

BIODIESEL PRODUCTION THROUGH ULTRASONIC CAVITATION PROCESS AND PERFORMANCE TESTING

A Major thesis submitted

In partial fulfillment of the requirements for the award of the degree of

Master of Engineering

In

Thermal Engineering

By

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Session 2007-09

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This is certified that the work contained in this dissertation entitled “**BIODIESEL PRODUCTION THROUGH ULTRASONIC CAVITATION PROCESS AND PERFORMANCE TESTING**” by ABHISHEK SINGH is the requirement for the partial fulfillment for the award of degree of Master of Engineering in thermal engineering at Delhi College of Engineering. This work was completed under our direct supervision and guidance. He has completed his work with utmost sincerity and diligence.

The work embodied in this major project has not been submitted for the award of any other degree to the best of our knowledge.

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STUDENT DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled “**BIODIESEL PRODUCTION THROUGH ULTRASONIC CAVITATION PROCESS AND PERFORMANCE TESTING**”, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Thermal Engineering, submitted in the Department of Mechanical Engineering, Delhi College of Engineering. This is an authentic record of my own work carried under the supervision of **Dr. S.S. Kachhwaha, Asst. Professor and Mr. Amit Pal, Sr. Lecturer** of Mechanical Engineering Department, Delhi College of Engineering, Delhi.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

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ABSTRACT

Fuel crisis because of dramatic increase in vehicular population and environmental concerns have renewed interest of scientific community to look for alternative fuels of bio-origin such as vegetable oils. In this project biodiesel has been produced through various methods and its performance testing is done in C.I. engine. For this project biodiesel sample has been prepared by ultrasonic cavitation, hydrodynamic cavitation and magnetic stirrer method and comparison has been made between ultrasonic cavitation and magnetic stirrer method. For this project biodiesel has been prepared by three different oils namely jatropha oil, thumba oil and waste cooking oil and comparison also has been made between different oils. The performances of this biodiesels have been checked by the performance parameters like torque, brake power, brake thermal efficiency and specific fuel consumption and emission characteristics by opacity. Performance testing has been performed in 4-stroke, 4-cylinder, water cooled Tata indica C.I. engine which is attached by eddy current dynamometer for loading purpose. Performance parameters has been obtained from the computer (software is "Enginesoft") which is incorporate with the engine panel box. The results obtained are in favor of biodiesel over diesel oil. More torque obtained at starting speed. Brake power and brake thermal efficiency has increased except at 2000 rpm and has a higher value at initial speed. Specific fuel consumption is reduced for higher load and for higher percentage of blends. Opacity is reduced for higher blends of biodiesel.

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1. INTRODUCTION

1.1 General

Today the world is facing two major challenges which include the energy (fuel) crisis and environment degradation. The costs of crude oil products depend on international markets and petroleum reserves are limited to nearly 40 years with current consumption rate. Many countries all over the world have been developing new crops since the mid-1970s in order to increase the biomass resource base for production of bio energy. India's economy has often been unsettled by its need to import about 70% of its petroleum demand from the highly unstable and volatile world oil market. India is projected to become the third largest consumer of transportation fuel in 2020, after the USA and China, with consumption growing at an annual rate of 6.8% [1]. In India 90% of imported oil is consumed for the transportation and energy generation and its economy are highly depending on the import of crude oil. Therefore role of bio fuel as a transportation fuel will play a very vital role.

The idea of using vegetable oil as a substitute for diesel fuel was demonstrated by the inventor of the diesel engine, Rudolph Diesel, around the year 1900, when vegetable oil was proposed as fuel for engines. The oil use as diesel fuel was limited due to its high viscosity (near 10 times of the gas oil). In order to adapt the fuel to the existing engines the properties of vegetable oil had to be modified. Various products derived from vegetable oils have been proposed as an alternative fuel for diesel engines [2].

ASTM International defines biodiesel as the "mono alkyl esters of long chain fatty acids derived from renewable lipid feedstocks, such as vegetable oils and animal fats, for use in compression ignition engines." In the 1980s and 1990s significant R&D was conducted to evaluate a variety of biodiesel blending stocks, develop emissions data, assess engine/vehicle performance, and develop cost-effective manufacturing processes.

The main commodity sources of biodiesel in India are non edible oils obtained from plant species such as *Jatropha*, *Pongamia pinnata* etc [3]. Biodiesel can be blended at any level with petroleum diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition engine; which essentially require very little or no engine modifications because biodiesel has properties similar to petroleum diesel fuels. It can be stored just like petroleum diesel fuel and hence does not require separate infrastructure. The use of biodiesel in conventional diesel engines results in

substantial reduction of un-burnt hydrocarbons (HC), carbon monoxide (CO) and particulate matters [4]. But uses of biodiesel slightly increase nitrogen oxide (NO_x) which can be reduced by incorporating EGR system. Biodiesel is considered as a clean fuel since it has almost no sulphur, no aromatics and has about 10% built in oxygen, which helps it to burn fully. Its higher cetane number improves the ignition quality even when blended in the petroleum diesel. Due to the fact that vegetable oils are produced from plants, their burning leads to a complete recyclable CO₂ (green house gas).

There are also some drawbacks in the bio diesel fuel as compared to petroleum fuels which includes high cost of biodiesel which is around 1.5 times to that of petroleum diesel, unavailability at large scale, and requirement of large area of land.

Now a day's various techniques have been developed for producing biodiesel. Some of them are mechanical stirring, ultrasonic cavitation, hydrodynamic cavitation and supercritical methanol.

Advantages of the bio-diesel over petroleum based diesel fuel are given below:

1. Biodiesel is a good lubricant about 66% better than petro diesel
2. Biodiesel produce less smoke and particulated matters as it is free of sulphur and aromatics.
3. Biodiesel have higher cetane number having good anti knocking property.
4. Produce lower carbon monoxide and hydrocarbon emissions.
5. Bio-diesel is renewable, biodegradable and non-toxic.

