CHAPTER-1

INTRODUCTION

With the growth of civilization the need for the energy in the construction, domestic and transportation sector is increasing exponentially. The increased energy demand has led to steep rise in the demand of petroleum based fuels. Moreover the finite reserves of crude oil are concentrated in certain regions of the world and most of the developing countries are net importer of the crude oil.

Rapid depletion in petroleum reserves resulted in their high cost and their combustion causes heavy air pollution. This is becoming a deadliest threat to the survival of not only humans but may destroy the whole ecological system of mother earth. Biomass derived vegetable oils are quite alternative promising fuels for agriculture and transport diesel engines.

Demand for petroleum products, in particular diesel, is set to increase rapidly. Transport sector is one of the fastest-growing energy sub-sectors in the economy for two reasons: one, concomitant with growth of the economy would come the increasing demand for both freight and passenger movement; and two, India's base as far as mobility is concerned is very low as compared to the rest of the world. The worrisome aspects of India's growth for transport demands are the fact that: Over 80% of passengers and 60% of freight are moved by road, There is an increasing dependence on personal modes of transport, and Diesel and petrol contribute to 98% of the energy consumed in the transport sector.[1]

All fossil fuels also make net addition of Carbon to theatmosphere. In addition, diesel emits particulate matter (PM), especially below 2.5micronwhich passes the protection system of the body to get lodged in lungs causing reductionin its vital capacity. In association with the particulate matter the un-burnt oil is carcinogenic. In addition Carbon Monoxide(CO), Hydrocarbon(HC) and Sulphur emissions are on the higher side.[2]

1.1 Why Bio-fuels:

In the context of shrinking crude oil reserves, rising demand and the resultant rise in prices of petroleum, as well as the concerns about global climate change and energy security, bio-energy is becoming increasingly relevant as a possible and potential alternative to fossil fuels. Bio-fuels are liquid or gaseous fuels produced from biomass resources and used in place of, or in addition to,diesel, petrol or other fossil fuels for transport, stationary, portable and other applications.[3]

Two problems have come out from this review that the amount of pollution and carbon dioxide produced is affecting our environment; and, since the supply of petroleum and diesel is finite, it will run out. As energy demand and population growth is continually increasing, the petroleum and diesel supply and condition of our environment continually degrade. The need for alternative renewable fuels is equalled only by the need for more efficient, less polluting vehicles.

1.2 History of Biodiesel Fuel:

Developed in the 1890s by inventor Rudolph Diesel, the diesel engine has become the engine of choice for power, reliability, and high fuel economy, worldwide. Early experimenters on vegetable oil fuels included the French government and Dr. Rudolf Diesel himself, who envisioned that pure vegetable oils could power early diesel engines for agriculture in remote areas of the world, where petroleum was not available at the time.

Due to the widespread availability and low cost of petroleum diesel fuel, vegetable oil-based fuels gained little attention, except in times of high oil prices and shortages. World War II and the oil crises of the 1970's saw brief interest in using vegetable oils to fuel diesel engines. Unfortunately, the newer diesel engine designs could not run on traditional vegetable oils, due to the much higher viscosity of vegetable oil compared to petroleum diesel fuel. A way was needed to lower the viscosity of vegetable oils to a point where they could be burned properly in the diesel engine. It was a Belgian inventor in 1937 who first proposed using transesterification to convert vegetable oils into fatty acid alkyl esters and

use them as a diesel fuel replacement. The process of transesterification converts vegetable oil into three smaller molecules which are much less viscous and easy to burn in a diesel engine. In the early 1980s concerns over the environment, energy security, and agricultural overproduction once again brought the use of vegetable oils to the forefront, this time with transesterification as the preferred method of producing such fuel replacements.[4]

India took initiatives on biofuels nearly a decade ago to reduce its dependence on oil imports and improve energy security. The country began a 5% ethanol blending pilot program in 2001 and formulated a National Mission on Biodiesel in 2003 to achieve 20% biodiesel blends by 2011–2012. Its National Policy on Bio-fuels, adopted in December 2009, proposes a non-mandatory blending target of 20% for both biodiesel and ethanol by 2017.[5]

1.3 Definition of Biodiesel:

Biodiesel is a renewable alternative fuel created from vegetable oils, animal fats, and greases through a chemical process. The chemical process involves reaction of natural oils with an alcohol, and then refining the mixture to create molecules which can be easily burned in a diesel engine. Glycerin is the by product of the biodiesel production process, and can be used in personal care products or a variety of chemical applications.

General Definition of Biodiesel:

Biodiesel is a domestic, renewable fuel for diesel engines derived from natural oils like soybean oil, Thumba Oil, Jatropha Oil etc.

Technical Definition for Biodiesel and Biodiesel Blend:

Biodiesel : A fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100

Biodiesel Blend : A blend of biodiesel fuel meeting with petroleum-based diesel fuel, designated BXX, where XX represents the volume percentage of biodiesel fuel in the blend.

1.4 Indian Energy Scenario of Biodiesel:

The country's energy demand is expected to grow at an annual rate of 4.8 per cent over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels – coal, petroleum based products and natural gas. Domestic production of crude oil can only ful-fill 25-30 percent of national consumption rest we are importing from other countries. In these circumstances bio-fuels are going to play an important role in meeting India's growing energy needs. India's bio-fuel production accounts for only 1% of the global production. This includes 380 million litres of fuel ethanol and 45 million litres of biodiesel.

The Government of India (GOI) approved the National Policy on Bio-fuels on December 24, 2009. The policy encourages use of renewable energy resources as alternate fuel to supplement transport fuels and had proposed an indicative target to replace 20 percent of petroleum fuel consumption with bio-fuels (bio-ethanol and bio-diesel) by end of 12th Five-Year Plan (2017).In a bid to renew its focus and strongly implement the Ethanol Blending Program (EBP), the Cabinet Committee of Economic Affairs (CCEA) on November 22, 2012, recommended 5 percent mandatory blending of ethanol with gasoline [6] .

It also recommended that the procurement price of ethanol shall now be decided by between the Oil Marketing Companies (mostly PSU) and suppliers of ethanol. The Government's current target of 5 percent blending of ethanol in gasoline has been partially successful in years of surplus sugar production and unfilled when sugar production declines.

Presently, the contracted ethanol supply for calendar year 2013 is sufficient to meet 2.9 percent blending target.

National Policy on Bio-fuels: An Overview

• An indicative target of 20% blending of bio-fuels both for biodiesel and bio-ethanol by 2017.

• Biodiesel production from non-edible oilseeds on waste, degraded and marginal lands to be encouraged.

• A Minimum Support Price (MSP) to be announced for farmers producing non-edible oilseeds used to produce biodiesel.

• Financial incentives for new and second generation bio-fuels, including a National Bio-fuel fund.

• Biodiesel and bio-ethanol are likely to be brought under the ambit of "declared goods" by the Government to ensure the unrestricted movement of bio-fuels within and outside the states.

• Setting up a National Bio-fuel Coordination Committee under the Prime Minister for a broader policy perspective.

• Setting up a Bio-fuel Steering Committee under the Cabinet Secretary to oversee policy implementation.[7]

1.5 Resources of Biodiesel :

Alternative diesel fuels made from natural, renewable sources such as vegetableoil and fats. The most commonly used oils for the production of Biodiesel are soybean, sunflower, palm, rapeseed, canola, cotton seed andJatropha.Sincethepricesofediblevegetableoilsarehigherthanthat of diesel fuel, therefore waste vegetable oils and non-edible crude vegetable oils are preferred as potential low priced Bio-diesel sources. Use of such edible oil to produce Bio-diesel in India is also not feasible in view of big gap in demand and supply of such oils. Under Indian condition only such plants can be considered for Biodiesel, which produce non-edible oil in appreciable quantity and can be grown on large scale on non-cropped marginal lands and waste lands.

The source of Biodiesel usually depends on the crops amenable to the regional climate. In the United States, soybean oil is the most commonly Biodiesel feedstock, whereas the rapeseed (canola) oil and palm oil are the most common source forBiodiesel, in Europe, and in tropical countries respectively.[8]

Biodiesel can be produced by animal fats, cooking waste and vegetable oils. Biodiesel production from various vegetable oils in different countries is given inTable.1.

Table.1: Production of Biodiesel Worldwide[9]

USA	Soyabean (mustard is under study)
Brazil	Soyabean oil
Europe	Rapeseed Oil (>80%) and Sunflower Oil
Spain	Linseed and olive oil
France	Sunflower Oil
Italy	Sunflower oil
Ireland	Animal Fat ,Beef Tallow
Indonesia	Palm Oil
Malaysia	Palm Oil
Australia	Animal fat, Rapeseed Oil
China	Guang Pi
Germany	Rapeseed Oil
Canada	Vegetable Oil/Animal Fat

The government of India has launched the National Bio-diesel Mission (NBM) identifying Jatropha curcasas the most suitable tree-borne oilseed for bio-diesel production. The Planning Commission of India had set an ambitious target covering 11.2 to 13.4 million hectares of land under *Jatropha* cultivation by the end of the 11th Five-Year Plan. The central government and several state governments are providing fiscal incentives for supporting plantations of Jatropha and other non-edible oilseeds. Several public institutions, state bio-fuel boards, state agricultural universities and cooperative sectors are also supporting the bio-fuel mission in different capacities.[10]

1.6 Properties of Biodiesel:

The advantages of Biodiesel over Diesel fuel are higher combustion efficiency, higher cetane number and higher bio-degradability and less carbon monoxide emissions. Along with the inherent advantages of Biodiesel, the disadvantages of

using Biodiesel are worth mentioning. The disadvantages of Biodiesel include slightly higher NOx emissions, cold start problems, lower energy content, higher copper strip corrosion and fuel pumping difficulty resulting from higher viscosity. Currently, Biodiesel is expensive to produce than Diesel, which appears to be the primary factor in preventing its more widespread use. Current worldwide production of vegetable oil and animal fat is not enough to replace liquid fossil fuel use. These reasons gave rise to the increasing importance of blends of other fuels like Diesel fuel, Bio-ethanol etc with Biodiesel.

The properties of biodiesel are as follows:

➤ **Kinematic Viscosity:** The viscosity of Biodiesel is typically higher than that of petroleum diesel often by a factor of two. High viscosity can cause larger droplet sizes, poorer vaporization, narrower injection spray angle, and greater in-cylinder penetration of the fuel spray. This can lead to overall poorer combustion, higher emissions, and increased oil dilution.[9,12] It is seen that as we increase the percentage of biodiesel in the blend kinematic viscosity of blend increases.

➤ **Density**: In general, density of Bio-diesel is slightly higher than those of petroleum diesel, and increasing the level of Biodiesel blends increases the blend's density. It has been reported that Biodiesel density is also affected by chain length, with higher chain length leading to lower fuel density.[12]

➤ **Cetane number**: Cetane number (CN) is a measure of a fuel's auto ignition quality characteristics. Since Biodiesel is largely composed of long-chain hydrocarbon groups (with virtually no branching or aromatic structures) it typically has a higher CN than petroleum diesel .The CN of pure FAME molecules increases with chain length, but this effect is masked when considering complex mixtures of FAME fuels.[12]

➤ **Cloud Point and Pour Point**: Cloud point is defined as the temperature below which wax in diesel or bio-wax in biodiesels form a cloudy appearance. The presence of solidified waxes thickens the oil and clogs fuel

filters and injectors in engines. Pour point is the temperature at which the amount of wax out of solution is sufficient to gel the fuel. Biodiesel has a higher CP and PP compared to conventional diesel.[12]The properties of biodiesel which affect the freezing point of biodiesel are degree of unsaturation, chain length and degree of branching. Fully saturated fatty acids tend to freeze at higher temperature. Producing biodiesel by ethanol instead of methanol tends to reduce the Cloud Point and Pour point by few degrees.[9]

➢ **Flash Point**: The flash point is defined as the "lowest temperature corrected to a barometric pressure of 101.3kPa (760 mm Hg), at which application of an ignition source causes the vapours of a specimen to ignite under the specified conditions of test. The flash point values of vegetable oil methyl esters are much lower than those of vegetable oils.[12]

Physical properties of Biodiesel and their values or range are given below in the Table 2.

Table 2. Physical Properties of Biodiesel[12]

Common name	Biodiesel (bio-Diesel)
Common Chemical name	Fatty Acid Methyl Ester (FAME)
Chemical Formula Range	C14–C24 methyl esters
Kinematic viscosity range	(mm^2/s, at 313 K) 3.3–5.2
Density Range (kg/m3, at 288 K)	860–894
Boiling point range (K)	>475
Flash point range (K)	420–450
Distillation range (K)	470–600
Vapour pressure (mm Hg, at 295 K)	<5
Solubility in water	Insoluble in water
Physical Appearance	Light to dark yellow, clear liquid
Odour	Light musty/soapy odour
Biodegradability	More biodegradable than petroleum

	Diesel
Reactivity	Stable, but avoid strong oxidizing agents

1.7 Objective:

The aim of this thesis is to produce biodiesel by using Waste Cooking Oil through different methods (e.g. mechanical stirring method , ultrasonic cavitation method and hydrodynamic cavitation method), to study effect of different parameters like molar ratio , change in catalyst percentage and reaction time on yield of biodiesel.

Further experimental work is done on a single cylinder four-stroke water-cooled direct injection, constant speed diesel engine for performance and emission characteristics by varying the load on the engine for different blend and a comparison of performance characteristics for different blends with pure diesel is done.

Chapter-2

LITERATURE OVERVIEW

This chapter contains an overview of the research performed on production of biodiesel through different methods and effect of various parameters on yield of biodiesel. This chapter also contains an overview of research performed on performance and emission testing on different engines using biodiesel and diesel blends as a fuel.

2.1 Mechanical Stirring Method:

Refat(2010)[13] used waste vegetable oil from many different sources, including domestic, commercial and industrial. It was observed that The optimum reaction conditions for base-catalyzed transesterification using methanol (methanolysis) involve using the alcohol in excess of stoichiometric proportion (preferably 100 % excess) and using KOH or NaOH as a catalyst in a concentration of 1 % of the weight of the oil.

The temperature positively influences the biodiesel yield nearly up to about the boiling point of the alcohol (usually 60-65 ℃) if other parameters are kept unchanged. For maximum conversion to the ester, a molar ratio of6:1 is the most acceptable. With further increase in molar ratio the conversion efficiency more or less remains the same but the energy required for the recovery of methanol becomes higher.

For maximum yield of esters catalyst percentage should be in between 0.5 and 1.0 wt%. For higher values the yields were lower.

Sharma et al.(2013)[14]study was intended to consider various aspects related to the feasibility of the production of biodiesel from castor oil (High free fatty acid (FFA) feedstock) and cottonseed oil (Low FFA feedstock). The molar ratio of alcohol considered is 6:1 and 9:1 in castor oil . Potassium Hydroxide (purity 99%) is used as a catalyst and methyl alcohol with purity 99.5 % were used in this study. From the obtained results, the best yield percentage obtained for castor oil using a

methanol/oil molar ratio of was 9:1, potassium hydroxide as catalyst (1%) and 65 °C temperature for ninety minute. the best yield percentage obtained for cottonseed oil using a methanol/oil molar ratio of was 6:1, potassium hydroxide as catalyst (1%) and 45 °C temperature for ninety minute. It was reported that the low free fatty percentage oil has higher yield as compared to high percentage FFA. The cottonseed oil biodiesel is one of the good alternative bio-fuel as compared to biodiesel from castor oil.

Gnanaprakasam(2013)[15]has used waste cooking oil as a raw material because cost of biodiesel can be reduced by using waste cooking oil as feed stock. High fatty acid content in waste cooking oil could be reduced by pretreating waste cooking oil with acid catalyst. Water produced during the esterification process can inhibit acid catalyst, and this can be eliminated by stepwise reaction mechanism. Methanol is the most suitable alcohol because of its low cost and easy separation from biofuel. Methanol to oil ratio for the acid-catalyzed reaction depends on amount of free fatty acid.

To produce three moles of alkyl esters, three moles of alcohol and one mole of triglyceride are required. if the concentration of alcohol is increased automatically, the rate of product formation will be accelerated. Further increase in the molar ratio of alcohol to oil will increase the product formation. The recovery of glycerol and un-reacted methanol becomes tedious and also increases the cost of product biodiesel by increasing its post treatment cost .For base-catalyzed reaction, 6 : 1 is optimum ratio for transesterification reaction.

Increase of enzyme concentration will increase the percentage conversion. But beyond the certain limit, agglomeration of enzyme will take place. It will decrease the active site available on substrate. Stirrer speed also helps to enhance rate of reaction. In most cases, optimum speed of stirrer was maintained in the range of 200–250 rpm.

Bojan(2012)[16] produced biodiesel from crude Jatropha Curcas oil with a having high free fatty acid contents (6.85%) obtained from rural areas within India. In one step conventional base catalyzed transesterification, the presence of high free fatty

acid concentration (8.67%) reduced the biodiesel yield significantly(80.5%).High FFA in the oil deactivates the catalyst and the addition of excess catalyst as compensation gave rise to the formation of emulsion which increased the viscosity, leading to the formation of gels and the problems associated with glycerol separation and loss in ester yields. Therefore a two step acid pretreatment esterification and base catalyzed transesterification process was selected to improve the yield.

During the first step the FFA content of the Jatropha was reduced by a significant level using acid catalyst esterification. During the second step biodiesel was produced via alkali catalyst based transesterification from the product of the first step and the factors affecting the yield of biodiesel were also investigated. In two step method The optimum methanol to oil molar ratio was 5.41:1 and the optimum catalyst to oil ratio was 0.55% w/w. At these optimum conditions the biodiesel yield was 93% which was higher than the yield of one step direct alkali catalyzed transesterification.

2.2 Ultrasonic Cavitation Method:

Sebyang et al.(2010)[17] used an ultrasonic type of clamp on tubular reactor at 20 kHz for conversion of waste cooking oil to biodiesel with sodium hydroxide as catalyst.it was observed that FAME product was successfully produced and equilibrium can be reached in the short reaction. The time reaction of 5 minute, with molar ratio methanol to triglyceride is 6:1, frequency ultrasonic of 20 kHz and catalyst NaOH of 1%wt was obtained high conversion of 95.6929%wt. When molar ratio was increased from 6:1 to 12:1, the conversion of WCO to FAME decreased slightly from 95.6929%wt to 71.8487%wt.

It was also observed that ultrasonic results in 94.6214% at 5 min (for molar ratio 9:1) whereas the mechanical stirring results in much lower extend of conversion 89.3176% at 120 minutes. The indication results that the reactions under ultrasonic tubular reactor are much faster than those under the mechanical stirring process. Ultrasonic technique was faster than mechanical stirrer and a smaller amount of methanol was required to obtain a high conversion of methyl ester.

Pal et al.(2013)[18] has developed the laboratory test rig for conversion of WCO into biodiesel using ultrasonic cavitation method and hydrodynamic cavitation method. An ultrasonic horn type processor which consumes around 150 kW and produces 30-40 hz frequency was used. Experiments were carried out for molar ratio 4.5:1, 6:1 and catalyst concentration was varied from 0.5 % to 1% (by weight of the oil). It was reported that both the methods can be successfully applied for trans-esterification and more than 90 %yield can be achieved with catalyst 0.5 % (by weight of the oil) and 4.5: 1 molar ratio.

It was also reported that yield obtained was higher for ultrasonic method as compared to the conventional mechanical stirrer method. It was reported that yield obtained by ultrasonic cavitation method is 95% after 45 minutes which was 10% higher than the yield obtained by mechanical stirrer method.

It was also reported that reaction time is also less for ultrasonic cavitation method and catalyst required is also less when compared to the conventional mechanical stirring method. Thus cavitation techniques are faster than the mechanical stirrer technique at laboratory scale of production.

Babajide et al.(2009)[19] used waste cooking oil in the transesterification conversion to biodiesel. Transesterification reaction of waste sunflower frying oil with base catalysts (KOH) using both mechanical stirring and ultrasonication was studied. It was found that the conversion efficiency of the waste oil using ultrasound was higher than with the mechanical stirring method.

A FAME yield of 96.78% was recorded from the waste cooking oil under the ultrasonic condition which was higher than a value of 87.30 % recorded under the conventional stirring method at lower temperature (30 °C) and shorter time (30 min) this can be attributed to the fact that sonochemical effect induced by the acoustic cavitation was stimulated by the ultrasonic irradiation on the oil and methanol molecules to form micro-scale fine emulsions causing them to suspend each other easily.

It was found that the optimized variables of 6:1 methanol/oil ratio at reaction temperature of 30 °C for 30 min and 0.75% KOH (wt/wt) catalyst concentration was obtained for the transesterification of the waste oil via the ultrasound technology. The reason for this is the emulsion between triglycerides and alcohols occurs more rapidly compared to the stirring condition because the smaller size of emulsion droplets would be formed with the use of the ultrasound and when they are formed the contact surface area of immiscible solution increases, resulting in the higher rate of the transesterification reaction.

