Major Project –II

"SOME EXPERIMENTAL STUDIES ON USE OF ALTERNATIVE FUELS IN A DUAL FUEL ENGINE"

Submitted to **Delhi Technological University** in partial fulfillment of the requirement for the award of the Degree of

Master of Technology

In

Thermal Engineering

By

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DECLARATION

I, hereby declare that the work embodied in the dissertation entitled **"SOME EXPERIMENTAL STUDIES ON USE OF ALTERNATIVE FUELS IN A DUAL FUEL ENGINE"** in partial fulfillment for the award of degree of MASTER of TECHNOLOGY in "THERMAL ENGINEERING", is an original piece of work carried out by me under the supervision of Prof. Naveen Kumar, Mechanical Engineering Department, Delhi Technological University. The matter of this work either full or in part have not been submitted to any other institution or University for the award of any other Diploma or Degree or any other purpose what so ever.

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CERTIFICATE

This is to certify that the work embodied in the dissertation entitled **"SOME EXPERIMENTAL STUDIES ON USE OF ALTERNATIVE FUELS IN A DUAL FUEL ENGINE"** by **ASHISH KUMAR SINGH, (**Roll No.-**2K13/THE/07)** in partial fulfillment of requirements for the award of **Degree of Master of Technology in Thermal Engineering**, is an authentic record of student's own work carried by him under my supervision.

This is also certified that this work has not been submitted to any other Institute or University for the award of any other diploma or degree.

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ABSTRACT

Rapid depletion of fossil fuels is urgently demanding an extensive research work to find out the viable alternative fuel for meeting sustainable energy demand without any environmental impact. In the future, our energy systems will need to be renewable, sustainable, efficient, cost-effective, convenient and safe. Therefore, researchers has shown interest towards alternative fuels like vegetable oils, alcohols, LPG, CNG, Producer gas, biogas in order to substitute conventional fuel i.e. diesel used in compression ignition (CI) engine. However, studies have suggested that trans-esterified vegetable oils retain quite similar physico-chemical properties comparable to diesel. Besides having several advantages, its use is restricted due to higher emissions i.e. NOx, CO, HC and deposits due to improper combustion. Hence, there is a need of cleaner fuel for diesel engines for the forthcoming stringent emissions norms and the fossil depletion. In the current exhaustive investigation CNG is used with Jatropha oil methyl ester (JOME) in a dual fuel mode for complete combustion of charge present inside the combustion chamber, and for the reduction of emissions associated with CI engines. For that CNG is fed to engine along with air through inlet manifold during the suction stroke. In order to initiate the combustion of CNG charge a small pilot injection of Various blends of JOME (Viz. JOME25, JOME50, JOME75 and JOME) is injected during the end of compression stroke, which have high volatility with low auto ignition temperature. The engine trials were conducted on a stationary air cooled constant speed agricultural direct injection diesel engine by increasing load from 0-100%.The effects of the pilot charge on various performance and emission characteristics were evaluated on all range of load. While comparing the results with diesel an increment in Brake Thermal Efficiency (BTE) and reduction in the emissions i.e. CO, HC, smoke were found with the dual fuel mode of CNG-JOME in CI engine.

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NOMENCLATURE

A/F	Air to Fuel
JOME	Jatropha oil Methyl Ester
AVL-437	AVL-437 Smoke Meter
JOME25	Diesel 75% + JOME 25%
JOME50	Diesel 50% + JOME50%
JOME75	Diesel 25% + JOME 75%
BMEP	Break Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
BTDC	Before Top Dead Center
Cc	Cubic centimetre
CFCs	Chloro Fluoro Carbons
FY	Financial Year
GDP	Gross Domestic Product
CI	Compression Ignition
CN	Cetane Number
LPG	Liquefied Petroleum Gas
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon Dioxide
cSt	Centi Stoke
CV	Calorific Value
DI	Direct Injection

DF	Diesel fuel
g	Gram
g/cc	Gram per cubic centimetre
HC	Hydrocarbon
HP	Horse Power
IC	Internal Combustion
IDI	Indirect Injection
IS	Indian standard
Kgoe	Kilogram of oil equivaleant
LPM	Liter per Minute
Min.	Minute
ml	Milliliter
mm	Millimeter
Mt	Million Tonnes
Mtoe	Million Tonne of Oil Equivalent
NO	Nitric Oxide
No.	Numbers
NO_2	Nitrogen Di-oxide
NO_x	Oxides of Nitrogen
PM	Particulate Matter
ppm	Parts per million
rpm	Revolutions Per Minute
sfc	Specific Fuel Consumption
TDC	Top Dead Center
HC	Hydrocarbon

v/v	Volume/ Volume
ρ	Density
%	Percent

CHAPTER 1

INTRODUCTION

1.0 ENERGY CRISIS

Abundant and economical energy is the life blood of modern civilizations. Adequate availability of inexpensive energy is the most important demand of today. Economic growth and industrialization both are dependent on the availability of energy. Many of the developed Western-European countries as well as developing countries depends a great extent on imports of energy resources to meet the bulk of their requirements. Globalization and rapid economic growth has resulted in exhaustive use of energy resources worldwide. [1-3].

Inexpensive and seemingly abundant non-renewable energy drove the twentieth century economy, but looking at the twenty first century, it seems that cleaner and greener form of energy in complete congruence with environment are the only hope for a sustainable future. In this context, the gulf crisis was an eye opener for both developed and developing countries and it was then for the first time the world seriously started looking for alternative source of energy along with efficient utilization. The recent volatility in petroleum prices and the growing awareness related to the clean environment have stimulated the recent interest in alternative energy sources [4].

As far as India is concern the situation is not much different from other developing countries. With a humongous population, rapid economic growth and huge potential for massive upward swing in energy intensive sectors such as industry, infrastructure, transportation etc. the resurgent India is consuming more energy than it consumed in its entire course of existence. Amongst various energy intensive sectors, transport, agriculture and decentralized power etc. are the matter of concern. The common denominators in all these sectors in India are characterized by the popular diesel engines. India does not have large oil reserves and relies on imported crude oil to fuel its domestic demands of petroleum diesel. On account of fluctuating international crude oil prices, increasing oil imports and the consequent widening in trade deficit, there is an urgent need to substitute mineral diesel by locally available alternative and renewable fuels. [5].

In the light of the above fact, scientists around the world have explored several alternative energy resources, which have the potential to quench the ever-increasing energy thirst as well as hazardous emissions of the contemporary human civilizations. In this context, various bio-origin fuels such as biomass, biogas, primary alcohols, vegetable oils, etc are seriously evaluated as potential renewable substitutes for mineral diesel in various capacities [6].

1.1 ENERGY SCENARIO

World is naturally anxious to think about future, because knowing the bitter truth that a day will ultimately come when no more coal or oil will available. It will mean energy crisis. People who have made careful calculation feel that at present level of exploitation, the worldwide coal deposits will last till 2080 and it is also true that poor quality coal with the carbon content of 40 percent only is not conducive for electricity generation [7].

As already discussed, energy is one of the most important factors concerned for socio-economic development of any country. Many developing countries are not able to fulfill their energy demand from the resources available in their own country and have to depend on other countries for accomplishing it.

Supply and use to fuel economic development at present,' energy poverty' hinders the economic and social development of very large numbers of people.

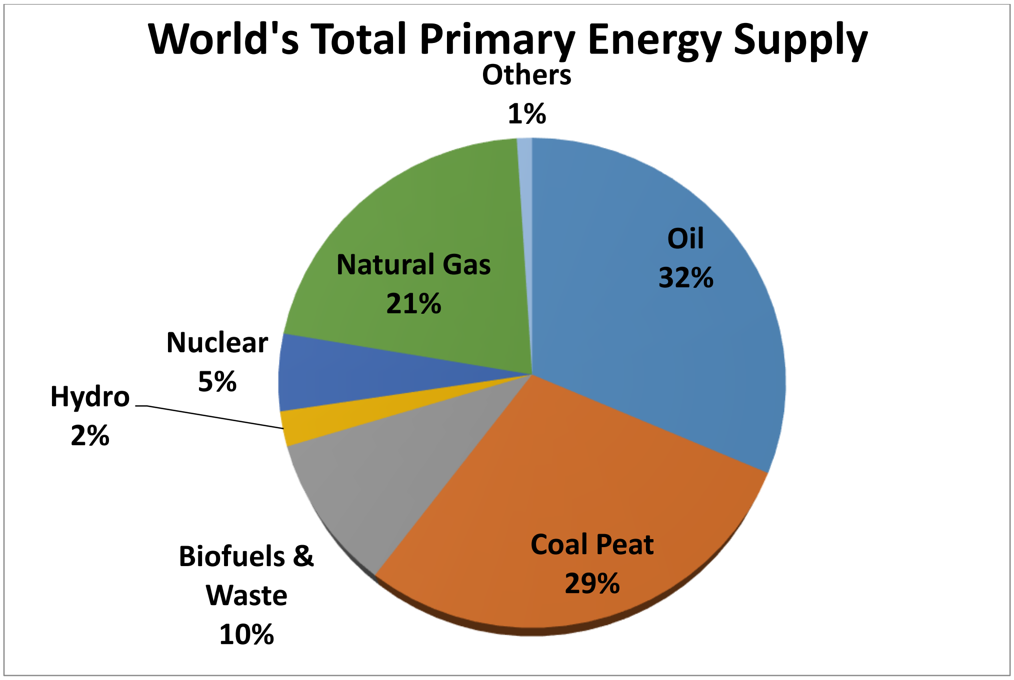

Figure 1.1: Worlds total primary energy supply (13 113 Mtoe) [1].

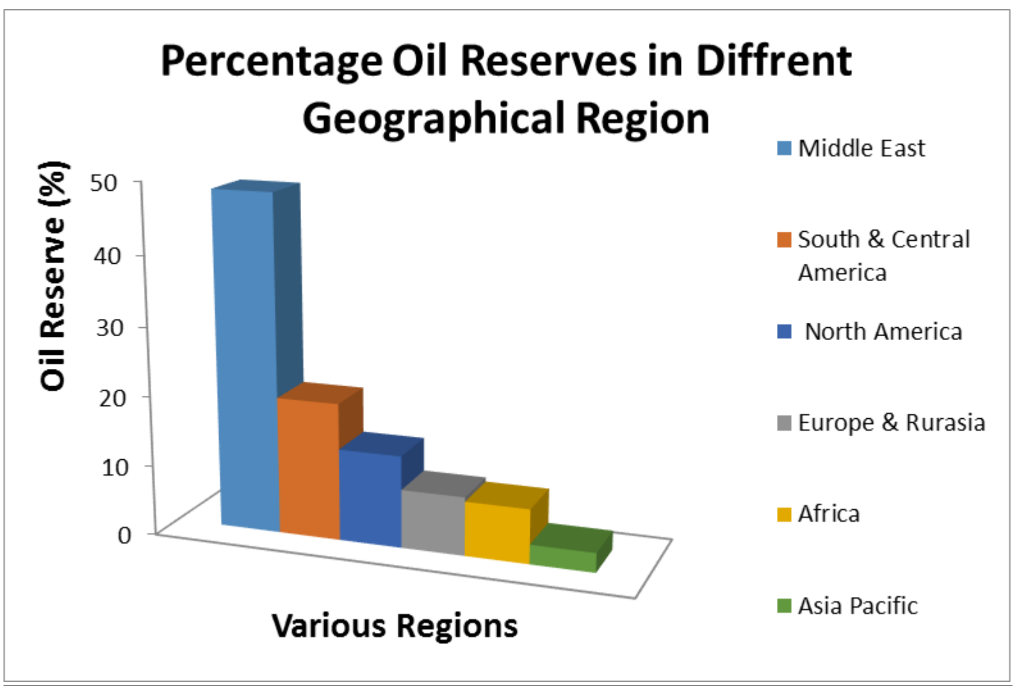

Figure 1.2: Oil reserves in different geographical regions (1668.9 thousands million barrels) [1].

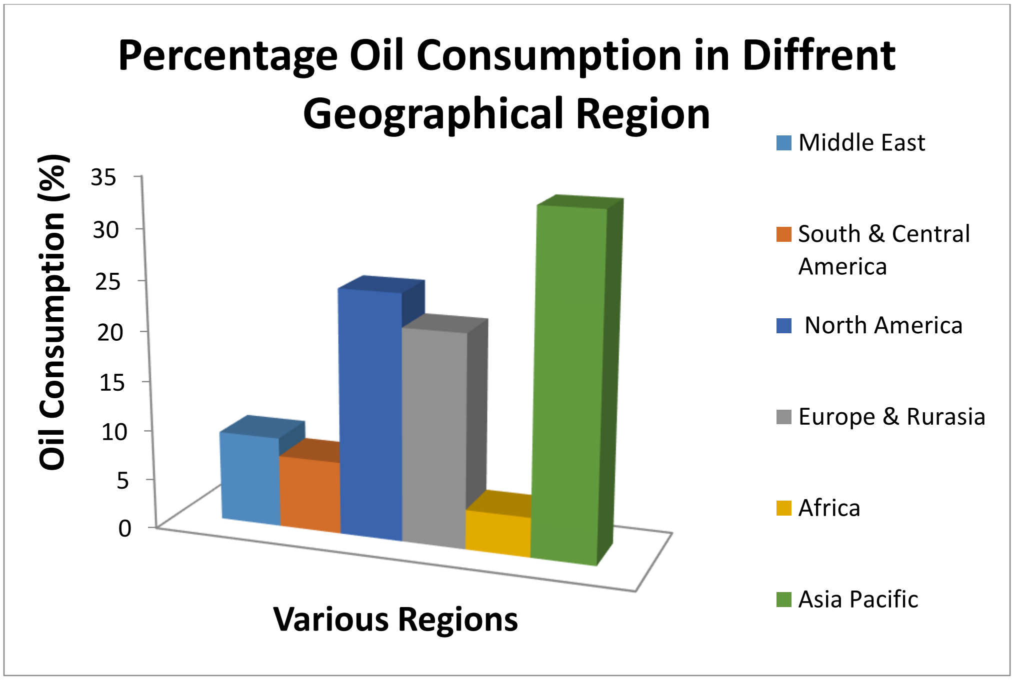

Figure 1.3: Oil Consumption in different geographical regions (89774 thousand barrels) [1].

1.2 FUTURE ENERGY OUTLOOK

For instance, energy consumption is a vital component in economic growth, and hence it may adversely affect real GDP (Gross Domestic Product). However, a unidirectional causality running from economic growth to energy consumption signifies a less energy dependent economy, so energy conservation policies may be implemented with little or no adverse effect on economic growth [8].

For better economic growth, the major challenges on the rate of energy consumption are industrial and transportation sector. These sectors have been allocated a remarkable proportion of their energy consumption in the form of petroleum products; especially by the developing countries. Globally, transportation is the second largest energy consuming sector after the industrial sector and accounts 26% of the world's total delivered energy. Since, this sector has experienced steady growth in the past 30 years, it is believed that it is currently responsible for nearly 60% of total world oil demand and will be the strongest growing energy demand sector in the future [9].

