PERFORMANCE AND EMISSION STUDIES OF ETHANOL-DIESEL BLEND IN AN UNMODIFIED DIESEL ENGINE WITH TETRAHYDROFURAN AS A SURFACTANT

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY
IN
THERMAL ENGINEERING

Submitted by

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CANDIDATE DECLARATION

I hereby declare that the work, which is being presented in this dissertation, entitled "**Performance and Emission Studies of Ethanol-Diesel Blend in an Unmodified Diesel Engine with Tetrahydrofuran as a Surfactant**" toward the partial fulfilment of the requirement for award of the degree of Master of Technology in Thermal Engineering, from Delhi Technological University Delhi, is an authentic record of my own work carried out under supervision of Prof. Naveen Kumar Department of Mechanical Engineering , Delhi Technological University, Delhi.

This matter embodied in this dissertation report has not been submitted by me for award of any other degree/diploma.

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To best of my knowledge, the result contained in this dissertation have not been submitted to any university or institution for an award or any degree

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ACKNOWLEDGMENT

Any accomplishment requires efforts of many people and this work is no exception. We appreciate the contribution and support which various individuals have provided for the successful completion of this project and report.

I wish to express my sincere gratitude towards my project supervisor and mentor, **Prof. NAVEEN KUMAR**, Department of Mechanical, Automobile, Production & Industrial Engineering, Delhi Technological University, who provided me a golden opportunity to work under his supervision. His scholastic guidance and sagacious suggestions helped me to complete the project in this field.

I wish to thank Mr. Mukul Tomar, Research scholar**, Department of Mechanical Engineering, Delhi Technological University**, for constantly motivating us and providing able guidance.

I am also thankful to the staff of Department of Mechanical Engineering for their continual support and cooperation.

Finally, but importantly, I would like to express my heartfelt thanks to my beloved family and friends who have endured the long working hours and whose motivation kept me going.

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ABSTRACT

This investigation presents an experimental examination into the effects of ethanol-diesel blends stabilized with the help of tetrahydrofuran on running diesel engines. Ethanol-diesel Blended fuel provides a method to alternative fuels without any modification of the engine technology present till date, yet allowing for reducing the NO_x and particulates. The blending of diesel and ethanol were done at room temperature (300k). The accepted blends were described to determine the chemical composition and physicochemical properties, i.e., density (ρ), kinematic viscosity (ν), calorific value (cv). According to the properties that are obtained from experiments, engine performances, spray characteristics and emission characteristics were evaluated. Some advancement was detected when working with the prepared blends estimate diesel concerning engine performances and emission characteristics. According to the physicochemical valuation, it was demonstrated that diesel-ethanol-tetrahydrofuran blends could be used as alternative fuel in diesel engines. This study shows how by blending ethanol with petroleum diesel at intervals of E2, E4, E6, E8, E10, and E15 with tetrahydrofuran as surfactant decrease particle emissions and oxides of nitrogen while keeping same performance output and efficiency concerning 100% petroleum diesel. The different chemical, physical and thermal properties of ethanol-diesel blends can be used to improve emissions and performance of the diesel engine. This work used experimental investigation to find out the influence of ethanol and ethanol-diesel blends on advanced diesel engine strategies and on understanding which of the properties of ethanol and ethanol-diesel blends control engine performance. With the much more use of traditional fuel source at a high rate and expanding environmental contamination has persuaded extensive research in elective fuel. The engine trials are performed on a single cylinder air-cooled (radial cooled) vertical diesel engine test rig. Emission characteristics were also examined using AVL gas and smoke analyzer. Emission characteristics or variation of amount of gases emitted by engine at different loads are estimated and examined including smoke opacity and plotted against bmep. This project is an effort towards obtaining the influence of ethanol-diesel blended fuel as a replacement over diesel in diesel engines to reduce engine emissions and regular diesel consumption. Thus, ethanol which can be produced both naturally and artificially with the intention to replace some amount of diesel with performance fulfilling the standards.

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LIST OF SYMBOLS, ABBREVIATIONS

A/F	Air to Fuel
Al	Aluminium
AVL	AVL DITEST Gas 1000 BL Exhaust gas analyser
bmep	Brake mean effective pressure
BTE	Brake thermal efficiency
BSEC	Brake specific energy consumption
^0C	Degree Celsius
cc	Cubic centimetre
C	Carbon
CI	Compression ignition
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CV	Calorific Value
D100	Diesel
DEE	Diethyl ether
DI	Direct injection
E	Ethanol
E2	2% Ethanol blend
E4	4% Ethanol blend
E6	6% Ethanol blend
E8	8% Ethanol blend
E10	10% Ethanol blend
E15	15% Ethanol blend
F/A	Fuel to Air

g/cc	Gram per cubic centimetre
HC	Hydrocarbon
H	Hydrogen
H_2O	Water
HP	Horse Power
IC	Internal combustion
KWh	kilowatt hour
KW	kilowatts
MW	Mega watt
M	Methanol
N	Nitrogen
NOx	Oxides of nitrogen
O	Oxygen
ppm	Parts per million
rpm	Revolution per minute
THF	Tetrahydrofuran
Vs	Versus
v/v	Volume/ Volume
ρ	Density
υ	Kinematic viscosity
%	Percent

CHAPTER-1

INTRODUCTION

Diesel fuel is used in internal combustion engines in many fields which include: automotive, engineering machinery, marine propulsion. Numerous types of air contaminations is due to consumption of conventional fuels, that is nitrogen-oxides, particulate matter, carbon-monoxide and other harmful substances. Also, approximately 60% of greenhouse gas emissions such as carbon-dioxide are derived from the direct combustion of fuels. Therefore, raises the necessity to replace part of the diesel fuel used presently with other alternatives. One of these alternatives is ethanol which can be manufactured from bio/renewable materials and by a process that would make it bio-ethano1. Waste biomass materials, molasses, sugarcane, corn, sugar beets, barley, cellulose are the raw materials from which Ethanol can be synthesized. Ethanol has been used before mainly in blending with petrol, but it has been tested with diesel fuel also, and the blends obtained were technically acceptable for CI engines. To test the viability of using the diesel-ethanol blends in compression ignition engines, it is essential to compare the physical properties of the blends and to see if they are comparable and within standards that allow them to be used in these engines. Such properties include, but are not restricted to stability, density, viscosity, lubricity, flash point, safety. These properties vary with the quality of the components used, for example, the water content of the Ethanol or the aromatic compound content of the diesel fuel. Therefore it is essential to describe the substances used because the results are only available for these specific concentrations. Studies have shown that diesel- ethanol blends, that contain no more than 15% (v/v) Ethanol, are a solution to reduce the quantity of fossil fuel used by IC engines. They are stable at moderate temperatures, but for lower temperatures, to sustain the stability, additives need to be added. The most of these additives are surfactants that reduce the surface tension between the two substances, making them more suitable in terms of miscibility. Surfactants that have been used earlier that include biodiesel, stearyl alcohol (saturated), 1-hexanol, oleyl alcohol (unsaturated), methyl oleate (unsaturated with ester group). To improve the effectiveness of these substances, some additional additives can be added. Due to their role and the quantity in which they are added, this being lower compared to the surfactants, they are called co-surfactants. Some of these are: tetra hydro furan, Cetrimonium bromide, Benzalkonium chloride etc.

1.1 ENERGY CRISIS AND NEED FOR ALTERNATE FUELS

There is an understanding all over the globe that the petroleum resources or fossil fuel that are non-renewable are limited and are being depleted at an fast rate. The rising need for energy and steady depletion of fossil fuels has to tends to an energy crisis. For the most part of the power for industries and transportation is derived from oil and coal as primary fuels.

Table 1:-Energy sector in India [1]

Electricity coverage	82.53% (2018)
Installed capacity	344.00 GW
Share of fossil energy	81.9%
Share of renewable energy	15.3%
GHG emissions from electricity generation (2015)	2066.01 MtCO2
Average electricity use (2016-17)	1,122 KWh per capita
Transmission & Distribution losses (2015-16)	21.81%
Residential consumption (% of total, 2016-17)	24.32%
Consumption in industrial sector (% of total, 2016-17)	40.01
Consumption in agriculture sector (% of total, 2016-17)	18.33%
Consumption in commercial sector (% of total, 2016-17)	9.22%
Consumption in traction sector (% of total, 2016-17)	1.61%

Specific attention need to be paid for automobiles sectors where the entire combustion engine uses fuel are derived from crude which is not replanishable. Since then, several price hikes have taken place, upsetting economy of most of the nation. Mostly all the internal combustion engines use petroleum fuels which are limited and expected to be depleted in around 40 years. Inadequate energy sources lead to the caution of possible be short of power in the near future. Nearly 33% of the petro fuels are utilise in the IC engines which have power less than 190 kW and gases released from the exhaust from these prime movers is an obvious reason for the global environmental contamination. In most recent years, numerous studies on the IC engines focusing on the reduction of exhaust emissions have been worked out by changing operating parameters viz "valve timing, injection timing, and rate of atomization". At the same time, diminution of fossil fuels and environmental considerations has led to investigations on the renewable fuels such as ethanol, hydrogen, and bio fuels.

1.1.1 ENERGY SCENARIO: INDIAN CONTEXT

India is heavily dependent upon the import of petroleum to provision to its need for an automobile and other application.245.38 Million tons of oil imported during 2017-2018. With rapid industrialization and very fast increasing number of the automobile due to the general economic uplift of society, the demand for petroleum is increasing at a very rapid rate.

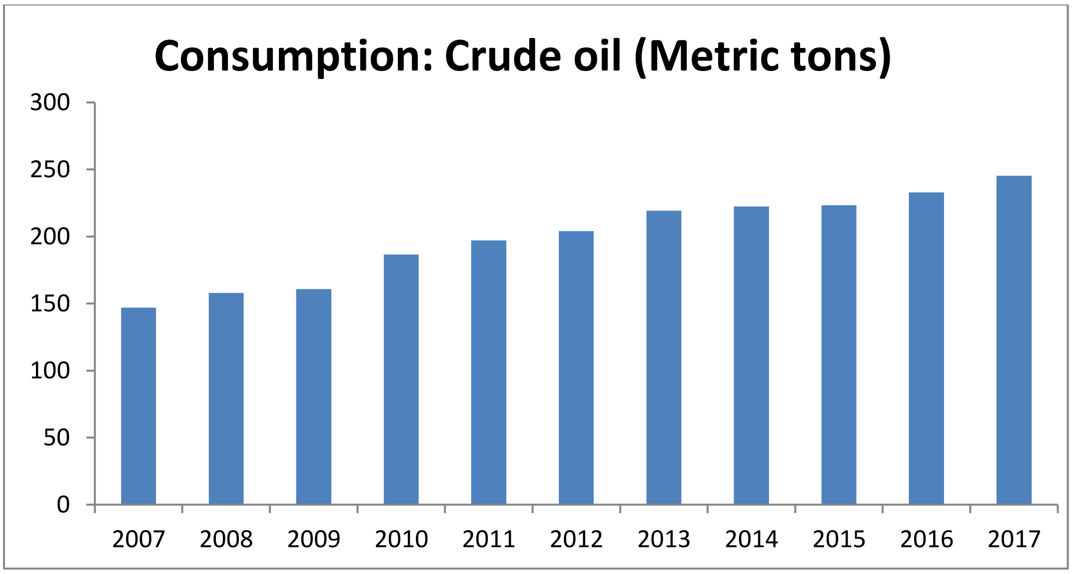


Figure 1:-Details of consumption of crude oil [2]

This will lead to greater scarcities and higher prices. With consequent unfavourable effects on the economy of the Added to the problem of fast dwindling resources of petroleum fuels and the economic and political factor associated with their procurement environmental pollution generated by the combustion of these fuels in automobiles and other stationary sources, have focused the attention of researchers in this area to search for the clean-burning renewable alternative fuels for automobiles.

1.1.2 COMPRESSION IGNITION ENGINES AND ALTERNATE FUELS

The compression ignition engine is based on the works of Rudolf Diesel, a German scientist, around 1892 and operates on a cycle of events known as diesel cycle. The C.I. engine can be envisioned as a conventional spark ignition engine with spark plugs replaced by fuel injectors, and hence it offers the advantage of dependability by the elimination of electrical equipment (high voltage). There is no carburettor or associated air throttle thereby eliminating the throttling losses, and hence it provides idling and part load economy .higher compression ratio used in C.I. engine offer it the high thermodynamic efficiency. In addition to its popularity for the mass transport system, it is getting popular in small automobile engine for passenger cars and light trucks due to its better part load performance and improved emission characteristics. There are more 2 million diesel engine that is single cylinder used for electricity and water pumping. The possible alternatives energy sources for use in diesel engines are hydrogen, biogas, and alcohols. Hydrogen may prove to be a potential long-term fuel since many problems associated with its economic production; hazardous nature, storage and handling are yet to be sorted out. Bio-gas required high storage pressure if it has to be used in automobiles. Leakage from the cylinder may cause a problem. Hence the use of biogas as a substitute fuel for automobiles is ruled out until simple and safe storage, and handling facilities are developed. The market for diesel is roughly 5 times higher than the market for petrol in India. The trans-esterification of vegetable oil is the current Indian bio fuel technology. The Grand National Biodiesel Mission is expressed by government to meet 20% of the India's diesel requirements. From the point of view of availability, storage, and managing alcohols appear to be the most attractive alternate fuels. Methanol and ethanol are commonly considered for automotive application. Methanol has some problem such as its low calorific value and poisonous in nature.

1.1.3 ETHANOL AS SUPPLEMENTARY FUEL IN C.I. ENGINES

From biomasses with the help of fermentation and distillation ethanol can be produced. In India presently the existing manufacturing price of ethanol and biodiesel in India is about Rs. 40.85/litre, and that of petrol and diesel are Rs 80 and 70 respectively. With the help of ethanol it offers the significant decreases in the emission of diesel engine. Ethanol can be produces from municipal waste. This places the ethanol in helpful position for meeting India's energy needs, more than ever as the price of petroleum is expected to maintain its rising trend. In addition to providing energy security and a decreased dependence on oil imports, Ethanol offer many significant benefits such as decreased emission of contaminants and greenhouse gases and increased employment in the agricultural sector. For that reason, it can be well thought-out as a renewable fuel.

Ethanol has few favourable benefits over diesel fuel, such as the lower the level of soot in the exhaust, CO and unburned HC emissions. Despite the fact that having these favourable advantages, due to constraint in technology, economic and regional factors, ethanol still cannot be utilized widely. on the other hand, ethanol blended diesel fuels can be practically used in CI engines [5, 6].

Ethanol is a pure substance. Though, diesel fuel is made out of C_3–C_{25} HCs and has extensive intermediary properties. Ethanol contains an oxygen atom so that it can be seen as a partly oxidized HC. Ethanol is completely miscible with water because it is polar in nature. This is the cause that corrosion problems on the mechanical components because blended fuel contain water, and this leads to, in particular for components made from Al, brass, and copper. To lessen the risk of corrosion on the fuel delivery system, such given materials stated above should be avoided. it is good to use fluorocarbon rubber as a replacement for rubber. The self-ignition temperature of ethanol 365^0C which is higher than that of diesel fuel which is 210^0C [1], which makes it safer for transportation and storage. On the other side, a disadvantage regarding safety is that the ethanol has lower flash point than that of diesel fuel [7, 8].

Alcohol, particularly Ethanol or ethyl alcohol, it is very difficult to use in compression-ignition, because of their (lower CN) low ignition quality. A high-octane fuel (gasoline) necessarily has a low cetane value (diesel fuel). It is interesting that India was the earliest to recognize the merits of burning C_2H_5OH in diesel engines. It is understandable from the growing fame of light-duty diesel engines, it is must to use an alternative fuels such as alcohols in diesel fuel. if they are to contribute significantly as replacement for petroleum-based fuels. Though, in the past, slight awareness has been given to the utilization of C_2H_5OH fuels in CI engines. In diesel engine some complications encountered while attempting to use C_2H_5OH in diesel engines.

The main difficulties are:

1. Mass and volume require more ethanol fuel than diesel fuel.
2. More than 20% of ethanol is not economical to mix with diesel fuel because it requires enormous quantity of surfactant; hence use of diesel- ethanol blends is not feasible. Also, because of existence of water in ethanol separation of blends takes place [8].
3. Too much low cetane number of ethanol, whereas fuel having high cetane number (45-55) is desirable the diesel engine, which easily self ignite and give small ignition delay [9].
4. Because of sulphur content diesel fuels work as lubricants for a diesel engine. But the similar Lubricating qualities are not available in alcohol fuels [10, 8].
5. Due to the volatile nature of ethanol and its poor self ignition characteristics it leads to severe knock [11,8].

