and biodiesel is increased to certain value that lies in between 5% and 7.5% DEE percentage then drops steeply after 7.5% of DEE proportion. So, the best characteristics for span lies somewhere between 5% and 7.5% blends.

Figure28 shows the variation of cumulative volume in ppm with percentage replacement of diesel with DEE and jatropha biodiesel.

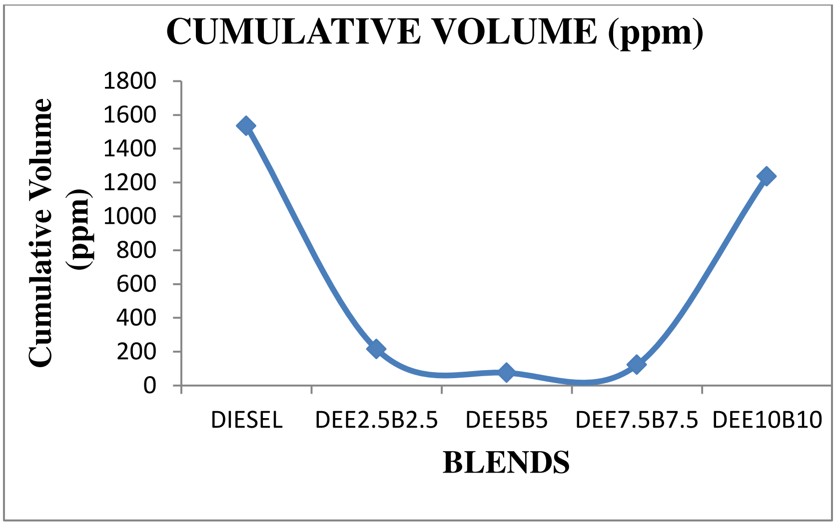



**Figure 28: Variation of Cumulative volume (ppm) vs Percentage of DEE**

Cumulative volume decreases as the percentage of DEE increases and then again increases steeply after 7.5% DEE blend. The minimum of cumulative volume lies somewhere between DEE5B5 to DEE7.5B7.5. So, the optimum cumulative volume characteristics lies between DEE5B5 to DEE7.5B7.5. Cumulative volume is directly associated with Sauter Mean Diameter as higher the Sauter Mean Diameter higher will be the cumulative volume. Sauter Mean diameter is the indicator of average particle size so as result larger particle size results in higher cumulative volume.

Figure 29 shows the variation of Specific Surface Area ($m^2/cm^3$) with percentage replacement of diesel with DEE and jatropha biodiesel. The profile of SSA curve is similar to that of Span. SSA increases with replacement first and then decreases.

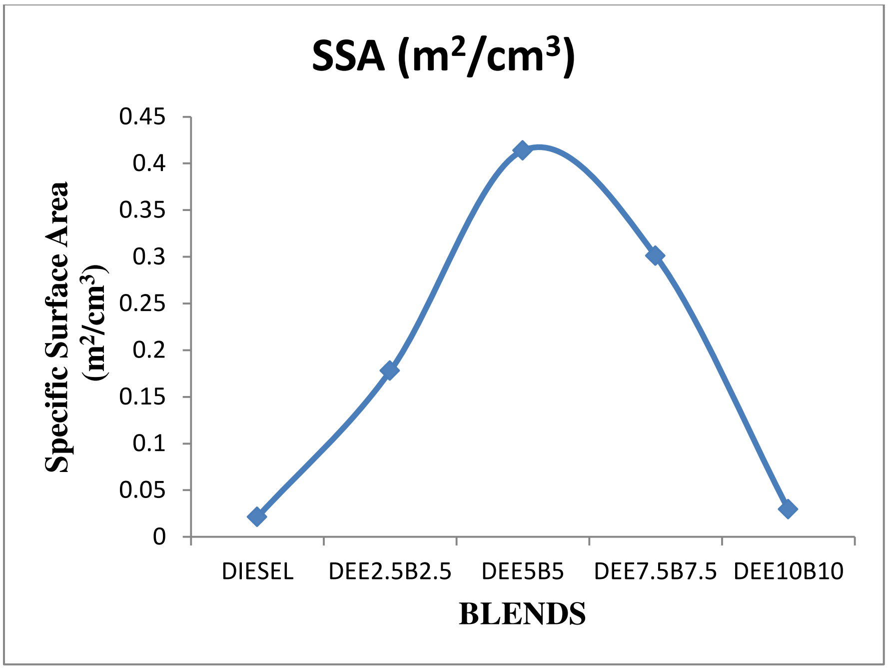



**Figure 29: Variation of Specific Surface Area (sq.m/cu.cm) vs Percentage of DEE**

SSA i.e. the specific surface area of particle which is defined as the ratio of surface area of particle to volume of particle, generally measured in $m^2$/cc. It is the quantity that governs the knocking characteristics in compression ignition engine. Larger the SSA of particle lesser will be the delay period which might ultimately results in good combustion characteristics. According to the above plot the blend that will give best combustion characteristics will lie between DEE5B5 to DEE7.5B7.5.

Figure 30 shows the variation of Sauter Mean Diameter (μm) with percentage replacement of diesel by DEE and jatropha biodiesel. Sauter Mean Diameter reflects the same curve profile to that of Cumulative volume.