Between 2006 and 2030, around three quarters of the projected increase in oil demand is expected to come from the transportation sector [10, 11]. On top of that, transportation sector is responsible for a large and growing share of emissions that affects global climate change [12]. So, the energy conservation and emissions are the rising concerns for a large number of countries around the world. Therefore, from last two decades automotive manufacturers are trying to find ways to reduce pollutant emissions and improve fuel conversion efficiency of internal combustion engines. As these engines are basic need for the transportation, so the emissions that come out from the engines are point of concern.

Hence, in the development of transport sector, diesel engines occupy a very important position due to their high thermal efficiency and high power to weight ratio. However, in recent time's diesel engine powered vehicles have come under heavy attack due to various problems created by them and air pollution being the most serious of these problems. Air pollution can be defined as addition of any material to our atmosphere which will have a deleterious effect on life upon our planet [13]. The main pollutants contributed by automobiles are carbon monoxide (CO), unburned hydrocarbons (UBHC), oxides of nitrogen (NOx), smoke, and particulate matter (PM). Researchers all over the world have evaluated the health risks associated with the exposure to automobile emissions [14-16].

At the same time when it comes to energy security, resources are used to generate energy; their scarcity and the rising impact of those resources on the global environment have made energy conservation a top agenda on the tables of high government officials around the world. Global demand for transportation appears unlikely to decrease in the fore seeable future as the World Energy Outlook projects that it will grow 40% by 2035 [9]. Therefore, in order to minimize the oil consumption and emissions from transportation sector, the policy makers are seeking for the improved vehicle efficiency along with limiting the emissions by promoting the development of alternative fuels.

As already discussed, transportation sector mainly depends on the diesel engines due to their high thermal efficiency and high torque at low rpm. Hence, for the reduction in the oil consumption, various researchers are gearing towards the implementation of fuels which can substitute diesel without major engine modifications or significant emission increments while sustaining the desired petroleum demand. Such kinds of fuels mainly include the vegetable oil and the other oil emulsions like ethanol-diesel and diesel water emulsion. These new technologies are mainly developed in pursuit of fuels having low emissions.

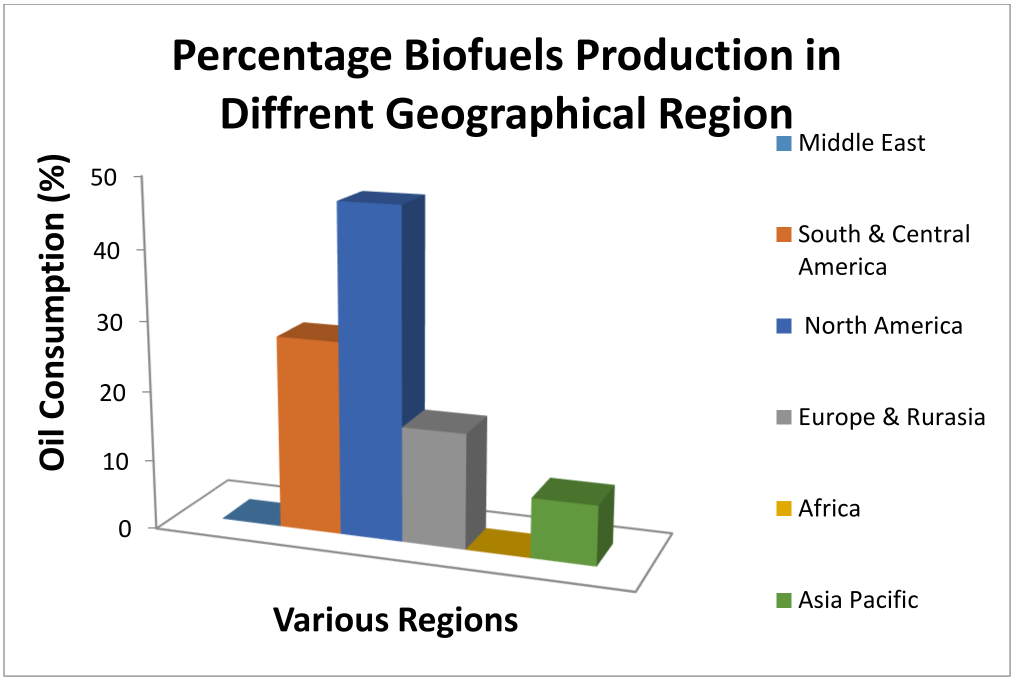

Figure 1.4: Biofuel Production in different geographical regions (60220 Thousand tonnes oil equivalent) [1].

1.3 ENVIROMENTAL DEGRADATION AND ITS GLOBAL EFFECT

The global energy requirements and environmental degradation due to accelerated use of fossil fuels have raised significant concerns worldwide. Current patterns of production and consumption of both fossil fuels and food are draining freshwater supplies; triggering losses of economically-important ecosystems such as forests; intensifying disease and death rates and raising levels of pollution to unsustainable levels. The in-efficient use of energy has strained the global environment to its limits as it can be seen from the unprecedented and hostile responses of the nature in the recent few years. Greenhouse effect, global warming, acid rain, smog, deforestation, shift in climatic conditions etc. are some of the indications of over usage of fossil fuels which seriously affect nature.

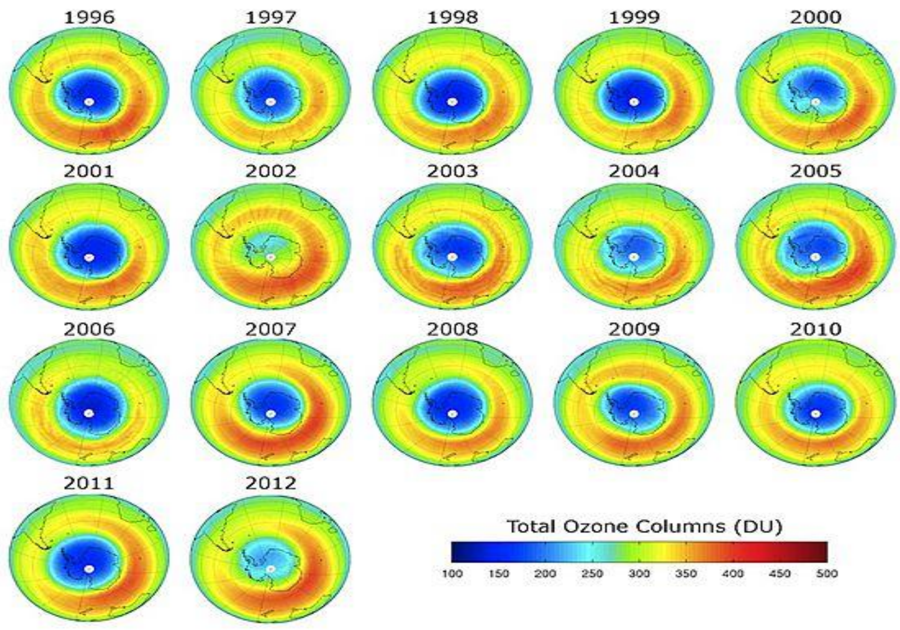

Figure 1.5: Ozone layer depletions over Antarctica from 1996 to 2012.

The ozone layer is a layer in Earth's atmosphere which contains relatively high concentrations of ozone (O_3). The distribution of ozone in the stratosphere is a function of altitude, latitude and season. It is determined by photochemical and transport processes. The ozone layer is located between 10 and 50 km above the Earth's surface and contains 90% of all stratospheric ozone, though the thickness varies seasonally and geographically. This layer absorbs 97–99% of the Sun's high frequency ultraviolet light, which potentially damages the life forms on Earth. Measurements carried out in the Antarctic have shown that at certain times, more than 95% of the ozone concentrations found at altitudes of between 15 - 20 km and more than 50% of total ozone are destroyed. The ozone layer can be depleted by free radical catalysts, including nitric oxide (NO), nitrous oxide (N_2O), hydroxyl (OH), atomic chlorine (Cl), and atomic bromine (Br) [17, 18].

The main potential consequences of this ozone depletion are:

- Increase in UV-B radiation at ground level: a one percent loss of ozone leads to a two percent increase in UV radiation. Continuous exposure to UV radiation affects humans, animals and plants, and can lead to skin problems (ageing, cancer), depression of the immune system, and corneal cataracts (an eye disease that often leads to blindness). Increased UV radiation may also lead to a massive die-off of photoplankton (a CO_2 "sink") and therefore to increased global warming.

- Disturbance of the thermal structure of the atmosphere, probably resulting in changes in atmospheric circulation.
- Reduction of the ozone greenhouse effect: ozone is considered to be a greenhouse gas. A depleted ozone layer may partially dampen the greenhouse effect. Therefore efforts to tackle ozone depletion may result in increased global warming.

Changes in the tropospheric ozone and in the oxidizing capacity of the troposphere [18].

Usage to renewable fuels and strict government regulations and global policies has certainly reduced the depletion of ozone layer. A study has revealed that Antarctica ozone levels have already recovered by an amount of 15% since the late 1990s [18].

1.4 GLOBAL WARMING

Global Warming effects on the natural balance of environment. Global Warming is the increase of Earth's average surface temperature due to effect of greenhouse gases, such as carbon dioxide emissions from burning of fossil fuels or from deforestation, which trap heat that would otherwise escape from earth.

There are many causes of Global Warming. The destruction and burning down of tropical forests, traffic clogging up the city streets , rapid growth of unplanned industries, the use of CFCs in packaging and manufacturing products, the use of detergents etc. cause Global Warming.

Besides all theses, overpopulation, deforestation are the causative factors of Global Warming. The setting up of mills and factories in an unplanned way has a great effect on environment. These mills and factories produce black smoke which gets mixed with air and increases the amount of CO_2 [19].

For last few decades, it effect has increased mainly due to industrialization and modernization. From the three main greenhouse gases liberated in the atmosphere i.e. CO_2, NO_X and methane; CO_2 is produced in abundance and it plays a major role in causing global warming [20].

Raising sea levels, glacier retreat, Arctic shrinkage, and altered patterns of agriculture are cited as direct consequences, but predictions for secondary and regional effects include extreme weather events, an expansion of tropical diseases, changes in the timing of seasonal patterns in ecosystems, and drastic economic impact. Concerns have led to political activism advocating proposals to mitigate, eliminate, or adapt to it [20, 21].

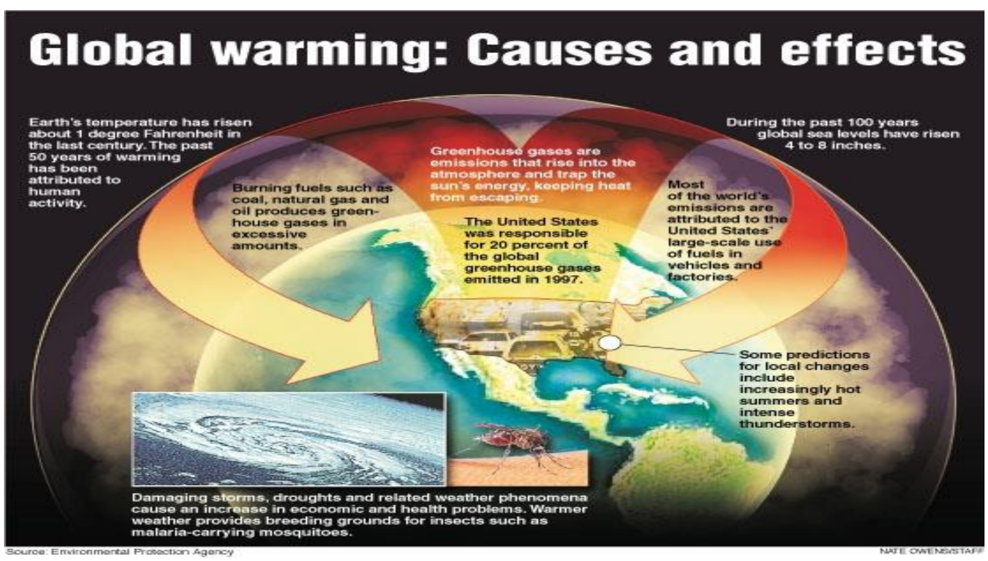

Figure 1.6: Cause and its effect of global warming.

Although, being a greenhouse gas CO_2 has adverse effects on environment these are the possible consequences of global warming. The greenhouse effect refers to the interaction between the Earth’s atmosphere and surface to absorb, transfer, and emit energy as heat, cycling it through the atmosphere and back to the surface. The natural greenhouse effect is necessary for life as it exists on Earth today [22].

1.5 DIESEL ENGINE AND INDIAN ECONOMY

Diesel Engine plays a crucial role in Indian economybut also contributes to pollution significantly. During April-May 2014, diesel consumption grew 5.9% compared to period 2013. The overall diesel consumption growth for 2013-14 was 6.8%, compared to 7.8% during 2012-13 [23].

According to the data provided by the Petroleum Planning and Analysis Cell, petrol consumption in India in April-January this fiscal was 12.35 million tonnes. India is expected to end up consuming 14.82 million tonnes of petrol in the year, registering growth of 4.41% in FY14. Consumption of diesel is expected to be 63.91 million tonnes, registering growth of 6.4% [24].

The diesel engine is typically more efficient than the gasoline engine due to higher compression ratio. Diesel engines also do not suffer from size and power limitations, which the SI engine is prone to. In India, diesel engines are used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment etc. The dual problem of fast depletion of petroleum based fuels and air pollution can be judiously handled by switching from fossil fuel based economy to renewable source of energy.

Indian economy is agriculture based economy and agriculture is an energy transformation process as energy is produced and consumed in it. The production of energy is carried through process of photosynthesis in which solar energy is converted into biomass. Agriculture in India is heavily based upon petroleum and its derived products such as fertilizers and pesticides. Energy sources used in agriculture are oil and electricity whereas indirect energy sources are chemical fertilizers and pesticides.

Oil and electricity are two major fuels which are used in agriculture sector. Because of mechanized farming the amount of energy consumed has increased multifold since independence in terms of oil and electricity.

1.6 STRATEGY FOR FUEL SECURITY AND SUSTAINABILITY

The security of fuels availability as energy carrier should be maintained and becomes a priority goal both for short and long term. The indicators for fuel security have evolved not only a physical availability of fuel but also considering various aspects [25]. Concern on environmental deterioration and climate change has driven to formulate stringent emissions legislations. Therefore, acceptability of fuel combustion to meet the emission legislations was also taken into consideration. The globally uneven of oil reserves and consumption, Middle East countries have 62% of the global oil reserves while the OECD (Organisation for Economic Co-operation and Development) countries only have 9% but consume 50% of global oil, has put accessibility as another indicator for fuel security [26].

The discussion in this section will focus on the use of gaseous and alternative liquid fuels as diversification of fuel for transport sector in dual fuel engine mode. Dual fuelled engine and the use of alternative fuels principally are means to simultaneously reduce fossil fuel consumption, thus keeping the fuel security, and air pollution or greenhouse gases [25,27].

