Investigation on Performance of Diesel Engine Fuelled with Mustard Oil Blends

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Abstract - Increasing oil prices and global warming activates the research and development of substitute energy resources to maintain economic development. The methyl esters of vegetable oil, known as biodiesel are becoming popular because of their low ecological effect and potential as a green substitute for compression ignition engine. Diesel engines are more efficient and cost effective than other engines. An experimental study was conducted to study the effect of blending esterified vegetable oil (mustard oil) by different volume with diesel fuel. Performance and emissions of a 4- stroke diesel engine comprising of single cylinder. The engine ran at different torque but at a constant speed where diesel is considered to be the base fuel. As mustard oil is highly viscous oil, therefore it is not directly mixed with diesel fuel. Instead velocity must be reduced for the test fuel. This can be done by many methods viz trans-esterification, mixing with very less viscous fuel etc. here trans-esterification was preferred. Three blends were prepared being 10%, 20% and 30% and blended with diesel fuel named B10, B20 and B30 respectively. Performance parameters that were observed involved bsfc, brake thermal efficiency and exhaust gas temperature, whereas emissions that were analyzed were Nitrogen oxides (NO_x) and carbon dioxide(CO_2), total Hydrocarbon (HC), Carbon monoxide (CO) and smoke opacity (SO). Bsfc got reduced by nearly 4.67% when B30 was used in place of B10 in the blend thus indicating decrease in bsfc when oil percentage was increased. NO_x, CO_2 and unburnt total hydrocarbon were found to increase with increase in biofuel percentage by 17.25%(B10), 13.46%(B10) and 30%(B20) respectively at full load capacity but CO and SO were were found to decrease by nearly 33.33% and 32.83% (for B10) respectively at full load capacity.

Index terms :biofuel, trans-estertification emission and perfromances

INTRODUCTION

1.1. Energy Scenario -Energy is primary and most all-inclusive measure of all kind of work by man and nature. World's energy requirements are increasing day by day with rise in population rate and high growth rate. Recent assessments suggest that as many as 1.3 billion people lack access to electricity, and more than 2.6 billion people depend on conventional biomass for cooking. Upto 60 crores are in sub-Saharan Africa, and more than 30 crores are in India alone.Firmness and energy markets don't go together-booms. But recently energy markets were struck by two distinct factors: in the recent years energy markets have been rocked continually by the sort-lived skeptical shocks, and that too oil market being in particular. On the other side i.e. demand: the transition was led by the swift growing developing economies, led by the Chinese and the Indians. And on the contributor's side, profane movement towards cleaner and lesser carbon generating energy sources. With 1/3 of the total increase in primary energy, renewable energy (including biofuels) (12,55 mtoe%) was once again the fastest growing energy sources in the world that too with only a share of about 4%. China continued to govern renewable progress, bestowing over 40% of global growth- higher than the entire OECD and overtaking the United States and to become leading producer in non-conventional energy sector [1]. Although the wind remains to still give the lion's share of the increas in renewable power, solar is catching up fast.

Fig 1 Electricity deficit – country wise

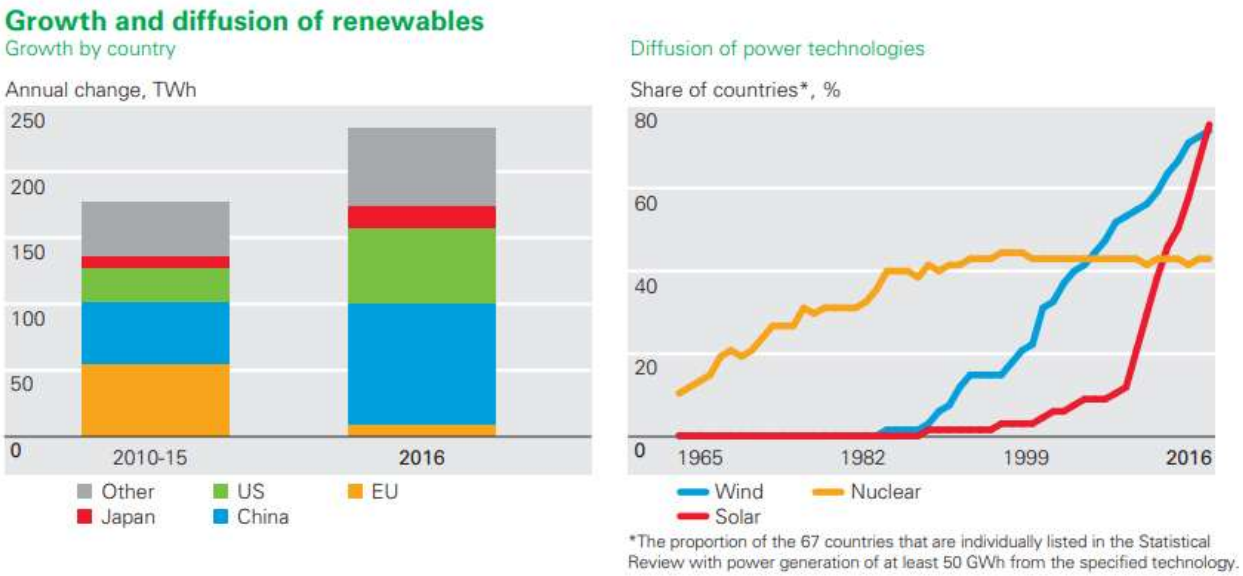


Fig 2 Growth and diffusion of renewables country wise

WEO 2017 had listed four major shifts in the global energy system set:

1. Rapid reducing costs of clean energy technologies,
2. Rapid rise in electrification of energy,
3. Transition to a cleaner energy and services-oriented economy as in China, and
4. USA's pliability of shale gas.

In the New Policies Scenario, world energy requirements is predicted to expand by nearly 30% between present and 2040 but still being slow-moving as compared to past. This is nearly equivalent to sum of China's and India's energy demands. Such traditional changes are supposed to be led by developing major giant like India which is moving towards center stage and that too at a period when distinction among energy producers and consumers are being smeared.

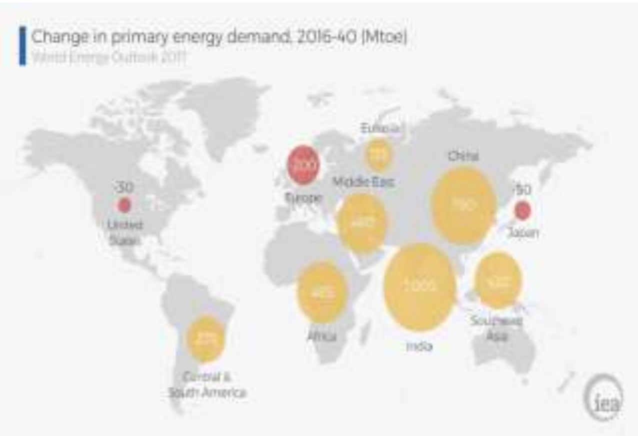
Global economy is increasing at an average rate of 3.4%/year with population rising from 7.4 billion today to more than 9 billion in 2040. A city with a size of of Shanghai is being added to global urbanized population at every 4 months are being major key that support the projections. Nearly 30 % demand growth share comes from India, whose share in world energy use is going to rise to 11% by 2040, but still being lower to its 18% share in foreseen global population. Nearly 2/3 of global energy demands comes from developing nations of Asia, rest impending from the African, Middle East and Latin America. The energy growth of Southeast Asia can be observed growing at nearly twice the pace of China.

Future of renewables:

For many countries renewables are going to become source with minimum cost for power production therefore it is forecasted that these are going to capture nearly 2/3 of global investment in power plants to 2040. With United States shale revolution turning to export and its exceptional capability to unlock new cost-effective resources has pushed country's combined oil and gas output to a level 50% higher than any other country. US is already a net exporter of gas and is going to become net exporter of oil (late 2020s) and LNG (in mid 1920s)

Electric car fleet (nearly 900 million cars by 2040) may foresee a much higher expansion owing to infrastructure supports and better policy making. With major oil giant's ability to bear the storm of decreased revenues from hydrocarbons, prices could be easily managed in $50-70/barrel range to 2040. However, not enough to shoot the major change in oil use globally. A strong policy action in remaining sectors along with rapidly transforming passenger car flee

t is the need of the hour else consumer would have fewer economic incentives to switch away from oil even in a lower oil price world.



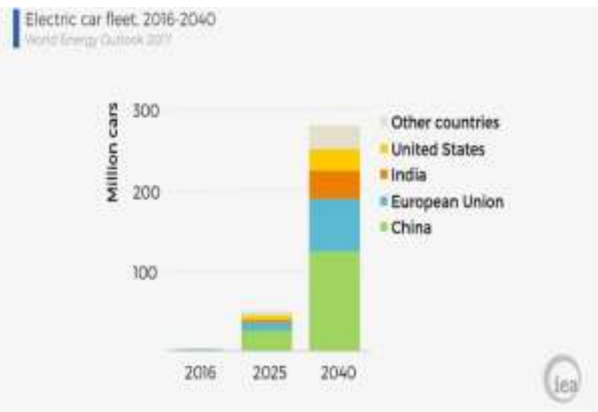
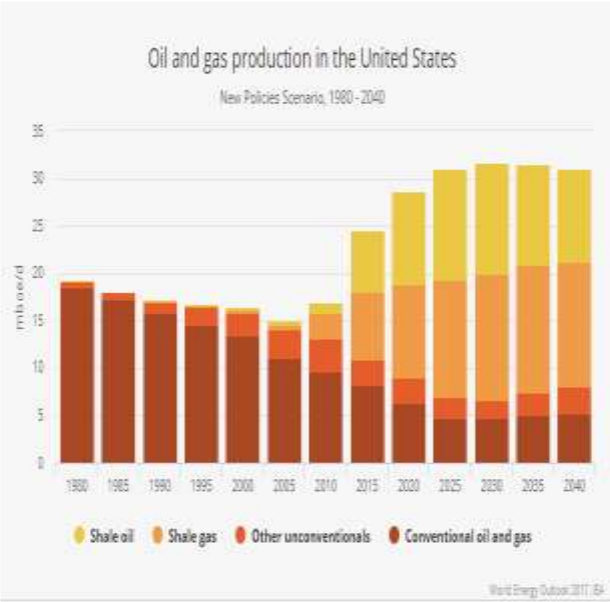


Fig. 3 Change in primary energy demand 2016-2040Fig.4 Electric car fleet 2016-2040

In the New Policies Scenario, natural gas would account to nearly a quarter of global energy by 2040, thus becoming the second major fuel in the global mix after oil. With 80% of the projected gas growth demand taking place only in developing economies, that too led by China, India and other Asian nations. Most of these countries imports the gas and thus transportation costs becomes vital with still lacking

infrastructure required for the job. Gas looks a better alternative fit for policy makers and to set priorities in the region, further generating heat, power and mobility with lesser CO_2 and polluting emissions than other fossil fuels, thus helping to raise the air quality.
In 2016 Asia, apart from dominating global coal consumption (about 73.8% of world consumption), became the leading consumer of renewables in power production, overtaking Europe & Eurasia. Europe & Eurasia remains the leading consumer of natural gas and nuclear power.