While it is very challenging to replacement completely diesel fuel

1.1.4 ETHANOL SOURCES

In India ethanol is manufactured by the fermentation of molasses – a by-product of sugar production. The production cost of ethanol can be decreased by utilizing enhanced agricultural practices to increase sugarcane yield and to use energy-efficient ethanol dehydration techniques like membrane separation, pressure-swing and adsorption. Limiting government policies need to be changed to untie constraints on ethanol production.

Molasses: A by-product of the sugar industry.

Sugarcane: Major source of ethanol production in India.

Sugar beet: Sugar beet cultivation and its processing to ethanol are not very popular in the country.

Starch (grain, corn, etc.): Corn oil is edible and its use in India for production of ethanol is not considered.

1.1.5 ETHANOL CAPACITY IN INDIA

India is the eight largest ethanol producer after Argentina, its average production per day in thousand barrels per day is 5.30. Ethanol output amounting to 225 millions of liquid gallons per year. For a 5 percent C_2H_5OH blended in petrol nationwide, Current capacity can potentially satisfy this demand.[1]

- Second largest producer of sugarcane in the world.
- Fourth most significant producer of C_2H_5OH.
- Capacity utilization of 65%.
- Gasoline demand expected to increase from 7.9 MT to 16.4 MT in 2016-17

1.2 PROPERTIES OF ETHANOL

Ethanol is a type of alcohol which is isometric in nature unfortunately both DME di-methyl-ether and ethanol can be expressed by the same chemical formula C_2H_6O. However they may have same physical formula.

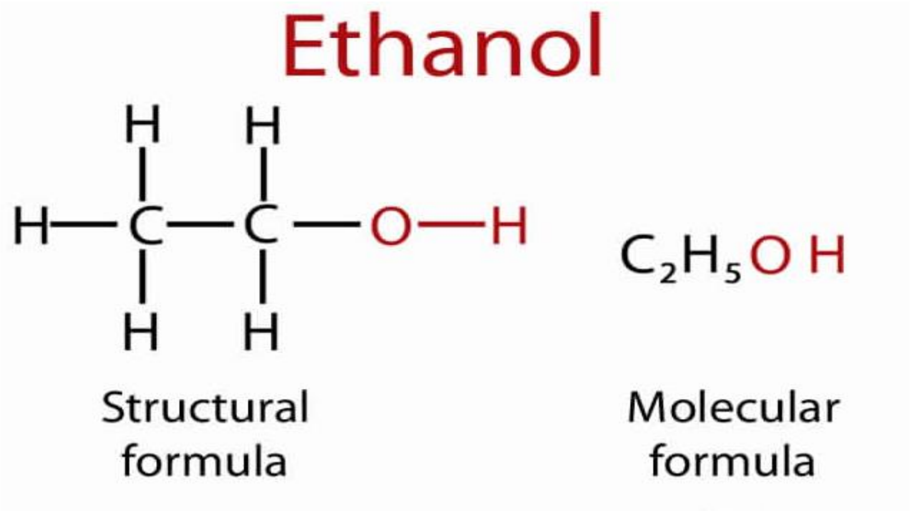


Figure 2:- Ethanol structural and molecular formula.

The oxygen-atom in ethanol probably induces 3 hydrogen bonds. But notably ethanol has different thermodynamic behaviour from that of DME on account of the stronger molecular alliance via hydrogen bonds in ethanol. This thought of using alcohol as a diesel engine fuel is a best way to significantly reduce the poisonous emissions (aldehydes). The way of transesterification also resolves the difficulty of corrosion of numerous engine parts using alcohol as a fuel. Alcohols have been attracting attention worldwide. An end user wants a cleaner safer fuel that can reduce the risk of damage to environment and healthiness. The goal of Government is to reduce dependence on imported energy and support domestic renewable energy programs, which could utilize domestic resources and create new economic activities.

Table 2: Properties of ethanol and diesel [5]

Properties	**Ethanol**	**Diesel**
Chemical formula	C_2H_5OH	$C_{12}H_{26}$—$C_{14}H_{30}$
Molecular weight (g)	46.01	170–198
Density (g/cm^3, at 20°C)	0.788	0.837
Boiling point (°C)	78.3 ± 0.09	180–330
Heat of evaporation (KJ/kg)	280	856
Lower heat value (MJ/kg)	27	45
Kinematic viscosity(υ)@ 40°C(mm^2/s)	1.20	2.0776
Flash point (°C)	13.5	78
Auto ignition temperature (°C)	365	235
Cetane number	5-8	45
Carbon content (wt%)	52.2	87.4
Oxygen content (wt%)	34.3	0
Latent heat of vaporization (kJ/kg)	921.1	620

Though bio fuels remain relatively small in use compared to more traditional energy forms, the scenario is changing rapidly. When factors are tied with immense agri-resources, innovative technologies that trim down cost, give emphasis to environment and pollution, the markets for bio fuels are slowly but surely gaining momentum.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the kinds of literature collected by the researcher on ways of ethanol production from biomass materials are discussed first. Then the types of research available on the utilization of ethanol-diesel blends in CI engines are explained.

2.1 OVERVIEW OF ETHANOL PRODUCTION

Production of ethanol is not new knowledge. Over many years ethanol has been manufactured by fermentation. As the value of alternative fuels was understood due to the jump in the cost of petroleum fuels and alertness on protecting the environment, research and development on the making of ethanol have developed extensively.

The production of Ethanol can be produced from the direct fermentation of simple sugars, or polysaccharides like starch or cellulose that can be transformed into sugars. As ethanol can be provided in a more significant quantity in comparison with the other liquid alternative fuels such as biodiesel, many researchers are trying to investigate available sources and ways of ethanol production.

Many researchers documented their research works about the ethanol production in the following categories; (i) biomass sources containing sugar, (ii) biomass sources containing starch, (iii) cellulosic and lignocellulosic materials [11-34].

2.1.1 SUGAR FEEDSTOCK

Biomass materials containing a large amount of glucose or precursors can be fermented utilizing microorganisms to create ethanol. These microbes can commonly utilize the 6-carbon sugars, one of the most familiar being glucose. One case of feedstock used in this process is sugar. In human life sugar is one of the important product, these materials are usually too costly to use for the production of ethanol.

Badger summarized et al. in his review that, fungi, bacteria, and yeast microorganisms can be used for fermentation; a particularly yeast Saccharomyces. It is often used to ferment glucose for the production of ethanol. He reported that 51.4 g of ethanol and 48.8 g of CO_2 would produce by 100 gram of ethanol. However, in practice, the real yield is under 100% because for the growth the microbes use some of the glucose. Other sources biomass feedstocks which rich in sugars (materials called saccharides) include various fruits and sugar beet [19].

Production of Ethanol is usually performed in three steps: (a) the collection of a solution of fermentable sugars, (b) fermentation of sugars into ethanol, and (c) ethanol separation and purification, usually by distillation–rectification–dehydration [36]. The step before fermentation, to obtain fermentable sugars, is the main difference between the ethanol production processes from simple sugar, starch or lignocellulosic materials. Sugar crops need only a milling process for the extraction of sugars to ferment (not requiring any step of hydrolysis), becoming a comparatively easy method of sugar conversion into ethanol. In this process, ethanol can be fermented directly from cane juice or beet juice or from molasses, generally obtained as a byproduct after the extraction of sugar [13]. Currently cell recycling with batch process is carried out for ethanol, and a small part is produced through multi-stage continuous fermentation with cell recycling [37].

2.1.2 STARCHY FEEDSTOCKS

Starch is another possible feedstock for ethanol production. The processes of ethanol production using starchy crops are well established and documented. Starch molecules consist of long chains of glucose molecules. So, starchy materials can also be fermented after breaking the starch molecules into simple glucose molecules. Cereal grains, potato, sweet potato, and cassava are some of the commonly available feedstocks available in this category. It is reported that maize and wheat are the two cereal grains used for ethanol production in the USA. Starchy materials involved the reaction of starch with water (hydrolysis) to breakdown the starch into fermentable sugars (saccharification). Typically, hydrolysis is performed by mixing the starch with water to form a slurry, which is then stirred and heated to break the cell walls. Specific enzymes that will break the chemical bonds are added at different times during the heating cycle.

Demirbas et al. grains like corn, require saccharification before fermentation. In this step, starch is gelatinized by food preparation, and subjected to enzymatic hydrolysis to form glucose monomers, which can be fermented by microbes [20]. In order to produce ethanol from starch, it is necessary to breakdown the chains of this carbohydrate for obtaining glucose syrup, which can be further converted into ethanol by yeast. This type of feedstock is the most utilized for ethanol production in North America and Europe. Corn and wheat are mainly used for these purposes. Yeast cannot be used with starch directly for ethanol production. Therefore, ethanol production from grains involves milling and hydrolysis of starch, that has to be wholly broken down to glucose, by the combination of two enzymes, α-amylase and amylo glucosidase, before it is fermented by yeast to make ethanol. In tropical countries, other starchy crops such as tubers (e.g. cassava) can be used for the commercial production of fuel ethanol [16, 38]. Today, most fuel ethanol is produced from corn, by either the dry-grind (67%) or wet-mill (33%) process. [40-42]. Figure 3 shows the block diagram of ethanol production from the starch materials

2.1.3 ETHANOL PRODUCTION FROM CELLULOSIC MATERIALS

The production of ethanol from sugar and starchy materials also affects the food chain and fuel price. Substituting-cellulosic and lignocellulosic materials can replace the food chain based feedstock-sugar molasses and starch materials. Hence, ethanol produced from biomass materials is known as bioethanol [42]. Examples of cellulosic materials include paper, cardboard, wood, and other fibrous plant materials. Cellulosic resources are generally Available in different kinds. For example, forests comprise about 80% of the world"s biomass which can be used from ethanol production. Cellulosic materials which are composed of lignin, hemicellulose and cellulose are called lignocellulosic materials. Lignin provides structural support to the plant. Thus, generally, trees have higher lignin content than grasses. Lignin which has no sugars encloses the cellulosic and hemicellulosic molecules, making them difficult to reach. Cellulosic particles consist of long chains of glucose molecules as do starch molecules but have a different structural configuration.

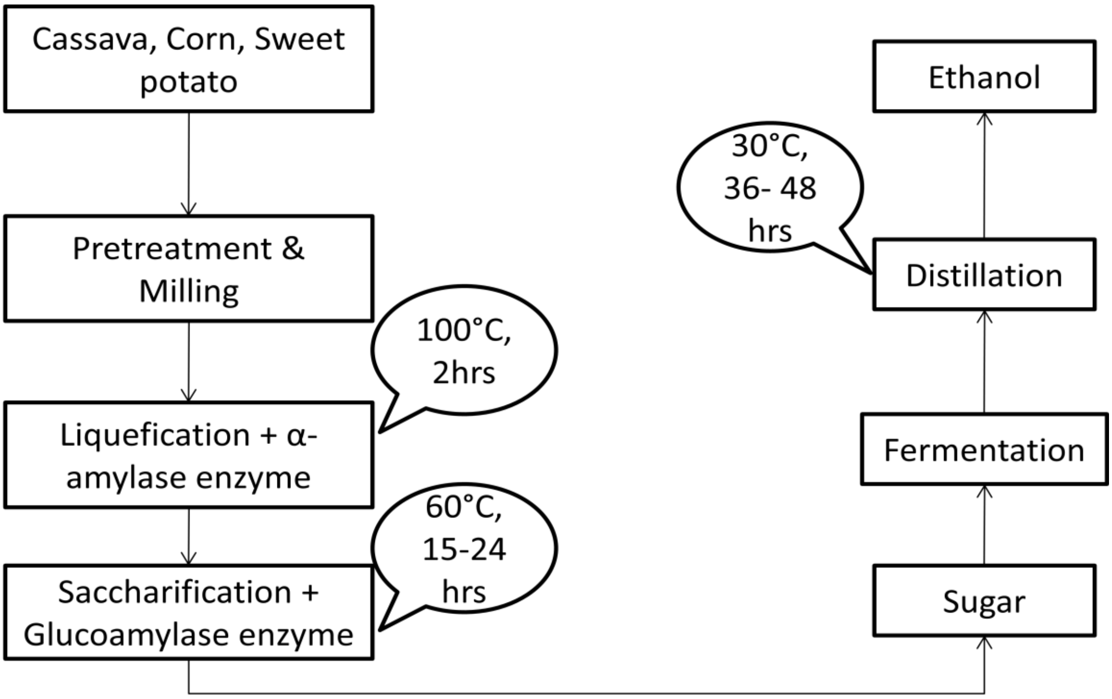


Figure 3:- Production of ethanol

Because of these structural characteristics and their encapsulation by lignin, the cellulosic materials cannot be as readily hydrolyzed as starchy materials. Hemicellulose is comprised of long chains of sugar molecules; but it also contains, in addition to glucose (a 6-carbon or hexose sugar), pentoses (5-carbon sugars).

Badger et al. since 5-carbon sugars comprise a high percentage of the available sugars, and the capability to recover and ferment them into ethanol is significant for valuable production of ethanol. Individual microbes have been genetically produced, which can ferment 5-carbon sugars into ethanol with relatively high efficiency. Researchers have a unique concentration on bacteria, because of their rapid fermentation. Generally, bacteria can ferment in minutes as compared to yeast it can be ferment in hours[21].

There are three types of ethanol production from cellulosic materials; they are (a) acid hydrolysis, (b) enzymatic hydrolysis, and (c) thermochemical conversion. The most common method is acid hydrolysis.

2.2 ACID HYDROLYSIS

Any acid can be used for acidic hydrolysis; however, sulfuric acid is most commonly used since it is usually the cheapest. There are two types of acid processes: dilute acid and concentrated acid, each with variations. Dilute acid procedures are organized under high pressure and temperature and have reaction times in the range of few seconds or minutes, which smoothens continuous processing. For instance, using a dilute acid method with 1% sulphuric acid in a continuous flow reactor for a residence time of 0.22 minutes and at a temperature of 237°C (458°F) with pure cellulose, provided a yield of over 50% sugar. In this case, 0.9 ton (1 ton) of dry wood would produce about 189 L (50 gallons) of pure ethanol. The mixture of the acid and high temperature and pressure, require unique reactor materials, which can make the reactor expensive. The most dilute acid processes are limited to a sugar recovery efficiency of around 50%. The reason for this is that, as a minimum two reactions are part of this process. The first reaction converts the cellulosic materials to sugar and the second reaction converts the sugars to other chemicals. Once the cellulosic molecules are broken apart, the reaction proceeds quickly to break down the sugars into other products, most remarkably furfural, a chemical used in the plastics industry. Not only does sugar degradation reduce the sugar yield, but the furfural and other degradation products can be poisonous to the fermentation microorganisms. The most significant benefit of the dilute acid process is its fast rate of reaction, which facilitates continuous processing. One of the demerits is its low sugar yield. For rapid continuous processing, to allow adequate acid dispersion, feedstock's must also be less in size, so that the most of the particle dimension is in the range of a few millimetres(mm). Since 5-carbon sugars diminish more quickly than 6-carbon sugars, one method to decrease sugar disgrace is to have a two-stage process. The first stage is conducted under moderate process circumstances to improve the 5-carbon sugars, while the second stage is conducted under harsher conditions to strengthen the 6-carbon sugars. Poorly, sugar degradation is still a problem, and the yields are limited to around 272 L/t (80 gallons of ethanol/ton) of dry wood. The concentrated acid process uses comparatively mild temperatures and the only pressures involved are usually those generated by forcing materials from vessel to vessel. One focused acid process was first developed by United States Department of Agriculture (USDA), and further refined by Purdue University and the Tennessee Valley Authority (TVA). In the TVA concentrated acid process, corn stover was mixed with dilute (10%) sulfuric acid, and heated up to 100ºC from 2 to 6 hours in the first (or hemicellulose) hydrolysis reactor. The low temperature and pressure minimize the degradation of sugars. To recover the sugars, the hydrolyzed material in the first reactor was soaked in water and drained several times. The solid residue from the first stage was then dewatered and immersed in a 30% to 40% concentration of sulfuric acid from 1 to 4 hours as a pre-cellulose hydrolysis step. This material was then dewatered and dried so that the acid concentration in the document was increased to about 70%. After reacting in another vessel from 1 to 4 hours at 100ºC, the reactor contents were filtered to remove the solids and recover the sugar and acid. The sugar/acid solution from the second stage was recycled to the first stage to provide the acid for the first stage hydrolysis. The sugars from the second stage hydrolysis were thus recovered in the liquid from the first stage hydrolysis. The advantage of the concentrated process is the high sugar recovery efficiency, which can be in the order of over 90% of both cellulose sugars and hemicelluloses. The low temperature and pressure employed also allow the use of relatively economical materials, such as fibreglass tanks and piping. But, it is a relatively slow process, and cost of active acid recovery systems has been complicated to Develop. Without acid recovery, large quantities of lime must be used to neutralize the acid in the sugar solution. This neutralization forms large amounts of calcium sulphate, which requires disposal and creates additional expense.