1.7 FUELS UTILISATION

1.7.1. BIOGAS

Biogas, a combustible gaseous fuel, is produced by anaerobic fermentation of organic matter by a consortium of microorganism. Biogas can be made from organic residue of agriculture, and by-product of ethanol or biodiesel production. It also can be made from animal manure, and many wastewaters containing organic compounds such as food processing and industrial and municipal wastewater [28]. The production process is possible if there is lack of oxygen in all natural environments. The process involves three stages; hydrolysis, acid formation, and methane fermentation. Biogas is principally a mixture of methane (CH_4) and carbon dioxide (CO_2) along with other trace gases [28-29]. In addition, the contents and quantities of biogas produced (from digester) heavily depend on the feed stocks and the process conditions such as water content, temperature, pH etc. [29].

1.7.2. LIQUEFIED PETROLEUM GAS (LPG)

LPG refers to a group of hydrocarbon-based gases obtained mostly from gas wells and by-product of crude oil refining processes. The predominant constituents of LPG are mainly butane and propane [30]. In cold countries propane is the most abundant component of LPG in order to provide adequate vapour pressure in winter, whilst in the warmer countries butane has higher percentage [31].

The emissions of LPG-driven vehicles are low and LPG is commercially available in most places. It has been proven that LPG-operated vehicles have benefit in reducing emissions compared to that of gasoline. A decrease in main emissions such as HC, CO, NO_X, PM and CO_2 is obtained mainly due to high hydrogen-carbon ratio and no aromatic hydrocarbons of LPG [30].

1.7.3. HYDROGEN

The decrease of primary energy sources (i.e. fossil fuels), the pollutant emissions associated to the combustion of fossil fuel, and the need to maintain the energy supply security has encouraged the use of hydrogen as one of the alternative fuels both for transportation and powertrains systems [25].

Apart from motor vehicles can run well with hydrogen, the hydrogen emission benefits (no presence of carbon) and its inherent benefits such as high calorific value in terms of mass, wide flammability limits, and flame propagation speed allows better efficiency improvement favoring its application in automotive [32].

It has been shown that hydrogen is a good substitute fuel for gasoline as hydrogen has high octane number. Therefore, it can resist knock under SI engine operation [33]. It also offers other advantages such as low pollution, controllability and safety. Hydrogen-fuelled vehicles can operate at low equivalence ratio as hydrogen is able to burn at lean mixture allowing stability combustion at lean operation. However, at high engine load the hydrogen-fuelled internal combustion engine has a possibility to produce NO_X [14]. Other issue that may arise is premature ignition and backfire which can cause engine knocking [25, 32, 33].

Hydrogen has high mass specific LHV (lower heating value) compared to other gaseous fuel (such as methane) or liquid fuel. For stoichiometric combustion, hydrogen requires high mass of combustion air. It requires an air-hydrogen ratio of about 34:1 by mass for complete combustion which is much higher than that of gasoline which has air-fuel ratio about 14.6 [33].

1.7.4. NATURAL GAS

Natural Gas (NG) has been found in various locations in oil and gas bearing sands strata located at different depths below the earth surface [34]. It has been recognized as one of the promising alternative fuels due to its significant benefits compared to gasoline fuel and diesel fuel. These include reduced fuel cost, cleaner exhaust gas emissions and higher octane number. Therefore, the numbers of engine vehicles powered by NG were growing rapidly [35-36]. NG is safer than gasoline in many respects [35]. The ignition temperature of NG is higher than gasoline fuel and diesel fuel. Advanced NG engines undertake significant advantages over the conventional gasoline engine and diesel engine [37]. However, the investigation of applying NG as an alternative fuel in engines will be a beneficial activity, because the liquid fossil fuels will be finished and will become scarce and expensive [38]. It is a cleaner fuel than either gasoline or diesel as far as emissions are concerned. NG is considered to be an environmentally clean alternative to those fuels [35, 37-38]. Advantages of NG as a fuel its octane numbers are extraordinarily suitable for spark ignition (SI) engines. NG engine can be operated in high compression ratio [38].

1.7.5. BIOFUELS

Biodiesel is one of the alternative fuels that have been gaining a growing interest which is produced from renewable sources such as waste cooking oils, animal fats, and vegetable oils [39]. However, due to low cost of diesel and gasoline the utilisation of biodiesel for motor vehicles decreases. As the global crude oil price increases due to its gradually declining sources and the concern for the environmental problem, the attention for its utilisation arise again. In addition, the main raw materials for biodiesel production are abundant, biodegradable and relatively easy to find and hence can reduce the dependency on petroleum [39-40].

Biodiesel, as an alternative fuel, has relatively similar properties to diesel fuel and it can be used in most diesel engines (neat or as an additive) without any significant engine modifications while at the same time can substantially reduce engine-out emissions such as HC and CO [40]. Apart from its oxygen content it also contains virtually no sulphur and free aromatics thus emit low PM. As additive, the more biodiesel content in the fuel blend the more emission advantages. It is also a nontoxic and biodegradable fuel and hence minimizing the risk to environment and ground water [39-41]. Because of all the advantages biodiesel has been used widely as a vehicular fuel. However, biodiesel has some limitations which need to be addressed. Some major properties that can affect the engine performance and emissions are higher viscosity, less favorable cold flow properties, and lower heating value and volatility. In addition, its high bulk modulus of compressibility can lead to the advanced fuel injection timing which can increase NO_X emissions [41]. The lower heating value results in an increase in fuel consumption while its cold flow property results in difficulty to start the engine in cold weather. However, its high viscosity improves engine lubricity thus can lengthen the engine life [37, 41]. In addition, it is suggested that the combination of biodiesel and gaseous fuels with their specific characteristics in dual fuel engine may become a solution for dual fuelling system to overcome the emission issues [42].

Biodiesel can be produced through transesterification which aims to reduce the viscosity, improve cold flow properties and cetane number of the raw material. In this process ethanol and methanol are usually used due to their relatively low price, and chemical and physical advantages [40].

1.8 ENGINE TECHNOLOGY THROUGH DUAL FUEL SYSTEM

The utilisation of gaseous fuel and diesel-like fuel at the same time is called dual fuel engine. Driven by the fossil fuel depletion, the utilisation of gaseous fuel in IC engines has got more positive response as a possible method and at the same time can reduce engine emissions [43]. In addition, dual fuel operating strategy has economic benefits because various alternative fuels can be used which typically has lower cost than that of conventional fossil fuel and requires no major hardware modifications. It also can be operated on any combinations of gaseous and liquid fuel.

Dual fuelled engine concept combines the type of combustion CI engines and SI engines. The admission of gaseous fuels can be performed in several ways such as carburetion, intake manifold injection, intake port injection, and direct in-cylinder injection [44]. With this engine mode the air intake and gaseous fuel is mixed together then is compressed like in a diesel engine. This mixture cannot auto-ignite because its low cetane number therefore a small amount of injected diesel fuel at the end of the compression phase (called pilot fuel) is required to ignite the mixture [45].

The use of different fuels with different flammability limits, both liquid and gaseous fuel is a benefit to get better engine-out emissions and performance if appropriate conditions suit for their mixing and combustion [44-45].

In dual fuel combustion the amount of heat released is associated to the concentration and type of gaseous fuels. Heat released in the combustion chamber can be divided in three phases. Firstly, the premixed combustion of pilot fuel and part of gaseous fuel-air mixture. Secondly, the combustion of gaseous-air mixture close to the pilot fuel sprays zone and diffusive burning of pilot fuel. Thirdly, gaseous fuel-air mixture combustion dues to flame propagation from spray zone [33, 44].

From some strategies applied to introduce gaseous fuels into the cylinder the fumigation of gaseous fuel in the intake manifold to mix with the intake air is the basic way of gaseous fuels induction. This is a simple method and preferable for the engine which does not have electronically controlled unit for diesel injection [40]. For stable engine running conditions the dual fuel system is operated at part load condition while at idle and full engine load the engine is operated under normal condition (100% diesel). This is necessary to avoid knocking. Diesel fuel is required to ignite the premixed gaseous fuel-air mixture as gaseous fuel is resistant against auto-ignition. Therefore, the engine cannot be run exclusively on the gaseous fuel [46].

However, in order to save gaseous fuel a technique has been developed with locating the gas injector in the intake manifold which can be controlled electronically. In this method the quantity and the injection timing of the pilot and gaseous fuels can be set according to the operating conditions [43, 45]. Therefore, a desirable composition of the air-fuel ratio can be achieved and hence knocking and misfiring can be avoided. Improvements in fuel consumption, HC and CO emissions could be obtained without increasing NO_X and PM emissions. However, some problems can arise from this injection mode such as atomisation, the degree of air-fuel mixture homogeneity and liquid fuel layer formation in the intake pipe [44-46].

Other gaseous fuel injection strategy is by high pressure direct injection into the combustion. Two fuel injectors are mounted in the combustion chamber both for liquid and gaseous fuels. The engine operation has advantage as it has the ability to be operated on very limited amount of liquid fuel thereby resulting in the engine producing very low PM and NO_X emissions [42, 47].

1.9 PRESENT WORK

Present work involves development and experimental investigation of a Dual Fuel Engine. The main objective of the investigation are:

1) To develop experimental setup for Dual Fuel Engine by modifying injection manifold of a single cylinder engine for the induction of compressed natural gas, so the engine works in a dual fuel mode.
2) To prepare biodiesel of Jatropha oil and investigate the performance and emission characteristics of the Dual Fuel Engine with CNG as gaseous fuel and blends of Jatropha Oil Methyl Ester as liquid pilot fuel.
3) Comparison of the performance and emission behavior of the Dual Fuel system with baseline data of diesel.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

All over the world fossil fuel reserves are diminishing at an alarming rate. As a result, shortage of crude oil leading to increased oil prices is quite natural in foreseeable future. Apart from limited life span, global climate change due to unrestricted combustion of fossil fuels is also a major concern. In addition, there is a serious issue of deteriorating urban air quality and stringent legislations for automotive emissions. The versatility of internal combustion (IC) engines in terms of range and acceleration over battery powered and fuel cell engines makes this main workhorse in the transportation sector. IC engines also enjoy more power to weight ratio than that of its competitors namely battery powered or fuel cell operated vehicles [48]. These factors have influenced scientists and researchers to develop environment friendly technologies and to introduce cleaner alternative fuels like alcohol, biodiesel, natural gas etc for ensuring the safe survival of the existing IC engines technology.

2.1 LITERATURE SURVEY

Namasivayam et al. [49] experimented using dimethyl ether (DME), a gaseous high-Cetane fuel and two water-in-fuel emulsions with different water concentrations (5% and 10% water by volume) as a test fuel. It has been found that at low loads and low speed (1000 rpm) NO emission was reduced by 20%. However, above an equivalence ratio value of about 0.55, NO emissions increased to values approaching those of neat rapeseed methyl ester (RME). For DME HC and CO emission was found higher than that of RME. The DME pilot and both emulsions produced lower peak combustion pressures than the neat RME pilot. The emulsified pilot fuels produced similar thermal efficiencies as the neat RME pilot, while the DME pilot produced lower thermal efficiencies throughout the load range.

Ryu [50] investigated the effect of pilot injection pressure on the engine performance and exhaust emissions characteristics with biodiesel–CNG DFC mode in a diesel engine. The results showed that IMEP of biodiesel–CNG DFC mode was lower than that of diesel SFC mode at high injection pressure, but the IMEP of DFC increases with increases in engine load and pilot injection pressure. It is found that the combustion stability of biodiesel–CNG DFC mode is increased with increases in pilot injection pressure The ignition delay in the DFC mode is about 1.2–2.6^0 CA longer than that in the diesel single combustion mode, but the ignition delay decreases with the increasing pilot injection pressure

Mustafi et al. [51] experimented to examine the effect of dual fuel combustion on the performance and pollutant emissions of a DI diesel engine operated on NG and BG. It had been found that BSFC increased as biogas was introduced into the engine and was proportional to the amount of CO_2 present in the simulated biogases. A longer ignition delay period was calculated for diesel low load and dual fuel conditions compared to that of diesel high load. About 27% and 30% higher maximum NHRR were obtained for D+NG and D+BG fueling respectively compared to diesel fueling. Specific NO_X emissions for dual fueling was always lower than the diesel fueling conditions. Specific NO_X concentration was found to be reduced by about 9 to 12% for different D + BG fueling conditions with increasing CO_2 contents compared with DH fueling.

Tira et al. [52] examined the capability of reformate and H_2 combustion to enhance the thermal efficiency and reduce gaseous (both regulated and unregulated) and particulate emission with respect to LPG–diesel dual fuel combustion. It was found that smoke and PM was improved especially in the case of H_2 was 2% and 0.5%, while there were not significant further reductions in 1% LPG addition. Therefore, the amount of the inducted H_2 can be optimized in order to get the best compromise between NO_X and soot.

Saravanan et al. [53] experimented on a diesel engine using hydrogen in the dual fuel mode and hydrogen with DEE as ignition source. Hydrogen in both dual fuel and with DEE operation showed an increase in brake thermal efficiency by about 22% and 35%, respectively compared to diesel. A significant reduction in NO_X emissions was obtained with DEE operation hydrogen diesel dual fuel mode as well as baseline diesel. A severe knocking was noticed during the operation of the engine with hydrogen-DEE operation beyond 75% load due to the instantaneous combustion of hydrogen at high loads.

Korakianitis et al. [54] utilized hydrogen as a test fuel and determined various performance and emission characteristics. Maximum thermal efficiency were found to be higher for a constant low speed engine. Hydrogen dual-fuel CI engine operation with all the tested pilot fuels increases NO_X emissions; while smoke, unburnt HC and CO levels remain relatively unchanged compared with normal CI engine operation. During natural gas dual-fuel operation, higher unburnt HC and CO emissions compared with the other engine operating modes are recorded at low and intermediate engine loads as a result of lower combustion efficiencies. Hydrogen operation achieves a similar CO_2 reduction as natural gas operation despite a lower gaseous fuel enthalpy fraction (about 40% maximum for hydrogen, about 70% maximum for natural gas).

Bedoya et al. [55] developed an experimental setup to evaluate the effects of mixing system and the pilot fuel quality on a stationary dual fuel engine performance using biogas as primary fuel. The results showed that full diesel substitution is attainable using palm oil biodiesel as pilot fuel on biogas dual fuel engine. The combination of a supercharger and Kenics mixer in the inlet system of biogas dual fuel engines can be applied as a strategy to increase thermal efficiency and substitution level of pilot fuel as well as to reduce methane emissions at part load.

Yoon et al. [56] examined the effects of the dual-fuel combustion mode on the combustion characteristics. At low loads the total BSFCs for dual-fuel combustion for both fuels were considerably higher than for single-fuel combustions. At high loads the increase of the conversion of biogas into work led to a large improvement of the total BSFC with dual-fuel combustions. Significantly lower NOx emissions were emitted under the dual fuel operation for both pilot fuels compared to the single-fuel mode under all test conditions. The concentrations of HC and CO emissions were considerably higher for the dual-fuel mode with both pilot fuels than those for the single-fuel mode under all test conditions. Biodiesel combustion with both modes yielded higher concentrations of CO_2 emissions, because the oxygen in biodiesel fuel allowed more CO emissions to be oxidized into CO_2.