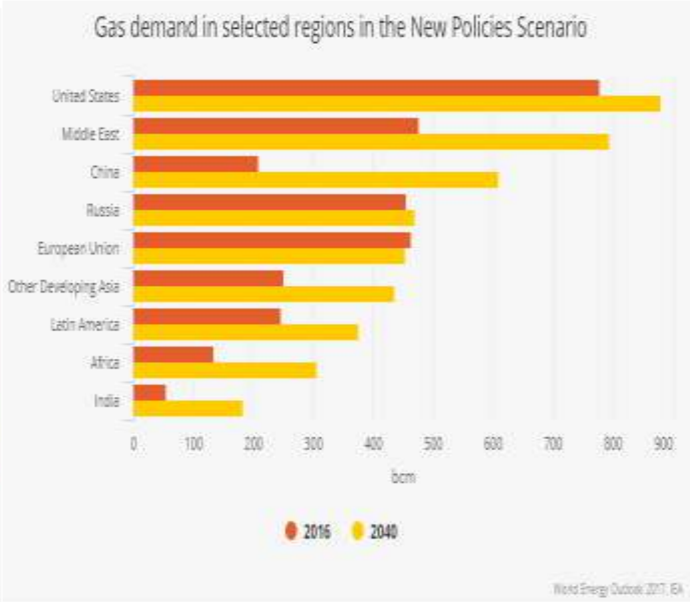


Fig.5 Oil and gas production in the United StatesFig 6. Gas demand in selected regions in new policies scenario

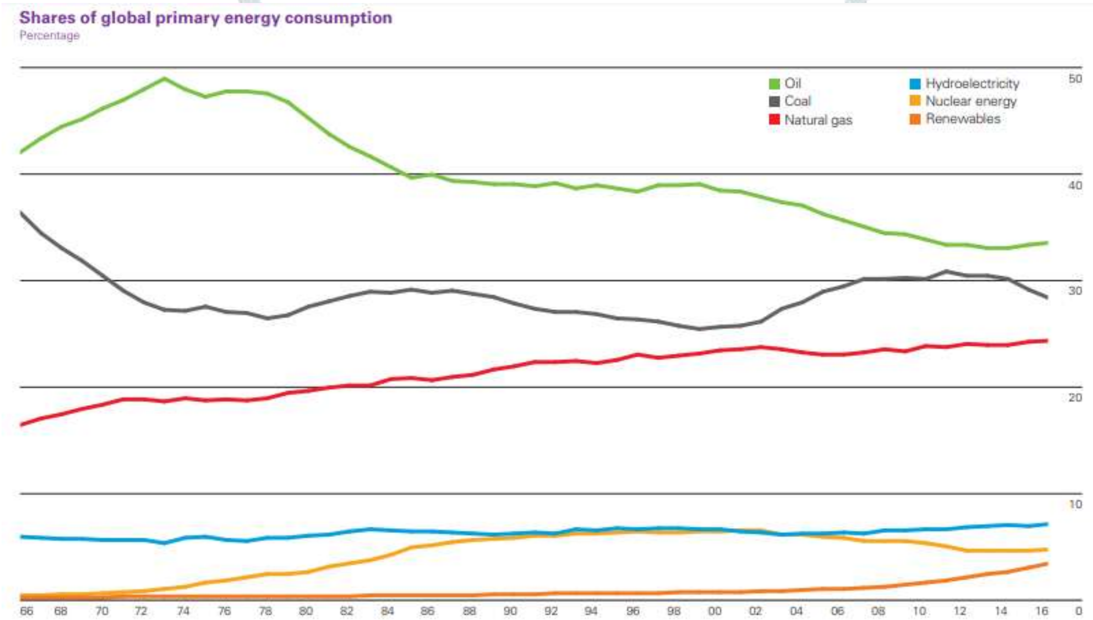


Fig.7 Global primary energy consumption

Oil remains the world's superior fuel, making up roughly a third of all energy consumed. After continuous decline in global marked share for 15 years from 1995 to 2014 oil gained its share for 2nd year in a row in 2016. Whereas coal's market share declined to 28.1%, the minimum since 2004. But renewables in power production reckoned for a record of 3.2% of global primary energy utilization [1]. But global oil production increased by only 0.4 million b/d in 2016, the steadiest since 2013.

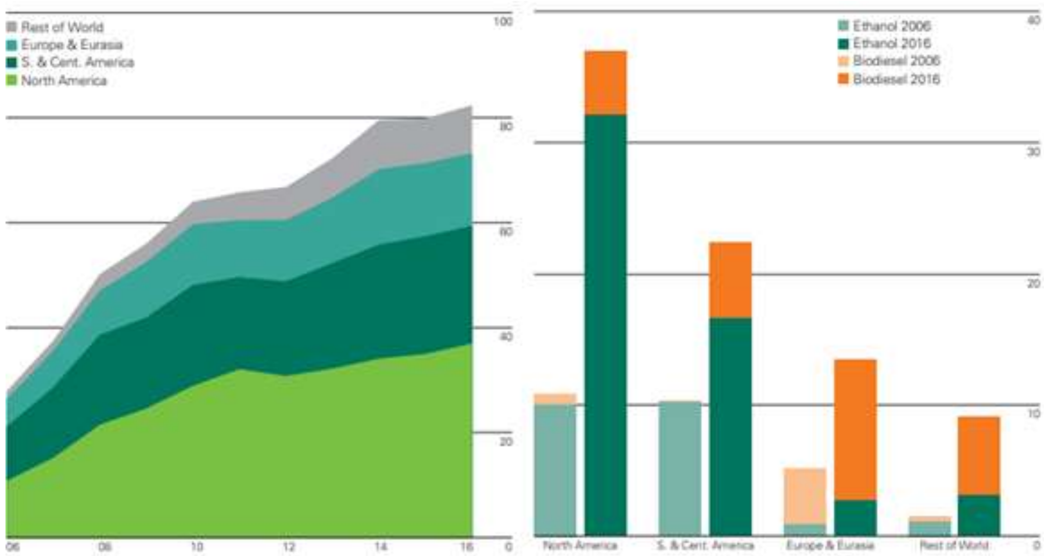


Fig. 8 World biofuel production

In 2016, a rise of about 2.6% in world biofuels production was seen still lower to the 10-year average of 14.1%, but faster than in 2015 (0.4%). The maximum increment (1930 thousand tonnes of oil equivalent, or ktoe) being provided by the USA. Global ethanol production increased by only 0.7%, but declined in Brazil. With Indonesia accounting for nearly 50% increase (1149 ktoe), biodiesel production rose by 6.5%.

1.2 Energy scenario in India

India is one of the largest and fastest growing economies in the world. With an expansive population of above 1.2 billion people its demand for energy requirement is also very high. At present this demand is satisfied mainly by coal, foreign oil and petroleum. Most of which are not only non-renewable in nature but are also detrimental to the environment, and thus are not among the permanent solution for its energy crisis.

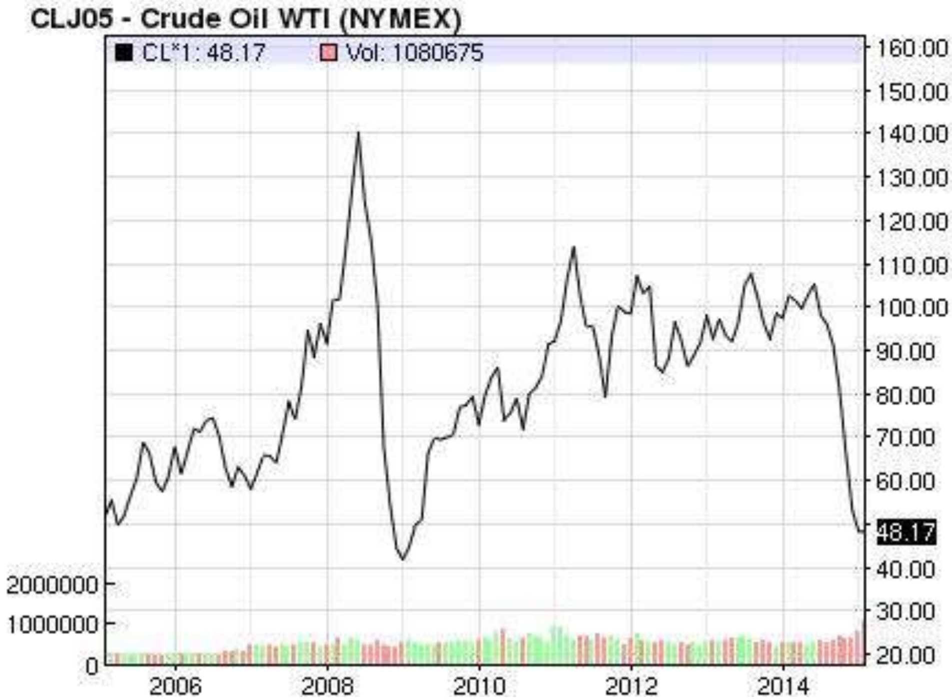


Fig 9 Graph: crude oil price WTI NYMEX

According to the 2015 edition of BP's Energy Outlook, India's energy production is projected to rise by 117% to 2035, while consumption grows by 128%. Coal has been regarded as the most vital source for electricity generation in India amongst different sources. Nearly $3/4^{th}$ of India's coal is consumed in the power sector. Petroleum consumption has enormously risen not only in industries but also in transport sector. These two factors being most vital for economic development of any country. Observations indicate rise in fossil fuel demands is leading to depletion of petroleum reserves at an alarming rate. Also the mounting in petroleum price products and environmental concern have led to an intensive studies on use of alternative fuels in various fields. There is lack of sufficient oil reserves in India. Due to growing demand of petroleum products our government is spending billions for their imports.

Important fractions of petroleum distillation are listed below (by increasing boiling temperature range).

Table 1 . Common fractions of petroleum as fuels

Fraction	Boiling range °C
LPG	-40
Butane	-12 t o -1
Gasoline	-1 to 110
Jet fuel	150 to 205
Kerosene	205-260
Fuel Oil	205-290
Diesel	260-315

Crude oil is being consumed at a much faster rate and since it is not being replaced naturally at the rate we consume it, it become a non-renewable resource. Crude oil consist of HC deposits and other organic materials kin an unrefined natural form in nature. It therefore need to be refined to produce usable products like petrol, diesel, kerosene, petrochemicals etc. Drilling is carried out only after studying structural geology, sedimentary basin analysis, and reservoir characterization (mainly in terms of the porosity and permeability of geologic reservoir structures). Refining is carried to separate (generally by distillation) raw fuel into different by-products viz petrol (gasoline), kerosene, asphalt and chemical reagents used to make plastics and pharmaceuticals. Petroleum has a wide usage in different categories. Estimations indicates that 95 million barrels each day is being utilized through the globe.
There are serious consequences on society that is largely dependent over earth's limited oil-reserves. The concept being known as peak oil. Earth’s atmosphere has been impacted negatively by the use of fossil fuels. Ecosystems are being damaged through oil spills and releasing a range of pollutants into the air including ground-level ozone and sulphur dioxide from sulphur impurities in fossil fuels. The impact of burning fossil fuels on raising global warming has also become matter of concern throughput the world that can’t be ignored.