2.3 USE OF ETHANOL IN CI ENGINES

As ethanol is a type of alcohol, this section presents the literature review about the advantage of ethanol in CI engines. The lower cetane number of ethanol compared to that of diesel is the main problem, in using ethanol in the diesel engine (CI engines).

Six different techniques have been suggested and adopted by many investigators, mainly to use ethanol in CI engines; they are as follows;

- diesel-alcohol solutions and emulsions
- surface-ignition
- dual injection
- spark-assistance
- cetane improving additives
- fumigation

2.4 DIESEL-ETHANOL BLENDS

Ethanol can be blended with diesel fuel using a proper surfactant or emulsifier. It can also be dissolved in diesel fuel (diesel or biodiesel) in the form of minute droplets to make an emulsion. In a review [15], it was suggested that the two fuels, however, do tend to separate, and an ethanol-diesel fuel emulsion is relatively unstable. These mixtures and emulsions could combust thoroughly in CI engines. It was also considered that it would be possible to use up to 20% of ethanol/methanol by volume in the form of an emulsion. Beyond 20% there would be a chance of drastic loss of performance.

Letcher et al. evaluated the use of some co-solvents and ternary diagrams for the stability of the ethanol-diesel blends. The solubility of ethanol in diesel was affected mainly by two factors, the water content, and temperature of the blend. This was avoided by the addition of a co-solvent and an emulsifier. Co-solvents allowed fuels to be splash-blended which simplifies the blending process, but emulsification usually required heating and blending steps to generate the final blend. He identified tetrahydrofuran and ethyl acetate as effective co-solvents, which were obtained from agricultural waste materials and ethanol respectively. He concluded that the ratio of ethyl acetate to ethanol to ensure complete miscibility down to 0 °C was 1:2 [22].

Baker et al. investigated the use of stabilized and unstabilized emulsions of methanol-in-diesel fuel and ethanol-in-diesel fuel, in a two-cylinder, two-stroke engine. He reported that 9:10 and 3:2 parts by volume of alcohol to emulsifier were required for methanol and ethanol, respectively, to create stable emulsions. The maximum alcohol content was limited in emulsion or solution, to avoid the engine knocking due to a reduction in the cetane number. The thermal efficiency was improved at low load only compared to that of diesel [23].

Hansen et al. reviewed research works related to ethanol-diesel fuel blends in diesel engines. They summarised that the ethanol percentages of 10% or less had no noticeable differences in the performance compared to diesel. They also mentioned that the addition of ethanol to diesel fuel would have a beneficial effect in reducing at least the particulate matter (PM) emissions. The NOx emission was reduced, while the CO and THC emissions were marginally higher than those of diesel. It was suggested that an advanced emission control system could minimize the CO and THC emissions. A small adjustment in the fuel injection system would be required for better results. Also, proper storage, handling and dispensing of ethanol and diesel blends would be necessary [33].

Strait et al. studied the difficulties that were found with diesel and ethanol blends. They described that though the diesel and anhydrous ethanol were miscible at room temperature, only bit amounts of water (H_2O) in the diesel and ethanol blends might cause phase separation, and the fuel of low density may shift to the top of the container. A water concentration of only 0.05% might create phase separation at 0 °C, and hence, the water tolerance of ethanol and diesel blends was inadequate for possible use [24].

Wrage and Goering et al. studied the technical usefulness and performance parameters of diesel and ethanol blends. The efficiency and smoke emission of the engine with the blends were seen to be decreased compared to that of diesel. They also stated that the most critical problem associated with the ethanol blends was phase separation. Generally, the water tolerance of the blends increases with temperature [25].

Hardenberg and Ehnert et al. described the effect of ignition quality and cetane number of ethanol-diesel blends when they were used as fuels in a diesel engine. They estimated that the cetane number of ethanol was between 5 and 15, and when it was blended with diesel, it lowered the cetane number. Generally, a lower cetane number may exhibit a longer ignition delay which can allow more accumulation and more time for vaporization of the fuel. The initial burning rates were reported to be faster, and sudden peak heat releases were obtained at a constant volume, which was a more efficient conversion process of heat into work. They reported that this might also lead to the noisy operation of the engine. Sometimes, more addition of ethanol might hinder the ignition quality due to a fall in the cetane number below. So, it was suggested to add an ignition improver to increase the cetane number of the ethanol-diesel blends, so that they would fall within the acceptable range equivalent to that expected of diesel [26].

Moses et al. concluded that approximately 2% of a surfactant was required for each 5% aqueous ethanol to get the stable ethanol-diesel micro emulsions with a minor stirring. The micro emulsion was thermodynamically stable for several months, and it was also noticed that the dispersion sizes were found to be lesser than a quarter of the wavelength of light. The effect Of the cetane number with emulsified ethanol was found to be less compared to that of ethanol solution/blends. This was due to the shielding effect of the emulsion structure which caused a delay in the evaporation of ethanol as compared to the solutions, where the ethanol molecules were free to evaporate immediately. They also observed a reduction in the BSEC and an improvement in the thermal brake efficiency [27].

Schaefer and Hardenberg et al. discussed some biomass-derived nitrates as ignition improvers for the ethanol-diesel blends. They reported that trimethylene glycol dinitrate.(TEGDN) was a satisfactory ignition improver for the ethanol-diesel blends, which is manufactured from ethanol itself [28].

Hardenberg and Schaefer et al. investigated the use of 95% ethanol with 1% castor oil in a fleet of trucks and buses in Brazil. They stated that the quality of ethanol had a strong influence on its corrosive effects. They also studied the viscosity and lubricity properties of the fuel. For ethanol-diesel blends, the evaporation time is very less because of lower viscosities [29].

Battelle et al. studied the flammability limits and storage of the ethanol-diesel blends. He considered 10%, 15% and 20% of the ethanol-diesel blends in his test. With the ethanol addition, the flash point of the blends decreased. More ethanol in the blends formed a vapour at the head of the storage tank, and was flammable in storage tanks at 12-42 °C, compared to diesel which was flammable at 64-150 °C. So, flame arrestors were installed in the filler necks. About 10-20% ethanol blends showed similar properties to those of diesel [30].

Boruff et al. used organic additives to form co-solvents and micro emulsions of aqueous ethanol and diesel blends, and also checked the suitability of these fuels in a naturally-aspirated, water-cooled DI diesel engine. The micro emulsion of 190-proof ethanol with diesel was done using a surfactant prepared from unsaturated (soybean) fatty acids, N, N diethyl ethanolamine, 2•amino-2•methyl-l•propanol, and named as hybrid fuels. The detergents micro emulsion was prepared by using 1-butanol and was found to be superior in engine performance compared to the ionic micro emulsion which was developed from soybean fatty acids. The engine was able to achieve higher power and brake thermal efficiency compared to that of diesel with these hybrid fuels. Also, the exhaust gas temperature, exhaust smoke (about 64%) and CO emission were found to be lower with the hybrid fuel operation [31].

Gerdes and Suppes et al. have explained that the aromatic content and mean distillate temperature would have a significant impact on the miscibility limits of the ethanol-diesel blends. The miscibility of ethanol in diesel was improved with a reduction of the aromatic. The content of diesel. It also affected the amount of emulsifier required for the stable emulsion [32].

Stage de Caro et al. conducted experiments in DI and IDI engines by using 10-20% ethanol-diesel blends. They used two additives to get stability and to improve the ignition quality of the blends. They added 2% each of two additives such as 1-octylamine-3-octyloxy-2-propanol and dinitrate derivative N-(2-nitrate-3-octyloxy propyl), N-octyl nit amine for comparison purposes. They concluded that the additives kept the cetane number above 45, which ensured suitable ignition. The cetane number was increased by about 2% with 10% ethanol-diesel emulsions compared to that of diesel. When 20% of ethanol with an additive was used, the cetane number was found to be decreased by about 6.5% compared to that of diesel. The ignition delay was reported to be longer, and cyclic irregularities were observed when the ethanol content was increased in the emulsion[33].

Lapuerta et al. examined the stability range and effect of temperature, the water content in the blends. They considered the test conditions of a sample as 5 °C and 2.5% water up to E-20 blend. The separation ratio was also discussed for better results of stability. They concluded that the blends with the ethanol contents up to 10% v/v could be used in diesel engines, in countries where winter temperatures rarely fall to 5 °C. And blends with 7% bio ethanol, such as those commercially used, could be used in even colder countries [34].

Rakopoulos et al. investigated the performance and emission parameters of a six-cylinder, turbocharged and after-cooled, heavy duty, direct injection (DI), Mercedes-Benz engine, fuelled with 5% and 10% (by vol.) of bio ethanol in the ethanol-diesel blends. The specific fuel consumption was observed to be higher with increasing percentage of ethanol in the blends, and the efficiency was marginally improved. The smoke density was significantly reduced with the ethanol-diesel fuel blends, concerning that of diesel with a corresponding increase in the percentage of ethanol in the blend. A marginal increase in the HC emission was observed with the blends, and also the NO and CO emissions were marginally reduced in comparison with diesel at full load, with the increase in the percentage of the ethanol content.[35].

Huang et al. investigated the engine performance and exhaust emissions of a single cylinder, four strokes, and water cooled DI diesel engine fuelled with 10%, 20%, 25% and 30% ethanol-blended diesel fuels with and without the additive. The additive n-butanol about 5% was used to increase the blend stability and properties. The BTE found to be decreased as the amount of ethanol in the diesel–ethanol blends increased. The smoke emission was observed to be lower when the blend fuelled the engine compared to that of regular diesel at full load. The CO emission was noticed to be lower at and above half loads compared to that of diesel but was higher at low loads and low speeds. The HC emission was higher except at full loads and high speeds, while NO emissions varied at different speeds, loads and blends [36].

Li et al. studied the effects of ethanol-diesel blends in a single-cylinder DI diesel engine with ethanol of 5%, 10%, 15% and 20% blend on volume basis and found that BTE, BSFC, and THC were increased while the CO, NOx and smoke emissions were significantly reduced in comparison with neat diesel fuel [37].

Arapatsakos et al. used ethanol amount of 20% to 30% on a volume basis in the diesel– ethanol blends and studied the performance and emission characteristics of a

4-cylinder John Deer Tractor engine at full load. The concluded that the addition of ethanol showed a positive effect on the CO and HC emissions, but an adverse effect on engine power due to the small calorific value of ethanol [38].

Ganesh et al. emulsified ethanol at a percentage of 30%, 40% and 50% by volume with diesel using sorbitan monooleate as a surfactant and experimented with a single cylinder, four-stroke, water cooled, DI diesel engine to determine the effects of Emulsion/blend on the performance, combustion, and emissions. They concluded that the 50% ethanol-diesel blend was best, compared to those of diesel and other blend ratios. Using the optimal blend, the delay period was reduced at a 24° injection angle. The BTE and NO emissions were found to be increased, but smoke density and PM were reduced, and the maximum heat release, peak pressure, cumulative heat release and cylinder pressure were noticed to be improved [39].

Banugopan et al. investigated the performance and emission characteristics of a single cylinder, four strokes, water cooled, DI diesel engine using ethanol-diesel emulsion/ blends. They added 1% of iso propanol with 10%, 15%, 20%, 25% and 30% of ethanol-diesel blends, as an additive for enhancing homogeneity and preventing phase separation. The inlet air was preheated to 40, 50 and 60 °C. The total fuel consumption (TFC) and specific fuel consumption (SFC) increased as ethanol concentration increased, while the BTE was found to be decreased without preheating. Simultaneously, they observed that preheating inlet air had an adverse effect on CO and HC emissions [40].

Kumar et al. studied the effect of the addition of emulsifier at the different percentage on the performance, combustion and emission characteristics of a DI diesel engine. They prepared the ethanol-diesel micro-emulsions with the addition of ethyl acetate (EA) emulsifier at the volume percentage of 7%, 13% and 17% and ethanol value of 13%, 17%, and 23%. They reported that the phase separation did not occur with ethanol-diesel micro-emulsions containing 13% of ethanol and 7% of EA, for which the BSEC and BTE were improved without any power reduction at a lower load. The NO and smoke emissions were found to be decreased, while the HC and CO emissions were increased at lower loads. The HC and CO emissions were improved at higher loads, but BSEC was increased [41].

Lei et al. studied the effects of ethanol-diesel blends on performance and emissions characteristics of a turbo-charged diesel engine under different atmospheric pressures (81, 90 and 100 kPa) conditions and compared the results with that of diesel. The amount of ethanol considered for the blend was 10%, 15%, 20% and 30% by volume basis. They found that the BSFC was significantly improved below 90 kPa, but a sharp increase in HC and CO emissions with increasing engine speed, load, and the ethanol concentration were observed at 81 kPa. On the other hand, atmospheric pressure and ethanol blending percentage did affect NO emission at 90 and 100 kPa, while smoke was reduced below 90 kPa [42].

Song et al. carried out the engine experiment in a 6-cylinder, heavy duty, non-catalyst turbocharged intercooler DI diesel engine with diesel and ethanol-diesel fuel blends at 1200, 1800 and 2600 rpm and studied the carbonyl emissions from the engine. They used the ethanol amount of 15% with a stability additive of 0.3% and 1.2% in diesel to prepare the blends/emulsion. The experimental results revealed that acetaldehyde was the foremost carbonyl produced by both fuels, followed by formaldehyde, acrolein, acetone, propionaldehyde, and crotonaldehyde. The addition of ethanol to diesel fuel resulted in a decrease in acrolein emissions, while the other carbonyls increased at low engine speed. The brake specific emissions of each carbonyl compound decreased with the increase in engine load during the constant speed test. Carbonyl carbon (CBC) emissions from both diesel and the diesel–ethanol blends were found to be the highest at high engine speed, while the total CBC emissions from the ethanol-diesel blends were higher than those from diesel under most engine operating conditions [43].

2.6 CONCLUSION OF LITERATURE REVIEW

It is clear from the above literature review that ethanol production from biomass can substitute an even minor percentage of diesels. Many researchers have reported that the exploration of a significant amount of bio fuel from the biomass to ease the demand of energy security as well as reduction of engine exhaust emissions which is the measure cause of climate change. The literature indicates that the ethanol derived from the biomass provide the significant reductions in GHG and smoke emissions compared to those of diesel fuels. Though a lot of work has been carried out on utilization of ethanol, the researcher tried to explored ethanol from new biomass feedstock's and decided to first characterize ethanol for its suitability to be used as an alternative fuel for a CI engine, by using various instruments, and then to adopt different techniques for its possible utilisation.

2.7 LITERATURE GAP

- Physicochemical properties of ethanol-diesel blends with THF as a surfactant are rarely investigated.
- The effect of varying quantity of ethanol in ethanol-diesel blends with THF as a surfactant is rarely investigated.
- Spray characteristics of ethanol-diesel blends are not worked out.
- Performance of ethanol-diesel blend at different engine parameters like compression ratio, speed, air fuel ratio is not performed till now.
- Emission characteristics of ethanol-diesel blends with THF are not evaluated.

2.8 OBJECTIVES OF THE STUDY

The objectives of the rest research work are as follows;

- Comprehensive literature survey.
- To characterize the ethanol for its suitability for alternative fuel for an engine.
- To ensure the substitution of ethanol to diesel by the maximum percentage by evaluating combustion, performance, and emission of a single cylinder, four strokes, air cooled, DI diesel engine adopting few fuel modification.
- Determination of spray characteristics of different blends using Malvern Spraytec.
- Analysis of results.
- To validate the experimental results.
- Durability study for long-term benefit.

CHAPTER 3

SYSTEM DEVELOPMENT AND EXPERIMENTAL PROCEDURE

The foremost reason for the problem of blend stability results from the different polarity of the components: ethanol is a polar compound while diesel oil is non polar.

Ethanol has a high affinity to water, it dissolves in it without any restriction. It absorbs moisture from air. Ethanol-diesel blends, standard diesel fuel is typically blended with up to 15% (by volume) of ethanol using an additive package that helps to maintain blends stability and other properties-most importantly cetane no. and lubricity.

3.1 SURFACTANT

The word “Surfactant” is a short form of the three words “Surface Active Agents.” Surfactants are substances that decrease the surface tension (or tension acts between at interface) between a liquid and a solid or between two liquids or between a solid and a liquid.