Pal et al.(2011)[20]used non-edibleThumba (Citrulluscolocyntis) oil as the biodiesel feedstock and KOH as a catalyst. A comparative detail of biodiesel production process using low frequency ultrasound energy (28.5 kHz) and conventional mechanical stirrer method was reported. Transesterification reaction was performed for molar ratios 6:1and 4.5:1 respectively. Further for each molar ratio, catalyst quantity has been taken as 0.5%, 0.75% and 1.0% (by weightof oil) respectively.

It was also reported that ultrasound cavitation can be successfully applied to transesterification reactions with more than 90% yield of the product and significant reduction in time for molar ratio4.5:1 and minimum catalyst percentage of 0.5.

For a given molar ratio, the yield initially increases and then decreases with increase in catalyst percentage(varied from 0.5% to .75% and then 1% .

For mechanical stirring method, yield (%) varies as 79 to 90%, whereas for ultrasound method yield (%) values are 81 to 95% respectively. The yield data for ultrasound method is 2 to 5 % higher as compared to conventional mechanical stirring method.

2.3 Hydrodynamic Cavitation Method:

Supardan(2012)[21] used two step transesterification process to convert waste cooking oil into biodiesel. It was reported that hydrodynamic cavitation results in 89.4% as the highest yield at methanol to oil molar ratio of 6 whereas the

conventional stirring method results in lower extent of the highest yield of 86.2% at methanol to oil molar ratio of 9. It can be deduced that the reactions under hydrodynamic cavitation consumed a lower quantity of methanol and provided a higher yield than those under the mechanical stirring process.

It is also observed that It was observed that the use of hydrodynamic cavitation enhances the yield of biodiesel for all of methanol to oil molar ratios. Thus, the use of hydrodynamic cavitation is effective both in enhancing the rate of reaction as well as in shifting the equilibrium for resulting a higher product yields.

it was observed that with an increase in the methanol to oil molar ratio from 3 to 6, the yield of bio-diesel increased from 79.5 to 89.4% at 150 min of reaction time. However, further increase in the methanol to oil molar ratio to 9 and 12, the yield of biodiesel decreased slightly to 85.6 and 85% respectively.

Pal et al.(2014)[22] has worked on waste Frying Oil (WFO) because it is not suitable for human utilization, and whose safe disposal is a challenge, may be suitably used for biodiesel production. Hydrodynamic cavitation can be successfully applied to transesterification reactions, more than 90% yield of the product for molar ratio 4.5:1 and minimum catalyst percentage of 0.5%. Changing molar ratio to 6:1 does not give any appreciable increase in yield %. It is also observed that yield increases as reaction time increases and eventually it becomes constant after 75 min of reaction time. The yield is more for molar ratio 6:1 and 1 % catalyst as compared to molar ratio 4.5:1 and 0.75% catalyst.

As per performance testing performed in this work it can be seen that waste Frying oil biodiesel blends give better thermal efficiency and have got safer impact on environment. The maximum thermal efficiency achieved by Waste Frying Oil B40 blend is around 40.33 % at 4.0 kW as compared to diesel fuel.

2.4 Performance and emission characteristics:

Gopal et al.(2014)[23] has performed experiments on a constant speed, single cylinder,4-stroke, air cooled DI diesel engine designed for agricultural purpose was used to test the fuel. Raw material used for biodiesel production was waste cooking

oil, which was collected from different sources such as hostels, restaurants, canteen and cafeterias. He concluded from his experiments that the diesel engine can perform satisfactorily on biodiesel and its blends without any engine modifications. Specific Energy Consumption changes with increase in percentage of biodiesel in the blends due to the lower heating value of biodiesel. BTHE for WCME is lower than that of pure diesel This is because of lower heating value , higher viscosity and higher density of WCME. It is also shown that there is significant reduction in CO, UBHC and smoke emissions for biodiesel and its blends compared to diesel fuel. UBHC emissions decrease with increasing WCME percentage in the blend. Experimental results reveal that CO concentration of biodiesel and its blends is 59%, 38%, 35% and 31% lesser for WCME20, WCME40, WCME80 and WCME100, respectively, when compared to diesel fuels operation. However, NOx emission of WCME biodiesel is marginally higher than petroleum diesel.

Shahidet al.(2012)[24] has performed experiments on a four stroke, three cylinder, naturally aspirated, direct injection diesel engine, at 1500 rpm. It was observed that the rate of fuel consumption increases with the increase of load for pure diesel as well as for all of its blends. It was also observed that with the increase in percentage of biodiesel in the blend, fuel consumption increases because of lower heating value of biodiesel as compared to diesel. It was also observed that although B100 can be used in an engine, yet B20 is more acceptable as the results obtained with B20 are very much close to those obtained by using pure diesel. When the engine was fuelled with B20 there was just 10% increase in fuel consumption and 10% decrease in BTHE.

Amount of CO_2 produced is less when the engine is fuelled with used cooking oil biodiesel compared to the use of diesel for same power because diesel has 85% carbon atoms while biodiesel has about 76%, hence the combustion of used cooking oil methyl ester produces less carbon dioxide.

The percentage of CO in the exhaust increases with the increase of load for diesel and all of its blends with used cooking oil methyl ester. Amount of CO decreases with increase in biodiesel percentage in the blend.

Zakiya et al.(2014)[25]used biodiesel from waste cooking oil and its blends with petroleum diesel for testing on a four stroke direct injection diesel engine. There was a slight reduction in brake mean effective pressure (BMEP) and BHP when diesel and biodiesel blends were used. The values of BHP for all tested fuels were very close and followed by increments with diesel fuel registering the highest BHP, followed by B20, B40, B60, B80 and B100 registering the lowest BHP. High BHPs were obtained when the engine was fueled by blends with low biodiesel content. It was found that the average BSFC of B100 was 9.45% higher than that of diesel fuel. BSFCs were lowest for diesel fuel and highest for B100. It increased proportionally with the addition of biodiesel blends. This was due to the low heating value of the blends.

The emission factor was observed to be much lower compared to those for petroleum diesel. When B100 was used the average emission factors were 0.0001g/kW-h for HC, 1.1397g/kW-h for CO, 0.00391g/kW-h for SO2 and for smoke opacity it was lower by 76.19% compared to diesel fuel.

Sharmaet al.(2014)[26]conducted experiments on a single cylinder CI engine for performance and emission analysis using diesel and sate cooking oil methyl ester blends. WCO-B20 AND WCO-B40 blend brake thermal efficiency values are higher as compared to diesel at higher load. This is due to better combustion efficiency of blends caused by presence of extra amount of oxygen.For diesel and diesel-biodiesel blends the specific fuel consumption decreases sharply with increase in brake power and afterward remains stable. In case of blends specific fuel consumption values are higher at the beginning because of higher viscosity.

The opacity value for pure diesel is higher as compared to all type of blends for wide range of Brake power. At all brake power condition the opacity of all blends has less value than diesel oil. Maximum value of opacity has obtained at 59.21 at 4.0 kW brake power for pure diesel and for blends 45.9 at 4.0 kW for B-20. With

the addition of biodiesel, CO emission also decreases. The peak concentrations at the 0.5 kW brake power are0.045%, 0.034% and 0.035%, for diesel, WCO-B20, WCO-B40 respectively. The reason lies in the fact that the oxygen contained in the biodiesel fuel enhances complete combustion in the cylinder and reduces CO emission.

For Diesel, the HC emission decreases with increase of brake power due to the increase in combustion temperature associated with higher engine load. For biodiesel blended fuel, the HC emission is lower than that of diesel and decreases with increase of biodiesel in the fuel.

Arslan(2011)[27] used the waste cooking oil (WCO) methyl ester as an alternative fuel in a four-stroke, four cylinders, direct injection and 85 HP turbo diesel engine. A test was applied in which an engine was fueled with diesel and three different blends of diesel/biodiesel (B25, B50 and B75) made from WCO. The smoke emissions of WCO methyl ester were lower than those for diesel fuel at all the engine speeds. Reduction of smoke number for B25 with an average of 23%, for B50, with an average of 52% and for B75, with an average of59% was obtained. A higher thermal efficiency indicates better and more complete combustion of fuel, which implies that a lesser amount of un-burnt hydrocarbons are present in the engine exhaust emissions. Therefore, lower smoke density values are achieved with biodiesel blends than with conventional diesel.

Total hydrocarbon emissions were lower when WCO methyl ester was added to the diesel fuel. It was shown that hydrocarbon emissions decreased when the diesel engine was run with B25, B50 and B75 and there was a reduction of 9,5 and 7% at all operating speeds when compares with pure diesel.

Srinivas et al.(2013)[28]conducted experiments on a single cylinder, four strokes naturally aspirated, and water-cooled kirloskar computerized diesel engine test rig. Brake thermal efficiency increased with all blends when compared to the conventional diesel fuel. The brake thermal efficiency of B20 blend is 37.855% and it is 0.275% less than that of standard diesel operation. The Brake specific fuel consumption is increased with the blends when compared to diesel. It is seen that

at low load the BSFC is 0.373 KG/KW hr for diesel and for B20 blend is 0.382KG/KWhr. At full load the BSFC is 0.205 KG/KW hr for diesel and for B20 blend is 0.21 KG/KW hr.

CO and HC emissions are decreased significantly with the blends when compared with diesel. There was a 15.8% reduction of CO emission for the B20 blend at full load. It was observed that HC emissions for diesel fuel is 40 ppm at low load and 62 ppm at full load and for B20 blend it is 17 ppm at low load and 30 ppm at full load. Comparatively a slighter increment in NOx emission was found while working with all blend at all loads. And there is a slight decrease by adding additive. The increase in NOx emission is observed in not only waste vegetable oil but also in all vegetable oils due to the presence of oxygen in the oil extracted from vegetable products. For B20 blend, the NOx emission was 1461 ppm compare to 1236 ppm of Standard diesel.

Rao et al.(2008)[29]used single cylinder, 4.4 kW direct-injection air-cooled stationary C.I. engine coupled with swinging field electrical dynamometer for the experimental study. Used cooking oil methyl ester (UCME) has lower calorific value than that of diesel. Hence the specific fuel consumption is slightly higher than that of diesel for UCME and its blends. BTE of UCME and its blends is lower compared to that of diesel. At rated load the BTHE of UCME is lower than that of diesel by 2.5%.

It is observed that the exhaust gas temperature increases with load because more fuel is burnt at higher loads to meet the power requirement. It is also reported that the exhaust gas temperature increases with percentage of UCME in the test fuel for all the loads. This may be due to the oxygen content of the UCME, which improves combustion and thus may increase the exhaust gas temperature.

Un-burnt hydrocarbon (UBHC) emissions are reduced over the entire range of loads for UCME – diesel blends. It decreases with increase in % of UCME in the blend. Since the UCME is an oxygenated fuel, it promotes combustion and results in reduction in UBHC emissions. The emission of CO is reduced by 15% for 20%UCME and by 50% for UCME when compared to diesel at rated load

condition. CO is predominantly formed due to the lack of oxygen. Since UCME is an oxygenated fuel, it leads to better combustion of fuel resulting in the decrease in CO emission. A gradual increase in the emission of nitrogen oxides (NO_X) is observed with increase in percentage of UCME in the fuel.

Algasim et al.(2010)[30] has performed experiments on a four stroke, direct injection diesel engine, turbocharged diesel test engine. Standard diesel produced the highest brake torque and power at the engine for all engine speeds. This was due to the lower calorific value of the biodiesel compared to standard diesel. In brake specific fuel consumption and thermal efficiency, the increase in engine speed decreased the brake thermal efficiency for all tested fuels. This can be attributed to the decreased torque and increased fuel consumption with the speed. At full load operation, the lowest specific fuel consumption was for the standard diesel comparative to biodiesel. The standard diesel produced the highest CO2 concentrations at the different loads at speed.

The pure standard diesel fuel produced the highest Total hydrocarbon (THC) emissions followed by the pure biodiesel at an engine speed under full load. Overall, the addition of biodiesel to the blends decreased the THC emissions at different speed and full load operation. Biodiesel is better than the standard diesel in producing lower greenhouse gasses at different load operation.

CHAPER-3

EXPERIMENTAL WORK ON BIODIESEL PRODUCTION

This chapter contains the different techniques of production of biodiesel using waste cooking oil and effect of various different parameters (e.g. reaction time, molar ratio, change in catalyst percentage etc.) on the yield of biodiesel produced by various methods.
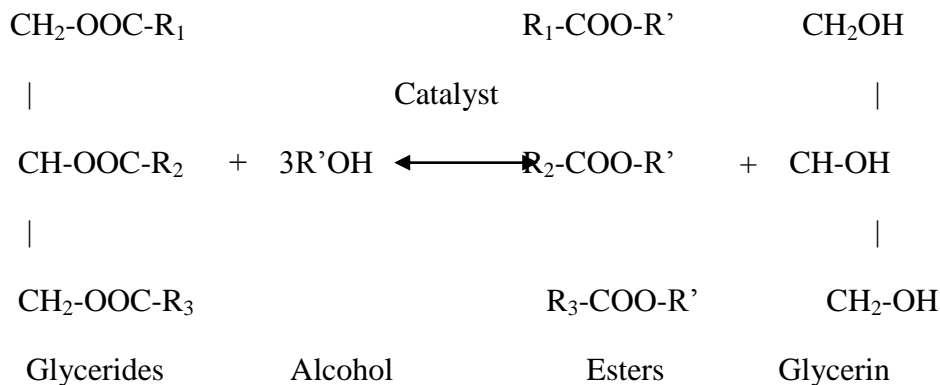
There are several methods to produce biodiesel using vegetable oils biodiesel e.g. blending and transesterification , Microemulsions with simple alcohol , Thermal cracking (pyrolysis) with alkanes, alkenes etc. , and several others e.g. reaction with supercritical methanol. Out of the above mention methods we have used the transeserification reaction with different molar ratios of vegetable oil and alcohol.

3.1 Transesterification Reaction:

Viscosity of pure vegetable oil is quite high as compared to diesel That is why we cannot use vegetable oils directly in direct injection diesel engines. One of the wayto reduce the viscosity of pure vegetable oil is Transesterification.

In Transesterification reaction vegetable oil i.e. a triglyceride react with some alcohol i.e. Methanol (CH_3OH), Ethanol(CH_3CH_2OH) etc. to produce ester and glycerin in the presence of some catalyst.

Transeseterification reaction for different vegetable oils is as follows:

CH$_2$-OOC-R$_1$ R$_1$-COO-R'   CH$_2$OH

| Catalyst |

CH-OOC-R$_2$ +   3R'OH ⟵————— R$_2$-COO-R'   +   CH-OH

| |

CH$_2$-OOC-R$_3$ R$_3$-COO-R'   CH$_2$-OH

Glycerides   Alcohol   Esters   Glycerin

The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step, from triglycerides diglyceride is obtained, from diglyceride monoglyceride is produced and in the last step, from monoglycerides glycerin is obtained. In all these reactions esters are produced. The stochoimetric relation between alcohol and the oil is 3:1.

Different types of catalysts are used in a transesterification reaction to enhance the reaction rate, Some of them are described as below:

> **Alkali catalyst based transesterification**: Alkali based Transesterification is used with those vegetable oils which are containing low levels of free fatty acids (FFA).This includes soybean oil, canola (rapeseed) oil, and the higher grades of waste restaurant oils.

> **Acid catalyst based transesterification**: Acid based transesterification is used with those vegetable oils whose FFA content is quite high. Because of presence of free fatty acids in the vegetable oil, When these vegetable oils are treated with alkali catalyst , There will be soap formation due to reaction of free fatty acid and alkali catalyst. This soap will inhibit the separation of glycerol. For these cases, an acid catalyst such as sulfuric acid can be used to esterify the FFAs to methyl esters in the following reactions.

> **Lipase Catalyst based transesterification**: Lipases are enzymes used to catalyze some reaction such as hydrolysis of glycerol, alcoholysis and

acidolysis, but it has been discovered that they can be used as catalyst for tranesterification reactions too.

3.2 Production of biodiesel through mechanical stirrer method:

3.2.1 Principle:

In mechanical stirrer method a beaker containing a mixture of vegetable oil and alcoxide is kept on a heating plate. A magnet is dropped in the beaker to produce the stirring action and throughout mixing of vegetable oil and alcoxide. Temperature of the mixture is controlled with the help of a temperature controlling knob and speed of the stirrer is maintained with the help of speed control knob.

3.2.2 Experimental setup:
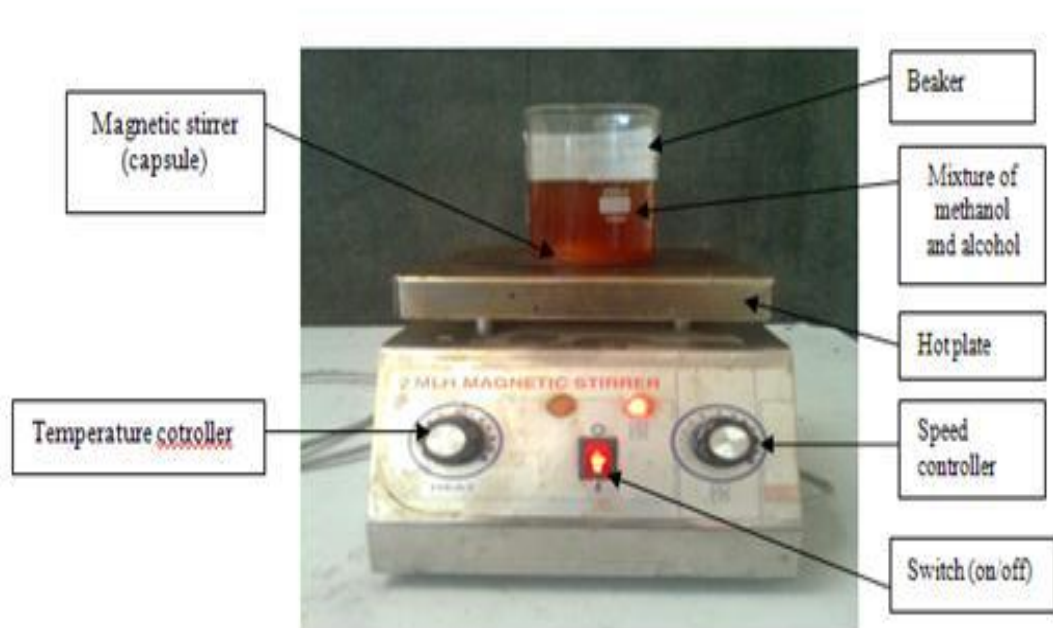
Fig.1. A mechanical stirrer

3.2.3 Materials used:

1. Waste cooking oil, 100g/sample for preparing experimental biodiesel sample.

2. Methyl alcohol (CH_3OH) (99% pure) for removing the free fatty acid from the oil.

3. Base catalyst (KOH) (85% pure) for accelerating the reaction mixture.

3.2.4 Experimental procedure:

Detailed experimental procedure to produce biodiesel by magnetic stirrer method is explained as below:

1. Waste cooking oil (100 g) is taken in a beaker and filtered to remove the impurities.

Oil is heated to about 110^0C to remove the moisture content present in the oil, then it is cooled to about $50\text{-}60^0C$.

2. Methyl alcohol (For 3:1 molar ratio -11 g, for 4.5:1 molar ratio -16.5 g , for 6:1-22 g) and catalyst Potassium hydroxide (0.5% , 0.75 % or 1%) are mixed in a beaker. This solution is now kept on a magnetic stirrer to form mehoxide.

3. This mehoxide solution and waste cooking oil were mixed in a beaker .A magnetic capsule was also dropped in the solution. The mixture of vegetable oil , alcohol and catalyst is kept on the magnetic stirrer.

4. Temperature of the mixture during the reaction is kept in between $55\text{-}65^0C$.

5. When the reaction is completed, beaker is kept for separation. As density of glycerine is quite high as compared to biodiesel produced, it will settle down at bottom of the separating funnel. This glycerine is removed from the bottom.

6. After the glycerine is separated, water (30% by weight of vegetable oil taken) is heated to 40^0C and poured in the beaker containing biodiesel for water washing process.

7. After 4-5 hours water containing excess of KOH and other impurities will settle down in separating funnel.

8. Water is removed from the bottom and biodiesel obtained is heated to 110^0C to remove the excess of moisture and methanol.

9. Weigh the pure biodiesel and calculate the yield obtained.

3.2.5 Experimental data:

(A) Materials

The experiments are performed with alcohol to oil molar ratio as 3:1, 4.5:1 and 6:1. The amount of oil, alcohol and catalyst taken is shown in Table.3.

