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COMPARATIVE ASSESSMENT OF BLENDED AND FUMIGATED ETHANOL IN AN AGRICULTURE DIESEL ENGINE

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2009

CERTIFICATE

This is to certify that the dissertation entitled "Comparative Assessment of Blended and Fumigated Ethanol in an Agriculture Diesel Engine" submitted by Mr. HARI SINGH RATHOUR, 05/THR/07 in partial fulfillment for the award of the Degree of Master of Engineering in Thermal Engineering, is an authentic record of student's own work carrying by him under my guidance and supervision. It is also certified that this dissertation has not been submitted to any other Institute/University for the award of any degree or diploma.

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ABSTRACT

The increasing industrialization and motorization of the world has lead to a steep rise for the demand of petroleum-based fuels. Petroleum-based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. Therefore, the countries not having these resources are facing energy and foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc. Ethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce emissions simultaneously in compression–ignition engine.

The present study was undertaken to evaluate and compares the effects of ethanol fumigation and ethanol diesel fuel blends on the performance and exhaust emissions of an agriculture diesel engine. Ethanol fumigation was achieved by using a simple carburetor whereas ethanol diesel blend was prepared by inline mixing. 10%, 20%, 30% ethanol was supplemented in diesel in both the techniques. The series of test were conducted using each of the above mentioned ethanol based fuels to test an agriculture diesel engine and performance and emission characteristics were evaluated

The brake thermal efficiency showed an upward trend and brake specific energy consumption exhibited a downward trend on ethanol substation than diesel fuel operation. This may be mainly due to increase in the ignition delay upon ethanol substitution, so a rapid rate of energy is released which reduces the heat loss from the engine because there is not enough time for this heat to leave the cylinder through heat transfer to the coolant Exhaust temperature, in general, were found lower for ethanol based fuel than diesel as large amount of latent heat absorbed by combustion chamber to evaporate ethanol and thus exhaust temperature decreases.

As far as CO, HC emissions are concerned, they were found to increase with ethanol substitution than diesel operation. The fumigation showed lower increase in these emissions as compared to blending. A thickened quench layer created by the cooling effect of vaporizing alcohol or increase in ignition delay could have played a major role in the increased CO production. The NO_x emissions were found lower for ethanol based fuels than the diesel fuel. This may be due to reduction in combustion temperature to reduce due to introduction of ethanol as vaporization of ethanol takes heat from combustion chamber.

The smoke opacity was found lower for blended or fumigated ethanol as the engine is running ‘leaner’, with the combustion being now assisted by the presence of the fuel-bound oxygen of the ethanol even in locally rich zones. Also, diesel fuel has a high tendency to smoke due to its low H/C ratio and the nature of its combustion process

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NOMENCLATURE

AC	Alternate Current
ASTM	American Society for Testing and Materials
ATDC	After Top Dead Center
AVL-437	AVL-437 Smoke Meter
BIS	Bureau of Indian Standard
BMEP	Break Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
BTDC	Before Top Dead Center
^oC	Degree Celsius
cc	Cubic centimeter
CI	Compression Ignition
cm^{-1}	Per Centimeter
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CV	Calorific Value
DI	Direct Injection
DF	Diesel fuel
^oF	Degree Fahrenheit
F/A	Fuel to Air
HC	Hydrocarbon
H_2O	Water
HP	Horse Power
IC	Internal Combustion
IDI	Indirect Injection
KVA	Kilo Volt Ampere
Kw	Kilo Watt
kW-h	Kilo Watt Hour
LPM	Liter per Minute

Min.	Minute
ml	Milliliter
mm	Millimeter
Mt	Million Tonnes
Mtoe	Million Tonne of Oil Equivalent
NO	Nitric Oxide
Nos.	Numbers
NO_2	Nitrogen Di-oxide
NO_x	Oxides of Nitrogen
O_2	Oxygen
ppm	Parts per million
rpm	Revolutions Per Minute
SAE	Society of Automobile Engineering
sfc	Specific Fuel Consumption
TDC	Top Dead Center
THC	Total Hydrocarbon
UBHC	Unburnt Hydrocarbon
Vs.	Versus
ρ	Density
%	Percent

CHAPTER 1
INTRODUCTION

1.0 Introduction

All over the world, engine manufacturer are making stride to develop diesel engines with high thermal efficiency and specific power output and keep the engine emission with in the norms which are becoming more and more stringent. Significant achievements for the development of cleaner diesel engines have been made, over the last years

Biofuels made from agricultural products (oxygenated by nature), may not only offer benefits in terms of exhaust emissions, but also reduce the world's dependence on petroleum imports. Moreover, local agricultural industries can be supported and farming incomes enhanced, besides providing a better energy security for many developing countries.

The initial investigations into the use of ethanol in diesel engines were carried out in South Africa in the 1970's and continued in Germany and the USA during the 1980's.these are several critical issues to consider with the use of ethanol in the diesel fuel. While anhydrous ethanol is soluble in gasoline, additives must be used in order to ensure solubility of anhydrous ethanol (that is highly hygroscopic and thus practically impossible to stay as such) in the diesel fuel under a wide range of conditions. Particularly at lower temperatures, the miscibility is limited; It was determined that the aromatic content (having a co-solvent action), intermediate distillate temperatures and wax content of diesel fuel had a significant impact on the miscibility limits. Furthermore, adding ethanol to diesel fuel can reduce lubricity and create potential wear problems in sensitive fuel pump designs. Ethanol possesses also lower viscosity and lower calorific value, with the later imposing minor changes on the fuel delivery system to establish the maximum power delivered by the use of the neat diesel fuel.

Ethanol has a very low cetane number that reduces the cetane level of the diesel-ethanol blend, requiring normally the use of cetane enhancing additives, which improve ignition delay and mitigate cyclic irregularity, thus requiring extra precautions and suitable technique to ensure safe handling and use of ethanol as a diesel engine fuel.

1.1 Energy Scenario

There is a realization throughout the world that the petroleum resources which are non renewable are limited and are being consumed at an alarming rate. The growing demand for energy and gradual extinction of fossil fuels has lead to an energy crisis. Most of the power for industries and transportation is derived from oil and coal. In automobile sector all the fuels are derived from petroleum, a non renewable source of energy. The name energy shortage was sharply brought into focus by the first oil crisis of 1973. Since then, several price hikes have taken place, upsetting economy of most of the nation. Energy can be classified into several types.

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth’s interior, and potential energy due to earth’s gravity. The major primary and secondary energy sources are shown in Figure 1.1. Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity

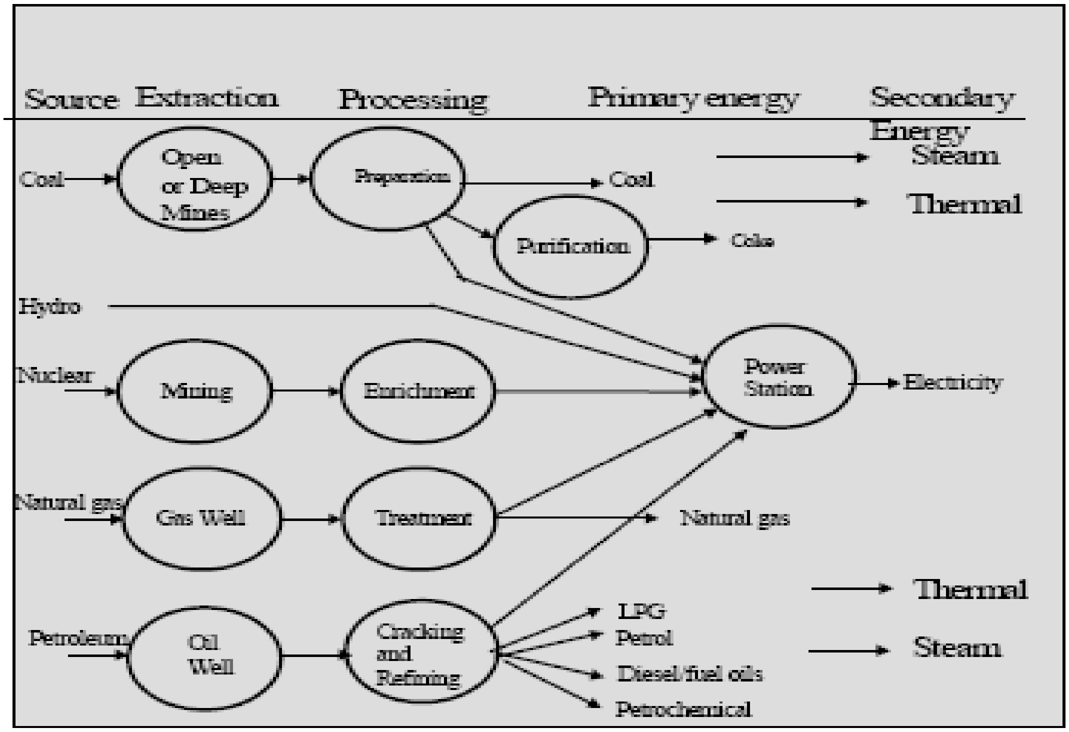


Figure 1.1: Major primary and secondary energy sources [1].

1.1.1. World energy scenario

World Energy reserves

Energy drives our daily lives. Most of the energy that is produced today is generated from fossil fuels. The demand for energy is increasing every day. There are two key reasons for increasing energy demand; first, the population of the earth is growing at an ever-increasing rate and second, societies worldwide are becoming more and more industrialized. While energy demand is growing, fossil fuel reserves are being depleted. In about next 40-50 years almost all fossil fuel reserves would be depleted, so it is necessary to find alternative sources of energy before that happens. Table 1.1 shows the available fuel reserves in year 2007.

Table 1.1: World Energy Reserves [2]

fuel	Quantity	Unit
oil	1237.9	Thousand million barrels
Natural gas	177.36	Trillion cubic meter
coal	847488	Million tones

The price of fossil fuels is increasing every year. The gas, will be available for another 65 years if there are no interruptions in the supplies found in the Middle East and Russia, the world's largest gas and oil suppliers. Proven coal reserves should last another 130 years, but if gas and oil is depletes before then in that case, coal reserves wouldn't last more than 100 years.

World Energy consumption

Figure.1.2 depicts the primary energy consumption of world in the last ten years. It is apparent that world energy is mainly dominated by fossil fuels, as already elaborated

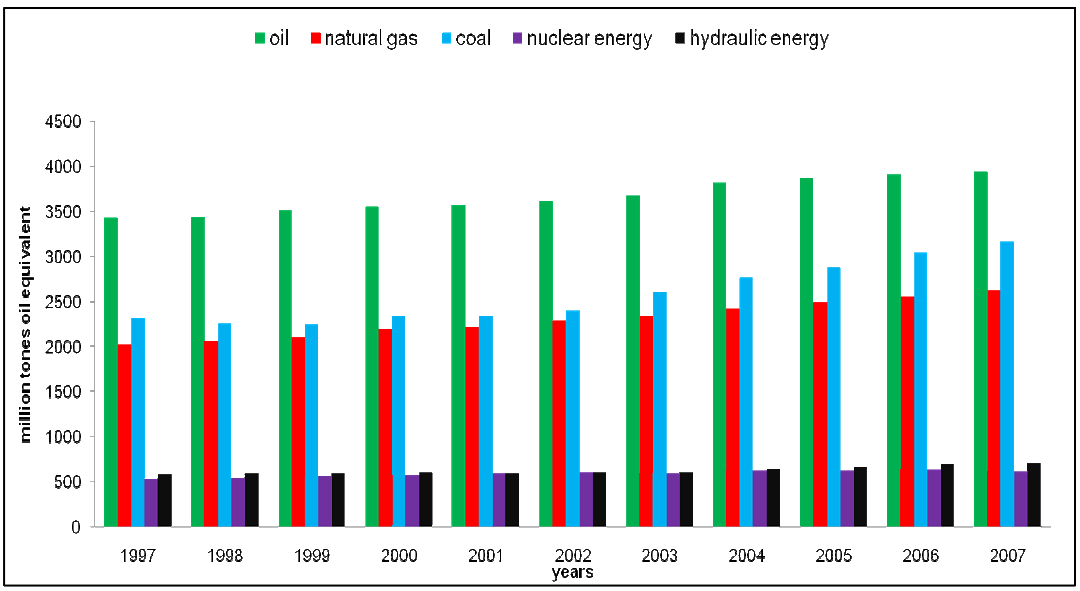


Figure 1.2.World primary energy consumption by fuels in million tones oil equivalent (yearly)[2]

The World primary energy consumption increased by 2.4% in 2007 which is down from 2.7% in 2006, but still the fifth consecutive year of above-average growth. The Asia-Pacific region accounted for two-thirds of global energy consumption growth, rising by an above-average 5% even though consumption in Japan declined by 0.9%. North American consumption rebounded after a weak year in 2006, rising by 1.6% which is double the 10-year average. Chinese growth of 7.7% was the weakest since 2002, although still above the 10-year average (as was China's economic growth). China again accounted for half of global energy consumption growth. Indian consumption grew by 6.8%, the third-largest volumetric increment after China and the US. EU energy consumption declined by 2.2%, with Germany registering the world's largest decline in energy consumption. [2]

Global oil consumption grew by 1.1% in 2007 or 1 million barrels per day, which is slightly below the 10-year average. Consumption in the oil-exporting regions of the Middle East, Southland Central America and Africa accounted for two-thirds of the world's growth. The Asia-Pacific region grew by 2.3%, roughly in line with the historical average even though growth in China and Japan was below average, with strong growth in a number of emerging economies. OECD consumption fell by 0.9%, or nearly 400,000b/d. The global growth rate for light distillates matched that of middle distillates for the first time since 2002 due to strong petrochemicals demand.

Gas consumption rose by 3.1% in 2007, slightly above the 10-year average. The US accounted for the largest incremental growth in both production and consumption. Coal was the fastest growing fuel in the world for the fifth consecutive year. Global consumption rose by 4.5%, above the 10-yearaverage of 3.2%. Consumption growth was widespread, with growth in every region except the Middle East exceeding the 10-year average. Chinese coal consumption rose by 7.9%, the weakest growth since 2002 but still sufficient to account for more than two-thirds of global growth. Indian consumption rose by 6.6% and OECD consumption rose by 1.3%, both above-average figures. Nuclear power output fell by 2%, the steepest decline on record. However, more than 90% of this decline was accounted for by Germany and Japan, which saw the world's largest nuclear power plant closed following an earthquake. Hydroelectric generation increased by 1.7%, slightly below the 10-yearaverage. Increased capacity in China and Brazil, along with improved hydro availability in

Canada and Northern Europe, was partially offset by drought-related declines in the US and southern Europe. [2]

Renewable energy remains a small share of total global energy use, but most renewable sources experienced rapid growth in 2007.Ethanol output rose by 27.8%. Global capacity for wind and solar electricity generation grew broadly in line with historical averages of 28.5%and 37%, respectively. [2]

Figure 1.3 depict the word primary energy consumption by countries for year 2007. it is clear that USA have the maximum energy consumption that is approximate 2361.4 Mtoe and china having second place with approximate 1863 Mtoe. Indian primary energy consumption was approximate by 404 Mtoe.[2]

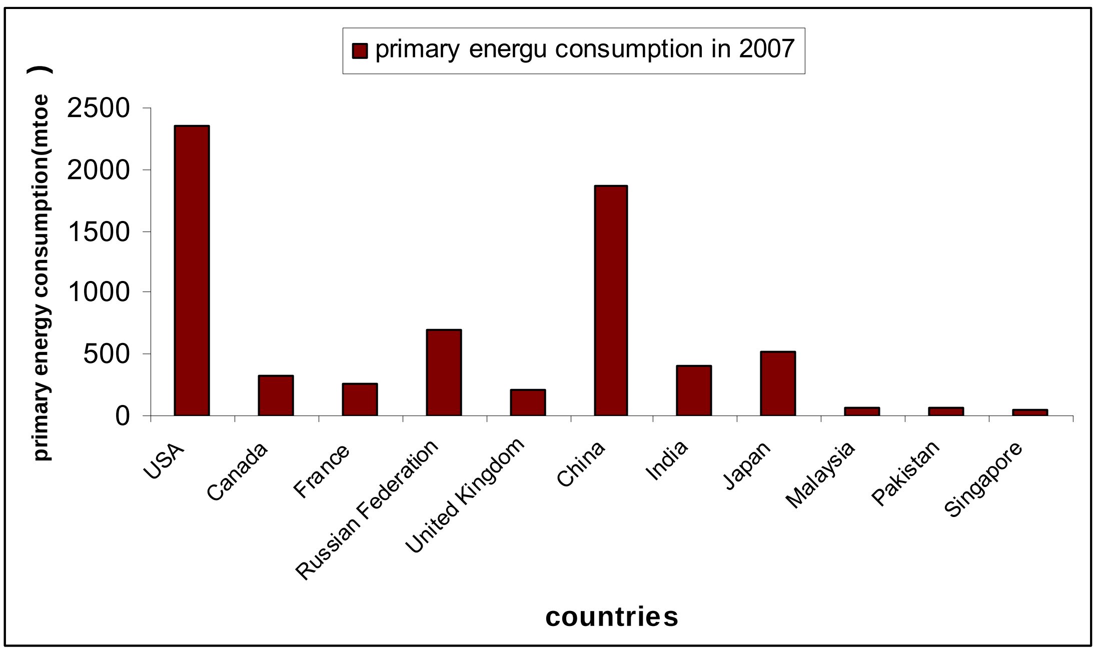


Figure 1.3. World primary energy consumption by countries in year 2007 [2]

Figure 1.4 describes the primary energy consumption by fuels for different countries in year 2007. it clearly show that for china major primary energy is dominate by coal and for India also primary energy consumption by coal is highest. But for USA, the primary energy consumption is dominated by petroleum oil.