Carlucci et al. [57] carried out a test to study the combustion development and its implications on the engine performance, in terms of pollutant emission levels and fuel consumption, on a dual-fuel CNG–air engine. During tests, the engine was operated at two different conditions and, for each of them, methane and diesel fuel injection pressure, together with pilot fuel amount, was varied. It was observed that an analysis of the ROHR is not sufficient to explain the effect of each of the injection parameters on the pollutant emissions. In the case of NO_X it was found that the penetration of the jet holds the same importance as the quantity of pilot fuel injected. The more the jet penetrates into the combustion chamber, the more its combustion will spread into the same chamber, and then the local temperatures will be closer in value to the bulk temperature.

Roy et al. [58] concluded tests of hydrogen in a supercharged dual-fuel engine for leaner fuel-air equivalence ratios maintaining high thermal efficiency. The hydrogen-operation produced the maximum IMEP of about 908 kPa and a thermal efficiency about 42% with the highest fuel-air equivalence ratio of 0.3. There were hardly any CO and HC emissions. However, the NOx emissions were high considering the future regulations. The hydrogen with N_2 dilution (40–50%) produced the highest IMEP of about 1013 kPa, which was about 13% higher than that at hydrogen operation. There was a dramatic reduction of NOx with different percentage of N_2 dilutions. The maximum NOx reduction of 100% was achieved with 60% N_2 dilution maintaining 10% higher IMEP than hydrogen operation.

Lounici et al. [59] studied, the effect of dual fuel operating mode on combustion characteristics, engine performance and pollutants emissions of an existing diesel engine using natural gas as primary fuel and neat diesel as pilot fuel, has been examined. At low engine loads, the total BSFC for dual fuel mode is higher than the conventional diesel. At high and moderate loads, the results showed a very interesting behavior of the dual fuel mode compared to conventional diesel. In fact, the total BSFC was lower for all the examined engine speeds. At those loads, the enhancement of the gaseous fuel utilization due to higher temperatures and richer mixtures, leads to a relevant improvement in the total BSFC and a higher heat release rate in the premixed-combustion phase for dual fuel mode. Consequently, the in-cylinder pressure peak for dual fuel mode becomes higher than the corresponding one for conventional diesel. Regarding the nitric oxides concentration (NO_X), a reduction is also observed with dual fuel mode at low and moderate loads.

Daniel et al. [60] investigated the effect of amalgamating PFI and DI technology involving the use of DMF and ethanol compared with gasoline on dual-injection engine. Using dual-injection, the is HC emissions of D25 (G-D_{50} DI) were comparable to DI for the load conditions between 3.5 bar and 8.5 bar IMEP (±4%). Dual-injection offers marginally lower HC emissions than DI. For instance, D50 blends in G-D_{50} DI result in up to 4% lower HC emission than in DI (D_{50} DI), regardless of the engine load.. The NOx emissions of G-D_{25} DI were between 13% and 16% higher than D $_{25}$ DI as the load were varied from 3.5 bar to 8.5 bar IMEP.

Geo et al. [61] found the effect of duel fueling with hydrogen. It had been observed that hydrogen enhances the brake thermal efficiency due to increase in the premixed combustion rate. At full load, with hydrogen induction, the brake thermal efficiency of RSO and RSOME increases from 26.56% to 28.12% and 27.89% to 29.26% at the hydrogen share of 8.39% and 8.73% on the energy basis. The increase in brake thermal efficiency with lower loads is minimum. The maximum hydrogen energy share that can be tolerated with knock limit was highest with diesel (12.69%) and decreases with RSOME (11.2%) and RSO (10.76%) at full load. The hydrogen can be used in the dual fuel mode with rubber seed oil and its ester to improve the combustion process.

Bose et al. [62] investigated that the brake thermal efficiency increases by 12.9% without EGR with the supply of .15 kg/h of hydrogen. However, at high rates of hydrogen admission the combustion becomes uncontrolled and hence the thermal efficiency decreases. Use of EGR had a negative effect on engine efficiency that increases with its percentage. The smoke level decreases by 42% and CO_2 by 40% for hydrogen enrichment without EGR compared to neat diesel operation. When EGR was used it was found that smoke level increases but still at low level compared to neat diesel operation. EGR reduces availability of oxygen for combustion of fuel, which results in higher smoke level.

Abdelaal et al. [63] investigated the effect of oxygen enrichment and found that enrichment of oxygen decreases the ignition delay period while increases the peak in-cylinder pressure at all loads. About 5% increase in the peak in-cylinder pressure can be attained at high load when the oxygen concentration of the cylinder was increased from 21% (normal air) to 25%, reduces both HC and CO emissions. The effect was more voluminous at low and intermediate load conditions. About 28% reduction in brake specific HC and CO emissions can be attained at medium load when the oxygen concentration of the cylinder is increased from 21% (normal air) to 30%.however, oxygen-enrichment significantly increases NO_X emission. Brake specific NO_X emission is multiplied four times when the oxygen concentration of the cylinder was increased from 21% (normal air) to 30%, at part load.

Paul et al. [64] examined diesel-ethanol and diesel-CNG combinations. The diesel-ethanol blend, D95E5 produced better performance characteristics than diesel-CNG combination. As an alternative to conventional diesel, D95E5 and D90E10 showed higher brake thermal efficiency (21.53% and 19.5% respectably) than any Diesel-CNG combination. Further, Low CNG enrichment of both diesel ethanol blends was found to be extra beneficial in increasing. Both of the engines and was found to be an even better alternative. In terms of brake specific energy consumption, CNG with pilot diesel clearly increased the energy intake of the engine. Again, increasing ethanol percentage in base fuel resulted in a reduction in BSEC. Low CNG enrichment of the blends also reduced the energy intake of the engine.

Yang et al. [65] observed NO_X and soot reductions of E-HPCC having high equivalence ratio and high temperature region in the combustion chamber. Compared to LTC, the two HPCCs produce more incomplete combustion products and consequent lower combustion efficiencies, which can be improved by increasing gasoline ratio. In the two HPCCs, the substantial heat release was determined by the oxidation effect of OH radical derived from the low temperature reaction of diesel fuel, and the staged reaction of diesel and gasoline leads to reasonable MPRR values; the fuel stratification in LTC mode leads to a fast heat release rate and high MPRR because of the coupling combustion reaction of gasoline and diesel taking place in regions with higher fuel concentration.

Liew et al. [66] investigated that addition of H_2 reduced the emissions of PM. With the addition of up to 7% H_2 at 10–70% load, maximum PM reductions of 34% (at 30% load) to 80.6% (at 50% load) were obtained. When measured using the 13-mode ESC, the addition of 2% and 4% H_2 reduced PM emissions by 18.5% and 27.8%, respectively. The addition of a small amount of H_2 substantially increased the emissions of NO_2 relative to NO. The addition of H_2 beyond a certain level started to reduce NO_2 emissions again. However, even in this regime the engine still produced more NO_2 than for baseline diesel operation.

Imran et al. [67] examined that alcohol fumigation decreases BTE at low engine loads but there was a little increase in BTE at medium and high engine loads. The decrease in BTE had been found in the range of 5–13% and increase in BTE has been found in the range of 2–9%.Regarding gaseous emission, alcohol fumigation decreases NO_X emission compared to diesel fuel. NO_X emission is significantly affected by engine loads. The maximum reduction has been found to be 20% compared to pure diesel fuel at lower engine load for 30% fumigation in most of the experiments.

Cacua et al. [68] experimentally studied the effect of addition of oxygen in the test fuel. Small additions of O_2 to intake combustion air improve combustion stability in a biogas-diesel engine. The additional O_2 helps to attenuate negative effects of CO_2 in the combustion such as decreases in overall gas-air mixture temperature and low burning velocities of biogas regarding to methane. Oxygen enrichment was a viable technique for dual diesel-biogas engine at light loads due to improvement in important characteristics of performance such as thermal efficiency, decreases in the ignition delay, high burning rates, as well as decreases in methane emissions.

Kose et al. [69] conducted the performance test using hydrogen as a test fuel. Various hydrogen samples were taken to carry the experiments. It has been observed that the average of specific fuel consumption decreases 4% and 3.5% with H2.5 and H5 of hydrogen addition at full load compared to SDI. The lower BSFC was 192.785 g/kWh for H2.5 fuel rate of hydrogen compared to 243.516 g/kWh in the case of SDI at full load and at 1000 min^{-1}. The average of brake thermal efficiency was increased 23%, 20% and 10.8% with the all additions hydrogen rates compared to SDI at full load. The maximum brake thermal efficiency H 2.5 obtained 40.4% compared to SDI 33% at 1750 min^{-1}. The increase in brake thermal efficiency shows better combustion process than SDI fuel combustion. The exhaust temperate for all additional hydrogen rates increased averagely 4%, 8.3% and 9.4% comparing with SDI at full load, respectively.

Chapman et al. [70] studied that a simple approach to incorporating DME in a direct injection diesel engine, by fumigating the intake air with DME, yields mixed results. The DME-air charge provided an atypical high temperature environment for the diesel fuel to proceed through its combustion process. Nonetheless, significant divergence from the conventional diesel combustion process was achieved in this study and substantial differences in emissions were observed with DME fumigation in the intake air. While NO_X emissions were reduced and energy conversion efficiency increased at levels of energy addition as DME up to 44%, mass emissions of CO, HC and PM all increased. In addition, the ratio of NOx/NO significantly increased with addition of DME.

Lu et al. [71] investigated the effect of DFSC using n-heptane/alcohols and DFSC with n-heptane/iso-octane. It has been observed that at the same overall equivalence and premixed ratios, the soot emissions produced by DFSC using n-heptane/alcohols are negligible compared with DFSC with n-heptane/iso-octane. However, the NOx emissions of DFSC with different directly injected fuels were similar. The bulk gas temperature, active radical concentrations, and charge cooling effects of the directly injected fuel primarily influence the ignition behavior of the directly injected fuel.

Lakshmanan et al. [72] collected and analyzed the effect of EGR. It was found that above 5% EGR, there was negative effect in the thermal efficiency at rated load. The exhaust gas temperature decreased in the case of dual fuel operation of acetylene without EGR and with EGR. At rated load NOx value for acetylene, manifold injection without EGR is 9.68 g/kWh whereas with 20% EGR NOx value was 7.60 g/kWh. With the application of EGR, due to lower excess oxygen available for combustion it results in incomplete combustion leading to slight increase in CO and HC emission level. The CO_2 emission decreases by 18% for acetylene enrichment without EGR compared to neat diesel operation at rated load. There was an increase in the peak cylinder pressure and rate of pressure rise and advancement in occurrence of peak cylinder pressure due to higher burning velocity of acetylene, when gas was inducted without EGR. In the case of EGR, the rate of pressure rise, occurrence of peak pressure and rate of heat release decreased..

Selim [73] observed that dual fuel engine using LPG as primary fuel exhibits higher combustion noise than that using methane. Increasing the dual fuel compression ratio while using LPG as main fuel leads to excessive combustion noise and cyclic variation at high loads in addition to loss in Imep. Advancing the injection timing of the pilot diesel fuel for dual fuel engine using LPG as main fuel resulted in an increase in the combustion noise, cyclic variation, and loss in Imep. Injection timing of about 30–35^0 BTDC resulted in the least cyclic variations and moderate combustion noise. Increasing the mass of pilot diesel fuel resulted in an increase in the Imep, however, it increased the combustion noise.

Saleh [74] investigated that variation in LPG composition caused a variation in the exhaust emissions. Higher butane content leads to lower NO_X levels while a higher propane content reduces CO levels. NOx and SO_2 Emissions for fuel 3-diesel blend decreased by 27%, 69% at full load and 35%, 51% at 25% load, respectively in comparison with the conventional diesel engine however CO emissions increased about 15.7% at full load and reached to 100% at 25% load. With EGR rate 5%, the fuel conversion efficiency of fuel 3-diesel blend is improved at part loads. A better trade-off between CO and NO_X emissions can be attained within EGR rate of 5–15%.

Karabektas et al. [75] utilized natural as a test fuel for duel fuel engine operation and found that use of natural gas as a dual fuel has a significant negative effect on the engine performance at low and medium loads. However, the engine performance improves at high engine loads. The use of natural gas as a dual fuel caused lower NO emissions at low and medium loads, while yielding higher NO emissions at high loads compared with the use of DF. CO and HC emissions increased considerably with the use of natural gas at low and medium loads, while showing a decreasing trend at high loads. The addition of DEE to pilot fuel in a diesel engine using dual fuel caused lower specific energy consumption and higher brake thermal efficiency compared with the use of C40. Furthermore, DEE addition leads to an improvement in NO and CO emissions at all engine loads, which is mainly due to the high cetane number and oxygen content of DEE. Moreover, the higher the DEE content, the better the engine performance and exhaust emissions.

Xiao et al. [76] conducted an experiment and examined that, Using EGR instead of the throttle to control engine load allows the development of high power density engines using TWC for after-treatment. The SDCI combustion can achieve high indicated thermal efficiencies in a relatively wide load range (IMEP of 4.3–8.0 bar) because of the higher compression ratio, shorter combustion and smaller pumping loss. A very high ISFC of 190.8 g/kW h has been achieved in at a medium load. The PM emissions of SDCI combustion (accumulation mode) are lower by up to 90% in number than the conventional CI diesel combustion results. In SDCI combustion mode, the NO_X emission after treated by the TWC rather than controlled by high EGR, removing the traditional NOx-PM trade-off compromise in engine design.

Geng et al. [77] carried out an experiment and found that, when the tested engine operates in the DMDF mode, the dry-soot emission decreases significantly with the increase of methanol at low and medium loads, but increases at high engine load. Diesel/methanol dual fuel method can effectively reduce the number and mass concentrations of particles at low and medium loads, while there is an increase in particulate matter emissions at high engine load. The temperature of intake air decreases with the injection of methanol. There was a significant decrease in the total mass and number concentrations of particles with the decrease of intake air temperature when operated in the DMDF mode. The diesel oxidation catalyst can effectively reduce the mass and the number concentrations of the particulate in the pure diesel mode and DMDF mode.

As an outcome of exhaustive review of literatures, the following major findings can be drawn;

1. Dual fuel operation is feasible and well known in today's generation, because of its various advantages (e.g. low emission and higher efficiency) at intermediate and high load conditions over diesel fuel engines.
2. Various alternative fuels (like Hydrogen, CNG, LPG, Biogas and Biodiesel ect.) can be used as a primary fuel as well as pilot fuel. However, some problems may be encountered during dual fuel operation.
3. During dual-fuel operation using natural gas as primary fuel, higher unburnt HC and CO emissions compared with the other engine operating modes are recorded at low as a result of lower combustion efficiencies.
4. When natural gas dual-fuel operated at intermediate and high engine loads, unburnt HC and CO decreases dramatically which result in high combustion efficiencies.
5. At intermediate and high loads, the total BSFC is lower for all the examined engine speeds using various alternative primary fuels (CNG, LPG, Hydrogen and biogas).
6. Dual-fuel CI engine operation with all the tested pilot fuels increases NO_X emissions at intermediate and high engine loads.