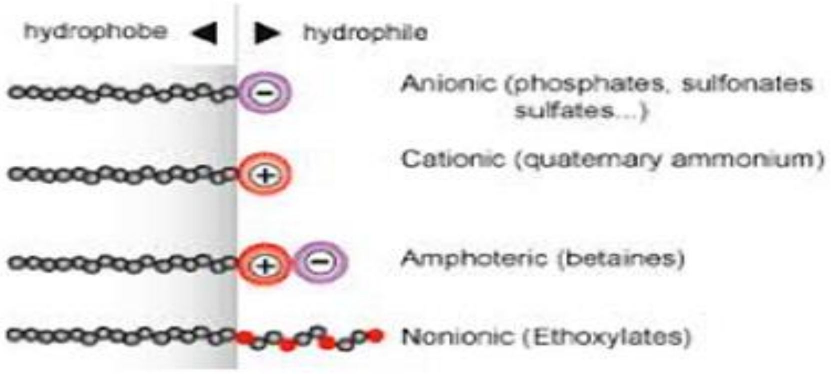


Figure 4: Types of surfactant

Generally, any material that alters the interfacial surface tension can be recognized as a surfactant, but in the practical sense, surfactants may act as emulsifiers, wetting agents, dispersants and foaming agents. Surface active agents act a main role as emulsifying, cleaning, wetting, dispersing, emulsifying, foaming and anti-foaming agents in lots of useful applications and products, as well as paints, emulsions adhesives, inks, biocides (sanitizers), shampoos, toothpaste, fire fighting (foams), detergents, and insecticides.

Generally four types of surfactants

- Non-ionic: it has no charge groups in its head
- Anionic: the head of an ionic surfactant carries a negative charge
- Cationic: the head of an ionic surfactant carries a positive charge
- zwitterionic: if a surfactant contains a head with two oppositely charged groups.

3.1.1 TETRAHYDROFURAN

It is an organic compound with the formula $(CH_2)_4O$

- polar
- colourless and water miscible
- low viscosity

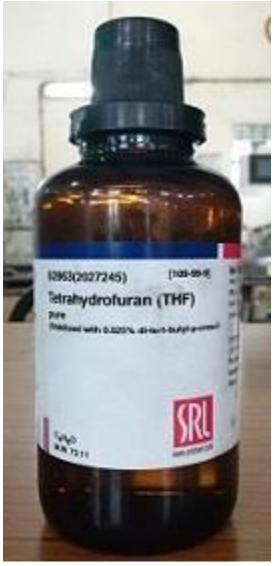


Figure 5: Tetrahydrofuran

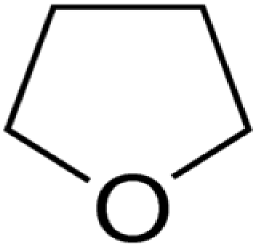


Figure 6: Structure of THF

Production

Acid-catalyzed dehydration of 1-4-butanediol.butanediol is derived from condensation of C_2H_2 acetylene with formaldehyde followed by hydrogenation.

3.2 EQUIPMENT:

3.2.1 UTUBE OSCILLATING APPARATUS FOR MEASURING API GRAVITY

Density of ethanol-diesel stabilized with tetrahydrofuran as a surfactant were measured using an automated DMA 4500 density meter, equipped with U-tube oscillating apparatus for measuring api gravity as shown in figure.

Figure 7: Density meter

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”

Concentration Measurement

In dual mixtures, the density of the blend is a function of its composition. Thus, by using density/concentration tables, the density value of a binary mixture can be used t0 calculate its c0mp0siti0n. This is als0 p0ssible with s0-called quasi binary mixtures. These are mixtures c0ntaining tw0 maj0r c0mp0nents and s0me additi0nal c0mp0nents which are present in very small c0ncentrati0ns c0mpared t0 the tw0 main c0mp0nents. Many decarb0nised s0ft drinks, f0r example, can be measured t0 be quasi binary s0luti0ns 0f sugar in water because the c0ncentrati0n 0f flav0rs and acids are very small c0mpared t0 sugar and water. Thus, the sugar c0ncentrati0n can be measured with a density meter.

The density of standard diesel fuel at 15^{0}C is 825.0kg/m^3, diesel-ethanol blends stabilized with THF, ethanol and THF pure components. It can be observed that for all the samples that the density decreases as increasing the percentage of ethanol. However, the density at 15^{0}C of the blends is acceptable for the Bharat 6 standard (820-845kg/m^3); the inferior limit for diesel density is 0.8200 g/cm3.

3.2.2 KINEMATIC VISCOMETER

Kinematic viscosity of ethanol-diesel stabilized with tetrahydrofuran as a surfactant was measured using an automated kinematic viscometer, equipped Gravimetric Capillary technique as shown in figure.

Figure 8: Viscometer

According to the obtained data, blends which contained 2% and 5% ethanol present a kinematic viscosity at 40^{0}C higher than the minimum level of viscosity for diesel fuel (2 mm^2/s) which can be considered an acceptable limit for a standard diesel fuel (figure 8). However, the increase of ethanol concentration to 15% and the addition of the needed THF for stabilization, leads to a decrease of viscosity, value which exceeds the required minimum for diesel fuel. A low viscosity could cause more fuel pump leakage that would limit the amount of fuel delivered during high load conditions. A lower viscosity would also cause the pulverized fuel droplets to have a smaller dimension which would lead, for the same amount of volume injected, to an increase of surface area of the fuel droplet which would influence the evaporation characteristics

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 are made of glass.

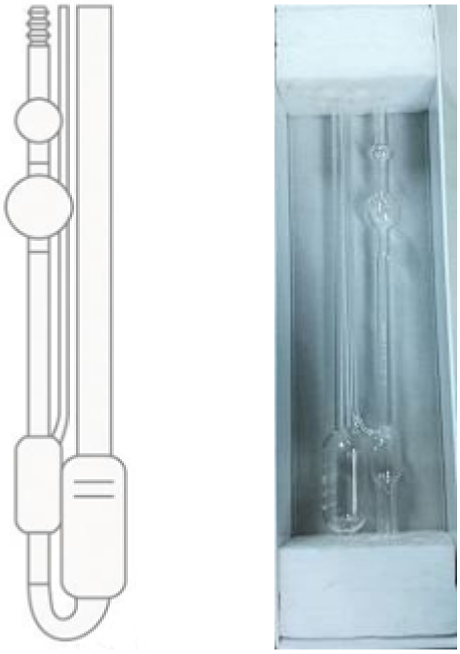


Figure 9: Ubbelohde glass capillary types of kinematic viscometer

3.2.3 AUTOMATIC MICROPROCESSOR CONTROLLED CALORIMETER 6100 CALORIMETER OPERATION

Density of ethanol-diesel stabilized with tetrahydrofuran as a surfactant were measured using an Automatic Microprocessor controlled Calorimeter 6100 Calorimeter Operation as shown in figure 10

Figure 10: Calorimeter

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.
13. Put the bomb into the bucket. Note that the bomb will sit on the embossed circle on the bottom of the bucket.

3.3 SPRAY CHARECTERSTICS

The fuel-air mixture having spray particle and droplet size formation is earlier to as well as after self ignition is important in diesel engine. Spray particle and droplet size plays an important role for improving combustion and emission characteristics of fuel because it primarily affects the fuel-air mixture formation. Spray particle and droplet size of fuel chiefly depends up on atmospheric pressure, fuel injection pressure, temperature, fuel density and fuel viscosity. The improvement of spray particle and droplet size leads to batter performance of diesel engine. During the ignition of fuel in IC engine the main property which affects the spray particle and droplet size are density and viscosity.

3.3.1 MALVERN SPRAYTEC

With the help Malvern spray tec we are able to find out the Spray particle and droplet size distributions of all the 6 blends. It uses the laser diffraction technique. This requires the angular intensity of light speckled from a spray to be well thought-out as it passes through the laser beam. The recorded spreading pattern is then analyzed by means of a suitable optical model to give up a size distribution. Original multiple spreading algorithm is used for calculating particle size. This makes sure perfect particle size distribution can be calculated at up to 98% obscuration, far away from as compared to the range of other laser diffraction systems. In addition, a maximum data achievement rate of 10 kHz ensures that any sequential fluctuations in the spray size are detected and understand.

Features That Spraytec Delivers

- Maximum achievement rate is 10 KHz
- Configuration of lens is unique, imaging spreading over a large working range.

- Lens systems are 300 mm and 750 mm, covering a 0.1-2000µ dynamic range.
- Auto-align are rapid.
- Design and construction is strong.
- Set up arrangement of optical bench is personalized.
- Analysis is highly concentrated.
- An option is flexible triggering options which are used for measurement synchronization.[45]

Figure11: Malvern Spraytec [45]

3.3.2 PROCEDURE OF ANALYSIS MALVERN SPRAYTEC

Access to the spraytec's power measurement capabilities is controlled via an equally imposing software interface that makes specific spray measurements totally clear-cut [45].

Step-1: Set up your standard operating procedure (SOP) using the system's integrated method definition wizard. Sops lockdown all aspects of the process measurement including the hardware arrangement, analysis setting, triggering options, result factor reporting and data averaging. Online help supports way specs for different spray types.

Step-2: Run the measurement by selecting the desired SOP from the menu system. This routinely configures the system and ensures the whole thing is optimally set to bring accurate results, as well as auto-alignment of the optical system. Synchronization of outer 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. Prompt sensor that the correct sample preparation, handling and disposal procedures are followed.

Step-4: View the results using the size history window. This displays there corded particle size distributions along with a size history chart showing how the spray developed overtime. Users can playback the spray event and select records for further analysis.

3.4 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.

Roughly in India 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 little 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 stipulation 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.

3.5 INSTALLATION OF THE CONTROL 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 (figure 12). Electrical load banks, i.e., 12 bulbs each of 500 watts (figure 13), were mounted on the rear side of the control panel which is shown in figure and their switches provided on the front side of the control panel.

Figure 12: Control panel

Figure 13: 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. 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.

Figure 14: Fuel Flow Measuring System

3.7 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

Figure15: Engine Speed Measurement

3.8 EXHAUST EMISSION ANALYSIS

The major pollutants appearing in the exhaust of a diesel engine are the oxides of nitrogen. Exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO_2 and NOx. For measuring the smoke opacity, AVL smoke analyzer was utilized. This instrument gave reading in terms of percentage opacity. Of the light beam projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particles in the exhaust.

Table 3: 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

3.9 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

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

3.10 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 20%, 40%, 60%, 80%, 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

4.1 STABILITY OF PREPARED BLENDS

Stable blends of ethanol and diesel are prepared with the help of tetrahydrofuran as a surfactant. Because one is polar and other in non polar. After the numerous number trials with different proportion of THF, ethanol and diesel were mixed and stable blends are prepared which were stable at room temperature. The total volume proportions of blends are discussed in the table.

Table 4: Percentage of diesel, ethanol and THF used for preparation of blends

Sample	Ethanol (%v/v)	THF (%v/v)	Diesel (%v/v)
D100	0% Ethanol	0	100
E2	2% Ethanol	0.6	97.4
E4	4% Ethanol	1.0	95.0
E6	6% Ethanol	2.0	92.0
E8	8% Ethanol	4.4	87.6
E10	10% Ethanol	5.0	85.0
E15	15% Ethanol	5.0	80.0

With concentration of THF between 0.6% to 5%, for diesel 70% to 97.4% and for ethanol 2% to 15%. The stability of the blends was monitored for 2 months until the prepared blends were considered homogenous. Therefore, very beginning of stability study, 0.6% THF was added into the 1% and 2% ethanol blends and 1% THF into the 3% to 6% ethanol blends and mixed using a magnetically stirrer, followed by keeping at normal temperature for 3-4 days to observe if the ethanol gets separated from the diesel. Based on the observation it was noted that, after 2 weeks, by adding some additional amount of THF a total percent volume of 0.6% and 2% THF, the blends which contain 2% and 6% ethanol was stabilized. For blends which contain over 8% ethanol stability has been attain by adding more than 4.4% of THF.

Since ethanol and diesel present different structure and chemical characteristics, in time, the blends become unstable, leading to the separation of components. Immiscibility of ethanol into diesel fuel is caused by H_2O traces present in ethanol and aromatic compounds in diesel fuel.

4.2. PHYSICOCHEMICAL PROPERTIES

4.2.1 DENSITY

The variation of density of 6 different blends is represented in figure 16. It is observed that for all 6 samples, the density varies according to proportion of THF and ethanol. The blends Density of standard diesel fuel (0.832 g/cm^3). Increase the percentage of ethanol, density of the blend decrease but have E4, E6, and E8 has in increase in order because of the higher density of THF component, still the density of THF is higher than the upper limit for density of diesel. Still, the density at 25^{0}C of all the 6 blends is satisfactory limit EN standard which is 820-845 kg/m^3; The variation of density of standard diesel fuel is in between 810 kg/m^3 to 880 kg/m^3. The properties CN, viscosity, volatility, density and combustion heat are interrelated. An increment of 10% in the density increases the energy content (MJ/m^3) of the fuel nearly by 6%. Engine calibration is affected by the density of the fuel. The obtained results are by the results presented in the figure.

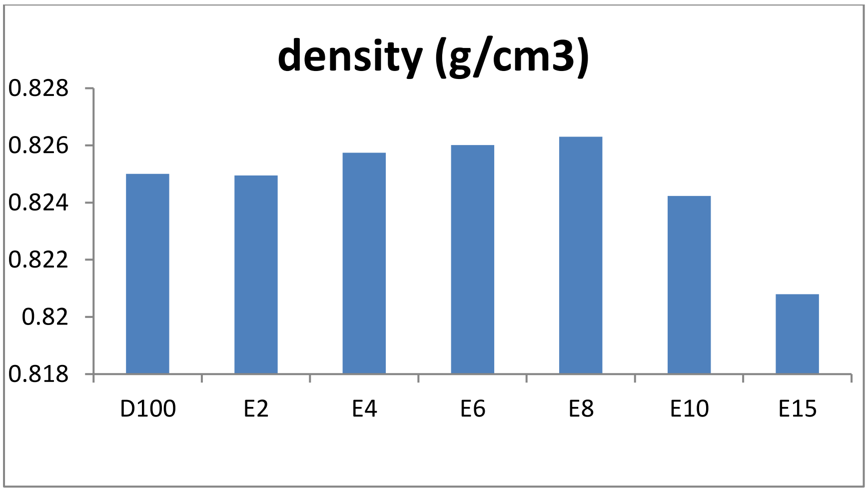


Figure 16: Density of different blends

4.2.2 KINEMATIC VISCOSITY

The variation υ of 6 different blends are represented in the figure, as we increase the % of ethanol the kinematic viscosity decrease linearly. With diesel have highest kinematic viscosity among all the 6 blends a viscosity of around 2.7092 mm^2/s. Also, ethanol presents low kinematic viscosity with variations between 2.20 mm^2/s at 0^{0}C and 1.08 mm^2/s at 40^{0}C. According to the obtained data, blends which contained 2% and 4% ethanol (before adding THF) present a kinematic viscosity at 40^{0}C higher than the minimum level of viscosity for diesel fuel (2 mm^2/s) which can be considered an acceptable limit for standard diesel fuel. However, the increase of ethanol concentration to 15% and the adding up 5% of THF is needed for stabilization, leads to a decrease of viscosity, value which exceeds the required minimum for diesel fuel. A low viscosity could cause more fuel pump leakage that would limit the quantity of fuel delivered during high load conditions.

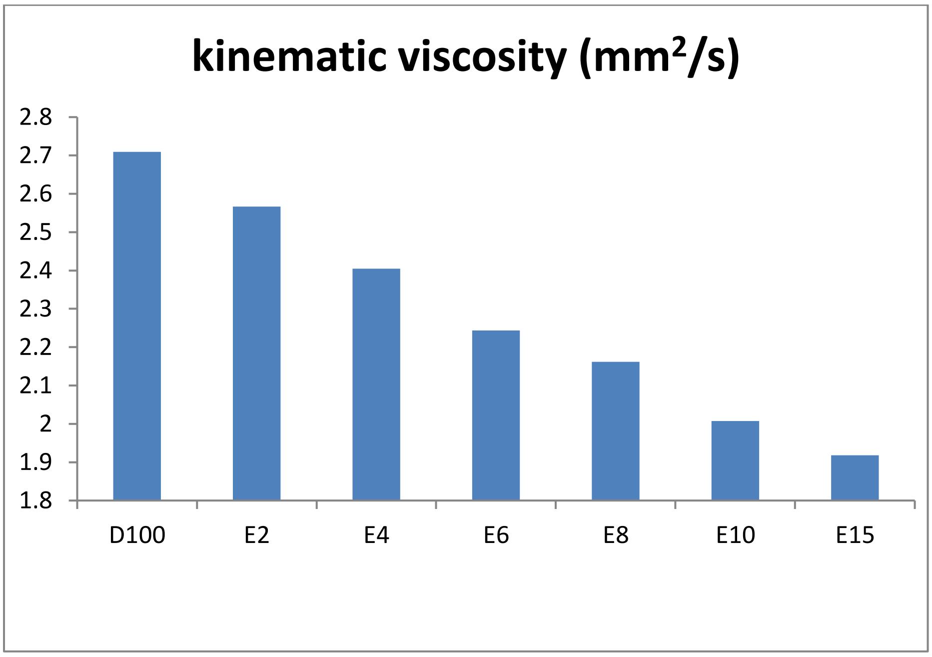


Figure 17: Kinematic viscosity (υ) of different blends

Fuel atomization is strongly influence by viscosity of diesel, a low viscosity fuel resulting in smaller fuel droplets. Which would lead to increase of surface area for the same amount of volume injected of fuel droplet, which would influence the evaporation characteristics. Spray cone angle reduces with increment in the viscosity and spray penetration increases with increase in viscosity. On the other hand lower the value of (υ) viscosity results in leakage in pump element and loss of calibration in fuel system. Surface tension plays an important role in the fuel's combustion, affecting its initial stage, i.e. fuel atomization and spray characteristics. But by Even if the density (ρ), viscosity (υ) and properties of blends which contain ethanol in concentrations lower than 8% have good characteristic for utilization as fuel in diesel engines, the safety properties need to be considered for shipping and storage classification and safety measures should be taken in handling and transporting of the prepared blends.