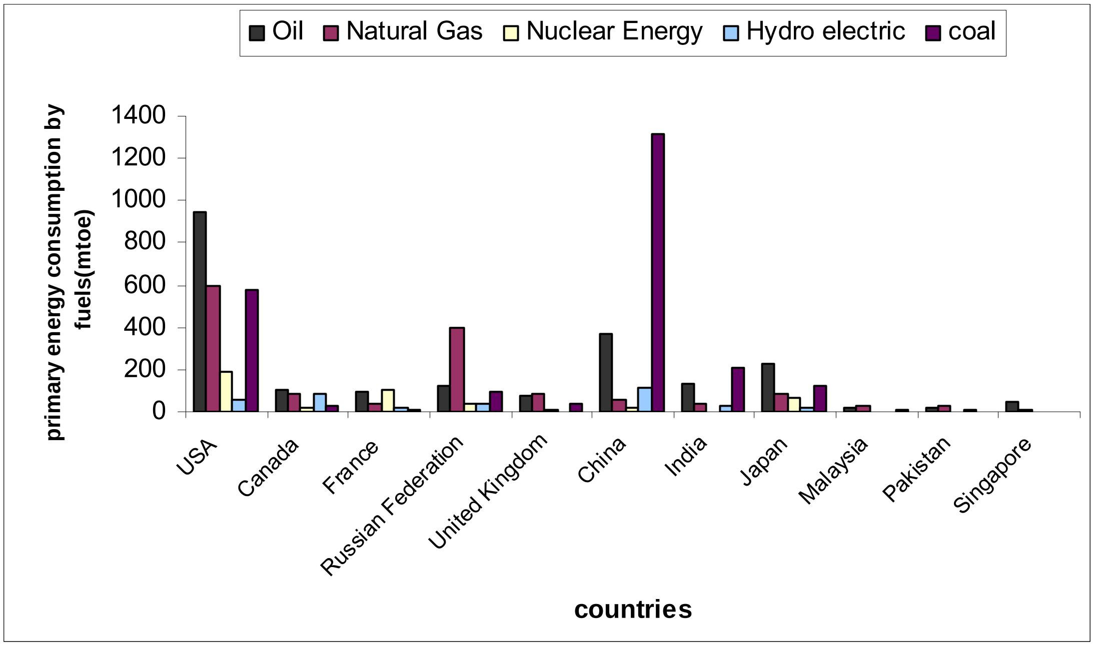


Figure 1.4.World primary energy consumption by fuels for different countries for Year 2007 [2]

1.1.2 Energy Scenario: Indian Context

Table 1.2: Indian energy reserve [2]

fuel	quantity	unit	Reserve to consumption ratio(years)
oil	15.5	Thousand million barrels	11.3
Natural gas	1.88	Trillion cubic meter	27.2
coal	56498	Million tones	118

India is heavily dependent upon the import of petroleum to cater to the needs of its Automobile industry and other sectors.121.67 Mtoe was imported during 2007-08 worth Rs 2726.99 billion [3]. Table 2 depicts total Indian fuel reserves and reserves to consumption ratio. It is found that if the current consumption rate remains the same, proven oil reserves will last about 11.3 years. As for gas, it will be available for another 27.2 years and proven coal reserves should last another 118 years.

Indian Energy Consumption

With rapid industrialization contributing to an increase in the per capita income, there has been a phenomenal increase in the number of automobiles, which has lead to a steep increase in demand for crude oil. This will lead to shortage of our valuable resource and adversely contribute to price rise. The comparison of Indian energy consumption by fuel is given in figure 1.5. it can be see that in the year 2007-08 India's oil consumption was approximate 128.5 million tones, natural gas consumption was 36.27 million tones oil equivalent and coal consumption was 208.6 million tones oil equivalent.[2]

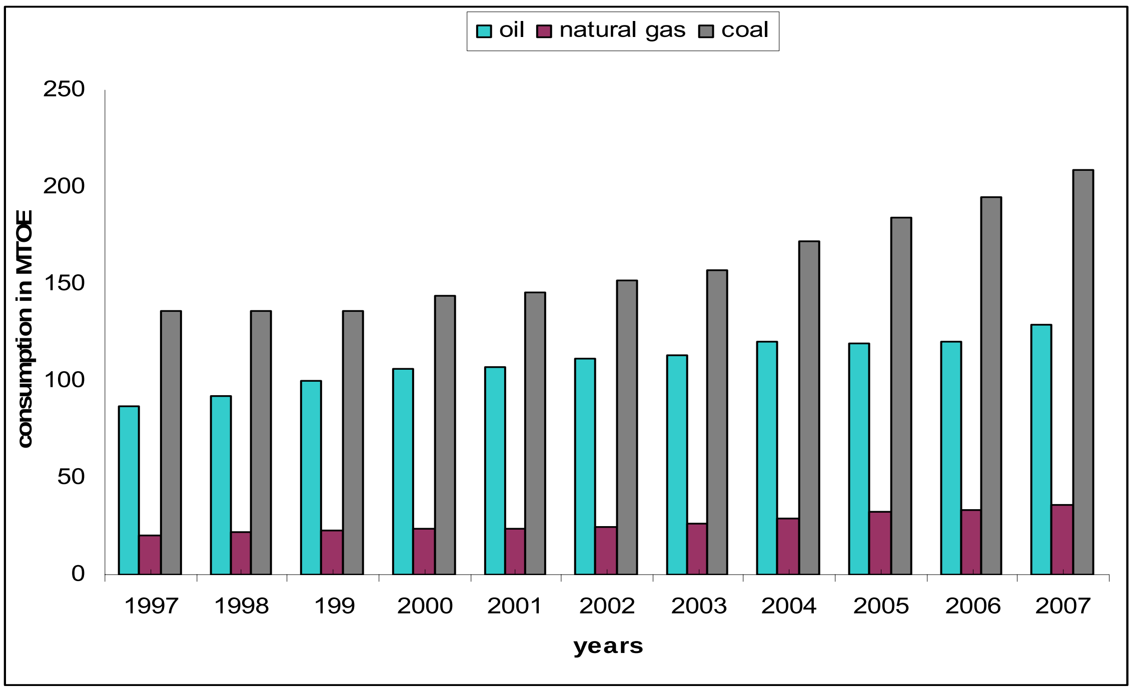


Figure 1.5: Indian Energy Consumption by fuel for last 10 years [2]

Figure 1.6 shows a comparison between demand and supply of petroleum in India. It is seem India's production is approximate 37.3 metric Mn tones and demand is approximate 150 metric Mn Tones in the year 2007-08.[3]

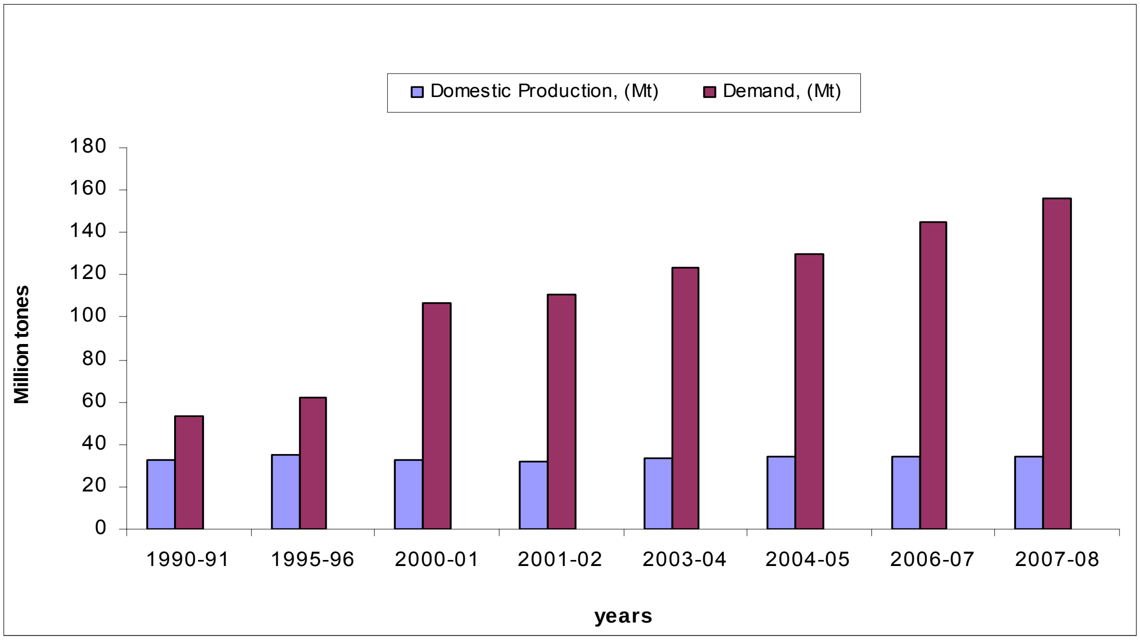


Figure 1.6: Details of domestic production and demand of Indian petroleum Oil[3]

1.2 Role of Diesel Engine in Indian Economy

Figure 1.7 depicts sector wise petroleum consumption in India and India's 50% of petroleum consumed in transport sector And diesel engine play a major role in transport sector in India.

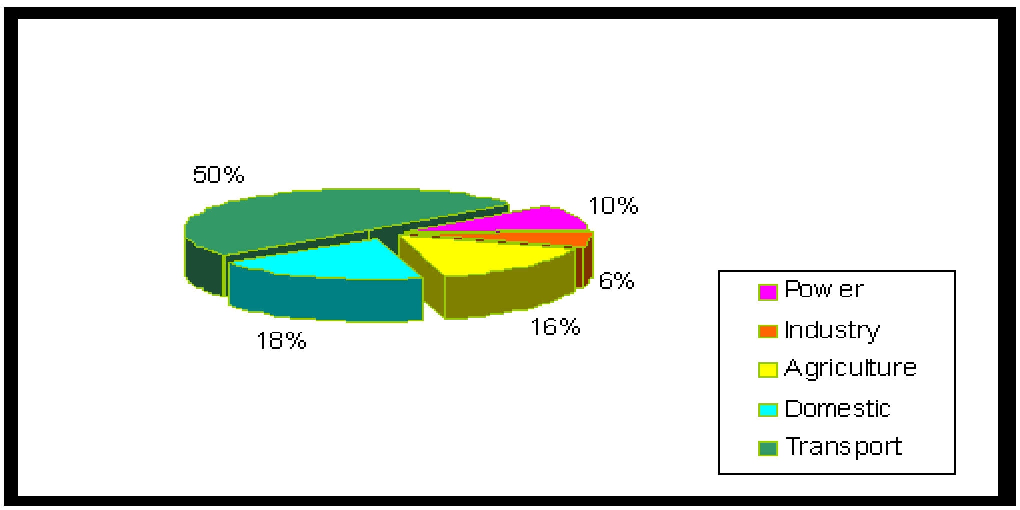


Figure 1.7: Sector wise petroleum consumption in India [3]

If diesel and gasoline consumption of India is compared, it shell be reveled that diesel consumption is 4 to 5 times higher making substitution of diesel by renewable fuels more relevant

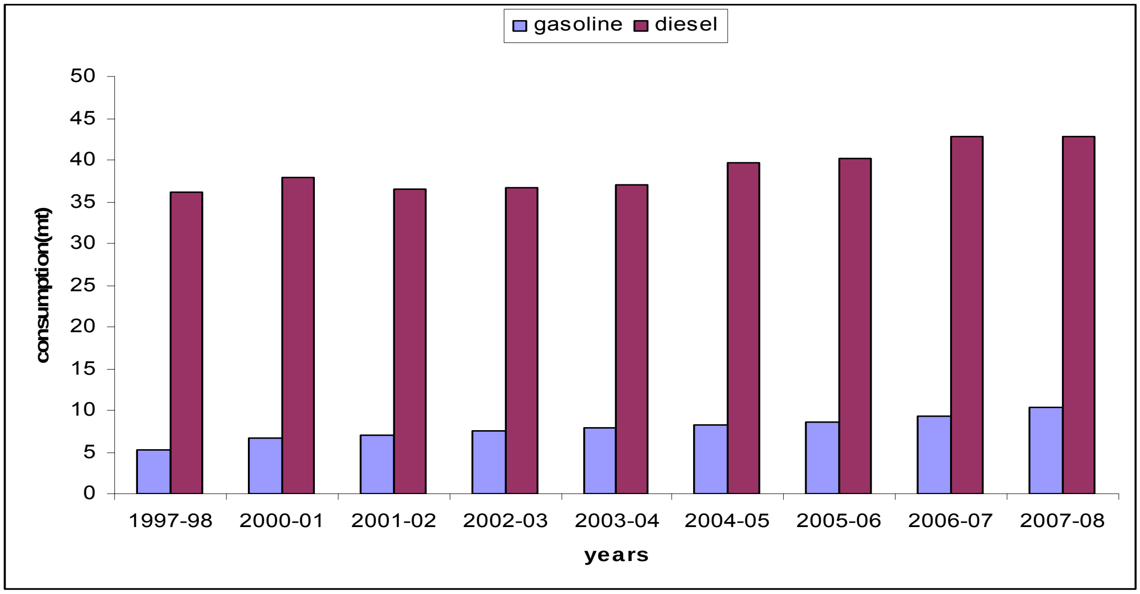


Figure 1.8: Diesel vs. gasoline consumption in India [2]

Environmental pollution caused by the combustion of gasoline or diesel fuels in automobiles and other stationary sources , have necessitate the attention of researchers to search for the clean burning renewable alternative fuels for automobiles.

1.3 Necessity of Alternative Fuels

Exhaustible fossil fuels represent 80% of the total world Energy supply. But the basic problems of using these fuels are depletion of fossil fuel and environmental degration

As known Fossil fuels are consumed very rapidly, further the combustion of fossil fuels; have made the blanket of greenhouse gases (water vapour, carbon dioxide, methane, ozone etc.) around the earth thicker. The resulting increase in global temperature is altering the complex web of systems that allow life to thrive on earth such as rainfall, wind patterns, ocean currents and distribution of plant and animal species. The principal pollutants produced by industrial, domestic and traffic sources are sulphur dioxide, nitrogen oxides, particulate matter, carbon monoxide, ozone, hydrocarbons, benzene, 1,3-butadiene, toxic organic micro pollutants, lead and heavy metals. A variety of air pollutants have known or suspected harmful effects on human health and the environment. These air pollutants are basically the products of combustion from fossil fuel use. Air pollutants from these sources may not only create problems near to these sources but also can cause problems far away. Air pollutants can travel long distances, chemically react in the atmosphere to produce secondary pollutants such as acid rain or ozone.

1.4 Alternative Fuels for Compression Ignition Engine

Due to CI engine popularity for mass transportation system, they are getting popular in automobile engines for passenger cars and light trucks due to its better performance and sturdiness. In India, a large number of C.I. engine are used for different application and as per the estimate more than 2 million single cylinder diesel engines are used for electricity and water pumping.

The possible alternatives energy sources for use in diesel engines are

1. Alcohal

2. CNG

3. Vegetable oil

4. Biodiesel

5. Hydrogen,

6. Biogas

. Hydrogen may prove to be a long term possible fuel. Since many problems associated with its economical 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 cylinder may cause problem. Hence use of biogas as substitute fuel for automobiles is ruled out till such time as simple and safe storage and handling facilities are developed.

As already elaborated, the demand of diesel is four to five times more than the gasoline demand in India and while the ethanol industry is mature; the biodiesel industry is still in its infancy. India's current biodiesel technology is based on the transesterification of vegetable oil. Since the demand for edible vegetable oil exceeds supplies, the government has decided to use non-edible oil from Jatropha curcas seeds as biodiesel feedstock. Extensive research has shown that Jatropha offers the following advantages: it requires low water and fertilizer for cultivation, is not grazed by cattle or sheep, is pest resistant, is easy propagated, has a low gestation period, and has a high seed yield and oil content, and produces high protein manure.

The main problem in getting the biodiesel program rolling has been the difficulty in initiating the large-scale cultivation of Jatropha because farmers do not consider Jatropha cultivation rewarding enough. The government needs to sponsor confidence-building measures such as establishing a minimum support price for Jatropha oilseeds and assuring farmers of timely payments.

Alcohols seem to be an attractive alternative fuels from the point of view of availability, storage and handling. Two alcohols commonly considered for automotive application are methanol and ethanol. Methanol has certain disadvantage such as its low calorific value and toxic effects and as such more attention is focused on utilization of ethanol in diesel engine.