7. Significantly higher NOx emissions were emitted under the dual fuel operation for biodiesel as pilot fuels compared to the single-fuel mode under all test conditions.

8. With the application of EGR, the NO_X emission reduced. But slight increase in CO and HC emission level will occurs.
9. Use of EGR increases the brake thermal efficiency by 12% in case of hydrogen dual fuel operation.
10. H_2 combustion has shown to have the capability to increase the thermal efficiency and reduce gaseous and particulate emission with respect to LPG- diesel or CNG–diesel dual fuel combustion.

Knocking was noticed during the operation of the dual fuel engine with hydrogen operation beyond 75% load due to the instantaneous combustion of hydrogen at high loads.

2.2 LITERATURE GAP

After the exhaustive review of literature, the following research gaps were identified.

1. Use of biodiesel as a pilot fuel is concentrated only on jatropha oil methyl ester. However, some other biodiesels are available which gave better combustion performance than jatropha biodiesel.
2. Limited work is done to analyze and understand the effect of reformate addition (both H_2 + CO and H_2 only) in the dual fuelling on combustion and emissions characteristics.
3. The work has been carried out for finding the feasibility of advanced injection timing in dual fuel engine is not adequate.
4. Limited work has been done on the fuel injection modelling for dual fuel engines.
5. Use of EGR (Exhaust Gas Recirculation) for NO_X reduction in dual fuel engine is not adequate.
6. Fuel injection pressure is a very important parameter in dual fuel engine but very little work is done in that direction.

7. The use of biodiesel increases the NO_X formation due to enrichment of oxygen availability in biodiesel. This results in very limited work on biodiesel as pilot fuel.
8. Work for improving the brake thermal efficiency and emissions of dual fuel engine at low load condition are not adequate.
9. No work has been done using two different primary fuels simultaneously with any pilot fuel in dual fuel engine.
10. No work has been carried out to reduce knocking in dual fuel engines (using hydrogen as primary fuel) at high load.

CHAPTER 3

SYSTEM DEVELOPMENT & EXPERIEMNTAL PROCEDURE

3.0 INTRODUCTION

Diesel engines are amongst the most useful and efficient prime movers amongst all power producing machines. Due to this reason it has becomes necessary to develop alternative fuels with properties comparable to petroleum based diesel fuels with the view of protecting global environment and concerns for long-term energy security.

For countries like India and many other developing countries; fuels of bio-origin provide a feasible solution to the above twin crisis. Bio-fuels are getting a worldwide attention because of global stress on reduction of greenhouse gases (GHGs) and clean development mechanism (CDM).

The fuels of bio-origin may be alcohol, vegetable oils, animal tallow, biomass, and biogas. Amongst all Vegetable oils have comparable Physico-chemical properties with mineral diesel and they are biodegradable, non-toxic, and have a potential to significantly reduce pollution.

In many countries the qualities of this fuel, environmentally as well as technically, have pushed this fuel close to the final stages of commercialization. Each country can proceed in the production of particular oil, depending upon the climate and economy. In recent years many countries have taken initiatives in this field and re-forestation has a very important role to play in meeting the challenge of Climate Change. Several initiatives have been taken indifferent parts of the country to promote large scale cultivation of oilseed bearing plants. Amongst the various plant species, oil extracted from seeds of Jatropha tree has been found very suitable as a substitute to diesel fuel.

In spite having several advantages use of JOME is limited as combustion of JOME increases various emissions compared to that of mineral diesel. Hence a gaseous fuel is introduced in the combustion chamber to give complete and cleaner combustion. Therefore a slight modification in injection manifold of engine is done to modify it as a dual fuel engine.

3.1 PRODUCTION OF BIODIESEL FROM JATROPHA OIL

Biodiesel from Jatropha seed is important because most of the states of India are tribal where it is found abundantly. Jatropha seed contain 30-40 percent fatty oil called Jatropha oil. The Jatropha tree starts bearing seeds from seventh year of planting. Jatropha seed oil is a common ingredient of hydrogenated fat in India. It is obtained from the seed kernels and is a pale yellow, semi-solid fat at room temperature. It is also used in the manufacture of various products such as soap and glycerin. Crude Jatropha oil generally contains high % Free Fatty Acid (FFA) and conversion of FFA to biodiesel is very important Properties of biodiesel depend on the nature of the vegetable oil used for preparation of biodiesel by esterification and/or transesterification. From the chemical composition it is found that Jatropha oil is almost similar to that of other non-edible oils.

Bio diesel was produced from Jatropha (Jatropha Curcas) oil through esterification followed by transesterification.

3.1.1 ESTERIFICATION

Jatropha Oil free from water and contaminants was taken in the flask. Heat was supplied to the setup. Measured amount of p-toluene sulphonic acid and Methanol were added to the oil .Heat was supplied and stirred continuously maintaining a steady temperature. Reaction time was conducted for 1hours. Intermittently samples were collected at regular intervals and FFA was determined. After the confirmation of complete reduction of FFA to less than 2%, the heating was stopped this oil sample was further treated for transesterification step to obtain methyl esters.

3.1.2 TRANSESTERIFICATION

Solution of known amount of catalyst potassium hydroxide was prepared in methanol. The solution and the rest required amount of methanol was added to the oil sample and was put on mantle heater. The system was maintained airtight to prevent the loss of alcohol. The reaction mix was maintained at temperature just above the boiling point of the alcohol i.e. around 70°C to speed up the reaction. Recommended reaction times varied till around 1 hour. Excess alcohol was normally used to ensure total conversion of the oil to its esters. After the confirmation of completion of methyl ester formation, the heating was stopped and the products were cooled and transferred to a separating funnel. The ester layer containing mainly methyl ester and methanol and the glycerol layer containing mainly glycerol and methanol were separated. The methyl ester was washed and dried under vacuum to remove traces of moisture.

Flow diagram represents the two step transesterification process of conversion of vegetable oil into methyl ester.

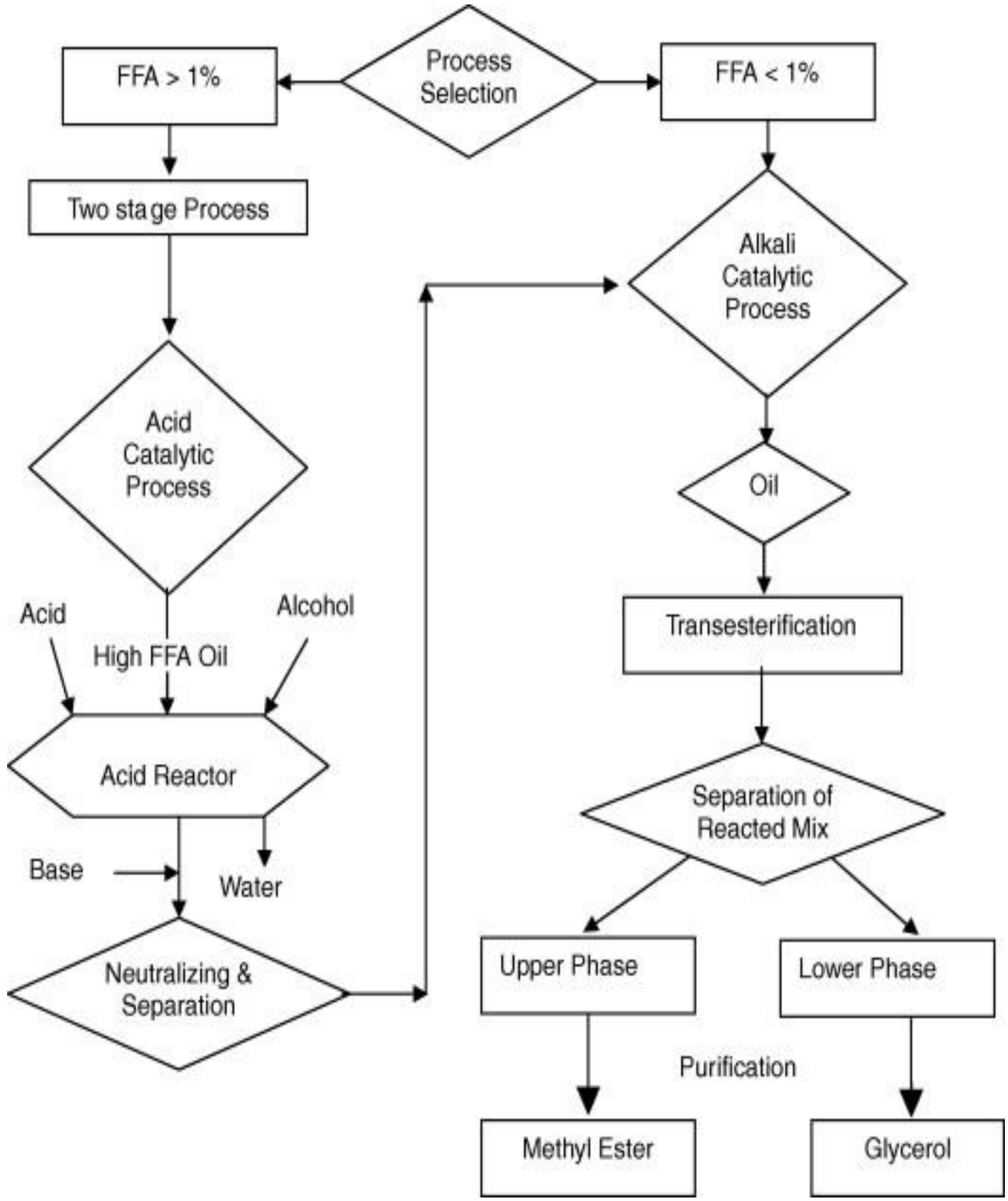
Process
Selection
FFA > 1%
FFA < 1%
Two stage Process
Alkali
Catalytic
Process
Acid
Catalytic
Process
Oil
Acid
Alcohol
High FFA Oil
Transesterification
Acid Reactor
Separation of
Reacted Mix
Base
Water
Neutralizing &
Separation
Upper Phase
Lower Phase
Purification
Methyl Ester
Glycerol

Plate 3.1 Jatropha oil Methyl Ester

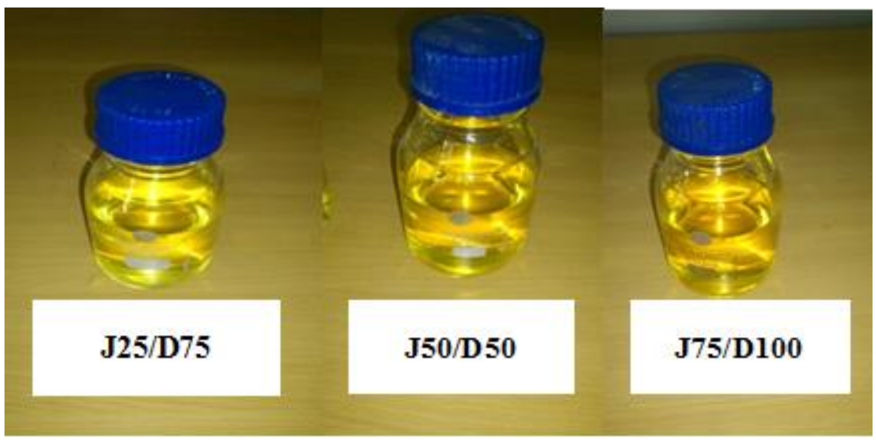

Plate 3.2 Various Blends of Jatropha Oil Methyl Ester

3.2 DETERMINATION OF PHYSICO-CHEMICAL PROPERTIES FOR JOME

3.2.0 EQUIPMENTS

The following equipments were used in the laboratory for determination of Physico-chemical properties of the fuel for the specified project. These are used in CASRAE of Delhi Technological University, Delhi.

3.2.1 BIODIESEL RANCIMAT

Rancimat is an instrument used to measure the oxidation stability of biodiesel and biodiesel blends. The oxidation stability is the ability of a biodiesel sample to resist oxidation under conditions of heat and continuous air flow. Oxidation stability is one of the limiting factors in the use of bio-fuels, as this determines the shelf life of fuels. If the bio-diesel oxidizes, it forms fatty acids, which being acidic, corrodes the fuel injection system, and the engine cylinder. The Rancimat operation is based on air bubbling through the given fuel sample and testing for acidity by electrical conduction through the sample, between two electrodes. The equipment in CASRAE is of Metrohm brand, and has been acquired. The instrument is used extensively in determining the detrimental effects of metallic contaminants and the ameliorating effects of chelators and antioxidants.

PLATE 3.3: Biodiesel Rancimat

3.2.2 KINEMATIC VISCOSITY

Viscosity is an important property of fuel and it can be defined as measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. In general too viscous fuel tends to form scum and deposits on cylinder walls, piston head etc., and cause atomization problems. So it is desirable that viscosity of fuel should be low. The different blend samples are prepared are investigated for viscosity at 400 C using a kinematic viscometer as per the specification given in ASTM D445. It consists of a capillary tube in which sample to be test is filled. The capillary tube has two marks engraved on it. The time for flow of fuel sample from upper mark to lower mark is measured and kinematic viscosity is calculated using time taken by each sample. The plate of the kinematic viscometer apparatus is shown below.

The kinematic viscosity of different fuel blends can be calculated as:

$$\upsilon = k \times t$$

Where,

υ= kinematic viscosity of sample;

k = constant for viscometer;

t = time taken by the fluid to flow through capillary tube.

PLATE 3.4 Kinematic Viscometer

3.2.3 GAS CHROMATOGRAPH

A gas chromatograph is a chemical analysis instrument for separating chemicals in a complex sample. A gas chromatograph uses a flow-through narrow tube known as the column, through which different chemical constituents of a sample pass in a gas stream (carrier gas, mobile phase) at different rates depending on their various chemical and physical properties and their interaction with a specific column filling, called the stationary phase. As the chemicals exit the end of the column, they are detected and identified electronically. The function of the stationary phase in the column is to separate different components, causing each one to exit the column at a different time (retention time). Other parameters that can be used to alter the order or time of retention are the carrier gas flow rate, column length and the temperature.

In a GC analysis, a known volume of gaseous or liquid analyte is injected into the "entrance" (head) of the column, using a micro syringe (or, solid phase micro extraction fibers, or a gas source switching system). As the carrier gas sweeps the analyte molecules through the column, this motion is inhibited by the adsorption of the analyte molecules either onto the column walls or onto packing materials in the column. The rate at which the molecules progress along the column depends on the strength of adsorption, which in turn depends on the type of molecule and on the stationary phase materials. Since each type of molecule has a different rate of progression, the various components of the analyte mixture are separated as they progress along the column and reach the end of the column at different times (retention time). A detector is used to monitor the outlet stream from the column; thus, the time at which each component reaches the outlet and the amount of that component can be determined. Generally, substances are identified (qualitatively) by the order in which they emerge (elute) from the column and by the retention time of the analyte in the column.

