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Experimental Investigations of Performance and Emission Characteristics on C.I Engine by Using Biodiesel with Oxygenated Additives

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INTRODUCTION

In this world of modernisation, the economic development of a country mainly depends on industrialisation. Generally in industry, energy is one of the major aspect influences on its development. As the world of industrialisation is increasing, the energy inputs should be more to keep update with changing requirements according to the day to day advancements.

In major industries and power plants fossil fuels are used as there inputs such as coal and petroleum products up to the extreme limits. As they are non-renewable energy sources they are depleting day by day.

According to world statistics of automobile production, India produced 3.9 million units in 2011, Around the world, there were about 806 million cars and light trucks on the road in 2007, The major source of automobile depends on the petroleum products, consuming over 260 billion US gallons (980,000,000 m^3) of gasoline and diesel fuel yearly, as they are non-renewable and inchmeal decreasing, there will be a large cranny between production of fuels and the need.

As fossil fuel resources become less plentiful, they will become more and more expensive to acquire. Global politics also influence fossil fuel prices. Pollution emissions from fossil fuels may be harmful to ecosystems accelerate climate change. All fossil fuels produce greenhouse gasses such as CO_2 emissions when burned.

India was the fourth-largest energy consumer in the world after China, the United States, and Russia in 2011, and its need for energy supply continues to climb as a result of the country's dynamic economic growth and modernization over the past several years. According to the International Monetary Fund (IMF) India was the third-largest economy in the world in 2013. India is increasingly dependent on imported fossil fuels. Primary energy consumption in India has more than doubled between 1990 and 2012, reaching an estimated 32 quadrillion British thermal units (Btu). The country has the second-largest population in the world, at more than 1.2 billion people in 2012, growing about 1.3% each year since 2008, according to World Bank data. At the same time, India's per capita energy consumption is one-third of the global average, according to the International Energy Agency (IEA), indicating potentially higher energy demand in the long term as the country continues its path of economic development. In the International Energy Outlook 2013, EIA projects India and China will account for about half of global energy demand growth through 2040, with India's energy demand growing at 2.8% /year.

India's transportation sector, primarily fuelled by petroleum products, India has increased its total net oil imports from 42% of demand in 1990 to 71% of demand in 2012 and it was the fourth-largest consumer of oil and petroleum products after the United States, China, and Japan in 2013, and it was also the fourth-largest net importer of crude oil and petroleum products. The gap between India's oil demand and supply is widening, as demand reached nearly 3.7 million barrels per day (bbl/d) in 2013 compared to less than 1 million bbl/d of total liquids production. India's demand for crude oil and petroleum products is projected to continue rising, barring a serious global economic recession. Oil import dependence will continue to climb if India fails to achieve production growth equal to demand growth.

According to the World Bank, India's Annual population growth rate for year 2013 is 1.26% and total petroleum consumption from 2009-2013 is 3112 thousand barrels/day to 3509 thousand barrels/day and by 2040 India's demands will more than double to 8.2 million bbl/day.

In Andhra Pradesh itself, there are 57.53 lakhs of Motor vehicles in different categories. The vehicular population is increasing day by day and smoke emission from Automobile is causing pollution and also becoming hazardous to health, the total vehicular pollution load (VPL) in twin cities of Hyderabad and Secunderabad alone is 1500 T/day various pollutants released into the atmosphere. Which effects on earthlings health, causes a serious problem in coming days.

Present day, whole world is looking towards developments of renewable fuels which are eco-friendly such as biodiesel. As Worldwide, energy security is becoming a hot topic in government and society. Nearly every country in the world depends on imports of various forms of fossil fuel energy, including oil, coal and natural gas. Without a steady supply of affordable energy a country's economy grinds to a halt, with no fuel for transportation, energy to run power plants and factories.

Indian government has started a research project in search of alternate fuels and setup a PCRA (petroleum conservation research association) with a mission of "Efficient energy utilization and environment protection leading to Improvement in Quality of Life". PCRA started a National Biofuel centre of India (NBC), its objective is to support and facilitate efforts for adoptions and information dissemination for substitution of petroleum products with alternate and renewable fuels, and several state governments also started agencies, such as Karnataka State Biofuel Development Board.

Bio-diesel is an alternative to petroleum-based fuels derived from vegetable oils, animal fats, and used waste cooking. Biodiesel are widely available from various sources, and it has good heating power and provides exhaust gas with almost no sulphur and aromatic polycyclic compounds. Biodiesel can be used as fuels for diesel engines without any modifications, but their viscosities are much higher than usual diesel fuel.

The high viscosity causes difficulty during injection process. There are different methods for reducing viscosity such as by adding additives to fuel in a definite proportion, by blending with base fuel, by preheating of fuel and by used in dual fuel mode. Generally biodiesel are prepared from edible oils like soybean, sunflower, canola, and palm and fish oil. As the prices of edible oils are higher than Petroleum, by which the biodiesel production leads food versus fuel issue. So, to avoid that knot, scrutiny is made and found non-edible oils such as Jatropha oil, Pongamia oil, Rapeseed Oil, Mahua oil, Olive oil, Rice Bran oil, Linseed oil, Cotton seed oil, Beef Tallow, Lard, Guang-Pi oil. The main advantages of biodiesel given in the literature include domestic origin, reducing the dependency on imported petroleum, high flash point, inherent lubricity, lower toxicity compared to petroleum diesel fuel, and biodegradable and A joint study conducted by the U.S. Department of Agriculture, and the U.S. Department of Energy determined that biodiesel reduces net carbon dioxide emissions to the atmosphere compared with petroleum diesel fuel.

Thus, to decrease the cranny between need and supply of energy source and to protect earthlings form various undesirable pollution effects, it is essential to go for eco-friendly fuels. As a step in that direction, an attempt is made in this project to know the feasibility of using blend of biodiesel [Palm Stearin], oxygenated additive [Diethyl Ether], in place of diesel by conducting experiment on diesel engine. From the experimental data, engine performance and emissions of biodiesel with oxygenated additives is evaluated.

CHAPTER-2
LITERATURE SURVEY

A vigorous research is being carried out on suitability of using biodiesel and its blends with oxygenated additives in compression ignition engine which gives better performance and less emission with little or no modifications. In this regard, various works carried out by different researchers were studied.

M. Mofijur et al. [1], discussed the impact of bio fuel on diesel engines emission. From his review it is found that bio fuel significantly reduces engine emissions and it has potential to reduce more than 80% of GHG emission. Finally, bio fuel can be a viable alternative to be used as a transportation fuel.

S. Jaichandar et al. [2], in their paper reviews the history of biodiesel development and production practices. Fuel related properties are reviewed and compared with those of conventional diesel fuel. The effect of use of biodiesel fuel on engine power, fuel consumption and thermal efficiency are collected and analyzed with that of conventional diesel fuel. The engine emissions from biodiesel and diesel fuels are compared, paying special attention to the most significant emissions such as nitric oxides and particulate matter.

Yahuza I et al. [3], in their review discussed the properties and specifications of ethanol blended with diesel fuel. Special emphasis is placed on the factors critical to the potential commercial use of these blends. These factors include blend properties such as stability, viscosity and lubricity, safety and materials compatibility. The effect of the fuel on engine performance, durability and emissions is also considered. The formulation of additives to correct certain key properties and maintain blend stability is suggested as a critical factor in ensuring fuel compatibility with engines. However, maintaining vehicle safety with these blends may require special materials and modification of the fuel tank design. Further work is required in specifying acceptable fuel characteristics, confirming the long-term effects on engine durability, and ensuring safety in handling and storing ethanol-diesel blends.

H.M. Mahmudul et al. [4], in their paper summarized the information on bio-fuel development, feed stocks around the world, oil extraction technique, biodiesel production processes, advantages of biodiesel compared to fossil fuel. Moreover, the test of fuel properties is very important before using in the engine which depends on the type of feed stocks, origin country, and production process. It has been reported that the use of biodiesel in diesel engine reduces engine power slightly but reduces the harmful emission significantly. Finally, the study concludes that biodiesel has the potential to be used as a diesel fuel substitute in diesel engines to solve the energy and environment crisis.

M. Vijay Kumar et al. [5], in their review done a comparative study to find out the effects of additives for biodiesel fuel and efforts to recover the combustion and performance and to diminish the emissions. It has been concluded that the uses of additive to the second generation of biodiesel are the best in improving the combustion performance and emission reduction.

S. Kathirvel et al. [6], focussed on the study of the performance, combustion and emission parameters of CI engines using WCOME and to explore the possibility of utilizing WCOME blends with diesel extensively in place of diesel. It also includes the study of WCOME from different origins in various types of diesel engines. Most of the studies comply with the decrease in carbon monoxide (CO) emissions and the increase in brake thermal efficiency while using WCOME in CI engines.

Sanjay Bajpai et al. [7], in their investigations used methanol, ethanol, propanol and butanol for the formation of alkyl esters of Jatropha, Karanja and castor. The composition of Jatropha, Karanja and castor oil were analysed and alcoholysis process for preparing alkyl esters of Jatropha, Karanja and castor oil with various alcohols was optimised. Alkyl ester-diesel blends were used to test the diesel engine at different load conditions and extensive performance and emission studies were conducted in single cylinder direct injection CI engines. It is concluded that lower blends of ethyl, propyl, and butyl esters of jatropha and karanja feedstock have physico-chemical properties similar to methyl esters. However, deviation from the properties became larger for higher blending ratio.

CH.S. Naga Prasad [8], in his paper analysed the performance and emission characteristics by using linseed oil, castor oil, Mahua oil, Neem oil and their respective esters derived through transesterification process. Better results were found when compared with that of diesel.

Pankaj S. Shelke et al. [9], in their research used cotton seed vegetable oil to produce biodiesel by transesterification process using methanol and KOH as catalyst. The combustion characteristics of a cotton seed biodiesel with its blends (B5, B10, B15, and B20) are analysed. It has been concluded that cotton seed biodiesel can be used in blended form as an alternative fuel in any diesel engine without any modification and the characteristics such as ignition delay, start of combustion, cylinder pressure show better performance compared to base biodiesel.

Wojciech Tutak et al. [10], presented a comparative study of combustion and emission characteristics of diesel engine fuelled with diesel-ethanol and biodiesel-ethanol blends. The parameters such as IMEP and ITE, engine power, HC and NO_x emissions, CO and CO_2 emissions are compared.

Hasan Bayindir et al. [11], In their study produced biodiesel from canola oil by transesterification process and the blended test fuels B80 & K20 (Biodiesel 80% , kerosene 20%), B80K10D10 (Biodiesel 80%, kerosene 10%, diesel 10%) are used. Combustion, performance and emission characteristics of the blend fuel were analyzed and concluded that mass fuel consumption and BSFC were slightly increased for blend fuels, HC emissions slightly increased while NO_x emissions considerably reduced for blends.

Ambarish Datta et al. [12], carried out a numerical simulation in their work to evaluate the performance, combustion and emission characteristics of a compression ignition engine using different biodiesel-alcohol blends as fuels. The effects of two alcohols, namely ethanol and methanol addition to palm stearin biodiesel have been separately investigated and compared. The predicted results show slightly higher brake specific fuel consumption as well as brake thermal efficiency with biodiesel-alcohol blends compared to neat biodiesel. An effective reduction of NOx emission is also observed with the biodiesel-alcohol blends. However, the instantaneous heat release rate, ignition delay, PM and smoke emission are found to be more with alcohol blended fuels.

Puneet Verma et al. [13], made an effort to find out feasibility of biodiesel obtained from eucalyptus oil and its impact on diesel engine. Various fuel properties like calorific value, flash point and cetane value of biodiesel and biodiesel–diesel blends of different proportions were evaluated and found to be comparable with petroleum diesel. The result of investigation shows that Brake Specific Fuel Consumption (BSFC) for two different samples of B10 blend of eucalyptus biodiesel is 2.34% and 2.93% lower than that for diesel. Brake Thermal Efficiency (BTE) for B10 blends was found to be 0.52% and 0.94% lower than that for diesel. Emission characteristics show that Smoke Opacity improves for both samples, smoke is found to be 64.5% and 62.5% cleaner than that of diesel. Out of all blends B10 was found to be a suitable alternative to conventional diesel fuel to control air pollution without much significant effect on engine performance.

Sanghoon Lee et al. [14], investigated the effects of blending ratio of Karanja oil methyl ester (KOME) on spray characteristics and analyzed the engine performance and exhaust emissions of Karanja biodiesel blend. In the engine experiment, lower max torque, brake thermal efficiency (BTE) and exhaust gas temperature, in addition to higher brake specific fuel consumption (BSFC) were observed for biodiesel blend compared to diesel due to lower heating value of Karanja biodiesel.

Soo-Young No [15], in his paper reviewed the application of SVO produced from the triglycerides based biomass to IC engines such as CI engines and gas turbines. For the application of SVO as an alternative fuel for diesel fuel, the selection of inedible SVO is preferable because of the great need for edible oil as food. The blended SVO in the fuel modification strategy and the preheating SVO in the engine modification technique were mainly investigated. The optimum blending ratio of inedible SVO with diesel was found to be 20%. The optimum preheating temperatures were 60–85 °C for edible SVOs, and 80–120 °C for inedible SVOs, respectively. In addition, the preheating temp and the blending percentage were 65 °C and 50% for edible SVOs, and 65–80 °C and 50% for inedible SVOs. The most practical and effective method for decreasing the viscosity of SVO is found to be the preheating and blending SVO simultaneously.

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S. Ramkumar et al. [16], in their paper reviewed the performance and emission characteristics of biodiesel in C.I engines, the influence of engine modifications, various additives, and various proportions of blends of biodiesel with diesel. The physical and thermal characteristics of biodiesel have a great influence in the performance and emission. It also attempts feasibility of admitting vegetable oil in IC engine through Thermal Cracking.

T. M. Yunus Khan et al. [17], investigated on the emergence of the necessity of using biodiesel as an alternative fuel which has comparable properties with that of fossil fuels. Their paper reviews the effects of different engine variables such as compression ratio, load and speed, fuel injection parameters, air swirl, piston design on the performance of engine. It has been concluded that the use of electronic control unit would help the engine-variables to give better performance and cause fewer emissions.

P. Mohamed Shameer et al. [18], enlightened the momentous of injection parameters like injection timing and injection pressure on the engine emission characteristics. It also touches upon the advancement and retardation methods of fuel injection timing and injection pressure to inspect the engine emission indicators such as carbon monoxide, hydrocarbon, oxides of nitrogen, Smoke, particulate matter and carbon dioxide contents. It is concluded that the biodiesel production from various feed stocks have an immense significance as a substitute power source for diesel. The emission characteristics of the compression ignition engine fuelled with biodiesel can be enhanced to an eco-friendly rank by advancing the injection timing and increasing injection pressure to an extent based on the biodiesel properties.

Sakthivel Gnanasekaran et al. [19], in their work reviewed the feasibility of using fish oil biodiesel as a fuel for operating a diesel engine under variable load conditions. Performance, emission and combustion characteristics were analysed. It is concluded that Oxides of Nitrogen (NOx), Un burnt Hydro carbon (UBHC) and Carbon Monoxide (CO) emissions in biodiesel blends were lower than diesel, whereas smoke was found to be higher. The brake thermal efficiency for B20 was higher compared to diesel in the entire load spectra. The ignition delay and combustion duration were shorter for biodiesel blends than diesel which results in lower heat release rate, peak pressure and rate of pressure rise. Retardation of injection timing caused decrease in emission and combustion parameters like NOx, HC, CO, peak pressure, ignition delay, combustion duration and heat release rate which increased with advancement in injection timing.