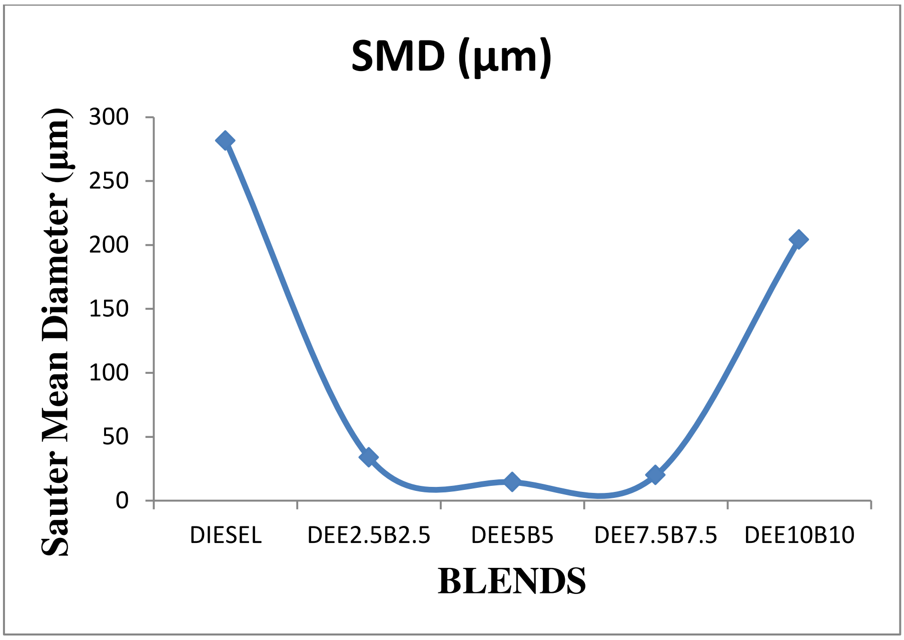



**Figure 30: Variation of Sauter Mean Diameter (μm) vs Percentage of DEE**

Now, lastly, the most important measurement parameter in spray characteristics is SMD (Sauter Mean Diameter) which is the measure of average particle size considering equivalent sphere. Lesser values of SMD is desired for a fuel in compression ignition engine. Least value of SMD lies in between DEE5B5 to DEE7.5B7.5.

## 4.4 ENGINE PERFORMANCE ANALYSIS

A series of engine trials were carried out on a Single cylinder Air Cooled medium capacity Kirloskar diesel engine (DAF) at different loads viz no load, 20% load, 40% load, 60% load, 80% load and at full load with ternary blends of diethyl ether and jatropha biodiesel in diesel. The performance characteristics such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC) and the exhaust temperature were evaluated and plotted against brake mean effective pressure (BMEP). The results were finally compared with baseline data for the diesel fuel.

Performance characteristics as mentioned above are plotted and explained in the following section:

### 4.3.1 BRAKE THERMAL EFFICIENCY

Figure 31 shows the variation of brake thermal efficiency with BMEP i.e. at different loading conditions. The efficiency shows an increasing trend till near about 60% load and decreases afterwards. BTE decreases sharply after 80% load.

Maximum efficiency of 28.4% is witnessed with neat diesel at about 60% load and for blends in which diesel is replaced by DEE and jatropha biodiesel shows a maximum efficiency of 27.9% with DEE7.5B7.5 blend.

The blend that resulted in most inferior efficiency trend is DEE10B10, resulting in a maxima of BTE as 25.1%. In overall prospect, performance of engine in terms of BTE is quite comparable to that with diesel, no significant hampering to engine performance is witnessed with ternary blends of DEE and jatropha biodiesel in diesel. The most superior fuel among the blends was DEE7.5B7.5 giving highest efficiency among all blends.

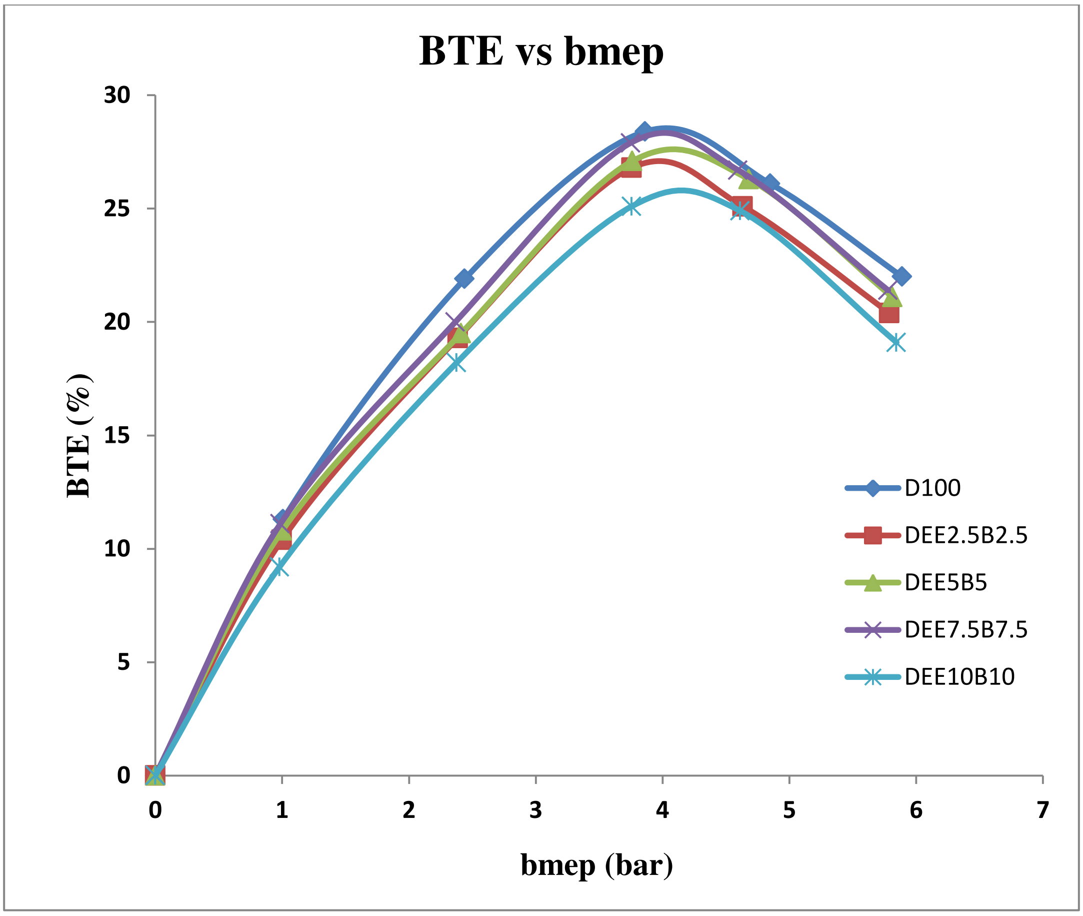



**Figure 31: Variation of Brake Thermal Efficiency with BMEP**

### 4.3.2 BRAKE SPECIFIC ENERGY CONSUMPTION

Figure 32 shows the variation of brake specific energy consumption at different loading conditions. Brake specific energy consumption is plotted against BMEP and the same is compared for different blends at different loads with baseline data of diesel.

Brake specific energy consumption in general for all blends and diesel as well decreases sharply with increasing load till 40% loading condition. Highest brake specific energy consumption is witnessed for DEE10B10 for respective loads. Trends for BSEC for diesel are on the lower sides as compared to DEExBy blends. Maximum BSEC is observed for DEE10B10 at full load i.e. 29458 kJ/kWh.