4.2.3 CALORIFIC VALUE

The variation of different six blends is represented in the figure 18. The CV is determined by the Automatic Microprocessor controlled Calorimeter. The blends which contain 2%, 4%, 6%, and 8% of ethanol have the higher values amongst the other blends. The highest value of CV found for the blend E2 which has the value 47.87 MJ/Kg. Though the CV of ethanol is very lower than diesel which is 27 MJ/Kg but the CV of E2 blend is higher than that of diesel which is 45 MJ/Kg and the calorific value of tetrahydrofuran is 34.8 MJ/Kg. The blend which has lower calorific value is desirable because temperature of the combustion decrease decreases the NO_x emission. The blends 4% ethanol, 10% ethanol, 15% ethanol has relatively lower calorific value than other blends.

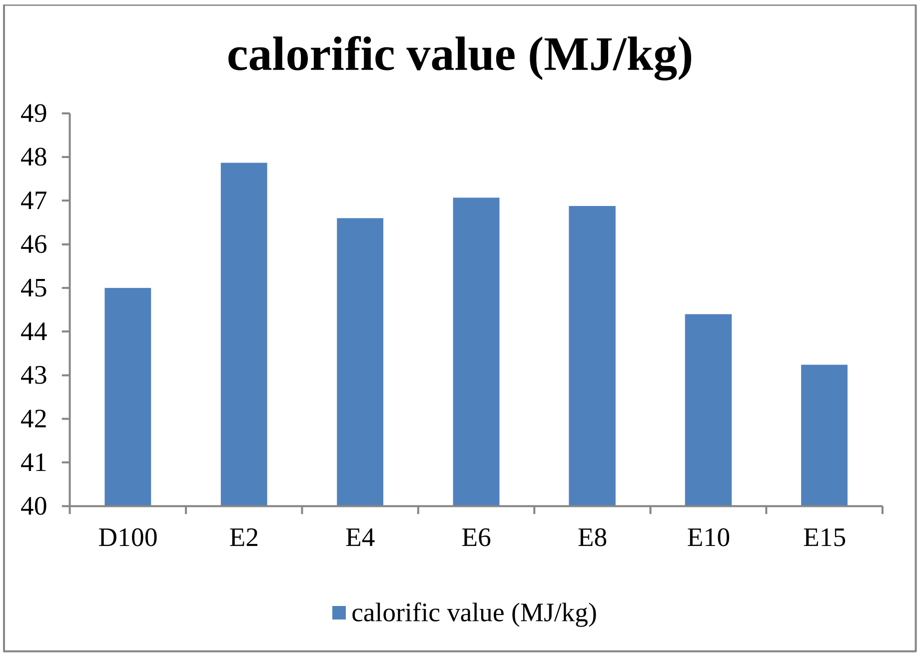


Figure 18: CV of different blends

4.3 SPRAY CHARACTERISTICS

4.3.1 SPRAY CHARACTERISTICS OF D100

The particle size distribution for D100 is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 19%. Where the specific surface area is more important Souter mean diameter is more relevant. Here in this particle size distribution test two readings D[3,2] and D[4,3] so if concentration is to monitor the size of the fines particulates then D[3,2] would be most appropriate on the other hand if concentration is to monitor the size of coarse particulates then D[4,3] would be the best option. SMD is defined as the diameter of a sphere that has the same volume/surface area ratio as a particle of interest i.e. D[3][2]. Cumulative volume is the total transmitted volume during the course of test conducted. Can be measured in ppm, cc, LWC etc. Path length is the length from the nozzle through which fuel stream is issued to the vicinity of nozzle and it is measured in mm. The measurements parameters are estimated from the tests are given below:

Cumulative volume= 1535 ppm and Span =1.939

Mean Sauter Diameter= 281.5µm and Path Length= 100 mm.

Specific surface area =0.0213m^2/cc.

In general SMD is defined in the 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 is surface area and V_p is volume of a particle. Souter diameter for given particle is[1]

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

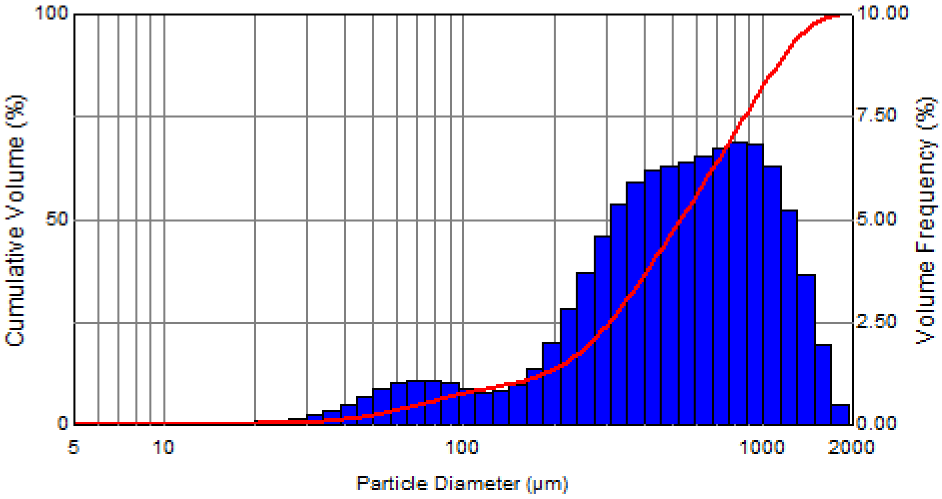


Figure 19: Particle size distribution for D100

4.3.2 SPRAY CHARACTERISTICS OF E2

The particle size distribution for neat diesel is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 75.2%. Mean sauter diameter D[3][2] for 2% ethanol blend is 263.2 µm. The measurements parameters are estimated from the tests are given below:

Cumulative volume= 244.6 ppm and Span =1.554

Mean Sauter Diameter= 263.2µm.

Specific surface area =0.0228 m^2/cc.

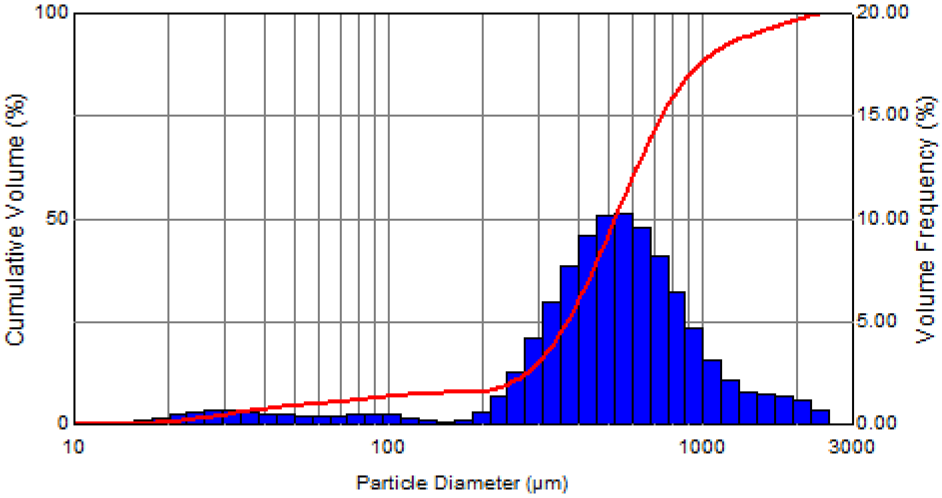


Figure 20: Particle size distribution for E2 blend

4.3.3 SPRAY CHARACTERISTICS OF E4

The particle size distribution for neat diesel is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 92.6%. Mean sauter diameter D [3][2]for 4% ethanol blend is 156.3 µm. The measurements parameters are estimated from the tests are given below:

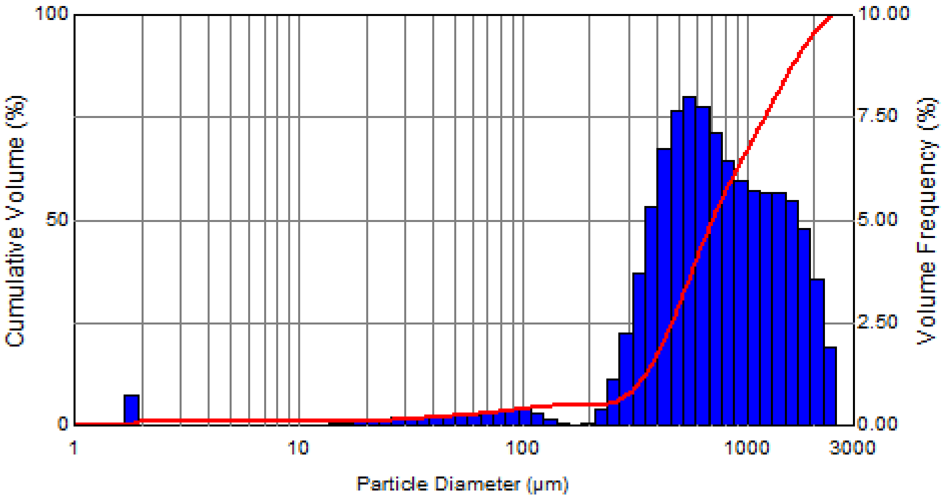


Figure 21: Particle size distribution for E4 blend

Cumulative volume= 35.69 ppm.

Mean Sauter Diameter= 156.3µm.

Specific surface area =0.0384m^2/cc.

Span =1.945

4.3.4 SPRAY CHARACTERISTICS OF E6

The particle size distribution for neat diesel is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 24.8%.

Mean sauter diameter D[3][2]for 6% ethanol blend is 220.5 µm. The measurements parameters are estimated from the tests are given below:

Cumulative volume= 981.3 ppm.

Mean Sauter Diameter= 220.5µm.

Specific surface area =0.0272 m^2/cc.

Span =1.478

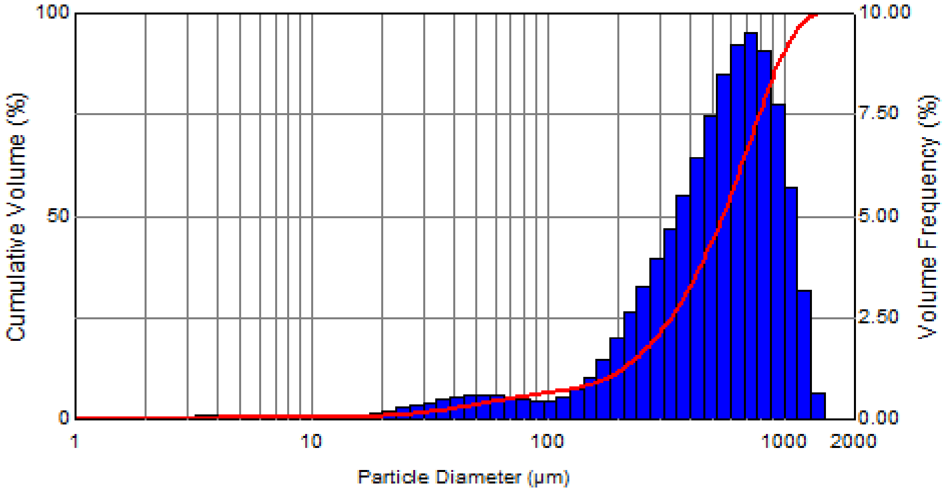


Figure 22: Particle size distribution for E6 blend

4.3.5 SPRAY CHARACTERISTICS OF E8

The particle size distribution for neat diesel is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 89.9%. Mean sauter diameter D[3][2]for 8% ethanol blend is 69.4 µm. The measurements parameters are estimated from the tests are given below:

Cumulative volume= 23.11 ppm.

Mean Sauter Diameter= 69.4 µm

Specific surface area =0.0864 m^2/cc.

Span =1.7

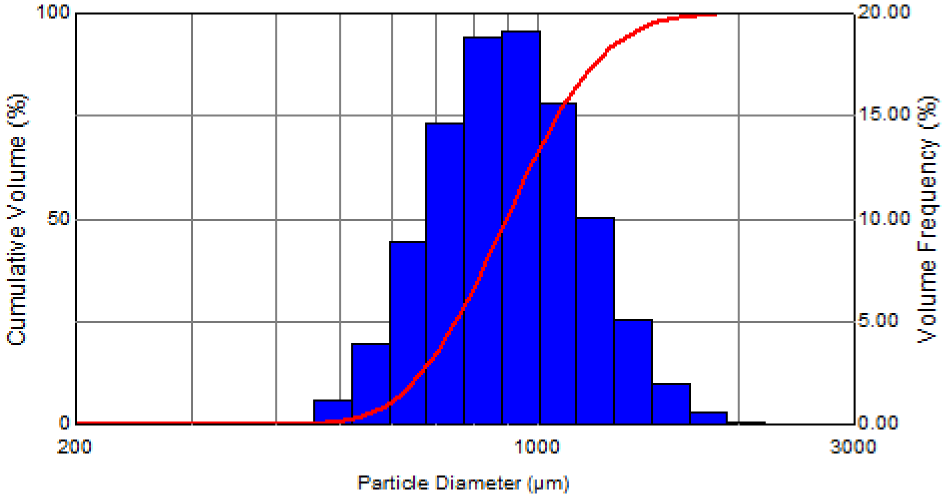


Figure 23: Particle size distribution for E8 blend

4.3.6 SPRAY CHARACTERISTICS OF E10

The particle size distribution for neat diesel is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 27.2%. Mean sauter diameter D[3][2] for 10% ethanol blend is 537.4 µm. The measurements parameters are estimated from the tests are given below:

Cumulative volume= 1149 ppm.

Mean Sauter Diameter= 274.9 µm.

Specific surface area =0.0218 m^2/cc.

Span =1.382

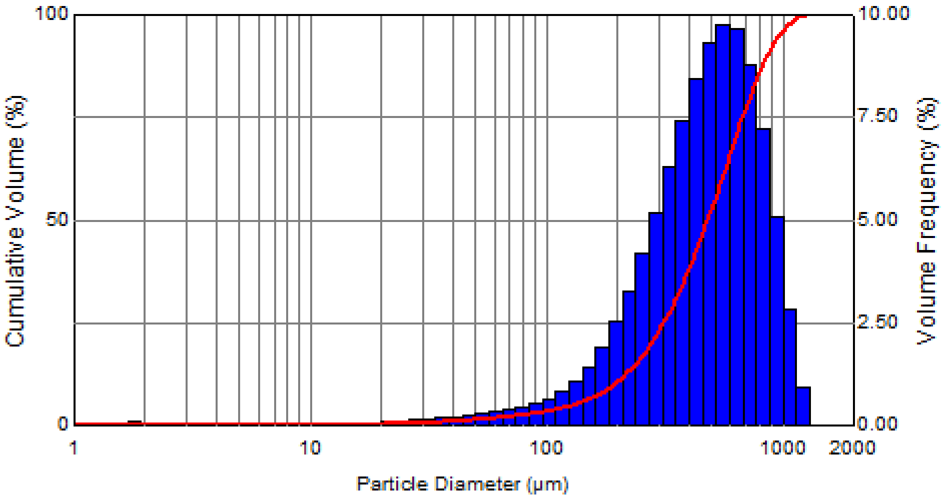


Figure 24: Particle size distribution for E10 blend

4.3.7 SPRAY CHARACTERISTICS OF E15

The particle size distribution for neat diesel is measured for the transmittance (transmittance is the % of time for which the laser captured the readings when test is conducted.) of 17.6%. Mean sauter diameter D[3][2] for 15% ethanol blend is 277.9 µm. The measurements parameters are estimated from the tests are given below:

Cumulative volume= 1574 ppm.