In comparison with petroleum-based diesel fuel, biodiesel is characterized by:

- Lower heating value (by about 10-12%)
- Higher cetane value (typically 45-60)
- About 11% oxygen content (petroleum-based diesel contains no oxygen)
- No aromatics contents (and no PAHs)
- No sulfur or extremely low sulfur content
- Better lubricity
- Higher viscosity
- Higher freezing temperature (higher cloud point and pour point)
- Higher flash point
- No toxicity or low toxicity
- Biodegradability

- Different corrosive properties

Some of the above properties, such as the high cetane value or good lubricity, are obvious advantages of biodiesel while others, including the lower heating value, high freezing point (and inferior flow properties at low temperature), or corrosion properties are its drawbacks. Biodiesel changes the character and can increase the intensity of the odour of diesel exhaust [5].

1.2 Indian scenario in biodiesel

The country's energy demand is expected to grow at an annual rate of 6.8 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. Past and projected increased demand is shown in Table 1.1. Domestic production of crude oil can only fulfil 25-30 per cent 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. Bio fuels offer an attractive alternative to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize the positive and minimize the negative aspects of bio fuels.

Table 1.1 Demand of energy for the consumption in India

Source	Units	1994-95	2001-02	2006-07	2011-12
Electricity	Billion units	289.36	480.08	712.67	1067.88
Coal	Million tonnes	76.67	109.01	134.99	173.47
Natural gas	Million cubic meters	9880	15730	18291	20853
Oil products	Million tonnes	63.55	99.89	139.95	196.47

Planning commission report, 2003

The government of India has formulated an ambitious National Biodiesel Mission to meet 20 per cent of the country’s diesel requirements by 2016-2017. Requirement of bio fuel for blending under different scenario are given in Table 1.2. A commercialization period during 2007-2012 will continue Jatropha cultivation and install more transesterification plants which will position India to meet 20 per cent of its diesel needs through biodiesel.

Table 1.2 Demand for diesel and biodiesel requirement

year	Diesel demand Mt	Biodiesel blending requirement (in metric ton)		
		@5%	@10%	@20%
2006-07	52.32	2.62	5.23	10.46
2011-12	66.91	3.35	6.69	13.38
2016-17	83.58	4.18	8.36	16.72

Planning commission report, 2003

The main problem in getting the biodiesel programme rolling has been the difficulty in initiating the large-scale cultivation of *Jatropha* because farmers do not consider *Jatropha* cultivation rewarding enough. Therefore government needs to sponsor confidence-building measures such as establishing a minimum support price for *Jatropha* oilseeds and assuring farmers of timely payments. The plantations under this mission will be established by NGOs, public and private sectors. The Ministry of Forests and Environment (MoEF) and the National Oilseed and Vegetable Oil Development (NOVOD) Board will serve as responsible agencies for the cultivation in the forest and non-forest areas, respectively by providing the necessary information and financial assistance.

In India, there are about 100 varieties of oil seeds but only 10-12 varieties have been tapped so far, amongst which *Jatropha* and *Pongamia* are the key wild plant species identified as the potential feedstock for biodiesel production. Their cultivability in wasteland and relatively adverse climatic conditions are the key attribute for their promotion as a feedstock material. According to the Economic Survey of Government of India, out of the total cultivated land area, about 175 million hectares of land is classified as waste and degraded land. It is perceived at various levels of government that encouraging sustainable cultivation of *Pongamia* and *Jatropha* trees on these lands can meet part of the country's energy requirements. With this background, the Planning Commission of India, along with the Ministries of Petroleum, Rural Development, Poverty Alleviation and Environment, has conceptualized a national mission that recommends a major multi-dimensional program to commercialize the biodiesel industry in India. One prime objective is the progressive replacement of petro-diesel by blending in 5%, 10%, and, eventually, 20% of biodiesel.

There are many key challenges and market barriers for biodiesel promotion in India. Information regarding the agro economic practices are limited, which often discourages the risk-averse small and marginal farmers from growing non-edible oil seeds. Still there is uncertainty about the potential yields and reliability of seeds. Further cultivation of such crops having relatively longer gestation period such as Jatropha (3 years) & Pongamia (5 Years). At present the country is relying on imported technology, which is extremely expensive and is also proven for edible oil as feedstock. There are risks associated with the technology for its costs and compatibility. Though indigenous technologies are available at low costs and in smaller plant sizes with lower levels of performance regarding conversion of oil to diesel. Finance of biodiesel projects are a major constraint but few venture capital firms and banking institutions are coming forward to finance biodiesel-manufacturing plants. The production costs of bio-diesel are currently higher than conventional fuels, so it will be very difficult to gain market share without Government intervention in terms of favourable duty and taxation levels. At present wide and uncertain price band ranging from Rs 17-45 per litre of biodiesel discourage the seller & distributor to set up separate distribution channels. Lack of mandate to blend biodiesel at certain % of fossil diesel does not encourage oil-marketing firms to get sufficiently encouraged for involving in its promotion. Furthermore, lack of adequate consumer awareness regarding its reliability and performance also discourages the end users to use it in their vehicles voluntarily.

1.3 Resources of Biodiesel

Many developed countries have active biodiesel programs. Currently biodiesel is produced mainly from field crop oil like rapeseed, sunflower etc. in Europe and soybean in US. Malaysia utilizes palm oil for biodiesel production while in Nicaragua it is jatropha oil.

The productions of vegetable oil globally and in India are given in Table 1.3. There are many countries which have large amount of bio-diesel potential. And if this potential is used for the production of biodiesel than the crisis of petroleum based diesel and fossil fuel can be solved. The global warming problem can also be solved because biodiesel is bio- fuel and it has no harmful emission in diesel engine. In Table 1.4 top 10 countries biodiesel potential (Liter) and there production cost (\$/Liter) is given.