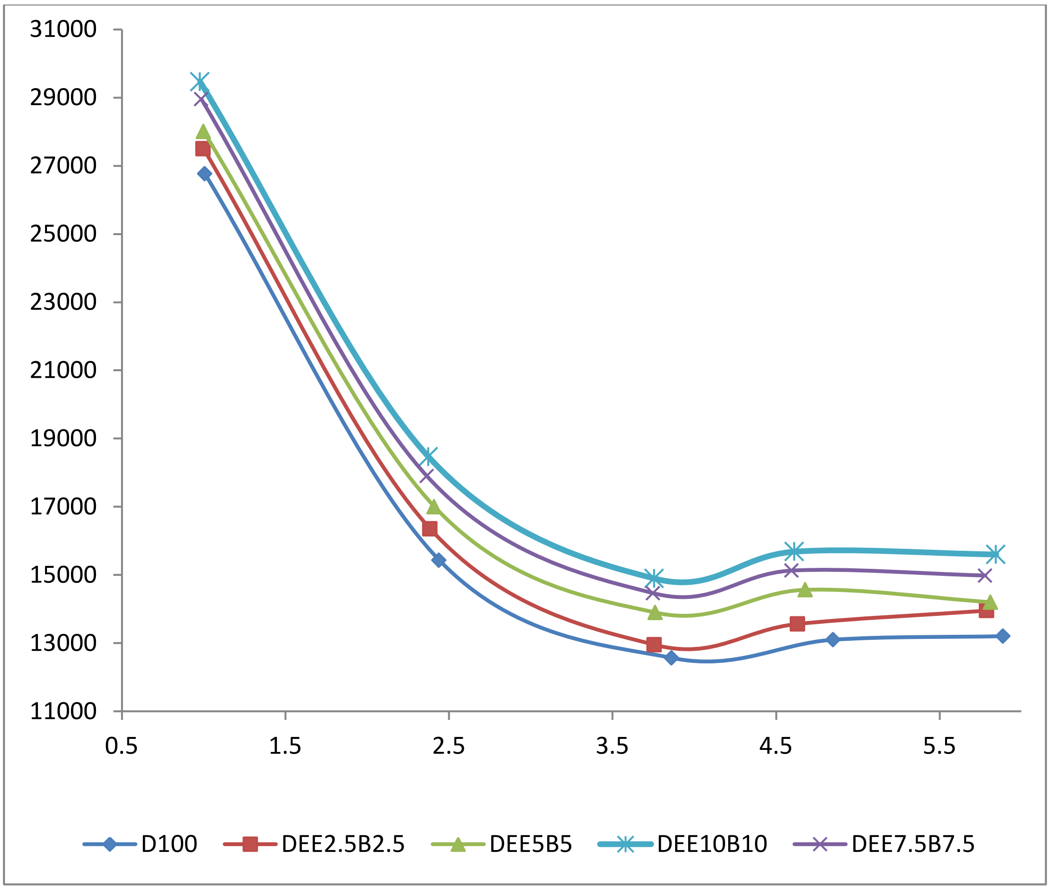



**Figure 32: Variation of Brake Specific Energy Consumption with BMEP**

### 4.3.3 EXHAUST TEMPERATURE (˚C)

Figure 33 shows the variation of exhaust temperature at different loading conditions plotted against BMEP. Exhaust temperature shows an increasing trend with load. Maximum exhaust temperature reached is with diesel fuel i.e. 347˚C at full load while the maximum exhaust temperature is minimum for DEE5B5 i.e. 303˚C.

As far as blends are compared excluding diesel fuel DEE2.5B2.5 shows a maximum exhaust temperature of 322˚C. Diesel shows overall higher exhaust temperature as compared to ternary blends for respective loads and bmep.