1.3. Need for alternatives

Though diesel engines play a vital and indispensable role in today’s modern life, it contributes to pollution substantially. Burning fossil fuels emit carbon dioxide (CO_2), a gas which is the chief heat trapping gas causing the well-known phenomenon of greenhouse effect. With the greenhouse effect on earth, the concentration of CO_2 in the atmosphere is claimed to form a kind of blanket over the surface of the earth stopping heat radiated from the earth from escaping to the outer space. It has been proved that this phenomenon has been responsible for observed and predicted increase in the average temperature on the surface of the earth. The consequence of the increase of temperature of the surface of the earth is the threat for sea levels to rise, fierce storms, winds and heat waves. Over the years, agencies have been set up all over the world to formulate rules and procedures to curb the increase of CO_2 and other environmentally damaging gases like chlorofluorocarbons (CFCs), SO_2 and NO_x. Reduction of CO_2 emission has been targeted as the main step in checking the greenhouse effect and one of the most effective ways is by switching to non-fossil fuels, demanding higher-mileage cars and energy-efficient industries.
The need of various transportation systems is increasing daily in such a fast developing world, and due to this, number of vehicles are increasing while conventional fuel like diesel and petrol are vanishing gradually with time. So to have an alternative to above conventional fuels becomes the need of the hour.
Internal combustion engine (ICE) is still the most widely used power unit mainly in automobile industry. The main type of ICE are SI engines (when ignited by spark) and CI engine (when temperature and pressure rise is sufficient enough to cause spontaneous ignition of the fuel). Diesel engines are most widely used by agricultural applications, in industrial sectors for transportation and in decentralized power production because of their high fuel conversion efficiency and relatively easier operation.
With increased in requirements for automobiles, energy storage and environmental pollution have become most significant and serious problems. To achieve high efficiency and clean combustion in engines it is the need of the hour to search new alternative fuels and if possible develop some advanced combustion process. Need for alternative fuel also becomes important as crude oil resource on earth is also limited and thus fossil fuel sustainability becomes important. Biofuels remains promising with remarkable benefits over fossil fuels as far as renewability and emission are to be considered. At present, commonly used biofuels include alcohols, ethers and biodiesel. Alcohol fuels are generally liquid at N.T.P. and are easy to store and transport. Soot emissions are also significantly reduced during combustion of alcohol fuels due to presence of oxygen atoms. Methanol, ethanol and n-butanol are widely used due to their simple production process and low cost.

1.4. Alternate fuels

1. **Renewable Energy**
2. **Nuclear Power**
3. **Hydrogen**
4. **Fuel Cell**
5. **Alcohol**
6. **CNG**
7. **Propane**
8. **Biodiesel**

1.5. Vegetable oil as fuel in C.I. engines

After the first commercial blow in 1973 and then in 1979 owing to unforeseen rise in prices of petroleum products by the exporting countries notice and focus deflected to find out the alternative to diesel fuel [10]. Hydrogen, coal gas, producer gas, biogas, natural gas, methanol, ethanol, water slurry and vegetable oils were taken into consideration from time to time as an alternative for diesel. Hydrogen appeared to be a promising fuel but its production, storage, handling and hazardous nature still remains the major challenges that are needed to be dealt out first. Whereas major problems that remain with gaseous fuels like biogas, producer gas etc. is their storage owing to their gaseous nature. Also biogas and producer gas also have low calorific value. Beside producer gas is also harmful for operator as it is poisonous. Methanol and ethanol too have a low cetane number as well as low energy content with poor lubricating properties, hence may give rise to complications in fuel injection System. Further alcohols also require compression ratio of about 28 for its use as fuel in conventional Compression Ignition Engine. The concept of coal water slurry as C.I engine fuel is in preliminary stages as problems like wear of cylinder liners, position rings, erosion of fuel nozzles, etc. are associated with it. Further its usage limited to slow and medium stage engines.

LITERATURE REVIEW

2.1 History of biodiesel

At present an intensive forage is being carried in flourishing C.I. engine fuel blends and lubricants based on vegetable oils. It had become inevitable and the time demands for research in alternative fuels. Availability of vegetable oils is good in rural areas and these are also renewable which again goes in its favour to be used as a fuel. Since the advent of the I.C. engine, usage of such oil fuels have been studied. However it has been only recent that great focus has been laid upon usage of vegetable oils in C.I. Engines owing to the fact that they have comparable properties to diesel fuel. In the similar regards, many researchers with slight modifications on engine and also with varied fuel properties had been working continuously using different vegetable oils. It had also been found that problems like high viscosity, filter clogging and flame propagation have been associated with vegetable oils which in turn led to search for more alternative by scientists.

In general diesel have much lower viscosity than vegetable oils. But viscosity of fuel decreases as the heating temperature of fuel is raised. So basically any of the following methods can be employed to bring down the viscosity of the vegetable oils– trans-esterification, mixing with lighter oil and heating the oil.

Scientists J Patrick and E. Duffy conducted trans-esterification of vegetable oil as early as 1853. In August, 1893 Rudolf Diesel's primary engine model comprising of single iron cylinder with a flywheel at its base ran on its own power for the first time in Augsburg, Germany.

In early 1920s, alteration in diesel engine by manufacturers to utilize the lower viscosity of the petro diesel (fossil fuel) rather than vegetable oil, a biomass fuel was incorporated. But the petroleum industries were able to make it to compete successfully in fuel markets it was much cheaper to produce it as compared to the biomass alternatives.

France launched diester (local biodiesel fuel) in the 1990s, which was produced by the trans-esterification of rapeseed oil. Proportions varied from 5% (regular diesel fuel) to 30 % (used in public transportation by fleets).

From 1978 to 1996, the U.S. National Renewable Energy Laboratory experimented algae as a biodiesel source for the "Aquatic Species Program". A latest paper from Michael Briggs at the UNH biodiesel Group, suggested to substitute entire vehicular fuel with biodiesel prepared from employing algae that has greater than 50% natural oil content.

An illustration was shown by Rudolph Diesel of his compression ignition engine at the World's Exhibition in Paris, by using the peanut oil in 1898. He believed biomass fuel to be an important substitute to the resource consuming steam engine. Vegetable oils were used in diesel engines till as early as the 1920's when a change was made in the engine, making it possible to run on residue of petroleum –which later came to be known as diesel.

Diesel was not the only inventor who believed in the fact that the key to the mainstay of transportation industry rests with biomass fuel. Early automobile model (Model T) designed by Henry Ford in 1908 used ethanol. It was on his belief only that he even built a plant to make ethanol in the Midwest and in a partnership with Standard Oil to sell it in their distributing stations. During the 1920's, this biofuel was capable to fetch a share of about a quarter of Standard Oil's sales in that area. But with the rise of fossil fuels in the petroleum industry Standard Oil shifted towards the fossils. But Ford continued to promote the use of ethanol through the 1930's but with advent of time owing to the low prices of petroleum and undercutting in Biofuels sales by the petroleum industry the plant was closed by 1940.

The years since have brought many changes. In the United States alone more than 200 major fleets use biodiesel as fuel. Among the major users being are the US Post Office, the United States Military, metropolitan transit systems, agricultural concerns, and school districts. Today unaltered diesel engine can be run by the biodiesel produced at almost all temperatures with application ranging from the individual automobile to larger engines and machines. The base biomass being originated from soybeans and corn in the Midwest with tallow from the slaughter industries becoming a third source. Sugar cane provides the biomass for Hawaii and forest wastes are becoming a source in the Northwest. The embargo on Cuba halted oil importation depriving it of heating oil. They then found out that good biomass can be recycled from fryer oil as fuel. Today, the fast-food business is one of the largest and fastest growing industries in the world. This industry can provide a major resource for Biofuels - the recycled fryer oil. The Veggie Van traveled 25,000 miles around the United States on recycled fryer oil as did a group of women.

At present time, there is an option in Europe for biodiesel in many gas stations and vehicles that use diesel are readily available. Over a thousand stations in Germany alone offer biodiesel to their customers. Over 5% of all of France's energy uses are provided by biodiesel. Currently, producing petroleum diesel turns out to be much cheaper than to producing biodiesel, which further turns out to be the major reason for widespread use of diesel fuel. Considering total world-wide production of biofuel from both vegetable oil as well as animal fat it is not much to replace the present liquid fossil fuel usage. Environmental groups like NRDC may object to the huge amount of farming for raw material that is required to produce additional vegetable oil as over-fertilization, pesticide use, and land use conversion would be its major requirement.

Naseer et al. [2] conducted a study for determining the consequences of blending kerosene with diesel fuel and studied its performance and emissions on diesel engine running at constant speed with varying loads (torques). He found that the BSFC got reduced by 14.1% and 20.1% when he fueled the engine with 10% and 20% kerosene-diesel blend respectively at low load compared with pure diesel. BTE increased with kerosene blends as compared with diesel fuel.

O. Obodeh [3] investigated effects of diesel-kerosene blends working of diesel base combustion engine. Exhaust gas temperature was found to be 16.7% higher at 30% kerosene blend compared to diesel fuel at full load capacity. Brake power increased for all the fuel blends with rated load. The BP at full load capacity was about 19.8% higher at 30% kerosene blend as compared to diesel fuel. SFC at full load capacity was 7.5% lower at 30% kerosene blend compared to diesel fuel. Hence it was concluded that of 30% kerosene along with diesel fuel will result in nearly 10% saving on fuel cost.

M .A Hazrat et al. [4] concluded that by adding 1% biodiesel, ULSD's lubricity can be enhanced by 30%, whereas nearly 20% of biodiesel in the fuel it can best serve as a clean alternative. The order of lubricity has that is determined is as COOH > CHO > OH > $COOCH_3$> C=O >C-O-C. Vivek et al. [5] studied the biodiesel production from karanja oil. The optimumparameters for conversion were 1 atm pressure, 68 -70°C temperature using KOH catalyst with reaction time being 30-40 min and temperature ranging 68 -70°C. He confirmed that emissions are less in case of biodiesel. He also mentioned various methodologies for production of biodiesel which included direct blending, pyrolysis, micro-emulsion and transesterification.

S.V. Ghadge et al.[6] produced biodiesel from mahua oil (madhucaindica) which hadhigh free fatty acid content. It resulted with yield as high as 98% mahua biodiesel. S. Zullaikah et al. [7] studied 2-step acid catalysed methanolysis process that was used forthe conversion of rice bran oil into fatty acid methyl ester. C. Anju et al. [8] used potassium hydroxide to prepare the crude pongamia biofuel oil. He ended up on using KOH as a catalyst along withthe methanol to finish trans-esterification of the fuel. He observed that 1 % KOH with molal ratio of 1:10 at 60°C yielded 92% oil. L.C. Meher et al. [9] studied the optimum conditions for methanolysis ofkaranja oil and ended up with yield of 99% at optimum conditions.

Tutak et al. tested diesel and wet ethanol blends fuel in diesel engine. While studying emissions characteristics, an increase of about 6 bars in peak cylinder pressure was reported. Misfiring was observed if ethanol ration was raised more than 30%. Also increase in bsfc, hydrocarbons and NO_x were observed along with reduction in carbon monoxide with increase of ethanol fraction.