Table.3: Oil, alcohol and catalyst during the experimentation:

Molar ratio (alcohol/oil)	Quantity of non-edible oil (g)	Quantity of methanol (g)	Catalyst (KOH) (g)		
			0.5%	0.75%	1.0%
3:1	100	11	0.5	0.75	1.0
4.5:1	100	16.5	0.5	0.75	1.0
6:1	100	22	0.5	0.75	1.0

(B) Calculations

(i) For calculation of molar ratio following data are used

Molecular weight of triglycerides from vegetable oil = 870

Molecular weight of methanol = 32

Hence, 1 gm mole of vegetable oil = 870 gm

1 gm mole of methanol = 32 gm

Catalyst (KOH) = 0.5%, 0.75% and 1% by weight of oil

(ii) Amount of methanol for 100 g of vegetable oil

For 3:1 molar ratio = (32 / 870) ×100 × 3= 11 g

For 4.5:1 molar ratio = (32 / 870) ×100× 4.5 = 16.56 g

For 6:1 molar ratio = (32/870)×100×6=22g

(C) Time and yield produced from Waste cooking oil: Yield produced from waste cooking oil by varying the molar ratio and percentage of catalyst used is shown in table 4-6.

Table.4: Conventional mechanical stirring method (molar ratio 3:1)

Quantity of waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	11	0.5	0.5	71.92	71.92	73.20	73.20	75.95	75.95	75.90	75.90
100	11	0.75	0.75	67.73	67.73	68.20	68.20	72.65	72.65	72.90	72.90
100	11	1.00	1.00	66.23	66.23	67.20	67.20	70.30	70.30	71.45	71.45

Table.5:Conventional mechanical stirring method (molar ratio 4.5:1)

Quantity of Waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	16.5	0.5	0.5	77.22	77.22	81.5	81.5	84.22	84.22	85.26	85.26
100	16.5	0.75	0.75	74.95	74.95	77.85	77.85	82.76	82.76	83.32	83.32
100	16.5	1.0	1.00	74.12	74.12	75.22	75.22	81.28	81.28	81.92	81.92

Table.6: Conventional mechanical stirring method (molar ratio 6:1)

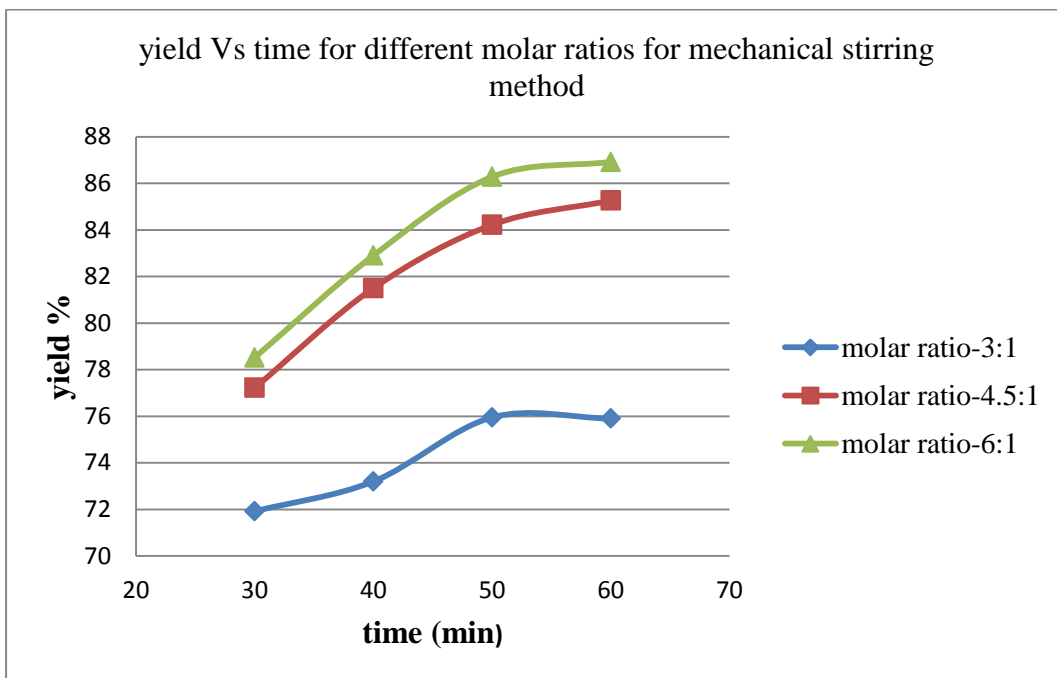| Quantity of waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	22	0.5	0.5	78.52	78.52	82.9	82.9	86.28	86.28	86.92	86.92
100	22	0.75	0.75	76.15	76.15	78.95	78.95	83.96	83.96	84.62	84.62
100	22	1.0	1.0	75.15	75.15	77.25	77.25	83.15	83.15	83.55	83.55

Fig.2: Yield Vs reaction time for different molar ratios for mechanical stirring method for catalyst percentage 0.5 %
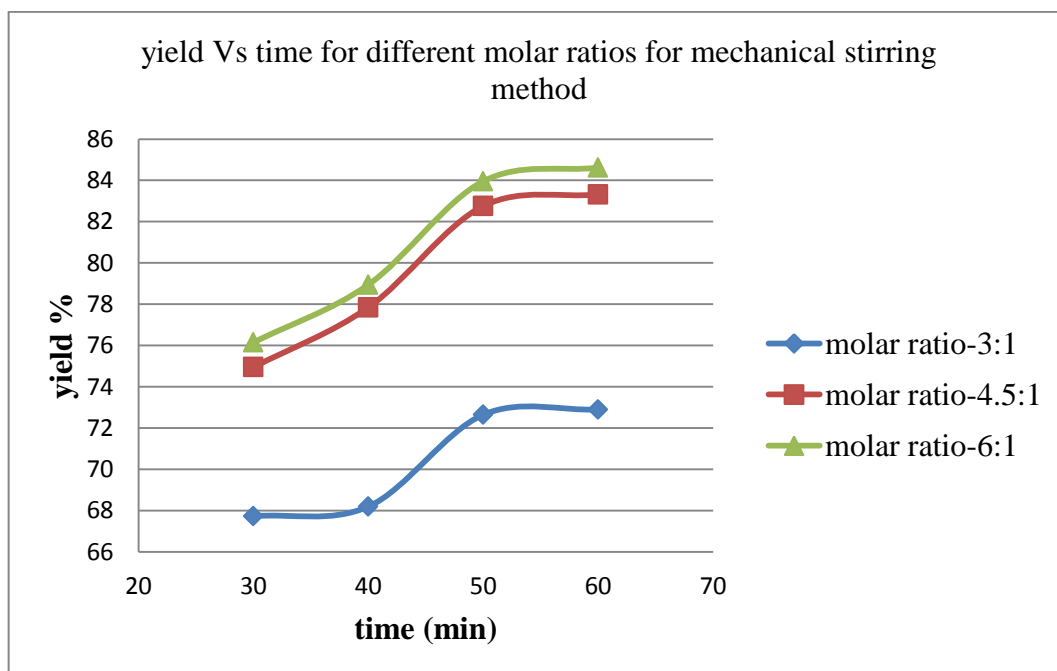

Fig.3: Yield Vs reaction time for different molar ratios for mechanical stirring method for catalyst percentage 0.75 %
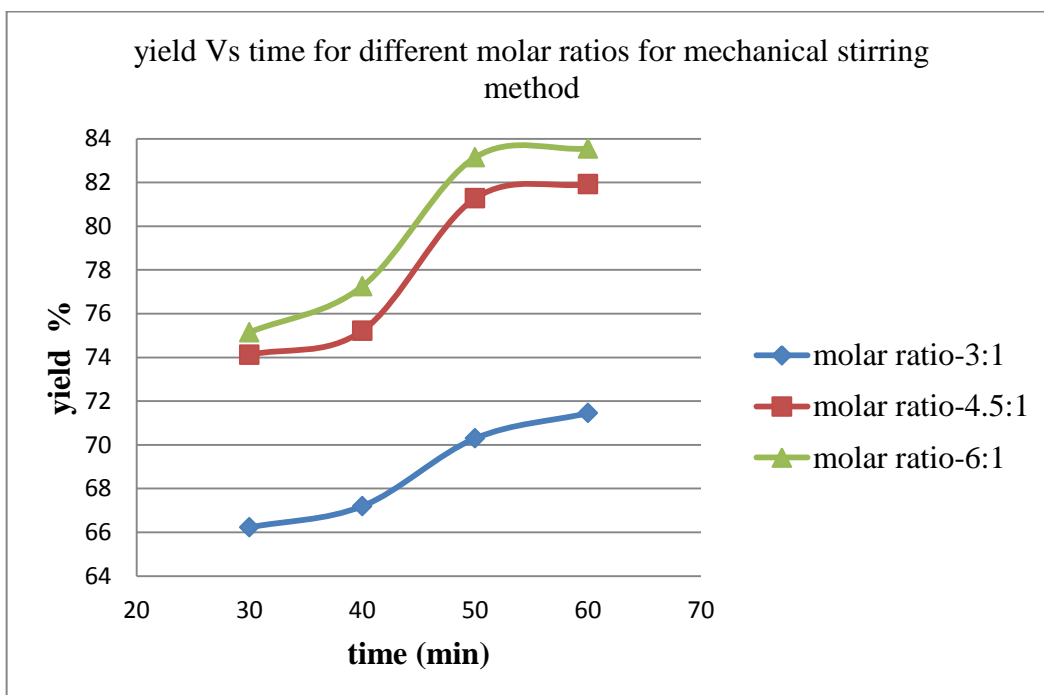
Fig.4: Yield Vs reaction time for different molar ratios for mechanical stirring method for catalyst percentage 1.0 %
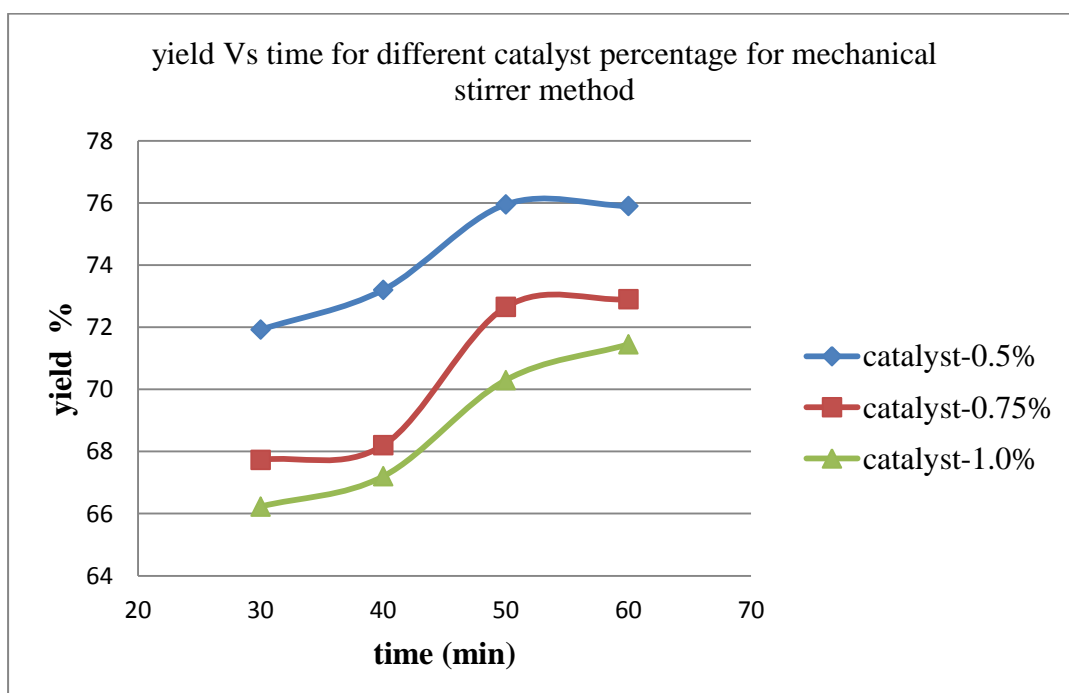

Fig.5: Yield Vs reaction time for different catalyst percentage for mechanical stirring method for molar ratio 3:1

yield Vs time for different catalyst percentage for mechanical stirrer method

catalyst -0.5%
catalyst-0.75%
catalyst-1.0%

yield %

time (min)

Fig.6:Yield Vs reaction time for different catalyst percentage for mechanical stirring method for molar ratio 4.5:1

yield Vs time for different catalyst percentage for mechanical stirrer method

catalyst-0.5%
catalyst-0.75%
catalyst-1.0%

yield %

time (min)
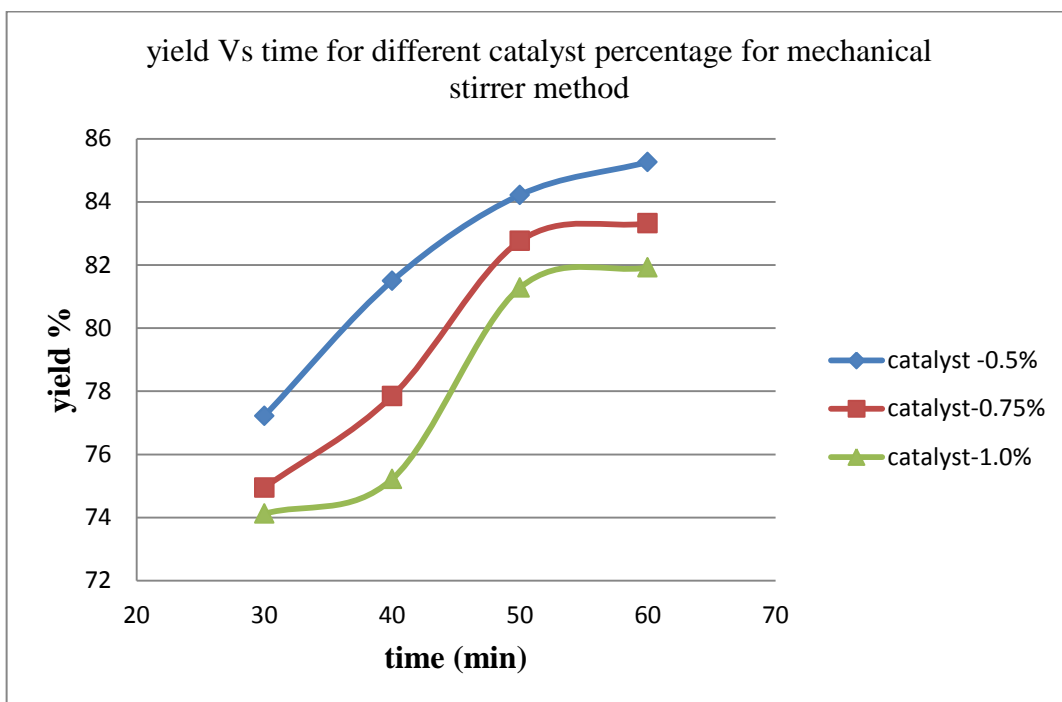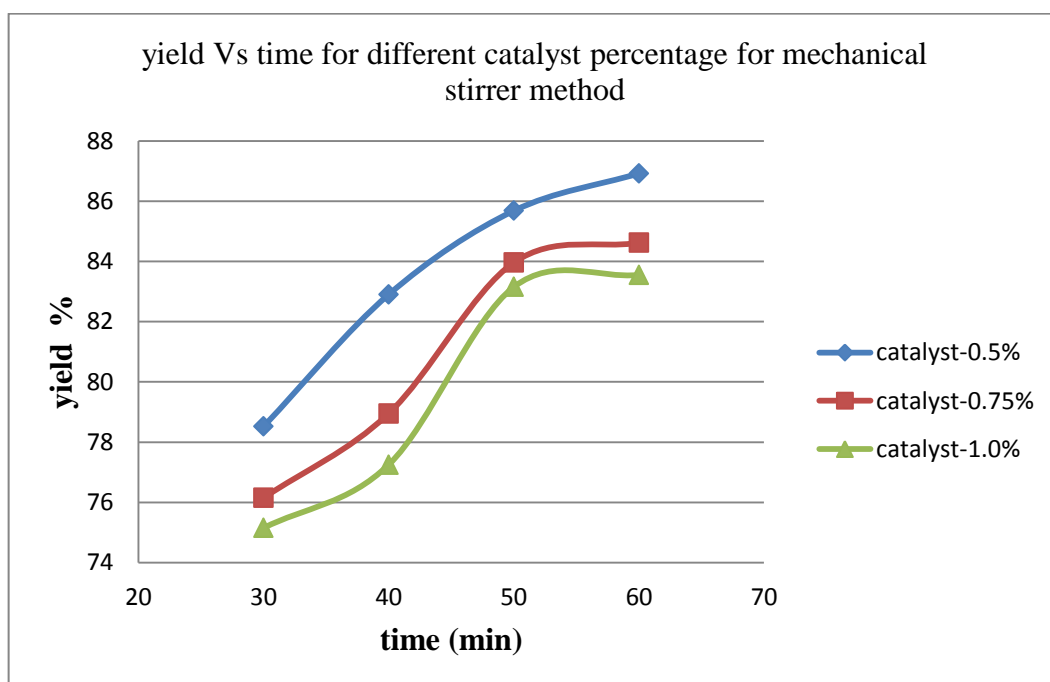
Fig.7: Yield Vs reaction time for different catalyst percentage for mechanical stirring method for molar ratio 4.5:1

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3.2.6 Result and discussion:

➢ **Effect of reaction time:**

It can be concluded from Fig.2 that as we are increasing the reaction time for different molar ratios for 0.5 % catalyst yield obtained is increasing. Similar trend are also seen in Fig.3 and Fig.4 i.e. increase in yield with increase in reaction time is also observed for 0.75 % catalyst and 1% catalyst.

An increase in yield of biodiesel with increase in reaction time for molar ratio 3:1 for catalyst 0.5 %, 0.75% and 1% is shown in Fig.5. Similar trend are also seen in Fig.6 and Fig.7 i.e. increase in yield with increase in reaction time is also observed for molar ratio 4.5:1 and 6:1.

➢ **Effect of molar ratio:**

It is shown in Fig.2 that for catalyst 0.5 % (by weight of oil taken) , as we are increasing the molar ratio from 3:1 to 6:1 yield obtained also increasing i.e. max yield is obtained for molar ratio 6:1 and yield is minimum for stchiometric molar ratio 3:1.

A similar trend for increase in molar ratio is also observed for 0.75% and 1.0% catalyst in Fig.3 and Fig.4 respectively.

➢ **Effect of change in catalyst percentage:**

It is shown in Fig.5 that for molar ratio 3:1 , as we are increasing the percentage of catalyst used from 0.5%(by weight of oil taken) to 1% catalyst yield obtained is decreasing i.e. max yield is obtained with 0.5 % catalyst and yield is minimum with 1.0% catalyst.

A similar trend is also observed (i.e. yield obtained decreases as we increase the percentage of catalyst in the solution) for different molar ratios for molar ratio-4.5:1 and molar ratio-6:1 in Fig. 6 and Fig.7.

3.3 Production of biodiesel through ultrasonic cavitation method:

3.3.1 Principle:

In ultrasonic cavitation method, cavities are created by the irradiation of power of ultrasonic with sufficient energy in immiscible liquid (oil and alcohol are not miscible with each other) as a result micro fine bubbles are formed and these bubbles are collapsing at various place of the reactor and disturb the phase boundary between two immiscible liquid and resulted emulsification of mixture.

3.3.2 Experimental setup:

Fig.8. An ultrasonic horn type processor

3.3.3 Experimental procedure:

1. Waste cooking oil (100 g) is taken in a beaker and filtered to remove the impurities.

Oil is heated to about 110^0C to remove the moisture content present in the oil, then it is cooled to about 50-60^{0}C.

2. Methyl alcohol (For 3:1 molar ratio -11 g, for 4.5:1 molar ratio -16.5 g , for 6:1-22 g) and catalyst Potassium hydroxide (0.5% , 0.75 % or 1%) are mixed in a beaker. This solution is now kept on a magnetic stirrer to form mehoxide.

3. This mehoxide solution and waste cooking oil were mixed in a beaker. The mixture of vegetable oil , alcohol and catalyst is kept on the ultrasonic horn.

4. Cavities are created due to high energy ultrasonic waves, as a result of that very fine bubbles are created in the mixture. When these bubbles collapse, emulsification of mixture is resulted.

5. Temperature of the mixture during the reaction is kept in between 55-65^{0}C.

6. When the reaction is completed, beaker is kept for separation. As density of glycerine is quite high as compared to biodiesel produced, it will settle down at bottom of the separating funnel. This glycerine is removed from the bottom.

7. After the glycerine is separated, water (30% by weight of vegetable oil taken) is heated to 40^{0}C and poured in the beaker containing biodiesel for water washing process.

8. After 4-5 hours water containing excess of KOH and other impurities will settle down in separating funnel.

9. Water is removed from the bottom and biodiesel obtained is heated to 110^{0}C to remove the excess of moisture and methanol.

10. Weigh the pure biodiesel and calculate the yield obtained.

3.3.4 Experimental data:

(A) Materials

The experiments are performed with alcohol to oil molar ratio as 3:1, 4.5:1 and 6:1. The amount of oil, alcohol and catalyst taken is shown in Table.7.