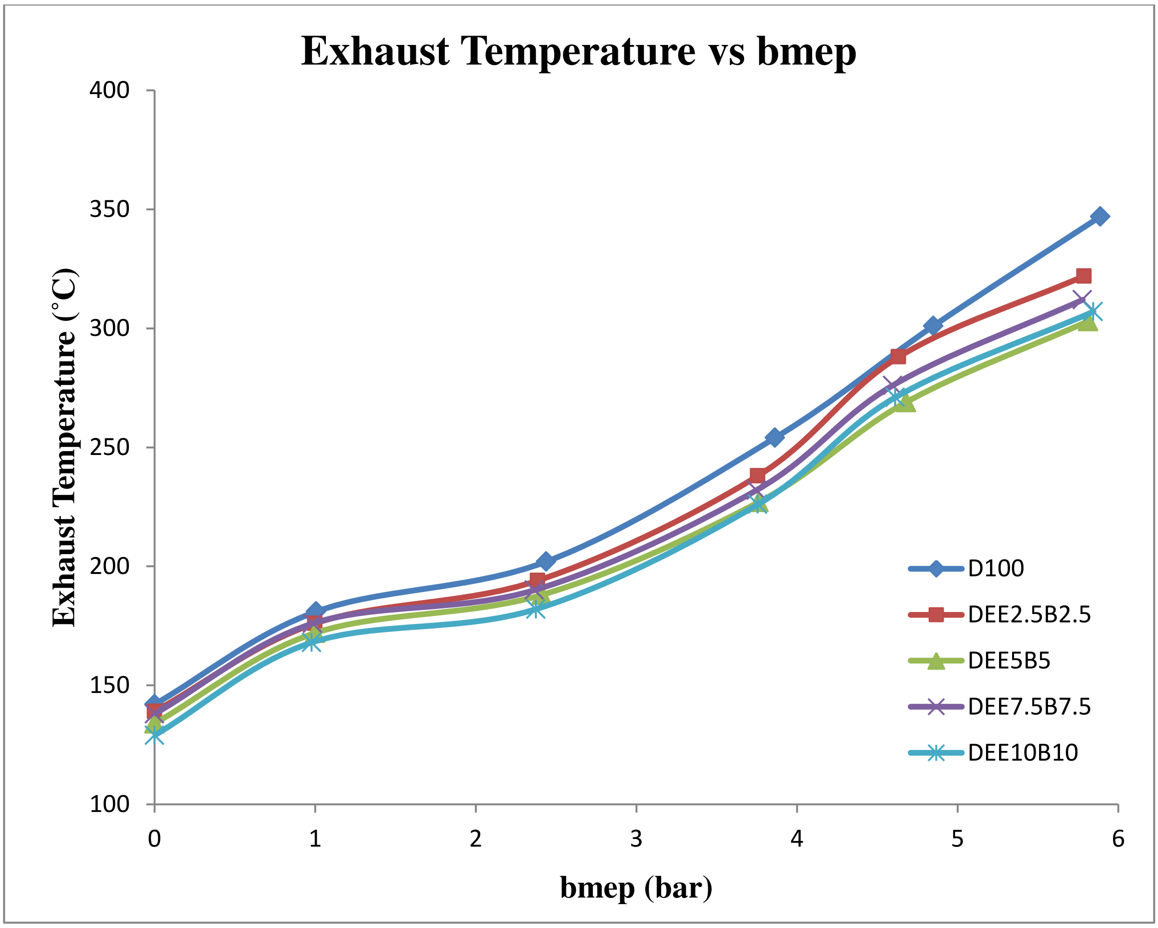



**Figure 33: Variation of Exhaust Temperature with BMEP**

## 4.4 ENGINE EMISSION CHARACTERISTICS

Emission characteristics are also examined using AVL gas and smoke analyzer. Emission characteristics or variation of amounts of gases emitted by engine at different loads are estimated and examined including smoke opacity and plotted against BMEP (brake mean effective pressure).

Engine test was carried out on a CI engine. Diesel and DEExBy are used as a fuel to run the engine. The results of different emission characteristics are given below.

### 4.4.1 CO EMISSIONS

Figure 34 shows the variation of CO emissions at different loading conditions plotted against BMEP. CO emissions are steady till 60% load conditions after 60% load CO emissions rises sharply. CO emissions for diesel, DEEDEE2.5B2.5 and DEE7.5B7.5 are nearly same with no significant variation at respective loads. Emission of CO with DEE2.5B2.5 gives the best result with emission of 0.242%, minimum amongst all at full load. The worst emission reading was recorded for DEE10B10 giving higher emissions at all loads as compared to other blends and diesel as well.

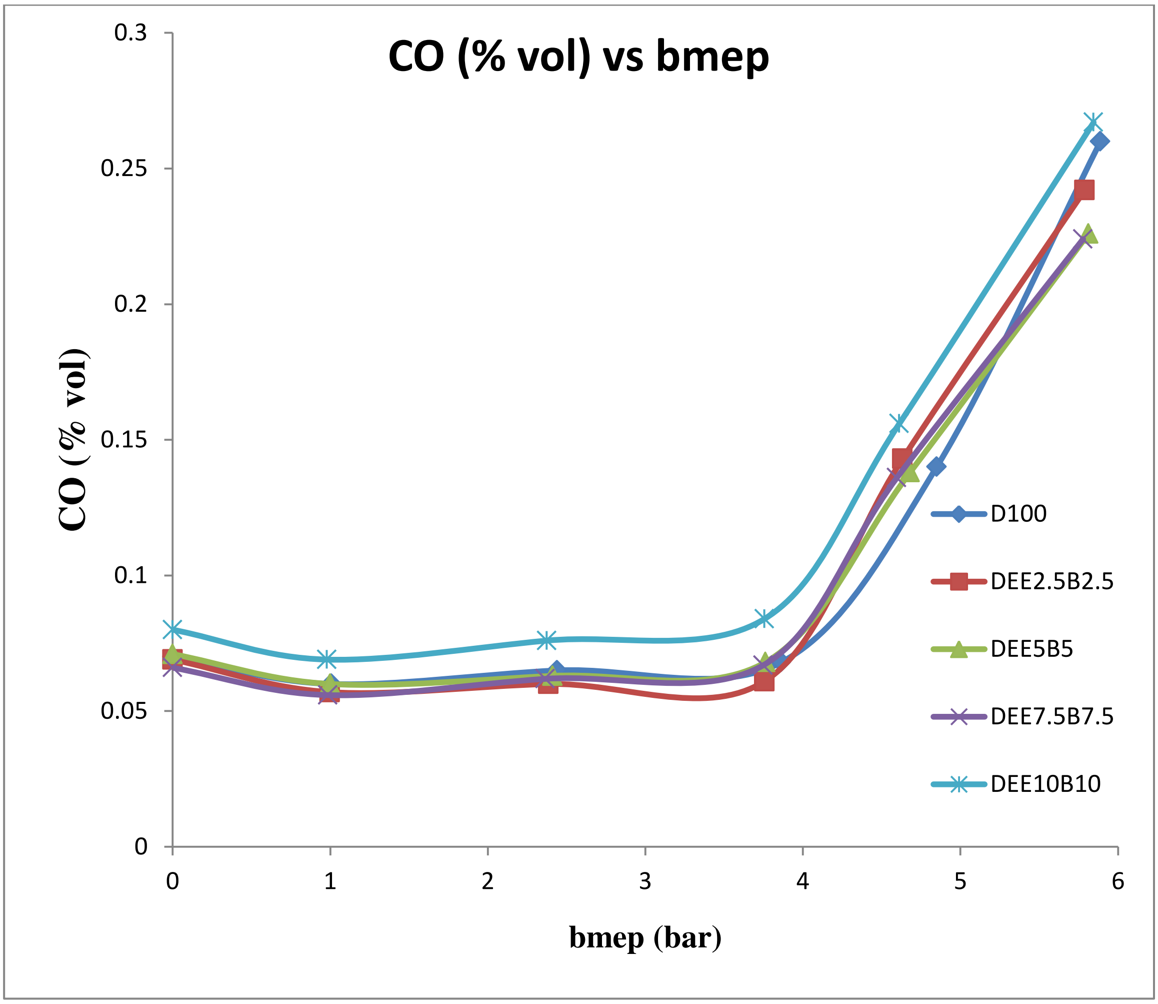



**Figure 34: Variation of CO (% vol) with BMEP**

### 4.4.2 $CO_2$ EMISSIONS

Figure 35 shows the variation of $CO_2$ emissions at different loading conditions plotted against BMEP. $CO_2$ emissions are minimum for diesel as compared to other blends at all loading conditions. A blend where diesel is replaced by DEE, which is an oxygenated fuel, provides excess oxygen atoms resulting in lower CO emission but relatively higher $CO_2$ emissions. Highest emission of $CO_2$ is witnessed for DEE10B10 with maxima at no load condition. $CO_2$ emissions show a decreasing trend as the load increases and an increasing trend as the replacement of diesel increases.