Melakuu Tesfaye et al. [20], studied the effect of poly (lactic acid)-oligomer (OLLA) on cold flow properties. IC engine performance and subsequently, exhaust gas emission characteristics is evaluated using microwave synthesized biodiesel from soybean oil. Cloud point, pour point, flash point and fire point of synthesized biodiesel were analyzed as reference properties. The engine performance test reveals the comparative utilization of brake specific fuel consumption and break thermal efficiency with significant reduction in carbon monoxide and incombustible hydrocarbon in the exhaust gases. Hence, the research demonstrates the use of OLLA for improvement in the cold flow properties of biodiesel and the exhaust gas emission characteristics.

H.H. Masjuki et al. [21], in their study, introduced HHO gas with ordinary diesel (OD) and 20% (v/v) palm biodiesel blended with OD (PB20) for evaluating the engine performance and emission characteristics. Optimum yield of HHO was found using single anode and two cathodes from a solution containing 1% KOH and 100 ml of water producing 2150 cc of HHO gas when electrolysis was carried out for 15 min. Using the HHO generator, about 2% more power and 5% less consumption was observed for biodiesel blended fuel in a single cylinder CI engine at full load variable speed operating conditions. Besides, on an average 20% and 10% reduction of CO and HC emission were observed respectively.

A.K. Azad et al. [22], in their paper critically reviewed the recently developed combustion strategies for biodiesel combustion in CI engine. Low temperature combustion (LTC) is one of the recently developed strategies that have three different categories, namely homogeneous charge, premixed charge and reactive controlled compression ignition. The study identified that LTC strategy can significantly reduce PM and NOx emission by combustion of biodiesel. However, CO and HC emission increases due to higher rate of exhaust gas recirculation (EGR). It also identified that CI engine produces lower break thermal efficiency and higher break specific fuel consumption (BSFC) under LTC combustion strategies. The study concluded that biodiesel combustion under LTC combustion strategies significantly reduces NOx emissions by reducing peak combustion temperature using EGR. In some cases, the condensation of un-burnt fuel increases PM emissions during LTC combustion due to the different fuel properties of biodiesel mixture. The main drawbacks in LTC strategies are higher brake specific fuel consumption and lower thermal efficiency, higher UHC and CO emission though it has excellent capacity for limiting NOx emissions.

Considering the above investigations, an attempt has been made in this project, to know feasibility of using blends of Biodiesel with additives, in the place of diesel. From the experimental data engine performance is evaluated considering thermal efficiency, specific fuel consumption, mechanical efficiency and the exhaust emissions. The above investigations may lead to substantial contribution to development of CI engine using Palm Stearin biodiesel with oxygenated additive.

CHAPTER-3
ALTERNATIVE FUELS

3.1. INTRODUCTION:

In this century, it is believed that crude oil and petroleum products will become very scarce and costly.

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Day to day, fuel economy of engines is getting improved and will continue to improve. However, enormous increase in number of vehicles as started dictating the demand for fuel. Gasoline and diesel will become scarce and most costly in the near future. With increased use and the depletion of fossil fuels, alternative fuel technology will become more common in the coming decades.

All these years there have always been some I.C engines fuelled with non-gasoline or diesel oil fuels. However, their numbers have been relatively very small. Because of the high cost of petroleum products, some developing countries are trying to use alternate fuels for their vehicles.

Another reason motivating the development of alternate fuels for the I.C engine is the concern over the emission problems of gasoline and diesel engines. Combined with other air polluting systems, the large number of automobiles is a major contributor to the air quality problem of the world. Quite a lot of improvements have been made in reducing emissions from automobile engines. If a 35% improvement made over a period of years, it is to be noted that during the same time the number of automobiles in the world increases by 40%, thereby nullifying the improvement. Lot of efforts as gone in to for achieving a net improvement in cleaning up automobile exhaust. However, more improvements are needed to bring down the ever increasing the air pollution due to automobile population.

A third reason for alternate fuel development is the fact that a large percentage of a crude oil must be imported from other countries which control the larger oil fields. As of now many alternate fuels have been used in limited quantities in automobiles. Quite often, fleet vehicles have been used for testing. This paves way for comparison with similar gasoline fuelled vehicles, and simplifies fuelling of these vehicles.

The engines used for alternate fuels or modified engines which were originally designed for gasoline fuelling. They are, therefore not the optimum design for the other fuels. Only when extensive research and development is done over a period of years, maximum performance and efficiency can be realized from these engines. However, the research and development is difficult to justify until the fuels are accepted as viable for large numbers of engines.

Some diesel engines have started appearing on the market. They use methanol or natural gas and a small amount of diesel fuel that is injected at the proper time to ignite both fuels. Most alternate fuels are very costly at present since the quantity used is very less. Many of these fuels will cost much less if the amount of their usage gets to the same order of magnitude as gasoline. The cost of manufacturing, distribution and marketing would be less.

Another problem with alternate fuels is the lack of distribution points where the fuel is available to the public. The public will be reluctant to purchase an automobile unless there is a large-scale network of service stations available where fuel for that automobile can be purchased. On the other hand, it is difficult to justify building a network of these service stations until there are enough automobiles to make them profitable. Some cities have started a few distribution points for some of these fuels, like propane, natural gas, LPG and methanol. The transfer from one major fuel type to another will be a slow, costly, and sometimes painful process.

3.2. FUEL TYPES:

Internal combustion engines can be operated on different types of fuels such as liquid, gaseous and even solid fuels. Depending upon the type of fuel to be used the engine has to be designed accordingly.

3.2.1. Solid Fuels:

The solid fuels find little practical application at present because of the problems in handling the fuel as well as in disposing off, the solid residue or ash after combustion. However, in the initial stages of the engine development, solid fuels such as finely powdered coal was attempted. Compared to gaseous and liquid fuels, solid fuels are quite difficult to handle and storage and feeding are quite cumbersome. Because of the complications in the design of the fuel feed systems these fuels have become unsuitable in solid form. Attempts are being made to generate gaseous or liquid fuels from charcoal for use in IC engines.

3.2.2. Gaseous Fuels:

Gaseous fuels are ideal and pose very few problems in using them in internal combustion engines. Being gaseous, they mix more homogeneously with air and eliminate the distribution and starting problems that are encountered with liquid fuels. Even though the gaseous fuels are the most ideal for internal combustion engines, storage and handling problems restrict their use in automobiles. Consequently, they are commonly used for stationary power plants located near the source of availability of the fuel. Some of the gaseous fuels can be liquefied under pressure for reducing the storage volume but this arrangement is very expensive as well as risky. Because of the energy crisis in the recent years considerable research efforts are being made to improve the design and performance of gas engines which became obsolete when liquid fuels began to be used.

3.2.3. Liquid Fuels:

In most of the modern internal combustion engines, liquid fuels which are the derivatives of liquid petroleum are being used. The three principal commercial types of liquid fuels are benzyl, alcohol and petroleum products. However, petroleum products form the main fuels for internal combustion engines as on today.

3.3. VEGETABLE OILS:

Vegetable Oil is considered as one of the alternative fuels for diesel engines However, the viscosity of vegetable oil is higher compared to diesel. Therefore, it must be lowered to allow for proper atomization in engines designed to burn diesel fuel. Otherwise, incomplete combustion and carbon build up will ultimately damage the engine. Some literatures classify vegetable oil as Waste Vegetable Oil (WVO) and Straight Vegetable Oil (SVO) or pure Plant Oil (PPO) TO distinguish it from biodiesel. Copper and its alloys, such as brass, are affected by WVO. Zinc and zinc-plating are stripped by FFA′s and tin, lead, iron, and steel are affected too. Stainless steel and aluminium are generally unaffected.

As of 2010, the United States was producing in excess of 12 billion litres of Waste vegetable oil annually, mainly from industrial deep fries in potato processing plants, snack food factories and fast food restaurants. If all those 12 billion litres could be collected and used to replace the energy equivalent amount of petroleum almost 1% of US oil consumption could be offset. It is to be noted that use of waste vegetable oil as a fuel, competes with some other uses of the commodity. This as effects on its price as a fuel and increases cost as an input to the other uses as well.

The main form of SVO/PPO used in various countries is rapeseed oil which has a freezing point of -10^0C. Use of Sunflower oil, which gels at around -12^0C, is currently being investigated as a means of improving cold weather starting. Unfortunately oils with lower gelling points tend to be saturated and polymerize more easily in the presence of atmospheric oxygen. Most diesel engines are suitable for the use of SVO/PPO, with minor modifications. The relatively high kinematic viscosity of vegetable oils must be reduced to make them compatible with conventional CI engines fuel systems. It can be achieved either by co-solvent blending or can be reduced by preheating it using waste heat from the engine or using electricity. However, it is to be kept in mind that higher rates of wear and failure in fuel pumps and piston rings may occur and it should be appropriately tackled.

One common solution is to add a heat exchanger, and an additional fuel tank for “normal” diesel fuel (petro diesel or biodiesel) and a three way valve to switch between this additional tank and the main tank of SVO/PPO. Engine reliability would depend on the condition of the engine. Attention to maintenance of the engine, particularly of the fuel injectors cooling system and glow plugs will increase the life of the engine. Pure plant oiling contrast to waste vegetable oil, is not a by-product of other industries, and thus its prospects for use as fuel are not limited by the capacities of other industries. Production of vegetable oils for use as fuels is theoretically limited only by the agricultural capacity of a given economic. However, doing so detracts from the supply of other uses of pure vegetable oil.

3.4. BIODIESEL

Biodiesel fuel is a clean burning alternative fuel, produced from domestic, renewable resources such as plant oils, animal fats and used cooking oil. As Biodiesel burns clean, this means there will be a major reduction an all types of pollutants adding to smog and global warming. It is the only alternate fuel which has been approved by the Environmental Protection Agency (EPA). It has also passed every Heath-Effects Test of the Clean Air Act and meets the necessities of the California Air Resources Board (CARB).

Getting further with the explanation of biodiesel fuel, it is a clean burning alternative fuel from 100% renewable resources. Most people believe Biodiesel to be the fuel of the future. Also known as Biofuel, it does not contain petroleum. But can be blended with petroleum to produce a biodiesel blend which is then used in many different vehicles. Pure biodiesel fuel, can only be used in diesel engines. It is biodegradable and non-toxic, thus making it completely safe.

3.4.1. History of Biodiesel Fuel

Much earlier, in 1853 scientists E. Duffy and J. Patrick, conducted the trans-esterification of a vegetable. This was many years before the first diesel engine even became serviceable. According to the history of biodiesel fuel, Rudolf Diesel's prime model ran on its own power for the first time in Germany in 1893. To honour and remember this event, August 10 has been announced "International Biodiesel Day".

Looking into the origin of biodiesel fuel, the earlier engines worked so smoothly on earth-nut or pea-nut oil that only a few people were aware of it. These engines were then worked on vegetable oil without making any alterations. The French Government at the time was toying with the idea of testing the applicability to power production of the Arachide, or earth-nut. Diesel himself was supportive of the idea as he had conducted related tests. He believed that in course of time the use of vegetable oils for engine fuels will become very significant. Read on to know more about biodiesel fuel history.

Despite the extensive use of petroleum-derived diesel fuels, several countries during the 1930s and during World War II started showing curiosity in vegetable oils as fuels for internal combustion engines. The history of biodiesel fuel reflects that countries like Belgium, Portugal, France, Italy, Brazil, United Kingdom, Germany, Japan, Argentina, and China were reported to have tested and used vegetable oils as diesel fuels during this time. Although there were initial operational problems due to the high viscosity of vegetable oils as compared to petroleum diesel fuel.

In 1937, G. Chavannes in Belgium was granted a patent for a "Procedure for the transformation of vegetable oils for their uses as fuels" Belgian Patent 422,877. This patent described alcoholises of vegetable oils using ethanol. This probably is the first account of the production of what is known as "biodiesel" today in the biodiesel fuel history.

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In the recent times, Brazilian scientist ExpeditoParente carried out the first industrial process for the production of biodiesel successfully. Conferred as a "standardized identity and quality, this process is classified as biodiesel by international norms. At present, Patentee's company Tec bio is operational with Boeing and NASA to officially state bioquerosene or bio-kerosene, another product produced and patented by the Brazilian scientist. The history of bio-diesel fuel sure has seen a long course of time.

Researching trans-esterified sunflower oil and using it and refining it to diesel fuel standards, was first started in South Africa in 1979. By 1983, the procedure for manufacturing fuel-quality, engine-tested biodiesel was finished and published internationally. An Austrian company, Gaskoks, after buying the technology from the South African Agricultural Engineers, put up the first biodiesel pilot plant in 1987 in the history of biodiesel fuel.

The last decades have seen many new plants opening in many European countries in the biodiesel fuel history, for example: Czech Republic, Germany and Sweden. Experiments with 50% biodiesel fuel are underway. Countries in other parts of the world also witnessed the local production of biodiesel starting up. Today there are 21 countries with commercial biodiesel projects. In 2005 Minnesota in the U.S. became the first state to make it mandatory for all diesel fuel sold in the state to contain a content of at least 2% biodiesel.

3.4.2. Properties of Biodiesel Fuel

In comparison to other alternative fuels, there are a number of unique qualities and properties of biodiesel fuel. Meeting the standards of the 1990 Clean Air Act Amendments, it has also cleared all the health effects testing requirements, unlike other alternative fuels.

What makes a fuel different from others are its Cetane number and heat of combustion. The viscosity of a fuel is important because it influences the atomization of the fuel being inserted into the engine combustion chamber. For complete combustion to happen, a small fuel drop is required. . The biodiesel fuel property of having the viscosity much closer to diesel fuel than vegetable oil helps create a much lower drop, which burns cleaner.

The other main property of biodiesel fuel that we will discuss is its lubricating properties. It has much better lubricating and a higher cetane ratings than today's lower sulphur diesel fuels. Adding Biodiesel also helps in reducing fuel system wear. The fuel injection equipment depends on the fuel for its lubrication. The biodiesel fuel properties increase the life of the fuel injection equipment. Giving better lubricity and a more complete combustion increases the engine energy output, thus partially balancing for the higher energy density of petro diesel. Older diesel Mercedes are well known for running on biodiesel.

Observing the physical properties of biodiesel fuel, it is liquid which can be different in color, from golden and dark brown, all depending on the production feedstock. It is immiscible with water, has a high boiling point and low vapour pressure. The flash point of biodiesel is considerably higher than that of petroleum diesel. Biodiesel fuel has a density of ~ 0.88 g/cm³, which is less than that of water.

Studying the chemical properties of biodiesel fuel, its calorific value is about 37.27 MJ/L, which is 9% lower than regular petro diesel. It has practically no sulphur content, and is frequently used as an additive to Ultra-Low Sulphur Diesel (ULSD) fuel. Biodiesel fuel has an effect on copper-based materials and as well as zinc, tin, lead, and cast iron. However, the stainless steels and aluminium are not affected by bio fuel.