1.5 World Ethanol Scenario

World ethanol consumption is projected to increase by 3.0 percent per annum from 2000 to 2010. As MTBE is being phased out uniformly by ethanol, a sharp increase in ethanol consumption is being registered in the United States. The world ethanol price is slated to increase in a fluctuating manner during the period 2000-2010 and is estimated to reach US$1.05 in 2010. [4] World ethanol export is also projected to increase by 1.1 percent per annum. High domestic and international prices of ethanol stimulate its production and global ethanol production is projected to grow by 3 percent per year.

Brazil's ethanol consumption is projected to increase by 2.3 percent per annum. Moreover its market share in the bio fuel would be a staggering 51.5% by the year 2010. [5] Since gasoline demand in Brazil is slated to grow by 2.7 percent per year, ethanol consumption is predicted to increase proportionately. While hydrated ethanol and anhydrous ethanol for other uses are estimated to decrease by 0.9 percent per annum, ethanol production in Brazil is projected to increase by 2.3 percent. It is further hypothesized that, the government of Brazil will give priority to meet domestic demand rather than joining international markets but Brazil's ethanol exports are predicted to increase by 3.9 percent per annum [4]. Figure 1.10 summarizes the world ethanol consumption:

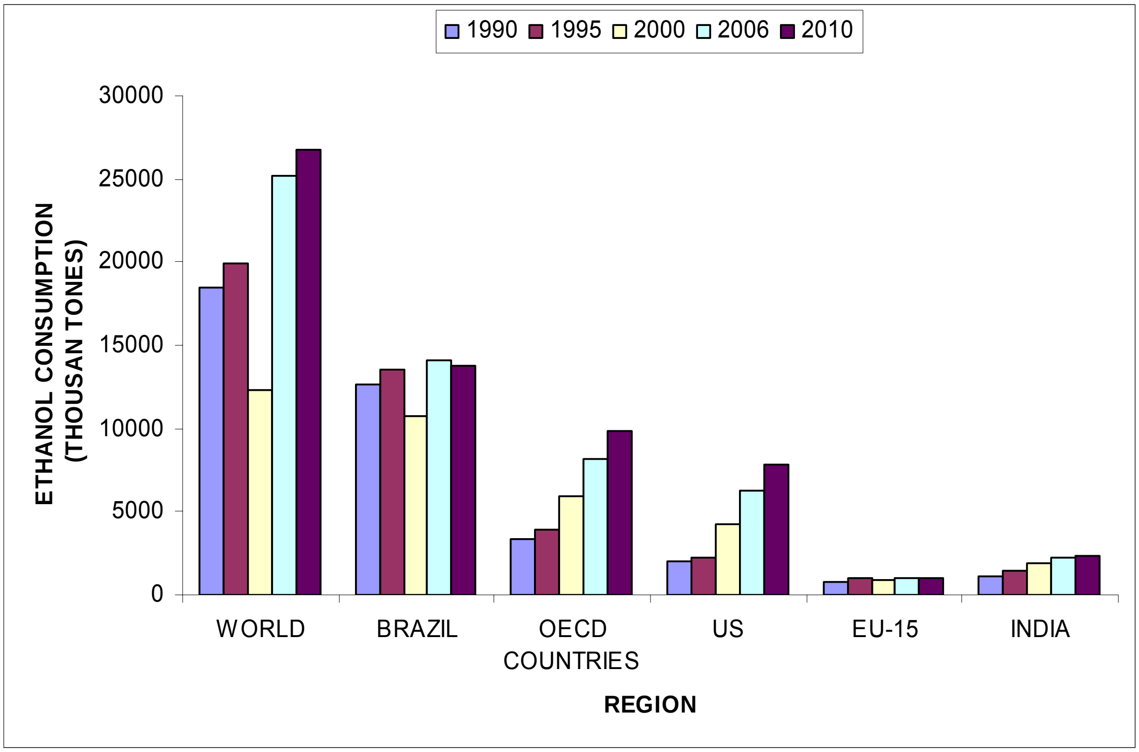


Figure 1.9: World ethanol consumption [5]

1.6 Ethanol Capacity in India

India is the fourth largest ethanol producer after Brazil, United States and China and it's 5 per cent ethanol blending in petrol is already inforce, the ethanol requirement was increases 640 million liters in 2007-2008 which is expected to be 810 million liters in the year 2011-2012. The Current capacity of ethanol in India can potentially satisfy this demand. [6] India is the second largest producer of sugarcane in the world having 315.5 million tonnes per annum. figure 1.11 depict the production and use pattern of ethanol in different application in India.

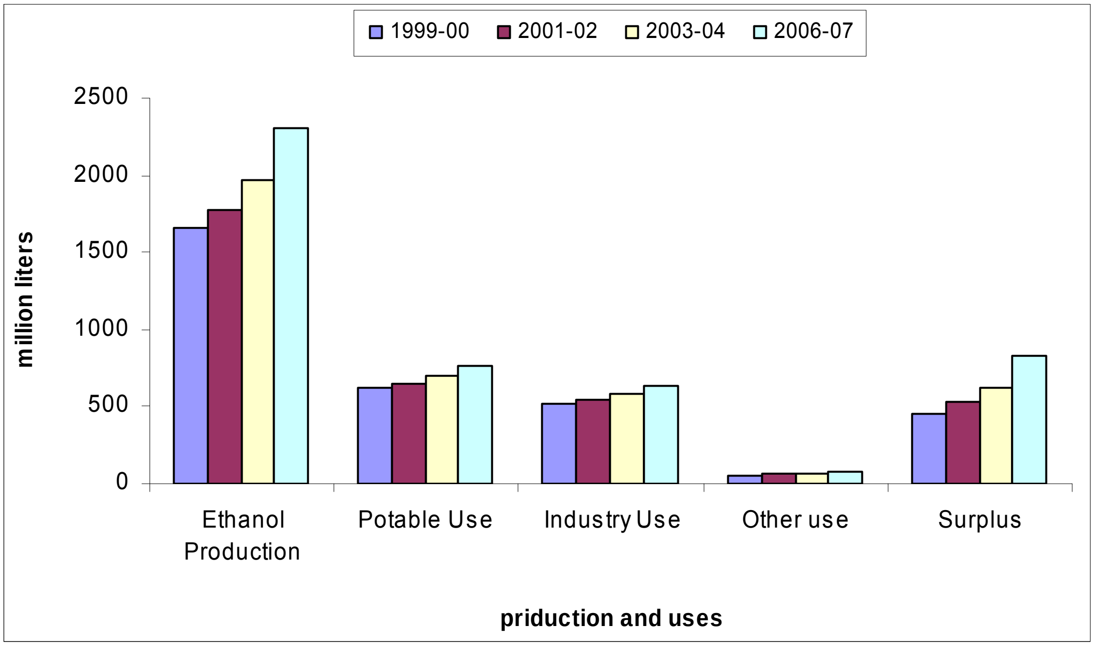


Figure 1.10: Production Capacity of Ethanol in India [6]

1.7 Indian Ethanol Scenario

Historical

- The Indian Ethanol Program started during World War II as there was a shortage of gasoline and as a result, Power Alcohol' was encouraged by the British. The 'Oil Shock' of mid 70s saw a revival of interest in Ethanol. Successful trials of ethanol were carried in 1979 - on 15 cars on 10% & 20% blend .[7]

Indian Initiatives

- In April 2001, 3 successful Pilot Projects using E5 were started. Two of them were in Maharashtra and one in UP. Under this program mixing at oil depots was done and supply to nearly 300 petrol pumps was carried. In December 10, 2001, Policy was announced to blend 5% ethanol with petrol. Rs 4 Cr. was sanctioned for R&D by the Indian government for Ethanol diesel blends and to provide a supportive environment, the Sugar Development Act was also amended [7].
- As per the September 13, 2002 Notification, it was made obligatory to mix 5% Ethanol in gasoline in 9 States (Sugar producing States) and in 4 UTs

by January1, 2003. A notice period of just 3.5 months was set aside for this initiative.

- In Union Budget presented in Feb 2003, Excise duty concession of Rs 0.30 per liter of ethanol was granted till Feb 29, 2004. A program initiated in financial year 2003-04 set guidelines to blend 290 million Liters of Ethanol in 5.8 billion Liters of petrol in 9 States.[7]
- In a view to increase country's ethanol output, Indian government is likely to raise the fixed price of ethanol nearly 5 percent to 10 percent from its current level in the coming months of year 2009. The government may raise the fixed price of ethanol up to Rs 24 per litter from Rs 21.5 per litter. The higher price of ethanol would encourage more output, which is necessary to hit India's mandatory 10 per cent biofuels blending target by October 2009.[6]

The following benefits to Indian Economy are envisaged by mixing ethanol with gasoline.

- Enhancing Energy Security
- Rural employment and development of economy
- Large multiplier/low capital intensity/higher employment per unit capacity
- Environment and Climate change
- Safer/cheaper Oxygenate as it replaces MTBE

CHAPTER 2
LITERATURE SURVEY

2.1 Ethanol as Supplementary Fuel

Since 19th century, ethanol has been used as an IC Engine fuel. Ethanol can be fermented and distilled from biomass. The current production cost of ethanol in India is about Rs. 21 per liter. This puts ethanol in a favorable position for meeting India's future energy needs, especially as the cost of petroleum is expected to continue its upward trend. In addition to providing energy security and a decreased dependence on oil imports, ethanol offer several significant benefits such as reduced harmful gaseous emission and greenhouse gases increased employment opportunity in the agricultural sector. Owing to its agro-based, it can be considered as a renewable fuel.

As a fuel for CI engines, ethanol has some advantages over diesel fuel, such as the reductions of soot, carbon monoxide (CO) and unburned hydrocarbon (HC) emissions. Due to limitation in technology, economic and regional considerations, ethanol still cannot be used extensively despite having many advantages. However, ethanol blended diesel fuels can be practically used in CI engines .Ethanol (C_2H_5OH) is a pure substance, however, diesel fuel is composed of C_3–C_{25} hydrocarbon, and has wider transitional properties. Ethanol contains an oxygen atom so that it can be viewed as a partially oxidized hydrocarbon. Ethanol is completely miscible with water. This may cause the blended fuel to contain water, and resulting in the corrosion of the mechanical components, particularly made from aluminum, brass, and copper. To diminish this problem on the fuel delivery system, such materials stated above should be avoided. Ethanol can react with most rubber and create jam in the fuel pipe. Therefore, it is advised to use fluorocarbon rubber as a replacement for natural rubber. The auto-ignition temperature of ethanol is higher than that of diesel fuel, which makes it safer for transportation and storage. On the other hand, ethanol has a much lower flash point than that of diesel fuel, a disadvantage with respect to safety [8, 9].

Alcohol, especially ethanol or ethyl alcohol, has been recognized as a quality motor fuel, as the design of the first automobile for the spark-ignition engine because of its high anti-knock value designated by the `octane Number' and better performance in terms of power and efficiency. It is only recently that interest was shown in the use of ethanol and methanol as diesel fuels. Ethanol is very difficult to burn by compression-ignition, because of their low ignition quality, usually designated by a low cetane number. A high-octane fuel (a virtue for a petrol engine), necessarily has a low cetane value (a curse for the diesel engine). The main research in diesel-alcohol technology was to find ways and means to force alcohol to ignite by compression in the diesel engine.

It is apparent from the increasing popularity of light-duty diesel engines that alternative fuels such as alcohols must be used for diesel combustion if they are to contribute significantly as substitutes for petroleum-based fuels. However, in the past, little attention has been given to the utilization of Ethanol fuels in compression ignition engines this is due to the difficulties encountered while attempting to use ethanol in diesel engines. The main difficulties are:

1. More Ethanol fuel than diesel fuel is required by mass and volume.
2. Large percentages of Ethanol do not mix with diesel fuel; hence use of diesel-Ethanol blends is not feasible. Also, the blends were not stable and separate in the presence of trace amounts of water [10].
3. Ethanol have extremely low cetane numbers, whereas the diesel engine is known to prefer high cetane number fuels [10,11] which auto-ignite easily and give small ignition delay [12].
4. Diesel fuels serve as lubricants for diesel engine. Alcohol fuels do not have same lubricating qualities [10, 11]
5. The poor auto-ignition capability of Ethanol is responsible for severe knock due to rapid burning of vaporized alcohol and combustion quenching caused by high latent heat of vaporization and subsequent charge cooling [10].

Although replacing diesel fuel entirely by alcohols is very difficult, an increased interest has emerged for the use of alcohols, and particularly lower alcohols (ethanol in particular) with different amounts and different techniques in diesel engines as a dual fuel operation during recent years

2.2 Method of Ethanol Production

Ethanol can be produced from biomass by the hydrolysis and sugar fermentation processes. Biomass contain a complex mixture of carbohydrate polymers from the plant cell walls known as cellulose, hemi cellulose and lignin. In order to produce sugars from the biomass, the biomass is pre-treated with acids or enzymes in order to reduce the size of the feedstock and to open up the plant structure. The cellulose and the hemi cellulose portions are broken down (hydrolysed) by enzymes or dilute acids into sucrose sugar that is then fermented into ethanol. The lignin which is also present in the biomass is normally used as a fuel for the ethanol production plants boilers. There are three principle methods of extracting sugars from biomass. These are concentrated acid hydrolysis, dilute acid hydrolysis and enzymatic hydrolysis.

2.2.1 Sugar Fermentation Process

The hydrolysis process breaks down the cellulosic part of the biomass or corn into sugar solutions that can then be fermented into ethanol. Yeast is added to the solution, which is then heated. The yeast contains an enzyme called invertase, which acts as a catalyst and helps to convert the sucrose sugars into glucose and fructose (both $C_6H_{12}O_6$).

The chemical reaction is shown below:

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow[\text{Catalyst}]{\text{Invertase}} C_6H_{12}O_6 + C_6H_{12}O_6$$

The fructose and glucose sugars then react with another enzyme called zymase, which is also contained in the yeast to produce ethanol and carbon dioxide. The chemical reaction is shown below:

$$C_6H_{12}O_6 \xrightarrow[\text{Catalyst}]{\text{Zymas}} 2C_2H_5OH + 2CO_2$$

The fermentation process takes around three days to complete and is carried out at a temperature of between 250C and 300C. [13]

2.2.2 Fractional Distillation Process

The ethanol, which is produced from the fermentation process, still contains a significant quantity of water, which must be removed. This is achieved by using the fractional distillation process. The distillation process works by boiling the water and ethanol mixture. Since ethanol has a lower boiling point (78.3^0C) compared to that of water (100^0C), the ethanol turns into the vapour state before the water and can be condensed and separated. [13]

2.3 Comparison of Various Primary Alcohols with Gasoline and Diesel

Table 2.1 summarizes and compare the important fuel prospects of different fuels:

	Methane	Methanol	Dimethyl ether	Ethanol	Gasoline	Diesel
Formula	CH_4	CH_3OH	CH_3OCH3	CH_3CH_2OH	C_7H_{16}	$C_{14}H_{30}$
Molecular weight (g/mol)	16.04	32.04	46.07	46.07	100.2	198.4
Density (g/cm^3)	0.00072	0.792	0.661	0.785	0.737	0.856
Normal boiling point (^{1}C)	–162	64	–24.9	78	38–204	125–400
LHV (kJ/cm^3)	0.0346[a]	15.82	18.92	21.09	32.05	35.66
LHV (kJ/g)	47.79	19.99	28.62	26.87	43.47	41.66
Carbon Content (wt%)	74	37.5	52.2	52.2	85.5	87
Sulfur content	7 – 2 5	0	0	0	~ 2 0 0	~ 2 5 0
Latent heat(kj/kg)	5 7 7	1109	465	854	2 9 3	3 0 1

Table 2.1: Comparison of Various Primary Alcohols with Gasoline and Diesel [6]

2.4 Method of Introducing Ethanol in Diesel Engine

There are several techniques involving alcohol-diesel dual fuel operation. The ignition of alcohol in dual fuel operation is ensured by the high self-ignition diesel fuel. The most common methods for achieving dual fuel operation are-

2.4.1 Ethanol diesel fuel blend

Ethanol diesel fuel blend is a macro or micro emulsion of ethanol in diesel. This emulsion requiring no technical modifications on the engine side .It is mentioned that stable emulsions usually refer to both solutions of anhydrous ethanol in diesel fuel (transparent) and micro emulsions of ethanol in diesel fuel (translucent). Anhydrous ethanol (200 proof) does not require an emulsifying agent or so called ‘surfactant’ to form a transparent solution in diesel fuel, but these solutions can tolerate only up to 0.5% water. Then, in the practical cases of using lower proof ethanol (say 190 proof or lower), an emulsifying agent is required to form the opaque macro-emulsion; this, however, could be separated into the two phases if allowed to stagnate for a long period . Blends with up to 20% (by vol.) ethanol in diesel fuel are considered relatively safe from the engine durability point of view.[14] there are some Properties which affecting ethanol diesel fuel blend

Blend stability

Ethanol solubility in diesel is affected mainly by two factors, temperature and water content of the blend. At warm ambient temperatures dry ethanol blends readily with diesel fuel. However, below about 10°C the two fuels separate, a temperature limit that is easily exceeded in many parts of the world for a large portion of the year. Prevention of this separation can be accomplished in two ways: by adding an emulsifier which acts to suspend small droplets of ethanol within the diesel fuel, or by adding a co-solvent or surfactant that acts as a bridging agent through molecular compatibility and bonding to produce homogeneous blend (15).