Table 1.3 Global productions of the major vegetable oils [6]

Oil	Production (million tons)	Oil	Production (million tons)	Oil	Production (million tons)
Soybean	27.8	Palm kernel	2.9	Sesame	0.26
Rapeseed	13.7	Olive	2.7	Castor	0.25
Cottonseed	4.0	Corn	2.0	Niger	0.03
Sunflower	8.2	Castor	0.5	Coconut	0.55
Peanut	5.1	Groundnut	1.40	Rice Bran	0.55
Coconut	3.5	Soya	0.82	Linseeds	0.1
Linseeds	0.6	Mustard	1.55	Cottonseed	0.44
Palm	23.4	Sunflower	0.3		
Total	86.3	Total	12.17	Total	2.18

Table 1.4: Top 10 countries in terms of biodiesel potential [7]

Rank	country	Volume potential (Liter)	Production cost (\$/L)
1	Malaysia	14540,000,000	\$ 0.53
2	Indonesia	7595,000,000	\$ 0.49
3	Argentina	5255,000,000	\$ 0.62
4	USA	3212,000,000	\$ 0.70
5	Brazil	2567,000,000	\$ 0.62
6	Netherlands	2496	\$ 0.75
7	Germany	2024	\$ 0.79
8	Philippines	1234	\$ 0.53
9	Belgium	1213	\$ 0.78
10	Spain	1073	\$ 1.71

1.4 Storage, Handling and Distribution

Biodiesel is significantly safer than diesel. The storage and handling procedures for petroleum diesel can also be used for biodiesel. The fuel is best stored in a dark, dry and clean environment, in storage tanks, preferably steel, aluminium, Teflon, fluorinated polyethylene or polypropylene. Materials which should be avoided include lead, copper,

brass, tin and zinc. Biodiesel has a flash point higher than diesel. Many diesel fuel suppliers recommend storing diesel for no more than three to six months unless using a stabilizing additive. The current industry recommendation is that biodiesel or biodiesel blends also be used within six months. A longer safe life is possible and storage enhancing additives can provide additional benefits. Acid numbers in biodiesel and biodiesel blends will become elevated if the fuel ages, or if it was not properly manufactured. Raised acid numbers have been associated with fuel system deposits and reduce the life of fuel pumps and filters. Pure biodiesel and biodiesel blends should be stored at temperatures higher than the pour point of the fuel. Biodiesel blends will not separate in the presence of water however it is recommended that good 'housekeeping' be maintained. This is in respect to tank and fuel maintenance, to ensure water in storage systems is monitored and minimised [8].

1.4.1 Additives for oxidative stability of biodiesel

Oxidative stability is a major industry issue for diesel and biodiesel fuels. Some biodiesels are more stable than others and some unstable biodiesel contain stability additives that perform very well. The tendency of a fuel to be unstable can be predicted by the Iodine number (ASTM D 1510) but the test method may not pick up the presence of stability additives. Iodine number actually measures the presence of C=C bonds that are prone to oxidation. The general rule of thumb is that instability increases by a factor of 1 for every C=C bond on the fatty acid chain; thus, 18:3 are three times more reactive than C18:0. Stability can be predicted from knowledge of the feedstock only if you know the proportion of C18:2 and C18:3 fatty acids present in the fuel and know whether or not the fuel has been treated for stability. High fractions of those two types of fatty acids can adversely affect fuel stability if additives are not used. Poor stability can lead to increasingly high acid numbers, increasing viscosity, and the formation of gums and sediments that can clog filters. Comparing the fuel's acid number and viscosity over time can provide some idea about whether or not the fuel is oxidizing, but you need to take a sample at the beginning when the fuel is fresh and then sample on a regular basis after that.

Long-term storage in the presence of diesel fuel, diesel additives, water, sediments, heat, and air has not been adequately documented in the field. Biodiesel and blends of biodiesel and diesel fuel should not be stored for longer than 6 months in either storage tanks or vehicles until better field data is available. If it becomes necessary to store biodiesel longer than 6 months, or the storage conditions are poor, use antioxidants. The common antioxidants that work with biodiesel are TBHQ (t-butyl hydroquinone), Tenox 21, and tocopherol (Vitamin E). Most of these are sold by food additive firms. Powdered antioxidants are

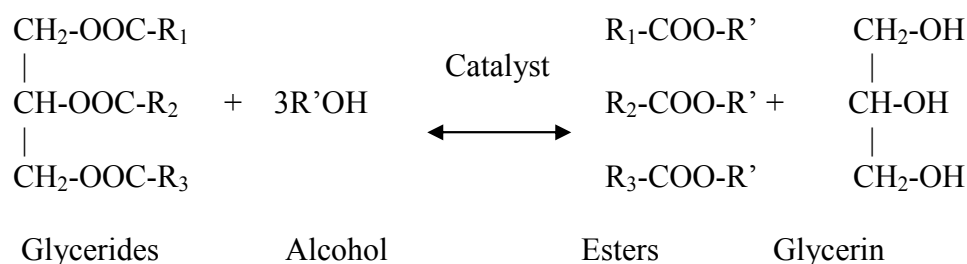
difficult to mix into biodiesel. A trick used is to heat a small amount of biodiesel (1 gal or so) up to 37.7 C or until all the powdered antioxidant is dissolved. Then mixed the treated biodiesel into the bulk biodiesel fuel [9].

1.4.2 Material compatibility

Brass, bronze, copper, lead, tin, and zinc will oxidize diesel and biodiesel fuels and create sediments. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change color and sediments may form, resulting in plugged fuel filters. Affected equipment should be replaced with stainless steel or aluminum. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. The effect of B20 on vulnerable materials is diluted compared to higher blends. Some slow oxidation can occur, although it may take longer to materialize. Biodiesel can also affect some seals, gaskets, and adhesives, particularly those made before 1993 made from natural or nitrile rubber. It is primarily for these reasons that vehicle and storage equipment are modified. Most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant. Earlier engine models or rebuilds may use older gasket and seal materials and present a risk of swelling, leaking, or failure. Fuel pumps may contain rubber valves that may fail. The typical approach is to create a maintenance schedule that checks for potential failures. Users can also contact engine manufacturers for more information [9].

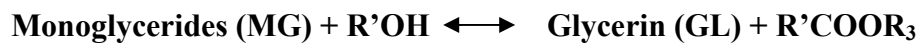
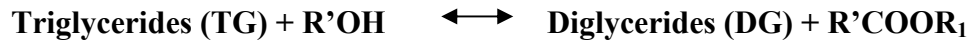
1.5 Chemistry of Biodiesel

Biodiesel is made using the process of transesterification. In the transesterification of different type of oils, triglycerides react with an alcohol, generally methanol or ethanol, to produce esters and glycerin. To make it possible, a catalyst is added to the reaction.



Where, term R represents to different alkyl groups.

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 stoichiometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product.



The catalyst used for the reaction is mainly of three types which is given below.