Jalpesh Solanki and Ashish Agarwal [10] mentioned the pros and cons of using biodiesels. He noticed that lubricity was enhanced when biofuels was mixed with diesel. It had lower aromatics and lower sulphur content and therefore is environment friendly. Cold weather operations of biodiesel was also found difficult. Finally he concluded that durability of oxidized fuel on engine performance is matter of research and needed through study

A. N. Phan et al. [11] investigated the effects of trans-esterification waste cooking oil by mixing it with methanol. He calculated optimum KOH concentration and temperature required for the biodiesel conversion. He carried out alkali catalyzed trans-esterification process of wastecooking oil. He obtained biodiesel yield of 88 to 90% with optimum conditions being -the methanol to oil ratios of 7:1 to 8:1, temperatures ranging from 30 to 50°C and KOH 0.75 wt%.

X. Meng et al. [12] in his observations noticed that free fatty acids formed major constituent of waste cooking oils (WCO). Production of biodiesel from WCO was majorly studied. In the study it was observed that conversion efficiency of reaction depends largely on factors like molar ratio of methanol to oil, amount of alkaline catalyst, reaction time and reaction temperature. Experiments were carried out to find the optimum conditions for trans-esterification process via orthogonal analysis three level set tests. The optimum conditions thus obtained were 1 % sodium hydroxide (NaOH), 9:1 methanol to oil molar ratio 50 °C temperature for nearly 90 minutes with ration of 6:1 being Methanol to oil molar ratio 6:1 the most appropriate. Biofuel can thus be used in an unmodified diesel engine was under all normal conditions was also found during the test analysis. B20 and B50 blends led to higher emissions while the 20% blend fuel reduced particles, hydrocarbon and carbon monoxide significantly.

J. PredojevicZlatica[13] produced biodiesel by 2-step alkalitrans-esterification of waste sunflower oils using methanol and potassium hydroxide as catalyst. Investigation of the influence on the properties and various blends by different purification methods was studied.J. D. Singh et al. [14] commented on huge availability of WCO inIndia. Biodiesel was prepared by mechanical stirring from waste cooking oil and later compared with diesel. As a result of experimental investigation to study the performance and combustion characteristics in a diesel engine it was found that due to lower calorific value of WCO engine torque and power were reduced. At higher loads smoke and emissions were also decreased to a great extent when WCO was used.Response Surface Methodology (RSM) had been used to optimize the performance and exhaust emission parameters. Study of performance parameters like BTE, BSFC, HC, CO, NO_x and smoke opacity have also been carried out and were seen to be near to diesel.

Kates et al. [15] analyzed various uninterrupted operations which were developedfor biodiesel generation from WCO or virgin vegetable oil under acidic or alkaline conditions on a commercial scale. Technological analysis of processes was done to evaluate their technical merits and demerits. Decrease in raw material cost if WCO was used as a biofuel was seen. Alkaline catalyzed process proved to be more complex than acid catalyzed process thus causing more competitive alternative for commercial biodiesel production if alkali was used.

Sajitha et al. [16] studied generation of coconut oil by using CaO as catalyst for trans-esterification. They performed tests with varying biodiesel concentration from 10% to 30% (by volume). Brake thermal efficiency was found to increase with load owing to fact that more power and less heat wastage.

Pangavhane et al.[17] used soyabean oil in diesel engines and found reduction by 21 and 47% in CO emissions and HC emissions respectively with some increase in NO_x with load. Similarly, S.M. Ameer Uddin et al. [18] used Mustard-Kerosene blends to study performance characteristics of a Diesel Engine and concluded that high viscosity was the main problem associated with the mustard blend when directly injected into the engine.

In his experiments, R. Vallinayagam et al. [19] investigated on feasibility of using pine oil in diesel engine. The importance of his findings was that he observed that pine oil without undergoing trans-esterification could be directly used in diesel engine due to its unique properties. The BTE of pine oil at low load and high load conditions increased by 10% and 5% respectively. An increase of about 27% in the maximum heat release rate of the engine at maximum power output was found when it was compared with diesel. Pine oil showed nearly 25% increase in NO_x whereas decrease of 65%, 30% and 70% in HC, CO, and smoke was noticed when compared with diesel at higher load conditions. Without pursuing any change or modification to the fuel injection system and other operating parameters thermal efficiency for at constant speed diesel engine increased for pine oil as fuel in but at the cost of higher NO_x.

The effects of water emulsion mixture with diesel on diesel engine were studied by M. Ebna Fahd et al.. Engine performance and emission tests were done to find effects of 10% emulsion diesel mixture. Slightly less power output was found with ED10 along with higher BSFC, but it had lower exhaust gas temperature and lower NO_x emission. Higher CO emission were seen at lower load and engine speed. But CO emission showed significant reductions at higher engine speed for a particular load. He finally concluded that 10% water emulsified diesel mixture had the potential of being considered as a competitive renewable fuel for diesel engines.

Pramod S. Methaet al., (2011) investigated performances and emission of neat Karanji biodiesel and its blends with methanol and found an increase of 4.1% in thermal efficiency by adding 10% methanol in biodiesel at 80% loading condition. Level of CO and HC were slightly higher in methanol blend relative to neat biodiesel but NO_x and smoke were relatively lower.

Erhan et al. [20] found that oxidation stability of vegetable oil(less polyunsaturated fatty acids) was increased by about 35% by adding blend of two chemical additives (2% $C_{22}H_{44}N_2S_4Zn$ and 2% $C_{33}H_{66}N_3S_6Sb$ and 20% diluent PAO). Oils including soybean oil, a high-linoleic soybean oil, a mid-oleic soybean oil, a high-oleic soybean oil, a high-oleic sunflower oil and a high-oleic sunflower oil, many being alkali refined.

Kalam et al. [21] used Jatropha oil blend with diesel in proportion varying from 10 to 50. And successfully ran diesel engine. In 1982, Diesel fleet ran successfully with a blend of 95% diesel and 5% vegetable oil. H.H. Masjukia et al. [22] studied the performance of Homogeneous Charge Compression Ignition (HCCI) engine fuelled by premix kerosene fuel. Reduction in No be approximately 25% was observed which was due to low combustion temperature of HCCI system. It led to incomplete oxidation of fuel and thus emission were increased.

Kalam and Zulkifli et al. [23] used palm oil based tri-methyl-propane ester to evaluate its wear preventive properties. Hydrodynamic (HDL), elasto-hydrodynamic and boundary lubrication (BL) were investigated. His results showed that 3% TMP ester mixed in ordinary lubricant can reduce the maximum amount of wear scar amount and reduces friction coefficient by 30% in BL regime. Whereas, in HDL regime, 7% TMP showed 50% reduction friction coefficient.

Cavalcante et al. [24] found that oleic acid could be used to produce biodiesels. Oleic acid is a monounsaturated fatty acid and is present in both edible and non-edible oils.it has a goof cold flow property due to unsaturation quality but is vulnerable to the oxidation stability.

Azeem Hafiz and Naveen Sankar [25] found that lesser amount of fuel is required to produce same amount of energy if higher C.V. fuel like kerosene is used in a diesel engine. He also observed that temperature of exhaust gas was also higher in case of kerosene may be due to presence of oxygen content in kerosene that improved combustion.

S.M. Ameer Uddin et al [26] identified high viscosity as a major problem in diesel engine when he used mustard oil directly. He then mixed mustard oil volumetrically with kerosene and successfully obtained viscosity near to diesel fuel. He then concluded that 20-30% mustard mixed with kerosene oil can be used as a substitute for diesel engine. But fuel consumption was observed to be higher for generating power as by diesel fuel. Due to late burning of fuels higher exhaust gas temperature was also seen. He finally concluded that mustard oil could be a good substitute for diesel fuel

Dr. B. Balakrishna [27] reviewed problems with vegetable oil as a fuel in C.I. He found that due to poor volatility vegetable oil found difficulty in vaporizing and igniting that further lead to thermal cracking which then resulted in higher smoke and heavy carbon depositions on combustion chamber. This tendency was attributed partly to higher viscosity of oil. He deduced that vegetable methyl esters gave performance and emission characteristics similar to diesel thus can be a possible substitute for diesel.

Avinash Kumar Agarwal [28] conducted an experiment in which utilization of waste heat from exhaust gas was use to preheat the vegetable oil. As viscosity of oils generally decreases with increase in temperatures. He also deduced that wear of vital moving parts of engine was higher when jatropha blend was used a fuel compared to diesel. He also studied the effect of straight vegetable oil on carbon deposits and wear of CI engine components.

Md. Abdul Wakil [29] determined optimum conditions for trans-esterification for Sesame oil, which were 3.5:1 M ratio of methanol to oil and 1% (w/w) catalyst. He extracted oil directly from seeds. Oil obtained was then chemically converted to fatty acid and methyl ester by an alkaline trans-esterification reaction. But separation of oil and glycerin was not possible.

A study was conducted by Anton A. Kiss [30] for methanol recovery and glycerol separation in biodiesel production. He found that in practice, segregation of the ternary mixture methanol-water-glycerol was done by two distillation columns that owed high energy demands economically costing to nearly 50% of plant operation cost. He found that Dividing Wall Column (DWC) technology was very appealing to industry as it had major benefits: 30% reduced investment costs and nearly 40% energy savings. Further the methanol used for trans-esterification could be also recovered to a great extent.

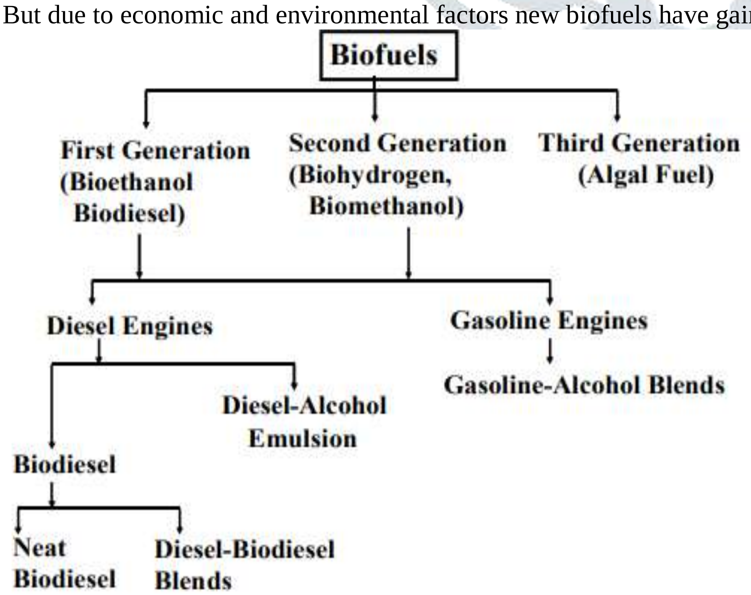
In summary, the literature suggests:

- Vegetable oils are suitable to operate in diesel engine without any basic changes in the engine
- Trans-esterification with alcohols can be done to decrease the viscosity of biofuel and thus increase the performance of fuel
- Improved brake thermal efficiency was obtained with different biofuels but effect of using biofuels can be studied as far as emission are to be considered.
-

MATERIALS AND METHODOLOGY

3.1. Biodiesel – The Energy

With increasing population, modernization and industrialization, oil availability and its security has become a topic extreme concern for the world. As such biofuel energy can play a vital role in the growth of any country. Recently interests of countries has increased in biofuel as an alternate source of energy owing to environmental problems like global warming and air pollution. Biofuels are basically categorized into first, second and third generation. At present time too more than 50% of population depends on biofuels for cooking their foods in rural areas. But due to economic and environmental factors new biofuels have gained significance.