Table.7: Oil, alcohol and catalyst during the experimentation

Molar ratio (alcohol/oil)	Quantity of non-edible oil (g)	Quantity of methanol (g)	Catalyst (KOH)(g)		
			0.5%	0.75%	1.0%
3:1	100	11	0.5	0.75	1.0
4.5:1	100	16.5	0.5	0.75	1.0
6:1	100	22	0.5	0.75	1.0

(B) Calculations

(i) For calculation of molar ratio following data are used

Molecular weight of triglycerides from vegetable oil = 870

Molecular weight of methanol = 32

Hence, 1 gm mole of vegetable oil = 870 gm

1 gm mole of methanol = 32 gm

Catalyst (KOH) = 0.5%, 0.75% and 1% by weight of oil

(ii) Amount of methanol for 100 g of vegetable oil

For 3:1 molar ratio = $(32 / 870) \times 100 \times 3 = 11$ g

For 4.5:1 molar ratio = $(32 / 870) \times 100 \times 4.5 = 16.56$ g

For 6:1 molar ratio = $(32/870) \times 100 \times 6 = 22$ g

(C) Time and yield produced from Waste cooking oil:

Yield produced from waste cooking oil by varying the molar ratio and percentage of catalyst used is shown in table 8-10.

Table.8: Ultrasonic cavitation method (molar ratio 3:1)

Quantity of waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	11	0.5	0.5	72.26	72.26	73.56	73.56	74.65	76.15	76.95	76.95
100	11	0.75	0.75	68.96	68.96	70.56	70.56	76.66	76.66	74.95	74.95
100	11	1.00	1.00	67.22	67.22	68.36	68.36	72.00	72.00	72.22	72.22

Table.9: Ultrasonic cavitation method (molar ratio 4.5:1)

Quantity of waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	16.5	0.5	0.5	78.16	78.16	82.5	82.5	86.52	86.52	87.2	87.2
100	16.5	0.75	0.75	75.85	75.85	79.27	79.27	83.92	83.92	84.32	84.32
100	16.5	1.0	1.00	74.95	74.95	77.28	77.28	83.15	83.15	83.65	83.65

Table.10: Ultrasonic cavitation method (molar ratio 6:1)

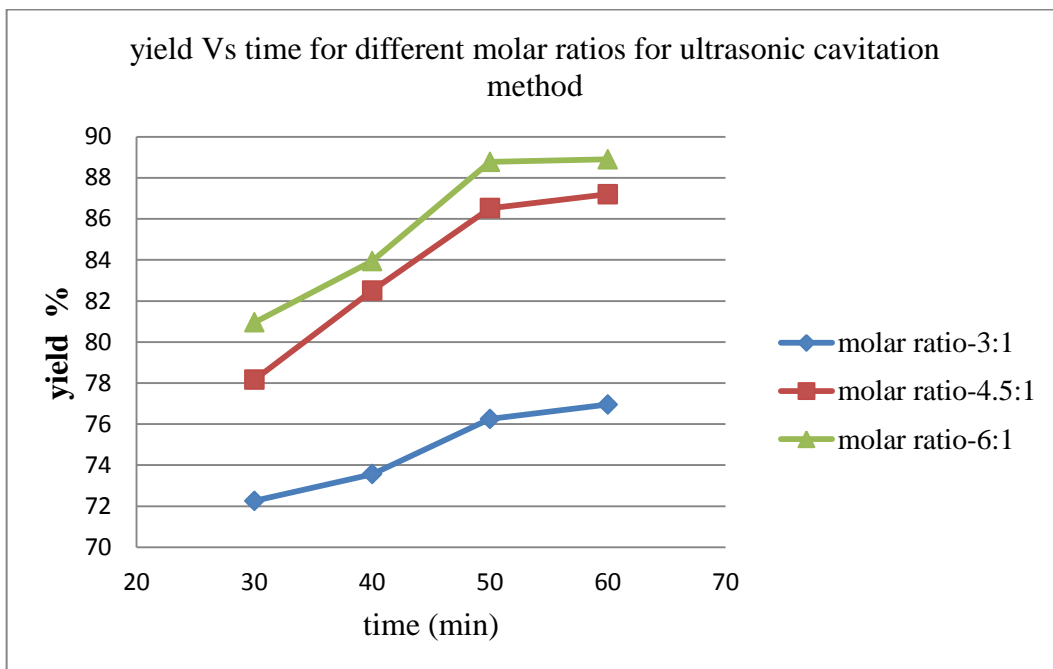| Quantity of waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	22	0.5	0.5	80.95	80.95	83.94	83.94	88.77	88.77	88.90	88.90
100	22	0.75	0.75	77.25	77.25	80.5	80.5	86.22	86.22	86.92	86.92
100	22	1.0	1.0	76.45	76.45	79.5	79.5	85.32	85.32	85.64	85.64

Fig.9.Yield Vs reaction time for different molar ratios for ultrasonic cavitation method for catalyst – 0.5 %
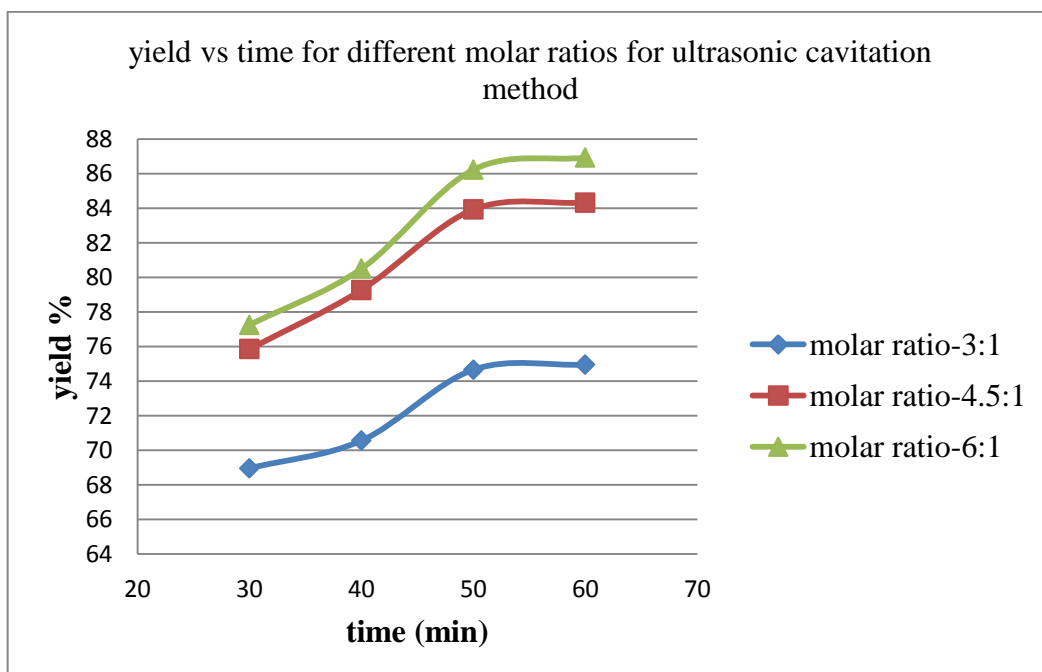

Fig.10. Yield Vs reaction time for different molar ratios for ultrasonic cavitation method for catalyst – 0.75 %
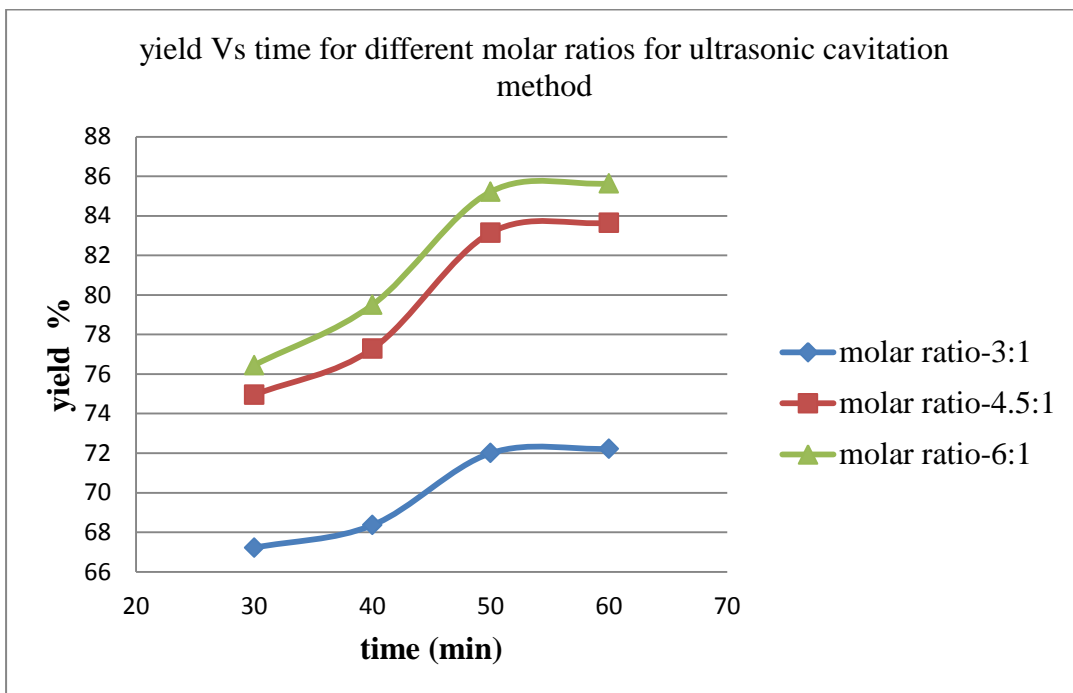
Fig.11. Yield Vs reaction time for different molar ratios for ultrasonic cavitation method for catalyst – 1.0 %
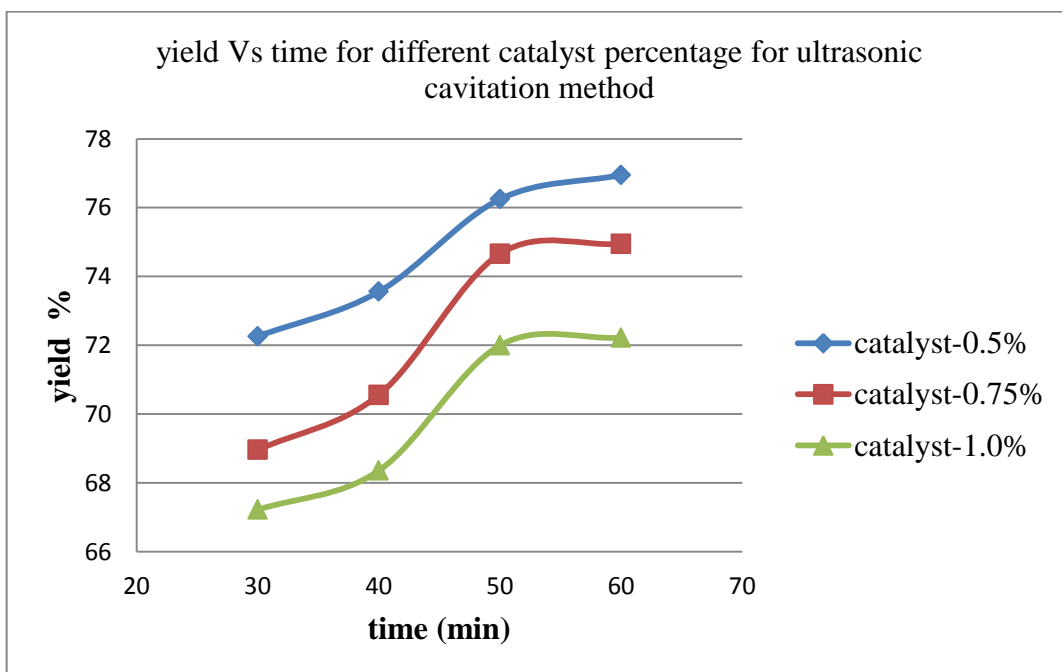

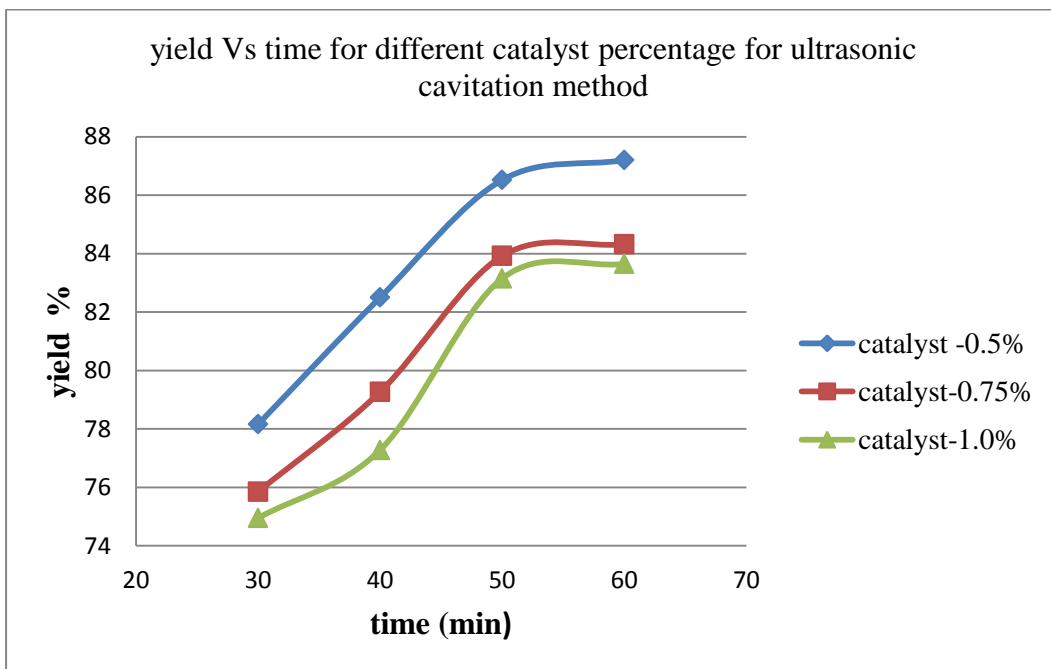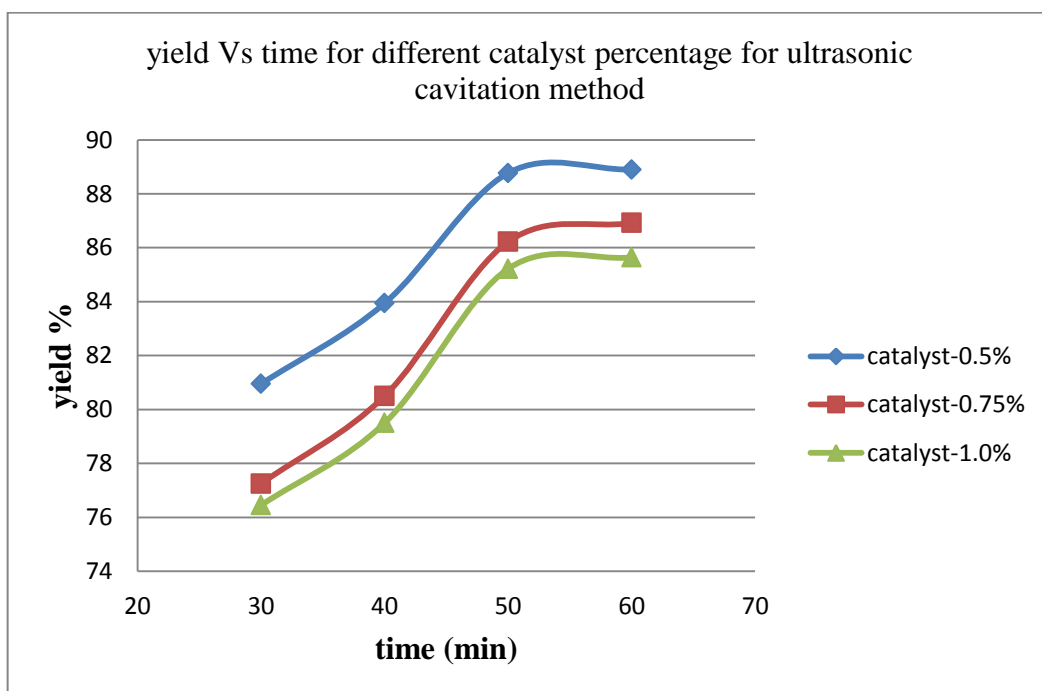**Fig.12.Yield Vs reaction time for different catalyst percentage for ultrasonic cavitation method for molar ratio 3:1**

Fig.13.Yield Vs reaction time for different catalyst percentage for ultrasonic cavitation method for molar ratio 4.5:1

Fig.14.Yield Vs reaction time for different catalyst percentage for ultrasonic cavitation method for molar ratio 6:1

3.3.5 Result and discussion:

➢ **Effect of reaction time:**

A similar trend as discussed with the mechanical stirrer method is observed with ultrasonic cavitation method also i.e. as reaction time is increased from 30 min to 60 min, yield of biodiesel is also increased.

Yield obtained for different molar ratios with catalyst 0.5 % is shown in Fig.9. A similar trend is observed for when catalyst is changed to 0.75 % and 1 % for various molar ratios in Fig.10 and Fig.11 respectively. Yield obtained with ultrasonic method is higher as compared to mechanical stirrer method.

➢ **Effect of molar ratio:**

A similar trend as discussed with the mechanical stirrer method is observed with ultrasonic cavitation method also i.e. as molar ratio is increased from 3:1 to 6:1 , yield of biodiesel is also increased i.e. yield obtained is max for molar ratio 6:1 and minimum for molar ratio 3:1 for a fixed reaction time and fixed catalyst percentage. Yield obtained for different molar ratios with catalyst 0.5 % is shown in Fig.9. A similar trend is observed for when catalyst is changed to 0.75 % and 1 % for various molar ratios in Fig 10 and Fig.11 respectively.

➢ **Effect of change in catalyst percentage:**

A similar trend as discussed with the mechanical stirrer method is observed with ultrasonic cavitation method also i.e. as we increase the catalyst percentage from 0.5 % to 1.0% yield of biodiesel decreases i.e. yield obtained is max for 0.5% catalyst and minimum for 1% catalyst for a fixed reaction time and fixed molar ratio. Yield obtained for catalyst percentage-0.5% , 0.75% and 1.0% for 3:1 molar ratio is shown in Fig.12. A similar trend is observed for various molar ratio-4.5:1 and molar ratio-6:1 for different catalyst percentage in Fig.13 and Fig.14 respectively.

3.4 Production of biodiesel through hydrodynamic cavitation method:

3.4.1 Principle:

The principle of hydrodynamic cavitation machine resembles the ultrasonic cavitation method as the fundamental of working is cavitation phenomena. In the cavitation process small bubbles are formed in liquids at mechanically weak points, usually at phase boundaries, as a result of intense sonication. The series of working is bubble formation, growth and when it collapses, due to the rapid kinetic motions of molecules due to high generation of pressure inside. Using cavitation as an alternative technique for the synthesis of biodiesel results in conditions of very high local temperatures and pressures at the same time releasing free radicals which intensifies many chemical reactions.

Cavitation is produced by pressure variations, which isobtained using the geometry of the system creating velocity variation. For example, based on the geometry of the system, the interchange of pressure and kinetic energy can be achieved resulting in the generation of cavities as in the case of flow through orifice, venturi. The series of working is bubble formation, growth and when it collapses, due to the rapid kinetic motions of molecules due to high generation of pressure inside.

3.4.2 Experimental setup:

Fig.15. A hydrodynamic cavitation setup

3.4.3 Experimental procedure:

1. Waste cooking oil (2.5 kg) is taken in a beaker and filtered to remove the impurities. Oil is heated to about 110^0C to remove the moisture content present in the oil, then it is cooled to about 50-60^{0}C.

2. Methyl alcohol (For 3:1 molar ratio -275 g, for 4.5:1 molar ratio -412.5 g , for 6:1- 550 g) and catalyst Potassium hydroxide (0.5% , 0.75 % or 1% by weight of the oil taken) are mixed in a beaker. This solution is now kept on a magnetic stirrer to form mehoxide.

3. This mehoxide solution and waste cooking oil were mixed in a beaker . The mixture of vegetable oil , alcohol and catalyst is poured in hydrodynamic test rig.

4. Cavitation is produced by pressure variations, which is obtained using the geometry of the system creating velocity variation, as a result of that very fine bubbles are created in the mixture. When these bubbles collapse, emulsification of mixture is resulted.

5. Temperature of the mixture during the reaction is kept in between 55-65^{0}C.

6. When the reaction is completed , beaker is kept for separation. As density of glycerine is quite high as compared to biodiesel produced, it will settle down at bottom of the separating funnel. This glycerine is removed from the bottom.

7. After the glycerine is separated, water (30% by weight of vegetable oil taken) is heated to 40^{0}C and poured in the beaker containing biodiesel for water washing process.