Alkali Catalyst

This catalyst can be used with methanol or ethanol as well as any kind of oils, refined, crude or frying. The main alkali catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH).

Acidic Catalyst

Acid transesterification is a great way to make biodiesel if the sample has relatively high free fatty acid content. The main acidic catalysts are Sulfuric acid (H₂SO₄) and Sulfonic acid.

Enzymes-catalyzed

Enzymes-catalyzed procedures, using lipase as catalyst, but the lipases are very expensive for industrial scale production and there are three-step process was required to achieve a 95% conversion. Due to this three step process the reaction time is too large.

1.6 Properties of Biodiesel

A general understanding of the various properties of biodiesel is essential to study their implications in engine use, storage, handling and safety [10].

Density/ Specific gravity

Biodiesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel). This allows use of splash blending by adding biodiesel on top of diesel fuel for making biodiesel blends.

Cetane Number

Biodiesels has higher cetane number than conventional diesel fuel. This result in higher combustion efficiency and smoother combustion.

Viscosity

In addition to lubrication of fuel injection system components, fuel viscosity controls the characteristics of the injection from the diesel injector (droplet size, spray characteristics etc.). The viscosity of methyl esters can go to very high levels and hence, it is important to control it within an acceptable level to avoid negative impact on fuel injection system performance. Therefore, the viscosity specifications proposed are same as that of the diesel fuel.

Flash point

Flash point of a fuel is defined as the temperature at which it will ignite when exposed to a flame or spark. The flash point of biodiesel is higher than the petroleum based diesel fuel. Flash point of biodiesel blends is dependent on the flash point of the base diesel fuel used, and increase with percentage of biodiesel in the blend. Thus in storage, biodiesel and its blends are safer than conventional diesel. The flash point of biodiesel is around 160 °C.

Cold filter plugging point (CFPP)

At low operating temperature fuel may thicken and not flow properly affecting the performance of fuel lines, fuel pump and injectors. Cold filter plugging point of biodiesel reflects its cold weather performance. It defines the fuels limit of filterability. Biodiesel thicken at low temperatures so need cold flow improver additives to have acceptable CFPP.

Cloud point

Cloud point is the temperature at which a cloud or haze of crystals appear in the fuel under test conditions and thus becomes important for low temperature operations. Biodiesel generally has higher cloud point than diesel fuels.

Aromatics

Biodiesel does not contain any aromatics so aromatic limit not specified.

Stability

Biodiesel age more quickly than fossil diesel fuel due to the chemical structure of fatty acids and methyl esters present in biodiesel. Typically there are up to 14 types of fatty acid methyl esters in the biodiesel. The individual proportion of presence of these esters in the fuel affects the final properties of biodiesel. Saturated fatty acid methyl esters (C14:0, C16:0, C16:0) increase cloud point, cetane number and improve stability whereas more polyunsaturates (C18:2, C18:3) reduce cloud point, cetane number and stability. There are three types of stability criteria namely Oxidation stability, Storage stability and Thermal stability

Iodine number

Iodine number refers to the amount of iodine required to convert unsaturated oil into saturated oil. It refers to the amount of unsaturated fatty acid in the fuel. One value of iodine number can be obtained by using several grades of unsaturated acids. Therefore an additional parameter, linolenic acid (C18: 3) content is specified and limited to 15% in Austrian Standard ON C 1191.

Acid number/ Neutralization number

Acid number reflects the presence of free fatty acids or acid used in manufacture of biodiesel. It also reflects the degradation of biodiesel due to thermal effect. The resultant high acid number can cause damage to injector and also result in deposit in fuel system and affect life of pumps and filters.

Some of the important properties of biodiesel proposed by BIS (Bureau of Indian standards) are given in Table 1.5.

Table 1.5 Summary of proposed BIS (Bureau of Indian Standards) standards for biodiesel [10]

Standard property	Unit	Proposed BIS specification
Density @ 15°C	g/cm ³	0.87 – 0.90
Viscosity @ 40°C	mm ² /s	3.5 - 5.0
Flash point	°C	>=100
Sulphur, max.	%mass	0.035
CCR,100%distilation residual max..	%mass	0.05
Sulphated ash,max,	%mass	0.02
Water.max	mg/kg	500
Total contamination, max.	mg/kg	20
Cetane no		>=51
Acid no	mg KOH/g	<=0.8
Methanol	%mass	<=0.02
Ester content	%mass	>=96.5
Diglyceride	%mass	<=0.2
Triglyceride	%mass	<=0.2
Free glycerol	%mass	<=0.02
Total glycerol	%mass	<=0.25
Iodine no		<=115
Phosphorus	ppm	<=10
Alkaline matter(Na,K)		<=10
Distillation, T 95%	°C	<=360

1.7 Motivation

The decrease of world petroleum reserves and high energy demand in the power industries and transport sector has necessitated the need for an alternative source of energy. Due to harmful emission and green house gas from fossil fuel, environment is continuously degrading .Therefore there is an also need of alternative fuel which improve the environmental condition. Biodiesel obtained from vegetable oil can be alternative source of

energy because its property is similar to petroleum derived diesel oil and produces favourable effects on the environment, such as a decrease in acid rain and greenhouse effect. Due to these factors, the use of biodiesel is considered an advantage to that of fossil fuels. Government of India has also setup national biodiesel mission to meet the aim of 20% blend of biodiesel with diesel by 2011-2012.

This work hoped a positive way towards security of energy in future. The aim of this project to search for optimum condition for biodiesel production and effective method of biodiesel production, then cheque performance in C.I Engine.

1.8 Organization of the report

First chapter is introduction which deals with the energy demand over world and need of renewable energy to secure the future demand of energy. This chapter comprises of various subheadings like general which is about biodiesel and its advantage over fossil fuel, Indian energy scenario which show the position of India on consumption of energy and contribution towards renewable energy source, resources of biodiesel which show existence of energy crops over the world, storage, handling and distribution of biodiesel and last one is biodiesel properties according to BIS standards.

Second chapter is literature review in which literatures available on biodiesel production and its performance testing are summarized.

Third chapter is biodiesel production methodology which deals with various techniques of biodiesel production and its feasibility. In this chapter conventional and supercritical methanol technology has discussed.