Mean Sauter Diameter= 277.9 µm

Specific surface area =.0216 m^2/cc.

Span =1.521

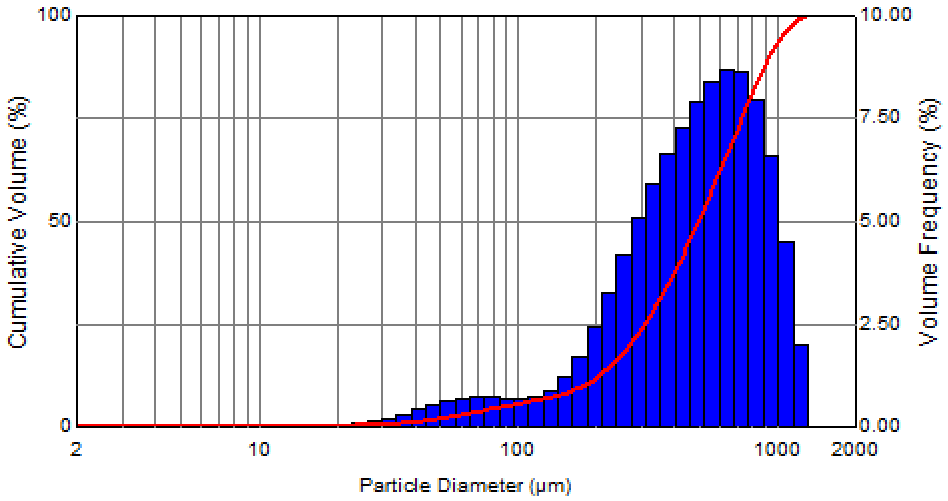


Figure 25: Particle size distribution for E15 blend

SMD decreases as the percentage of ethanol till 4% then increases till 6% then drops to a minimum at 8% ethanol diesel blends. So the best characteristics lie between 4% to 8% ethanol diesel blends. Overall characteristics are better than diesel between 2% to 8%. That is shown in the figure 26.

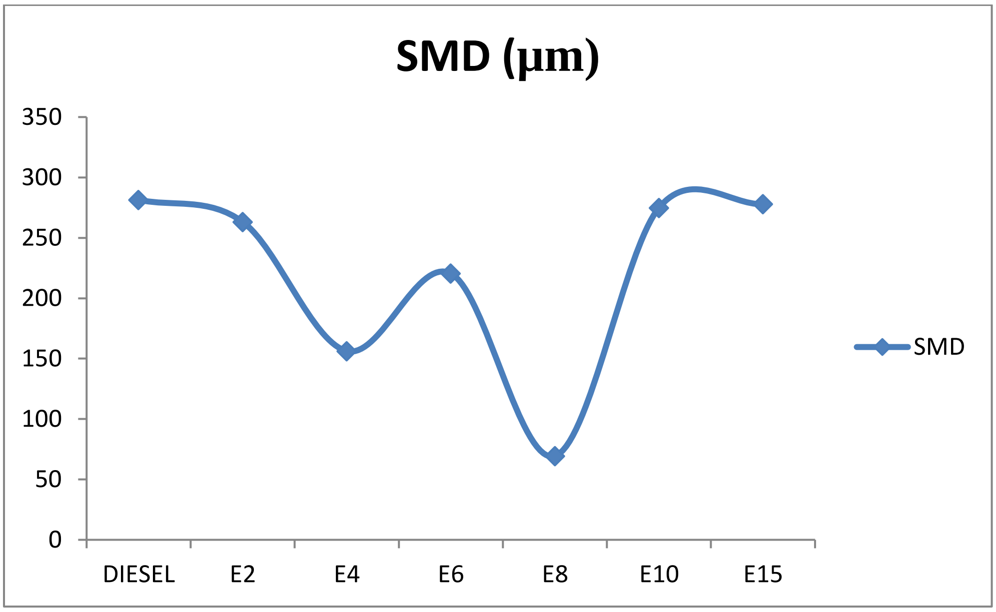


Figure 26: Variation of SMD with all blends

SSA increases as the percentage of ethanol till 4% then decreases till 6% then rises to a maximum at 8% ethanol diesel blends. So the best characteristics lie between 4% to 8% ethanol diesel blends. Overall characteristics are better than diesel between 2% to 8%. That is shown in the figure 27.

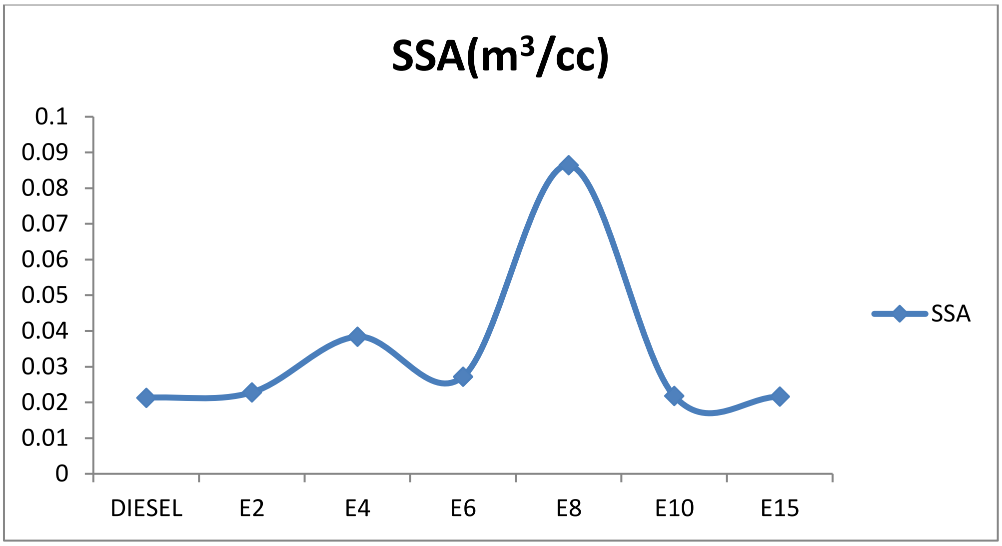


Figure 27: Variation of SSA with all blends

4.4 PERFORMANCE PARAMETERS

In this subdivision, the results which is pick up from the kirlosker engine fuelled with different ethanol-diesel blends are tested and analysed, and presented. The brake thermal efficiency (BTE), brake specific fuel consumption, temperature from the exhaust are important parameters, diesel engine performance are described by these parameters, when it is run with four fuel blends which are 4% ethanol, 8% ethanol, 10% ethanol, 15% ethanol. consequently, all these four blends are compared with diesel which is operating in the same engine are analysed and discussed in the following subsections.

4.4.1 BRAKE THERMAL EFFICIENCY

The variation of BTE of different fuel blends at different bmep is shown in figure 28. As we can see that in figure the blend which contain 8% of ethanol has BTE equivalent to that of diesel. On increasing load the BTE first increases reaches the maximum value and than decreases and maximum at nearly 60% load condition. The blends which contain 10% and 15% of ethanol has very low brake thermal efficiency as compare to that of diesel.

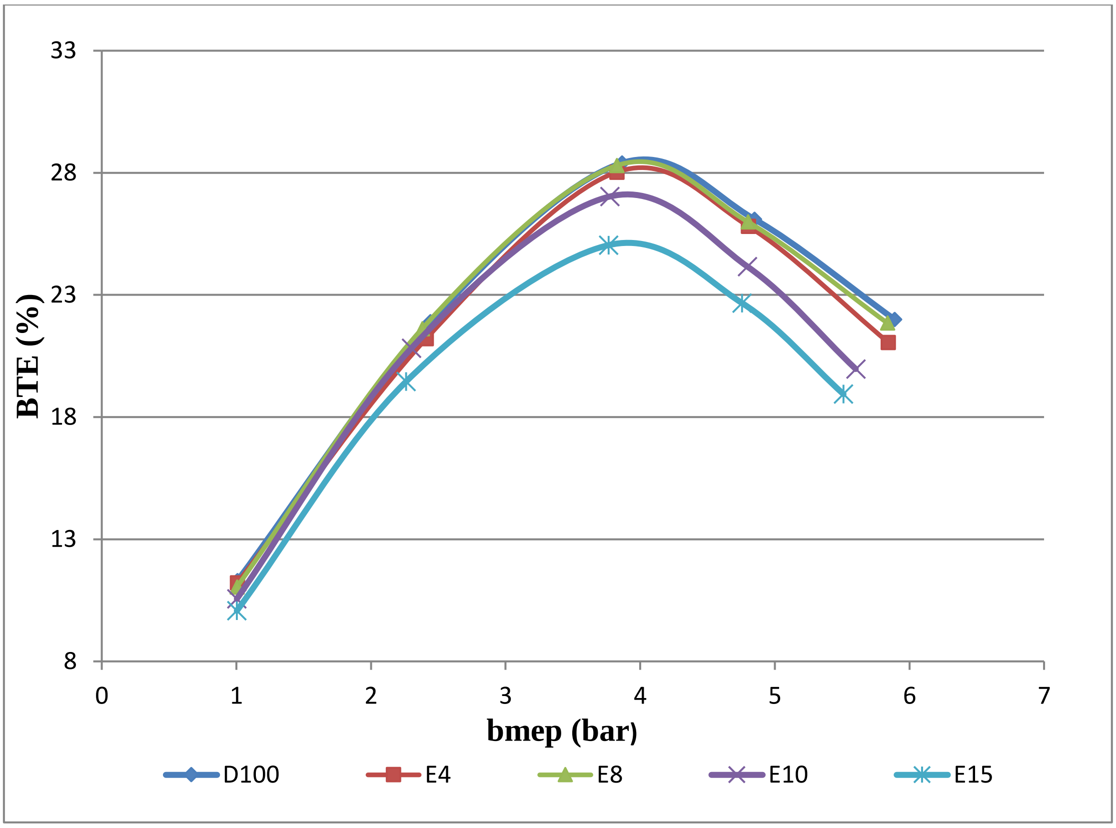


Figure 28: Variation of BTE for diesel and ethanol-diesel blends at different bmep

4.4.2 BRAKE SPECIFIC ENERGY CONSUMPTION

Figure 29 shows the deviation of the BSEC of diesel and the ethanol-diesel emulsions for different bmep. From the graph that BSEC decreases with increase increases in load and after that it increases with load because increases in load increase the cylinder temperature. The BSEC for the 10% ethanol and 15% ethanol blends is found to be higher than diesel. Ethanol has a lower calorific value than diesel but THF has higher than that of ethanol that is the reason that 4% ethanol and 8% ethanol has higher calorific value than diesel and the blend have 10% ethanol and 15% ethanol has lower heating value. This is the reason that the BSEC of E10 and E15 is higher than that of diesel. Ethanol is an oxygen rich fuel with lower boiling point and surface tension. So the chances of homogenate fuel mixture takes place in the combustion chamber due to rapid vaporization which is good for high quality combustion. High oxygen content in ethanol improves the heat efficiency.

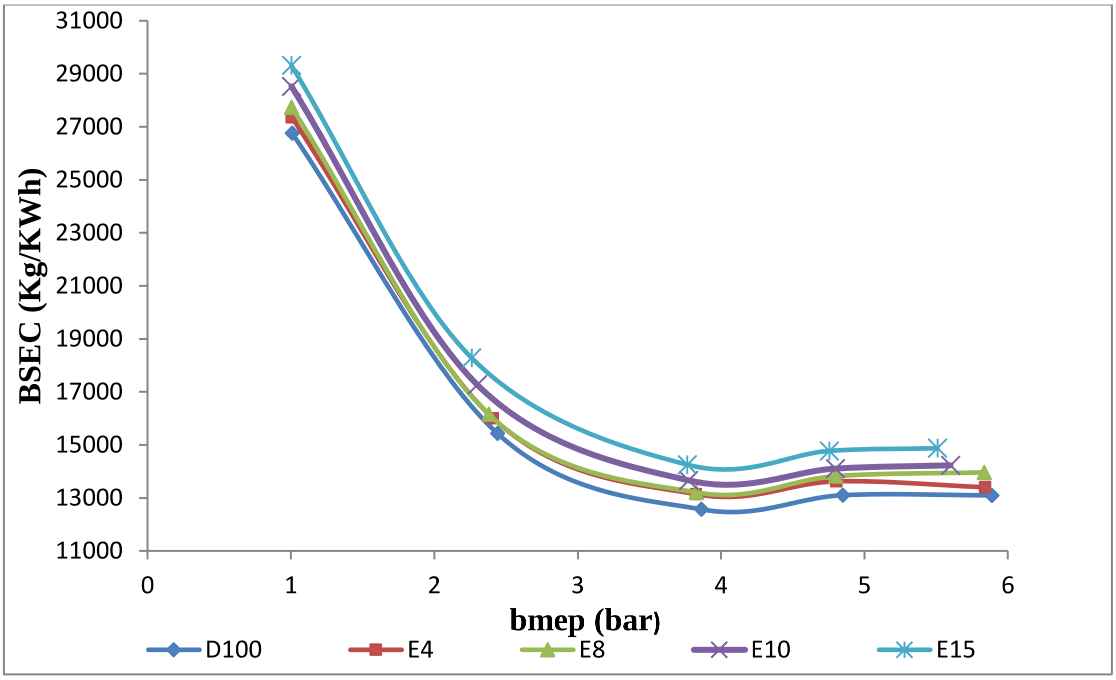


Figure 29: Variation of BSEC for diesel and ethanol-diesel blends at different bmep

4.4.3 EXHAUST GAS TEMPERATURE

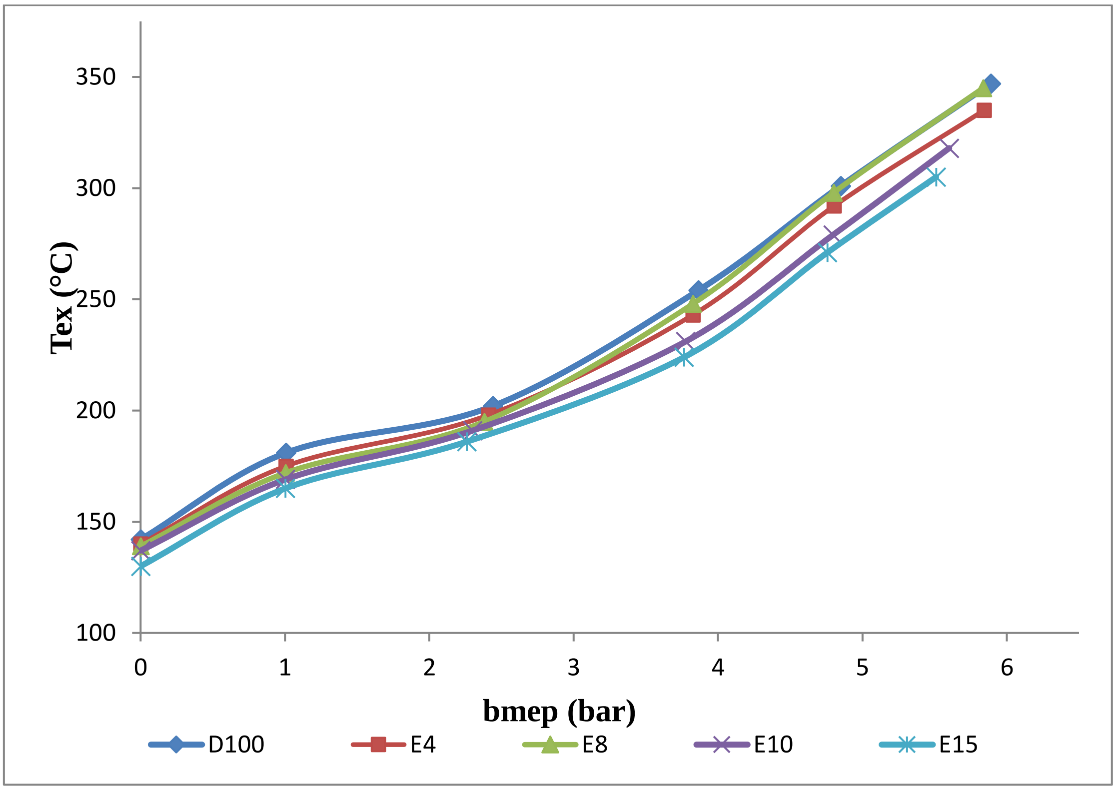


Figure 30: Variation of $T_{exhaust}$ for diesel and ethanol-diesel blends at different bmep

The temperature from the exhaust indicates that excellent energy conversion of the engine. Figure 30 shows the variation of $T_{exhaust}$ with different ethanol diesel blends for different loads. As increasing the load on the engine the $T_{exhaust}$ goes on increasing for all tested fuel blends. The blend which contains 8% of ethanol has exhaust temperature nearer to diesel at full load. This is due to the good combustion takes places in the whole engine operation. The blends which contain 10% and 15% ethanol have relatively lower exhaust temperature as compare to that of other blends.