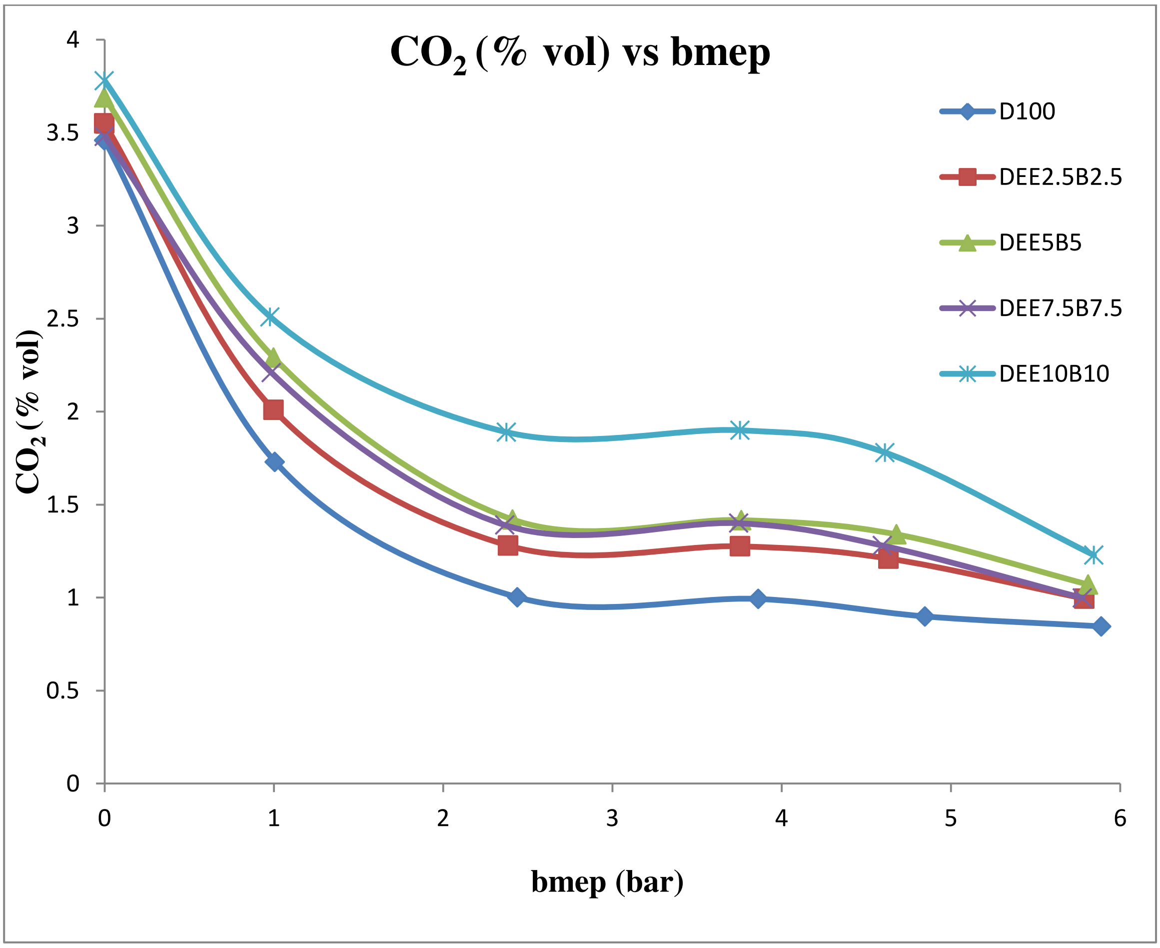



**Figure 35: Variation of CO2 (% vol) with BMEP**

### 4.4.3 HC EMISSIONS

Figure 36 shows the variation of HC emissions at different loading conditions plotted against BMEP. Hydrocarbon emissions increase as the load increases for all the fuel taken into consideration for engine trials. DEE2.5B2.5 shows best hydrocarbon emission characteristics at part load up to 40% load, after tat emissions increases sharply. HC emission for diesel was best after 40% load as compared to all other blends. DEE10B10 resulted in worst case as far as the HC emissions are considered, HC emission for DEE10B10 is higher at all loads as compared to other blends.