Fourth chapter is biodiesel production through cavitation technology which contents work performed in this project. This chapter contains biodiesel production through hydrodynamic and ultrasonic cavitation technology and difference analysis in terms reaction time required and yield obtained.

Fifth chapter is performance studies of biodiesel derived from jatropha, thumba and waste cooking oil. Performance parameters are torque, brake power, brake thermal efficiency, specific fuel consumption and opacity.

2. LITERATURE REVIEW

Chapter 2 deals with the biodiesel production techniques and performance studies available in the literature these are described below:

2.1 Biodiesel production techniques

In this topic literature belonging to biodiesel production is collected to review various techniques of biodiesel production. The literature contains biodiesel production through mechanical steering, supercritical methanol, hydrodynamic cavitation and ultrasonic cavitation. With these literatures it can be easily analyzed that which method is most suitable for the biodiesel production at optimum condition.

Demirbas [11], investigated the changes in yield percentage of methyl esters with supercritical methanol method with a molar ratio of 4:1. The critical temperature and the critical pressure of methanol were 512.4 K and 8.0 MPa, respectively. In that study, it was concluded that increasing reaction temperature, especially supercritical temperatures had a favourable influence on ester conversion.

The study by **Balat [12]**, investigated study the yields of ethyl esters from vegetable oils via transesterification in supercritical ethanol. Figure 2.1 Shows the changes in yield percentage of ethyl esters as treated with sub- and supercritical ethanol at different temperatures as a function of reaction time. The critical temperature and the critical pressure of ethanol were 516.2 K and 6.4 MPa, respectively.

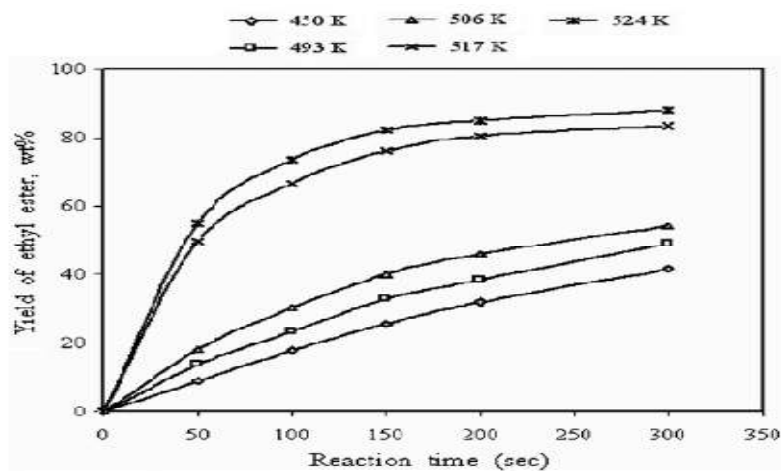


Figure 2.1: Change in yield percentage of ethyl ester with supercritical ethanol at different temperature as function of reaction time, molar ratio 1:40 [12]

Saka and Kusdiana [13], have developed a catalyst-free method for biodiesel production by employing supercritical methanol. The supercritical treatment at 350 °C, 43 MPa and 240 s with a molar ratio of 42 in methanol is the optimum condition for transesterification of rapeseed oil to bio-diesel fuel and it is found that more yielding from methyl ester at this optimum condition and the reaction time much less than any other process of bio-diesel production. The supercritical methanol biomass conversion system employed in this work is shown in Figure 2.2.

The 5 ml reaction vessel made of inconel-625 was used in this system in which pressure and temperature were monitored in real time covering up to 200 MPa and 550°C respectively. The reaction vessel is charged with given amount of rapeseed oil and liquid methanol with a molar ratio of 1: 42 the reaction vessel was then quickly immersed into the tin bath preheated at 350 °C and 400 °C, and kept for a set time interval for supercritical treatment of methanol, from 10 to 250 s and then moved to water bath to stop reaction. Treated oil was allowed to settle down for 30 min than three phases were visible. Top phase consisting of methanol was removed. And for remaining phase upper and lower evaporated at 90 °C for 20 min to remove remaining methanol. Result of this study is shown in the Table 2.1.

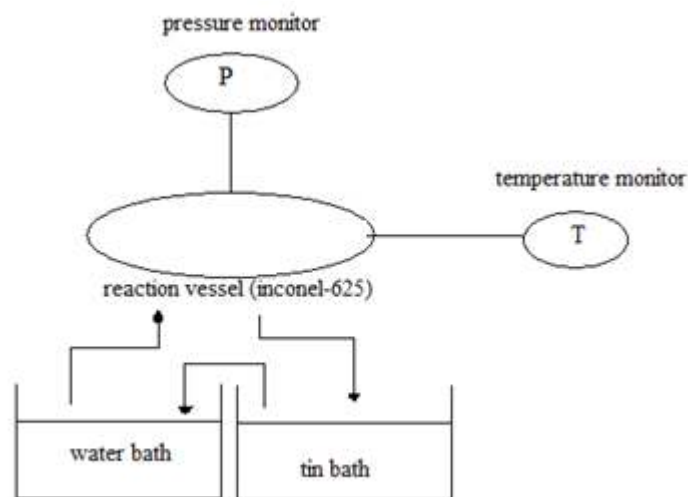


Figure 2.2: Supercritical methanol biomass conversion system [13]

Table 2.1 Comparison of yield in alkaline catalyzed, acid catalyzed and supercritical methanol[13]

Raw material	Free fatty acid (Wt %)	Water content (Wt %)	Yield of methyl esters (wt %)		
			Alkaline catalyst	Acid catalyst	Supercritical methanol
Rapeseed	2.0	.002	97	98.4	98.5
Palm	5.3	2.1	94.4	97.8	98.9
Frying	5.6	.2	94.1	97.8	96.9
Waste palm	>20.2	>61	-	-	95.8

Madras et al. [14], investigated the transesterification of sunflower oil in supercritical methanol and supercritical ethanol at various temperatures (200-400⁰C) at 200 bar. For reaction in supercritical methanol and ethanol, no catalyst is required and nearly complete conversion can achieve in very short time (2-4 min). This is because supercritical methanol and oil is in single phase. Synthesis of bio-diesel in supercritical methanol and ethanol were conducted in an 8 ml stainless steel reactor and the molar ratio is taken as 40:1. Initially maintained the desired reaction temperature (200-400⁰C) and pressure (200 bar). the reactor was put into furnace after predetermined reaction time reactor was quenched. Then the methanol or ethanol removed from reactor. The result of this investigation was in methanol, the conversion increased from 78% to 96% with increase in temperature. A similar trend was observed for conversion in ethanol but the conversion were higher, because the solubility parameter of ethanol is lower than that of methanol and closer to oil, the conversion are higher in ethanol compared to conversion obtained in methanol.