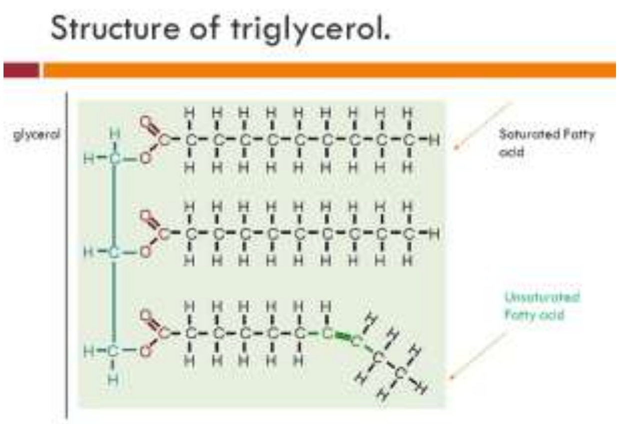


FIG 10. Classification of biofuelFIG 11. Structure of triglycerol

3.1.1. Biodiesel:

Vegetable oils and fatty oils predominantly are found in seeds and food pulps of different plants. These are being investigated throughout the world owing to increased energy demands. These olis are basically triglycerides (glycerol esters of fatty acids) that are chemically bonded compound formed by 1 molecule of glycerol and 3 molecules of fatty acids. Triglycerides have viscosities many times higher than diesel fuel and contain chains of HCs which differs in carbon length depending upon feedstock oil. In the trans-esterification of such oils, a triglyceride reacts with a monohydric alcohol in the presence of strong acid or base catalyst, producing a mixture of fatty acid alkyl esters (biodiesel) and glycerol as a co-product resulting in an overall sequential process of three consecutive reversible reactions, in which di and mono-glycerides are formed as intermediates. Chemical transformation is as follows:

During this reaction, glycerol so formed settles down at the bottom of container. Di-glycerides and mono-glycerides are the intermediaries. A little excess of alcohol is used to shift the equilibrium towards the formation of esters, reaction being reversible stepwise.

3.1.2. Process variables for trans-esterification

The most relevant variables in the process of trans-esterification are as follows:

1. Reaction temperature.
2. Ratio of alcohol to vegetable oil.
3. Amount of catalyst.
4. Mixing intensity (RPM).
5. Raw oils used.
6. Effect of free fatty acid and moisture content

3.1.3. Brief overview of types of transesterification

- **Acid catalyst For transesterification**
- **Base - Catalyst for Trans-esterification**
- **ProcessTransesterification with Heterogeneous Catalyst**

3.1.4. Biofuel production from Microalgae

Microalgae are single celled naturally occurring microorganisms found in fresh water marine type environment. They have more than 3,00,000 species and are better convertor of solar energy compared to other plants. The biomass yield from various sources are shown in Table 2.Several algae species may contain upto 80% oil content of their dry body weight while others could double their biomass within 24 hours with the doubling time being as minimum as 3.5 hours making them ideal renewable source for biofuel production [31]. Producing microalgae biomass is basically expensive as well as challenging as compared to growing crops. Its growth generally requires light CO_2 water and inorganic salts. The temperature should generally remain between 20°C to 30°C. Essential elements like nitrogen, Phosphorous, Iron and Silicon etc. must be provided by the growth medium. Recent researches show that waste water possess major possibility for mass production biofuel from algal biomass. But some problems that are associated with it are variation of wastewater composition due to source and high turbidity due to presence of pigments. Presence of competing micro-flora accumulation of growth inhibiting compounds which worsens with recycled water are associated with wastewater based algae cultivation [32].

TABLE 2 Oil yields per hectares

Oil Yields	Litre/Hectare/Year	Barrels/Hectare/Year
Soyabeans	400	2.5
Sunflower	800	5
Canola	1,600	10
Jatropha	2,000	12
Palm Oil	6,000	36
Microalgae	60,000-240,000	360-1500

3.2. Pros and cons of biodiesel

3.2.1. Key Benefits

- Higher cetane number than diesel.
- No major changes in diesel engine to burn biofuel.
- Burns 75% cleaner than conventional diesel fuel.
- Non-toxic, biodegradable, free of sulphur and benzene
- Improved emissions as contains virtually no sulphur.
- Improved lubricity.
- Biodiesel exhaust is not offensive and does not causes eye irritation.
- Clean fuel system.
- Mixes readily with petroleum diesel
- Safer to handle. Has a higher flash point than diesel (safer).
- Diesel skilled mechanics can easily operate to biodiesel engines
- Biodiesel can be produced from any vegetable oil or fat, including waste cooking oil.

3.2.2. Environmental benefits of biodiesel use

- ✓ Reduced SO_2 emissions
- ✓ Free of carcinogenic benzene
- ✓ Renewable energy source

3.2.3. Possible Drawbacks:

- Measures for use of pure biodiesel specially in cold conditions
- Cost of biofuel is higher than diesel as mass production is not done at present scenario.
- Limited availability of fuel commercially.
- Quality depends on blends.
- Biodiesel may deteriorate rubber thus need to replace rubber fuel hoses gaskets in older engines.
- Due to lower calorific value higher biofuel consumption is required to produce same amount of heat.

- Biodiesel contains 8 to 10% less energy than diesel owing to higher concentration of oxygen content in the biofuel.[33]
- Biodiesel has higher freezing point than diesel fuel. This causes combustion problem in cold climates.
- Biodiesel is less stable than diesel therefore long-term storage (more than six month) of biodiesel is not recommended because of its susceptibility to oxidation upon exposure to oxygen in ambient air.[34]

Note: Challenges are significantly reduced when biodiesel is used in blends with diesel fuel.

3.3. Mustard oil as Biofuel

Mustard oil is basically used to obtain the edible oil by crushing its seeds that is also a source of protein for domestic animals.It is also used as for cooking or frying the food. It is a mixture of different types of acids like linoleic acid and linolenic acid.

3.3.1. Synthesis of Biofuel

A refined pure mustard oil comprising of water and free fatty acids was used for the study. The conventional trans-esterification process can carried out by using ethanol or methanol. Sodium hydroxide or potassium hydroxide can used as catalyst. As literatures suggested that KOH and methanol resulted in higher yields, therefore these was used foe trans-esterification process. Hence methanol with 100% purity (purchased from Doon Scientific Instruments and Co., India) was used for synthesizing the fuels.

3.3.2. Synthesis of B100

B100 was prepared by bath trans-esterification process in a 500 ml cylindrical vessel equipped with heater and magnetic stirrer. First the pure oil was preheated till its temperature reached 60°C in a heater. Then it was poured in another vessel in which methanol and KOH has been earlier mixed. Suitable method were provided to maintain the stirrer speed and temperature. A molar ratio of 5:1(methanol to mustard oil) and KOH as catalyst was used. A 400 mL sample of mustard oil was heated in heater till 60°C. A measured quantity of solution containing KOH catalyst, dissolved in methanol, was then added and mixed at a constant stirring speed of 600 rpm for 60 minutes to ensure missing of solution uniformly. The mixture was then allowed to cool. Two distinct layers of ester and glycerol can now be seen. Ester is separated and washed with water 2 to 3 times and is dried for further testing.

M50B50 was prepared just by mixing Pine oil (50% v/v) and mustard oil (50% v/v) to prepare a fuel. Pure vegetable oil had viscosity of nearly 62 cP but on mixing it was found that M50B50 has viscosity of nearly 8 cP. This type of fuel can prepared directly can also be used to check emission and its effects on engine parameters. But here just this mixture was produced for comparison of properties like density and viscosity with B100 fuel.

Fig.12 Heating Plate **Fig.13 Magnetic Stirrer**

3.4. Determination of properties for different test fuels

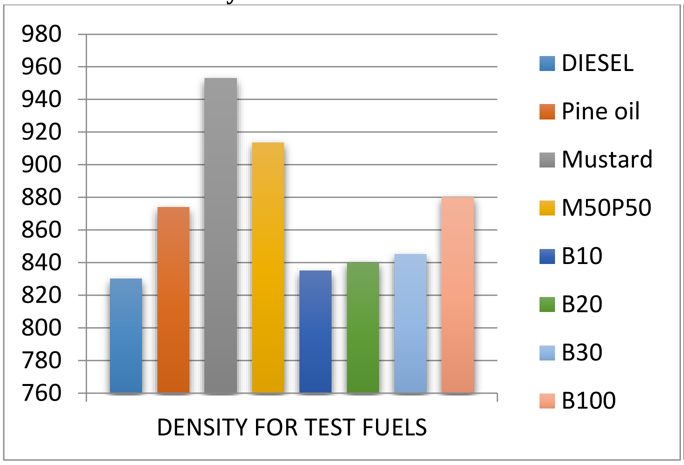
3.4.1. Density


FIG 14 Density Meter FIG 15. Digital Weighing Machine

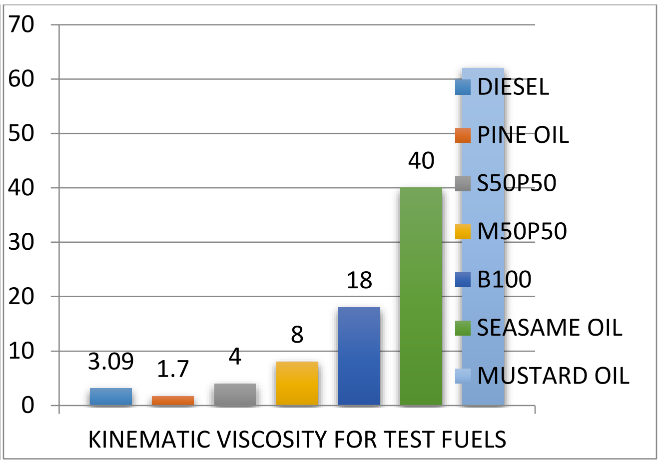
Density is an important property of any fluid. It is defined as the mass occupied by the fluid per unit volume. It determines the packing of molecules in the fuel structure. The properties of diesel fuel influencing emissions are usually correlated. An example of this is cetane number, aromatics content and density. Density has a strong relation with injection timing, ignition delay and NO_x emission.

Diesel fuels blending streams possessing high level of aromatics are generally denser with low cetane number. Density of all methyl esters was found to be higher than diesel fuel due to which these dense fuel end up with inferior combustion owing to improper mixing with air. Preheating was employed to reduce the density of biofuel. It was found that by preheating density can be reduced by 20-40 kg/m^3.