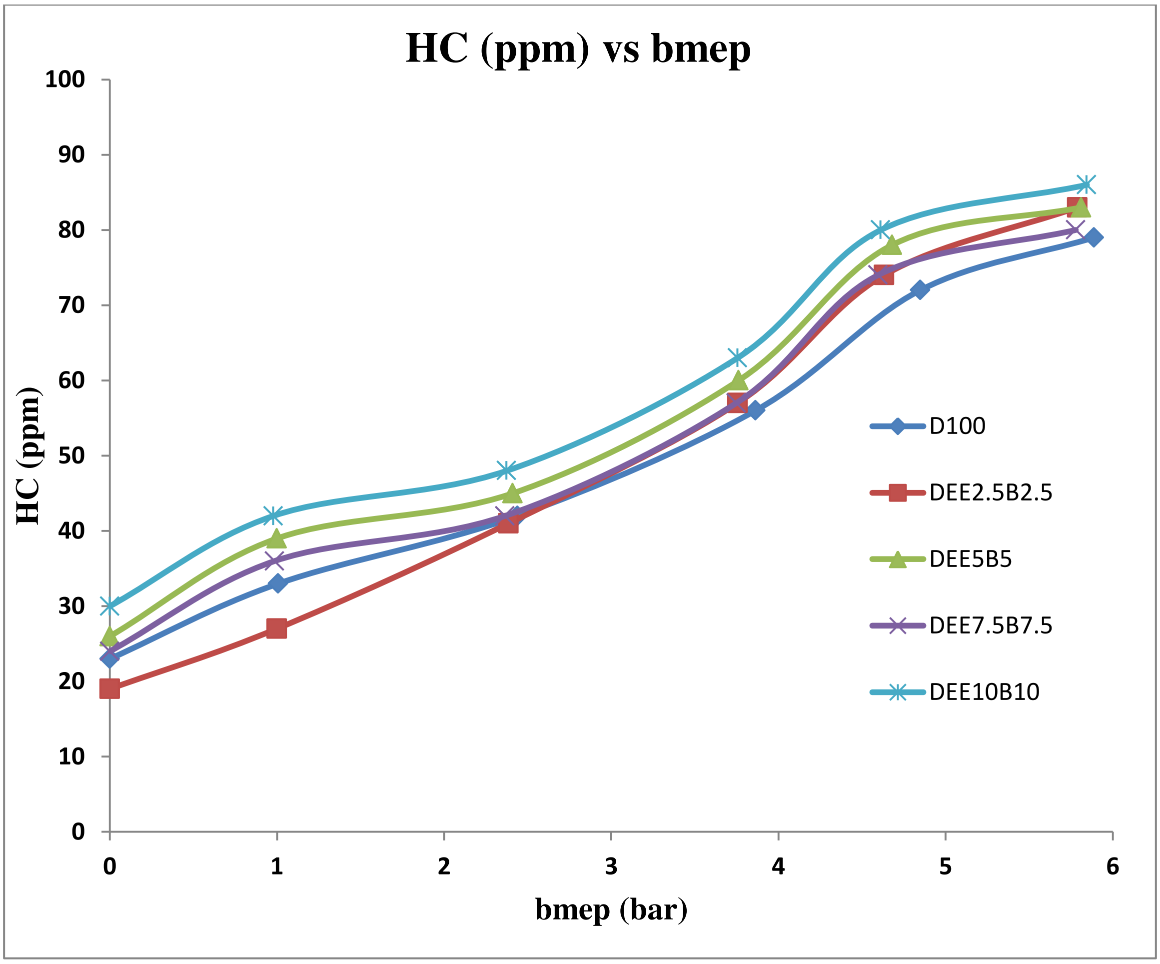



**Figure 36: Variation of HC Emission with BMEP**

### 4.4.4 $NO_X$ EMISSIONS

Figure 37 shows the variation of $NO_X$ emissions at different loading conditions plotted against BMEP. $NO_X$ emissions for diesel and DEE2.5B2.5 are quite comparable and are on higher side in comparison to other blends. DEE5B5, DEE7.5B7.5 and DEE10B10 shows lower $NO_X$ emissions out of which DEE7.5B7.5 gives minimum $NO_X$ at full load viz 666 ppm. Maximum $NO_X$ emission is given by diesel which is 702 ppm.

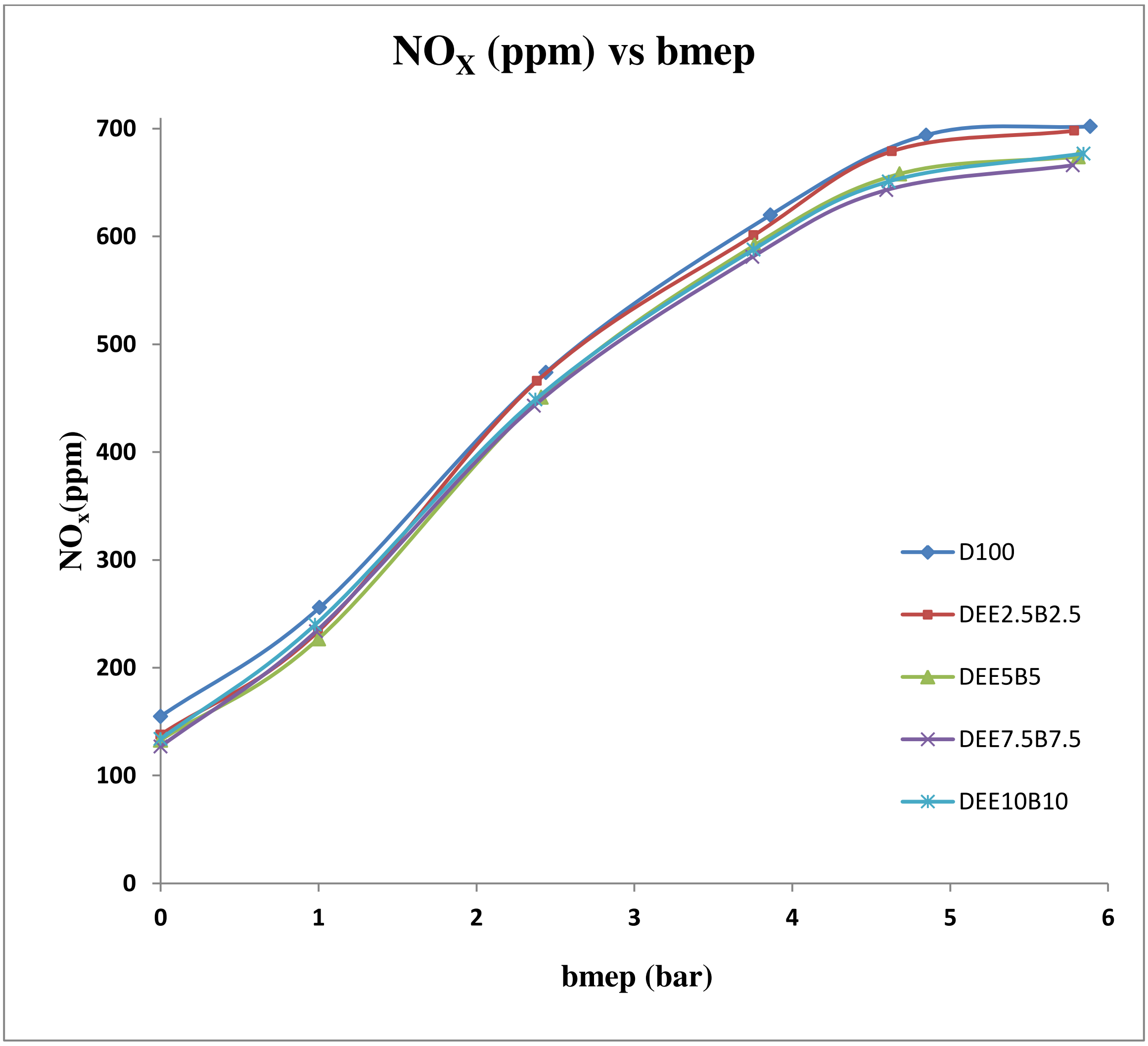



**Figure 37: Variation of NOx Emission with BMEP**

### 4.4.5 SMOKE OPACITY

Figure 38 shows the variation of smoke opacity emissions at different loading conditions plotted against BMEP. Smoke opacity is nearly same for all fuels tested in AVL Smoke Meter. Smoke opacity was least for DEE5B5 at all loads except for no load and 20% load. Maximum opacity is shown by DEE10B10 i.e. 84%. There is no significant variation of smoke opacity with percentage replacement of diesel by DEE and jatropha biodiesel. The trend for is increasing as the load increases till 80% load, afterwards it shows a decreasing trends.