8. After 4-5 hour water containing excess of KOH and other impurities will settle down in separating funnel.

9. Water is removed from the bottom and biodiesel obtained is heated to 1100C to remove the excess of moisture and methanol.

10.Weigh the pure biodiesel and calculate the yield obtained.

3.4.4 Experimental Data:

(A) Materials

The experiments are performed with alcohol to oil molar ratio as 3:1 , 4.5:1 and 6:1. The amount of oil, alcohol and catalyst taken is shown in Table.11.

Table.11: Oil, alcohol and catalyst during the experimentation

Molar ratio (alcohol/oil)	Quantity of non-edible oil (kg)	Quantity of methanol (g)	Catalyst (KOH) (g)		
			0.5%	0.75%	1.0%
3:1	2.5	275	12.5	18.75	25
4.5:1	2.5	414	12.5	18.75	25
6:1	2.5	550	12.5	18.75	25

(B) Calculations

(i) For calculation of molar ratio following data are used

Molecular weight of triglycerides from vegetable oil = 870

Molecular weight of methanol = 32

Hence, 1 gm mole of vegetable oil = 870 gm

1 gm mole of methanol = 32 gm

Catalyst (KOH) = 0.5%, 0.75% and 1% by weight of oil

(ii) Amount of methanol for 2.5kg of vegetable oil

For 3:1 molar ratio = $(32 / 870) \times 2500 \times 3 = 275$ g

For 4.5:1 molar ratio = $(32 / 870) \times 100 \times 4.5 = 414$ g

For 6:1 molar ratio = $(32/870) \times 100 \times 6 = 550$ g

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(C) Time and yield produced from Waste cooking oil: Yield produced from waste cooking oil by varying the molar ratio and percentage of catalyst used is shown below in table 12-14.

Table.12: Hydrodynamic cavitation method (molar ratio 3:1)

Quantity of waste cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(kg)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
2.5	275	12.5	0.5	1824	72.96	1855	74.22	1938	77.55	1948	77.95
2.5	275	18.75	0.75	1764	70.56	1838	73.12	1891	75.65	1898	75.95
2.5	275	25.0	1.00	1724	68.98	1764	70.65	1839	73.96	1853	74.15

Table.13: Hydrodynamic cavitation method (molar ratio 4.5:1)

Quantity of Waste Cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	16.5	0.5	0.5	2029	81.16	2098	83.92	2288	91.52	2291	91.66
100	16.5	0.75	0.75	1946	77.85	2024	80.97	2217	88.7	2235	89.4
100	16.5	1.0	1.00	1906	76.25	1954	78.18	2146	85.85	2153	86.15

Table.14: Hydrodynamic cavitation method (molar ratio 6:1)

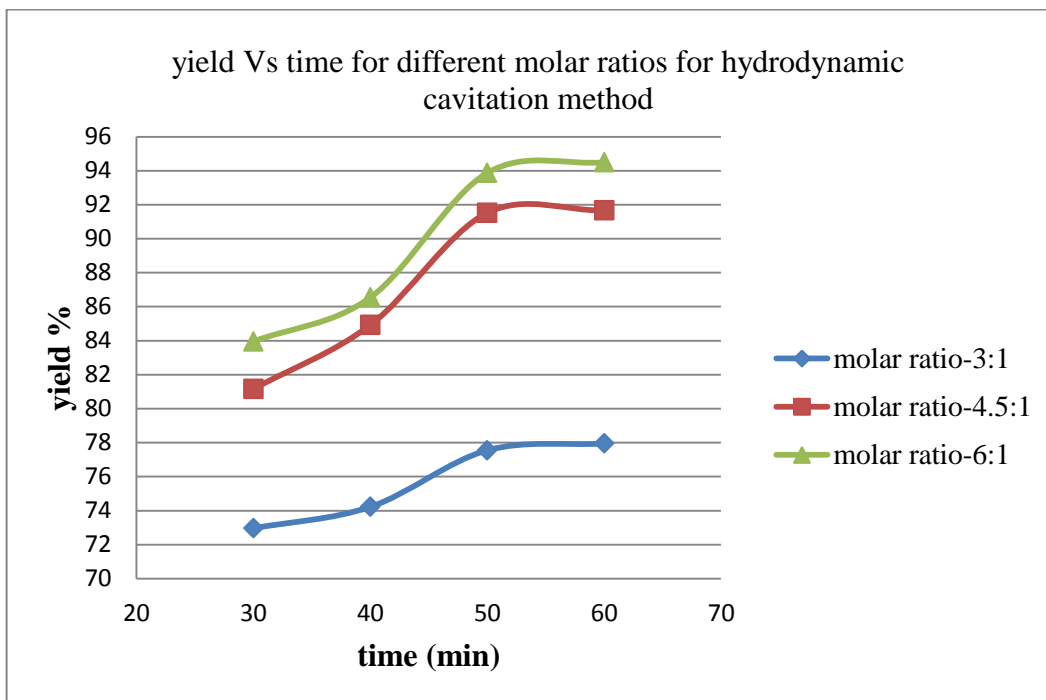| Quantity of Waste Cooking oil	Quantity of methanol	Catalyst used KOH		Yield obtained							
				30 min		40 min		50 min		60 min	
(gm)	(gm)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)	(gm)	(%)
100	22	0.5	0.5	2098	83.95	2163	86.54	2346	93.87	2362	94.50
100	22	0.75	0.75	1998	79.95	2071	82.87	2318	92.72	2331	93.26
100	22	1.0	1.0	1931	77.25	2024	80.97	2243	89.72	2256	90.26

Fig.16.Yield Vs reaction time for different molar ratios for hydrodynamic cavitation method for catalyst percentage-0.5 %
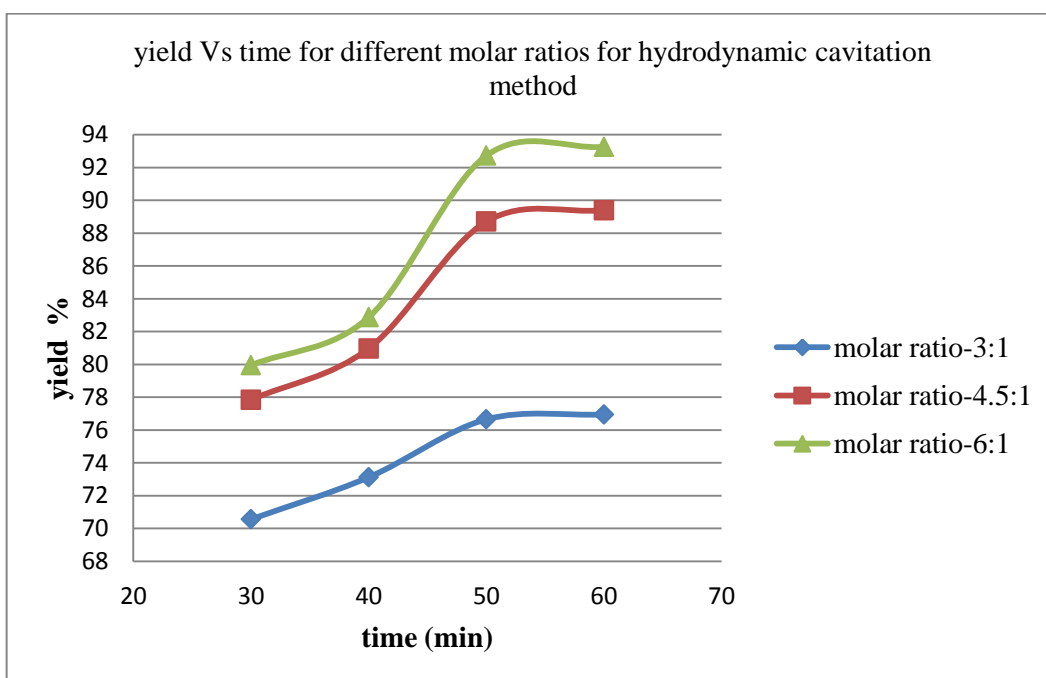

Fig.17. Yield Vs reaction time for different molar ratios for hydrodynamic cavitation methodfor catalyst percentage-0.75 %
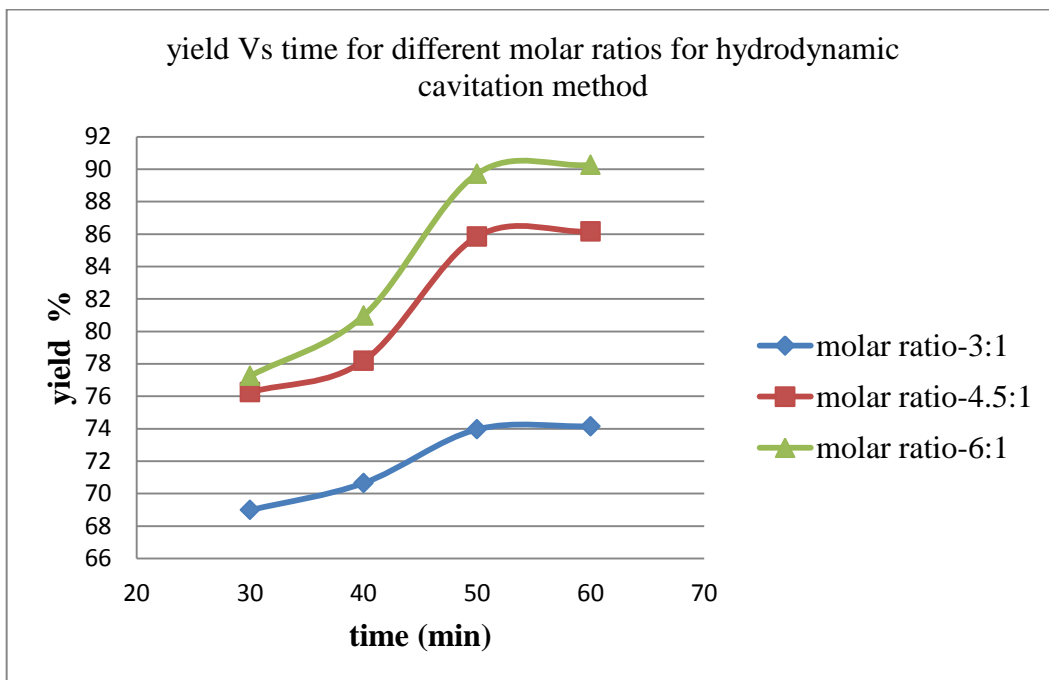
Fig.18. Yield Vs reaction time for different molar ratios for hydrodynamic cavitation method for catalyst percentage-1.0 %
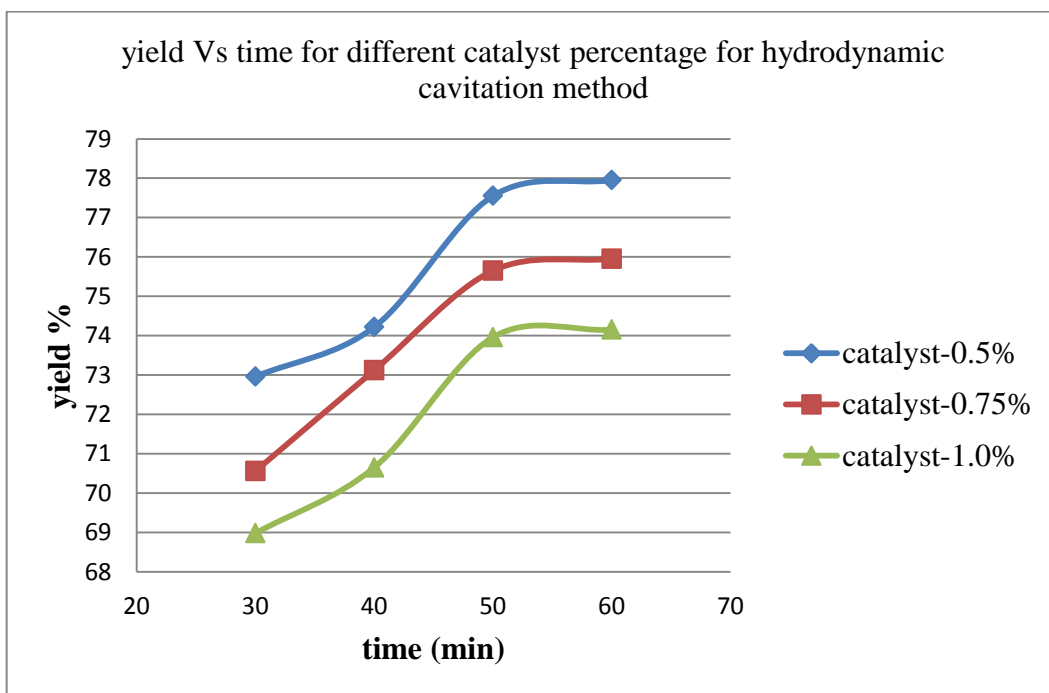

Fig.19.Yield Vs reaction time for different catalyst percentage for hydrodynamic cavitation method for molar ratio 3 :1
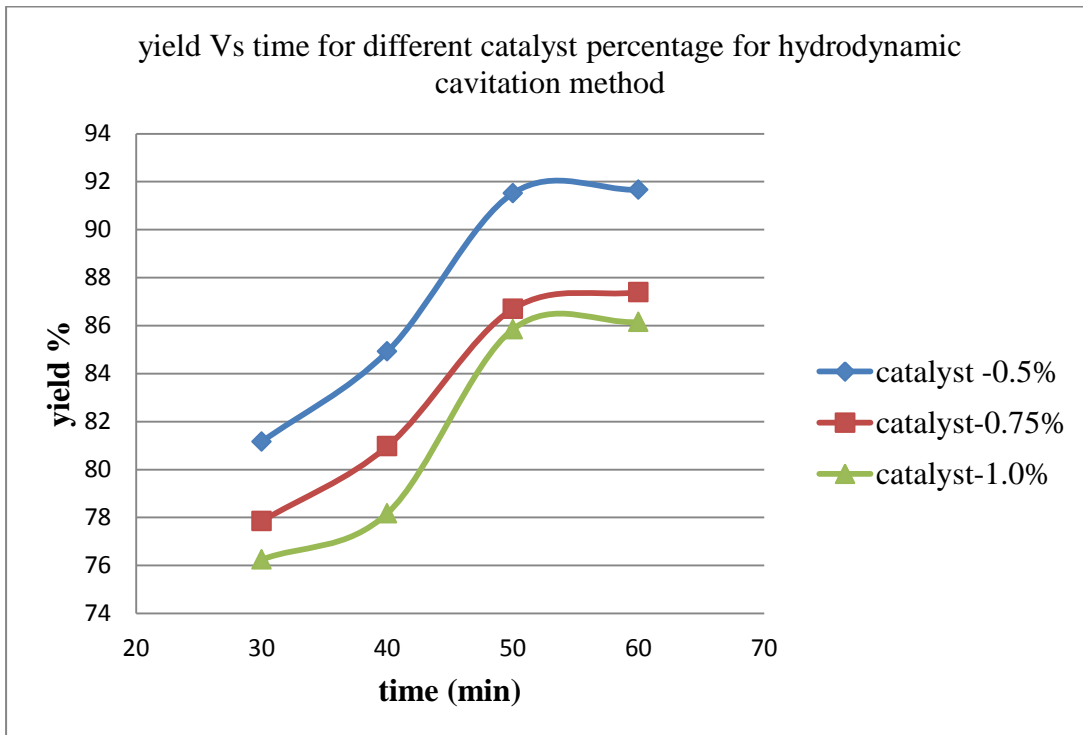
Fig.20.Yield Vs reaction time for different catalyst percentage for hydrodynamic cavitation method for molar ratio 4.5 :1
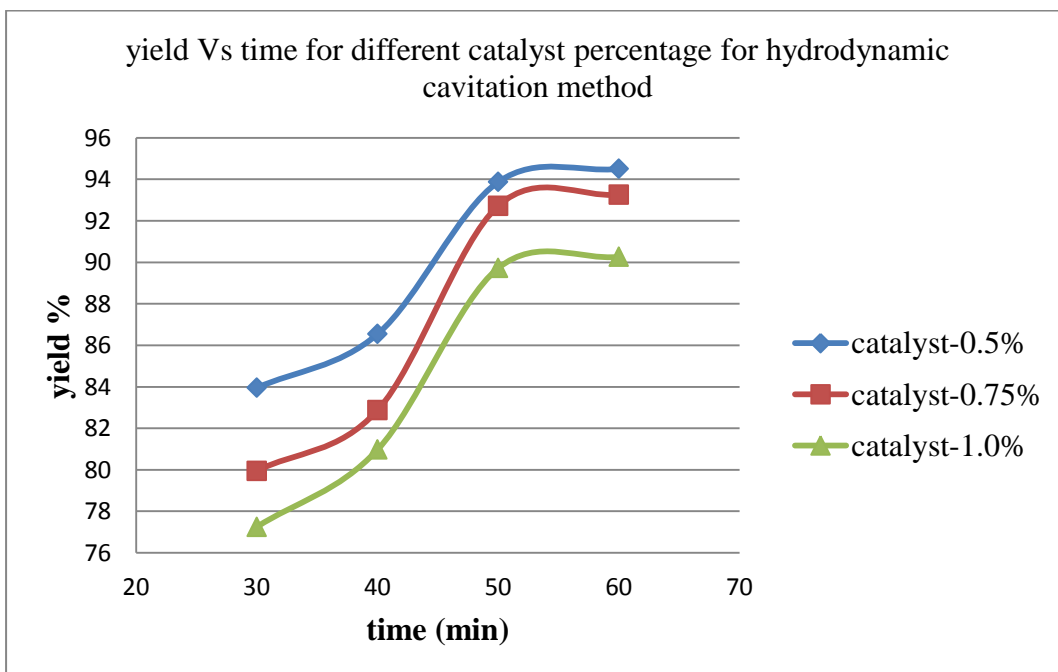
Fig.21.Yield Vs reaction time for different catalyst percentage for hydrodynamic cavitation method for molar ratio 6 :1

3.4.5 Result and discussion:

➤ **Effect of reaction time:**

It is observed from Fig.16 that when we increase the reaction time yield obtained is also increased for different molar ratios with catalyst-0.5%.A similar trend is observed with catalyst -0.75 % and 1.0% also in Fig.17 and Fig.18 respectively , but yield produced is nearly constant after 50 min for a particular molar ratio and catalyst percentage used.

It is observed from Fig.19 that when we increase the reaction time yield obtained is also increased with catalyst-0.5%, 0.75% and 1.0% for molar ratio 3:1. A similar trend is observed with molar ratio 4.5:1 and 6:1 also in Fig.20 and Fig.21 respectively.

➤ **Effect of molar ratio:** With hydrodynamic cavitation method also, yield is increasing as we are increasing the molar ratio from 3:1 to 6:1 but yield produced is higher with hydrodynamic cavitation method than conventional mechanical stirring and ultrasonic cavitation method for different molar ratios.

Variation of yield produced with respect to time is shown in Fig.16for different molar ratios (when KOH is 0.5%).A similar trend is observed for KOH-0.75 % and 1.0% also and is shown in Fig.17 and Fig.18 respectively.

➤ **Effect of change in catalyst percentage:**

With increase in percentage of KOH used, yield of biodiesel produced with hydrodynamic cavitation method decreases. Variation of yield with respect to time is shown in Fig.19 for molar ratio 3:1.

It is observed from the graph that produced yield is maximum for catalyst-0.5 % and minimum fot KOH-1%. A similar trend is observed for molar ratio-4.5:1 and 6:1 also and is shown in Fig.20 and Fig.21 respectively.