The aromatic content of diesel fuel also affects the Solubility of ethanol in diesel (16) and therefore the effectiveness of emulsifiers and co solvents. The polar nature of ethanol induces a dipole in the aromatic molecule allowing them to interact reasonably strongly, while the aromatics remain compatible with other hydrocarbons in diesel fuel. Hence aromatics Act to some degree as bridging agents and co-solvents. Reducing the aromatic content of diesel fuels will influence the miscibility of ethanol in diesel fuel and will affect the amount of additive required to achieve a stable blend.

Viscosity and Lubricity

Fuel viscosity and lubricity play significant roles in the lubrication of fuel injection systems, particularly those incorporating rotary distributor injection pumps that rely fully on the fuel for lubrication within the high pressure pumping mechanism. In the common rail accumulator fuel-injection system, the high-pressure pump that delivers fuel to the rail also relies on the fuel for lubrication. In in-line pumps and unit injectors, there is less reliance on the fuel for lubrication; however, there are still some metal interfaces that require lubrication by the fuel such as between plunger and barrel. Injector lubrication also is affected, particularly at the needle guide-nozzle body interface. Lower fuel viscosities lead to greater pump and injector leakage reducing maximum fuel delivery and ultimately power output. Hot restart problems also may be encountered as insufficient fuel may be injected at cranking speed when fuel leakage in the high-pressure pump is amplified because of the reduced viscosity of the hot fuel.[17]]

Material compatibility

The use of ethanol in gasoline engines in the early1980s resulted in numerous materials compatibility studies, many of which are also applicable to the effect of ethanol–diesel blends in diesel engines and particularly in the fuel injection system. The quality of the ethanol has a strong influence on its corrosive effects (18). In addressing the problems of ethanol corrosion associated with diesel blends, divided ethanol corrosion into three categories: general corrosion, dry corrosion and wet corrosion. [19] General corrosion was caused by ionic impurities, mainly chloride ions and acetic acid. Dry corrosion was attributed to the ethanol molecule and its polarity. [20] Wet corrosion is caused by azeotropic water, which oxidizes most metals [18]. Freshly formulated blends containing pH neutral dry ethanol would be expected to have relatively little corrosive effect. However, if a blend has been standing in a tank for sufficient time to allow the ethanol to absorb moisture from the atmosphere, it may tend to be more corrosives it passes through the fuel injection system [20]. In addition, the fuel may stand in the fuel injection pump for a number of months, for example in a combine harvester engine, thus allowing the fuel time to corrode parts of the pump internally. Corrosion inhibitors have been incorporated in some additive packages used with ethanol–diesel blends [20].

Energy content

The energy content of a fuel has a direct influence on the power output of the engine. Wrage and Goering[37] stated that it would be desirable for ethanol–diesel blends to have gross energy contents at least 90–95% of that for diesel to permit existing engines to deliver adequate power for the loads for which the vehicle is designed. The energy content of ethanol–diesel blends decreases by approximately 2% for each 5% of ethanol added, by volume, assuming that any additive included in the blend has the same energy content as diesel fuel.[21]]

Cetane number

The minimum cetane number specified by ASTM Standard D 975-02 for diesel is 40. With the inverse relationship of octane number and cetane number, ethanol exhibits a low cetane rating. Hence, increasing concentrations of ethanol in diesel lower the cetane number proportionately. Hardenberg et. Al. [22] stated that using cetane numbers to describe the ignition characteristics of ethanol–diesel blends was unreliable, because of discrepancies in the determination of cetane numbers below 30. However, they estimated that the cetane number of ethanol was between 5 and 15.

Lower cetane numbers mean longer ignition delays, allowing more time for fuel to vaporize before combustion starts. Initial burn rates are higher causing more heat release at constant volume, which is a more efficient conversion process of heat to work. Nevertheless, it is preferable to add an ignition improver to raise the cetane number of ethanol–diesel blends so that they fall within an acceptable range equivalent to that expected of diesel fuel

2.4.2 Ethanol Fumigation

Fumigation is a method by which alcohol is introduced into the engine by carbureting, vaporizing or injecting the alcohol into the intake air stream. This requires the addition of a carburetor, vaporizer or injector, along with a separate fuel tank, lines and controls.

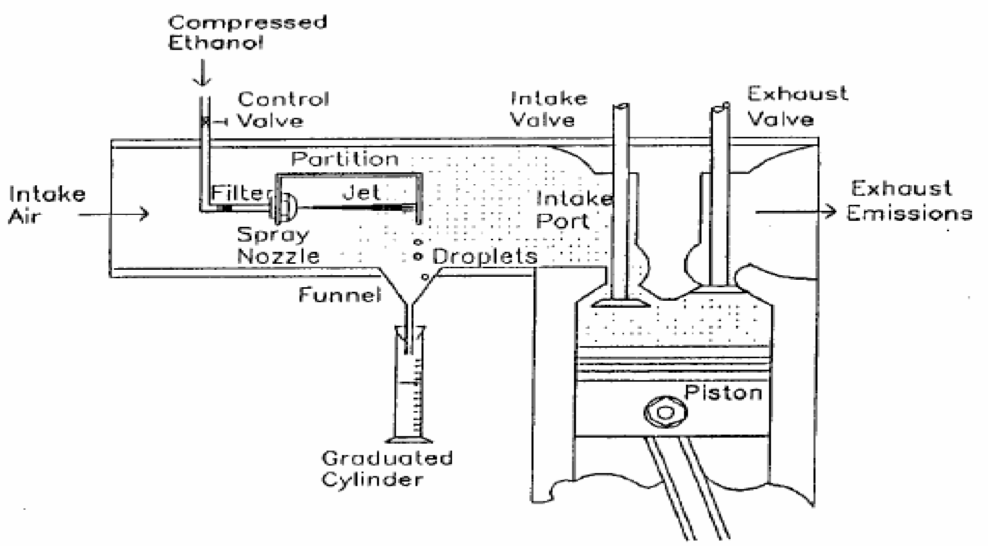


Figure 2.1: Schematic Diagram of Ethanol Fumigation System [23]

Fumigation has some following advantages:

1. It requires a minimum of modification to the engine, since alcohol injector is placed at the intake air manifold. Also, flow control of the fuel can be managed by a simplified device and fuel supply system.

2. The alcohol fuel system is separate from the diesel system. This flexibility enables diesel engines, equipped with the fumigation system, to be operated with diesel fuel only. The engine can switch from dual fuel to diesel fuel operation and vice-versa by disconnection and connection of the alcohol source to the injector.

3. If an engine is limited in power output due to smoke emissions, fumigated ethanol could increase the power output because alcohol tends to reduce smoke. This is because of good mixing of the injected charge with alcohol.

4. Fumigation can substitute alcohol for diesel fuel. Up to 50% of the fuel energy can be derived from alcohol by fumigation [23].

2.4.3 Inline Mixing

It is method of introducing ethanol in diesel on which ethanol and diesel are mixed prior to fuel pump by a mixing device say static mixer or mechanical stirring. Static mixer is a device which mixed two fluids without any emulsifier or surfactant. a small amount of energy is required to adequately mix diesel and ethanol in a pipeline using conventional shear, reverse flow and collision to produce a homogeneous mixture of ethanol and diesel downstream of the mixing element with minimal net pressure drop. Static mixers have no moving parts and are virtually maintenance free. Using the energy available from the fluid in the pipeline and calculating the number of elements required for mixing enables to achieve truly mixed liquids at the mixer's outlet. Figure 13 shows the principle of static mixer for mixing of oil and water. There are 4 step of mixing in static mixer [24]

1. Division of main stream.
2. Streams are forced to opposite to outside walls.
3. Creating a mixing vortex axial to the central line of the second element.
4. Mixing vortex shears step 1 reoccur in opposite rotation.

Above all 4 steps are shown in figure 2.2.

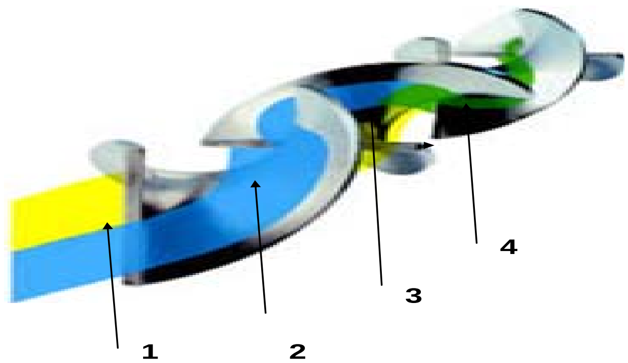
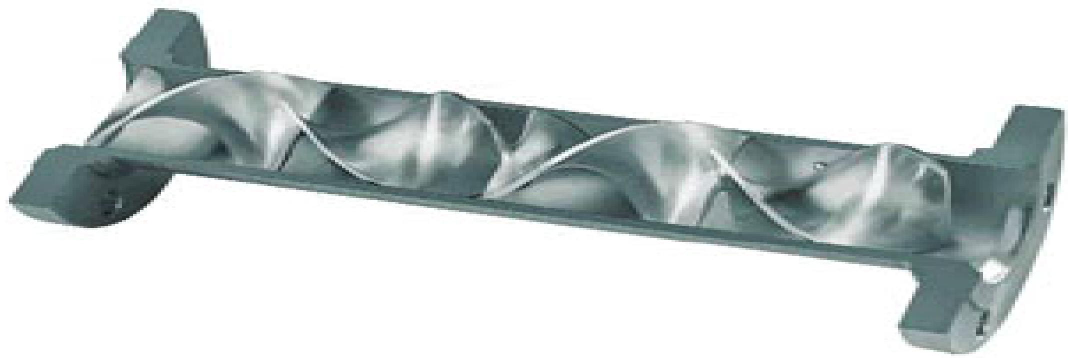


Figure 2.2: Static mixer working principal [24]

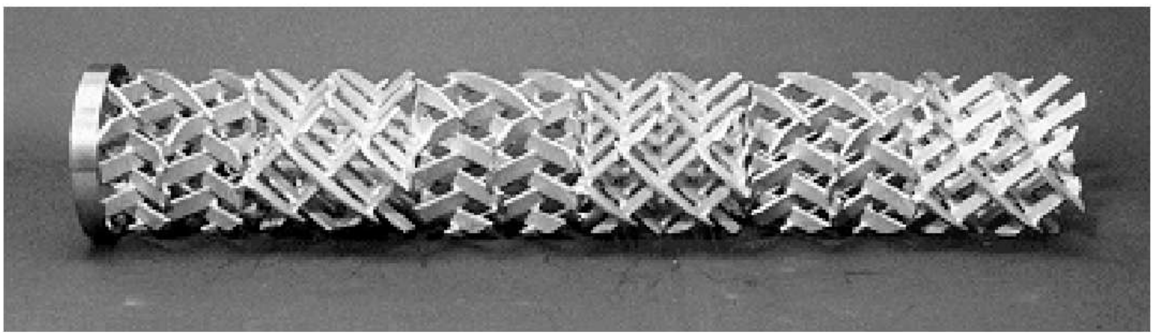
Conventional chemical reactors make use of mechanical stirrers for making blends. In general, such a stirred tank reactor consists of a vessel that is usually equipped with baffles on the sides, in which an impeller brings the fluid in motion. The baffles are used to prevent the fluid from rotating along with the impeller. This configuration is used for centuries for mixing.[25]

An alternative for the mechanical stirrer can be a static mixer. To enhance mixing, control the residence time, static mixers are added for making blends. Here, the static mixer can be compared to the impeller in a stirred tank. A static mixer has the advantage that is doesn't have moving parts, which leads to lower maintenance and operating costs. In principle, a static mixer is nothing more than a stationary object, which is placed inside the tube. Ideally, it disturbs the flow in such a manner that desired flow conditions are obtained. The most commonly used static mixers are the SMX and Kenics static mixer. The basic principle of these mixers is to split, stretch and recombine the fluid, in order to achieve mixing. [25]

The SMX static mixer has the advantages that a relatively short length is necessary to obtained full mixing. SMX mixer can be about 3.3 times shorter then the Kenics static mixer to obtain the same amount of distributive mixing. Under these conditions both mixers have similar pressure drops. If length is an issue the SMX mixer is favorable. The disadvantage of the SMX mixer is that it is more expensive then the Kenics static mixer. The kenix and SMx static mixer are shown in figure 2.3.



Kenics static mixer.



SMX static mixer

Figure 2.3: Example of the SMX and Kenics static mixer.[25]

. **2.5 Literature Survey**

The following literature review makes an attempt to examine the work carried by various researchers related to performance and emission of using ethanol in diesel engine.

Cai Lu et al [26] investigated the influence of cetane number improver on heat release rate and emissions of a high-speed diesel engine fueled with ethanol–diesel blended fuel. Different percentages of cetane number enhancer (0, 0.2 and 0.4%) were added to blends, and the engine tests were performed on a 4-cylinder high-speed DI diesel engine. The results show that: the brake specific fuel consumption (BSFC) increased, the thermal efficiency improved remarkably, and NOx and smoke emissions decreased simultaneously when diesel engine fueled with ethanol–diesel blend fuels; NOx and smoke emissions further reduced when CN improver was added to blends. From the combustion analysis, it can be found that the ignition delay prolonged, and the total combustion duration shortened for ethanol–diesel blend fuels when compared to diesel fuel; the combustion characteristics of ethanol–diesel blend fuel at large load may be resumed to diesel fuel by CN improver, but a large difference exists at lower load

Agarwal [27], found that ethanol diesel blends up to 20% can very well be used in constant speed CI engines without any hardware modification. Exhaust gas temperatures and lubricating oil temperatures were lower for ethanol diesel blends than mineral diesel. The engine can be started normally in both hot and cold weather conditions. Significant reduction in CO and NOx emission was observed while using ethanol diesel blends

Hayes, et al. [28].tested 100, 125, 150, 175 and 200 proof ethanol as fumigants in a 6-cylinder turbocharger diesel engine at 2400 rpm. Ethanol was injected directly into the intake ports. Six electronic fuel injectors were used, one for each cylinder. They found that the lower proofs ethanol reduced the maximum rate of pressure rise. Any proof at lower load reduced NOx levels. HC emissions increased greatly as the ethanol substitution was increased without depending on the ethanol proof.

Qudais et al [29]. Investigated the effects of ethanol fumigation and ethanol-diesel fuel blends on the performance and emissions of a single cylinder diesel engine experimentally. An attempt was made to determine the optimum percentage of ethanol that gives lower emissions and better performance at the same time. This was done by using a simple fumigation technique. The results show that both the fumigation and blends methods have the same behavior in affecting performance and emissions, but the improvement in using the fumigation method was better than when using blends. The optimum percentage for ethanol fumigation is 20%. This percentage produces an increase of 7.5% in brake thermal efficiency, 55% in CO emissions, 36% in HC emissions and reduction of 51% in soot mass concentration. The optimum percentage for ethanol diesel fuel blends is 15%. This produces an increase of 3.6% in brake thermal efficiency, 43.3% in CO emissions, 34% in HC and a reduction of 32% in soot mass concentration.

Weidman et al. [30] used a standard Volkswagen 4-cylinder, swirl-chamber diesel Engine to test the performance of alcohol-diesel fuel blends. The alcohols involved Ethanol and methanol. They reported that HC and CO emissions were increased and NO_x emissions decreased compared to diesel fuel. Also, alcohol-diesel fuel blends emit more aldehydes and less polycyclic aromatic hydrocarbons (PAH)

Hansen et al [31] evaluated that Ethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce particulate emissions in compression–ignition engines. He discussed properties and specifications of ethanol blended with diesel fuel and put special emphasis on the factors critical to the potential commercial use of these blends. These factors include blend properties such as stability, viscosity and lubricity, safety and materials compatibility. The formulation of additives to certain key properties and maintain blend stability has been suggested as a critical factor in ensuring fuel compatibility with engines. However, maintaining vehicle safety with these blends may entail fuel tank modifications.

Czerwinski [32] tested a 4-cylinder, heavy duty, direct injection diesel engine on 30% ethanol. He found that the addition of 30% ethanol to the diesel fuel causes longer ignition delay. The combustion temperatures were lower. At full load, all emissions were lower. At lower loads and speeds, CO and HC emissions were increased. It was possible to obtain emissions similar to diesel fuel, but with reduced power output up to 12.5%

Broukhiyan et al. [33] applied ethanol fumigation to a 5.7 liter, V-8, light duty, indirect injection diesel engine to study the effect of ethanol fumigation on the performance (efficiency), combustion knock characteristics and exhaust emissions by using a pressurized nitrogen cylinder with secondary air supply in amounts up to 50% of the total fuel energy.. For all conditions except the 1/4 rack setting (light load) condition, modest thermal efficiency gains were observed upon fumigation. However, engine roughness or the occurrence of severe knock limited the maximum amount of ethanol that could be fumigated. Brake specific NOx concentrations were found to decrease for all conditions tested. While decreasing the mass of particulate emitted, ethanol fumigation enhanced the biological activity of that particulate.

Ahin et.al [34] found ethanol fumigation not economical and advised to use ethanol fumigation for applications in which maximum efficiency and power is desired and fuel consumption is not considered very important.