Han [15], in this study a co-solvent was added to reaction mixture in order to decrease the operating temperature, pressure and molar ratio of alcohol to oil. Supercritical CO₂ is good solvent for small and moderate organic molecule and it is low cost and facile material. Therefore CO₂ is used as a co-solvent for study. The experiment was performed in 250 ml cylindrical autoclave at maximum pressure and temperature was 100 MPa and 450⁰C respectively. It was observed in the study that with optimum reaction temperature 280 ⁰C, molar ratio 24 and CO₂ to methanol ratio of 0.1, a 98% yield of methyl ester (biodiesel) was observed in 10 min at reaction pressure of 14.3 MPa, which make the supercritical method viable for the industrial purpose. it is observed that supercritical methanol with co-solvent process is superior to the conventional supercritical methanol method. CO₂ is both add and remove from the mixture when reaction is completed. Compared to the conventional

processes less energy is required for process and reaction pressure is reduced which make process safer and less costly.

Ji et al. [6], performed experiments on Power Ultrasonic (PU) (19.7 kHz), Hydrodynamic Cavitation (HC), and Mechanical Stirring (MS). They use soybean oil as vegetable oil mixed with KOH for production of biodiesel. In Power Ultrasonic (PU) method the reactions were carried out in an ultrasonic reactor. The temperature of the reaction mixture was controlled by a water bath. Vegetable oil (100 g) was poured into the reactor at the beginning. The reaction started when a quantitative amount of methanol liquor dissolved in KOH was poured into the heated reactor.

Orthogonality experiments were designed with 4 factors and 3 levels, which are listed in Table 2.2.

Table 2.2 Orthogonality experiments design [6]

factor	A, Power (W)	B, molar ratio	C, pulse frequency	D, temperature (°C)
I	100	3:1	0.4	25
II	150	4.5:1	0.7	35
III	200	6:1	1.0	45

A hydrodynamic cavitation reactor was designed and developed as shown in Figure 2.3. The reactor consists of a reservoir or a collecting tank with (10 l) capacity that is connected to the multistage centrifugal pump and a motor. Motor is having electric power rating of 1.5 kW. The pipe connected to the discharge side of the pump branches into main and bypass lines. The main line has the facility to incorporate different orifice plates to generate cavitation of different intensities and characteristics. The main line and bypass lines have throttling valves and pressure gauges for the adjusting the pressure

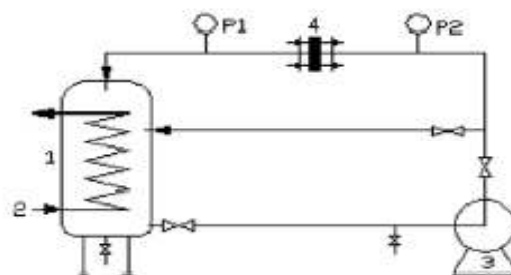


Figure2.3: Schematic diagram of hydrodynamic system setup where 1–tank; 2 – cold water; 3 –pump; 4 – orifice plate[6]

The result of PU and HC are found to be almost similar and are better than MS. Furthermore, scale-up of hydrodynamic cavitation to meet industrial-scale operations had better opportunities than the ultrasonic reactor by reason of its easier generating and less sensitivity to the geometric details of the reactor. The results of these two methods, together with mechanical stirring for improving the transesterification reaction, are presented in Figure 2.4.

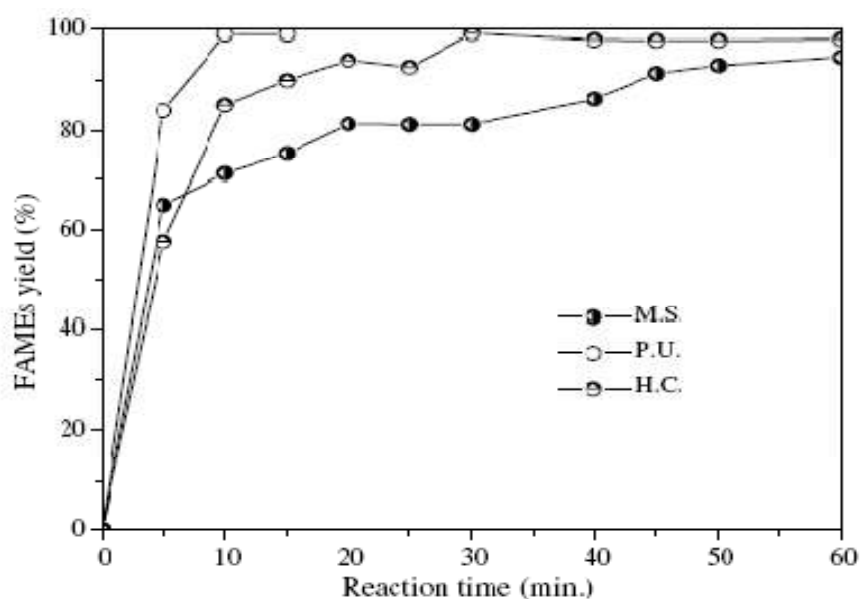


Figure 2.4: Effect of different methods on FAMES yields. [Reaction Conditions: substrate molar ratio 6:1; temperature 45 °C; KOH amount 1 wt. %; MS: speed 900 rpm; PU: frequency 19.7 kHz; power 150 W; HC: operation pressure 0.7 MPa; single orifice.][6]

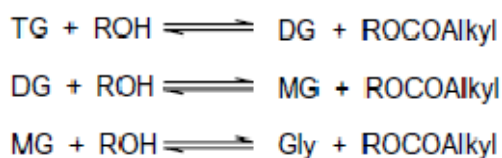
Table 2.3 Energy consumption for the transesterification of 1 Kg soybean oil by MS, PU and HC[6]

	MS	PU	HC
Energy consumption (Wh/kg)	500	250	183

The equilibrium reaction time was shortened in the order of PU, HC and MS. Power ultrasonic gave the shortest reaction time and the highest yield. Mechanical stirring offered the slowest reaction rate. PU and HC methods reduced the reaction equilibrium time to 10–30 min. The respective energy consumption of transesterification by MS, PU and HC was calculated according to 1 kg biodiesel formation regardless of heating. From Table 2.3, it can be seen that the PU and HC processes required approximately a half of the energy that was

consumed by the MS method. It is no doubt that PC and HC were efficient, concerning with time or energy.