3.5 Comparison of Mechanical Stirring, Ultrasonic cavitation, Hydrodynamic cavitation methods:
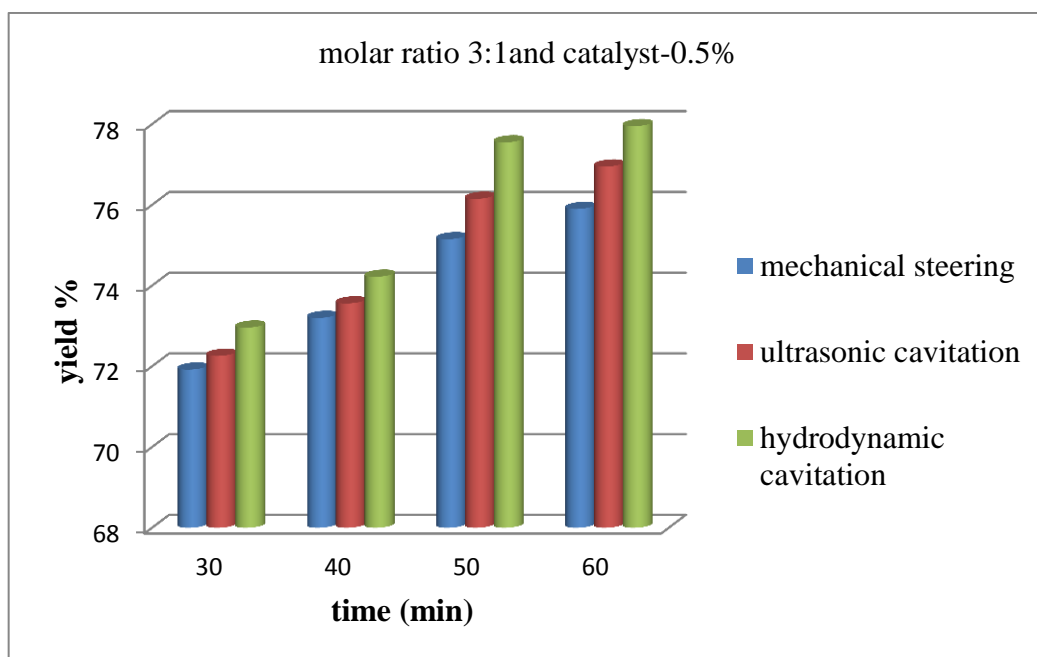

Fig.22.A comparison of methods yield Vs reaction time for molar ratio 3:1 and KOH-0.5%
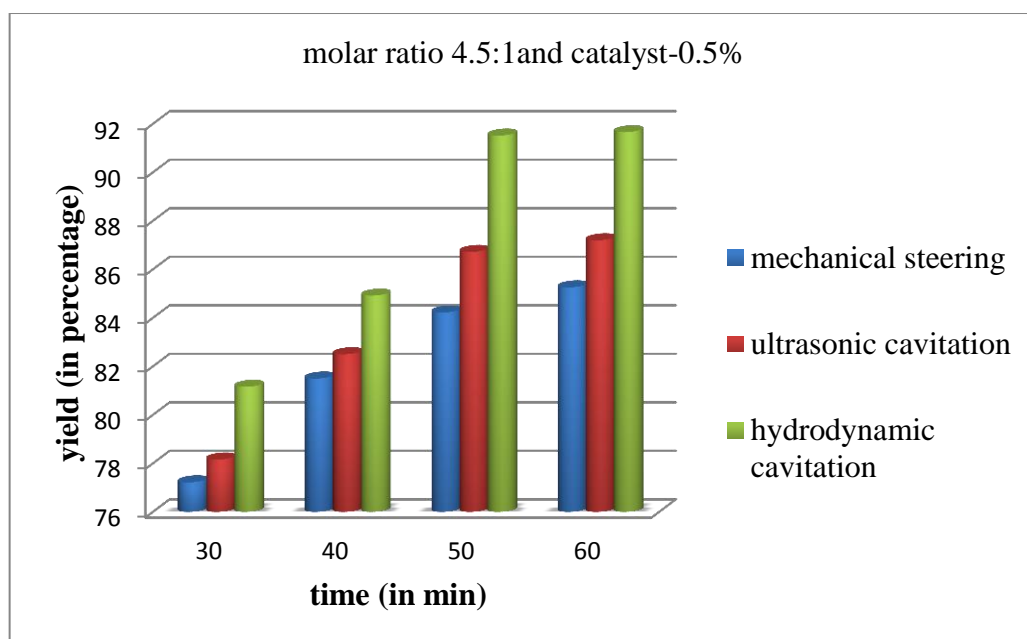

Fig.23.A comparison of methods yield Vs reaction time for molar ratio 4.5:1 and KOH-0.5%
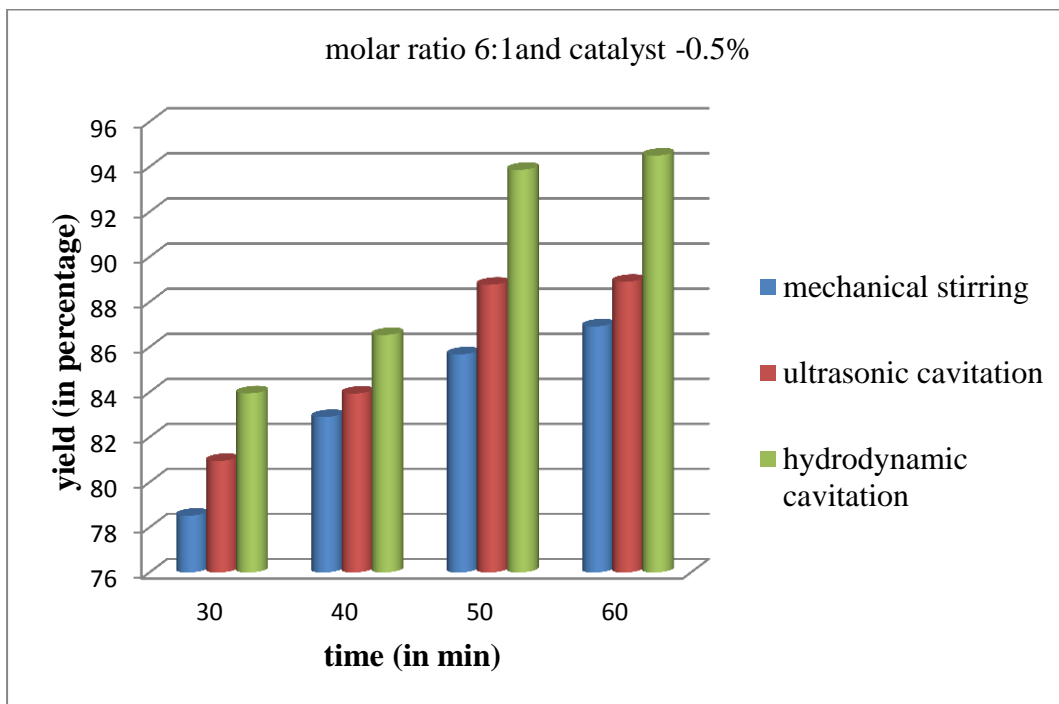
Fig.24.A comparison of methods yield Vs reaction time for molar ratio 6:1 and KOH-0.5%

It is clear from the graph in Fig.22, Fig.23 and Fig.24 that yield obtained is higher for hydrodynamic cavitation as compared to Ultrasonic Cavitation and conventional stirring method for different molar ratios when catalyst is taken as 0.5 %. For molar ratio 3:1 maximum yield of 75.9%, 76.9% and 77.06% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively. For molar ratio 4.5:1 maximum yield of 85.26%,87.20% and 91.66% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively. For molar ratio 6:1 maximum yield of 86.92%, 88.90% and 94.50% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively.
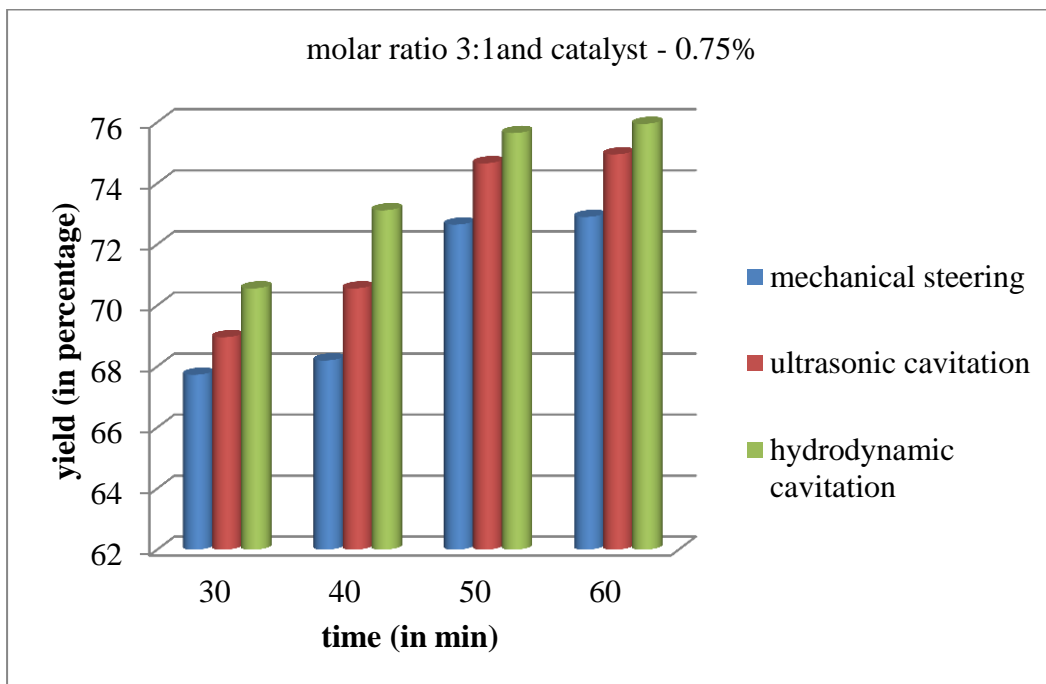
Fig.25.A comparison of methods yield Vs reaction time for molar ratio 3:1 and KOH-0.75%
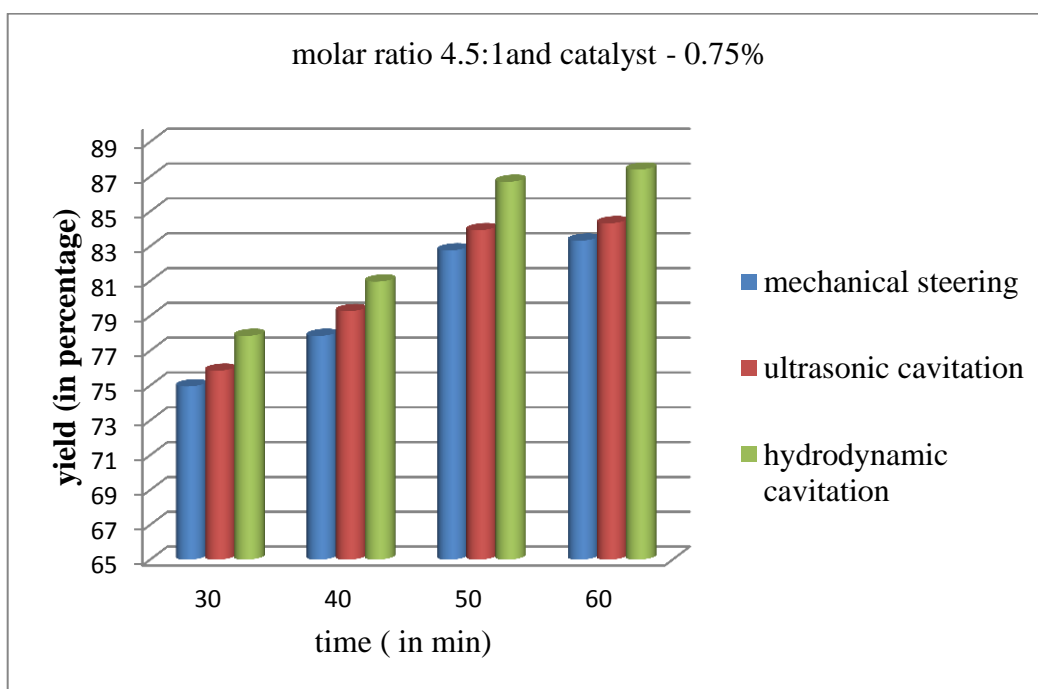

Fig.26.A comparison of methods yield Vs reaction time for molar ratio 4.5:1 and KOH-0.75
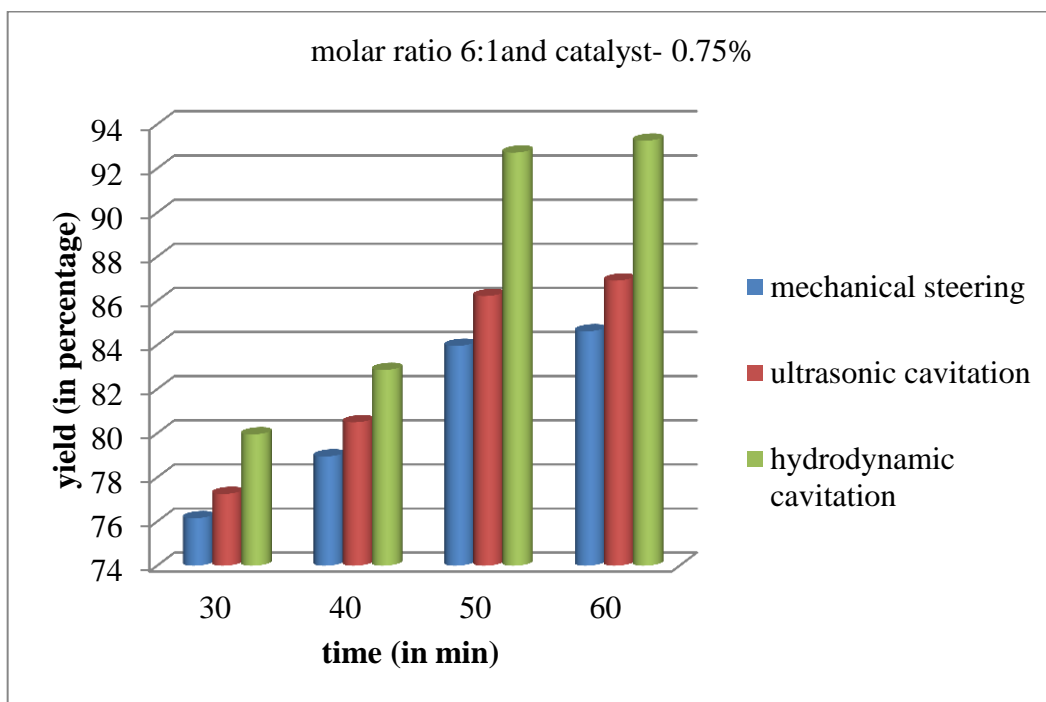
Fig.27. A comparison of methods yield Vs reaction time for molar ratio 6:1 and KOH-0.75%

It is clear from the graph in Fig.25, Fig.26 and Fig.27 that yield obtained is higher for hydrodynamic cavitation as compared to Ultrasonic Cavitation and conventional stirring method for different molar ratios when catalyst is taken as 0.75 %. For molar ratio 3:1 maximum yield of 72.90%, 74.95% and 75.95% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively. For molar ratio 4.5:1 maximum yield of 83.32%, 84.32% and 87.40% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively.For molar ratio 6:1 maximum yield of 84.62%, 86.92% and 93.26% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively.
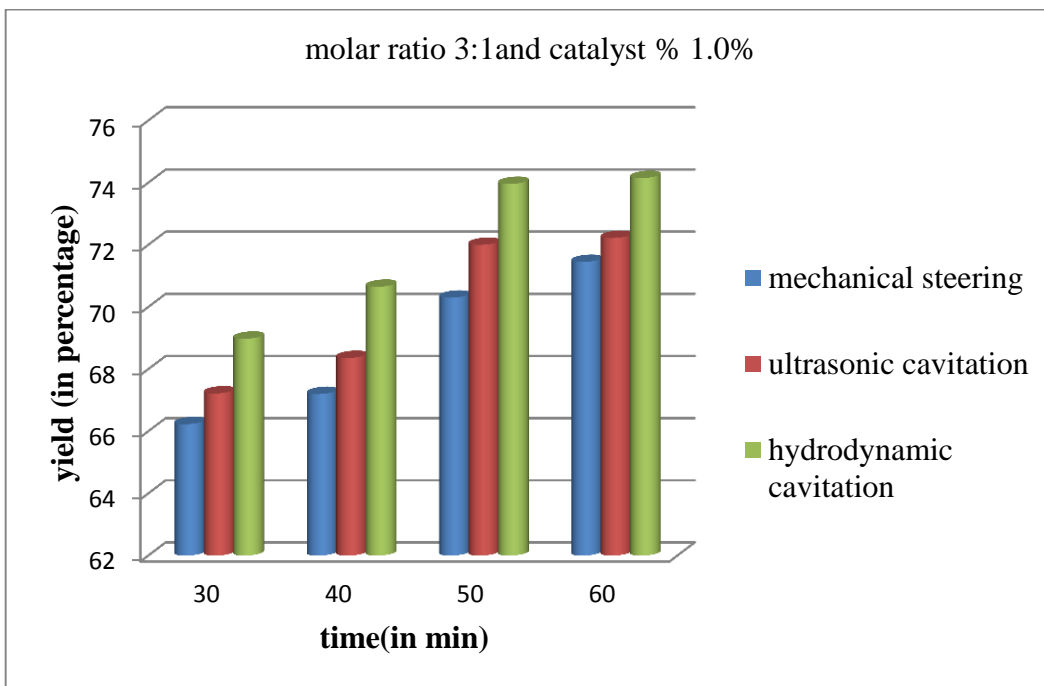
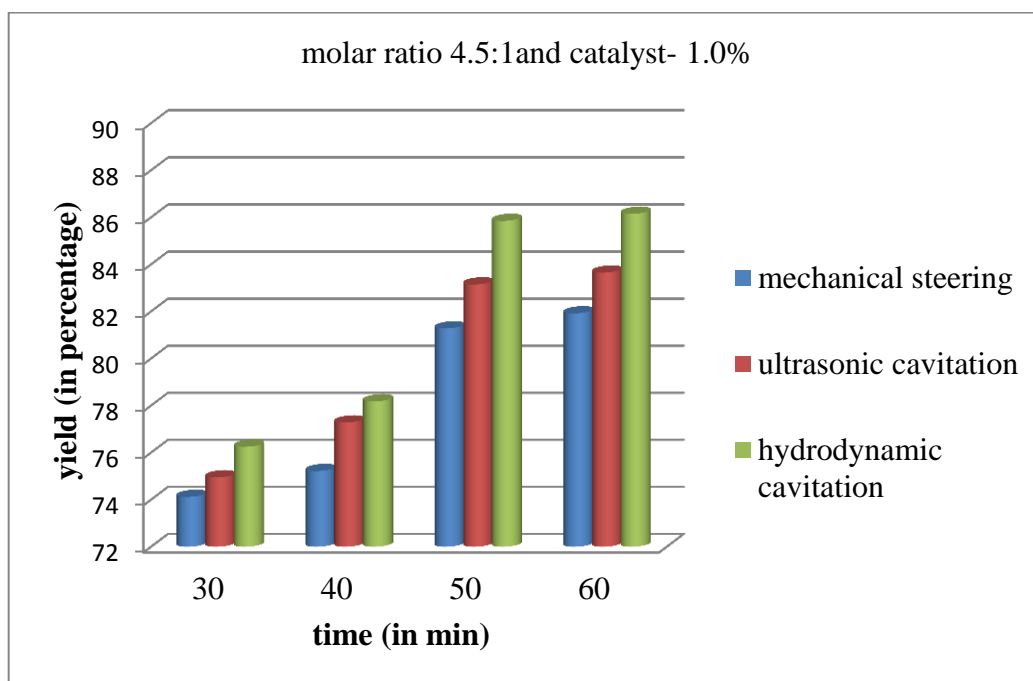**Fig.28.A comparison of methods yield Vs reaction time for molar ratio 3:1 and KOH-1.0%**

Fig.29.A comparison of methods yield Vs reaction time for molar ratio 4.5:1 and KOH-1.0%
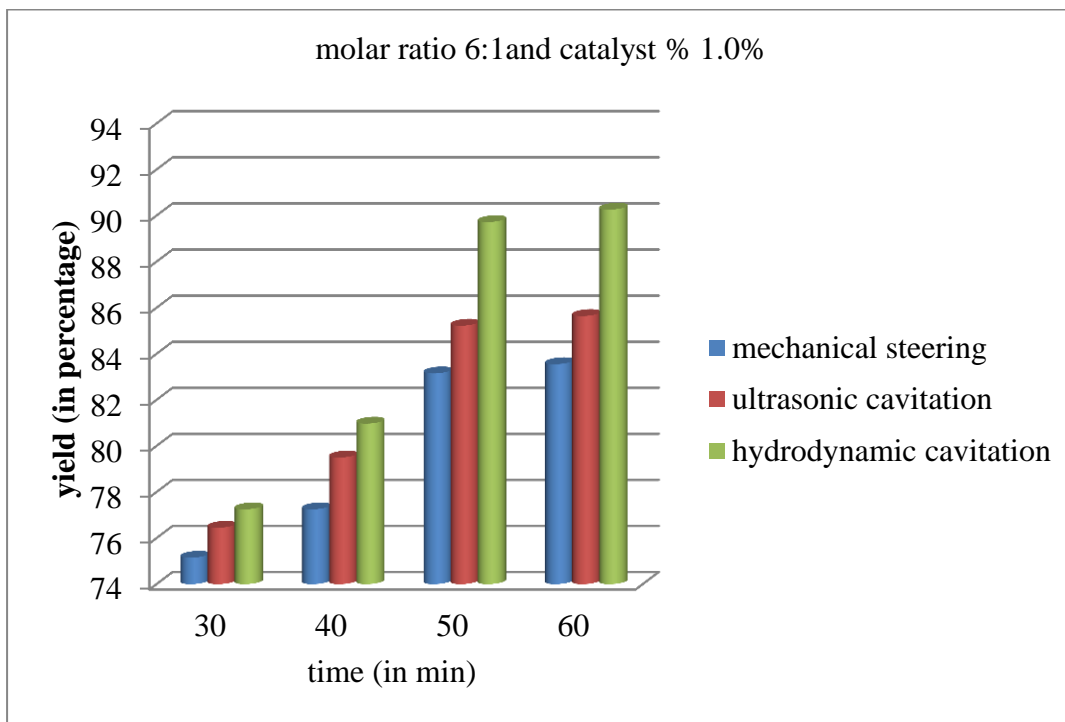
Fig.30. A comparison of methods yield vs reaction time for molar ratio 6:1 and KOH-1.0%

It is clear from the graph in Fig.28, Fig.29 and Fig.30 that yield obtained is higher for hydrodynamic cavitation as compared to Ultrasonic Cavitation and conventional stirring method for different molar ratios when catalyst is taken as 1.0%.For molar ratio 3:1, maximum yield obtained is 71.45%, 72.22% and 74.15% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively. For molar ratio 4.5:1 ,maximum yield obtained is 81.92%, 83.65% and 86.15% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively. For molar ratio 6:1, maximum yield obtained is 83.55%, 85.64% and 90.26% is observed for conventional mechanical stirring method, Ultrasonic cavitation method and hydrodynamic cavitation method respectively.