Rakopoulo et.al[35] evaluated and compared the performance and exhaust emission levels of ethanol as supplement in conventional diesel fuel, at ethanol blend ratios (by volume/volume) of 5/95 and 10/90, in a fully instrumented, six-cylinder, turbocharged and after-cooled, direct injection (DI), Mercedes– Benz, mini-bus diesel engine.. they reported that The smoke density was significantly reduced with the use of the ethanol–diesel fuel blends with respect to neat diesel fuel. This reduction was higher the higher percentage of ethanol in the blend. The NOx emissions remained the same or very slightly reduced with the use of the ethanol–diesel fuel blends with respect to those of the neat diesel fuel. The CO emissions were equal or slightly reduced with the use of the ethanol–diesel fuel blends with respect to those of the neat diesel fuel, with this reduction being higher the higher the percentage of ethanol in the blend. The unburned hydrocarbons (HC) emissions were increased with the use of the ethanol–diesel fuel blends with respect to those of the neat diesel fuel, with this increase being higher the higher the percentage of ethanol in the blend. Concerning the engine performance with the ethanol–diesel fuel blends against the neat diesel fuel case, a little higher specific fuel consumption was observed with increasing percentage of the ethanol in the blends, and a corresponding very slight increase of brake thermal efficiency.

Rahimi et. al [36] investigated, effect of Diesterol, a new specific term which denotes a mixture of fossil diesel fuel (D), vegetable oil methyl ester called biodiesel (B) and plant derived ethanol (E). they reported that to reduce engine exhaust NOx, CO, HC and smoke emissions due to application of biofuel and the increase of fuel oxygen content. It was needed to prepare suitable low cost and renewable additives. The diesterol properties such as pour point, viscosity, flash point, copper strip corrosion, ash content, sulfur content and cetane number were determined experimentally. The optimum ratio of bioethanol and biodiesel was found to be 40/60 considering fuel oxygen content, fuel price and mixture properties.. The experimental results showed that bioethanol plays an important role in determining the flash point of the blends. By adding 3% bioethanol to diesel and sunflower methyl ester, the flash point was reduced by 16 ^{0}C. The viscosity of the blend was also reduced by increasing the amount of bioethanol. The sulfur content of bioethanol and sunflower methyl ester is very low compared to diesel fuel. The sulfur content of diesel is 500 ppm whereas that of bioethanol and sunflower methyl ester is 0 and 15 ppm, respectively. This lower sulfur content is another factor enhancing the use of fuel blends in diesel engines. The bioethanol and sunflower methyl ester combination has sulfur content less than 20 ppm. The maximum power and torque using diesel fuel were 17.75 kW and 64.2 Nm at 3600 and 2400 rpm, respectively. Adding oxygenated compounds to the new blend seems to slightly reduce the engine power and torque and increased the average sfc for various speeds. The experimental measurement and observation of smoke concentration, NOx, CO and HC concentration indicated that both of these pollutants reduced by increasing the biofuel composition of diesterol throughout the engine operating range.

Lapuerta et.al [37] tested anhydrous bioethanol blended with conventional diesel, with 10% ethanol by volume and no additives. The resulting emissions have been compared with those from pure diesel. These results proved that the use of this renewable component provides a significant reduction on particulate emissions, with no substantial increase in other gaseous emissions. The use of e-diesel blends may cause slight improvements in the engine effective efficiency with respect to that obtained with commercial diesel, as a consequence of an increase in the diffusion flame speed, which compensates the delayed start of combustion caused by longer autoignition times, keeping the combustion centred in all tested modes. The detailed study of the combustion timing from the cylinder pressure signal shows that no modifications are needed in the injection system tuning, at least when blends contain less than 10% bioethanol.

Caro et. Al [38]. Selected two organic additives to study the behaviour of a diesel–ethanol mixture for their different physico-chemical parameters. These compounds had a glycerol skeleton bearing heteroatoms and amino-ether, hydroxyl, nitrate and nitramine functional groups. Properties directly related to engine parameters (viscosity, cetane number, heat content, volatility) and those characterizing fuel quality (homogeneity, cold properties, anticorrosive ness and volatility) were investigated. Fuel formulations were prepared with 2% additive and ethanol contents between 10 and 20% in volume in relation to the diesel fuel. Blends, with or without additive, were compared in two diesel engines with direct and indirect injection. Engine behaviour seemed to be improved in the presence of additives with a reduction of pollutant emissions in exhaust gas, cyclic irregularities and ignition delay. No trouble shooting, knocking or vapor-lock phenomenon were encountered during this study.

Shi et.al.[39] were prepared a blend of 20% ethanol-methyl soyate by volume and added to diesel fuel as an oxygenated additive at volume percent levels of 15 and 20% (denoted as BE15 and BE20). They also prepared a blend containing 20% methyl soyate in diesel fuel (denoted as B20). The fuel blends that did not have any other additive were stable for up to 3 months. Engine performance and emission characteristics of the three different fuels in a diesel engine were investigated and compared with the base diesel fuel. The results showed that particulate matter (PM) emission decreased with increasing oxygenate content in the fuels but nitrogen oxides (NOx) emissions increased. The diesel engine fueled by BE20 emitted significantly less PM and a lower Bosch smoke number but the highest NOx among the fuel blends tested. All the oxygenate fuels produced moderately lower CO emissions relative to diesel fuel. The B20 blend emitted less total hydrocarbon (THC) emissions compared with base diesel fuel. This was opposite to the fuel blends containing ethanol (BE15, BE20), which produced much higher THC emission.

Important finding from literature review

On the strength of work done by previous researches ,it is seen that the most common method of using ethanol in diesel engine are alcohol fumigation, alcohol diesel blend and preparation of macro and micro emulsion of ethanol in diesel. Use of static mixer for preparing the blend ethanol diesel is a very promising area and very small work has been done in this area. Fumigation is also an important area which is extensively studied by researchers. Therefore, it shall be relevant that effort should be made to develop a static mixer for blending of ethanol and diesel and to evaluate the performance end emission characteristics of a agriculture diesel engine on this fuel and compare the result with similar percentage of ethanol substitution through fumigation and base line data of diesel fuel.

Therefore, the following objectives were envisaged for the present research work.

1. Comprehensive literature survey.
2. Development of static mixture for inline mixing of ethanol and diesel.
3. Development of experimental diesel engine test rig for studies on fumigation and inline mixing.
4. Conducting exhaustive experiments
5. Analysis of result

CHAPTER 3

SYSTEM DEVELOPMENT AND EXPERIMENTAL SET UP

3.1 Engine Selection

There is no difference of opinion that India is going to face a severe fuel crisis in future because fuel consumption has increased in all the vital sectors specially transportation and agricultural sector. As diesel engines plays an indispensable role in transportation and agriculture sector and as such diesel consumption will increase multifold in time to come. The diesel engine continues to dominate the agriculture sector in our country in comparison to spark ignition engine and have always been preferred widely because of power developed, specific fuel consumption and durability. A through description of combustion mechanism in diesel engine is beyond the scope of this study. However, it would be worthwhile to inform that the fuel is burnt in diesel engine by self ignition at higher temperature and pressure conditions of the order of 600°C and 40 bar, respectively. Diesel as a fuel is injected into the combustion chamber at the end of compression stroke and after certain ignition delay; it burns to give the motive power.

In India, almost all irrigation pump sets, tractors, mechanized farm machinery and heavy transportation vehicle are powered by direct injection diesel engines. Considering the wide application of a small capacity diesel engine which has got great dominance in Indian agriculture sector, a similar engine has been selected for the present study. The controlling parameters could be changed with suitable arrangement provided in the engines. The direct injection (DI) diesel engine used for this study is manufactured by M/s Vimal Engines Limited. It is widely used in India in agriculture, many small and medium scale industries and in residences for emergency power generation. It is a single cylinder, naturally aspirated, four stroke, vertical, air-cooled engine. It has a provision of loading electrically since it is coupled with single phase alternator through flexible coupling. The engine can be hand started using decompression lever and is provided with centrifugal speed governor. The engine was started on diesel engine and then it was switched on to the straight emulsion, inline mixing or fumigation mode where it again run on part load for more than half hour then the actual data was taken from no load to full load.

The engine 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. The inlet and exhaust valves are operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump is driven from the end of camshaft.

The detailed technical specifications of the engine are given in table 3.1.

Table 3.1: Specifications of the Diesel Engine

Make	**Vimal**
Rated Brake Power (bhp/kW)	10/ 7.5
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	102 x 110
Compression Ratio	17.5:1
Cooling System	Water cooled
Lubrication System	Forced Feed
Cubic Capacity	0.78 Lit
Inlet Valve Open (Degree)	4.5 BTDC
Inlet Valve Closed (Degree)	35.5 ABDC
Exhaust Valve Open (Degree)	35.5 BBDC
Exhaust Valve Closed (Degree)	4.5 ATDC
Fuel Injection Timing (Degree)	26 BTDC

As already elaborated, the present study was aimed at using ethanol either in blended form by using a inline mixer or in fumigated form by using a carburetor system, the setup was prepared for inline mixing and fumigation and are described below:

3.2 Setup for fumigation

Fumigation is a technique of introducing fuel (ethanol) at intake manifold of engine. In the present study, a CV carburetor is used to introduce ethanol in intake manifold, where ethanol mixed with air and enters in the cylinder with intake air. The CV (constant velocity) carburetor used in this study is made by Likuni, Japan and is normally used in 125cc bike.

Plate 3.1 : Carburetor Arrangement **Plate 3.2 : CV Carburetor**

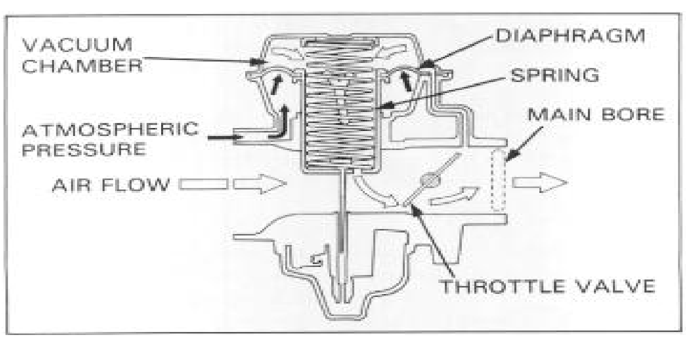


Figure 3.1: Working of CV carburetor

On conventional carburetors, the throttle cable is connected directly to the throttle slide. When throttle is twisted, this lifts the slide and immediately increases the size of the carburetor opening letting in more air/fuel mix and increasing the speed of the motor. On CV carburetors, the throttle cable actuates a butterfly valve, as the throttle is opened, the air pressure difference between the sealed chamber above the vacuum slide and inside the carburetor venturi forces the slide (located in front of the butterfly valve) up and down. The downside to the CV carburetor is a lack of immediate throttle response. Twisting the throttle gives relatively leisurely acceleration compared to a conventional carburetor. One of the advantages is that the carburetor adapts nicely to altitude changes and good gas mileage. In present work carburetor is connected to intake manifold where ethanol is mixed with air where it fumigated and then fumigated ethanol goes inside the engine cylinder with air. The flow rate of ethanol is controlled by throttling valve attached with carburetor. The flow rate of ethanol is measured by a burette which is connected to ethanol fuel tank.

3.3 Setup for Inline Mixing

In present work, ethanol diesel blend is prepared by inline mixing at the running condition of engine. For inline mixing a static mixer is used. Since space is not an issue, the Kenics static mixer seems favorable for this project due to its lower costs. Therefore, this study focuses on the Kenics static mixer. The geometry of the Kenics static mixer consists of a series of mixing elements, each consisting of a short helix of length, which is equal to 1.5 times the tube diameter. The helices are rotated clockwise and counterclockwise at an angle of 180^o and are placed at an angle of 90 ^{o}with respect to each other.

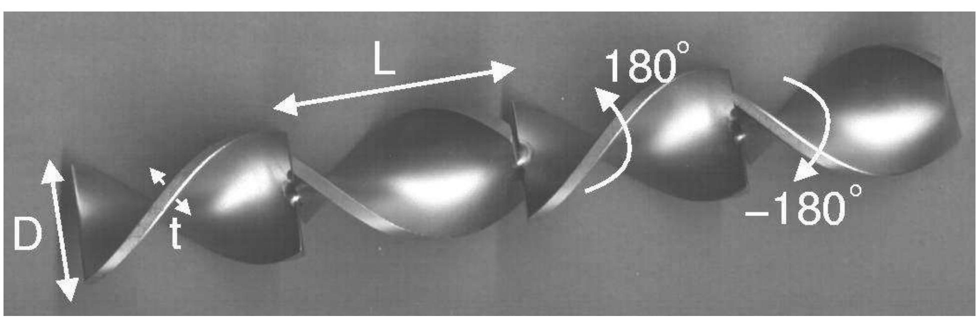


Figure 3.2: Geometry of the Kenics static mixer

Plate 3.3 and 3.4 depicts the static mixer for inline mixing of ethanol and diesel The length of static mixture is 400 mm and inside diameter is 15 mm.10 mixing element are placed in 300 mm length. As for available head, the velocity inside the static mixture reached up to 1 m/s which give good mixing. There are two inlets of static mixer, one for diesel and other for ethanol. A regulating valve is situated at the ethanol inlet. By this valve, the flow rate of ethanol is varied according to required blending. Ethanol flow rate is measured by burette which is connected to ethanol tank. Fuel (blend) consumption is measured by a second burette which is connected to static mixer outlet.

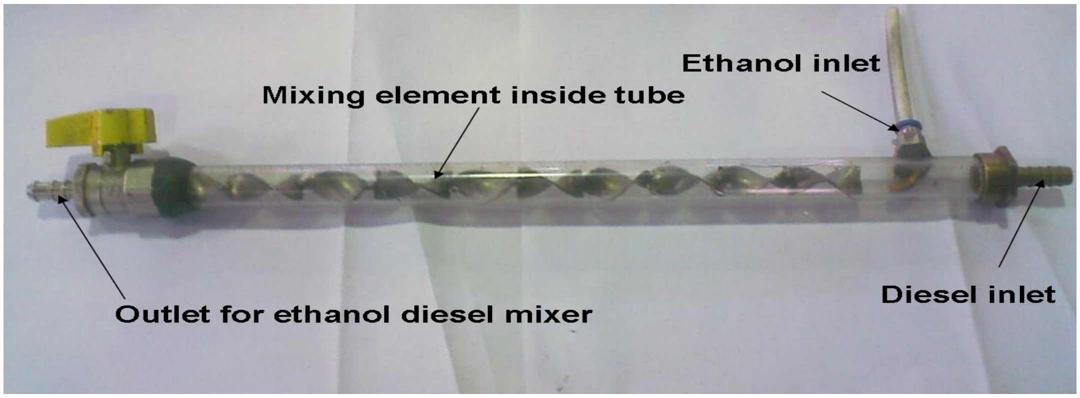


Plate 3.3: Static mixer used for experiment

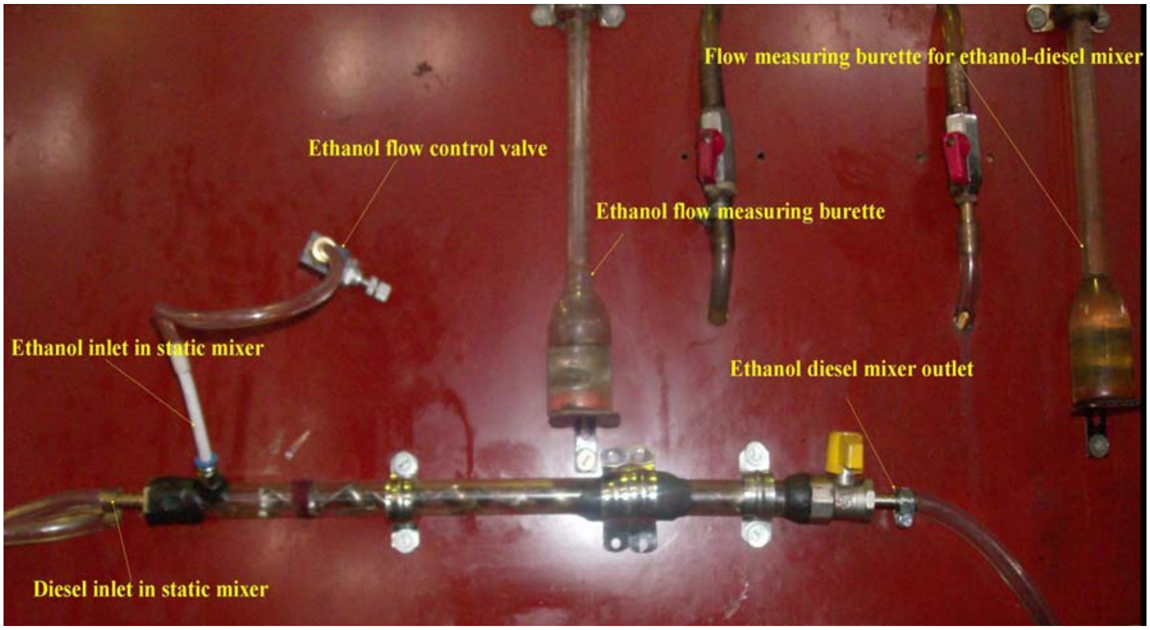


Plate 3.4: Arrangement of static mixer in engine setup

3.4 Apparatus for Performance and Emission Measurement

3.4.1 Air flow Measurement

Plate 3.5: Air Box **Plate 3.6: U-Tube manometer**

It is a box of dimension in mm 630*405*175 made by M.S. used to measure mass flow rate of air. Orifice size of box is 35 mm. For using with carburetor and inlet manifold simultaneously, it is fitted with two outlets. One is connected to carburetor (for fumigation) and other is connected to main engine inlet.