4.5 EMISSION ANALYSIS

In this part we compared the emission of different fuel blends with that of diesel emission. The emission parameters that are analysed are CO, CO_2, HC, NO_X, and smoke.

4.5.1 CO EMISSIONS

The variation of CO emissions with respect to different ethanol diesel blends for different bmep is shown in Fig 31. The CO emission in the exhaust is due to the incomplete combustion and due to the deficiency of oxygen in the air fuel mixture or

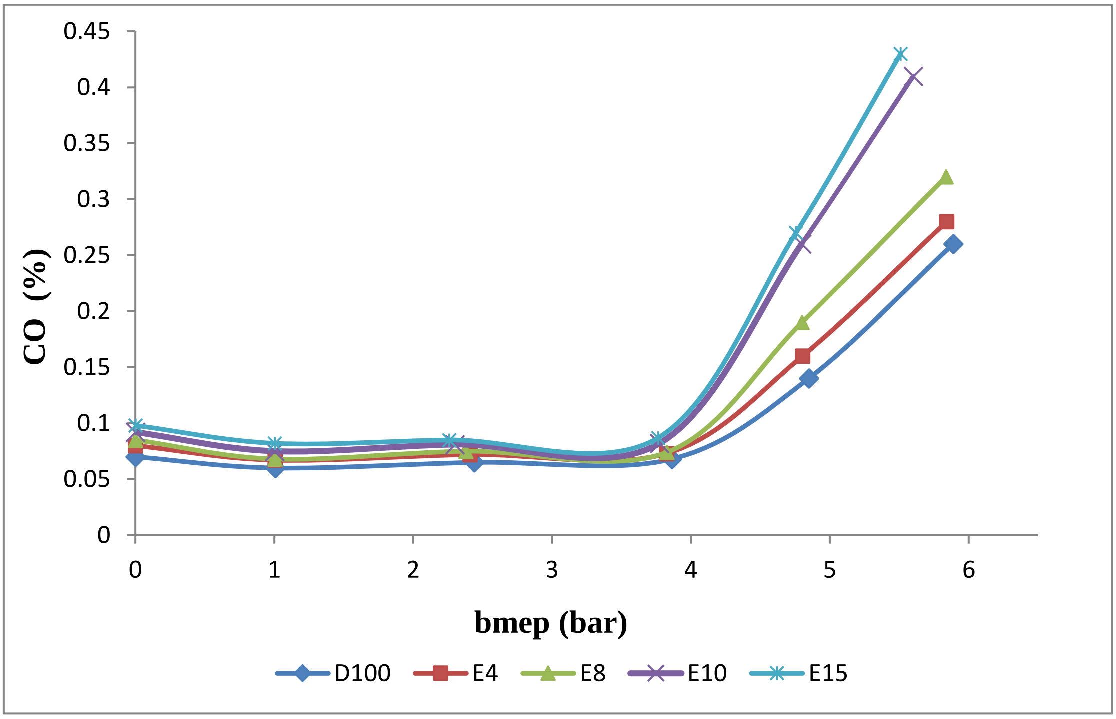


Figure 31: Variation of CO Emissions for diesel and ethanol-diesel blends at different bmep

due to inadequate time in the cycle for completion of combustion at every load. At full load condition there is the reduction in excess air ratio so the increase in the proportion of co emission is significantly. In the graph co emission is more in the blends which have 10% and 15% of ethanol. the blend which contain 8% of ethanol has co emission nearly to that of diesel

4.5.2 CO_2 EMISSIONS

The variation CO_2 emission with respect to different ethanol diesel blends for different bmep as shown in figure 32. From the figure as the load goes on increasing the emission of CO_2 goes on decreasing. The minimum CO_2 emissions is seen in the blends which contain 10% and 15% of ethanol this is due to less heat available in these blends which decreases the rate of formation of CO_2.

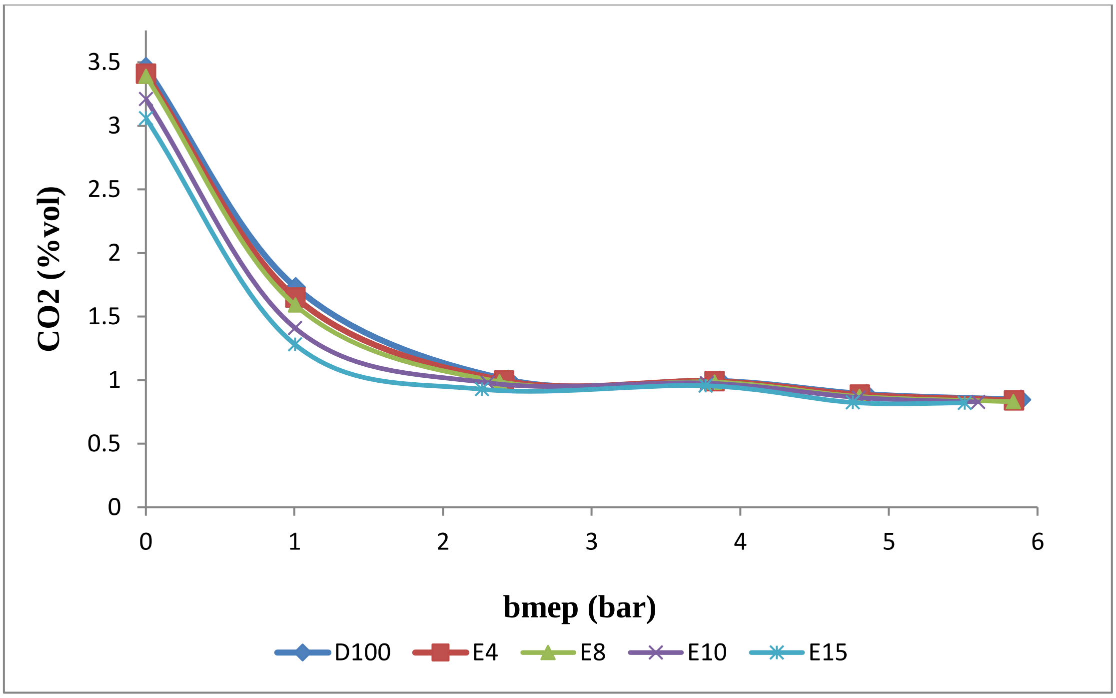


Figure 32: Variation of CO_2 Emissions for diesel and ethanol-diesel blends at different bmep

4.5.3 NO_x EMISSIONS

There are two most important factors which affect the NO_x emission in diesel engine these are gas temperature of cylinder and availability of oxygen for combustion. The variation of NO_x emission of different fuel blends for different loading conditions as shown in figure 33.

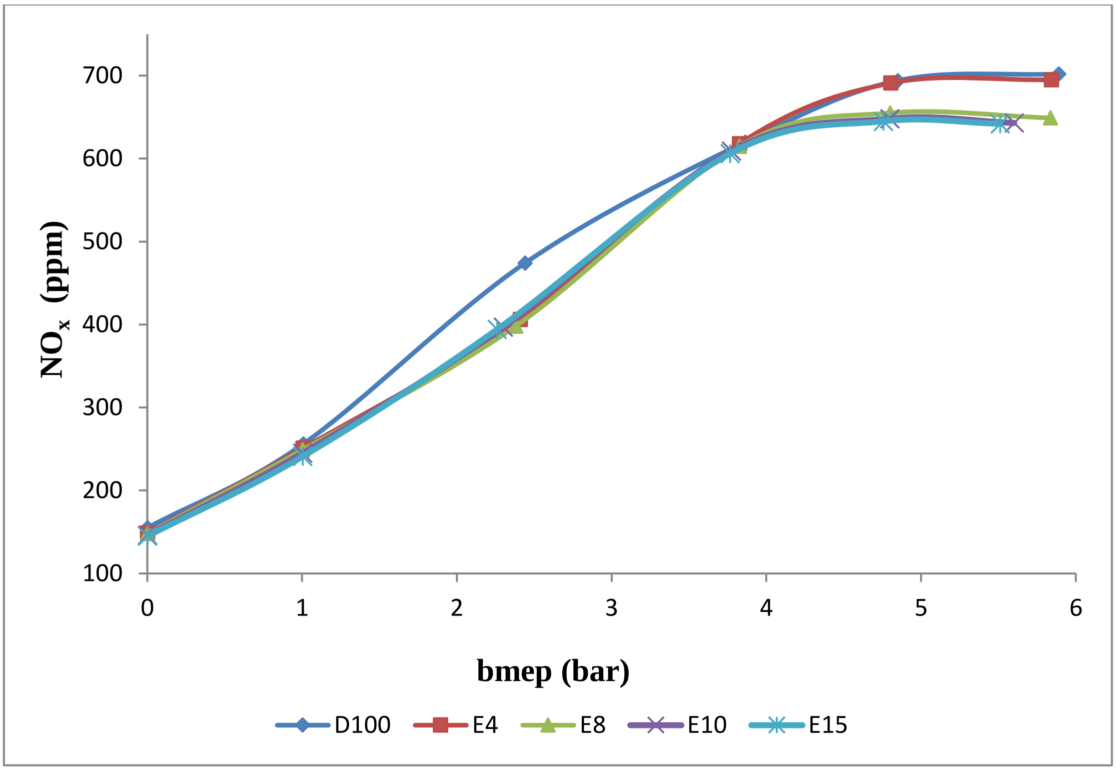


Figure 33: Variation of NO_x Emissions for diesel and ethanol-diesel blends at different bmep

Throughout the engine operation no emission are found lower for different this is mainly due to higher latent heat of vaporisation of ethanol this results in lower cylinder temperature.

4.4.4 HC EMISSIONS

Fuel quality is main important concern of HC emission in CI engine and availability of oxygen for proper combustion. It affect mainly to the ignition delay and reaction rate. As load on the engine increases the HC emission increases. Another conclusion is that as increasing the % of ethanol in diesel the HC emission increases. The chilling of cylinder wall is due to the higher latent heat of vaporisation which reduces the gas temperature. The variation of HC emission with respect to different fuel blends and for different bmep as shown in the figure 34

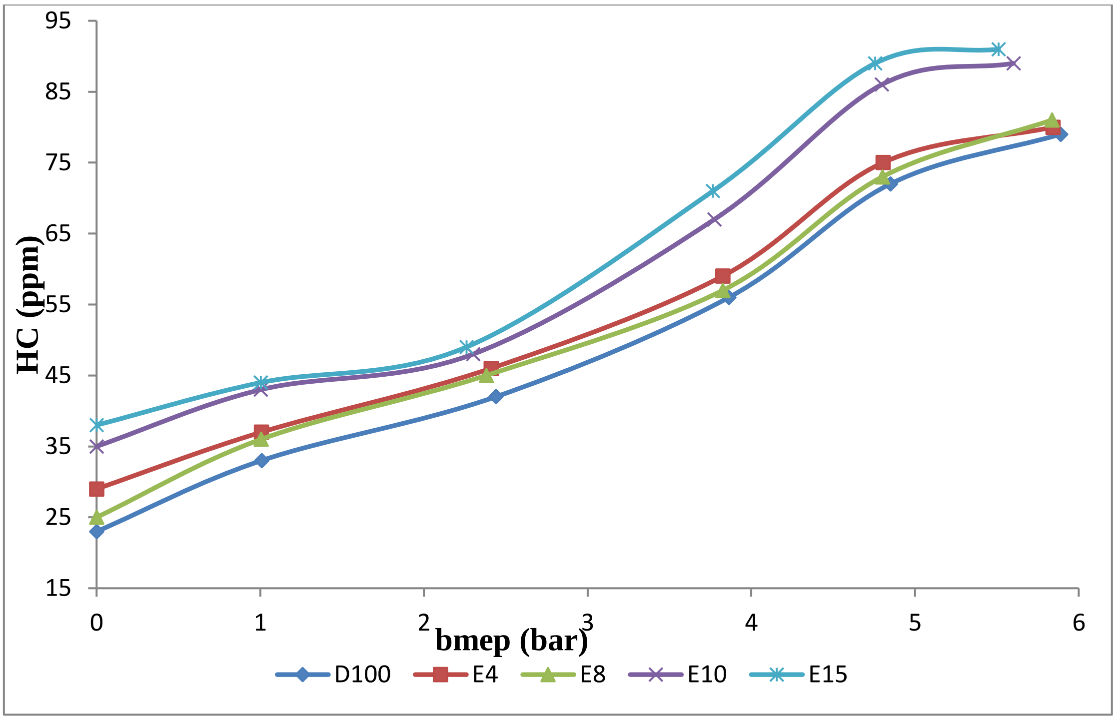


Figure 34: Variation of HC Emissions for diesel and ethanol-diesel blends at different bmep

4.4.5 SMOKE OPACITY

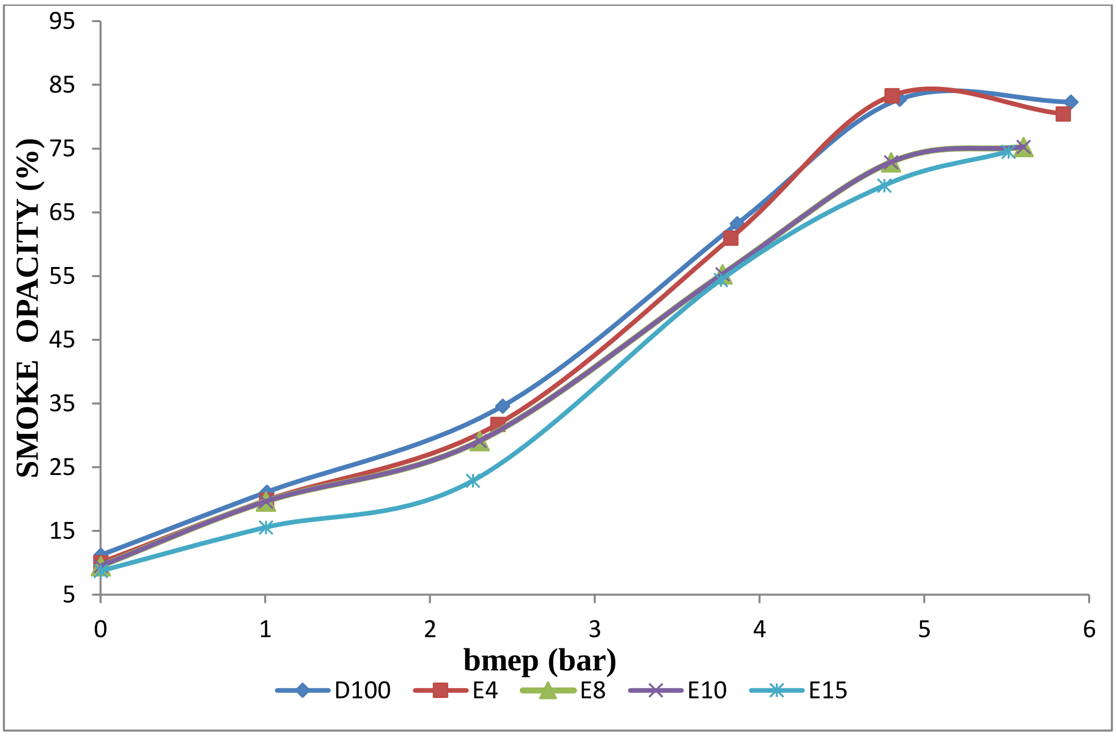


Figure 35: Variation of Smoke Emissions for diesel and ethanol-diesel blends at different bmep

The similar tendency of smoke emission is seen in ethanol diesel fuel blends as compared to that of diesel. As increasing the percentage of ethanol in diesel resulted in lower smoke emission. 10% ethanol, and 15% ethanol has the lowest smoke emission over the entire loading conditions. Figure 35 shows the variation of smoke emission of different fuel blend for different loading conditions.

CHAPTER 5

CONCLUSION AND SCOPE FOR FURTHER RESEARCH

5.1 CONCLUSION

To minimize the consumption of ‘fossil fuels and exhaust emission’, study has shown the acceptable utilization of diesel-ethanol blends as alternative Fuel in C.I. engine. The prepared blends were utilizes ethanol between 2% to 15% volume concentration and based on stability studies it was observed that at low concentration of ethanol (2% ethanol, 4% ethanol, and 6% ethanol), the blends were stabilized at 27ºC using (0.6% of THF, 1% THF, 2% THF respectively). While at high concentration of ethanol (8% ethanol, 10% ethanol, 15% ethanol), it becomes miscible and stable by adding up to 5% v/v THF. The obtained physicochemical properties of the diesel-ethanol-THF blends it was observed that as we increase the % of ethanol, the density of the blends are decreasing in nature and the density values are within the EN 590 limits (which is between 820-845 kg/m^3). While the kinematic viscosity (υ) values of the blends which contain up to 6% v/v ethanol are located near the inferior limit of the standard, but for the blends with above 6% v/v ethanol, the kinematic viscosity (υ) values are under the inferior limit, but overall these three parameters of the blends have good limit values for utilization as fuels in CI engines. However, due to the low flash point of both ethanol and THF Also, the surfactant THF, forming a bond between diesel and ethanol reaching to the formation of a miscible phase. The engine simulation shows that the engine operation with the blends yielded slightly lower cylinder pressures and temperatures, but better emission parameters as compared to the diesel operation.