3.4.2. Kinematics Viscoity



GRAPH 1 Density of test fuels



GRAPH 2 Kinematic Viscosity of test fuels

Viscosity is an important fluid property when analyzing liquid behavior and fluid motion near solid boundaries. A friction force starts developing when the two solid surfaces move relatively to each other that too at the contact surface. The property indication the internal resistance of a fluid is the viscosity. It is a measure of fluid's resistance to gradual deformation by shear stress or tensile stress. Kinematic viscosity is generally measured by noting the time taken for a fluid sample to travel through an orifice in a capillary under the force of gravity. It is important to note that most laboratories report viscosity as Kinematic Viscosity.

Fuel with high kinematic viscosity will have high coefficient of friction which results in lower flow rate. Generally, all the vegetable oil will have kinematic viscosity of about 9 to 16 times of diesel.

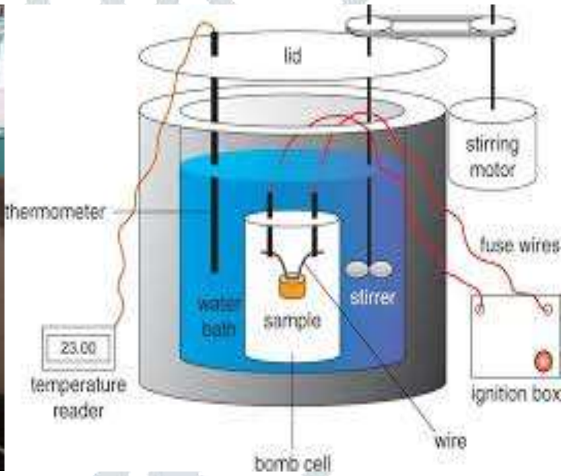
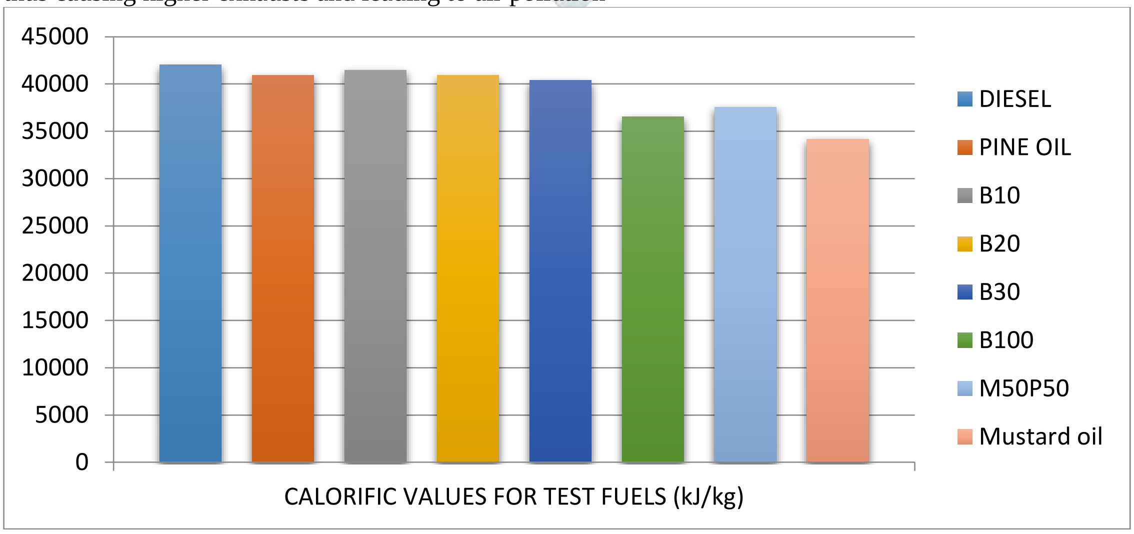


Fig. 16 Viscometer Fig.17 Bomb Calorimeter

The combustion is governed by fuel spray characteristics which has a direct association with kinematic viscosity. In particular, high viscous fuel will result in improper mixing with air in combustion chamber and there-by eventually forming deposits in engine.

3.4.3 Calorific Value

The calorific value of the fuel is the amount of heat released by burning of unit quantity of the fuel. Fuels with less calorific value tend to burn inefficiently thus causing higher exhausts and leading to air pollution



GRAPH 3 .Calorific Value for Test Fuels

A low calorific value indicates more water vapour absorption. It is used to identify "the Efficiency of a fuel". Higher calorific value or gross calorific value is defined as the heating value obtained by cooling the products of combustion to 25°C such that water vapour gets condensed. It is measured in kJ/kg.

A Bomb calorimeter (Model: 6200; Make: Parr, USA) as shown in Fig.17 was used to measure calorific values of the test fuels. 0.5 to 1 g sample was ignited in the combustion bomb. Oxygen atmosphere and hot wire contact of the sample was used to ignite it while it was placed on a stainless steel bomb. The rise in water jacket temperature was observed to calculate the energy released by the burning of the sample. The bomb calorimeter measured the enthalpy of reaction at constant volume conditions.

Procedure:

1. Place fuel in the silica crucible.
2. Magnesium wire touching the fuel sample is stretched across the electrodes.
3. Oxygen is supplied into the bomb till pressure becomes 30 atm.
4. Heat produced is transferred to H_2O that is being stirred throughout by the electric stirrer.
5. Finally maximum temperature that is shown by thermometer is observed.

Calculation:

$$w \times \Delta T = M \times H$$

w =Water equivalent (i.e the amount of water needed to absorb same amount of heat as that substance does for one degree rise in temp (Cal/˚C)

ΔT= Rise in temp in ˚C, M= mass of sample (grams), H = calorific Value in cal/grams.

3.5. TEST RIG FOR EXPERIMENT

A stationary diesel engine, KRILOSKAR make, naturally aspirated single cylinder 4-stroke having power of 5.20kW @ 1500 rpm has been used to test the biofuel samples.. Specifications of engine are as follows:

TABLE 3 Engine Specifications

Maker	Kirloskar
Model	TV1
Type	Four stroke Water cooled diesel engine
Number of cylinder	Single cylinder
Bore and stroke	87.5 mm × 110 mm
Compression Ratio	17.5:1
Swept Volume	661.45 cc
Connecting rod length	234 mm
Rated speed	1500 rpm
Rated power	5.2 Kw
Dynamometer	Eddy current
Lubricating oil	SAE40
Type of injection	Mechanical pump-nozzle injection
Inlet Valve opens	4.5° beforeTDC
Inlet Valve closes	35.5°after TDC
Exhaust Valve opens	35.5° before BDC
Exhaust Valve closes	4.5° after TDC
Fuel Injection starts	23° before TDC

TABLE 4. Combustion Parameters

Specific Gas Constant (kJ/kgK)	1.00
Air Density (kg/m^3)	1.17
Adiabatic Index	1.41
Polytropic Index	1.26
Number of cycles	10

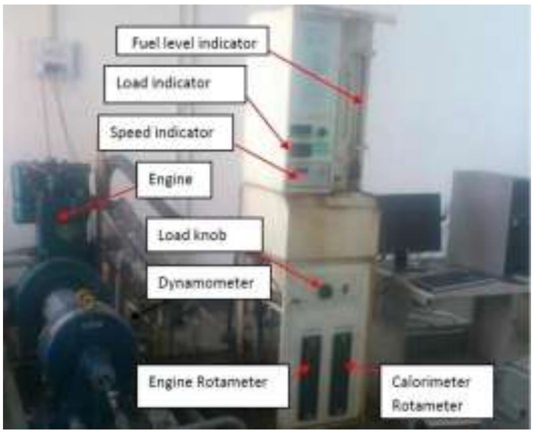


Fig. 18 .Diesel Engine setup

The engine being used is a four stroke diesel engine operating on a standard diesel cycle. During the suction stroke air is sucked in trough the inlet manifold, after being filtered through filter. An injection tank has been also deployed in the manifold to avert any fluctuations with the air flow. This damps out the pulsation produced by the engine too. Finally constant flow of air through the inlet manifold was maintained by keeping the suction pressure constant. Air is then compressed in the engine combustion chamber at compression ratio of 17.5 (default value), At last in the exhaust stroke, the exhaust gases were expelled out through the exhaust manifold and various regulated emissions such as HC, CO, CO_2, NO_X and smoke were measured. SAE 40 has been used for the lubrication of engine components, as lubrication oil, to prevent the wear and tear of the engine parts.

3.5.1 Performance Parameters and power measurement

TABLE 5. Performance Parameters

Orifice Diameter (mm)	20
Orifice Coeff. Of discharge	0.60
Eddy Current Dynamometer	Model AG10, of SAaj Test Plant Pvt. Ltd.
Temperature Sensor	Make Radix Type, Sheath dia 6mm X 110 mm
Piezo Sensor	Make PCB Piezotronics, Range 5000 psi
Load Sensor	Make SensoreonicsSanmae Ltd. Capacity 0-50kg
Dynamometer arm length (mm)	185
Fuel pipe diameter(mm)	12.40
Ambient temp. (deg C)	27
Pulses per revolution	360

The engineis loaded by the eddy current dynamometer that has been used to measure the power output of the engine consisting of stator and rotor. Rotor is coupled directly to the engine crankshaft whereas stator is surrounded by electromagnets. An opposing electromagnetic force is generated when the rotor rotates due to passing of current through the electro magnets. This induces a resistance to the rotor. The current supplied to the electromagnets is varied by an electronic controller to vary the load applied to the engine and this produces varying opposing forces. Thisforce (F), that is exertedon the dynamometer, is measured by a strain gauge and then the torque (T) is as

$$T = R \times F$$

R= the distance from center of the shaft to the pivot point of the strain gauge

Following the calculation of torque, the power developed by the engine can be evaluated if the speed at which the engine operates is known.

$B= \frac{2\pi NT}{60} \times S$ kW

Where, T is the torque in N-m, N is the rotational speed in rpm and S is the dynamometer constant.

Following parameters are calculated and later on plotted on graphs

a) Brake Specific fuel Consumption
b) Brake Thermal Efficiency
c) Exhaust Gas Temperature

3.5.2 Fuel Consumption Measurement

Fuel flow rate has been measured on volume basis by using a stop watch & burette. Time taken for the consumption of 10cc of fuel (t) was noted and total fuel consumption (TFC) or flow rate of the fuel was calculated as

$TFC = \frac{\rho v}{t}$ g/s

Where, ρ is the density of the fuel in g/cm^3, v is the volume of the fuel consumed in cm^3 ($v=l0\ cm^3$) and t is the time in seconds. BSFC has then been estimated from TFC and BP as follows,

$BSFC = \frac{TFC \times 3600}{BP}$ g/kWhr

3.5.3 Emission Parameters

The regulated emissions such as HC, CO, CO2 and NO_X were measured using AVL 444 gas analyzer on dry basis. The exhaust sample was passed through a cold trap (moisture separator).Flter element was used to block water vapor and particulates from entering into the analyzer. Carbon dioxide, Carbon monoxide and oxygen emissions were calculated in tens of percentage volume whereas hydrocarbons and NOx were measured in parts per million (ppm). Smoke levels were measured in hartridge smoke unit (HSU) using a standard AVL 437 C smoke meter. Principle for measurement of smoke is light extinction principle in which the amount of light blocked by the sample of exhaust gas from the diesel engine is measured in terms of smoke opacity.