3.4.2 Fuel Consumption Measurement

Fuel measurement is done by a burette of 50ml size. It is made of glass. One side of burette is connected to stop valve other is connected engine fuel filter. Fuel measurement is done with the help of stop watch time for 10 ml droop is noted. 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.

Plate3.7: Fuel Consumption Measuring Unit

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

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

$$bsfc = (Vcc \times \ell \times 3600) / (hp \times t) \qquad (3.3)$$

and

$$bsec = bsfc \times CV \qquad kJ/kW\text{-}h$$

Where,
- $bsfc$ = Brake specific fuel consumption, g/kW-h
- Vcc = Volume of fuel consumed, cc
- ℓ = Density of fuel, g/cc
- hp = Brake horsepower, kW
- t = Time taken to consume, cc of fuel, sec.

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

$$\eta_{th} = Ks / (HV \times bsfc) \qquad (3.4)$$

Where, η_{th} = Brake thermal efficiency, %

Ks	=	Unit constant, 3600
HV	=	Gross heat of combustion, kJ/kg
bsfc	=	Brake specific fuel consumption, g/kW-h

3.4.3. RPM Measurement

Plate 3.8: RPM Measurement

An 'NPN-NO' make RPM Sensor is used to measure the RPM of the engine and proximetric switch which sense one RPM and convert it in to pulse then this pulse transmitted to r.p.m.indicator which gives reading in digital form. It can measure any value from 0-9999 r.p.m.

3.4.4 Fuel Supply System

Arrangement has been made for two fuel supply tank one is for emulsion and other is for diesel. Diesel fuel capacity is 10 liters macro emulsion tank capacity is 3 liters and ethanol tank capacity is 2 liters. Both tanks are connected to burette.

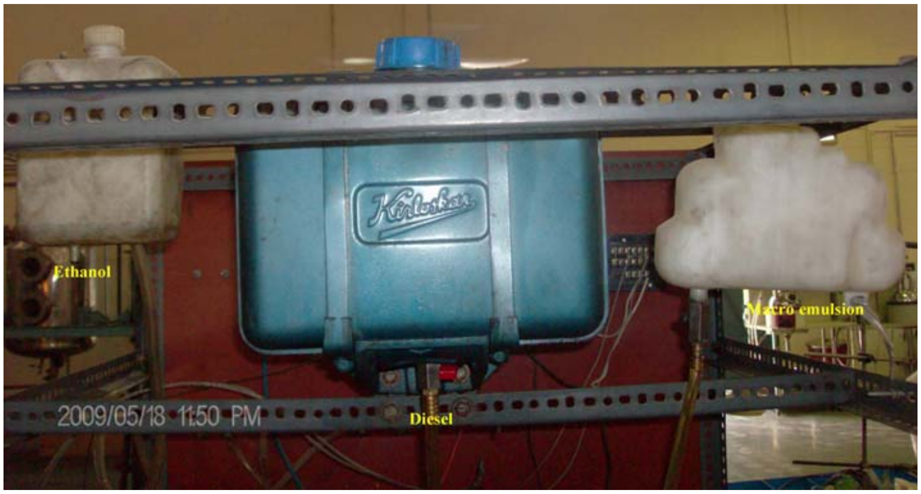


Plate 3.9: Fuel Tank Arrangement

3.4.5 Temperature Measurement

Plate 3.10: Temperature Measurement

Temperature measurement is done by a J-Type Thermocouple and a Creative temperature Indicator which can indicate the temperature in the range of 0-600°C

3.4.6. Emission Measurement:

The exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO_2 and NOx. For measuring the smoke opacity, AVL 437 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. The remaining portion of the light falls on a photocell, generating a photoelectric current, which is a measure of smoke density. The detailed technical specifications have been given in Appendix I.

For measurement of UBHC, CO, CO_2 and NOx, an AVL4000 Light Di-Gas Analyzer was used. The detailed specification of AVL Di-gas Analyzer has been given in Appendix II. AVL 437 Smoke meter and AVL Di Gas Analyzer are shown in Plate 3.11.

Plate 3.11: Smoke Meter and Di Gas Analyzer

Emission measurement is done by AVL DIGAS analyzer which able to measure CO_2, CO, NO_X**,** Un-burnt Hydro carbon, Smoke opacity, Smoke absorbity and Exhaust temperature.

3.4.7 Throttle Control System

Plate 3.12: Throttle Arrangement

Shown above a throttle control system which is made for controlling of throttle valve. With full closing and full opening of throttle we can vary ethanol mixing from 3 to 48 percent.

3.4.9 Experimental test rig

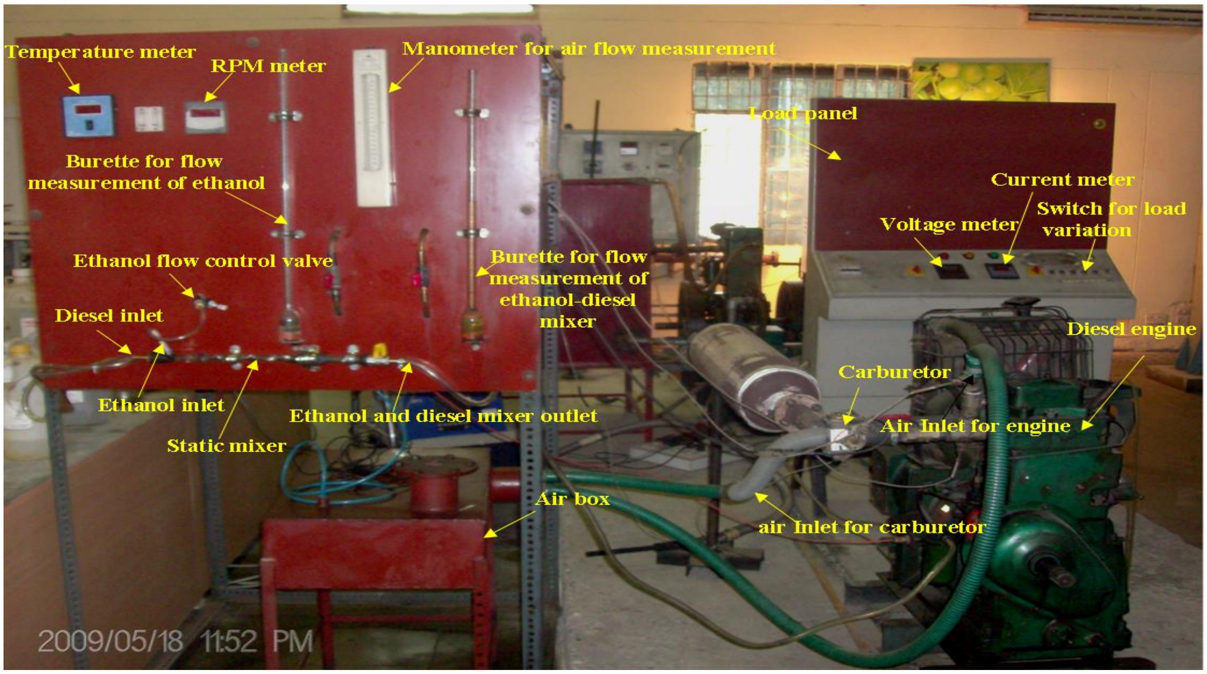


Plate 3.13: Photograph of the Experimental Test Rig (for emulsion and fumigation)

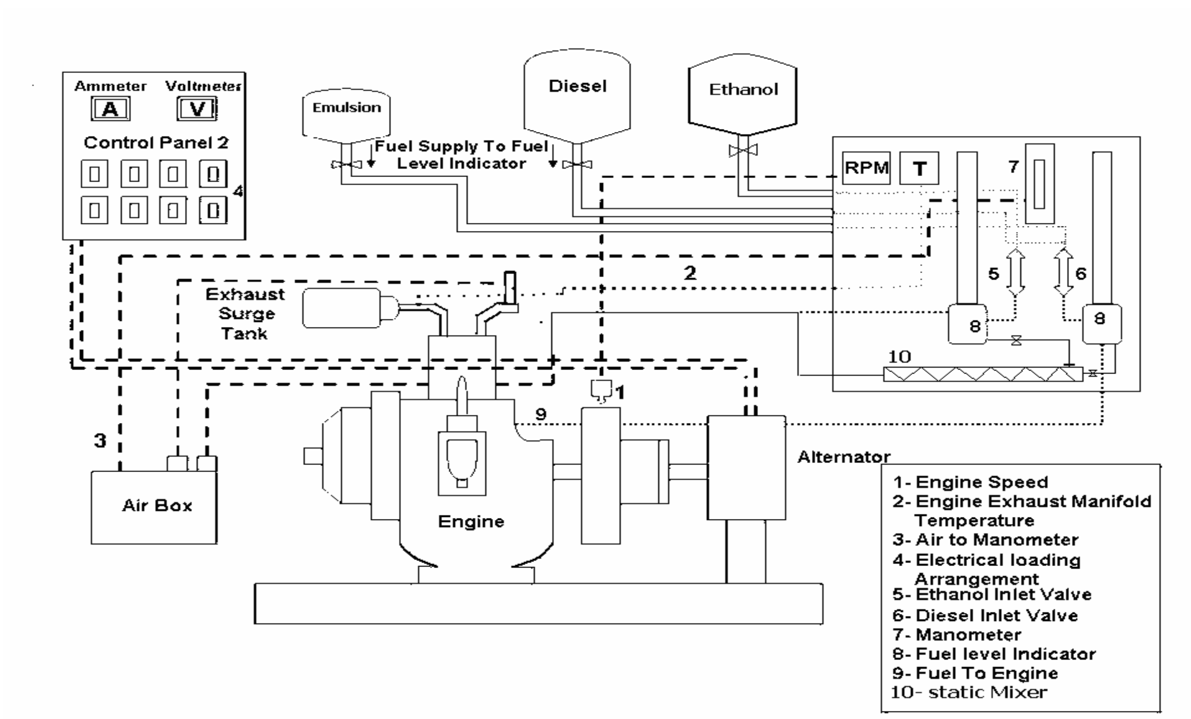


Figure 3.3.Schematic diagram of the Experimental Test Rig

3.5 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. Power produced by the engines
2. Engine speed (Rev/min)
3. Fuel consumption
4. Temperature
5. Speed of the engine
6. Exhaust gas emissions(NOx,CO,CO_2,HC,and smoke opacity)

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

1. Voltage generated by the alternator
2. Current generated by the alternator
3. RPM of the engine
4. Fuel consumption rate
5. AVL 437 smoke meter
6. AVL Di Gas analyzer

Once the parameters were selected, the essential instruments required for sensing these parameters were installed at the appropriate points in the experimental set-up.

3.6 Experimental Procedure

The engine was started on diesel fuel and 30 minute time is given for steady condition. 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. There is a series of precaution that are to be taken care off while performing the diesel engine test run. Readings were taken when the engine come into steady state .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 out put 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. Through special arrangements the thermocouple were mounted on the engine assembly. Optimization of the diesel engine hardware is necessary to avoid leakage of energy in order to obtain the results with best of accuracy.

For fumigation mode ethanol is supplied to ethanol measuring burette from ethanol tank where its flow rate has been measured and then it passes through carburetor. The percentage of fumigated ethanol is controlled by throttling valve of carburetor.

For inline mixing diesel tank outlet is connected to static mixer. and Ethanol tank outlet is connected to ethanol measuring burette which further connected to static mixer. After mixing in static mixer the blend is supplied to fuel measuring burette (where engine fuel consumption is measured) and then goes to engine.

CHAPTER 4

EXPERIMENTAL RESULT AND DISCUSSION

The chapter presents the results obtained from experimental data and these results are thoroughly discussed in subsequent sections. The main objective of the study was to access the performance and emission characteristics of diesel engine with blended and fumigated ethanol and the result compared with baseline data on neat diesel.

4.1 Performance Characteristics

The performance characteristics of agricultural diesel engine on diesel, blended ethanol and fumigated ethanol is summarized below

4.1.1 Brake thermal efficiency Vs BMEP

The variation of brake thermal efficiency of the engine with BMEP for different fuel is shown in figure 4.1:

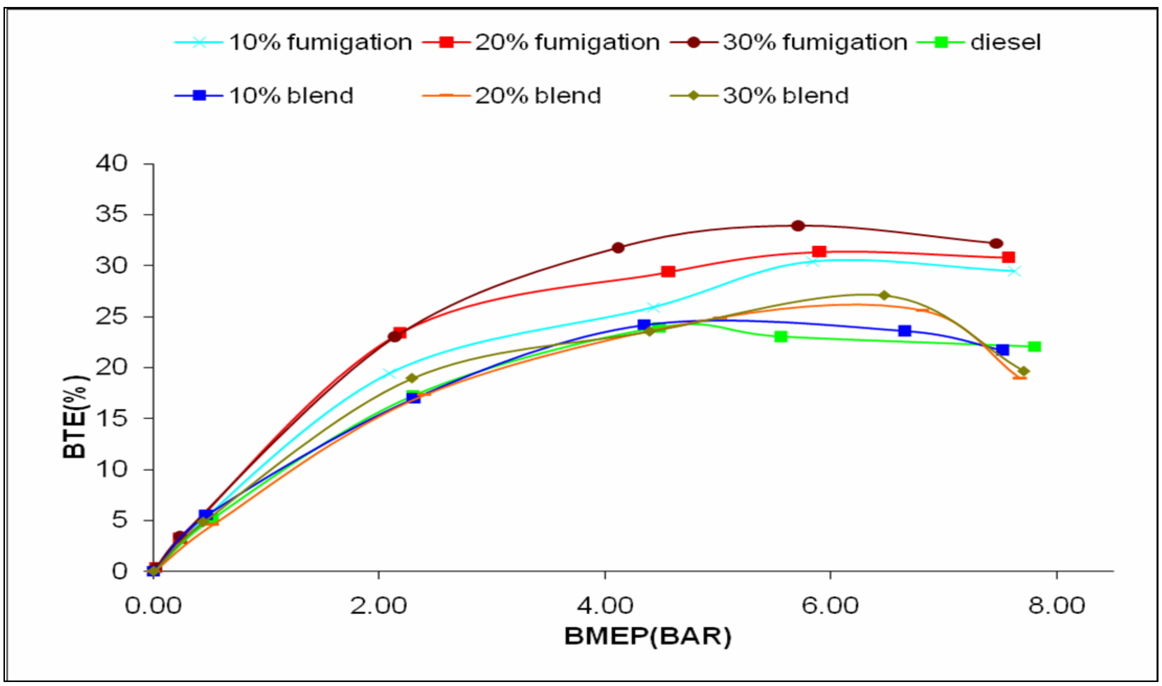


Figure 4.1: Brake thermal efficiency Vs **BMEP**

It was observed that initially with increasing load the brake thermal efficiency of all fuels was increased and then tended to decrease with further increase in load. The figure shows an improvement in the efficiency with increasing ethanol substitution in blending and fumigation. The improvement was higher for fumigation. The peak thermal efficiency for 30% blended ethanol is 27%, 33.91% at 30% ethanol fumigation, and for diesel it was only 24%.

The improvement in the thermal efficiency due to induction of ethanol is attributed to the changes occurring in the combustion process. The physical and chemical differences in fuel structure of ethanol and diesel fuel lead to a combination of changes in the combustion process. In general, the slight gain in thermal efficiency with increased ethanol substitution may be attributed to the increase in the ignition delay, so a rapid rate of energy is released which reduces the heat loss from the engine because there is not enough time for this heat to leave the cylinder through heat transfer to the coolant [23].

It was found that the fumigation is performing better than blending technique. This could be because that in fumigation ethanol is evaporated in intake manifold which lower the temperature of intake mixture and increases its density. Thus, more air is made available in the cylinder and greater amount of power can be generated. [23]

4.1.2 Brake Specific Energy Consumption Vs BMEP

Brake Specific fuel Consumption is not very reliable parameter to compare the performance of fuels of different density and calorific value. Therefore, brake specific energy consumption was taken as a parameter to compare the energy requirement for producing unit power in case of different test fuels. The BSEC at different load conditions for test fuels is shown in figure 4.2.