Biodiesel fuel properties also have an effect on some types of natural rubbers found in some older engine components. But the frequently used synthetic rubbers FKM- GBL-S and FKM- GF-S found in current vehicles are found to handle biodiesel in all conditions.

3.4.3. Making of Biodiesel

Biodiesel can be manufactured as a high quality fuel for compression ignition engines and is widely accepted. Biodiesel consists of the methyl esters of the fatty acid components of the triglycerides that make up most animal fats and vegetable oils. Initially Rudolf Diesel designed his engine with coal dust in 1893. Consequently, he designed his engine with vegetable oil in order to attract farmers to own engine with available fuel. Vegetable oils have sparkling lubrication possessions; they do not have sulphur content, and offer no storage difficulty. In addition, vegetable oils yielding trees absorb more carbon dioxide from the atmosphere during their photosynthesis than they add to the atmosphere on burning. There are two types of vegetable oils; edible and non-edible oils. Edible oils are the major sources to produce biodiesel fuel like sunflower, soybean, and palm oils. Due to higher prices of edible vegetable oils compared to diesel fuel, non-edible crude vegetable oils and animal fats are now being used as biodiesel sources.

Biodiesel is produced by trans-esterification, in which the fats/oils are reacted with methanol to form the biodiesel methyl esters and glycerol, the latter being sold as a by-product. It has a high cetane number, good lubricity properties, energy content comparable to conventional mineral diesel fuels the molecular weights of the methyl esters are similar to diesel fuels, making their transport properties and melting points superior to the fats and oils from which they were derived. Technically, biodiesel can be considered a good quality component as diesel fuel.

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3.4.3.1. Chemistry of Biodiesel:

The most common means of manufacturing biodiesel is the process of trans-esterification whereby the tallow or vegetable oil triglyceride is reacted with methanol in the presence of a catalyst to form the fatty acid methyl esters:

$$\begin{array}{llll} CH_2\text{-O-CO-R} & & CH_2\text{-OH} & CH_3\text{-O-CO-R} \\ | & & | & \\ CH\text{-O-CO-R'} & + \; 3\,CH_3\text{-OH} & = \; CH\text{-OH} & + \; CH_3\text{-O-CO-R'} \\ | & & | & \\ CH_2\text{-O-CO-R''} & & CH_2\text{-OH} & CH_3\text{-O-CO-R''} \end{array}$$

Triglyceride	Methand	Glycerol	Biodiesel Fatty Acid Methyl Esters

Glycerol (alternatively known as glycerine) is a by-product produced in significant quantities from the trans-esterification process. However, the reaction is an equilibrium reaction, in that it will not proceed to completion, leaving traces of the feed triglyceride and methanol in the product. However, conversion of triglycerides to methyl esters can be increased by increasing the concentration of methanol and decreasing that to glycerol in the reaction mix. Also mono- and di-glycerides can be produced due to partial reaction of the triglycerides and methanol. These factors are significant in the production process design and in the quality and necessary purification of the final products.

3.4.3.2. Production of Biodiesel:

The trans-esterification process consists of four principal steps:

- Pre-treatment of the tallow or oil feedstock to remove components that will be detrimental to subsequent processing steps.

- Trans-esterification, where the pre-treated triglycerides are reacted with methanol to form the raw methyl esters and glycerol. There are two basic steps: the reaction process followed by separation of the methyl ester and glycerol streams. In most technologies, these two steps are undertaken twice to push the trans-esterification closer to completion by reducing the concentration of glycerol in the second stage. The reaction is also pushed closer to completion by using an excess of methanol. Processes are generally designed to a high level of conversion, and methyl ester purity (>98%), as lower conversion rates result in increased levels of mono and di-glycerides, causing processing problems with emulsion formation and low temperature hazing problems with the biodiesel itself as these compounds have higher melting points (and viscosity) than the methyl ester.
- Methyl ester purification, which removes the excess methanol, catalyst and glycerol carried from the trans-esterification process. Methanol removed is recycled to the trans-esterification process.
- Glycerol purification, removing methanol for recycling to the trans-esterification process. Further impurities, such as catalyst, tallow and methyl ester, are carried in the glycerol and may be removed to produce a higher grade of glycerol if economics dictate.

The catalyst used in the trans-esterification process is usually either sodium hydroxide or potassium hydroxide and is mixed with part of the methanol feed into the reaction vessel. After reaction and separation is complete, the catalyst is carried in the glycerol stream and, as part of the glycerol treatment, is neutralised by an acid. Typically hydrochloric or sulphuric acids are used; producing salts such as sodium chloride or potassium sulphate, the latter can be sold as a fertiliser.

The trans-esterification process can be undertaken using simple equipment and biodiesel is manufactured on a small scale by enthusiasts for the fuel, using buckets amongst other paraphernalia. However, to produce the fuel on a commercial basis, more sophisticated conditions are required to meet consistent quality requirements for the large volumes involved and to improve yields and rates of reaction. A number of process configurations are used with the principal alternatives being batch and continuous processes and high and low pressure systems. Generally, the more modern systems favour lower pressures because of the attendant lower plant costs and continuous processes are used in the larger and newer plant although some companies prefer batch systems. The Viscosity and Calorific Value of the biodiesel are measured using Redwood viscometer and Bomb calorimeter respectively and are tabulated as shown in Table 3.1.

Table 3.1: Properties of Biodiesel (Palm Stearin)

Density at 30 ºC	864.3 kg/m^3
Kinematic Viscosity at 40 ºC	4.31 mm^2/s
Flash Point	160 ºC
Cloud point	17 ºC
Calorific Value	9786 K Cal/Kg

3.4.4. Blends of Biodiesel Fuel

Biodiesel fuel has been thoroughly and independently tested in nearly every type of diesel engine by a number of agencies in the laboratory as well as on the road. The performance of these blends of biodiesel fuel have been said to rate comparably to petroleum in all areas from power to efficiency, hauling and climbing. Although the Biodiesel fuel can be used in its pure form, more common use of it is seen as biodiesel blends or blended with petroleum fuel. The most common mix or biodiesel fuel blends is referred to as "B20" containing 20% biodiesel by volume, and 80% petroleum.

The blends of bio diesel fuel and conventional hydrocarbon-based diesel are products which are most frequently allocated for use in the retail diesel fuel marketplace. All over the world, the system of the "B" factor is used to state the quantity of biodiesel in any fuel mix. For example, B100 would mean a 100% biodiesel, while a 20% biodiesel fuel blends is labelled B20. Similarly, 5% biodiesel is labelled B5 and 2% biodiesel is labelled B2.

The greater the percentage of biodiesel fuel in its blend, the more ecology-friendly is the fuel. In US, it is common to see B99.9 because a federal tax credit is awarded to the first entity which blends petroleum diesel with pure biodiesel fuel. Biodiesel blends of 20 percent biodiesel with 80 percent petroleum diesel (B20) can usually be used in unmodified diesel engines. Although Biodiesel can be used in its pure form (B100), but certain engine modifications nay be necessary to avoid maintenance and performance problems.

Blending biodiesel fuel, B100 with petroleum diesel may be achieved by mixing in tanks at manufacturing point before the delivery to tanker truck or splash mix in the tanker truck. In-line mixing, the two constituents arrive at the tanker truck at the same time. In the metered pump mixing, petroleum diesel and Biodiesel meters are set to X total volume. The transfer pump then pulls from two points and the blending is complete on leaving pump.

3.4.5. Standards for Biodiesel Fuel

A number of technical standards for biodiesel fuel have been set in order to maintain its quality. The European standard for biodiesel fuel is EN 14214. This has been translated into the respective national biodiesel fuel standards for each country that forms the CEN. For instance, in United Kingdom, it is BS EN 14214 and for Germany DIN EN 14214. The major difference existing between EN 14214 standards of biodiesel fuel in different countries is the national annex which details climate related necessities of biodiesel in different CEN member countries.

The biodiesel fuel technical standards make sure that the following significant factors in the production process of the fuel are met with:

- Acidic value.
- Complete reaction.
- Elimination of glycerine.
- Removal of catalyst.
- Removal of alcohol.
- Absence of free fatty acids.
- Low Sulphur content.
- Cold Filter Plugging point.
- Cloud Point.

ASTM International has approved new technical standards for biodiesel fuels. According to the National Biodiesel Board (NBB), ASTM standards for the 20% biodiesel blends, or B20, are a vital obstacle for the complete acceptance of using such blends in diesel vehicles. Automakers and engine producers can test B20 in their diesel engines and know that consumers will be using Biodiesel fuel of the same quality... While setting the new B20 standards of biodiesel fuel, ASTM International also made changes to its conditions for B5 and for 100% biodiesel, or B100.

3.4.6. Biodiesel Fuel Feed Stocks

Biodiesel fuel is one of the easiest alternative fuels to use. A variety of oils as biodiesel fuel feedstock are used to produce the fuel. Here, we will focus on biodiesel feedstock.

The main biodiesel fuel feedstock are:

3.4.6.1. Virgin Oil Feedstock

Rapeseed and soybean oils are most commonly used raw material for biodiesel fuel. Soybean oil alone accounts for about ninety percent of all biodiesel fuel feed stocks in the US. It can also be acquired from field pennycress and jatropha. Many other crops like mustard, flax, sunflower, palm oil, coconut, hemp are good resources of Soybean oil.

3.4.6.2. Waste Vegetable Oil (WVO)

The waste vegetable oil (WVO) discarded from a restaurant is getting popular as feed stocks for biodiesel fuel. Many supporters propose that waste vegetable oil is the best raw material for biodiesel fuel production.

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3.4.6.3. Animal Fats

Tallow, lard, yellow grease, chicken fat, and the by-products of the production of Omega-3 fatty acids from fish oil are increasingly used as biodiesel fuel feedstock.

3.4.6.4. Algae

Algae can be grown using waste materials such as sewage and without making use of land used for food production. They are also looked upon as a good source of biodiesel feedstock.

3.4.6.5. Oil from Halophytes

Other feedstock for biodiesel fuel are Halophytes such as salicorniabigelovii, which can be grown using saltwater in coastal areas where conventional crops cannot be grown. They produce yields equal to the yields of soybeans and other oilseeds grown using freshwater irrigation.

Animal fats are a by-product of meat production. Although it would not be resourceful to raise animals simply for their fat, the use of the by-product as feedstock for biodiesel fuel adds value to the livestock industry. However, producing biodiesel fuel with animal fat would substitute only a small percentage of petroleum diesel usage. Today, multi-feedstock for biodiesel fuel are making animal-fat based biodiesel of high quality. At present, a 5-million dollar plant is being built in the USA, with the intention of making 3 million gallons of biodiesel fuel from some of the estimated 1 billion kg of chicken fat produced annually at the local Tyson poultry plant. Likewise, some small-scale biodiesel factories are using waste fish oil as biodiesel fuel feedstock. A Vietnamese plant aims to produce 13 tons/day of biodiesel from catfish from 81 tons of fish waste.

At present, the worldwide production of vegetable oil and animal fat as raw material for biodiesel fuel is not enough to substitute for the liquid fossil fuel use. In addition, production of additional vegetable oil would mean extensive amount of farming. This would means more fertilization, pesticide use, and land use conversion.

3.4.7. Usage of Biodiesel Fuel

Biodiesel fuel usage can be done in pure form or it may be blended with petroleum diesel at any concentration, as in most injection pump diesel engines.

New common rail engines with extreme high pressure have stern factory limits of using biodiesel fuel, B5 or B20 depending on manufacturer. As Biodiesel fuel has different solvent properties than petro-diesel, it can degrade natural rubber gaskets and hoses in vehicles. Plus Biodiesel has been known to break down deposits of residue in the fuel lines, so as a result, fuel filters may get clogged with particulates if there has been a fast transition to pure biodiesel fuel. Therefore, when using biodiesel fuel, it is suggested to change the fuel filters on engines and heaters in a while after first switching to a biodiesel blend.

Manufacturer acceptance and vehicular usage of biodiesel fuel began in 2005, when Chrysler released the Jeep Liberty CRD diesels into the American market with 5% biodiesel blends. This was an indication of at least partial acceptance of biodiesel fuel usage. 2004 saw the city of Halifax, Nova Scotia updating its bus system to allow the fleet of city buses to run completely on a fish-oil based biodiesel fuel. In 2007, McDonalds in UK announced that it would start producing biodiesel from the waste oil of its restaurants and use biodiesel fuel to run its fleet.

Usage of biodiesel fuel in railway was first seen in British Train Operating Company Virgin Trains, which was transformed to run on 80% petro-diesel and only 20% biodiesel. Some successful applications of biodiesel fuel were seen in the Royal Train in 2007 completed on its first ever journey run on 100% biodiesel fuel, ever since the Royal Train has successfully run on B100. Another example of biodiesel fuel usage was seen on a short-line railroad in Eastern Washington which ran a test of a 25% biodiesel / 75% petro-diesel in 2008. Disneyland too began operating its park trains on B98 biodiesel blends.

Incidents of aircraft using biodiesel fuel have not been too many. A Czech jet aircraft did undergo a test flight completely powered on biodiesel. Other recent jet flights using biodiesel fuel however, have been known to use other types of renewable fuels.

Applications of biodiesel fuel can also be seen as a heating fuel in domestic and commercial boilers. A blend of heating oil and standardized biofuel which is taxed somewhat differently than diesel fuel is used here. It is sometimes known as "bio heat" and is available in various blends; up to 20%. Using biodiesel fuel existing furnaces without modification is considered acceptable.

3.4.8. The Efficiency of Biodiesel Fuel

The use of Biodiesel fuel for standard diesel engines, either alone or in combination with other fuels, has gathered much attention mostly because of its possible environmental and long-term economic benefits over fossil fuel. The efficiency of biodiesel fuel is the more interesting subject for the researchers and scientists, mainly because its source is renewable.

According to a recent study, an average farm consumes fuel at 82 litres per hectare of land to generate one crop. However, an average crop of rapeseed makes oil at an average rate of 1,029 L/ha, and high-yield rapeseed fields produce about 1,356 L/ha. It is clear to notice the ratio of input to output in these cases which is roughly 1:13 and 1:16. Photosynthesis is known to have an efficiency rate of about 3-6% of total solar radiation. Therefore, if the entire crop mass is used for producing energy, the overall efficiency of this chain is currently about 1%.

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Comparing the efficiency level of biodiesel fuel to solar cells combined with an electric drive train, biodiesel is less costly to arrange for. However, the present data and statistics are not enough to demonstrate is any such a change will make economic sense. Additional factors must be taken into account to gauge the efficiency of biodiesel fuel. For instance, what would be the fuel corresponding to the energy required for processing? What would be the yield of fuel from raw oil? Will the biodiesel have any effect on food prices? Also the relative cost of biodiesel versus petro-diesel also needs to be looked into.

The debate over the energy balance and efficiency level of biodiesel fuel is still going on. Although non-food crops can be utilized to make biodiesel fuel, transitioning completely to biofuels could necessitate huge expanse of land. Since energy consumption scales with economic output, it can be a major problem for nations with large economies. Most nations perhaps will not have adequate arable land to produce biodiesel fuel for the nation's requirement. Many regions may not be able to divert land away from food production. But in the third world countries, biodiesel fuel sources using marginal land could make more sense, for example, honge oil nuts can be grown along roads or jatropha grown along rail lines. Biodiesel fuel efficiency hence makes more sense in these regions. To supply to the rising demand of biodiesel fuel in Europe and other markets, some tropical regions, such as Malaysia and Indonesia, are planting oil palm at a fast pace. Cost of producing Palm oil biodiesel fuel is less than one third of the production costs of rapeseed biodiesel.