The instrument present here is equipped with a FID (flame ionization detector), enabling us to quantify the quantities of various organic compounds present in the sample being tested. Hence, we can find out precisely the percentage of different fatty acid present in the biodiesel.

PLATE 3.5 Gas Chromatograph

3.2.4 BOMB CALORIMETER

The calorific value is defined in terms of the number of heat units liberated when unit mass of fuel is completely burnt in a calorimeter under specified conditions. Higher calorific value of fuel is the total heat liberated in kJ per kg or m^3. All fuels containing hydrogen in the available form will combine with oxygen and form steam during the process of combustion. If the products of combustion are cooled to its initial temperature, the steam formed as a result will condense. Thus maximum heat is abstracted. This heat value is called the higher calorific value.

The calorific value of the fuel was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D240. The combustion of fuel takes place at constant volume in a totally enclosed vessel in the presence of oxygen. The sample of fuel was ignited electrically. Then the fuel samples were burnt in bomb calorimeter and the calorific value of all samples were calculated. Parr Model 6100EF was used in laboratory for measuring calorific value of biodiesel. The Bomb Calorimeter used for determination of Calorific value is shown in plate 3.6

Plate 3.6 Parr 6100 calorimeter

3.2.5 DENSITY METER

Density meter used in laboratory is DMA 4500AntoParr model. This density meter works on the principle of oscillating U-tube. The oscillating U-tube is a technique to determine the density of liquids and gases based on an electronic measurement of the frequency of oscillation, from which the density value is calculated. This measuring principle is based on the Mass-Spring Model.

The sample is filled into a container with oscillation capacity. The Eigen frequency of this container is influenced by the sample's mass. This container with oscillation capacity is a hollow, U-shaped glass tube (oscillating U-tube) which is electronically excited into undamped oscillation (at the lowest possible amplitude). The two branches of the U-shaped oscillator function as its spring elements.

The direction of oscillation is normal to the level of the two branches. The oscillator's Eigen frequency is only influenced by the part of the sample that is actually involved in the oscillation. The volume involved in the oscillation is limited by the stationary oscillation knots at the bearing points of the oscillator. If the oscillator is at least filled up to its bearing points, the same precisely defined volume always participates in the oscillation, thus the measured value of the sample's mass can be used to calculate its density.

PLATE 3.7 Density Meter

3.2.6 COLD FILTER PLUGGING POINT (CFPP)

Cold Filter Plugging Point (CFPP) is defined as the minimum temperature at the fuel filter does not allow the fuel to pass through it. At low operating temperature fuel may thicken and does not flow properly affecting the performance of fuel lines, fuel pumps and injectors. Cold filter plugging point of vegetable oils reflects its cold weather performance.

It defines the fuels limit of filterability. The apparatus for CFPP measurement is shown in plate 3.9

Plate 3.8 Cold Filter Plugging Point Apparatus

3.3 SELECTION OF DIESEL ENGINE

Due to robustness and high load carrying diesel engines are preferred more than the gasoline engine in almost every sector like agriculture, marine, and other load carrying locomotives. Also due to economic point of view diesel engine attracted the manufacturers to make diesel engines.

Air pollution created by diesel engine is also more severe than the petrol engine. Also due to bulkiness in terms of more storage capacity of engine for moving more goods at same time they consume more fuel and so create more air pollution. Due to this reason by changing some trends to reduce the air pollution or harmful emissions by changing the fuel may bring considerable changes in the environment. Keeping all these specific features of diesel in mind, a typical engine system has been modified as dual fuel engine for present experimental investigations. As introduction of gaseous fuel will leads to lesser emission and give proper combustion.

3.4 EXPERIMENTAL TEST RIG

The base engine for this work is kirloskar four stroke, single cylinder, direct injection stationary constant speed diesel engine. The modification is being done in intake manifold to run engine on dual fuel mode. The engine intake system is modified via the installation of a specially designed venturi-type gas mixer that allows the introduction of natural gas, and mixes it with the fresh air. The mixture is allowed to preheat then induced to the cylinder as a result of engine suction. The natural gas is supplied through high-pressure (200 bar) commercial CNG bottles; typical to those used in vehicular applications. A multi stage pressure regulator is used to reduce CNG pressure to sub atmospheric level for suction of engine. An electrical dynamometer coupled to the engine was used as a loading device. The load can be assorted on the dynamometer and there by engine by switching on or off the load resistances. The setup enables study of Dual Fuel engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio. The detailed technical specifications of the engine are given in Table 3.1

Plate 3.9 Test Engine

Table 3.1: Specifications of the Diesel Engine

Engine Specification	
Make	Kirloskar oil Engine Ltd., India
Model	DAF 8
Rated Brake Power (bhp/kW)	8/5.9
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 X 110
Compression Ratio	17.5 : 1
Cooling System	Air Cooled (Radial Cooled)

Lubrication System	Forced Feed
Cubic Capacity	0.78 L
Starting	Hand Start with cranking handle
Dynamometer Specification	
Manufacturer	Kirloskar Electric Co. Ltd., India
Dynamometer Type	Single phase, 50 Hz, AC alternator
Rated Output	5 KVA @ 1500 rpm
Rated Voltage	230 V
Rated Current	32.6 A

The engine is to be started by hand lever. For conducting the desired set of experiments and together required data from the engine, it is essential to get the various instruments mounted at the appropriate location on the experimental setup. The schematic diagram of the experimental setup with all instrumentation is shown in Figure 3.1.

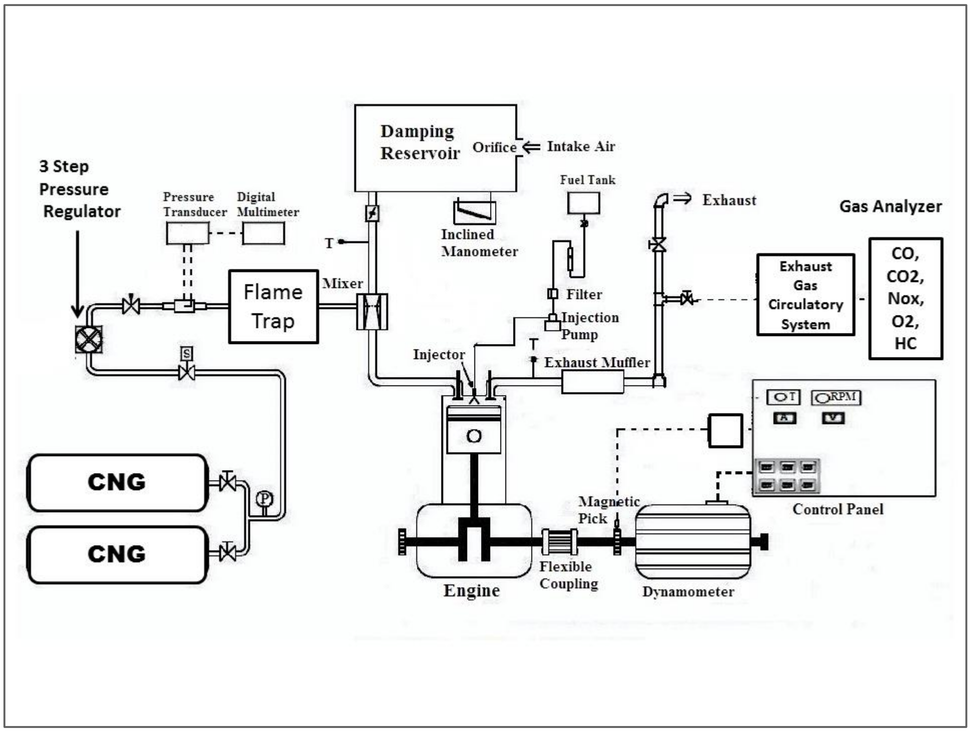

Fig. 3.1 Schematic Diagram of the Experimental Set Up

A voltmeter, ammeter and wattmeter were connected between alternator and load bank. A nut was welded on the flywheel and the photo reflective sensor was mounted on a bracket attached to engine body. The thermocouples were mounted in the exhaust manifold to measure the exhaust temperature. The AVL 437 smoke meter and AVL Di Gas Analyzer were also kept in proximity for the measurements of various exhaust gas parameters.

Thus such a system was chosen to examine the practical utility of dual fuel system with CNG and Jatropha oil Methyl Ester Blends in such applications. Besides being a single cylinder system it was light and easy to maintain. The engine was provided with suitable arrangement, which permitted wide variation of controlling parameters.

3.5 EXHAUST EMISSION ANALYSIS

The major pollutants appearing in the exhaust of a diesel engine are the oxides of nitrogen. Exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO2 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. For measurement of UBHC, CO, CO_2 and NOx, AVL 4000 Light Di-Gas Analyzer was used. Both the AVL 437 Smokemeter and AVL Di Gas Analyzer are shown in Plate 3.10.The details of test rig instrumentation are shown in table 3.2.The engine trial was conducted as specified in IS: 10,000.

Plate 3.10 AVL Smoke analyzer and AVL Di-Gas Analyzer

Table 3. 2 Test rig specification

S.N	Instrument Name	Measurement Range	Resolution	Measurement Technique	% uncertainty
	AVL DI GAS ANALYSER				
1	CO	0 – 10 % Volume	0.01 %volume	Non dispersive infra-red sensor	0.2%
2	HC	0 – 20.000 ppm Volume.	1ppm	Flame ionization detector-FID	0.2%
3	NO_x	0-5,000 ppm volume	1 ppm	Chemi-luminescence principle, electrochemical sensor	0.2%
	AVL SMOKE METER	**0 - 100%**	**±1 % volume**	**Hatridge principle**	**0.1%**

3.6 PARAMETERS SELECTION

The selections of appropriate parameters were essential for engine calculations, and parameters were selected very judiciously. The engine test was done as specified by IS: 10000. The main parameters desired from the engine are listed below.

1. Power produced by the engines
2. Brake Specific Energy Consumption
3. Brake Mean Effective Pressure
4. Engine speed (Rev/min)
5. Fuel consumptions
6. Temperature
7. Exhaust Gas Emissions
8. Exhaust Gas Temperature

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. Fuels consumption rate
5. AVL 437 smoke meter reading
6. AVL Di Gas analyzer reading

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

3.7 EXPERIMENTAL PROCEDURE

The engine was started at no load by pressing the exhaust valve with decompression lever and it was released suddenly when the engine was hand cranked at sufficient speed.

After feed control was adjusted so that engine attains rated speed and was allowed to run (about 30 minutes) till the steady state condition was reached. With the fuel measuring unit and stop watch, the time elapsed for the consumption of 10, 20 and 30cc of liquid fuel was measured and average of them was taken. While gaseous fuel was measured with the help of rotameter. Fuel Consumption, RPM, exhaust temperature, smoke density, CO, NOx, HC , CO_2 and power output were also measured. The engine was loaded gradually keeping the speed with in the permissible range and the observations of different parameters were evaluated. The performance and emission characteristics in dual fuel system having CNG with various blends of Jatropha oil methyl ester and diesel were evaluated and compared with baseline diesel fuel. The engine was always started with diesel as a fuel and after it was run for 20-25 minutes, it was switches over to Jatropha oil methyl ester blends, meanwhile fuel flow is controlled using governor and CNG is introduced by switching on the solenoid switch. Before turning the engine off, the Dual Fuel System was replaced with diesel oil and it was run on diesel oil till all Jatropha oil methyl ester in fuel filter and pipe line is consumed.

RESULT AND DISCUSSION

4.0 INTRODUCTION

The present study was done on a modified diesel engine which run on a dual mode operation. The main objective of the study was to fuel the diesel engine with blends of Jatropha oil methyl ester and diesel. The performance and emission studies on dual fuel mode with CNG and various blends were evaluated and compare the results with baseline diesel fuel.

4.1 RESULTS OF PHYSICOCHEMICAL PROPERTIES

4.1.1 GAS CHROMATOGRAPH

Fatty acid profile of the biodiesel was determined by gas chromatography.Figure 4.1 shows the gas chromatogram of Jatropha oil methyl ester. The peak of the graph indicates retention time. Table 4.1 indicates the composition of different fatty acid present in the Jatropha oil. The saturated fatty acid in the present biodiesel is higher than the unsaturated fatty acid, so its cetane number is higher; however, this biodiesel has poor cold flow property.

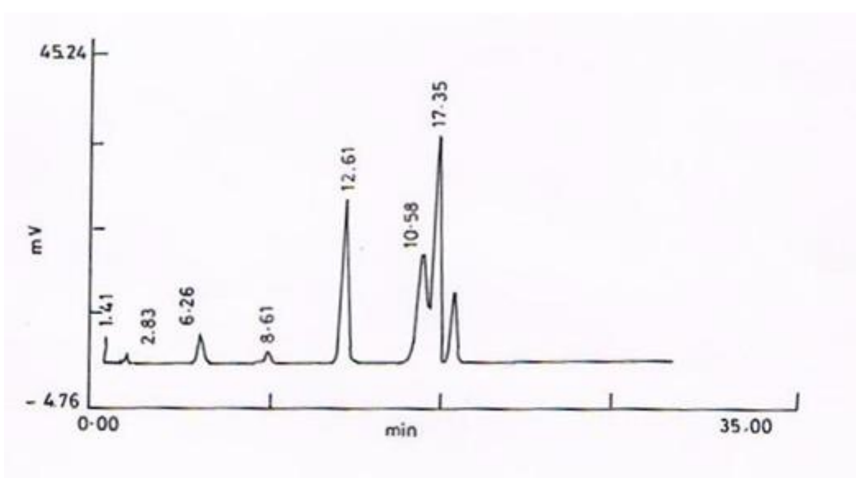

Fig 4.1 Graph obtained from Gas Chromatograph for Jatropha oil biodiesel

Table 4.1 Trivial names and percentage composition of fatty acids present in the Jatropha oil biodiesel

Trivial Name (C: D)	Composition (%)
MYRISTIC ACID (C: 0)	1.14
PALMITIC ACID (C16:0)	24.43
STEARIC ACID (C18:0)	23.47
OLEIC ACID (C18:1)	37.17
LINOLEIC ACID (C18:2)	9.57

4.1.2 OXIDATION STABILITY

The results obtained using Rancimat Test for different blends of Jatropha Oil Methyl Esters are obtained in the form of graphs, in between conductivity and time (in hours) is as follows:

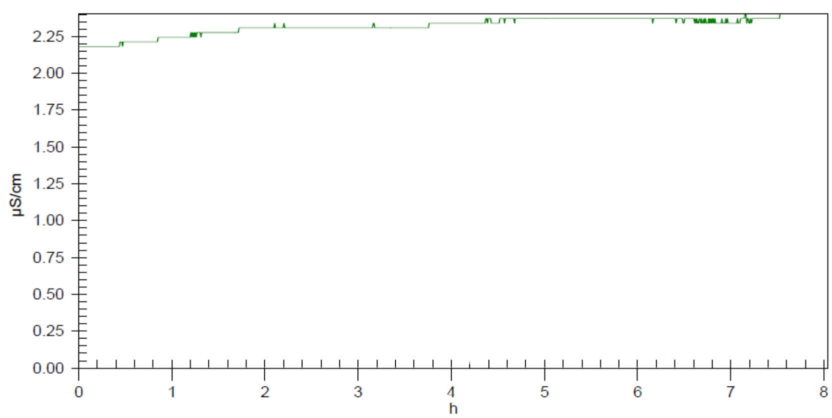

Fig 4.2 Oxydation Stability of JOME

Clearly, JOME passed through IP of 6 hours, satisfying the condition required for Rancimat Induction Test. Hence, the Jatropha oil methyl Ester can be blended with Diesel in optimum percentage, as it will maintain its Physico-chemical characteristics, over a certain period of time.