Stavarache et al. [16], has studied low frequency ultrasound (40 kHz) with the aim of gaining more knowledge on intimate reaction mechanism with the KOH (potassium hydroxides). The concentration of fatty acid methyl esters, of mono-, di- and triglycerides of the actual reaction mixture were determined at short reaction time. For this study alcohol to oil ratio 6:1 is taken and catalyst as 1% of the oil is used. the reaction is performed in Honda Electronics Ultrasonic Cleaner WS 1200–40, with a total power of 1200W, working power being set at 70% and the temperature remain 38 °C during the whole experiment. Samples of about 150 mg were taken after 3, 6 and 10 min of reaction and each sample are analysed for the TG, DG and MG. reaction obtained are



Where TG= Tri Glycerides , DG= Di Glycerides , MG= Mono Glycerides

By this analysis it is found that the major part of the ultrasonically driven transesterification of vegetable oils under base catalysis took place in the first 3–10 min of reaction. Triglycerides were found in small amounts during the ultrasonically driven transesterification process, while monoglycerides were detected in high amount, indicating that the last step of transesterification is slower.

In this study of **Stavarache et al. [9]**, the transesterification of vegetable oil with short-chain alcohols, in the presence of base-catalyst, by means of low frequency ultrasound (28 and 40 kHz) in order to obtain biodiesel fuel were studied. In this paper comparative analysis have been done with mechanical stirring and ultrasonic cavitation method. The reaction mixtures consisted in vegetable oil, alcohol and alkaline catalyst. The molar ratio of alcohol to oil was 6:1, and the quantity of catalyst was 0.5%, 1.0% and 1.5% (wt/wt) to the oil respectively. Mechanical stirring is performed in Matsushita Electric Ind. Model SCV35W stirrer at 1800 rev/min. The ultrasonic reactions were performed using Honda Electronics Ultrasonic Cleaners WS1200-28 and WS1200-40, with a total power of 1200 W, working power being set

at 60%. Samples were taken at 10 min time intervals and analyzed by TLC to check the conversion to biodiesel. TLC was chosen as a rapid analytical method and it gives quite accurate indication of oil and biodiesel content in the mixture. It was concluded that by using ultrasounds

- The reaction time is much shorter (10–40 min) than for mechanical stirring.
- The quantity of required catalyst is 2 or 3 times lower.
- The molar ratio of alcohol/oil used is only 6:1.

Normal chain alcohols react fast, while secondary and tertiary alcohols show some or no conversion after 60 min of reaction. Surprisingly, 40 kHz ultrasounds are much more effective in the reduction of the reaction time (10–20 min). Twenty eight kilohertz give slightly better yields (98–99%), but longer reaction time, while higher frequencies are not useful at all for the transesterification of fatty acids .The yield % is given in the Table 2.4

Table 2.4 Yield% of methyl ester [17]

Method	0.5% (wt/wt) NaOH		1% (wt/wt) NaOH		1.5% (wt/wt) NaOH	
	TIME (MIN)	YIELD (%)	TIME (MIN)	YIELD (%)	TIME (MIN)	YIELD (%)
Mechanical stirring	60	88	10	91	10	35
UC Irradiation 28kHz	40	98	10	95	10	75
UC Irradiation 40kHz	20	98	10	91	10	68

Gogate and Pandit [17], also performed the similar type of experiment using 1.5 kW rating motor and 10 liter feed tank for the production of biodiesel using hydrodynamic and acoustic cavitation technology and some other methods. They use waste vegetable oils as against virgin vegetable oil for the synthesis with an aim to reduce cost of production, and used concentrated Sulphuric acid (H₂SO₄) as catalyst. For hydrodynamic cavitation reactor they use tank with 10 liter capacity that is connected to the multistage centrifugal pump with power rating of 1.5 kw. The sonochemical reactor used by Gogate and Pandit is a conventional cleaning tank type reactor (ultrasonic bath) equipped with three transducers at the bottom of the tank arranged in a triangular pitch and operates at an irradiating frequency of 20 kHz and power dissipation of 120 W (calorimetrically measured exact power

dissipation was 45 W indicating about 37.5% energy conversion and transfer efficiency; the transfer efficiency is usually dependent on the operating frequency, shape, size and the number of the transducers, location of the transducers, etc., which can be optimized to get maximum energy conversion). The bath had dimensions of 15 cm × 15 cm × 15 cm. The maximum volume of the reaction medium that could be used directly in the case of ultrasonic bath was 3500 ml. The operation time was distributed in cycles of 10 min on followed by 10 min off to allow for cooling of the reaction mass using an external heat exchanger. The temperature was maintained around 28 °C with accuracy of ±2 °C.

Gogate et al. [18], perform the similar experiment on hydrodynamic cavitation, ultrasonic cavitation and mechanical stirring technique for biodiesel production. The use sunflower oil as vegetable oil, methanol as alcohol. In acoustic cavitation, 4 ml of methanol is mixed with 4 g of vegetable oil and catalyst concentration (NaOH) used is 0.5% of oil. Ultrasonic bath is the sonochemical reactor with 20 kHz frequency and 85 W as power dissipation. Operation with hydrodynamic cavitation is under optimized conditions: 4 : 4 ratio (w/v) of oil to alcohol, catalyst concentration (NaOH) is 1% of oil. Orifice plate 1 has 16 holes with 2 mm diameter. Volume of methanol is 4000 ml, with 4000 g of oil. There operating pressure was 3 kg/cm². For conventional approach, 4 ml of methanol is mixed with 4 g of vegetable oil and catalyst concentration (NaOH) used is 0.5% of oil (Case I: a stirrer is used for uniform mixing which consumes energy. Case II: a heater is used for maintaining reflux conditions).