3.4.9. Storage of Biodiesel

The general standards for biodiesel fuel storage and handling procedures are followed. The fuel should be stored in a clean, dry, dark environment and the storage tank materials should be made of aluminium, steel, fluorinated polyethylene, fluorinated polypropylene and Teflon. Storage tanks made of copper, brass, lead, tin, and zinc should be avoided.

3.4.10. Environmental Effects of Biodiesel Fuel

Although biodiesel fuel is fast emerging as the oil of the future, a number of environmental effects of biodiesel fuel are also surfacing associated with its use. These biodiesel fuel environmental effects potentially include decrease in greenhouse gas emissions, deforestation, pollution and the rate of biodegradation.

3.4.10.1. Greenhouse Gas Emissions

Whether using biodiesel is able to lower greenhouse gas emissions as compared to the fossil fuels may depend on many factors. Carbon dioxide is known to be one of the major greenhouse gases. The plant feedstock used in the making biofuels absorbs carbon dioxide from the atmosphere when it grows and once the biomass is converted into biodiesel and burnt as fuel, the energy released is used to power an engine while the carbon dioxide is released back into the atmosphere. When considering environmental effects of biodiesel fuel due to the total amount of greenhouse gas emissions, it is important to consider the whole production process. Several factors like production methods, type of feedstock play their role. Assuming today's production methods, with no land use change, biodiesel from rapeseed and sunflower oil produce 45%-65% lower greenhouse gas emissions than petro-diesel But calculating the carbon intensity of biodiesel fuels is a complex and inexact process. However, there is continuing research for improving the efficiency of the production process of the biodiesel fuels.

3.4.10.2. Deforestation

There can be grave effects of biodiesel fuel on environment if deforestation and monoculture farming techniques are used to grow biofuel crops. It may damage the ecosystems and biodiversity and increase the emission of climate change gases rather than helping controlling them. To meet the demand for cheap oil from the tropical region, the amount of arable land is being extended in order to increase production at the cost of tropical rainforest. As feedstock oils in Europe and North America are much more expansive than Asia, South America and Africa, imports to these more affluent nations are likely to increase in the future. Tropics forests are being cleared to make room for oil palm plantations. These can lead to serious biodiesel fuel environmental effects as deforestation can be threatening many species of unique plants and animals.

3.4.10.3. Pollution

Biodiesel fuel is the only alternative fuel to have effectively completed the Health Effects testing requirements of the Clean Air Act (1990). The particulate emissions as the consequence of production are lowered by around 50 percent compared with fossil-sourced diesel. Having a higher cetane rating than petro diesel, some positive effects of biodiesel fuel on environment can be seen as it can improve performance and clean up emissions. Biodiesel also consists of fewer aromatic hydrocarbons.

3.4.10.4. Biodegradation

Another of the environmental effects of biodiesel fuels can be sees in its biodegradation rates, which are 5 times faster than petroleum diesel over a period of 28 days. Biodiesel fuel blends can also accelerate the rate of petroleum diesel degradation through co-metabolism. Toxicity studies have revealed no mortalities and any toxic effects of biodiesel fuel on environment.

3.4.11. Current Research on Biodiesel Fuel

Presently, there is a continuing research on biodiesel fuel into finding more and more appropriate crops to enhance oil yield. In order to replace fossil fuel usage entirely, huge amounts of land and fresh water would be required to manufacture sufficient oil. Research on biodiesel fuel at present focuses on producing reasonably high oil yields. Specially bred mustard varieties are found to produce reasonably high oil yields, which are very useful in crop rotation with cereals.

One of the largest diesel fuel users in the world, the US navy and military has the NFESC, Santa Barbarabased Biodiesel Industries involved in developing biodiesel technologies and present research on biodiesel fuel, working for it. A company called Ecofasa with a group of Spanish developers announced a new biodiesel fuel made from trash. This fuel was produced from general urban waste which was then treated by bacteria to produce fatty acids, and later used to make biodiesel.

The current research on biodiesel fuel by the U.S. NREL involved experimenting with algae having a 50% more natural oil content, as a biodiesel source. These algae can be grown on algae ponds at wastewater treatment plants. The research on biodiesel fuel at present on the production of algae to harvest oil for biodiesel has not yet been undertaken on a commercial scale. Alga culture, unlike the crop-based biofuels does not threaten a decrease in food production, as it requires neither farmland nor fresh water. Many companies are pursuing algae bio-reactors for research on biodiesel fuel at present and aim at scaling up biodiesel production to commercial levels.

Some single-celled fungi have been used as biodiesel fuel research by a group at the Russian Academy of Sciences in Moscow, who stated that they had separated large amounts of lipids from these fungi in. an economically efficient manner. More research on biodiesel fuel using these fungal species is going on at present.

Some researchers recently have successfully produced biodiesel fuel from oil obtained from used coffee grounds. After extracting the oil, it underwent conventional processing into biodiesel. The estimated cost of producing biodiesel following this method could be for about one US dollar per gallon. Further this research on biodiesel fuel at present states that as there is much coffee around, several hundred million gallons of biodiesel could be made annually using this technique which is not difficult.

3.4.12. Advantages of Biodiesel:

Biodiesel can be considered as new variation of technology, taking into account as all these years people had gone for traditional fuels as diesel. Biodiesel has many advantages which makes a better option instead of diesel.

- Biodiesel is a renewable fuel as it is produced from various agricultural resources and fats.
- Biodiesel is eco-friendly fuel as it doesn't cause harm to environment than diesel, as it reduces net emissions and reduces life cycle greenhouse gas emissions.
- Biodiesel fuel can also be used in existing diesel engines without making any alterations.
- It's safer to handle and has virtually the same energy efficiency as petroleum diesel. In addition it has lubricity benefits that fossil fuels do not.
- Biodiesel has high cetane number than diesel which results in decrease of ignition delay.
- The use of Biodiesel helps reduce dependence on finite fossil fuel reserves. As an alternative energy source it is relatively easy to process and to all communities from rural communities in developing nations, to urban in developed countries.

3.4.13. Disadvantages of Biodiesel:

- Biodiesel fuel disadvantage is that it can harm rubber hoses in some engines.
- As Biodiesel cleans the dirt from the engine, this dirt can then get collected in the fuel filter, thus clogging it. So, filters have to be changed after the first several hours of biodiesel use
- Cost of some biodiesels in the market is higher than petroleum fuels however large production may reduce their cost.
- Pure biodiesel has significant problems with low temperatures.
- Biodiesel, despite emitting significantly less harmful carbon emission compared to standard diesel, still somewhat contributes to global warming and climate change.

Biodiesel is an oxygenated fuel which contains 10–15% oxygen by weight. These facts lead biodiesel to total combustion and less exhaust emissions than diesel fuel. Furthermore also the energy content or net calorific value of biodiesel is less than that of diesel fuel on a mass basis. Using optimized blend of biodiesel and fuel additives can help to reduce some significant percentage of the world's dependence on fossil fuels; Moreover Additives are an essential part of today's fuel. Together with carefully formulated base fuel composition, they contribute to efficiency reliability and long life of an engine. With use of fuel additives in biodiesel in CI Engine which furthers improve performance by enhancing the combustion characteristics. Most of the researchers/scientists have reported that the performance of blend of biodiesel is higher when an additive is used.

3.5. ADDITIVES:

At present for vehicular fuels, combustion of numerous chemical additives is used to improve the quality of biodiesel fuel and diesel fuel to convene up the most wanted performance level. Additives will help out the petroleum to recover its engine combustion, performance and emission environmental standards. The additives selection will be based upon the drawbacks of biodiesel fuel such as density, toxicity, viscosity, economic feasibility, additives solubility, auto ignition temperature, flash point, and cetane number for the fuel blending process. The Concentration of fuel additives is not regulated.

The additives for diesel engine are discussed and few reasons are listed out below

- Enhanced the nagging properties and immovability of the fuel.
- Shrinking the harmful emission from fuel combustion.

- Developing the combustion and performance properties of the fuel.
- Here to afford engine protection and cleanliness.
- Saving the fuel from optimized engine economy and performance.
- Protecting the petroleum tank, pipeline and other massively expensive corrosion.

3.5.1. Types of Additives:

3.5.1.1. Metal Based Additives

Here to get better quality of fuel, metal based additives are used in various applications. Mostly these additives are used in diesel and biodiesel to diminish the un-burn hydrocarbons in the IC engines and to minimize the exhaust gas harmful emissions. The metal based additives consist of catalytic effects. These additives consist of copper(II) chloride (CuCl2), iron (III) chloride (FeCl3), copper(II) oxide (CuO-nano structured), cobalt (II) chloride (CoCl2) and copper(II) sulphate (CuSO4) are added in fuel catalyst for diesel and biodiesel based on the necessity requirement.

3.5.1.2. Oxygenated Additives

The most important additives for diesel and Otto engine are oxygenated additives. The fuels that are containing oxygen and blending components contain at least one oxygen atom by the molecules at the side of the hydrogen and carbon atoms. The oxygenated additives are very useful to develop the combustion process and octane rating. Oxygenated additives are blended with diesel fuels and the oxygenated additives must be capable of mixing any ratio without separation of its two phases with various diesel and biodiesel fuels. By blending oxygenated additives in biodiesel and diesel sufficient, sufficient cetane number should be there in oxygenated additives and allowed the blend to increase the cetane number. The oxygen helps to support for burning the fuel without emitting any high amount of inert material such as nitrogen into the air and it causes the harmful material such as NOx emission at some operating load condition in CI diesel engine. The generally used oxygenated additives are alcohols, ether and ester. The few names of alcohols contain butanol, propanol, methanol and ethanol. On the other hand for ether diethyl ether, di-isopropyl ether, methyl tetra-butyl ether, dimethyl ether, and ethyl tertiary butyl ether are included and for ester aceto acetic esters, di-carboxylic acid esters and dimethyl carbonate esters are included are the efficient groups. By addition of oxygenated additives, the ignition temperature of biodiesel will be minimized and also reduction in smoke emission is observed in the diesel engine. According to the composition of diesel and biodiesel, the oxygenated additives will affect directly the properties such as cetane number, density, viscosity, volatility, flash point and calorific value. To ignite the fuel more efficiently oxygenated additives will support and as well as diminish environment pollution. The engine fuels will burn more completely due to the presence of oxygenated additives.

3.5.1.3. Cetane Number Improver Additives:

Delay period is the one of the most important role plays in diesel engine, in which the delay period varies with chemical and physical properties of the diesel or biodiesel fuels. To differ the delay period cetane number improvers are the main important parameter. To minimize the ignition delay during the combustion cetane number improvers help to get better working in diesel engine ignition. During the combustion process, shorter ignition delay period leads to more complete combustion of the fuel there in the internal combustion engine, reduces the noise of the engine and also reduces the unwanted harmful pollutants in the environment.

3.5.1.4. Antioxidant Additives:

The major purpose of using antioxidant to biodiesel fuels was to slow down the development of slush deposits and darkening of color. Petroleum products are very quick moving diesel fuels, but they are very rarely, are stored in for 1–3 years and are subjected to corrosion. Few names of antioxidant additives are butylated hydroxyl anisole (BHA), butylated hydroxyl toluene (BHT), pyrogallol (PL), diphenylamine (DPA), tert-butylhydroxyquinone (TBHQ) and propyl-gallate (PG).

In the present work Oxygenated additives are used.

3.5.2. Oxygenated Additives:

Oxygenated fuel/additive is nothing more than fuel that has a chemical compound containing oxygen. It is used to help fuel burn more efficiently and cut down on some types of atmospheric pollution. In many cases, it is credited with reducing the smog problem in major urban centres. It can also reduce deadly carbon monoxide emissions. This type of fuel works by allowing the fuel in vehicles to burn more completely. Oxygenated fuel has a number of different additives that can be inserted in order to produce the desired effects.

3.5.2.1. Properties of Good Oxygenated Additive:

Oxygenates that are to be mixed with biodiesel fuel must have fuel properties which can be appropriate for smooth running of diesel engines.

- The oxygenate additive must be miscible with various biodiesel fuels over the range of environmental temperatures seen in vehicle operation.
- The oxygenate additive must not show excessive volatility when mixed with various biodiesel fuel.
- The mixture of base fuel and oxygenate must have an adequate cetane number and preferably allow the mixture to show an increased cetane number.
- The oxygenate additive must show a sufficient water tolerance.

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3.5.2.2. Types of Oxygenated Additives:

Oxygenated additives are used by various researchers to improve performance and emissions of Diesel engine fuelled with Biodiesel, are: Diethyl Ether [DEE], 2-Ethoxy Ethyl Acetate [EEA], Di-Methyl Carbonate [DMC], Di-gym [DMG], Dimethoxy Methane [DMM]. Here, in this work chosen DEE as oxygenated additive to blend with biodiesel in ratio of 95% Biodiesel and 5% additive.

3.5.2.2.1. Diethyl Ether:

Diethyl ether, also known as ethoxy ethane, ethyl ether, is an organic compound in the ether class with the formula $(C_2H_5)_2O$. It is a colourless, highly volatile flammable liquid. As a fuel, Diethyl ether has a high cetane number approximately 85-96 and is used as a starting fluid, in combination with petroleum distillates for gasoline and diesel engines because of its high volatility and low flash point. For the same reason it is also used as a component of the fuel mixture for compression ignition engines.

Generally biodiesel have high oxygen level which increases combustion temperature and cause high NOx emission, which can be reduced by little higher cetane number (shorter ignition delay and so lower temperatures during the premixed combustion phase) and the absence of aromatics. On the other hand, biodiesel has some disadvantages, such as higher viscosity and pour point, and lower volatility causes poor cold flow, which may be improved by DEE blending with biodiesel. The Viscosity and Calorific value of Di Ethyl Ether which is an oxygenated additive are measured using Redwood viscometer and Bomb calorimeter respectively and are tabulated in the Table 3.2.

Table 3.2: Properties Of Di Ethyl Ether $(C_2H_5)_2O$

Property	DEE
Density	714 kg/m^3
Viscosity at 25 ºC	0.32 mm^2/s
Flash Point	45 ^{0}C
Auto ignition Temp	160 ^{0}C
Calorific Value	8100 K Cal/Kg

3.6. Diesel engine emissions:

Emissions from diesel engines can be classified in the same categories as those for the gasoline engines but the level of emission in these categories vary considerably. Typical level, of the constituents of the exhaust products of combination in 4-stroke cycle and 2-stroke cycle are given in the table at idling, accelerating, partial load and full load.