CHAPTER-4

PERFORMANCE AND EMISSION TESTING

This chapter contains the performance and emission testing of biodiesel extracted from waste cooking oil by applying various biodiesel production techniques, as discussed in the chapter 3. This chapter consist of engine details, procedure followed by various performance and emission parameters.

4.1 Engine Test Setup:

The setup consists of single cylinder, four stroke, Kirloskar Diesel engine connected to an eddy current type dynamometer for loading. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

Normally, the diesel engine produce excessive knocking that can damage the engine, besides that it produces gases like carbon monoxide, nitrogen oxides, unburnt hydrocarbon, smoke, soot and other forms of black carbon as well as particulate matter, such as lead. All the gases are harmful to the environment and human kind; they can cause greenhouse effect, acid rain and air pollution and thus harm the environment. Due to these effects, human beings may suffer from various diseases, such as lung cancer, breathing difficulties, poisoning and skin cancer etc.

The setup enables study of engine performance for brake power, indicated power, frictional power, BMEP, Indicated mean effective pressure (IMEP), brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Labview based Engine Performance Analysis software package "EnginesoftLV" is provided for on line performance evaluation. The aim of this experiment is to study the effects of various parameters on performance of Kirloskar engine for different blends of diesel and biodiesel.

An experimental setup for performance and emission testing are shown in Fig.31 and Fig.32.
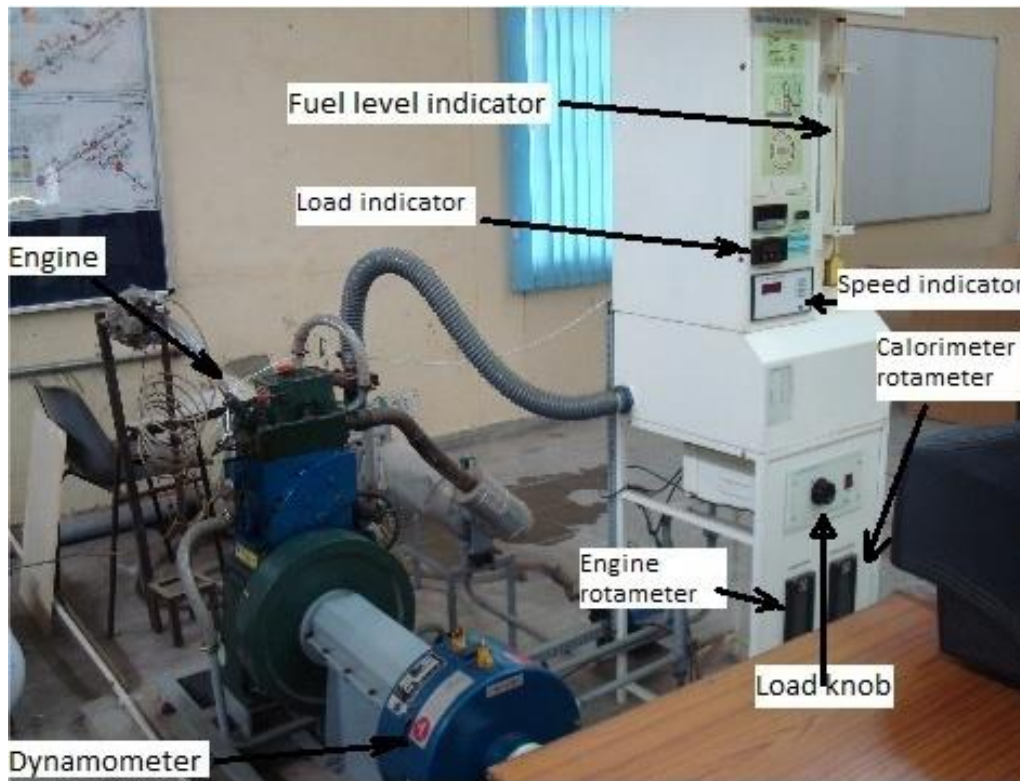

Fig.31. Experimental set-up of Kirloskar diesel engine

Fig.32. Rear view of the Kirloskar diesel engine

4.2 Engine specifications:

Table.15: Specifications of engine test rig.

Component	Specifications
Product	Kirloskar engine test setup 1 cylinder, 4 stroke, Diesel (Computerized)
Product code	234
Engine	Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5
Dynamometer	Type eddy current, water cooled, with loading unit
Propeller shaft	With universal joints
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 L with glass fuel metering column
Calorimeter	Type Pipe in pipe
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse
Data acquisition device	NI USB-6210, 16-bit, 250kS/s
Piezo powering unit	Make-Cuadra, Model AX-409
Digital milivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Type two wire, Input RTD PT100, Range $0–100^0$C, Output $4–20$ mA and Type two wire, Input Thermocouple, Range $0–1200\ ^0$C, Output $4–20$ mA
Load indicator	Digital, Range 0-50 Kg, Supply 230 VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Software	"Enginesoft" Engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH

4.3 Preparation of blends:

Three different diesel-biodiesel blends were prepared as explained below:

- B10 (10 % biodiesel + 90 % diesel): To prepare 500 ml of B10 Blend , 450 ml of pure diesel was taken in a beaker and it was mixed with 50 ml of biodiesel prepared from waste cooking oil.

- B20 (20 % biodiesel + 80 % diesel) : To prepare 500 ml of B20 Blend , 400 ml of pure diesel was taken in a beaker and it was mixed with 100 ml of biodiesel prepared from waste cooking oil.

- B30 (30 % biodiesel + 70 % diesel) : To prepare 500 ml of B30 Blend , 350 ml of pure diesel was taken in a beaker and it was mixed with 150 ml of biodiesel prepared from waste cooking oil.

Calorific value of pure diesel = 43000 kJ/kg

Calorific value of biodiesel = 38550 kJ/kg

Density of pure diesel = 821 kg/m^3

Density of biodiesel = 885 kg/m^3

The calorific value and densities for diesel and different blends of biodiesel were as calculated and shown in Table 16:

Table.16: Description of different blends of biodiesel

Type of blend	Amount of biodiesel (ml)	Amount of diesel (ml)	Resultant calorific value (kJ/kg)	Resultant density (kg/m^3)
Diesel	0	1000	43000	821
B-10	50	450	42555	827.4
B-20	100	400	42110	833.8
B-30	150	350	41665	840.2

4.4 Performance Evaluations

All experiments were performed on a single cylinder, 4 stroke kirloskar diesel engine. There were two separate fuel tanks in the setup, one for diesel and another for biodiesel-diesel blend. Fuel was supplied to the engine from an outside tank. A 5-min warm-up period is provided before first run data collection. The gap of 3 to 4 minutes was provided between the two consecutive runs. Engine speed, brake

power, torque, and fuel consumption, BSFC, heat balance were measured during each run.

During the test load on the engine was varied from 0 to 12 kg by adjusting the load knob provided on the control panel of the test rig. The tests were performed with pure diesel fuel and WCOME blends (B-10, B-20,B-30).

4.4.1 Formula used:

Torque (kg m) = Load × Arm length

Brake power (kW) = (2 × π × Speed × Torque × 9.81) / (60 × 1000)

$$\text{Brake Thermal Efficiency (\%)} = \frac{\text{Brake power} \times 3600 \times 100}{\text{fuel fow } \frac{kg}{hr} \times \text{calorific value } (\frac{kJ}{kg})}$$

$$\text{Specific fuel consumption} \left(\frac{Kg}{kwh}\right) = \frac{\text{Fuel flow } \frac{kg}{hr}}{\text{Brake power (kW)}}$$

$$\text{Specific energy consumption(MJ/kW} - \text{hr)} = \frac{\text{BSFC} \times \text{Calorific value}}{1000}$$

$$\text{Mechanical Efficiency (\%)} = \frac{\text{Brake power (kW)} \times 100}{\text{Indicated power (kW)}}$$

Heat supplied by fuel (kJ/h) = fuel flow (kg/h) × Calorific value (kJ/kg)

Heat equivalent to useful work (kJ/h) = Break power (kW) × 3600

$$\text{Heat brake power (\%)} = \frac{\text{Heat equivalent to useful work} \times 100}{\text{heat supplied by fuel}}$$

4.4.2 Experimental Data:

➤ **Pure diesel:**

Engine performance parameters obtained from performance testing in single cylinder CI engine against different loads for pure diesel are given below in Table.17.

Table.17: Performance parameters for pure diesel Vs brake power

SPEED (rpm)	TORQUE (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kWh)	BSEC (MJ/kWh)	Exhaust gas temperature(^{0}C)
1567	3.18	0.68	2.01	2.69	11.85	59.16	25.27	0.81	34.83	120.56
1537	9.28	1.67	1.79	3.46	24.62	56.04	48.23	0.42	18.06	155.35
1520	15.21	2.62	1.66	4.28	31.67	54.96	61.21	0.29	12.47	210.21
1499	22.06	3.70	1.44	5.14	34.87	52.37	68.44	0.28	12.04	265.04
1435	28.41	4.69	1.36	6.02	36.9	51.10	71.90	0.26	11.98	315.75

➤ **B-10 WCOME blend:**

Engine performance parameters obtained from performance testing in single cylinder CI engine against different loads for B-10 WCOME blend are given in Table.18.

Table.18: Performance parameters for B-10 WCOME Vs brake power

SPEED (rpm)	TORQUE (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kWh)	BSEC (MJ/kWh)	Exhaust gas temperature(^{0}C)
1563	3.03	0.67	2.38	3.05	15.48	53.42	21.90	0.83	35.32	139.12
1539	9.32	1.68	2.21	3.89	26.38	50.19	43.60	0.43	18.30	179.65
1512	15.79	2.72	2.02	4.74	32.53	47.54	57.73	0.31	13.19	227.11
1495	22.13	3.72	1.49	5.21	36.17	46.31	71.41	0.29	12.34	275.04
1455	29.65	4.71	1.07	5.78	37.65	44.91	81.63	0.28	11.91	329.31

> **B-20 blend:**

Engine performance parameters obtained from performance testing in single cylinder CI engine against different loads for B-20 WCOME blend are given below in Table.19.

Table.19: Performance parameters for B-20 WCOME Vs brake power

SPEED (rpm)	TORQUE (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kWh)	BSEC (MJ/kWh)	Exhaust gas temperature(^{0}C)
1578	4.38	0.71	1.38	2.39	16.14	47.19	28.40	0.85	35.79	164.85
1512	10.21	1.73	1.20	2.93	27.69	46.47	59.04	0.44	18.53	187.75
1490	17.96	2.67	0.36	3.00	34.73	47.89	89.34	0.33	13.89	235.05
1473	23.30	3.69	1.16	4.85	38.98	46.63	76.04	0.30	12.633	286.47
1457	30.60	4.67	0.53	5.20	38.15	44.87	89.65	0.29	12.211	334.54

> **B-30 blend:**

Engine performance parameters obtained from performance testing in single cylinder CI engine against different loads for B-30 WCOME blend are given below in Table.20.

Table.20: Performance parameters for B-30 WCOME Vs brake power

SPEED (rpm)	TORQUE (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kWh)	BSEC (MJ/kWh)	Exhaust gas temperature(^{0}C)
1580	4.10	0.68	1.42	2.10	15.12	46.78	32.38	0.89	37.08	170.74
1515	10.73	1.70	1.38	3.08	26.50	46.66	55.54	0.46	19.16	191.91
1492	17.11	2.66	1.24	3.9	33.76	46.98	68.19	0.34	14.16	238.58
1474	23.89	3.69	1.19	4.88	38.15	46.38	76.80	0.33	13.74	285.45
1457	30.80	4.67	1.14	5.81	39.05	44.64	80.30	0.31	12.91	336.30

4.4.3 Result and discussion:

➢ **Brake Thermal Efficiency Vs brake power for diesel and WCOME blends:**

It is observed that BTHE for pure diesel and WCOME increases with increase in load. It is also observed that Brake thermal efficiency increases with increase in percentage of biodiesel in the blend from B0(pure diesel) to B20. BTHE observed is max for B20 blend. The reason for increase in BTHE is the presence of more oxygen in Biodiesel blend as compared to pure diesel. With further increase in percentage of biodiesel in the blend a slight decrease in BTHE is seen. The reason for the decrease in BTHE may be due to less volatility of biodiesel as compared to pure diesel.

The maximum value of BTHE is 39.03% at a brake power of 4.7 kW observed for B30 blend. The value of BTHE for pure diesel at the same condition is 36.90 %.At minimum load value of BTHE is minimum (11.82%) for pure diesel and maximum (16.14%) for B20 blend is seen. Variation of BTHE Vs BP is shown in Fig.33.
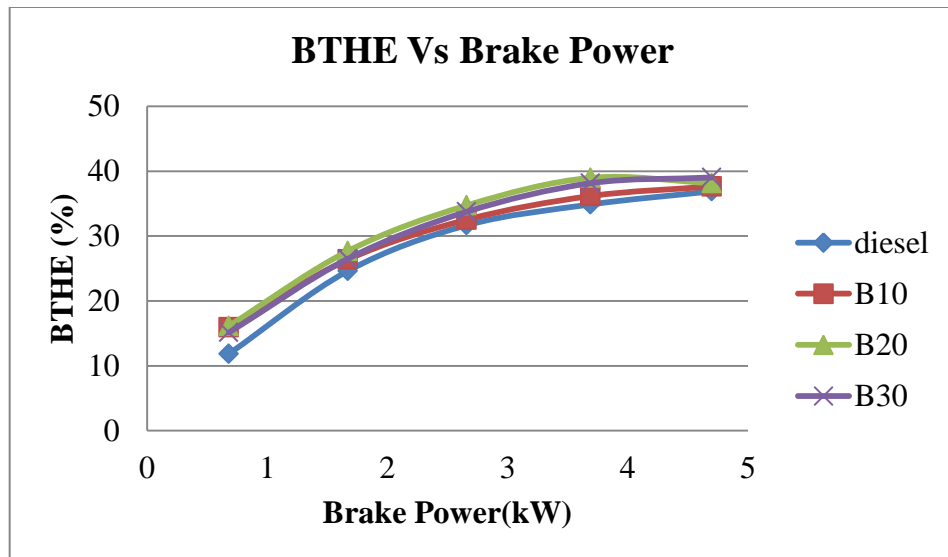

Fig.33. Brake thermal efficiency Vs Brake Power for diesel and WCOME blends

- **Exhaust Gas Temperature Vs brake power for diesel and WCOME blends:**

It is observed that exhaust gas temperature for pure diesel and various WCOME blends increases with increase in load on the engine. It is also observed that exhaust gas temperature increases with increase in biodiesel percentage in the blend. This is due to more oxygen content in biodiesel and more efficient burning of fuel. The reason for rise in the exhaust gas temperature may be due to larger ignition delay and increased quantity of fuel injected. The exhaust gas temperature can be reduced by adjusting the injection timing/injection pressure in to the diesel engine.

Exhaust gas temperature is max for 336.43 ^{0}C at 4.7 kW brake power for B30 fuel which is 6.5 % higher than that of pure diesel at the same conditions. For minimum load (i.e. 0.68 kW brake power) exhaust gas temperature for B30 blend is 170.74 ^{o}C which is 41.6 % higher than that of diesel for the same conditions .Variation of exhaust gas temperature with brake power for pure diesel and various WCOME blends is shown in Fig.34.
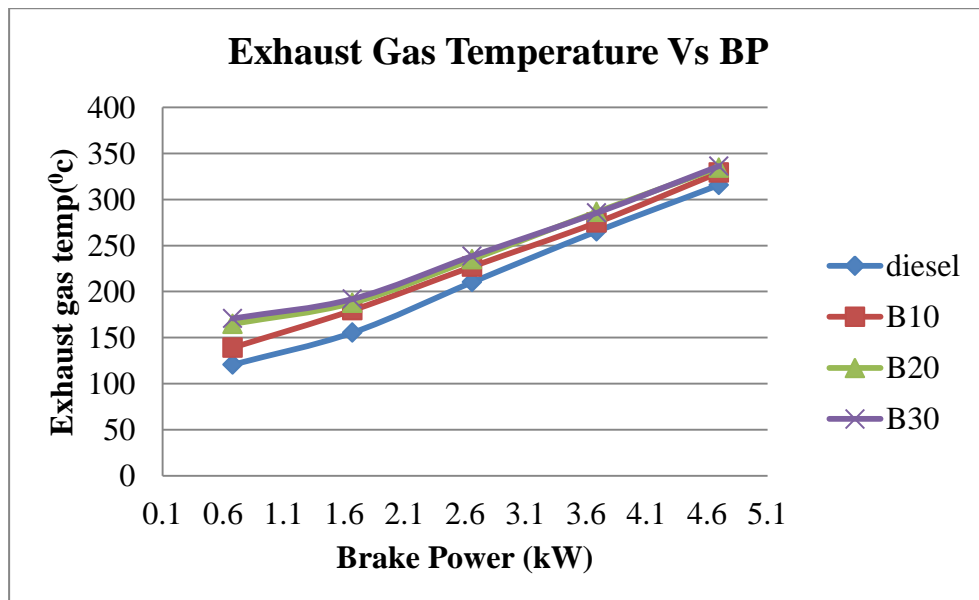

Fig.34. Exhaust Gas TemperatureVs Brake Power for diesel and WCOME blends

- **Brake Specific Fuel Consumption Vs brake power for diesel and WCOME blends:**

It is observed that Brake specific fuel consumption decreases with increase in load on the engine for pure diesel and WCOME blended fuel. As the total fuel consumption increases with increase in biodiesel percentage in the blend because more fuel has to be inducted due to lower calorific value of biodiesel as compared to that of pure diesel. Thus BSFC increases with increase in biodiesel percentage in the blend.

The brake specific fuel consumption for B10, B20, B30 at maximum brake power (i.e. 4.68 kW) is 0.28, 0.29 and 0.31(in kg/kW-h)respectively ,which are slightly higher than the pure diesel's value 0.26 kg/kW-h. At minimum load condition BSFC for B10, B20, B30 is 0.83, 0.85 and 0.89 (in kg/kW-h) respectively, which are slightly higher than that of pure diesel value 0.81 kg/kW-h.A variation of Brake specific fuel consumption Vs brake power is shown in Fig.35for pure diesel and various WCOME blends.
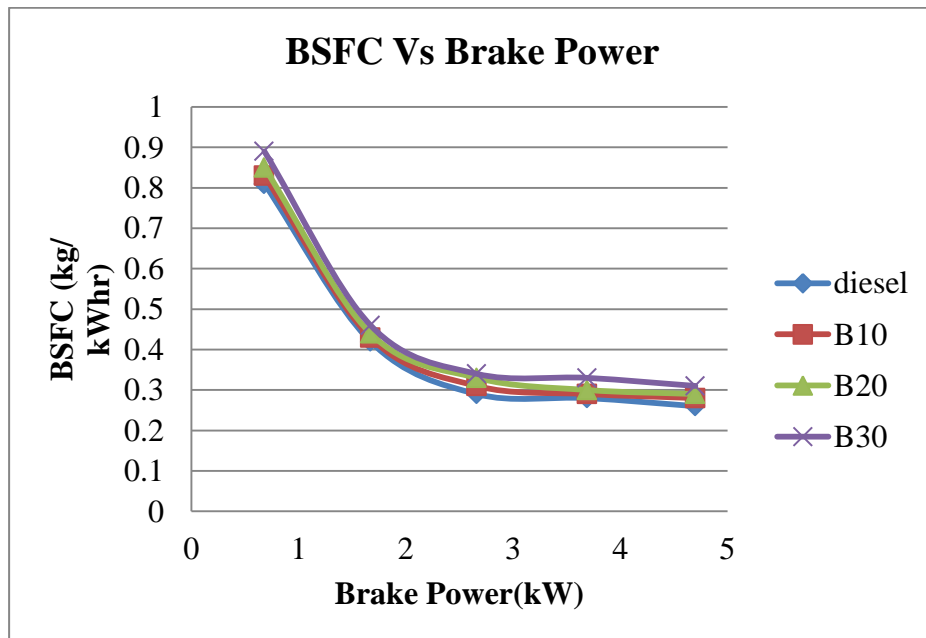

Fig.35. Brake Specific Fuel Consumption Vs Brake Power for diesel and WCOME blend

➢ Brake Specific Energy Consumption Vs brake power for diesel and WCOME blends:

The trend for the brake specific energy consumption is same as that of brake specific fuel consumption. Brake Specific Energy consumption decreases with increase in load on the engine. It is also observed that Brake specific energy consumption increases with increase in biodiesel percentage in the blend.