Following parameter were measured for different test fuels:

a) Hydrocarbon emission (HC)
b) Oxides Of Nitrogen (NO_x)
c) Carbon Dioxides (CO_2)
d) Carbon Monoxide(CO)
e) Smoke Opacity(SO)

Fig. 19 Smoke meter

RESULT AND DISCUSSION

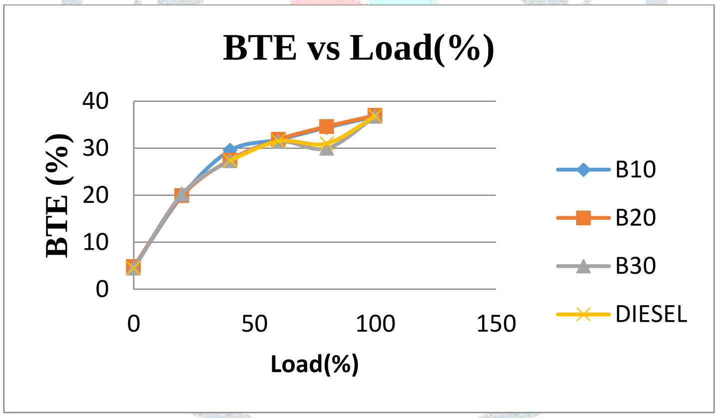
4.1. Engine Performance

Engine performances for Diesel and Diesel-Biodiesel blends (B10, B20 & B30) were found experimentally. After calculating these engine performance parameters carefully these were plotted against load (0%,20%,40%,60%,80%,100%). Various plots are as follows:

1. Brake Thermal Efficiency (BTE).
2. Brake Specific Fuel Consumption (BSFC).
3. Exhaust Gas temperature (EGT).

4.1.1. Brake Thermal Efficiency

Graph shows the variation of brake thermal efficiency of the test fuels with respect to load. Observations showed that BTE increases with load for all the biofuels as well as diesel. Load increases brake power since engine torque also increases. Increased suction pressure and increased in-cylinder temperature may have resulted in efficient combustion thus explaining increase of power with increase in load



Graph 4. BTE vs Load (%)

The trend of B30 is nearly is either similar or is lower in some cases as compared to diesel fuel. BTE is slightly increased for B10 and B20 when it is compared with diesel fuel. This high BTE in B10 and B20 may be due to additional lubricity that may have been provided by the biofuel itself. Whereas lower BTE in case of B30 can be seen as result of lower calorific value of biofuel as compared to diesel. High viscosity and higher density of vegetable oil can also be considered as a major factor for lower BTE in B30 which have resulted in poor atomization of the B30 fuel. Among all B20 can be considered best for maximum BTE.

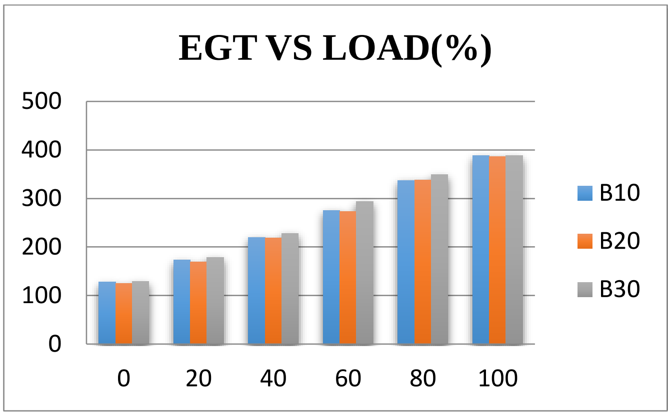
4.1.2. Exhaust Gas Temperature (EGT)

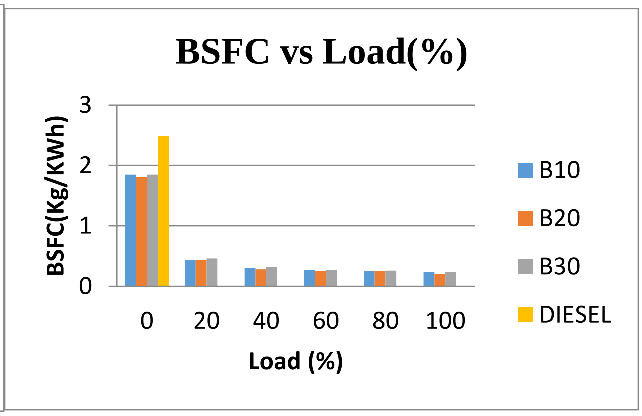
Consider graph 5. Exhaust Gas Temperature is an indication of proper combustion. It shows whether the combustion process is completed or not. It also indicates amount of wasted heat during combustion which can further give an indication of the %age of heat energy utilized for producing power. Higher EGT tells more heat has been wasted and vice-versa. Thus inverse relation of EGT with BTE and brake power (BP) can be seen.

Variation of EGT vs. load was plotted. The general trend of increases in EGT with increase in load was obtained for all the test fuels. From the study it is observed that EGT increases as the percentage of biodiesel increases in the blend. B30 has maximum EGT for all load conditions. B30 had nearly 7.12% and 6.37% EGT higher than B20 and B10 at 80% load. Since biodiesel has higher molecular weights that lead to continuous burning even during exhaust thus resulting in higher EGT. Higher EGT is also an indication of slow burning. Therefore higher NO_X may be seen in those cases in which EGT is higher.

4.1.3. Brake Specific Fuel Consumption

Consider graph 6.Variation of brake specific fuel consumption (BSFC) with load for different fuels was plotted. It was observed that BSFC decreases as the load increases, for all the tested fuels. Reason being increase in engine load increases BP at a higher rate than as compared to fuel consumption. This leads to increase in temperature inside the chamber and due to which conversion of heat to mechanical work increases thus BSFC decreases as load increases.

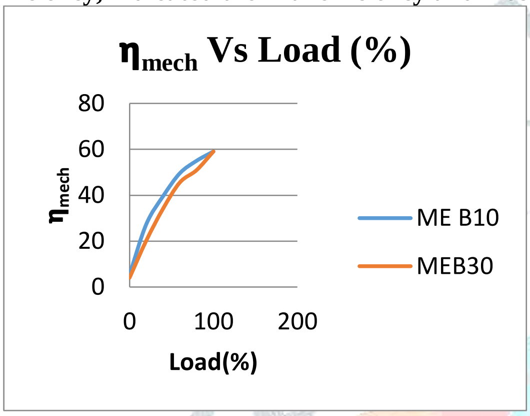


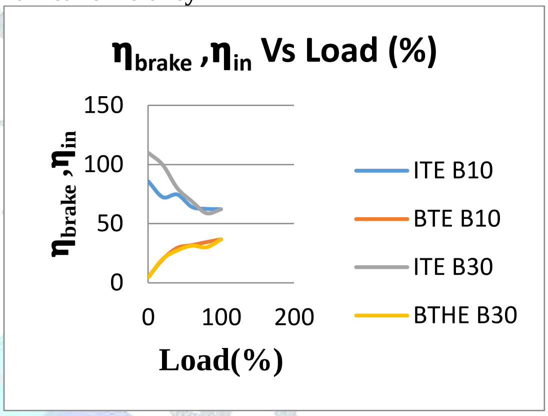


Graph 5.EGT vs Load (%) Graph 6. BSFC vs Load (%)

B20 had lowest BSFC than diesel and other biodiesel blends. B30 has highest BSFC among all biodiesel blends but still much lower than diesel. BSFC of biodiesel blends were much lower than diesel owing to fact of lower calorific value of biodiesel and its blends compared to diesel, thus increasing volume of fuel to produce same power. Md. NurunNabi et al. [35] found similar results for rapeseed oil-diesel blends.

4.1.4. Brake thermal efficiency, indicated thermal efficiency and mechanical efficiency





Graph 7 η_{mech}Vs Load (%) Graph 8 $\eta_{brake}\eta_{,in}$Vs Load (%)

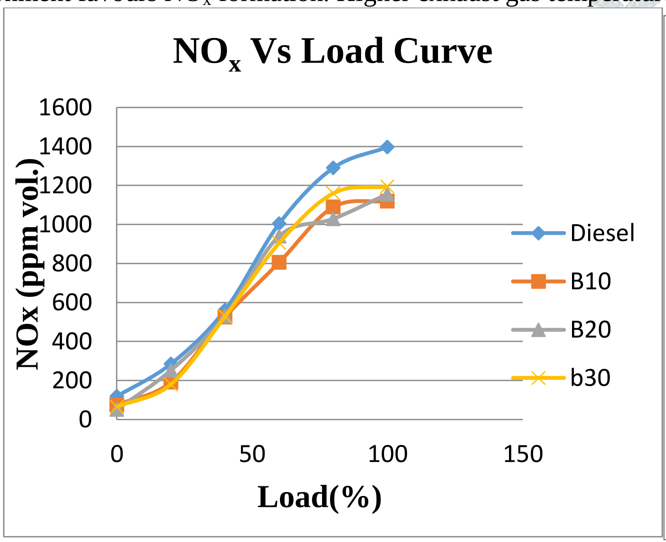
4.2. Engine Emissions

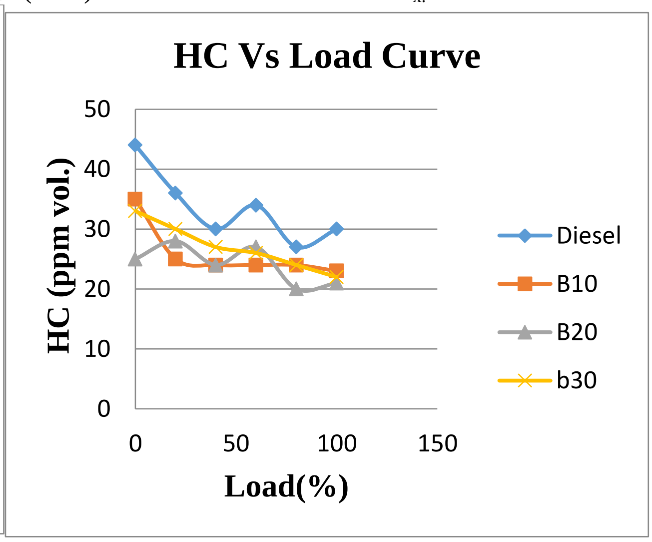
Engine emissions for Diesel and Diesel-Biodiesel blends (B10, B20 & B30) were found experimentally. After calculating these engine emissions carefully these were plotted against load (0%,20%,40%,60%,80%,100%) to analyse its effects. Various emission were as follows:

1. Oxides of Nitrogen (NOx)
2. Total Hydrocarbon (HC)
3. Carbon Monoxide (CO)
4. Smoke Opacity (SO)
5. Carbon Dioxides (CO_2)

4.2.1 Oxides of Nitrogen (NO_x)

Consider graph 9. NO_x formation takes place when nitrogen and oxygen react chemically at high temperature to form oxides of nitrogen (NO_x). These were found in the form of either NO or NO_2 in exhaust. It can be seen in Graph 9, NO_x formation increases with increase in load owing to the fact that the cylinder temperature increases with increase in load on engine. Also oxygen rich environment favours NO_x formation. Higher exhaust gas temperature (EGT) also results in increase in NO_x.