Table 3.3. Standard Emissions of Engine at Various Loads

Engine exhaust constituents	Concentration as measured in exhaust products			
	Idling	Accelerating	Partial load	Full load
Two stroke cycle engine				
1. CO%	0.01	0.25	0.01	0.35
2. CO_2%	0.85	5.5	3.8	5.30
3. HC ppm	250	500	350	550
4. NO_x ppm	200	1200	1100	1250
5. RCH ppm	17.0	9.5	1.0	5.5
6. Smoke Hartrige unit	4	44	4	10

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Four stroke cycle engine (Un-Supercharged)				
1. CO%	0.02	0.08	0.04	0.25
2. CO_2%	2.5	3.5	5.5	6.7
3. HC ppm	180	330	210	150
4. NO_x ppm	330	920	590	780
5. RCHO ppm	8.0	7.5	5.0	1.5
6. Smoke Hartrige unit	4	44	4	10

3.6.1. Emission Norms:

Emission norms are statutory requirements that set specific limits to the amount of pollutants that can be released into environment. Norms focus on regulating pollutants released by automobiles and other powered vehicles. They can also regulate emissions from industry, power plants, and diesel generators. The pollutants in general that are regulated are the emissions of nitrogen oxides (NO_x), sulphur oxides, particulate matter (PM) or soot, carbon monoxide (CO), or volatile hydrocarbons.

In the United States, emissions standards are managed by the Environmental Protection Agency (EPA). The state of California has special dispensation to promulgate more stringent vehicle emissions standards. Other states may choose to follow either the national or California standards. The European Union has its own set of emissions standards that all new vehicles must meet. Currently, standards are set for all road vehicles, trains, barges and non-road mobile machinery (such as tractors). No standards apply to seagoing ships or airplanes.

The European Union is to introduce Euro 4 effective from January 1, 2008, Euro 5 effective from January 1, 2010 and Euro 6 effective from January 1, 2014. These dates have been postponed for two years to give oil refineries the opportunity to modernize their plants. The first Indian emission regulations were idle emission limits which became effective in 1989. These idle emission regulations were soon replaced by mass emission limits for both gasoline (1991) and diesel (1992) vehicles, which were gradually tightened during the 1990's. Since the year 2000, India started adopting European emission norms and fuel regulations for four wheeled light duty and for heavy duty vehicles. Indian own emission regulations still apply to two and three wheeled vehicles.

3.6.2. Overview of the Emission Norms in India

- 1991 Idle CO limits for gasoline vehicles and free acceleration smoke for diesel vehicles, Mass Emission Norms for Gasoline Vehicles.
- 1992 Mass Emission Norms for Gasoline Vehicles.
- 1996 Revision of Mass Emission Norms for Gasoline and Diesel Vehicles, mandatory fitment of Catalytic Converter for cars in Metros on Unleaded Gasoline.
- 1998 Cold Start Norms Introduced
- 2000 India 2000 (equivalent to Euro I Norms, Modified IDC (Indian Driving Cycle), Bharat Stage II Norms for Delhi.
- 2001 Bharat stage II (equivalent to Euro II) Norms for all metros, emission norms for CNG and LPG vehicles.
- 2003 Bharat stage II (equivalent to Euro II) Norms for 11 major cities.
- 2005 From 1st April Bharat stage III (equivalent to Euro II) Norms for 11 major cities.
- 2010 Bharat stage III Emission Norms for 4-wheelers for entire country whereas Bharat Stage -IV (equivalent to Euro IV) for 11 major cities.

3.7. Applications of Four Stroke Diesel Engines

The four stroke diesel engine is one of the most efficient and versatile prime movers. It is manufactured in sizes from 50 mm to more than 1000 mm of cylinders diameter and with engine speeds ranging from 100 to 4500 rpm while delivering outputs from 1to 35000 kW.

Small diesel engines are used in pump sets, construction machinery, air compressors, drilling rigs and many miscellaneous applications. Tractors for agricultural applications use about 30 kW diesel engines whereas jeeps, buses and trucks use 40 to 100 kW diesel engines. Generally, the diesel engines with higher outputs than about 100 kW are supercharged. Earth moving machines use supercharged diesel engines in the output range of 200 to 400 kW. Locomotive applications require outputs of 600 to 4000 kW. Marine applications, from fishing vessels to ocean going ships use diesel engines from 100 to 35000 kW. Diesel engines are used both for mobile and stationary electric generating plants of varying capacities. Compared to gasoline engines, diesel engines are more efficient and therefore manufacturers have come out with diesel engines even in personal transportation. However, the vibrations from the engine and the unpleasant odour in the exhaust are the main draw backs.

3.7.1. Modern Diesel Engines

Carbon soot particulate generation has been greatly reduced in modern CI engine by advanced design technology in fuel injectors and combustion chamber geometry. With greatly increased mixing efficiency and speeds, large regions of fuel- rich mixtures can be avoided when combustion starts. These are the regions where carbon soot is generated, and by reducing their volume, far less soot is generated. Increased mixing speeds are obtained by a combination of indirect injection, better combustion chamber geometry, better injector design and higher pressures, heated spray targets, and air-assisted injectors. Indirect injection into a secondary chamber that promotes high turbulence and swirl greatly speeds the air-fuel mixing process. Better nozzle design and higher injection pressures create finer fuel droplets which evaporate and mix quicker. Injection against a hot surface speeds evaporation, as do air-assisted injectors. Some modern, top-of-the-line CI automobile engines have reduced particulate generation enough that they meet stringent standards without the need for particulate traps.

CHAPTER – 4
EXPERIMENTAL WORK

In this section, the information regarding various components of the engine, the instruments used for experimentation on four stroke single cylinder engine and the methodology followed during the experimentation are explained.

4.1. Experimental Setup:

The experiment have been carried out on the single cylinder, four stroke direct injection water cooled Kirloskar diesel engine present in Thermal Engineering Laboratory of mechanical engineering, Centurion University, Jatni Campus. It was provided with accessories for the measurement of load, fuel consumption, and exhaust gas temperature and air consumption.

The main components of the system are given below

1. Four -Stroke water cooled CI engine with Variable Compression Raito test rig (Kirloskar make)
2. Eddy current Dynamometer
3. Independent Panel Box and
4. Five gas analyser.

The line diagram and setup of the engine are shown in Fig.4.1 and Fig.4.2.

4.1.1. Test Engine Details:

IC Engine setup under test is Research Diesel having power 3.50 KW @1500 rpm which is 1 Cylinder, Four stroke, Constant Speed, Water Cooled, Diesel Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod Length 234.00(mm), Compression Ratio 18.00, Swept volume 661.45 (cc)

4.1.1.1. Combustion Parameters:

Specific Gas Constant (kJ/kgK):1.00, Air Density (kg/m^3):1.17, Adiabatic Index: 1.41, Polytrophic Index: 1.08, Number of Cycles: 10, Cylinder Pressure Reference: 4, Smoothing 2, TDC Reference: 0

4.1.1.2. Performance Parameters:

Orifice Diameter (mm): 20.00, Orifice Coefficient of Discharge: 0.60, Dynamometer Arm Length (mm): 185, Fuel Pipe diameter (mm): 12.40, Ambient Temperature (^{0}C): 27, Pulses Per revolution: 360, Fuel Type: Diesel, Fuel Density (kg/m^3): 800, Calorific Value of Fuel (kJ/kg): 43000

The technical specifications of the engine are given in Table 4.1.

Table 4.1. Specifications of Engine / System Constants

Engine Rated Power	3.5 kW
Rated Speed	1500 rpm
Cylinder diameter	87.5 mm
Stroke Length	110 mm
Connecting rod length	234 mm
Compression ratio vary	12 to 18 : 1

The engine is run at its rated speed 1500 RPM. Engine is directly coupled to eddy current dynamometer that permit engine motoring either fully or partially.

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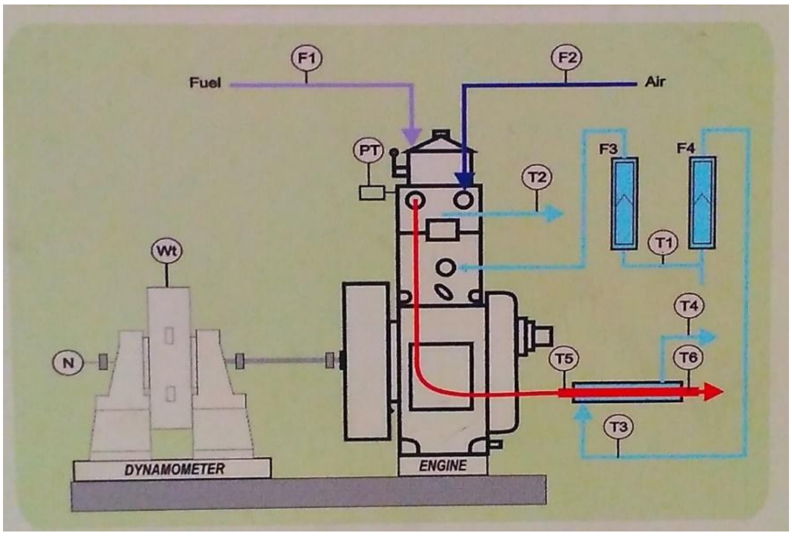

Fig.4.1. Line Diagram of the Engine

4.1.2. Eddy Current Dynamometer:

It consists of a stator or housing supported on trunnion bearings so that any tendency of the stator to rotate is read on fixed scale. Number of electromagnets is fitted on the stator and a rotor coupled to the output shaft of the engine. When rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets and the induced flux tends to rotate the stator in the same direction as the shaft. These eddy currents oppose the rotor motion, thus loading the engine. These eddy currents are dissipated in producing heat so that this type of dynamometer needs cooling arrangement. A moment arm measures the torque and a Load cell type strain gauge (range 0-50 Kg) is used in the present set up. Loading of the Eddy current Dynamometer is done by regulating the current in electromagnets.

Specifications of the dynamometer:

Type	:	Eddy current
Power	:	Max. 20 kW @ 2450 rpm
Speed	:	10000 rpm

Effective radius of arm: 0.195 m

Fig.4.2. Eddy Current Dynamometer

4.1.3. Independent Panel Box:

It's a stand fully powder coated panel box of air box, fuel tank, and manometer, fuel measuring unit, digital speed indicator and digital temperature indicator. Engine jacket cooling water inlet, outlet and calorimeter temperature is displayed on temperature indicator. Rotameters are provided for cooling water and calorimeter flow measurement.

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4.1.4. Exhaust Gas Analyser:

AVL Di gas 444 gas analyser is used for measuring exhaust gas emissions shown in figure 3. The specifications of gas analyser are given in table 2. The probe of the gas analyser is inserted into exhaust pipe before taking measurements. After the engine is stabilised in working condition, the exhaust emissions are measured. Carbon monoxide (CO), hydro carbon (HC), nitrogen oxides (NOx), carbon dioxide (CO_2), Oxygen (O_2), is measured for the blend of biodiesel-oxygenated additive, biodiesel, and diesel.

Table 4.2. Specifications of Exhaust Gas Analyser

Gas measured	Measuring range	Resolution
CO	0-10% Vol	0.01%
CO_2	0-20% Vol	0.1%
HC	0-15000 ppm	1ppm
O_2	0-25% Vol	0.01%
NO_x	0-10000 ppm	1 ppm

In this analyser the zero setting function sets the sensor to zero using span gas. On a times basis the analyser is being first turned ON a zero will be requested automatically at a time interval. The zero airport allows gas analyser to zero without removing the sampling probe exhaust tail. The ambient air from zero port drawn through a charcoal filter helps in setting HC to zero. The zero key on keyboard enables to set zero for CO, CO_2 and NOx to zero with ambient air and calibrated to 20.9% oxygen by volume. The exhaust gas analyser is shown in Fig.4.3.

Fig.4.3. Five Gas Analyser with Display

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Fig.4.4. Experimental Setup of Computerised C.I Engine

4.2. EXPERIMENTAL PROCEDURE:

4.2.1. Procedure for Blending:

In hand blending the following items are required:

1. 50 ml graduated cylinder
2. 1000 ml graduated cylinder
3. One- litre sample cans with screw-on lids

Firstly, 1000 ml of biodiesel is measured and poured in a can. After that 5% of Di ethyl ether which is 50 ml is measured and poured in the same can. Now, both the liquids of different viscosities are mixed up with the help of mechanical stirrer and thus hand blending is achieved in a quasi-static process.

4.2.2. Procedure for Evaluating Performance and Emission Characteristics

In this work, the experiment is carried out in three phases. In phase 1, the Diesel is used as a fuel in the engine. In phase 2, the biodiesel extracted from Palm Stearin is used as a fuel in the engine. In phase 3, the PS biodiesel blended with additive [PS+DEE] is used as a fuel in the engine.

The experimentation is carried out as below steps.

1. Initially the engine is started at no load using diesel fuel and allowed to run for 10 minutes to stabilize.
2. The readings such as fuel consumption exhaust emissions, temperatures etc., were taken as per the observation table.
3. The load on the engine was increased by 20% of full load using the dynamometer loading device controls on panel box and the readings were taken as step 2.
4. Step 3 is repeated for different loads from no load to full load.
5. After completion of test, the load on the engine was completely relieved and then the engine was stopped.
6. As above mentioned procedure, the experimental steps are followed on diesel engine by change of fuel with Biodiesel [PS], PS+DEE respectively.
7. The results were calculated as follows.

Note:

- Precautions were taken before starting the experiment.
- Always engine should be started with no load condition.

4.3 Procedure for Calculations:

1. Brake Power [BP]:

$$BHP = \frac{N \times W}{1500}$$

Where; N is Engine Speed [RPM]

W is Weight [kg]

BHP is Engine output power in, HP

BP = BHP x 0.746

Where; BP is Brake Power in, KW

2. Indicated Power [IP]:

IP = FP x BP [KW]

Where; FP is Frictional Power in, KW, is determined using Willian's Line method

3. Frictional Power [FP]:

Frictional power is calculated using Willian's Line Method. Gross fuel consumption Vs. Brake Power at a constant speed is plotted and the graph was extrapolated back till zero fuel consumption. The point where this graph cuts the BP axis that fives frictional power of the engine at that speed. This negative work represents the combined loss due to mechanical friction, pumping and blow by.

4. Brake Thermal Efficiency:

$$\eta_{bth} = \frac{\textbf{BP x 3600}}{\textbf{Mf}*\textbf{CV}}$$

Where; CV is Calorific Value of Fuel in, KJ/Kg

M_f is mass flow rate of fuel in, Kg/hr.

5. Indicated Thermal Efficiency:

$$\eta_{ith} = \frac{\text{IP x 3600 x 100}}{\text{Mf x CV}}$$

Where; CV is Calorific Value of Fuel in, KJ/Kg

M_f is mass flow rate of fuel in, Kg/hr.

6. Mechanical Efficiency :

$$\eta_m = \frac{BP}{IP}\text{x}100$$

7. Volumetric Efficiency:

$$\eta_v = \frac{m/\rho}{\text{Vdis x } N/2}$$

Where ρ is inlet air density.

8. Specific Fuel Consumption [SFC]:

$$\text{SFC} = \frac{Mf}{BP}$$

Where; M_f is Mass flow rate of fuel consumption in, Kg/hr.