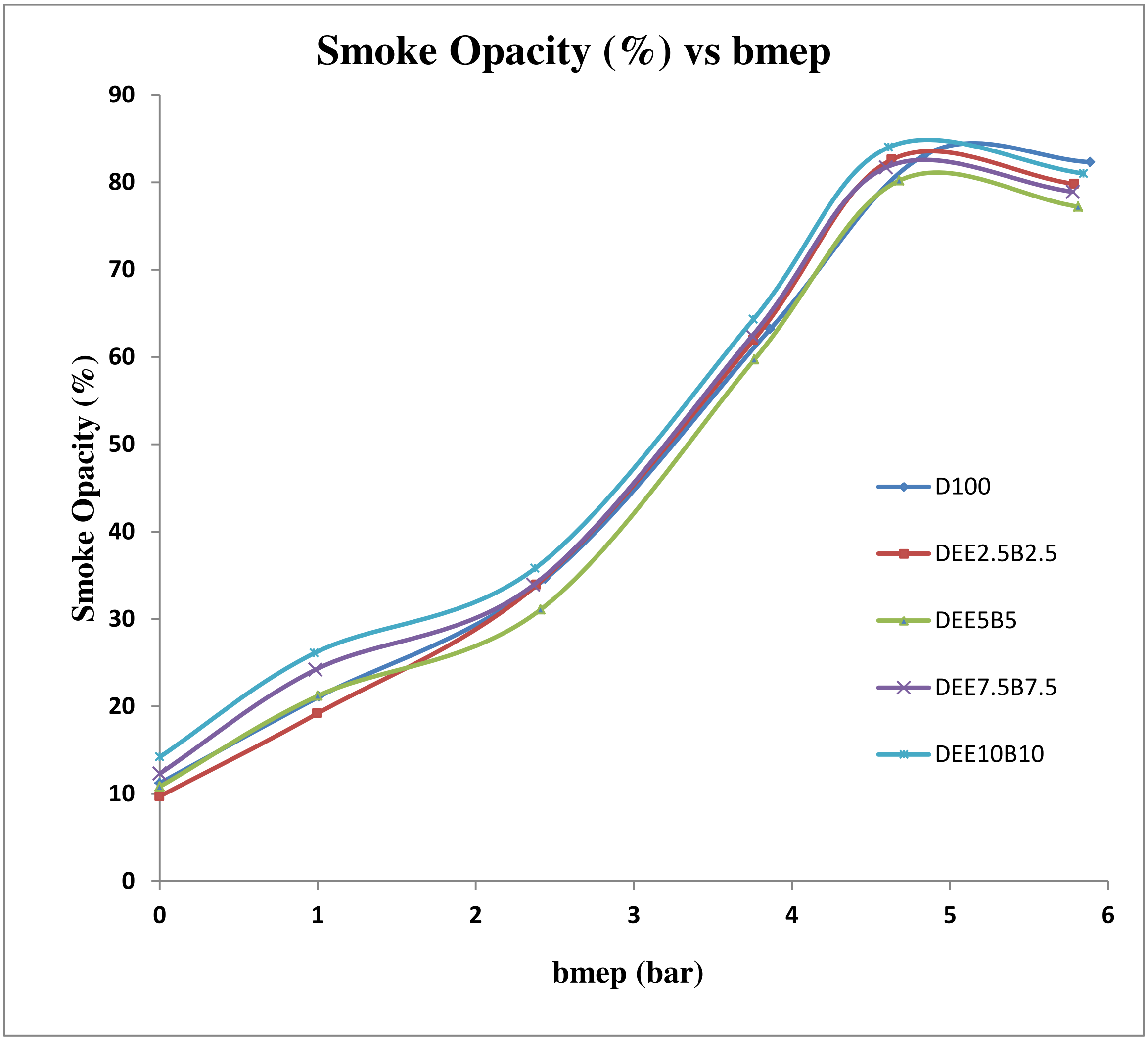



**Figure 38: Variation of Smoke Opacity with BMEP**

# CHAPTER 5

# CONCLUSIONS AND FUTURE RECOMMENDATIONS

## 5.1 CONCLUSIONS

This study has shown some exquisite results which helped in giving following conclusions:

- As the ternary blends were prepared and monitored for a significant period of time, so, it can be concluded that ternary blends of Di-ethyl ether and jatropha biodiesel in diesel are stable at atmospheric conditions. No other additives or surfactants are needed to stabilize the blends.

- Physico-chemical properties improved and were the best between 5% and 7.5% replacement of diesel. Calorific value of blends have shown irregular trends and has been maximum for DEE2.5B2.5 i.e. 46.57 MJ/kg.

- Spray characteristics were estimated for these blends and compared with baseline data of diesel. Spray characteristics analysis revealed that the Sauter Mean Diameter for blends were significantly smaller than that of diesel, smallest of all was observed for DEE5B5 which is 14.5 µm.

- Engine trials revealed that brake thermal efficiency does not have any significant effect of addition of DEE and Jatropha biodiesel. In fact the efficiencies are nearly equal to that of diesel or comparable to diesel. DEE7.5B7.5 yields the maximum efficiency of 27.9% which is nearly equal to that of maximum efficiency with diesel fuel 28.4%.

- Emission characteristics study revealed that the emission of CO, $NO_X$ and smoke opacity were reduced significantly at loads greater than 40%. At part load emission of $CO_2$ and Hydro-Carbons were less as compared to that with diesel.

## 5.2 FUTURE RECOMMENDATIONS

From the above studies and experimental investigations it is found that there is a clash of characteristics and properties for Diethyl Ether as additive and has more aspects to be found in this field.

- Diethyl ether has shown improvement in emission characteristics and spray characteristics without altering the engine performance parameters significantly.

- More studies can be carried out to study the behavior of Diethyl Ether as an alternative for diesel fuel.

- Emission studies for Perticulate Matter can be carried out as it is the most likely dangerous emission specially for cities like New Delhi where PM concentrations are very much high.