- With increasing in ethanol % the overall exhaust temperature of different blends have lower than that of diesel which help in reducing the NO_x formation but the blend E8 has similar exhaust temperature than that of diesel and the BTE of the blend E8 has similar trend that of diesel.

- With the increase in bmep, the unburned HC emission goes on increasing. As increasing the % of ethanol in diesel the HC emission increases and the blend E8 has HC emission nearly to that of diesel.
- The blend E8 has batter emission characteristics than other blends.
- The thermal efficiency of the engine was lower and bsec of the engine was higher when the engine was fuelled with E10 and E15 blends.

5.2 SCOPE FOR FURTHER RESEARCH

From the above studies and experimental investigations it is found that there is a conflict in characteristics and properties of ethanol as dopant and has following aspects to be found in the future:

- More surfactants can be explored for the betterment of stability of ethanol-diesel blends.
- Ethanol-diesel blends can be tested for emission of particulate matter and a comprehensive research can be carried out to reduce it.
- For engine design combustion behaviour of the different fuel can be done.
- An enhancement in the hydrodynamic properties of pure ethanol needs to be carried out for continuing use.
- For batter performance the optimum value of ethanol can also be varied.
- A meticulous study of the cyclic unevenness of the engines run on neat ethanol can be investigated.

REFERENCES

[1] https://powermin.nic.in/en/content/power-sector-glance-all-india accessed on 16 july 2018

[2] www.ceicdata.com|Ministry of Petroleum and natural gas

[3] Yüksel, F., & Yüksel, B. (2004). The use of ethanol–gasoline blend as a fuel in an SI engine. Renewable energy, 29(7), 1181-1191.

[4] Ajav, E. A., Singh, B., & Bhattacharya, T. K. (1998). Performance of a stationary diesel engine using vapourized ethanol as supplementary fuel. Biomass and Bioenergy, 15(6), 493-502.

[5] Xing-cai, L., Jian-Guang, Y., Wu-Gao, Z., & Zhen, H. (2004). Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with ethanol–diesel blend fuel. Fuel, 83(14-15), 2013-2020.

[6] R. L. Fuery and K. L. Perry; Composition and reactivity of fuel vapor emissions from gasoline–oxygenate blends; SAE paper 912429

[7] D. W. Nageli, P. I. Lacey and M. Alger; Surface corrosion in ethanol fuel pumps; SAE paper 971648

[8] E. M. H. Broukhiyan and S. S. Lestz; Ethanol fumigation of a light duty automotive diesel engine; SAE Paper No. 811209, 1981

[9] R. A. Baranescu; Fumigation of alcohols in multi-cylinder diesel engine-evaluation of potential, SAE Paper No. 860308, 1986

[10] H. A. Doann; Alcohol fuels. Boulder, CO: Westview Press, 1982

[11] J. B. Heisey and S. S. Lestz; Aqueous alcohol fumigation of a single-cylinder DI diesel engine; SAE Paper No. 811208, 1981

[12] Avinash Kumar Agarwal; Biofuel (alcohols and biodiesel) applications as fuels for internal combustion engines; November 2006

[13] Commission of the European Communities, Luxembourg, vol. L123, 2003. p. 42–47.

[14] S. Kim and B. E. Dale; Environmental aspects of ethanol derived from no-tilled corn grain: nonrenewable energy consumption and greenhouse gas; Biomass Bioenergy Vol.28, pp.475–89, 2005

[15] Silva JPA, Mussatto SI and Roberto IC. The influence of initial xylose concentration, agitation, and aeration on ethanol production by Pichia stipitis from

rice straw hemicellulosic hydrolysate. Applied Biochemistry and Biotechnology 2010; doi:10.1007/s12010-009-8867-6.

[16] Huang CF, Lin TH, Guo GL and Hwang WS. Enhanced ethanol production by fermentation of rice straw hydrolysate without detoxification using a newly adapted strain of Pichia stipitis. Bioresource Technology 2009; 100: 3914-20.

[17] Lin Y and Tanaka S. Ethanol fermentation from biomass resources: current state and prospects. Applied Microbial Biotechnology 2006; 69: 627-42.

[18] Hahn-Hägerdal B, Galbe M, Gorwa-Grauslund MF, Lidén G and Zacchi G. Bio-ethanol-the fuel of tomorrow from the residues of today. Trends in Biotechnology 2006; 24: 549-56.

[19] Hardenberg HO and Schaefer AJ. The use of ethanol as a fuel for compression–ignition engines. SAE Technical Paper 811211, 1981.

[20] Satge de Caro P, Mouloungui Z, Vaitilingom G and Berge JC. Interest of combining an additive with diesel and ethanol blends for use in diesel engines. Fuel 2001; 80: 565-74.

[21] Badger PC. Reprinted from: Trends in new crops and new uses. ASHS Press, Alexandria, VA, 2002.

[22] Letcher TM. Diesel blends for diesel engines. South African Journal of Science 1983; 79(1): 4-7.

[23] Baker QA. Use of alcohol-in-diesel fuel emulsions and solutions in a medium-speed diesel engine. SAE Technical Paper 810254, 1981.

[24] Strait J, Boedicker JJ, and Johanson KC. Diesel oil and ethanol mixtures for diesel powered farm tractors. Final report to the State of Minneasota Energy Agency from the Agricultural Engineering Department, University of Minnesota, St. Paul, 1978.

[25] Wrage KE and Goering CE. Technical feasibility of diesohol. ASAE (American Society of Agricultural Engineers) Paper No. 79•1052, MI 49085, 1979.

[26] Hardenberg HO and Ehnert ER. Ignition quality determination problems with alternative fuels for compression ignition engines. SAE Technical Paper 811212, 1981.

[27] Moses CA, Ryan TW and Likos WE. Experiments with alcohol/diesel fuel blends in compression–ignition engines. In: VI International Symposium on Alcohol Fuels Technology, Guaruja, Brazil, 1980.

[28] Schaefer AJ and Hardenberg HO. Ignition improvers for ethanol fuels. SAE Technical Paper 810249, 1981.

[29] Behera S, Mohanty RC and Ray RC. Ethanol production from mahula (Madhuca latifolia L.) flowers with immobilized cells of Saccharomyces cerevisiae in Luffa cylindrica L. sponge discs. Applied Energy 2011; 88: 212-5.

[30] Battelle. Flammability limits for ethanol/diesel blends. Final report prepared by Battelle, Columbus, OH, USA, 1998.

[31] Boruff PA, Schwab AW, Goering CE, and Pryde EH. Evaluation of diesel fuel-ethanol Microemulsions. Transaction of ASAE (American Society of Agricultural Engineers) 1982; 25(1): 47-53.

[32] Gerdes KR and Suppes GJ. Miscibility of ethanol in diesel fuels. Industrial Engineering Chemistry Resource 2001; 40 (3): 949-56.

[33] Hansen AC, Zhang Q and Lyne W. Peter Ethanol-diesel fuel blends-A review. Bioresource Technology 2005; 96: 277-85.

[34] Lapuerta M, Armas O and Garcia-Contreras R. Stability of diesel-bioethanol blends for use in diesel engines. Fuel 2007; 86: 1351-57.

[35] Rakopoulos DC, Rakopoulos CD, Kakaras EC and Giakoumis EG. Effects of ethanol-diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine. Energy Conversion Management 2008; 49: 3155-62.

[36] Huang J, Wang Y, Li S, Roskilly AP, Hongdong Y, Li H. Experimental investigation on the performance and emissions of a diesel engine fuelled with ethanol–diesel blends. Applied Thermal Engineering 2009; 29(11– 12): 2484-90.

[37] Li D, Zhen H, Xingcai L, Wu-Gao Z, Jian-Guang Y. Physicochemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines. Renewable Energy 2005; 30 (6):967-76.

[38] Arapatsakos C. Application of diesel–ethanol mixtures in tractor engine. International Journal of Energy and Environment 2009; 3(2): 77-84.

[39] Ganesh RS, Kumar SS, Dinesh S. Effect of ethanol addition on performance, emission and combustion characteristics of a diesel engine at various injection angles. Frontiers in Automobile and Mechanical Engineering 2010; 27: 108-12.

[40] Banugopan VN, Prabhakar S, Annamalai K, Jayaraj S, Sentilkumar P. Experimental investigation on DI diesel engine fuelled by ethanol diesel blend with varying inlet air temperature. Frontiers in Mechanical Engineering 2010; 25(27):128–34.

[41] Kumar C, Athawe M, Aghav YV, Babu MKG, Das LM. Effects of ethanol addition on performance, emission and combustion of DI diesel engine running at different injection pressures. SAE paper no. 2007-01-0626; 2007.

[42] Jilin Lei, Yuhua Y, Shen L. Performance and emission characteristics of diesel engine fueled with ethanol-diesel blends in different altitude regions. Journal of Biomedicine and Biotechnology 2011. http://dx.doi.org/10.1155/ 2011/417421.

[43] Song C, Zhao Z, Lv G, Song J, Liu L, Zhao R. Carbonyl compound emissions from a heavy-duty diesel engine fueled with diesel fuel and ethanol–diesel blend. Chemosphere 2010; 79: 1033-39.

[44] Surfactant.askdefine.com/

[45] http://instrumat.ch/wp-content/uploads/2016/08/Malvern-Spraytec-particle-sizing-MRK690-03-LRLL.pdf

APPENDIX 1

Technical specifications of the dma™ 4500 m density meter

Patents granted	AT 516420 (B1) AT 517082 (B1)
Patents pending	AT 517486 (A1)
Measuring range	Density: 0 g/cm^3 to 3 g/cm^3 Temperature: 0 °C to 100 °C (32 °F to 212 °F) Pressure: Up to 10 bar (145 psi)
Repeatability s.d.(1)	Density: 0.000005 g/cm^3 Temperature: 0.01 °C/0.02 °F
Reproducibility s.d.(1)	Density: 0.00002 g/cm^3
Accuracy(2)	Density: 0.00005 g/cm^3 Temperature: 0.03 °C/0.05 °F
Integrated tables and functions	Alcohol tables Extract/sugar tables API functions Acid/base tables 20 freely programmable tables/user functions (tables, polynomials, formulas, linear functions, and constants)
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 50 to 60 Hz 190 VA
Weight	22.5 kg (49.6 lbs)
Interfaces	4 x USB,RS-232,CAN,VGA,Ethernet

APPENDIX 2

Technical specifications of petrotest automated kinematic viscometer

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

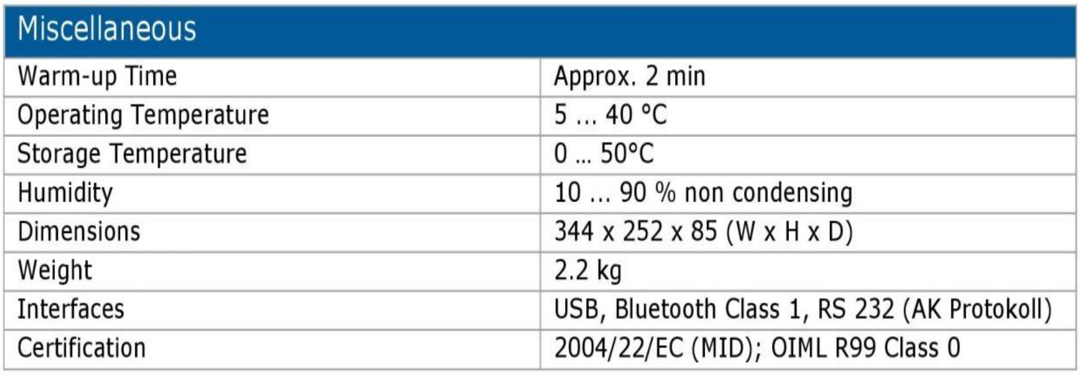
Air cooled (Radial cooled), 4 stroke cycle, totally enclosed, direct injection, cold starting, naturally aspirated, gravity feed fuel system with efficient paper element filter, force feed lubrication to main and large end bearing and camshaft bush.

Specifications:

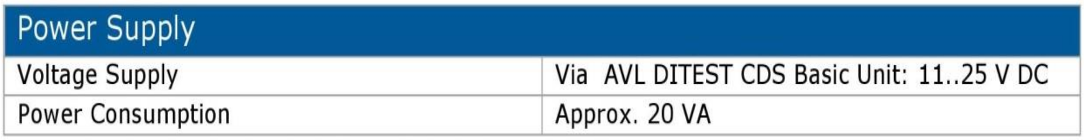
No. Of cylinders:	1
Bore X stroke:	95x110
Cubic capacity:	0.78 Lit.
Compression ratio:	17.5:1
Rated output as per BS5514/ ISO 3046 / ISO 10001:	5.9KW (8.0 HP) at 1500 rpm
Starting:	Hand start with cranking handle
SFC at rated hp/1500 rpm:	251g/Kwh (185 g/bhp-hr)
Lube oil consumption:	0.8% of SFC max
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

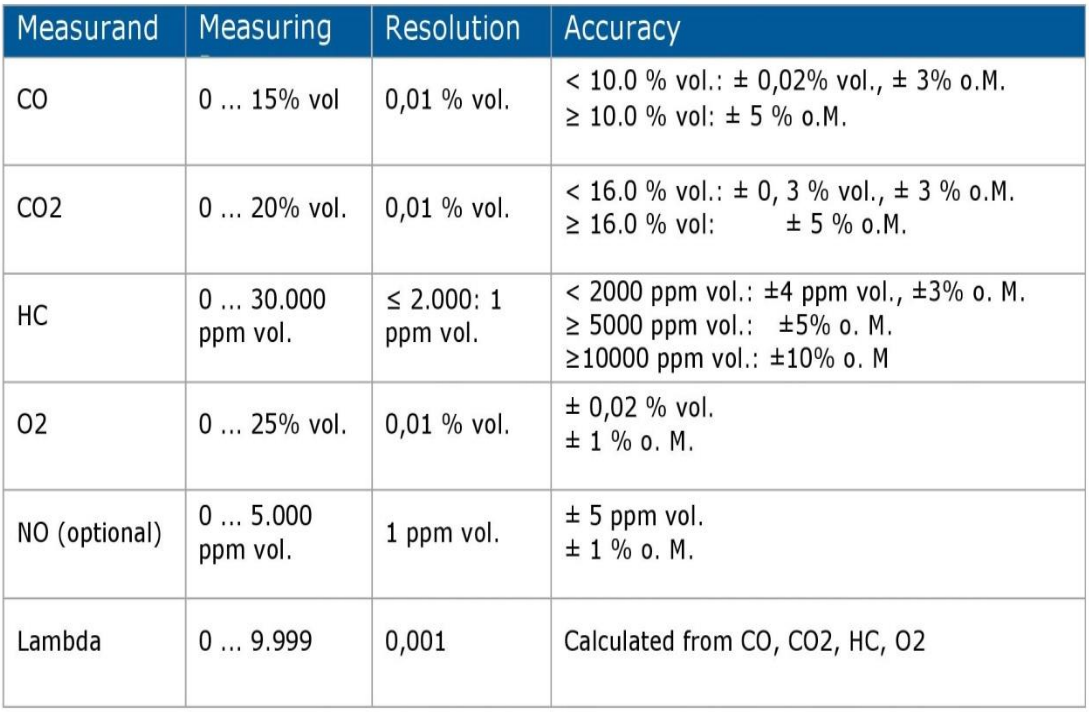
AVL DITEST GAS 1000 BL



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. ≥ 10.0 % vol: ± 5 % o.M.
CO2	0 … 20% vol.	0,01 % vol.	< 16.0 % vol.: ± 0, 3 % vol., ± 3 % o.M. ≥ 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. ≥ 5000 ppm vol.: ±5% o. M. ≥10000 ppm vol.: ±10% o. M
O2	0 … 25% vol.	0,01 % vol.	± 0,02 % vol. ± 1 % o. M.
NO (optional)	0 … 5.000 ppm vol.	1 ppm vol.	± 5 ppm vol. ± 1 % o. M.
Lambda	0 … 9.999	0,001	Calculated from CO, CO2, HC, O2