BP is Brake Power in, KW

CHAPTER 5
EXPERIMENTAL INVESTIGATION OF OILS IN THE TEST ENGINE

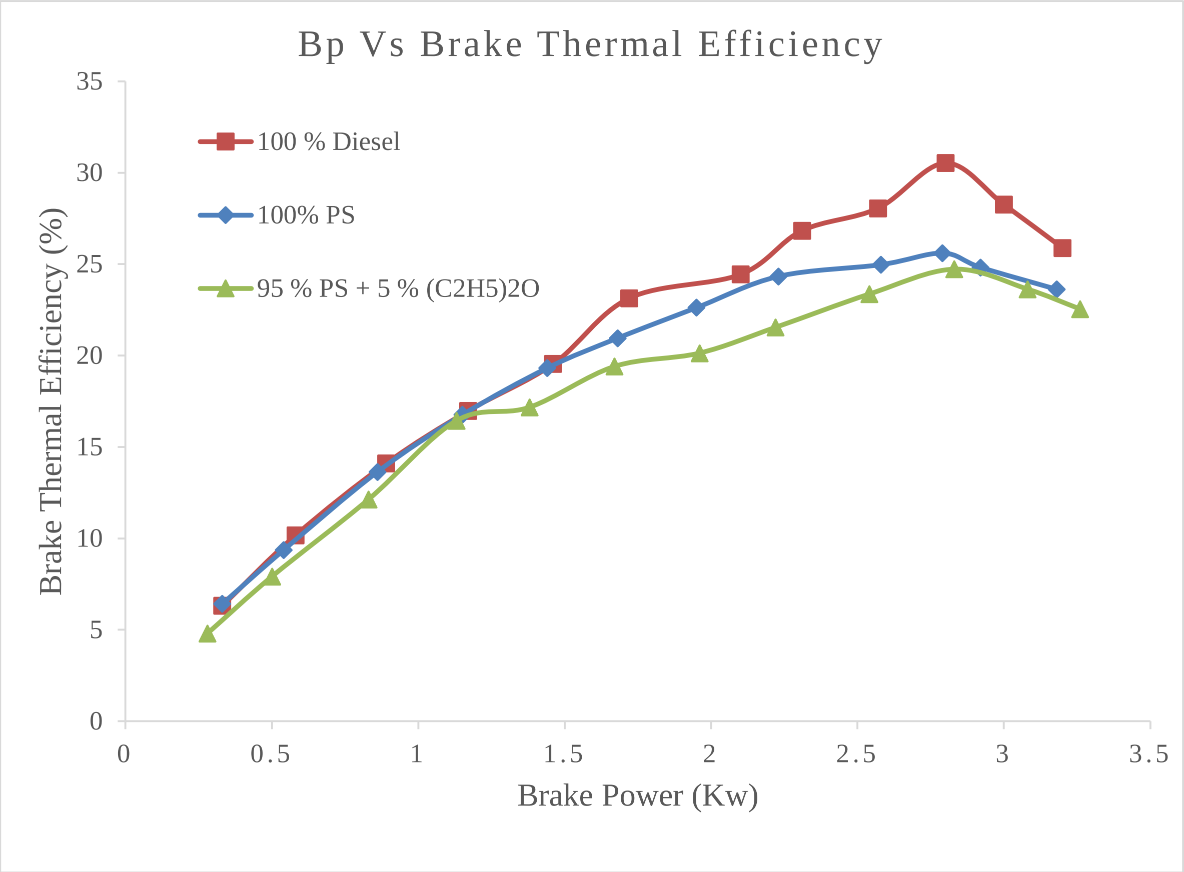
5.1. INTRODUCTION

Chosen oils such as Diesel, Bio-Diesel and Bio-Diesel blended with Di-ethyl ether are tried on the test engine with an objective to examine their suitability as alternate fuels. A series of load tests are carried out on diesel engine with computerized test engine, using vegetable oils and its blend. Five gas emission analyser is attached to the engine. The performance parameters such as Brake power(BP), Brake thermal efficiency (η_{bth}), Indicated thermal efficiency (η_{ith}), Mechanical efficiency (η_m), Volumetric efficiency(η_v), Specific fuel consumption(SFC), the emission parameters such as Carbon monoxide (CO), carbon dioxide (CO_2), Unburnt hydro carbons (UHC), Nitrogen oxides(NO_X), Oxygen(O_2) are evaluated and analysed from graphs. Oils which yield better performance and emission parameters are identified.

5.2 RESULTS AND DISCUSSIONS:

The experimental investigations are carried out using the above said oils on the test engine. The detailed analysis of these results are discussed in this section.

5.2.1 Engine Performance and Emission Parameters of the Test Fuels:



Graph.5.1. Variation of Brake Thermal Efficiency with Brake Power for the Test Samples

5.2.1.1 Brake Thermal Efficiency: Graph.5.1. Shows the variation of brake thermal efficiency with brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. Brake Thermal Efficiency for biodiesel is very close to that of diesel. Maximum brake Thermal efficiency is obtained at 10 kW load. The Brake Thermal Efficiencies for biodiesel and biodiesel with the blend are 25.60% and 24.72%, whereas for diesel it is 30.53%. Brake thermal efficiency for biodiesel and 5% blend is lower by 4.93% and 5.81% respectively compared to diesel. This is because of the fuel properties such as Viscosity and Density. As density increases mass flow rate of fuel increases and thus brake thermal efficiency decreases. As the decrease in brake thermal efficiency of biodiesel and the blend are minimum compared to diesel, they can be used as alternative fuels in C.I. engine.

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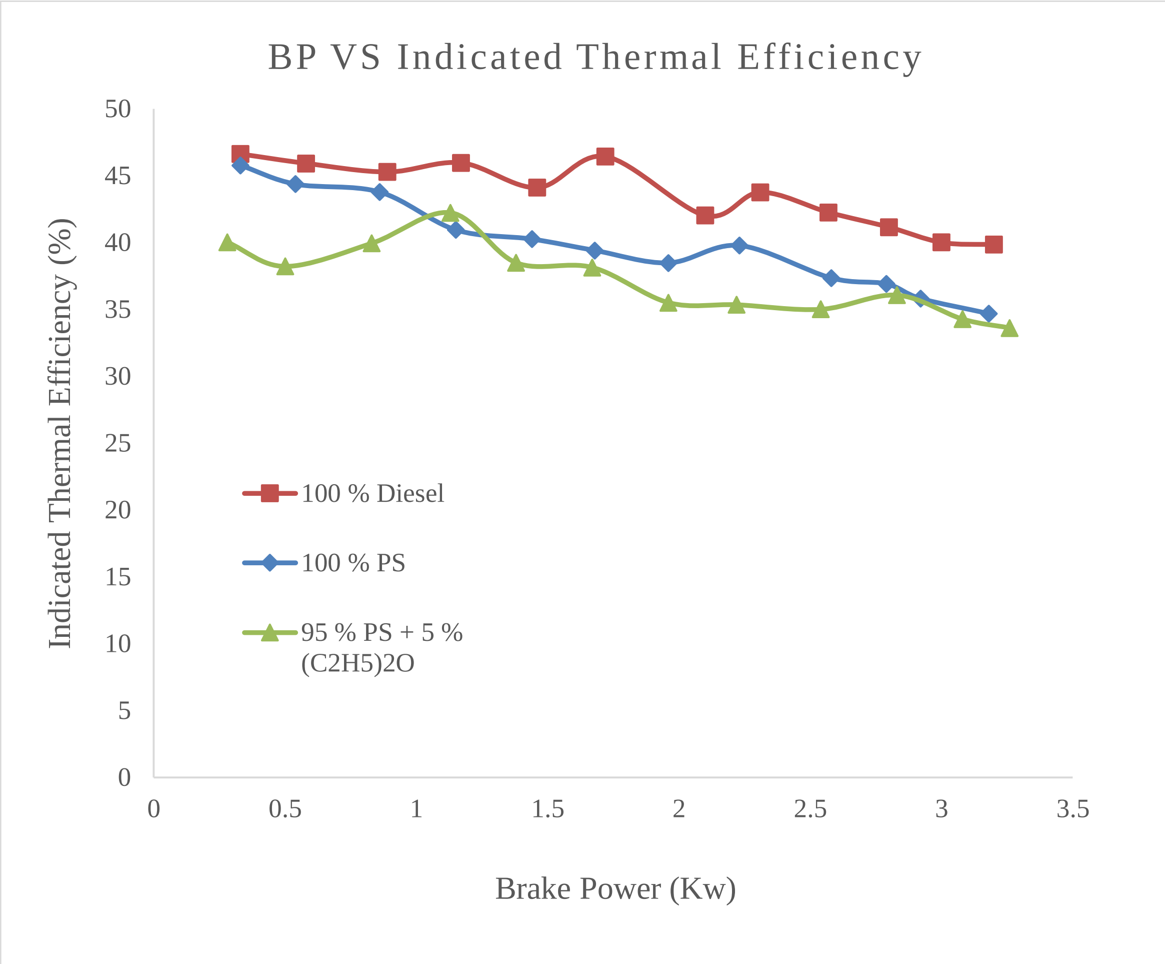

Graph.5.2.Variation of Indicated Thermal Efficiency with Brake Power for the Test Samples

5.2.1.2. Indicated Thermal Efficiency: Graph.5.2. Shows the variation of indicated thermal efficiency with brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. Indicated Thermal Efficiency for biodiesel is very close to that of diesel. The Indicated Thermal efficiencies for Biodiesel and biodiesel with the blend are 39.78% and 36.07%, at 8kw and 10kw load respectively, whereas for diesel it is 43.76%, at 8kw load. The above result shows that diesel has more indicated thermal efficiency than that of Bio-diesel and biodiesel with the blend. This is because of the fuel properties such as Viscosity and Density. As density increases mass flow rate of fuel increases and thus indicated thermal efficiency decreases.

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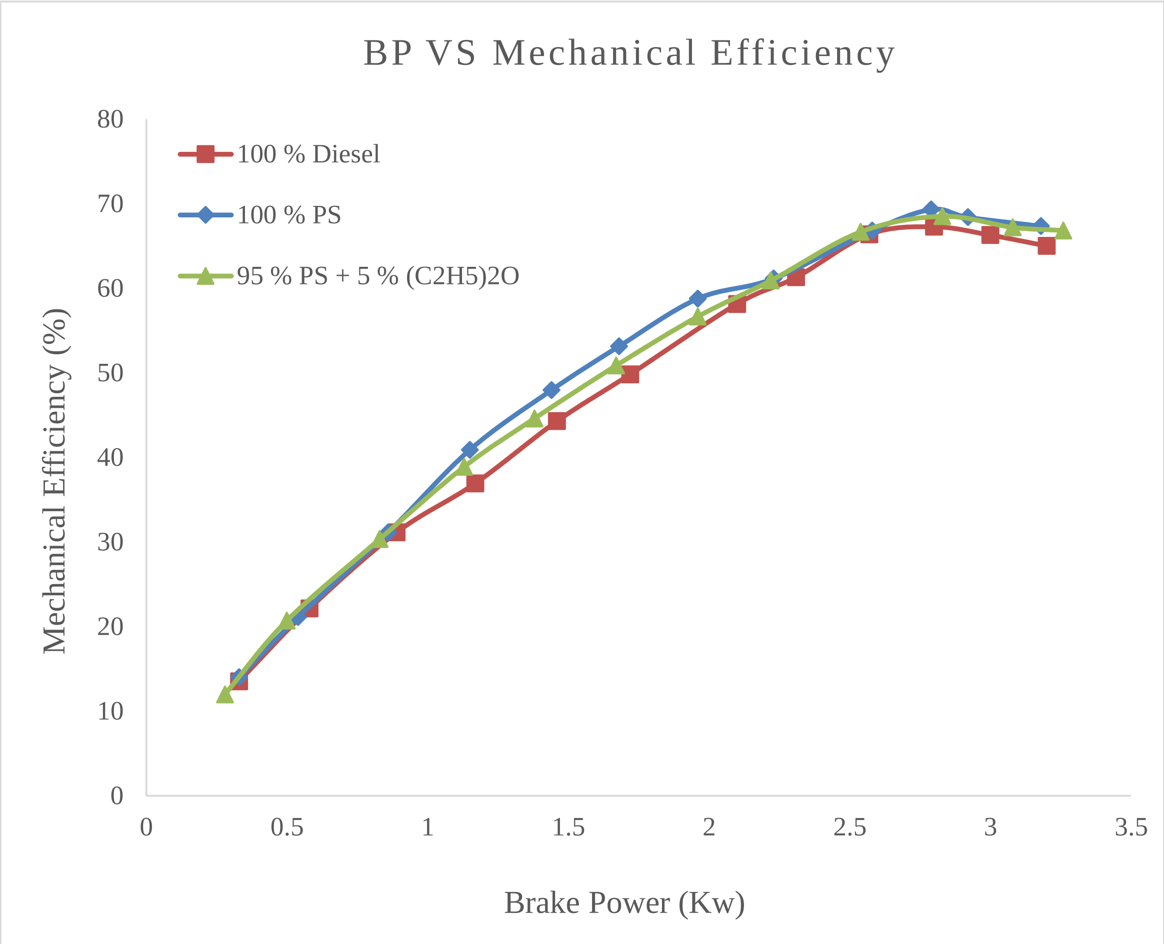
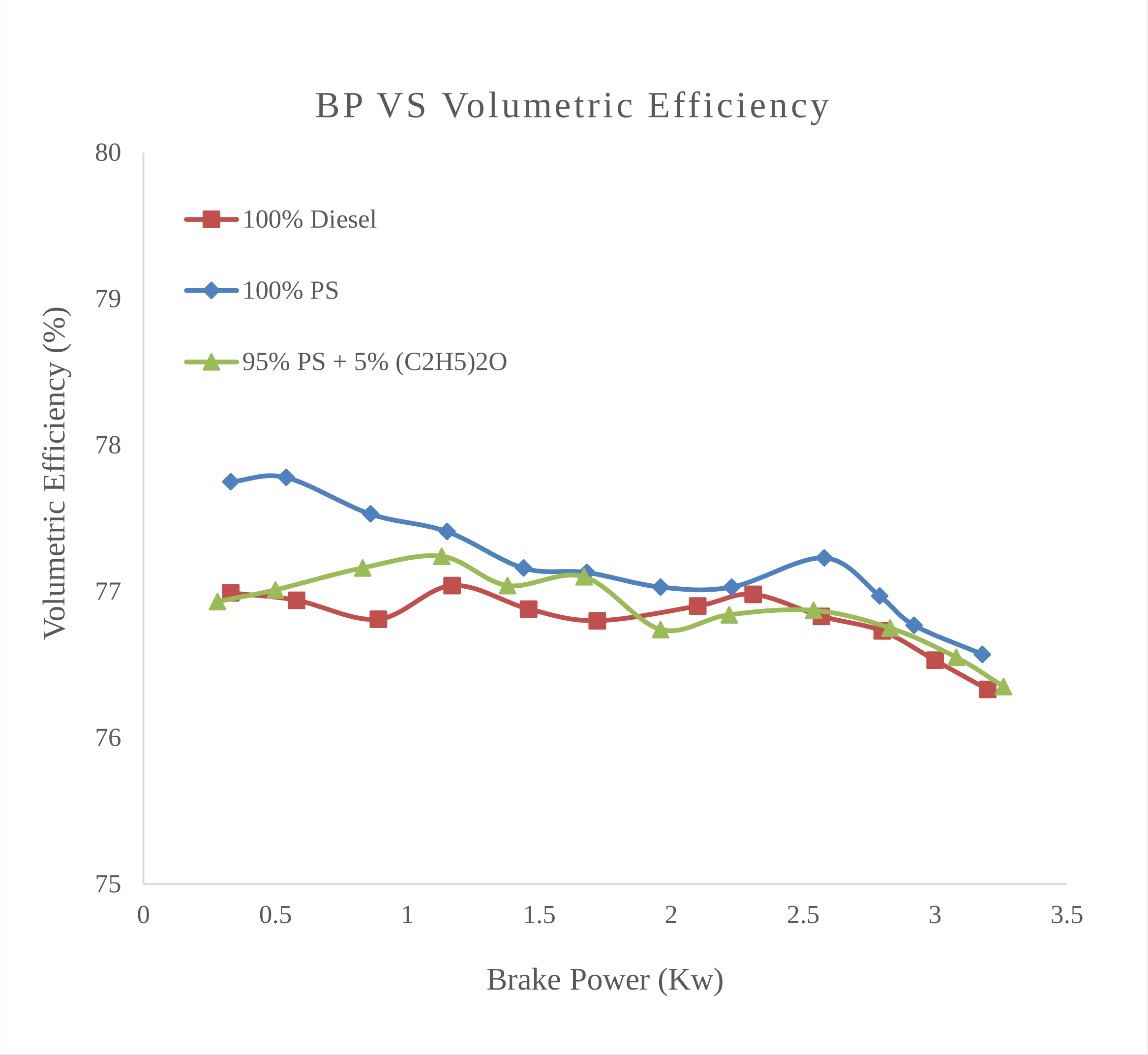