From this experiment it was clear that as oxidation deterioration advances with respect to time.From the above detailed experimental study, it can be concluded that Jatropha Oil with wonderful characteristics as a fuel, can be utilized in form of Methyl Ester as it satisfies the parameters and standards like EN-14214, EN-14112 and ASTM standard D-6751 with IP greater than 6 hours.

4.1.3 OTHER PHYSICO-CHEMICAL PROPERTIES

Physico-chemical properties of Jatropha oil methyl ester and its blend (in different volumetric proportion) with mineral diesel were evaluated using standard test facilities Neat Jatropha oil biodiesel has lower calorific value than that of mineral diesel but having high viscosity and density. The different blends prepared are as follows: D 100(mineral diesel), JOME 25 (25 % Jatropha biodiesel and 75 % pure diesel), JOME 50 (50% Jatropha biodiesel and 50 % pure diesel), JOME 75 (75% Jatropha biodiesel and 25 % pure diesel) and JOME 100 (neat Jatropha biodiesel) Kinematic viscosity and density increases with increase in percentage of biodiesel. But lower calorific value decreases as biodiesel content increases in the mixture, due to the presence of oxygen in the fuel and it requires more fuel to be burnt for a particular heat release. The Physico-chemical properties evaluated in respect of different blends are summarized in Table 4.2

Table 4.2 Physico-chemical properties of different blends of diesel and Jatropha biodiesel

Properties(unit)	D 100	JOME 25	JOME 50	JOME 75	JOME	ASTM Method
Density(kg/m^3)	820.07	837.63	855.19	872.75	890.31	D-4052
Kinematic viscosity at 40ºC (centistokes)	2.8	3.20	3.36	3.65	3.70	D-445
Calorific value (MJ/Kg)	43.226	42.589	41.951	41.314	40.676	D-4809
CFPP Result (ºC)	-14	-12	-7	1	5	

4.1.4 PHYSIO-CHEMICAL PROPERTIES OF CNG

Today CNG is considered as one of the most promising alternative fuels used in the IC engines worldwide. Typical composition of CNG available in India is given in Table 4.3. The main constituent of natural gas is methane, the lightest and simplest hydrocarbon, composed of one carbon and four hydrogen atoms. Ethane is typically the only other hydrocarbon found insignificant amount in CNG along with traces of carbon dioxide, nitrogen and very small amounts of hydrogen and helium.

Table 4.3: Typical Compositions (%V/V) of Compressed Natural Gas available in India [78]

Component	Symbol	% (V/V)
Methane	CH_4	94.42
Ethane	C_2H_6	2.29
Propane	C_3H_8	0.03
Butane	C_4H_{10}	0.25
Carbon dioxide	CO_2	0.57
Nitrogen	N_2	0.44
Others	H_2O	2.0

The composition of CNG is very important because it affects the physical properties which can influence its combustion characteristics. Table 4.4 shows the combustive properties of CNG compared to conventional fuels like gasoline and diesel. The stoichiometric ratio of CNG is higher than gasoline or diesel because it has a higher percentage of hydrogen. The higher flammability limits of CNG compared to gasoline and diesel suggests that more methane is required to create a flammable mixture, making it inherently safer in the event of an accidental leakage. Auto ignition temperature of CNG is significantly higher than that of gasoline or diesel, making it less susceptible to ignition when exposed to hot surfaces.

Table 4.4: Combustion Properties of Gasoline, CNG and Diesel [79]

Property	Gasoline	Diesel	CNG
Molecular Weight (g/mol)	114.23	233	16.69
Density (kg/m^3) at 25^{0}C and 1 atm	800	803	0.62
Molar Octane Number	80 - 90	-	120
Specific Gravity	0.692 (water)	0.8 (water)	0.51 (air)
Flash Point (^{0}C)	- 43	74	-188
Stoichiometric Air Fuel Ratio $(A/F)_s$	14.6	14.5	17.2
Latent Heat of Vaporization (kJ/kg)	349	233	510
Lower Heating Value (MJ/kg)	43.6	42.5	47.3
Flammability limits (vol % air)	1.3 - 7.1	0.6 - 5.5	5 - 15
Spontaneous Ignition Temperature (^{0}C)	480 - 550	250	645

4.2 PERFORMANCE CHARACTERISTICS

As we already been satisfied from the literature review that addition of CNG in JOME has a positive effect on the combustion efficiency. CNG makes a homogeneous mixing inside chambers which helps in the complete combustion. During the initial engine trials, a comparative study has been performed and various performance curves were plotted against the brake mean effective pressure, which are shown in figure 4.3-4.4:

4.2.1 BRAKE THERMAL EFFICIENCY (BTE)

The variation in brake thermal efficiency (BTE) is shown in Fig 4.3. From the experimental tests result it is observed that there is slight decrease in BTE for all the blends.

In fig. 4.3 it is observed that the brake thermal efficiency of CNG with JOME25 at 75% load is 33.45% compared to diesel of 29.3%. However, it is 31.25% for CNG-JOME. The increase in brake thermal efficiency of CNG-JOME25 mode was due to cooling of inlet charge which reduces the temperature about 12-15ºC and it also due to higher latent vaporization heat of JOME. However, at low loads lesser BTE was obtained due to improper mixing of charge. Cooling of inlet charge leads to the increase in charge density hence an improvement in BTE is noticed. This improvement also supported by the uniform mixing of the charge. However, CNG-JOME produces lowest BTE among dual fueling system at full load due to the lower calorific value and higher viscosity cause improper atomization of the blends which leads to improper combustion.

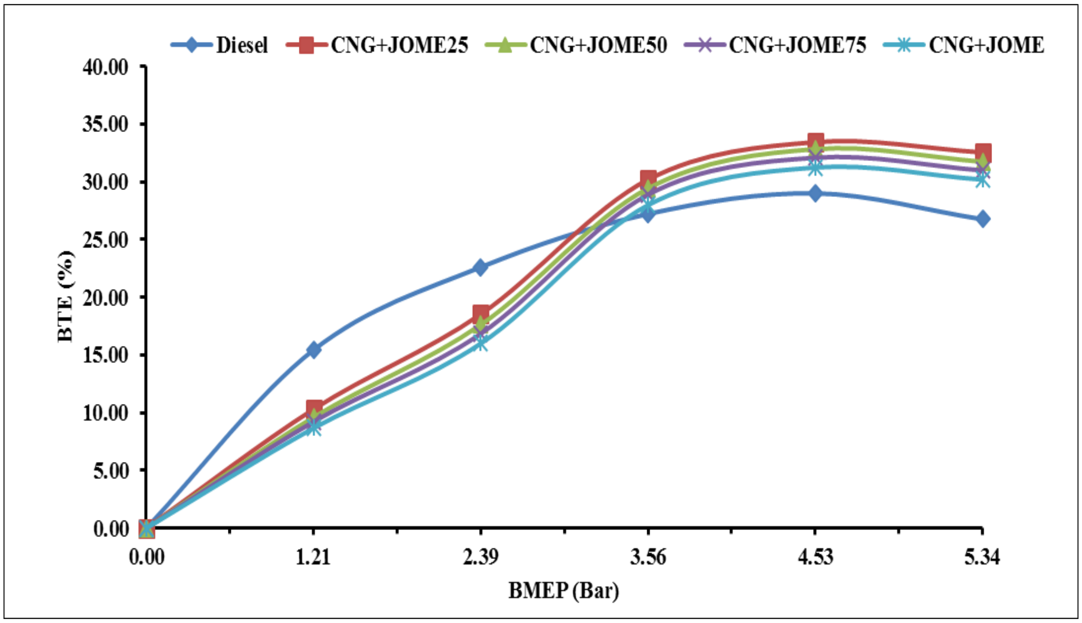

Fig4.3 Effect of BMEP on BTE

4.2.2 BRAKE SPECIFIC ENERGY CONSUMPTION (BSEC)

Brake specific energy consumption (BSEC) measures the amount of input energy required to develop one-kilowatt power. The BSEC is an important parameter of an engine because it takes care of both mass flow rate and heating value of the fuel. Basic specific energy consumption is an essential and ideal parameter for comparing engine performance of the fuels having different calorific value and density. Fig 4.4 it can be seen that, for diesel BSEC decreases with respect to engine load and same was observed for other operating conditions. However, the consumption of CNG-JOME blends was lower than that of diesel for higher and intermediate loads. Therefore, CNG-JOME is an economical substitute for diesel engines. Also BSEC of CNG-JOME blends dual fuel was reduced by 22% than diesel for dual fuel operation at 75% engine load. This decrease in BSEC is due to the homogeneous mixing of CNG and air which results in the better combustion.

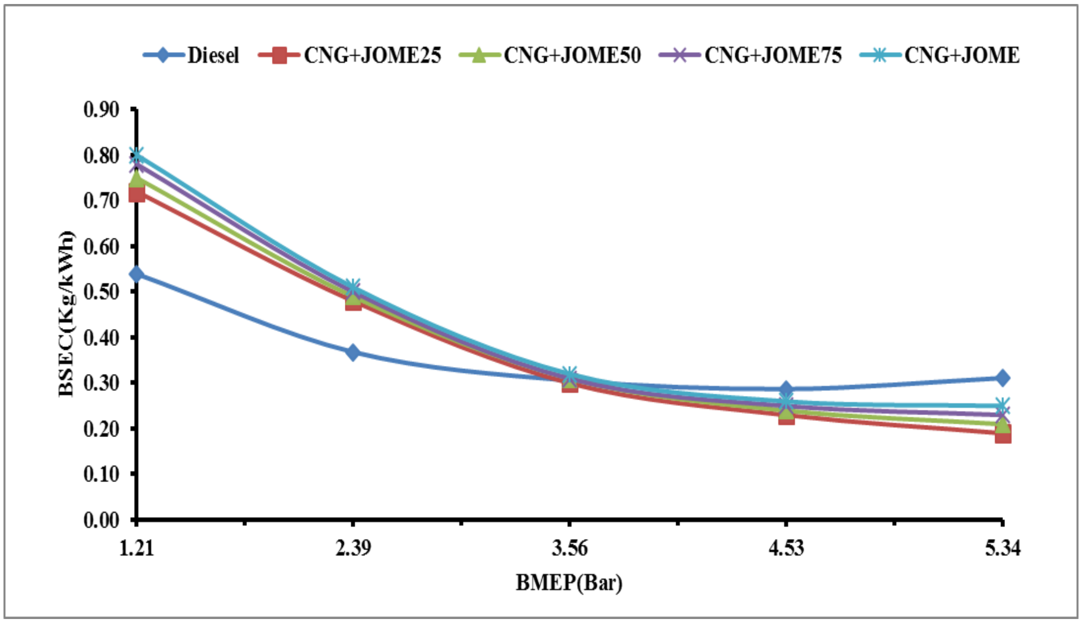

Fig 4.4 Effect of BMEP on BSEC

4.3 EMISSION CHARACTERISTICS

As we all know that, use of CNG-JOME improves the combustion quality which helps in producing fewer emissions as compared to diesel. Normally, diesel engine accounts for the emissions like CO (carbon monoxide), HC (hydrocarbons), NOx (oxides of nitrogen), and Smoke, which are explained from fig. 4.5 to fig.4.8

4.3.1 CO EMISSION

The variation of carbon monoxide emission is shown in Fig. 4.5. At 25% load condition CO emission was noted about 054 ppm for CNG-JOME mode. However, for CNG-JOME25 operation it was found 0.45 ppm compared to diesel of 0.02 ppm. The higher CO emission at low load during CNG-JOME operations is due to the lower combustion temperature which results in the incomplete combustion of fuel. At 75% load, the CO emission of diesel and CNG-JOME operations were found almost same i.e. 0.82 ppm. The lower CO emission of CNG-JOME fuel at higher load was due to the lower carbon content in CNG and also due to increases in amount of oxygen content in biodiesel helps in complete combustion and proper oxidation.

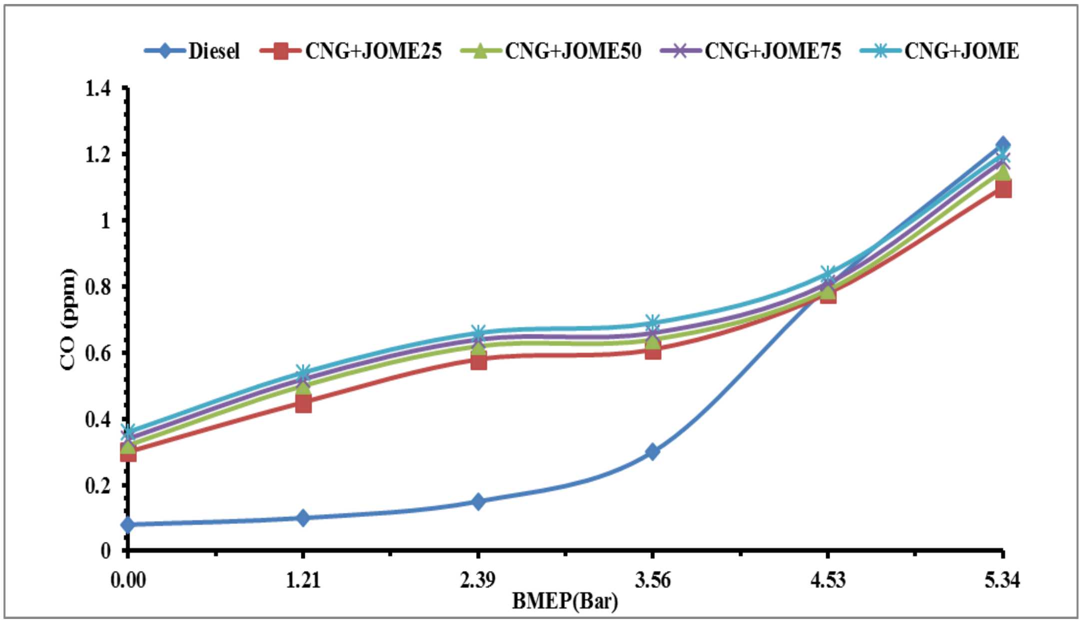

Fig4.5 Effect of BMEP on CO

4.3.2 HYDROCARBON (HC)

The HC emissions of different blends are shown in Fig.4.6. It is found that the CNG-JOME shows a high HC emission at low load than other operating conditions. This was due to the improper mixing of charge at lower load which reduces the combustion quality. Also, because of non-availability of oxygen during diffusion combustion period, CNG-JOME has ignition lag and hence it undergoes instantaneous combustion as soon as the ignition starts [80]. While, at higher load it has the lowest HC emissions due to the complete combustion. At all range of loads HC emissions are found higher for CNG-JOME operation than diesel. This was due to the higher viscosity of biodiesel which leads to indecent combustion. At 40% load, hydrocarbon emissions were found maximum for CNG-JOME mode i.e. 95 ppm compared to diesel which produces 34 ppm HC emissions.