Graph 9 NO_xVsLoad(%) Graph 10 HC VsLoad(%)

From the plot it is clear that that NO_x formation increases with increase in biofuel% I the blend, but still it is lower than diesel. Reason for this being the fact that biodiesel has constituents of higher molecular weights, that would only burn during the late phase of combustion resulting in higher exhaust temperature and thus higher NO_x. Normally, biodiesel combustion produces higher NO_x than diesel. This can be validated from the literatures of A.S.Ramadhaset al. [36], Md. NurunNabi et al. [37] and H. Sharon et al. It can be seen that as the percentage of biofuel increased NO_x also got reduced with B10(@100% load giving minimum NO_x.

4.2.2 Total Hydrocarbon (HC)

Consider graph 10. Hydrocarbon emissions are basically a result of fuel structure, engine configuration, availability of oxygen, residence time [38] & combustion temperature. Un-burnt hydrocarbon (UHC) emissions were found to be lower at partial load condition, which then increased at higher loads owing to relatively less oxygen available for the reaction when more fuel was injected. H.S. Pali et al. [38] observed the similar result for HC.

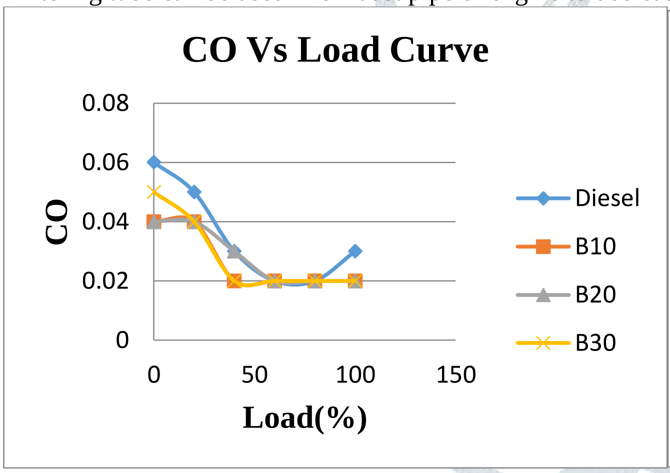
It can be seen that HC emissions decrease with an increase in load for diesel fuel but this was not the same for biodiesel. It was observed that emissions reduced for different biodiesel over the entire range of loads. B10, B20 and B30 generated lesser HC emissions at full load when compared to that of standard diesel. B20 and diesel showed nearly similar trends at different loading conditions only difference being that HC emission being lower with B20. This reduced emissions were due to the availability of high oxygen content in the biodiesel molecule, which lead to complete combustion. Similar result were observed by P.K. Devan et al. [39]. B20 blend had the lowest HC emission when compared to diesel fuel among all samples. These emissions had no adverse effect on the engine and environment.

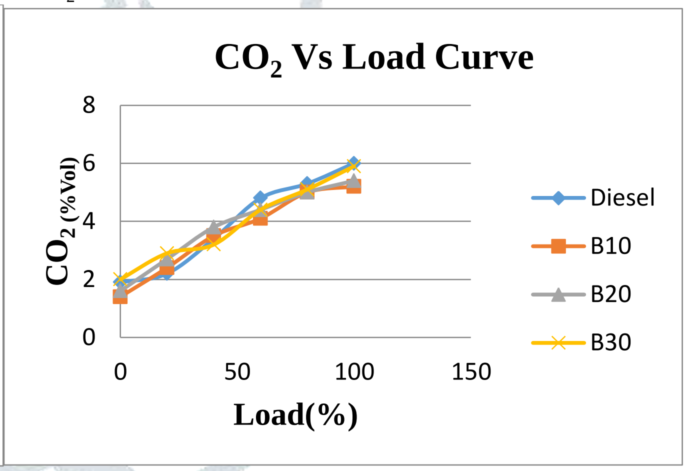
4.2.3 Carbon Monoxide (CO)

Consider graph 11. Carbon Monoxide is generated due to incomplete combustion or limited supply of oxygen Deficiency of O_2 does not allow the oxidation of carbon monoxide into carbon dioxide. Graph 11 shows the plot of CO emissions vs. load for all the tested fuel. CO emission are generally reduced with increase in load as can be seen. This is due to improved atomization owing to higher temperature of the cylinder. B10 and B20 has nearly same CO emission at part loads and at full load. B30 showed slightly higher CO at no load may be due to rich fuel mixture which causes incomplete combustion at no load condition. D. Barik& S. Murugan [40] observed the similar result. Catalytic converters (CC) can be installed to further reduce the CO emissions.

4.2.4. Carbon Dioxides (CO_2)

Consider graph 12. CO_2 emission increases with increase in load for all biodiesel samples. Biodiesel gave slightly higher CO_2 emission as compared to diesel as much of the CO has also been converted to CO_2 due to excess availability of oxygen and complete combustion of fuel. Thus decrease in CO resulted in increase in CO_2 emission. Only at some part loads CO_2 emission were higher in biofuel but at higher loads CO_2 emission were either nearly same or lower in biofuel as compared to diesel. Exhaust filtering tube can be used in exhaust pipe of engine to decrease CO_2 emission with no adverse effects on environment.



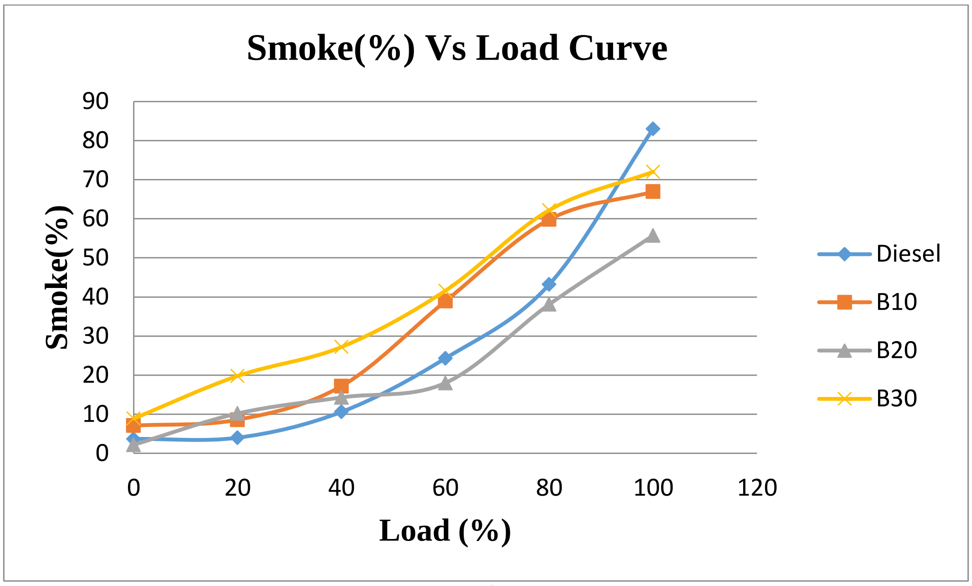


Graph 11. Carbon Monoxide vs. LoadGraph 12. CO_2VsLoad(%)

4.2.5. Smoke Opacity (SO)

Consdier graph 13. It was found that the general trend showed that SO emissions increases with loading for all the test samples. The reason behind this sharp increase of SO emissions can be decreased air-fuel ratio at higher loads in which higher volume of fuel is injected which further increased the un-burnt gases in the exhaust. Formation of smoke also takes place due to presence of gases in the combustion chamber for a shorter duration. Lower SO emissions in biodiesel were found owing to efficient combustion fuel due to presence of oxygen in the biofuel. This oxygen favoured complete combustion of fuel at local rich mixture regions.

B20 showed lower SO emissions at full load conditions compared to all others.B30 has slightly higher SO emissions than diesel at full load. This may be due lower brake thermal efficiency at higher loads and incomplete combustion. Same result were obtained by Senthil Kumar et al. [41]



Graph 13. SO VsLoad(%)

CONCLUSION AND SCOPE OF FUTURE WORK

5.1 Conclusions

It was found that vegetable oil-diesel blend can be effectively used as an alternative fuel without any change in the diesel engine. But it is to be noted that vegetable oil has a very high viscosity which need to be reduced before it is blended with diesel fuel. For this various methods can be employed viz trans-esterification, mixing with lighter and less viscous fuels etc.. Here viscosity is reduced by trans-esterification. It was found that

- ❖ The properties of the mustard oil like viscosity were slightly higher than petro-diesel.
- ❖ B20 blend showed higher BTE with comparable BSFC as compared to diesel, whereas B10 and B30 blends have nearly similar BTE
- ❖ The EGT of all blends are nearly similar with B20 being lower at part loads with B30 having nearly 7.12% and 6.37% EGT higher than B20 and B10 at 80% load.
- ❖ All blends have lower CO emissions as compared to diesel fuel, whereas B20 blend has highest reduction in CO emissions.
- ❖ All blends have lower UHC emissions compared to diesel fuel, whereas B20 blend has highest reduction in UHC emissions with 30% reduction
- ❖ All blends have lower NOx emissions as compared to diesel, whereas B10 blend has lowest NOx emissions being nearly 17.25% less when compared to diesel.
- ❖ Biodiesel gave slightly higher CO_2 emission as compared to diesel as much of the CO has also been converted to CO_2 due to excess availability of oxygen and complete combustion of fuel. Thus decrease in CO resulted in increase in CO_2 emission.

It has been concluded trans-esterified vegetable oil can be used as a fuel in diesel engine with B20 blend being the most effective with better performance and emissions characteristics.

5.2. Scope of future work

- ❖ Emissions cane be further decrease if biofuel if catalytic convertor and biofuel utilizing SCR be used.
- ❖ The emission and performance parameters can be studied for multi-cylinder diesel engine.
- ❖ As can be seen from Table 2. Microalgae can produce upto 360-1500 barrels of fuel per hectare per year compared to 36 for vegetable fuel that too cost effectively but producing microalgae biomass is basically expensive as well as challenging as compared to growing crops. Its growth generally requires light CO_2 water and inorganic salts. Microalgae can deficately be the future biofuel if effective method of controlling the growths are developed.

NOMENCLATURE

WEO	World Energy Outlook
OECD	The Organisation for Economic Co-operation and Development
EN Standards	European Committee for Standardization
FAME	Fatty Acid Methyl Ester
ASTM	American Society of Testing and Materials
BTE	Break Thermal Efficiency
BMEP	Break Mean Effective Pressure
BSFC	Break Specific Fuel Consumption
SFC	Specific fuel consumption
BP	Brake Power
HCCI	Homogeneous Charge Compression Ignition (HCCI)
TMP	trimetylopropane ester
$C_{22}H_{44}N_2S_4Zn$	zinc diamyldithiocarbamate
$C_{33}H_{66}N_3S_6Sb$	antimony dialkyldithiocarbamate
PAO	polyalphaolefin
EGT	Exhaust Gas Temperature

CO	Carbon monoxide
CO_2	Carbon dioxide
CV	Calorific Value
NO_x	Nitrogen Oxides
SO	Smoke Opacity
η_{mech}	Mechanical efficiency
WCO	waste cooking oil
KOH	Potassium Hydroxide
NaOH	Sodium Hydroxide
CNG	Compressed Natural Gas
UNH	University of New Hampshire
NRDC	National Research Development Corporation

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