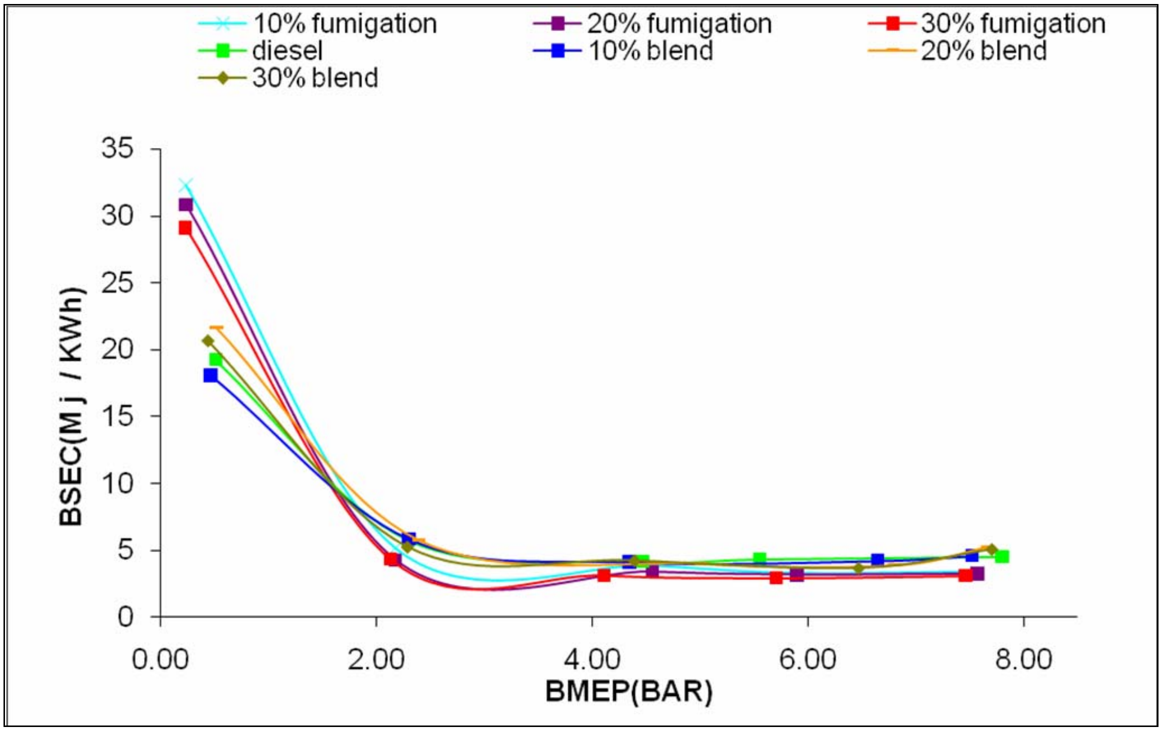


Figure.4.2: Brake Specific Energy Consumption Vs **BMEP**

It is clear from figure 4.2 that for fumigation and blending, brake specific energy consumption is little lower than corresponding diesel. The brake specific energy consumption is inversely proportional to brake thermal efficiency. As already elaborated, brake thermal efficiency increases with ethanol addition in diesel, therefore, brake specific energy consumption reduces with fumigation and blending [23]

.4.1.3. Exhaust Gas Temperature Vs BMEP

Figure 4.3 shows the variation of exhaust gas temperature with brake mean effective pressure for different test fuels.

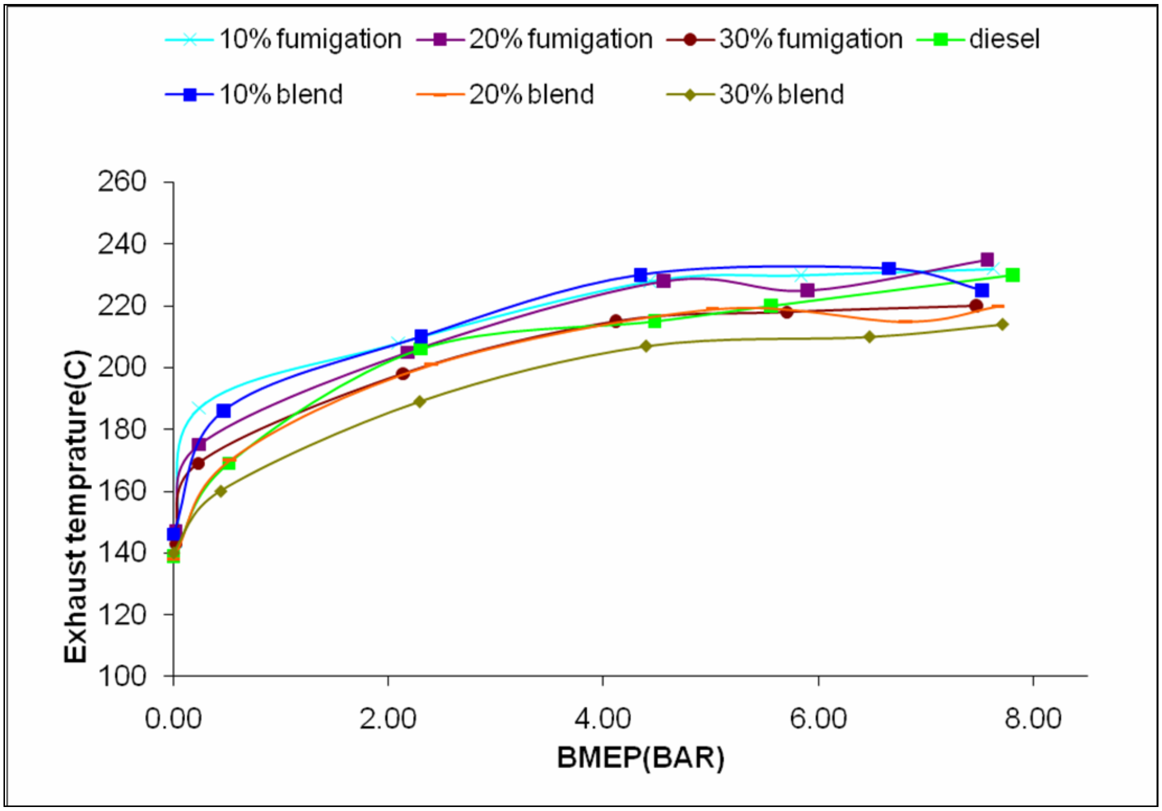


Figure 4.3: Exhaust Gas Temperature Vs BMEP

It is seen that exhaust temperature increases with increasing load for all the fuels. This is due to at more fuel injected at higher load which leads to higher combustion temperature.

It is clear from figure 4.3 that exhaust temperature for 10% ethanol blending and fumigation is same as diesel fuel but as percentage of ethanol increases in ethanol diesel blend, exhaust temperature reduces, and the reduction is higher for ethanol diesel blend. At full load, for 30% of ethanol, exhaust temperature for blend is 214^0C, for fumigation it is 220 ^{0}C and for diesel it is 237 ^{0}C.

At lower percentage of ethanol, inbuilt oxygen content help in combustion and there is lesser effect of ethanol higher latent heat of vaporization, therefore, the exhaust temperature remain same as diesel, but as ethanol substitution increases, a large amount of latent heat absorbed by combustion chamber to evaporate ethanol and thus exhaust temperature decreases.

In fumigation, reduction in exhaust temperature with increasing ethanol percentage is lesser as compared to blend mechanism. The reason for this is that in fumigation a homogeneous ethanol and air mixture enters to the engine which gives better air utilization and gives good combustion then ethanol diesel blend [23.44]

4.2 Emission Characteristics

The emission characteristics of the test engine on blended and fumigated ethanol and diesel are summarized below:

4.2.1 NO_x Emission Vs BMEP

The variations of NO_x emissions for all the test fuels are shown in figure 4.4.

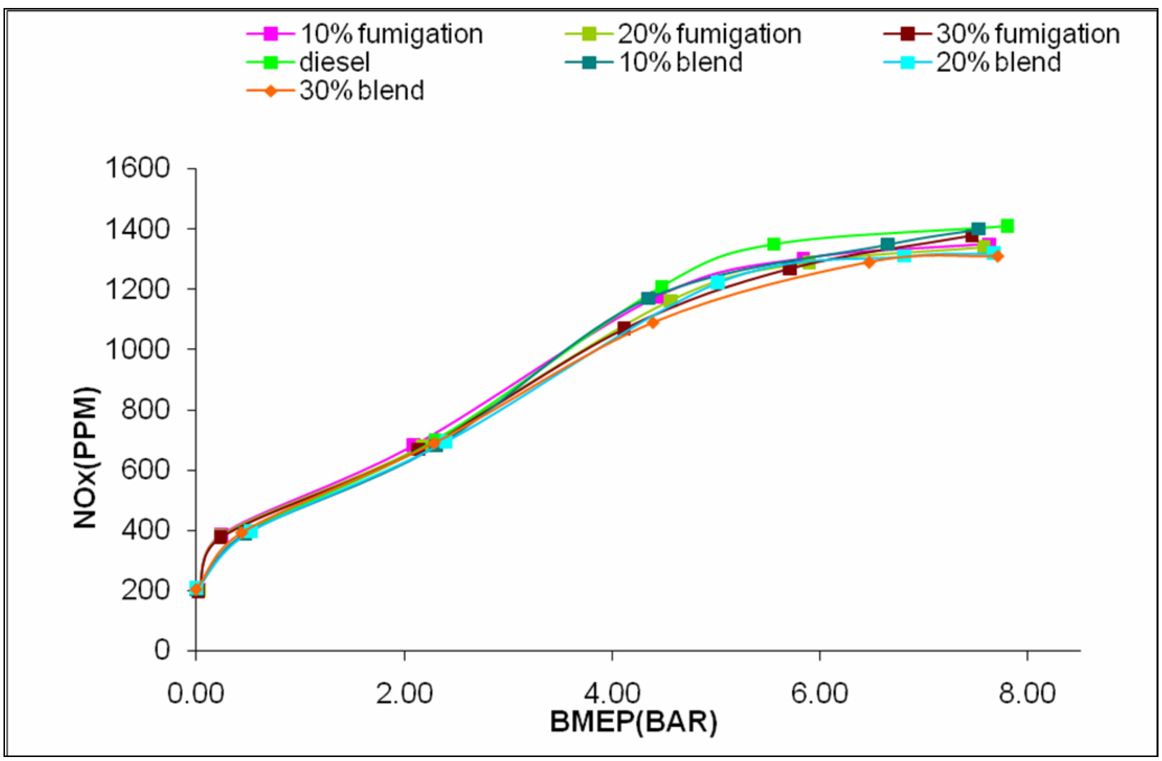


Figure.4.4: NOx Emission vs. BMEP

It is clear from figure that as engine load increases, NO_x emission increases since NO_X formation is a temperature dependent phenomenon and at higher load more fuel will inject in the cylinder this will give higher temperature. And for higher temperature more NOx is produced.

It is evident from figure 4.4 that NO_x emission is maximum (1410 ppm) at full load for diesel and with addition of ethanol in diesel NOx emission decreases. For 30% fumigation, it is 1380 ppm and for 30% blend it is 1310 at full load. As introduction of ethanol in diesel results in combustion temperature to reduce and reduction is higher for blending than fumigation. Therefore, there is less NOx formation in blend as compared to fumigation.

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4.2.2 CO Emission Vs BMEP

Figure 4.5 shows the comparison of the CO emissions for all the fuels at different engine load. As engine load increases, CO emission increases because at higher load the combustion occurs at rich fuel air ratio and for rich mixture CO emission increases due to poor combustion of charge.

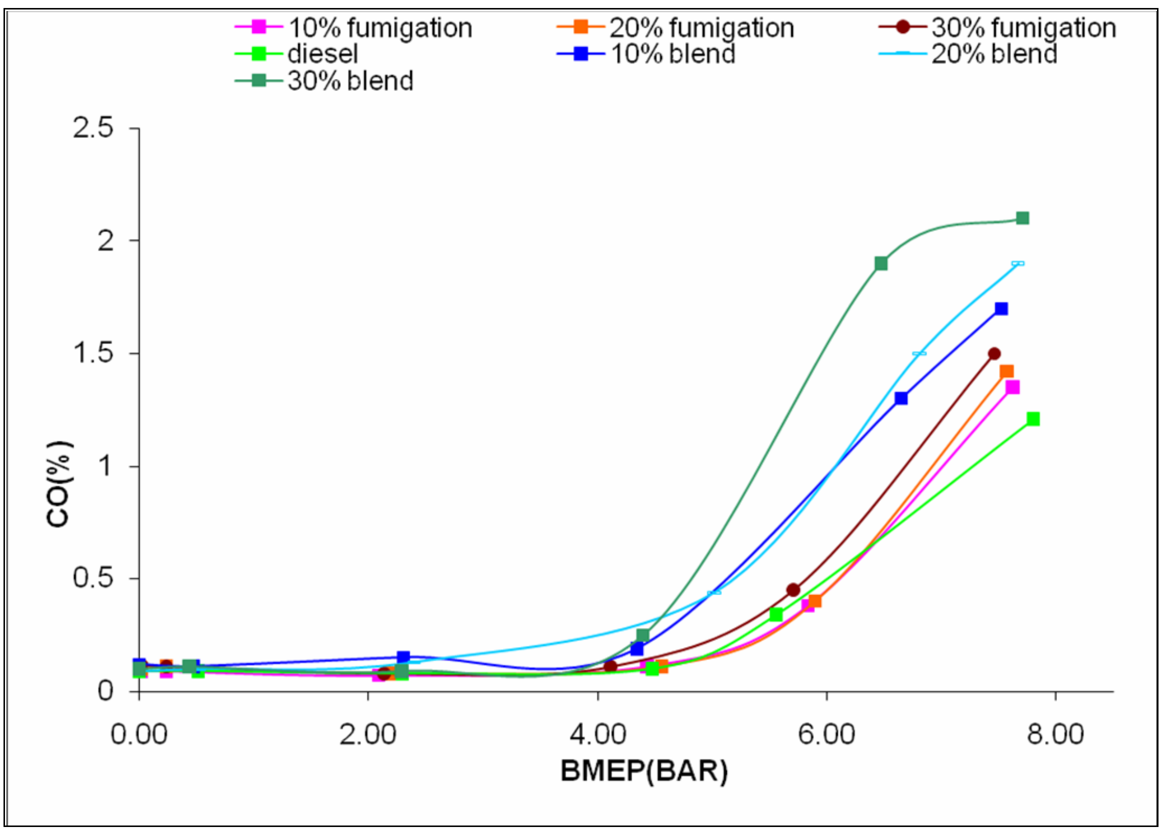

Figure 4.5: CO Emission Vs BMEP

Figs. 4.5 show the effect of ethanol substitution on CO formation. Generally, the CO formation was higher for ethanol based fuels than diesel. The CO emission was always higher when using the blended ethanol than fumigation. For 30% fumigated ethanol, the increase in CO emissions was in the range of 15% at full load, and for 20% blended ethanol, the increase in CO emissions was in the range of 35% at full load

The increase in the CO levels with increasing ethanol substitution is a result of incomplete combustion of the ethanol-air mixture. Factors causing combustion deterioration (such as high latent heats of vaporization) could be responsible for the increased CO production. Combustion temperatures may had a significant effect. A thickened quench layer created by the cooling effect of vaporizing alcohol could have played a major role in the increased CO production. Another reason for the increasing CO production is the increase in ignition delay. This could lead to lower temperatures throughout the cycle. This results in combustion of a proportion of the fuel in the expansion stroke, which lowers temperatures and reduces the CO oxidation reaction rate [23].

The produced emissions of CO from fumigation were lesser than for blends. Combustion temperatures for fumigation may be higher than for blends, better air utilization due to the presence of a homogeneous ethanol charge and lower effect of previous reasons .[23].

4.2.3 HC Emission Vs. BMEP

Figure 4.6 shows the comparison of the HC emissions for all the fuels at different engine load.

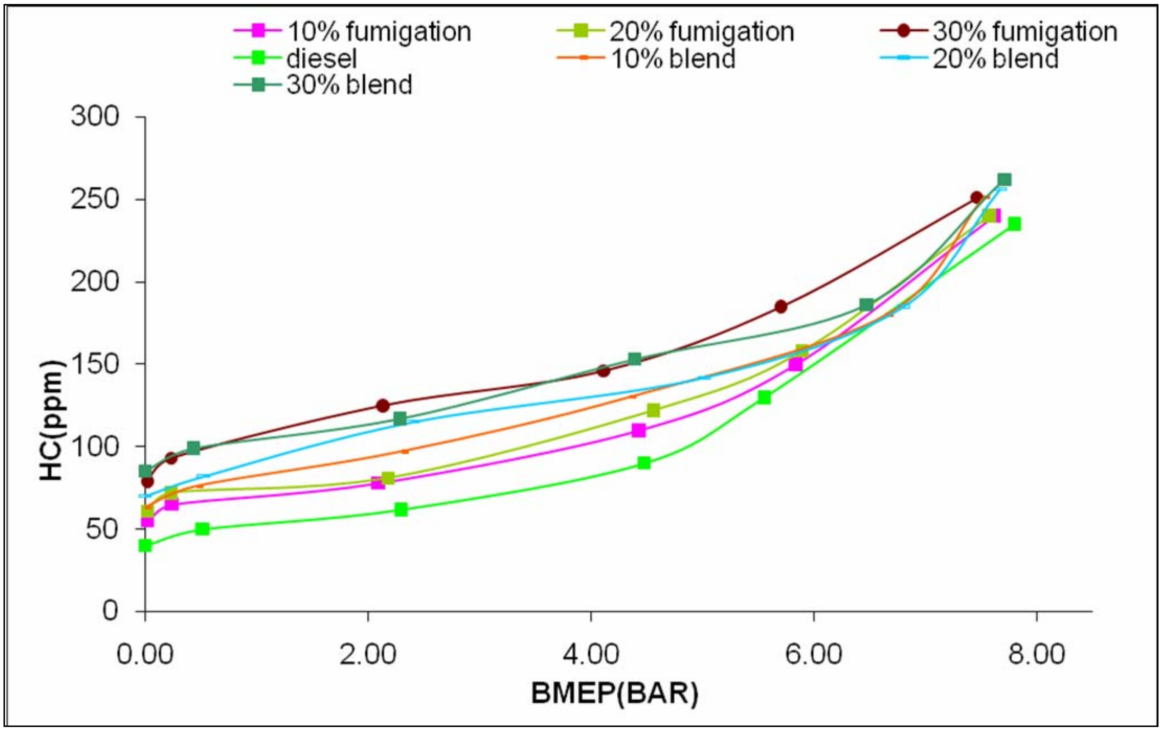

Figure 4.6: HC Emission Vs. BMEP

Figure 4.6 show the effect of ethanol substitution on HC emissions. For 30% fumigated ethanol, the increases in HC emissions were 6% at full, and for 30% blended ethanol, the increases was 11% at full load.