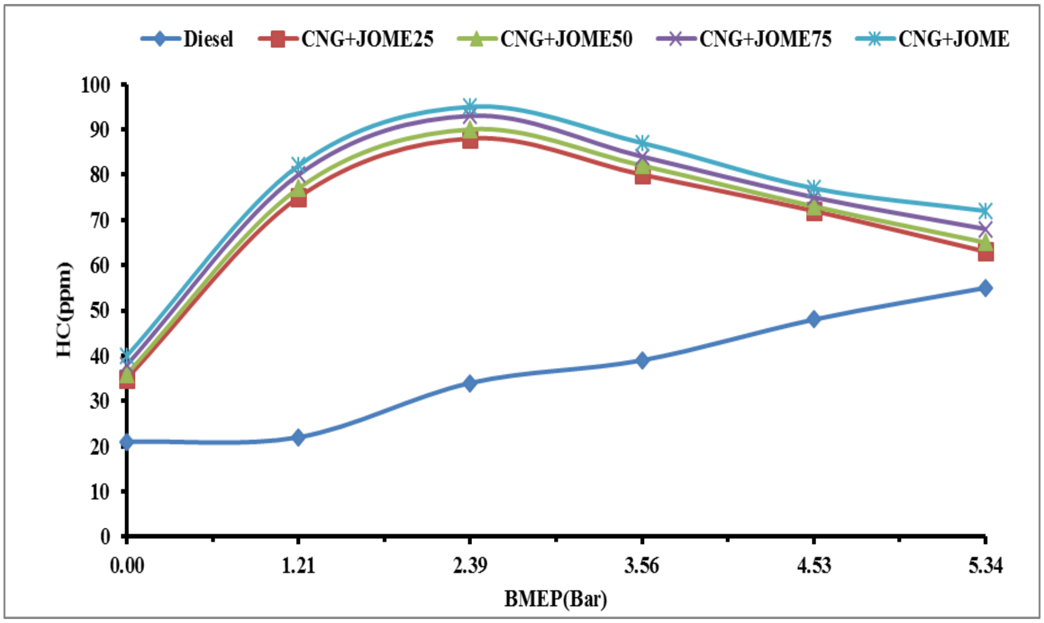

Fig 4.6 Effect of BMEP on HC

4.3.3 NITROGEN OXIDE (NO_X)

The NOx values as parts per million (ppm) of diesel and CNG-JOME operation in exhaust emissions are plotted in Fig 4.7. During the combustion of CNG-JOME at low loads the lower NOx concentration was due to the reduction in flame temperature for CNG-JOME operation due to improper mixing of charge. However, at high load higher concentration of NOx was found which is due to the high peak flame temperature generated because of better combustion [81].This could be attributed to the increased exhaust gas temperatures due to higher calorific value of CNG which produces a large amount of heat and the fact that biodiesel had some oxygen content in it which facilitated NOx formation. In general, the NOx concentration varies linearly with the load of the engine. NOx emissions are a direct function of engine loads. With increasing load, the temperature of the combustion chamber increases and NOx formation is enhanced because NOx formation is strongly dependent on the temperature. Another point is that the NOx emissions of biodiesel are higher than diesel fuel in spite of any blending rates. This is in accordance with their port on biodiesel from National Biodiesel Board of USA. As the load increases, the overall fuel-air ratio increases resulting in an increase in the average gas temperature in the combustion chamber and hence NOx formation, which is sensitive to temperature increase.

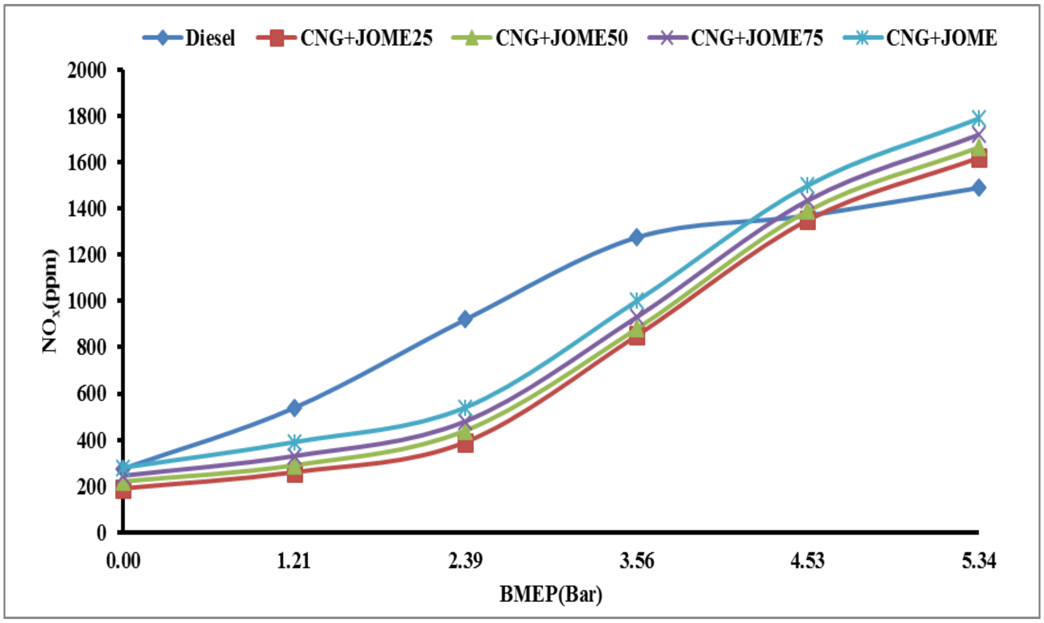

Fig 4.7 Effect of BMEP on NOx

4.3.4 SMOKE OPACITY

The variation of smoke is shown in Fig. 4.8. The smoke of 4.2 ppm was observed in CNG-JOME25 operation compared to base diesel fuel of 7.7 ppm and 5.6 ppm for CNG-JOME dual fuel at 75% load. The CNG on combustion produces mainly water vapor and does not form any particulate matter due to the absence of carbon atom, hence lower smoke level at higher load.

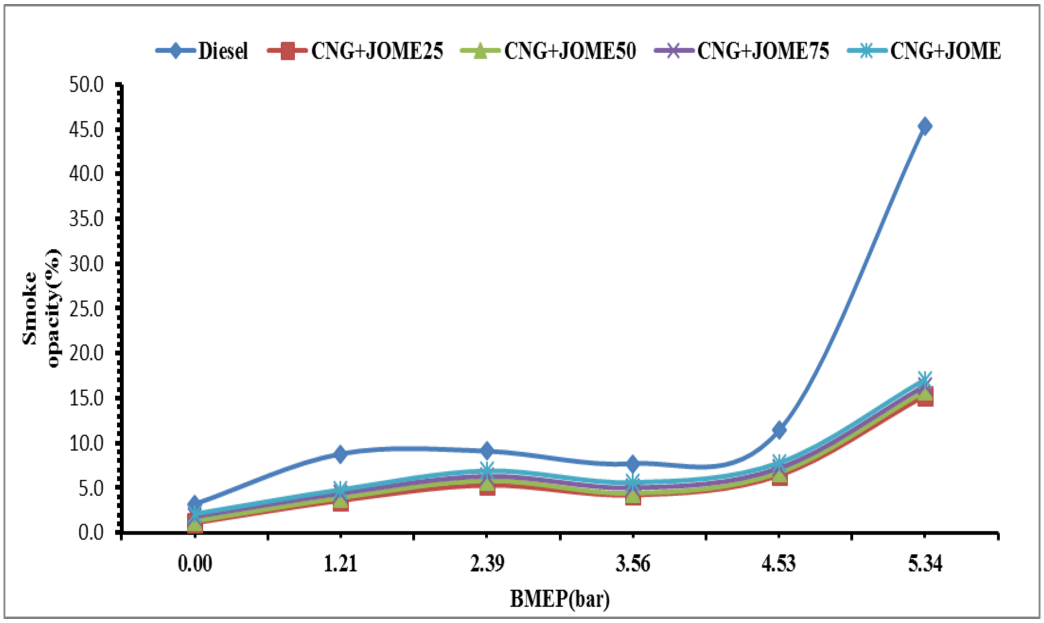

Fig 4.8 Effect of BMEP on Smoke Opacity

CONCLUSION AND SCOPE FOR FUTURE WORK

5.0 CONCLUSION

In the present study, the engine is slighlty modified to use it in a dual fuel mode and the experiments were conducted in dual fuel mode using CNG with blends of jatropha oil methyl ester and that of diesel. Subsequently performance, and emission studies were carried out .

Based on the experimental results, the following major conclusions have been drawn:

1. Full load brake thermal efficiency was found to be higher than diesel and CNG-JOME25 has highest BTE among all and with increase in JOME percentage in the blend BTE decreases slightly due to lower heating value of biodiesel.
2. Brake specific energy consumption of 13.44 MJ/kWh was observed for diesel at full load, while CNG-JOME dal fuel exhibits 22% lesser than it. Higher BSEC is observed in case of dual fuelling at lower load and tend to decreases with increase in load. At 50% load BSEC is almost equal for all the curves and retains property similar to that condition with diesel. With increase in percentage of JOME in the CNG-JOME blend, a steady increase in BSEC was observed.
3. Slightly increased NOx emissions are associated at high load with CNG-JOME operation, as higher calorific value of CNG and higher cetane rating of JOME leads to improved combustion, which rises the in-cylinder temperature resulting in higher NOx emission for blended fuels as compared to baseline data. Full load NOx emission was steeply increased by 23% for CNG-JOME as compared to diesel baseline.
4. CO emission were to be higher at low load during dual fuel operations is due to the lower combustion temperature which results in the incomplete combustion of fuel.

This is due to accumulation of fuel at part load which burns out with increase in load. At 75% load, the CO emission of diesel and CNG-JOME operations were found almost same i.e. 0.82 ppm. The lower CO emission of CNG-JOME fuel at higher load was due to the lower carbon content in CNG and also due to increases in amount of oxygen content in biodiesel helps in complete combustion and proper oxidation.

5. HC emission is much higher at low load for CNG-JOME dual mode and decreases with increase in engine load due to the improper mixing of charge at lower load which reduces the combustion quality. Also, because of non-availability of oxygen during diffusion combustion period, CNG-JOME has ignition lag and hence it undergoes instantaneous combustion as soon as the ignition starts
6. Variation in smoke opacity was substantial at lower loads for all the test fuels. However, at higher loads, CNG-JOME blends showed reduction in smoke opacity as compared to neat diesel operation. This is due to presence of CNGwhich produces mainly water vapor and does not form any particulate matter during combustion due to the absence of carbon atom, hence lower smoke level at higher load.

As a fair conclusion of the exhaustive engine trial, it may be stated that a CNG-JOME in dual fuel mode will result in better engine performance and emissions of HC,CO and smoke opacity .However, emission of NOx was found to get enhanced with increase in load which may be addressed through adequate catalytic converters. Furthermore this system reduces dependency over mineral diesel and overcome the llimitaion of using biodiesel by using it as a pilot quantity only necessary along with injection timing and duration for better combustion of biodiesel in diesel engines.

5.1 FUTURE WORK

On the basis of experience gained during the present experimental studies, the following diections are indicated for further investigation and development.

1. Investigate the feasibility of advanced pilot fuel injection timing and EGR (exhaust gas recirculation) addition on CNG-diesel, CNG-Biodiesel and H_2-Diesel dual fuelled engine operation.
2. Modifying the pilot fuel properties such as O_2 and, CN, density, bulk modulus, and H/C ratio by using different fuel additives will be useful. It is necessary to know and to specify the appropriate or the best pilot fuel characteristics for a specific gaseous fuel.
3. Setup a small combustion chamber which helps out to find the ignition delay of any liquid and gaseous fuels.
4. Find out the best optimum combination of CNG, LPG, H_2 with biodiesels.
5. Work on engine hardware modifications are worth investigating because of the direct effect on the combustion characteristics and emissions as well. Various fuel injection timings, multiple injections, and turbocharger are possible in the dual fuelled engine mode to further explore the fuel combustion characteristics.

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APPENDIX – I

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	:250ºC	
Temperature at entrance		

APPENDIX – II

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	

ANNEXURE 1

Formula for calculation of Brake Thermal Efficiency and Brake Energy Fuel Consumption

Brake Thermal Efficiency (η_{th}):

$$\eta_{th} = \frac{brake\ power}{fuel\ power}$$

$$\eta_{th} = \frac{3600\ \times BP}{FC \times Q_{lcv}}$$

Where:

η_{th} = thermal efficiency;

BP = brake power [kW];

FC = fuel consumption [kg/h = (fuel consumption in L/h) x (ρ in kg/L)];

Q_{lcv} = calorific value of kilogram fuel [kJ/kg];

ρ = relative density of fuel [kg/L].

Brake Fuel Energy Consumption:

$$\text{BSEC} = \frac{m_{f \times Q_{lcv}}}{1000 \times BP} \times 3600 [\text{MJ/KWh}]$$

Where:

m_f= mass flow rate [Kg/sec];

Q_{lcv} = calorific value of kilogram fuel [kJ/kg];

BP = brake power [KW].

ANNEXURE 2

List of Publications

S.N.	Title Of The Paper	Name of The journal/ Proceeding	Date Of Issue	Single/ Joint
Papers In Journal				
1	Performance and emission analysis of CI engine in dual mode with CNG and Jatropha oil methyl ester	Mangalmay Journal of Management & Technology. Print ISSN: 0973-7251	March, 1,2014	Joint
2	Orange Peel Oil- An alternative fuel in single cylinder diesel engine	Mangalmay Journal of Management & Technology. Print ISSN: 0973-7251	March, 1,2014	Joint
Papers In Conferences				
3	Performance analysis of a ci engine in dual mode with hydrogen and diesel	Proceedings of 4th International Symposium on the Fusion science and Technologies	January 14, 2015	Joint
4	Performance and Emission Analysis of a CI Engine in Dual Mode with CNG and Karanja Oil Methyl Ester	Proceedings of SAE 2014 Commercial Vehicle Engineering Congress	October 7, 2014	Joint
5	Experimental Investigation of Orange Peel oil methyl Ester on Single cylinder Diesel Engine	Proceedings of SAE 11th International Conference on Engine & Vehicle	September 15, 2013	Joint