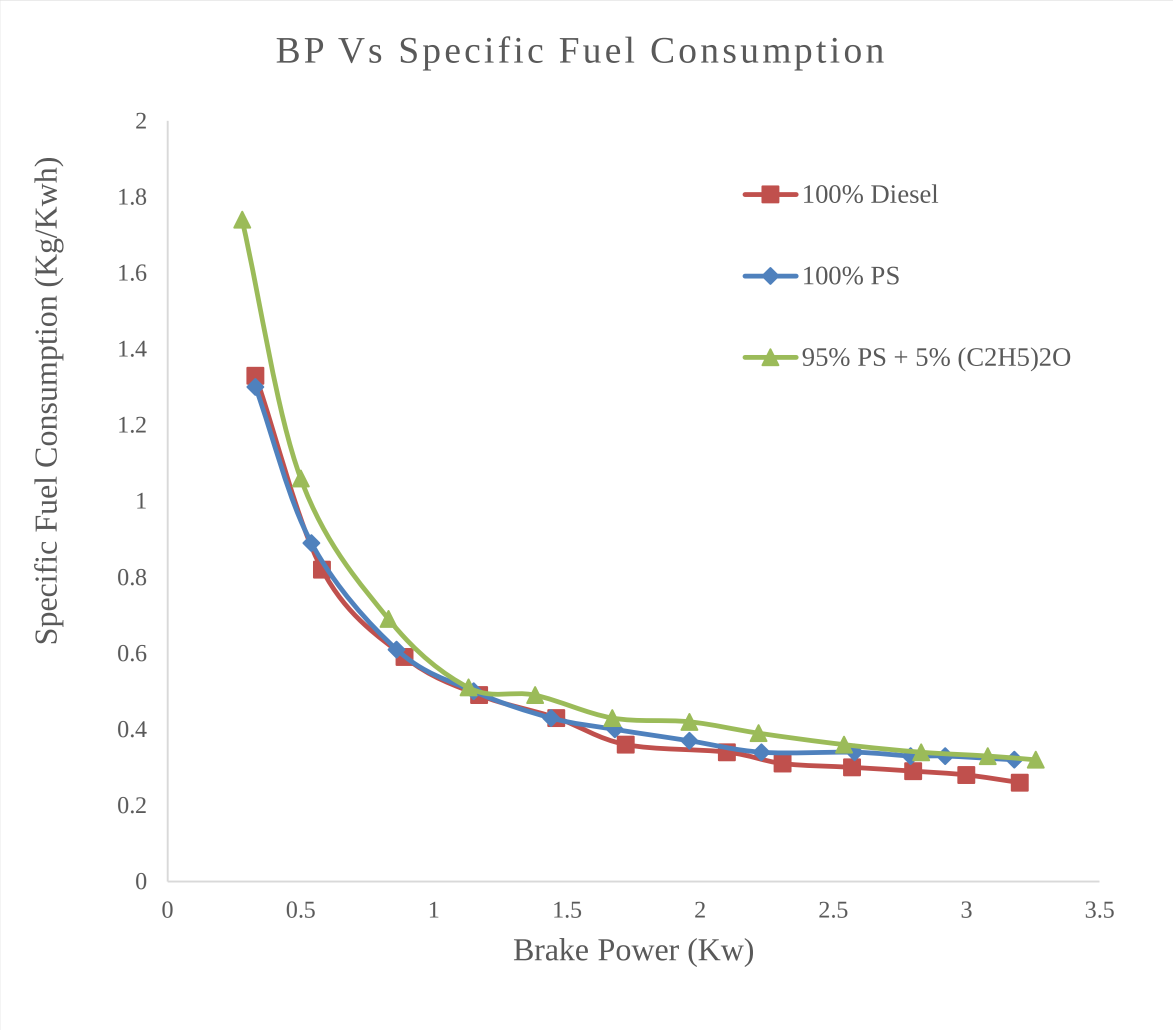
Graph.5.3. Variation of Mechanical Efficiency with Brake Power for the Test Samples

5.2.1.3. Mechanical Efficiency: Graph.5.3.Shows the variation of mechanical efficiency with brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. Mechanical efficiency measures the effectiveness of a machine in transforming the energy and power that is given as an input to the device into an output force and movement. Hence, mechanical efficiency indicates how good an engine is in converting the indicated power to useful power. Mechanical Efficiency for biodiesel is slightly higher to that of diesel. Maximum mechanical efficiency is obtained at 10kw load. The Mechanical efficiencies for biodiesel and biodiesel with the blend are 69.34% and 68.53% whereas for diesel it is 67.28%. Mechanical efficiency for biodiesel and 5% blend is higher by 2.06% and 1.25% respectively compared to diesel. Hence, biodiesel and biodiesel with the blend can be used as alternative fuels in C.I. engine.



Graph.5.4. Variation of Volumetric Efficiency with Brake Power for the Test Samples

5.2.1.4. Volumetric Efficiency: Graph.5.4.Shows the variation of volumetric efficiency with brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. Volumetric Efficiency for biodiesel is higher than that of diesel. The Volumetric efficiencies for biodiesel and biodiesel with blend are 77.23% and 76.87%, at 9 kW load, whereas for diesel it is 76.98%, at 8 kW load. The above result shows that the volumetric efficiency is greater for Bio-Diesel when compared to the blend and the Diesel. Due to the effective increase in efficiency of the biodiesel and the blend compared to diesel, they can be used as alternative fuels in C.I engines.



Graph.5.5. Variation of Specific Fuel Consumption with Brake Power for the Test Samples

5.2.1.5. Specific Fuel Consumption: Graph.5.5. Shows the variation of specific fuel consumption with brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. Biodiesel has the lowest SFC compared to the blend. SFC for biodiesel and the blend is slightly higher than that of diesel. The specific fuel consumption of the test fuels found decreased with increase in load. The above results show that diesel has less fuel consumption compared to other test fuels. This is due to lower calorific values of biodiesel and the blend when compared with diesel.

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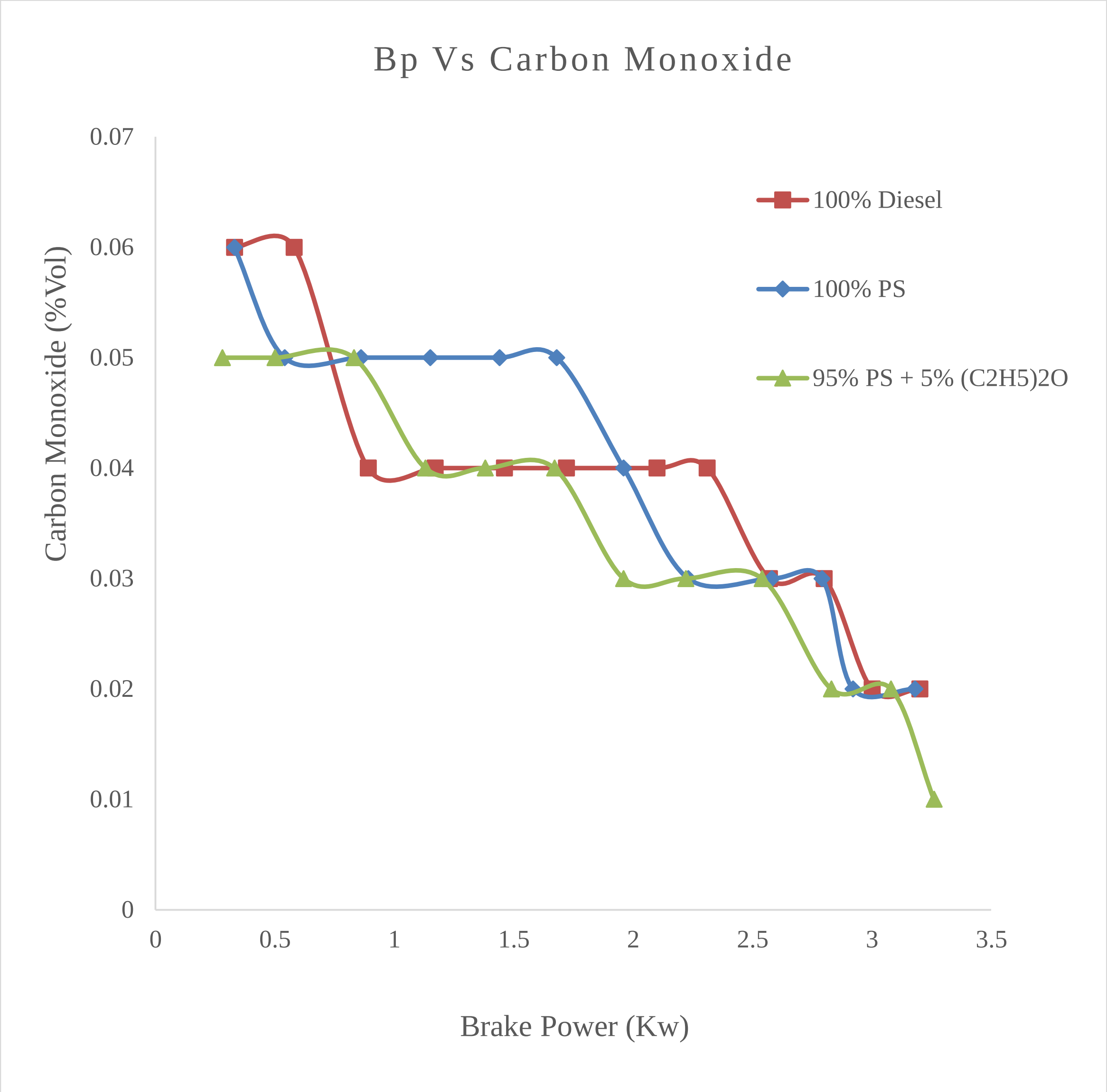

Graph.5.6. Variation Of carbon monoxide With Brake Power for the Test Samples

5.2.1.6. Carbon Monoxide: Graph.5.6.Shows the variation of carbon monoxide emissions with Brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. CO emissions for biodiesel and the blend are compared with diesel at all loads. Blend has lowest CO emissions compared to diesel and biodiesel. This is due to the oxygen content in the blend which makes easy burning at higher temperature in the cylinder. The CO emissions for blend is found to be constant for some load and later it decreased.

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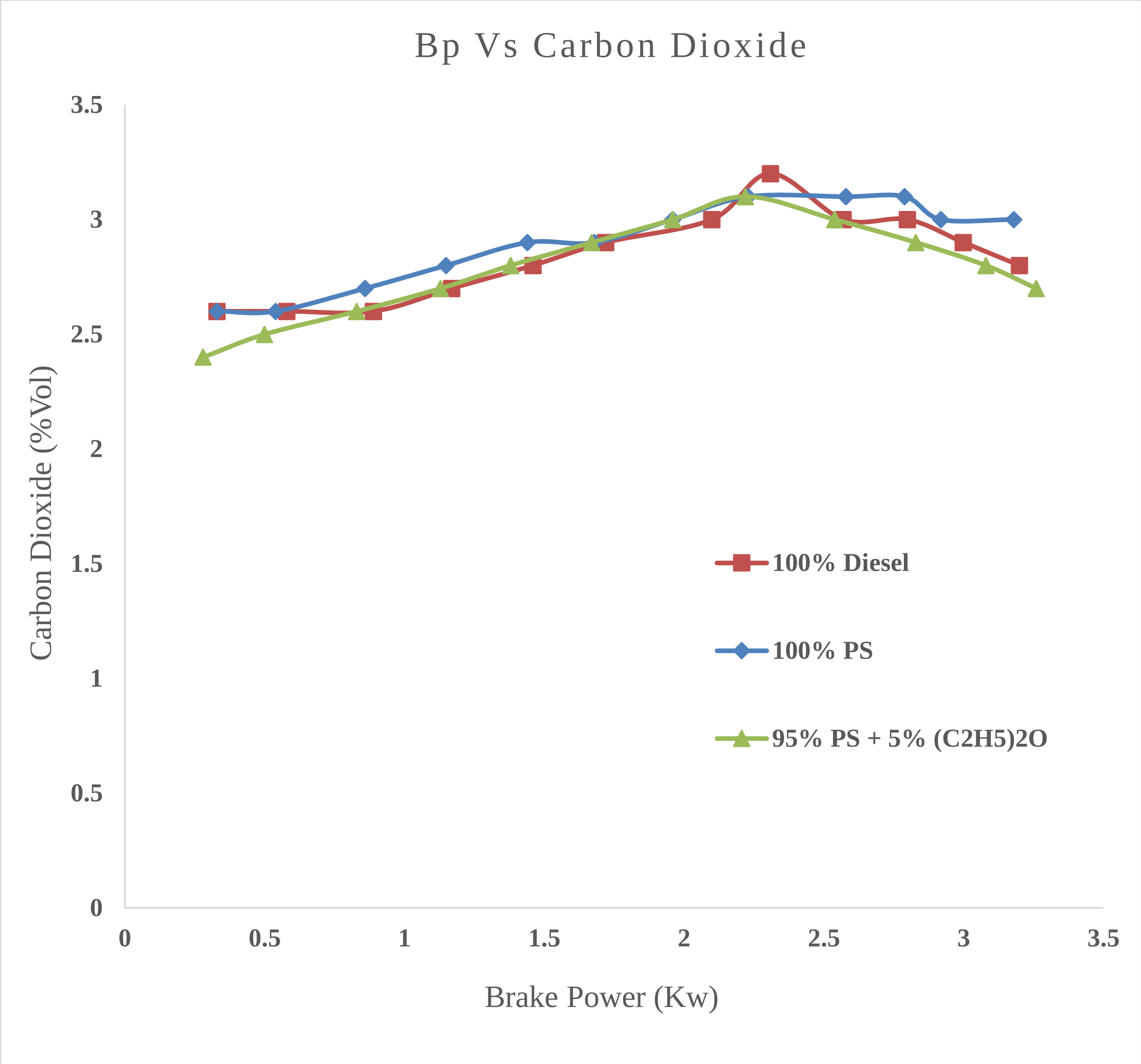

Graph.5.7. Variation of Carbon Dioxide with Brake Power for the Test Samples

5.2.1.7. Carbon Dioxide: Graph.5.7. Shows the variation of carbon Dioxide emissions with Brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. CO_2 emissions for biodiesel and the blend are compared with diesel. The result shows that the carbon dioxide emissions of blend are comparatively lower than that of bio-diesel and diesel. This is due to the oxygen content in the blend which makes easy burning at higher temperature in the cylinder. The other test fuels deviated due to viscosity. In engine load is higher, richer fuel air mixture is burned and thus more CO_2 is produced.