It is noticed that there is a resemblance in the results concerning CO and HC emissions production. The HC emissions tend to increase because of the quench layer of unburned fumigated ethanol present during fumigation and blending. There is no quench layer with diesel fuel injection alone because the combustion is droplet-diffusion-controlled and completely surrounded by air. Also, the high latent heat of vaporization can produce slow vaporization and mixing of fuel and air. These factors result in high HC levels.[23.44]

In fumigation, combustion temperature is higher than ethanol diesel blend which reduce the effect of flame quenching, thus HC emission is lower for fumigation.

4.2.4 Smoke opacity Vs. BMEP

Figure 4.7 shows the smoke opacity for various ethanol based fuels and diesel. For all fuels, smoke opacity increases with load and this is due to the fact that more fuel is supplied and rich mixture is formed at higher loads.

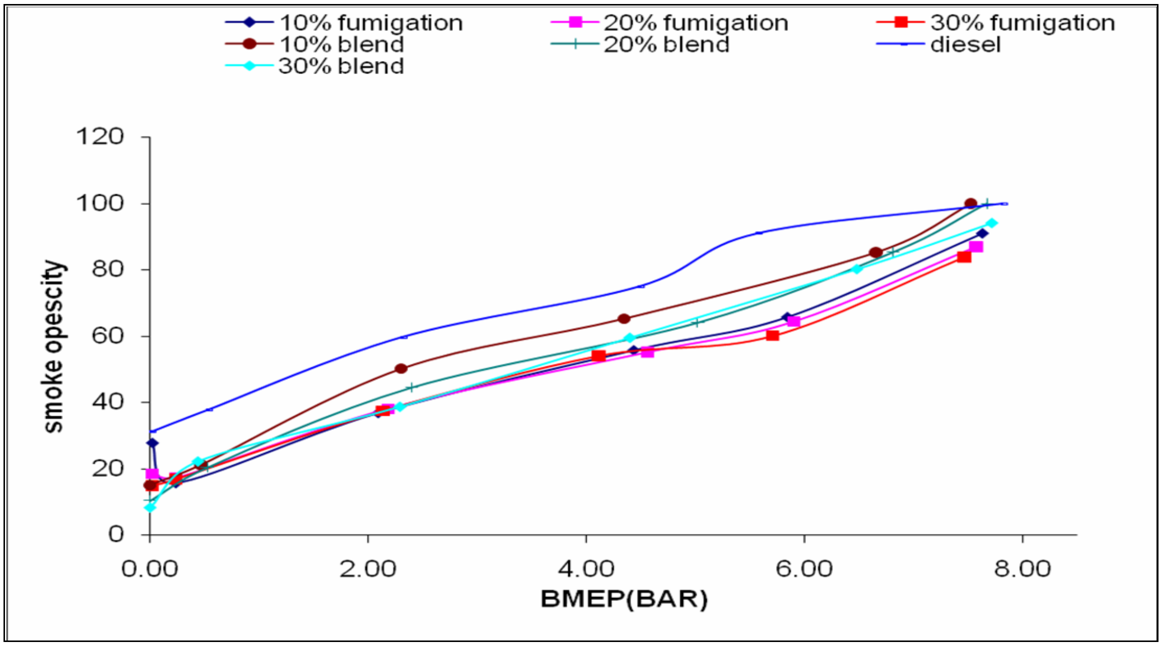

Figure 4.7: Smoke opacity Vs. BMEP

One can observe that the smoke emitted by the ethanol–diesel fuel blends and fumigated ethanol is significantly lower than the corresponding diesel fuel operation. The reduction was found higher for the higher percentage of ethanol either blended or fumigated. This may be attributed to the fact that engine is running ‘leaner’, with the combustion being now assisted by the presence of the fuel-bound oxygen of the ethanol even in locally rich zones. Also, diesel fuel has a high tendency to smoke due to its low H/C ratio and the nature of its combustion process. Using ethanol, either as a blend or as fumigant in a diesel engine, increases the hydrogen content and eventually reduces the engine smoke and leads to a soot free combustion of ethanol under normal diesel engine operating conditions.[23,44]

It is also clear from the figure that for fumigation technique, smoke opacity is lesser than the blend; it may be because in fumigation good combustion occur due to homogeneous mixing of ethanol in air which give good air utilization in combustion process.[23]

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

This work was undertaken to study and compares the effects of ethanol fumigation and ethanol diesel fuel blends on the performance and exhaust emissions of a agriculture diesel engine. Ethanol fumigation was achieved by using a simple carburetor whereas ethanol diesel blend was prepared by inline mixing. 10%, 20%, 30% ethanol was supplemented in diesel in both the techniques. The series of test were conducted using each of the above mentioned ethanol based fuels to test an agriculture diesel engine and performance and emission characteristics were evaluated. The broad conclusions which may be drawn from this study are as follows:

As far as engine performance is concerned, the brake thermal efficiency showed an upward trend and brake specific energy consumption exhibited an downward trend on ethanol substation than diesel fuel operation. This may be mainly due to increase in the ignition delay upon ethanol substitution, so a rapid rate of energy is released which reduces the heat loss from the engine because there is not enough time for this heat to leave the cylinder through heat transfer to the coolant Exhaust temperature, in general, were found lower for ethanol based fuel than diesel as large amount of latent heat absorbed by combustion chamber to evaporate ethanol and thus exhaust temperature decreases.

As far as CO, HC emissions are concerned, they were found to increase with ethanol substitution than diesel operation. The fumigation showed lower increase in these emissions as compared to blending. A thickened quench layer created by the cooling effect of vaporizing alcohol or increase in ignition delay could have played a major role in the increased CO production. The NOx emissions were found lower for ethanol based fuels than the diesel fuel. This may be due to reduction in combustion temperature to reduce due to introduction of ethanol as vaporization of ethanol takes heat from combustion chamber.

The smoke opacity was found lower for blended or fumigated ethanol as the engine is running ‘leaner’, with the combustion being now assisted by the presence of the fuel-bound oxygen of the ethanol even in locally rich zones. Also, diesel fuel has a high tendency to smoke due to its low H/C ratio and the nature of its combustion process

Due to engine durability and knocking concerns, higher percentage of ethanol (beyond 30%) was not used. The future researchers should make modification in diesel engine design so that higher percentage of ethanol could be used and also long term durability of engine with that higher percentage of ethanol should be conducted by future researchers.

REFERENCES:

[1] Demirbas Ayhan "Progress and recent trends in biofuels", Progress in Energy and Combustion Science Vol 33 pp 1–18, 2007

[2] BP Statistical Review of World Energy June 2008, www.finfacts.ie

[3] Ministry of petroleum & natural gas India, www.petroleum.nic.in and petroleum conservation research association India, http://www.pcra.org.

[4] Brazil Institute Special Report April 2007 Issue No. 3, www.wilsoncenter.org/brazil

[5] Ethanol Fact Book by The Clean Fuels Development Coalition, www.cleanfuelsdc.org and organization for Ethanol Producers and Consumers USA, www.ethanolmt.org and world watch institute, Washington, www.worldwatch.org

[6] www.ethanolindia.net

[7] Jai Uppal, "Indian Ethanol Scenario -Opportunities & Challenges" (Winrock International India), April 13, 2006

[8] KC Corkwell, MM Jackson, DT Daly. "Review of exhaust emissions of compression ignition engines operating on E Diesel fuel blends". SAE Paper no. 2003-01-3283; 2003.

[9] Rakopoulos CD, Antonopoulos KA, Rakopoulos DC, Hountalas DT. "Multi-zone modeling of combustion and emissions formation in a DI Diesel engine operating on ethanol–diesel fuel blends". Energy Conversion Management; 49 pp: 625–43, 2008.

[10] E E Ecklund, R L Bechtold, T J Timbario, P W McCallum" State-of-the-art report on the use of alcohols in diesel engines". SAE Paper no. 840118; 1984.

[11] O Durgun and Y Ayvaz" The use of diesel fuel–gasoline blends in diesel engines"; In Proceedings of the first international energy and environment symposium", pp. 9–20, July 29–31, 1996

[12] P Satge´ de Caroa, Z. Mouloungui a, G. Vaitilingomb, J.Ch. Bergec" Interest of combining an additive with diesel–ethanol blends for use in diesel engines", Fuel 80 pp 565–574,2001

[13] P.C Badger, "Ethanol From Cellulose: A General Review." p. 17–21. In: J. Janick and A. Whipkey (eds.), Trends in new crops and new uses. ASHS Press, 2002, Alexandria, VA. Retrieved on September 2, 2007

[14] Alan C. Hansen , Qin Zhang , Peter W.L. Lyne "Ethanol–diesel fuel blends––a review", Bioresource Technology,Vol 96 ,pp 277–285, 15 June 2004

[15] T.M Letcher, 1983. Diesel blends for diesel engines. S. Afr. J. Sci. 79 (1), 4–7.

[16] K.R Gerdes, G.J Suppes, 2001." Miscibility of ethanol in diesel fuels." Ind. Eng. Chem. Res. 40 (3), 949–956.

[17] H.O Hardenberg, A.J Schaefer,1981. "The use of ethanol as a fuel for compression–ignition engines". SAE Technical Paper 811211.

[18] A Brink, C.F.P Jordaan, J.H le Roux, N.H Loubser, "Carburetor corrosion: the effect of alcohol–petrol blends". In: Proceedings of the VII International Symposium on Alcohol Fuels Technology, Paris, France. 1986

[19] de la Harpe, "Ignition-improved ethanol as a diesel tractor fuel". Unpublished MSc. Eng. Thesis, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, South Africa. 1988

[20] Bosch, "VP44 endurance test with E diesel. Internal Report No.00/47/3156, Robert Bosch Corporation, Farmington Hills, MI, USA 2001.

[21] K.E Wrage, C.E., Goering, 1980. "Technical feasibility of diesohol Trans". ASAE 23 (6), 1338–1343.

[22] H. O. Hardenberg, A.J Schaefer, 1981. The use of ethanol as a fuel for compression–ignition engines. SAE Technical Paper 811211

[23] M. Abu-Qudais, O. Haddad, M. Qudaisat" The efect of alcohol fumigation on diesel engine performance and emissions" Energy Conversion & Management Vol 41, pp 389±399,16 May 1999

[24] Manual of Static Mixer, Koflo Corporation, www.koflo.com

[25] Design of a static mixer reactor for copper recovery from waste streams by W.F.C. van Wageningen. Printed by: Optima Gra-sche Communicate Pearl Bookplates 37 3069 BZ Rotterdam.

[26] Lu Xing-cai, Yang Jian-guang, Zhang Wu-gao,” Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with ethanol–diesel blend fuel “.Fuel ,Vol 83 ,pp 2013–2020,15 June 2004

[27] Avinash Kumar “Biofuels (alcohols and biodiesel) applications as fuels for internal combustion”, Progress in Energy and Combustion Science Vol 33 pp 233–271, 2007

[28] TK Hayes, LD Savage, RA White, SC Sorenson. “The effect of fumigation of different ethanol proofs on a turbo- charged diesel engine,” SAE Paper No. 880497, 1988

[30] K Weidmann, H Menard. ,”performance and emissions of diesel engine using different alcohol fuel blends”, SAE Paper No. 841331, 1984

[32] J Czerwinski,” Performance of HD-DI-diesel engine with addition of ethanol and rapeseed oil, SAE Paper No. 940545, 1994

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

[34] Z. Sahin , O. Durgun “ Theoretical investigation of effects of light fuel fumigation ondiesel engine performance and emissions” Energy Conversion and Management 48,pp 1952–1964 ,30 March 2007

[35] D.C. Rakopoulos, C.D. Rakopoulos , E.C. Kakaras, E.G. Giakoum “Effects of ethanol–diesel fuel blends on the performance and exhaustemissions of heavy duty DI diesel engine” Energy 32 1791–1808,2007

[36] Hadi rahimi , Barat Ghobadian , Talal Yusaf , Gholamhasan Najafi , Mahdi Khatamifar ” Diesterol: An environment-friendly IC engine fuel” Renewable Energy 34 (2009) 335–342

[37] Magı´n Lapuerta , Octavio Armas, Jose´ M. Herreros” Emissions from a diesel–bioethanol blend in an automotive diesel engine” Fuel 87 25–31, (2008)

[38] P. Satge´ de Caroa, Z. Mouloungui, G. Vaitilingomb, J.Ch. Berge’’ Interest of combining an additive with diesel–ethanol blends for use in diesel engines’ Fuel 80 (2001) 565–574

[39] X. Shia, Y. Yua, H. Hea, S. Shuaib, J. Wangb, R. Lib "Emission characteristics using methyl soyate–ethanol–diesel fuel blends on a diesel engine" Fuel 84 (2005) 1543–1549
[40] CD Rakopoulos, KA Antonopoulos, DC Rakopoulos. "Experimental heat release analysis and emissions of a HSDI diesel engine fueled with ethanol–diesel fuel blends". Energy 2007;32:1791–808.2000
[41] O. Durgun and Y. Ayvaz" The use of diesel fuel–gasoline blends in diesel engines"; In Proceedings of the first international energy and environment symposium", pp. 9–20, July 29–31, 1996
[42] Yu ksel F and Yu ksel B; "The use of ethanol–gasoline blends as a fuel in a SI engine; Renewable Energy",Vol.29, pp.1181–91, 2004
[43] Hu Chen , Jianxin Wang, Shijin Shuai, Wenmiao Chen," Study of oxygenated biomass fuel blends on a diesel engine" Fuel 87 (2008) 3462–3468
[44] Z. Sahin, O. Durgun ,"theoretical investigation of effect of light fuel fumigation on diesel engine performance and emissions" ,energy conversion and management, Vol 48. pp.1952-1964,(2007)

APPENDIX – I

TECHNICAL SPECIFICATION OF AVL Di-GAS ANALYZER

Measurement principle	CO, HC, CO_2	Infrared measurement
Measurement principle	O_2	Electrochemical
	NO (option)	measurement
Operating temperature	+5 ……. +45º C	Keeping measurement accuracy
	+1 ……. +50ºC	Ready for measurement
	+5 ……. +35º C	with integral NO sensor
		(Peaks of: +40ºC)
Storage temperature	-20 ….. +60º C	
	-20 ….. +50º C	With integrated O_2 sensor
	-10 ….. +45º C	With integrated NO sensor
	0 ….. +50º C	With water in filter and / or
		Pump
Air humidity	90% max., non-condensing	
Power drawn	150 VA	
Dimensions	432 x 230 x 470 mm (w x h x l)	
Weight	16 Kg	

APPENDIX –II

TECHNICAL SPECIFICATION OF AVL 437 SMOKE METER

Accuracy and Reproducibility	:	± 1% full scale reading.
Measuring range	:	0 - 100% capacity in %
		0 - ∞ absorption m^{-1}.
Measurement chamber	:	effective length 0.430 m ± 0.005 m
Heating Time	:	220 V …… approx. 20 min
Light source	:	Halogen bulb 12 V / 5W
Colour temperature	:	3000 K ± 150 K
Detector	:	Selenium photocell dia. 45 mm
		Max. Sensitivity in light,
		In Frequency range: 550 to 570 nm. Below 430 nm and above 680 nm sensitivity is less than 4% related to the maximum sensitivity.
Maximum Smoke Temperature at entrance	:	250ºC

APPENDIX –III

Properties of the Fuels used in the Test

Properties	**Ethanol**	**Diesel**
Formula	C_2H_5OH	$C_{12}H_{26}$—$C_{14}H_{30}$
Molecular weight	46.07	170–198
Boiling temperature (°C)	78.3	190–280
Density (kg/m^3, at 20°C)	811.5	820–845
Flash point (°C)	13	52
Auto ignition temperature (°C)	425	300–340
heating value (MJ/kg)	30	42.2
Cetane number	>15	50>
Vapor pressure (kPa, at 38 °C)	17	0.34
Stoichiometric air–fuel ratio	8.96	14.7
Latent heat ((kJ/kg)	854	301