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# APPENDIX 1

| | |
|---|---|
| Patents granted | AT 516420 (B1)<br>AT 517082 (B1) |
| Patents pending | AT 517486 (A1) |
| Measuring range | Density: 0 g/cm³ to 3 g/cm³<br>Temperature: 0 °C to 100 °C (32 °F to 212 °F)<br>Pressure: Up to 10 bar (145 psi) |
| Repeatability s.d.(1) | Density: 0.000005 g/cm³<br>Temperature: 0.01 °C/0.02 °F |
| Reproducibility s.d.(1) | Density: 0.00002 g/cm³ |
| Accuracy(2) | Density: 0.00005 g/cm³<br>Temperature: 0.03 °C/0.05 °F |
| Integrated tables and functions | Alcohol tables<br>Extract/sugar tables<br>Acid/base tables<br>20 freely programmable tables/user functions (tables, polynomials, formulas, linear functions) |
| Minimum sample amount | approx. 1 mL |
| Measuring time per sample(3) | 30 seconds |
| Dimensions (L x W x H) | 495 mm x 330 mm x 230 mm (19.5 in x 13 in x 9.1 in) |
| Data memory | 1000 measurement results (optional ring memory) |
| Power supply | AC 100 to 240 V<br>50 to 60 Hz<br>190 VA |
| Weight | 22.5 kg (49.6 lbs) |

# APPENDIX 2

**Viscocity**

| | |
|---|---|
| Viscosity range | 0.3 mPa.s to 10,000 mPa.s |
| Repeatability s.d. | up to 0.1 % |
| Accuracy | up to 0.5 % |

**Temperature**

| | |
|---|---|
| Temperature range | + 5 °C to 100 °C |
| Repeatability s.d. | 0.005 °C |
| Accuracy | 0.02 °C |

**Measuring time**

| | |
|---|---|
| Resolution | 0.001 s |
| Accuracy | 0.05 % |

**Further specifications**

| | |
|---|---|
| Test duration | minimal 30 s, typical 3 min |
| Sample volume | 0.1 mL to 0.8 mL |
| Inclination | 15° to 80° in 1° steps |
| Repeatability s.d. | 0.02 ° |
| Accuracy | 0.1 ° |
| Shear rate | 0.5 $s^{-1}$ to 1000 $s^{-1}$ influenced by capillary size and inclination |

# APPENDIX 3

## 6100 AUTOMATIC MICROPROCESSOR CONTROLLED CALORIMETER

The 6100 Automatic Compensated Jacket Bomb Calorimeter is a compact, motionless jacket calorimeter that works at nearly room temperature using full benefit of advanced microprocessor abilities. The microprocessor controller in the 6100 Automatic Compensated Jacket Bomb Calorimeter will automatically control the jacket temperature and implement the needed corrections in real time. The benefits of this system include less water, less energy, and less hardware while still affording good precision.

**Technical specifications of a calorimeter**

| | |
|---|---|
| Model Number: | 6100 |
| Tests Per Hour: | 2-3 |
| Operator Time Per Test: | 20-25Minutes |
| Temperature Resolution: | 0.0001 ℃ |
| Precision Classification: | 0.1 – 0.2% Class |
| Jacket Type: | Continuously Compensated |
| Oxygen Fill: | Automatic |
| Bucket Fill: | Manual |
| Bomb Wash: | Manual |
| Memory: | 1000 tests |
| Bomb Model Options: | 1108, Alloy 20 1108CL, Alloy G30 1108B, Alloy 20 1108BCL, Alloy G30 1108BP, Alloy 20 1108BPCL, Alloy G30 1108PCL, Alloy G30 1109A, 22mL Semi-micro Bomb 1104, High Strength Bomb |
| Balance Communication: | USB Port |
| Printer Communication: | USB Port |
| Network Connection: | TCP/IP via Ethernet |
| Dimensions (cm): | 57w x 40d x 43h |

# APPENDIX 4

**SINGLE CYLINDER AIR COOLED DIESEL ENGINE**

Air cooled (Radial cooled), 4 stroke cycle, totally enclosed, direct injection, cold starting, naturally aspirated, gravity feed fuel system with efficient paper element filter, force feed lubrication to main and large end bearing and camshaft bush.

**Specifications:**

| | |
|---|---|
| No. Of cylinders: | 1 |
| Bore X stroke: | 95x110 |
| Cubic capacity: | 0.78 Lit. |
| Compression ratio: | 17.5:1 |
| Rated output as per BS5514/ ISO 3046 / ISO 10001: | 5.9KW (8.0 HP) at 1500 rpm |
| Starting: | Hand start with cranking handle |
| SFC at rated hp/1500 rpm: | 251g/Kwh (185 g/bhp-hr) |
| Lube oil consumption: | 0.8% of SFC max |
| Lube oil sump capacity: | 3.7 lit. |
| Fuel sump capacity: | 11.5 lit. |
| Fuel tank re-filling time period: | Every 6.9 hours engine running at rated output |
| Engine weight (dry) w/o flywheel: | 118 kg |
| Weight of flywheel: | Genset – 64kg |
| Rotation while looking at flywheel: | CW |
| Power take of: | Flywheel end optional – gear and half speed drive or full speed drive |

# APPENDIX 5

## AVL DITEST GAS 1000 BL

| Miscellaneous | |
|---|---|
| Warm-up Time | Approx. 2 min |
| Operating Temperature | 5 … 40 °C |
| Storage Temperature | 0 … 50°C |
| Humidity | 10 … 90 % non condensing |
| Dimensions | 344 x 252 x 85 (W x H x D) |
| Weight | 2.2 kg |
| Interfaces | USB, Bluetooth Class 1, RS 232 (AK Protokoll) |
| Certification | 2004/22/EC (MID); OIML R99 Class 0 |

| Power Supply | |
|---|---|
| Voltage Supply | Via AVL DITEST CDS Basic Unit: 11..25 V DC |
| Power Consumption | Approx. 20 VA |

| Measurand | Measuring | Resolution | Accuracy |
|---|---|---|---|
| CO | 0 … 15% vol | 0,01 % vol. | < 10.0 % vol.: ± 0,02% vol., ± 3% o.M.<br>≥ 10.0 % vol: ± 5 % o.M. |
| CO2 | 0 … 20% vol. | 0,01 % vol. | < 16.0 % vol.: ± 0, 3 % vol., ± 3 % o.M.<br>≥ 16.0 % vol: ± 5 % o.M. |
| HC | 0 … 30.000 ppm vol. | ≤ 2.000: 1 ppm vol. | < 2000 ppm vol.: ±4 ppm vol., ±3% o. M.<br>≥ 5000 ppm vol.: ±5% o. M.<br>≥10000 ppm vol.: ±10% o. M |
| O2 | 0 … 25% vol. | 0,01 % vol. | ± 0,02 % vol.<br>± 1 % o. M. |
| NO (optional) | 0 … 5.000 ppm vol. | 1 ppm vol. | ± 5 ppm vol.<br>± 1 % o. M. |
| Lambda | 0 … 9.999 | 0,001 | Calculated from CO, CO2, HC, O2 |