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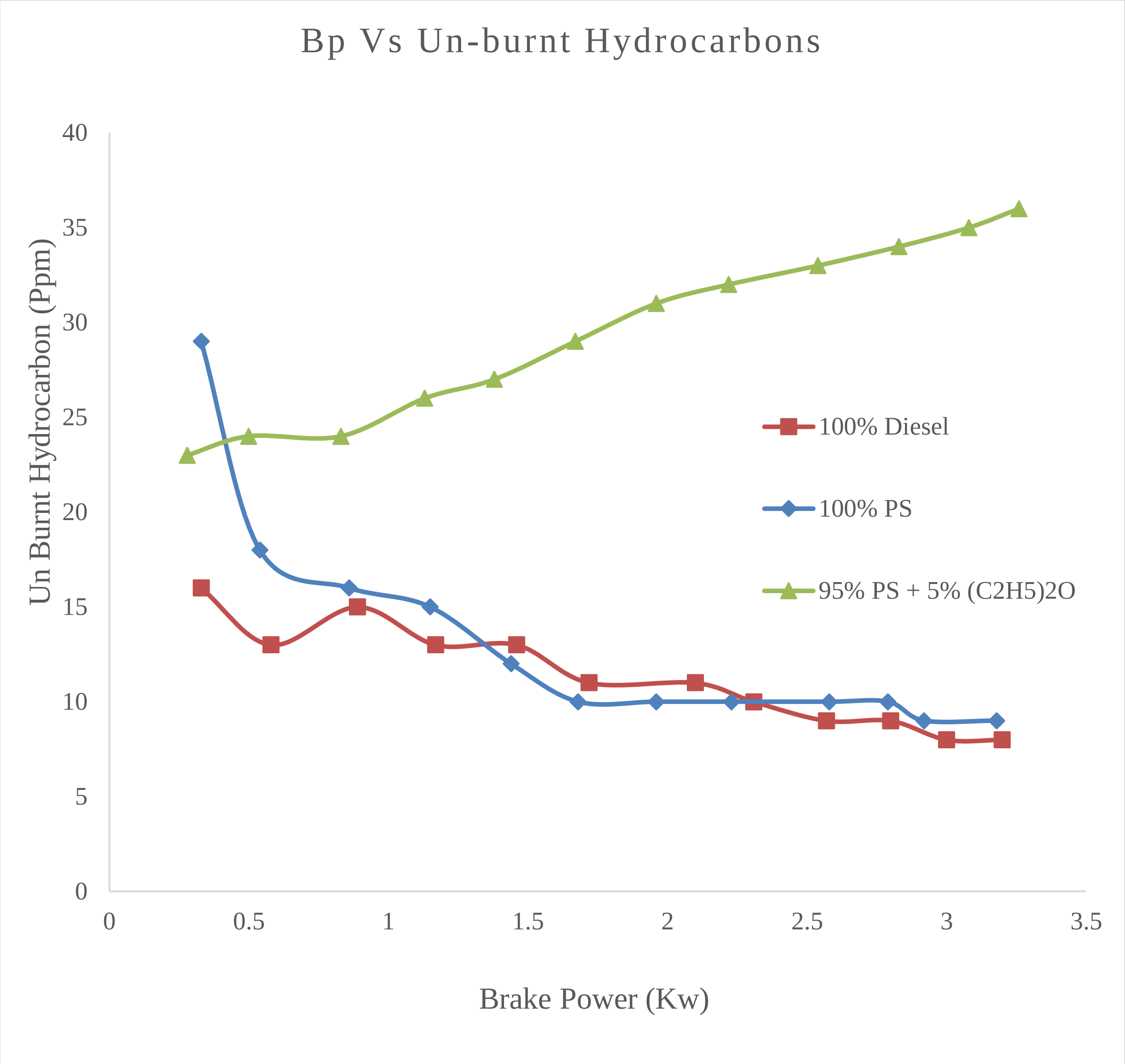
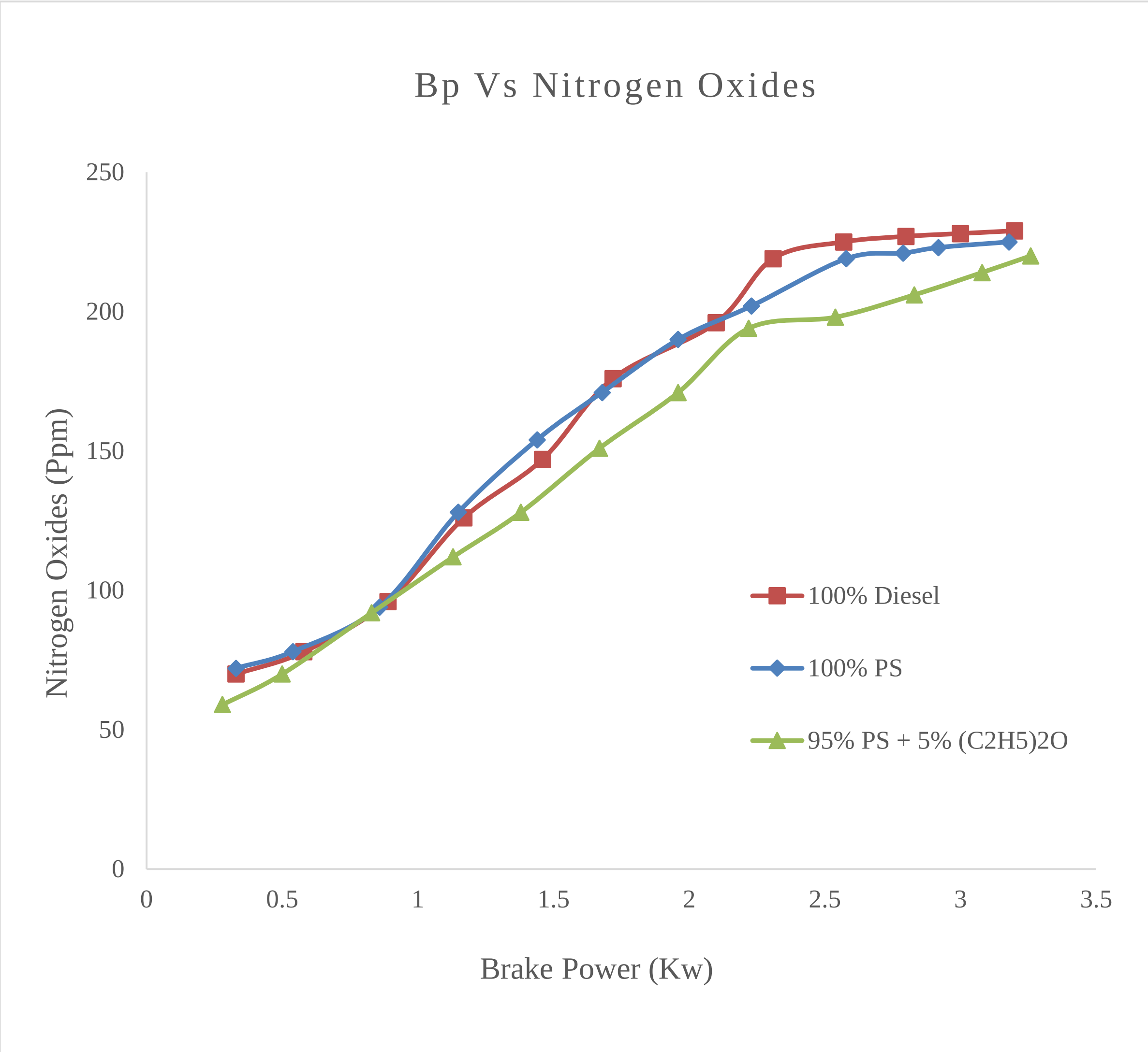


Graph.5.8. Variation of Un-Burnt Hydrocarbons with Brake Power for the Test Samples

5.2.1.8. Hydro Carbons: **Graph.5.8.** Shows the variation of Un-burnt hydro carbon emissions with Brake power output for diesel, bio-diesel and biodiesel blended with di ethyl ether in the test engine. It can be seen that Blend has higher emissions of UHC compared to diesel and bio-diesel. The above results show that the blend has increase in UHC, whereas the diesel and biodiesel has decrease in UHC. This is mainly due to the increase in viscosity of the blend fuel. Increase in HC emission causes because of the relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at high engine load. The lower calorific value and the higher viscosity of biodiesel result in highest HC emissions.



Graph.5.9. Variation of Nitrogen Oxides with Brake Power for the Test Samples

5.2.1.9. Nitrogen Oxides: Graph.5.9. Shows the variation of Nitrogen Oxide emissions with Brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. NO_X emissions for biodiesel and the blend are compared with diesel at all loads. Blend has lowest NO_X emissions for all loads compared to diesel and biodiesel. The NO_X emissions found to increase from no load to maximum load for the blend and in lesser ppm than the other test fuels. Though vegetable oils contain nitrogen in minimum percentage, the blending of the fuel with oxygenated additive made it possible in reducing NOx emissions.

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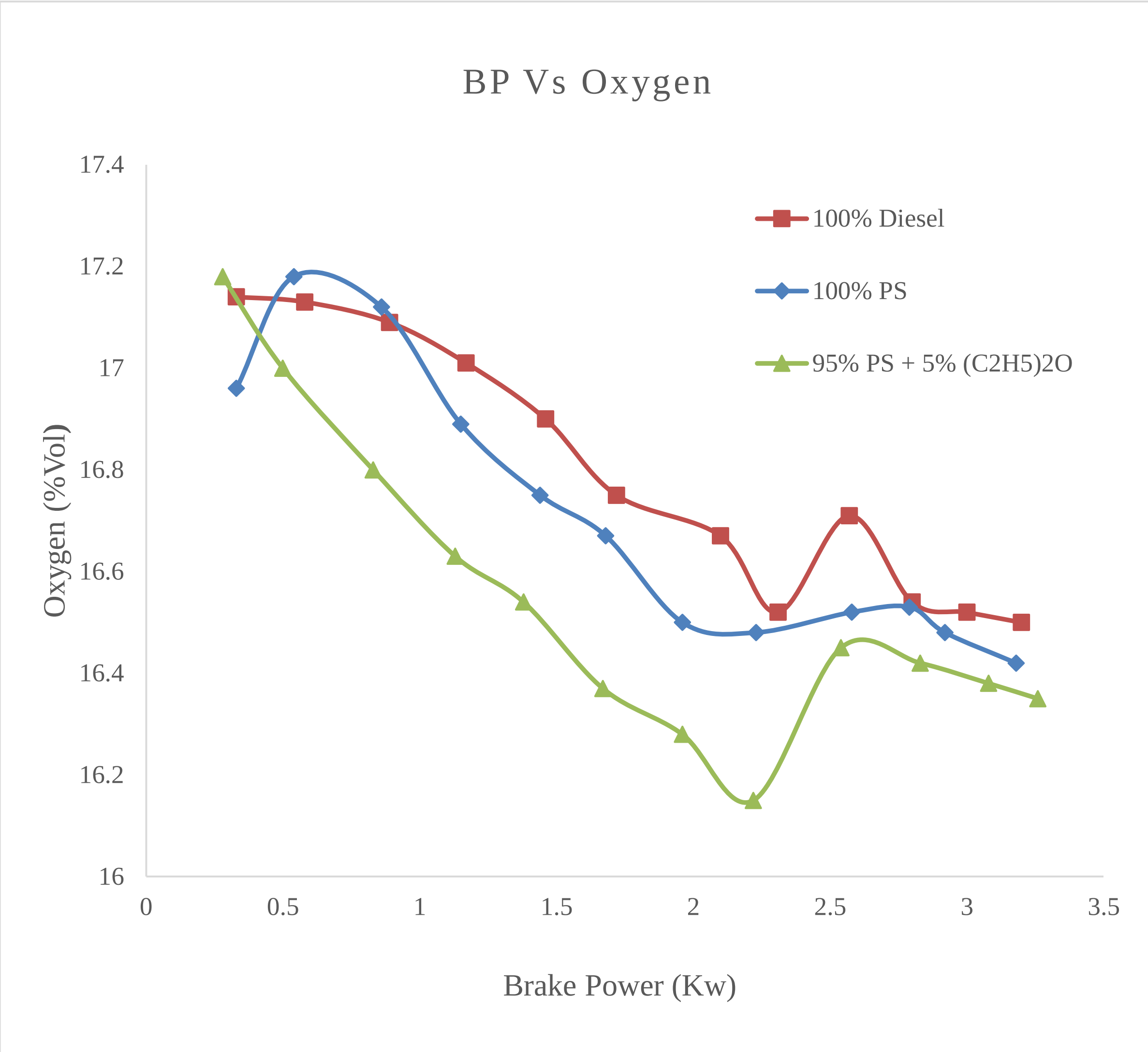

Graph.5.10. Variation of Oxygen with Brake Power for the Test Samples

5.2.1.10. Oxygen: Graph.5.10. Shows the variation of oxygen emissions with Brake power output for diesel, biodiesel and biodiesel blended with di ethyl ether in the test engine. O2 emissions for biodiesel and the blend are compared with diesel at all loads. Blend has lowest O2 emissions for all loads compared to diesel and biodiesel. This is due to complete combustion of the blend fuel inside the engine. This reduces the O2 level in the blend emission. Hence it is cleared that blend has better emission characteristics than bio-diesel and diesel.

CHAPTER- 6
CONCLUSIONS

The experimental investigations have been carried out on a CI engine performance and emission characteristics at different operating conditions. Based on the results, the following conclusions have been drawn:

Performance:

- Mechanical efficiency can be increased by using biodiesel and biodiesel with the blend.
- Volumetric efficiency can be increased by using biodiesel itself.
- Brake thermal efficiency can be improved by using diesel alone.
- Indicated thermal efficiency can be improved by using diesel alone.
- The total amount of fuel consumption can be reduced by using diesel.

Emissions:

- Carbon dioxide (CO_2) emissions can be decreased by using biodiesel with oxygenated additive.
- The emission of carbon monoxide (CO) is very much lesser while using biodiesel with oxygenated additive.
- Using biodiesel can reduce the HC emissions to the maximum extent as that of diesel.

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- The NO_X emissions can be regulated by using biodiesel with oxygenated additive.
- The percentage emission of oxygen (O_2) is low, while using biodiesel mixed with oxygenated additive.

This project with the Course Outcomes CO1 to CO5 has attained Program Outcomes PO1, PO2, PO3, PO4, PO7, PO8, PO9, PO10, PO11 and Program Specific Outcomes PSO1.

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