The brake specific energy consumption for B10, B20, B30 blends of bio-diesel at maximum brake power 4.67kW is 11.91, 12.21, 12.91in MJ/kW-h respectively, which are slightly higher than the pure diesel value of 11.92 kg/kW-h. At minimum load condition (i.e. at 0.67 kW brake power) , BSEC for B10 , B20 , B30 blends of WCOME is 35.32, 35.79, 37.08in MJ/kW-h respectively , which are slightly higher than the pure diesel value of 34.83 kg/kW-h. Variation of Brake Specific Energy consumption w.r.t brake power is shown in Fig.36 for diesel and various WCOME blends.
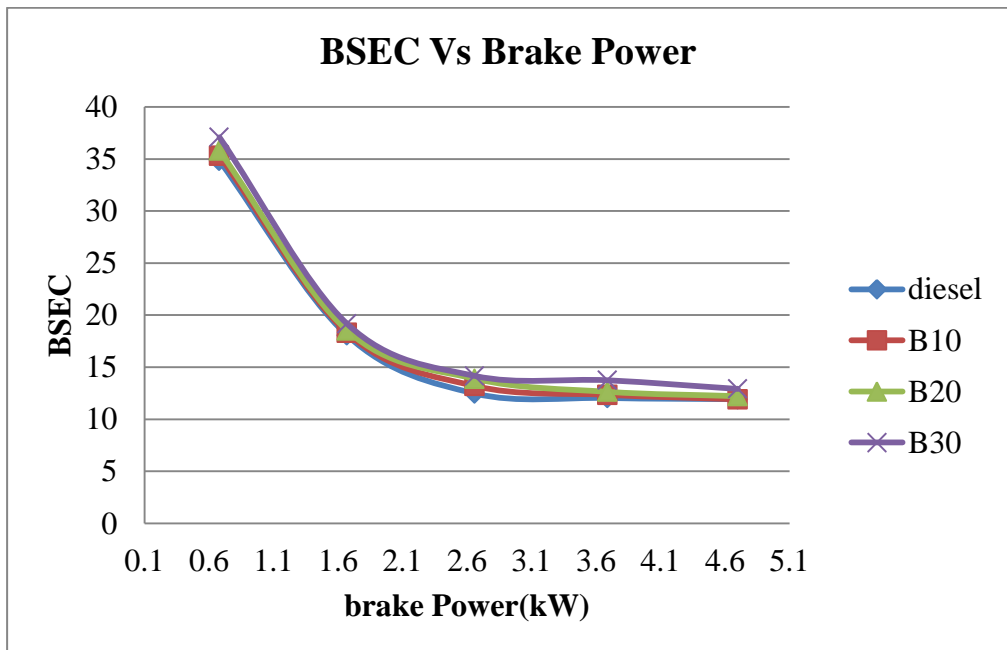

Fig.36. Brake Specific Energy Consumption Vs Brake Power for diesel and WCOME blend

4.5 Emission analysis:

4.5.1 Experimental Data:

➤ **Emission analysis for pure diesel:**

Engine emission parameters obtained from emission testing in single cylinder, four-stroke, CI engine against different loads for pure diesel are given in Table.21.

Table.21: Emission parameters Vs Brake Power for pure diesel

BP(kW)	CO (%vol)	CO_2 (%vol)	HC (ppm)	NO(ppm)	Opacity (%)
0.68	0.049	1.6	27	115	8.2
1.67	0.045	2.7	29	300	19.1
2.62	0.04	3.8	34	430	31.2
3.70	0.033	4.2	36	630	50.6
4.69	0.03	4.4	36	920	54.6

➤ **Emission analysis for B10 blend:**

Engine emission parameters obtained from emission testing in single cylinder, four stroke, CI engine against different loads for B-10 WCOME blend are given in Table.22.

Table.22: Emission parameters Vs Brake Power for B10 WCOME blend

BP (kW)	CO (%vol)	CO_2 (%vol)	HC (ppm)	NO (ppm)	Opacity (%)
0.67	0.045	1.80	25	125	5.6
1.68	0.04	3.00	26	322	11.1
2.72	0.04	4.00	30	517	25.4
3.72	0.03	4.70	32	812	38.5
4.71	029	5.40	33	1004	42.9

> **Emission analysis for B20 blend:**

Engine emission parameters obtained from emission testing in single cylinder, four stroke, CI engine against different loads for B-20 WCOME blend are given in Table.23.

Table.23: Emission parameters Vs Brake Power for B20 WCOME blend

BP (kW)	CO(% vol)	CO_2(% vol)	HC (ppm)	NO (ppm)	Opacity (%)
0.68	0.036	2.20	23	182	3.1
1.70	0.032	3.10	24	352	8.3
2.66	0.031	4.2	27	598	16.5
3.69	0.029	5.6	30	934	21.5
4.67	0.27	7.0	31	1306	24.5

> **Emission analysis for B30 blend:**

Engine emission parameters obtained from emission testing in single cylinder, four stroke, CI engine against different loads for B-30 WCOME blend are given in Table.24.

Table.24: Emission parameters Vs Brake Power for B30 WCOME blend

BP (kW)	CO (% vol)	CO_2(% vol)	HC(in % vol)	NO (% vol)	Opacity (%)
0.68	0.035	2.30	23	225	2.90
1.70	0.033	3.45	22	525	7.65
2.66	0.030	4.30	27	645	14.25
3.69	0.029	5.90	28	1190	17.5
4.67	0.25	7.20	30	1525	21.25

4.5.2 Result and discussion:

➢ **CO Vs brake power for diesel and WCOME blends:**

Carbon mono oxide is one of the intermediate products formed during the combustion of hydrocarbons in the cylinder. It is observed that amount of CO produced decreases with increase in load on the engine for pure diesel and various blends of WCOME, but at higher loads there is a steep increase in CO emission is observed. This may be due to less available time and lower A/F ratio (Richer mixture) for combustion of fuel at higher loads. It is also observed that amount of CO produced decreases with increase in percentage of biodiesel in the blend. The reason for this is oxygen content in the biodiesel which allows more carbon molecules to oxidize when a comparison is made to that of pure diesel.

It is revealed from the experiments that CO concentrations for B10 , B20 , B30 blends of biodiesel at maximum load condition is 3.33% , 10.00% , 16.6% lesser than that of pure diesel. For minimum load condition, CO concentrations for B10, B20, B30 blends of biodiesel at is 8.16%, 26.5%, 28.5% lesser than that of pure diesel. The variation of CO emission with BP for pure diesel and various WCOME blends is shown in Fig.37.
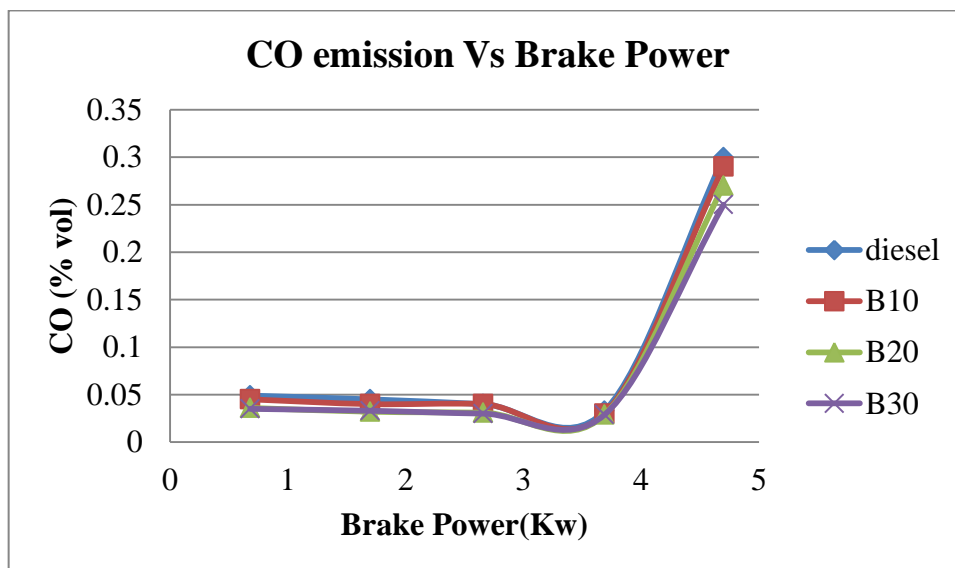

Fig.37. CO emissions Vs Brake Power for diesel and WCOME blends

> **HC Vs brake power for diesel and WCOME blends:**

It is observed that HC emission increases as the load of the engine was increased for diesel and blends of WCOME. The reason for this is increase in fuel consumption at high engine loads.

It is also observed that HC emission decreases with increase in percentage of biodiesel in the blend. The reason for this is availability of more oxygen due to presence of biodiesel. WCO biodiesel involves high oxygen content, which leads to more complete combustion and less HC emission.

It is revealed from the experiments that HC concentrations for B10 , B20 and B30 blends of biodiesel at maximum load condition is 8.33 % , 13.80% , 16.66% lesser than that of pure diesel. For minimum load condition, HC concentrations for B10, B20 , B30 blends of biodiesel is 7.40% , 14.81% , 18.51% lesser than that of pure diesel. The variation of HC emission with brake power for pure diesel and various WCOME blends is shown in Fig.38.
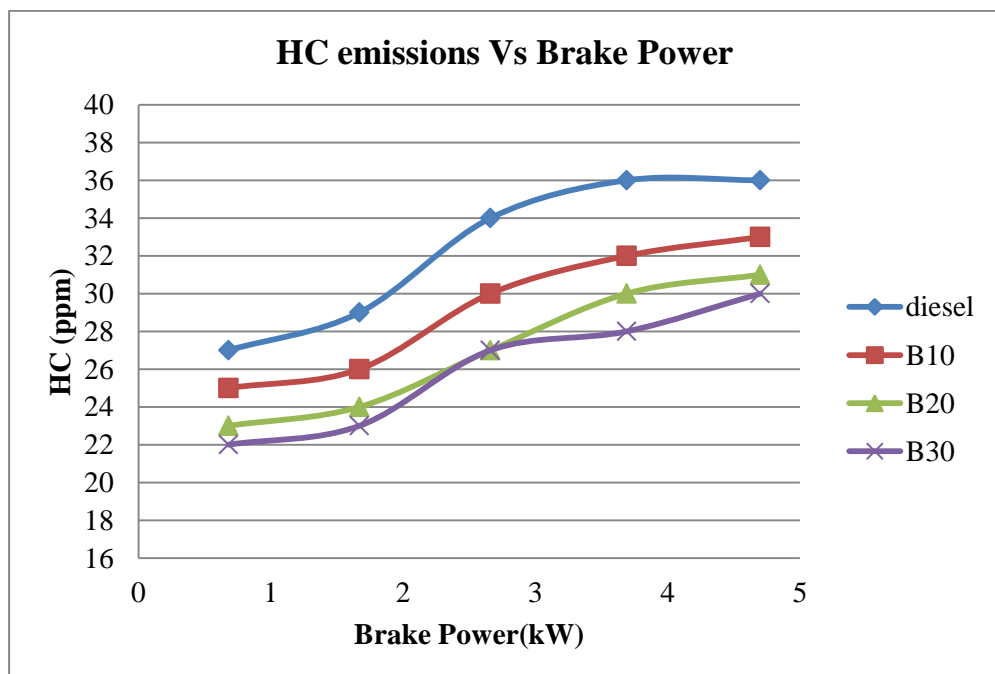

Fig.38. HC emissions Vs Brake Power for diesel and WCOME blends

➢ **NO$_x$Vs brake power for diesel and WCOME blends:**

The formation of oxides of nitrogen in the cylinder is affected by oxygen content, and combustion temperature. It is observed that NO$_x$ emission increases with increase in load on the engine. It is also observed that NO$_x$ formation for biodiesel blends is slightly higher than that of diesel fuel. This is due to the presence of oxygen in biodiesel which results in better combustion and causes higher temperature leading to higher NOx emission.

The NO$_x$ emission for B10, B20, B30 blends of bio-diesel at maximum brake power 4.67kW is 125, 182and 225 in ppm respectively, which are slightly higher than the pure diesel value of 115 ppm. At minimum load condition (i.e. at 0.67 kW brake power) , NO$_x$ for B10 , B20 , B30 blends of WCOME is 1004, 1306, 1525 in ppm respectively , which are slightly higher than the pure diesel value of 920 ppm. Variation of NO$_x$ emission with brake power is shown in Fig.39 for diesel and various WCOME blends.
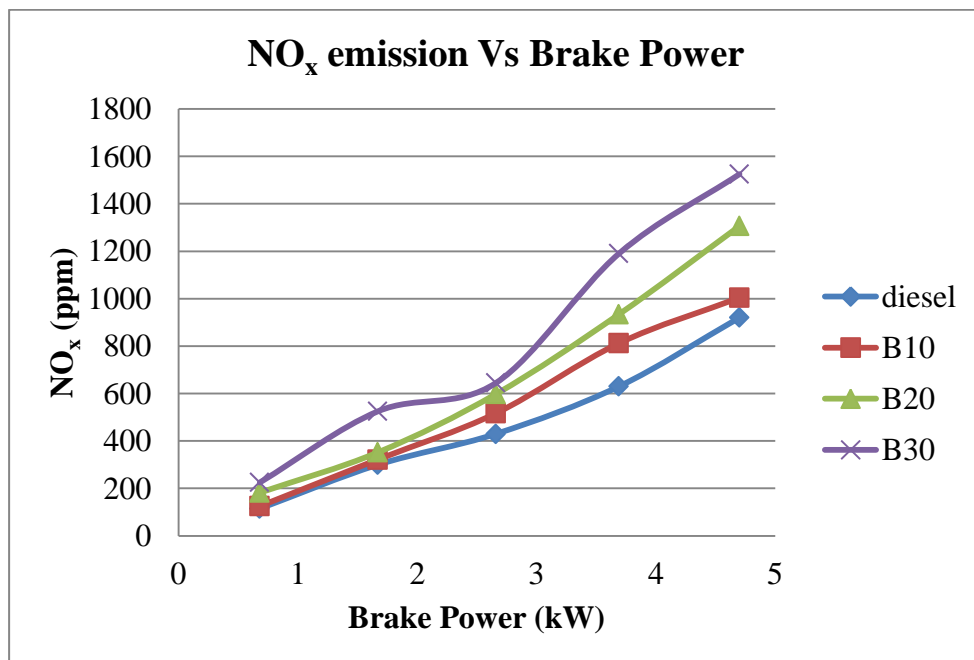

Fig.39.NO$_x$ emission Vs Brake Power for diesel and WCOME blends

➢ **Smoke Opacity Vs brake power for diesel and WCOME blends:**

It is observed that Opacity increases with increase in load on the engine.It is also observed that Opacity decreases with increase in biodiesel content in the blend.

At maximum load, the maximum value of opacity observed is for pure diesel (54.6 %) and minimum value of opacity observed is for B30 WCOME blend (21.25%). At minimum load the maximum value of opacity observed is for pure diesel (8.2 %) and minimum value of opacity is observed for B30 WCOME blend (2.9%).

The main reason for decrease in smoke with increase in bio-diesel percentage is that biodiesel is a sulphur free fuel. $SO_2$is the major source for smoke formation. With the use biodiesel in the blend sulphur content decreases, hence smoke formation also decreases.Variation of Smoke Opacity with brake power is shown in Fig.42 for diesel and various WCOME blends.
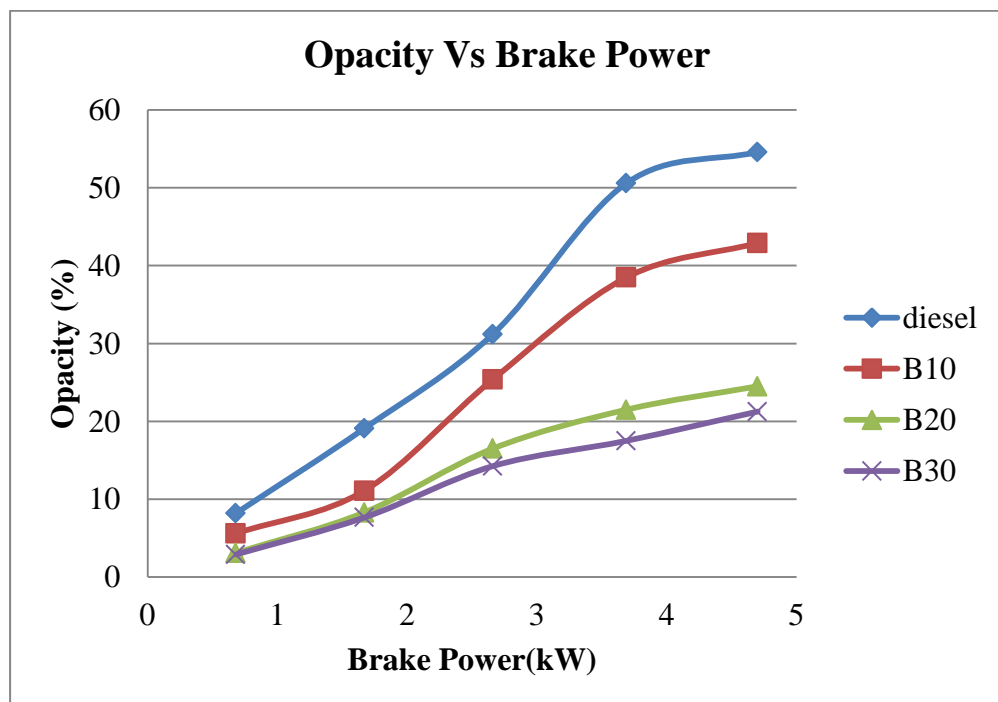

Fig.40. Opacity Vs Brake Power for diesel and WCOME blends

CHAPTER-5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion:

(A) Biodiesel Production Techniques:

Following conclusion has been made from the experiments:

1. The yield obtained was maximum for the hydrodynamic cavitation method for a fixed value of reaction time, molar ratio and catalyst percentage.

2. Slightly more yield is obtained by US technique as compare to MS method of biodiesel production.

3. The experimental results shows that by taking catalyst 0.5%, 0.75% and 1% of oil through the US and HC is 0.5% catalyst is optimum catalyst to be used because catalyst is an impurity and its use should be low as much as possible.

4. Higher biodiesel productivity is obtained using molar ratio 6:1 in biodiesel production techniques (HC, US & MS) as compare to molar ratio 3:1 and 4.5:1.

5. Both hydrodynamic cavitation and ultrasonic cavitation methods are industrially viable at large scale.

(B) Performance and Engine Testing:

Following conclusion has been made from the experiments:

1. From the engine performance testing it can be concluded that the performance parameter and emission characteristics for Waste Cooking Oil biodiesel have better results than that of pure diesel.

2. The BTHE increases proportionally with increase in brake power for lower and medium loads. This variation is due to better combustion with WCOME blends as compared to pure diesel.

3. BSFC also decreases with increase in brake power. The BSFC for WCOME blends is slightly higher than that of pure diesel. BSEC also decreases with

increase in brake power. The BSEC for WCOME blends is slightly higher than that of pure diesel.

4. The BSEC curves obtained by B20, B40, B60, B80 and B100 are very similar to the pure diesel performed on the same engine.

5. The exhaust emissions from Waste Cooking Oil biodiesel are lower than with regular diesel fuel.

6. The smoke opacity for B10, B20 and B30 blends of biodiesel at maximum brake power 4.5 kW achieved is 42.9, 24.5 and 21.5 respectively which are significantly lower than the pure diesel's value 54.6.

Finally it can be concluded that Waste Cooking Oil biodiesel is an industrially viable substitute for petrol-diesel engine and both hydrodynamic cavitation and ultrasonic cavitation are industrial viable methods.

5.2 Future Scope & Recommendations:

1. In production, effect of multi hole plate on yield of biodiesel is to be investigated by using hydrodynamic cavitation method.

2. For long term use of biodiesel in an engine, high maintenance required is need to be investigated.

3. Viscosity for biodiesel is an issue which affects the performance, while using in a diesel based engine and can be reduced by increasing the injector pressure.

4. To reduce the viscosity of biodiesel preheated biodiesel can also be used for a diesel based engine, for which preheated system needed to be designed.

5. As the biodiesel fuel has excellent lubricating property, so either some modification is required in the fuel injector of the engine or some additive should be searched to make it easily viable for a diesel based engine.

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