2.2 Performance studies

In this topic literature of performance study of biodiesel derived from various vegetable in diesel engine has been reviewed. In this literatures performance and emission of biodiesel is compared with diesel at various blend of biodiesel.

Hebbal et al. [19], have presented the investigation on deccan hemp, a non-edible vegetable oil in a diesel engine for its suitability as an alternate fuel. The performance and emission characteristics of blends are evaluated at variable loads of 0.37, 0.92, 1.48, 2.03, 2.58, 3.13 and 3.68 kW at a constant rated speed of 1500 rpm and results are compared with diesel. The thermal efficiency, brake specific fuel consumption (BSFC), and brake specific energy consumption (BSEC) are well comparable with diesel but the emissions were little higher for 25% and 50% blends. At rated load, smoke, carbon monoxide (CO), and unburnt

hydrocarbon (HC) emissions of 50% blend are higher compared with diesel by 51.74%, 71.42% and 33.3%, respectively.

Agarwal and Agarwal [20], conducted experiments were conducted using various blends of Jatropha oil with mineral diesel to study the effect of reduced blend viscosity on emissions and performance of diesel engine. The acquired data were analyzed for various parameters such as thermal efficiency, brake specific fuel consumption (BSFC), smoke opacity, CO₂, CO and HC emissions. While operating the engine on Jatropha oil (preheated and blends), performance and emission parameters were found to be very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be marginally inferior.

Purushothaman and Nagarajan [21], presented work the performance, emission and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine using orange oil as an alternate fuel were studied and the results are compared with the standard diesel fuel operation. Results indicated that the brake thermal efficiency was higher compared to diesel throughout the load spectra. Carbon monoxide (CO) and hydrocarbon (HC) emissions were lower and oxides of nitrogen (NO_x) were higher compared to diesel operation. Peak pressure and heat release rate were found to be higher for orange oil compared to diesel fuel operation.

Labeckas and Slavinskis [22], This article presents the comparative bench testing results of a four stroke Diesel engine when operating on neat rapeseed oil methyl ester and its 5%, 10%, 20% and 35% blends with Diesel fuel. The purpose of this research is to examine the effects of rapeseed oil inclusion in Diesel fuel on the brake specific fuel consumption (bsfc) of a high speed Diesel engine, its brake thermal efficiency, emission composition changes and smoke opacity of the exhausts. The brake specific fuel consumption at maximum torque and rated power is higher for rapeseed oil by 18.7% and 23.2% relative to Diesel fuel. The maximum brake thermal efficiency is higher for rapeseed oil at higher load.

The maximum NO_x emissions increase proportionally with the mass percent of oxygen in the bio fuel and engine speed. The carbon monoxide, CO, emissions and visible smoke emerging from the biodiesel over all load and speed ranges are lower by up to 51.6% and 13.5% to 60.3%, respectively. The carbon dioxide (CO₂) is slightly higher in case of biodiesel. The emissions of unburned hydrocarbons, HC, for all biofuels are low.

In the study of **Altuna et al. [23]**, a blend of 50% sesame oil and 50% diesel fuel was used as an alternative fuel in a direct injection diesel engine. Engine performance and exhaust emissions were investigated and compared with the ordinary diesel fuel in a diesel engine.

The experimental results show that the engine power and torque of the mixture of sesame oil–diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel. Hence, it is seen that blend of sesame oil and diesel fuel can be used as an alternative fuel successfully in a diesel engine without any modification and also it is an environmental friendly fuel in terms of emission parameters.

Sureshkumar et al. [24], presented the results of performance and emission analyses carried out in an unmodified diesel engine fuelled with *Pongamia pinnata* methyl ester (PPME) and its blends with diesel. Engine tests have been conducted to get the comparative measures of brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC) and emissions such as CO, CO₂, HC, NO_x to evaluate the behaviour of PPME and diesel in varying proportions. BSFC and BSEC for all the fuel blends and diesel tested decrease with increase in load. This is due to higher percentage increase in brake power with load as compared to increase in the fuel Consumption. For the blends B20 and B40, the BSFC is lower than and equal to that of diesel, respectively, and the BSEC is less than that of diesel at all loads. This could be due to the presence of dissolved oxygen in the PPME that enables complete combustion engine emits more CO for diesel as compared to PPME blends under all loading conditions The CO₂ emission increased with increase in load for all blends. The lower percentage of PPME blends emits less amount of CO₂ in comparison with diesel. Blends B40 and B60 emit very low emissions. This is due to the fact that biodiesel in general is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. HC emission decreases with increase in load for diesel and it is almost nil for all PPME blends except for B20 where some traces are seen at no load and full load. The NO_x emission for all the fuels tested followed an increasing trend with respect to load. The reason could be the higher average gas temperature, residence time at higher load conditions.

Lapuerta et al. [25], analyzed diesel engine emissions when using biodiesel fuels as opposed to conventional diesel fuels. The basis for comparison is engine power, fuel consumption and thermal efficiency. The engine emissions from biodiesel and diesel fuels are compared, paying special attention to the most concerning emissions: nitric oxides and particulate matter .according to this study:

- At partial load operation, no differences in power output, since an increase in fuel consumption in the case of biodiesel would compensate its reduced heating value. At full-load conditions, a certain decrease in power has been found with biodiesel.

- An increase in bsfc has been found when using biodiesel. Such an increase is generally in proportion to the reduction in heating value (9% in volume basis, 14% in mass basis). Consequently, the thermal efficiency of diesel engines is not appreciably affected when substituting diesel by biodiesel fuel either pure or blended.
- There is slightly increase of NO_x with biodiesel because of more oxygen content of biodiesel and at higher temperature it leads to increase NO_x.
- There is a sharp reduction in particulate emissions with biodiesel as compared to diesel fuel. This reduction is mainly caused by reduced soot formation and enhanced soot oxidation. The oxygen content and the absence of aromatic content in biodiesel have been pointed out as the main reasons.
- CO is usually found to significantly decrease with biodiesel. A more complete combustion caused by the increased oxygen content in the flame coming from the biodiesel molecules has been pointed out as the main reason.

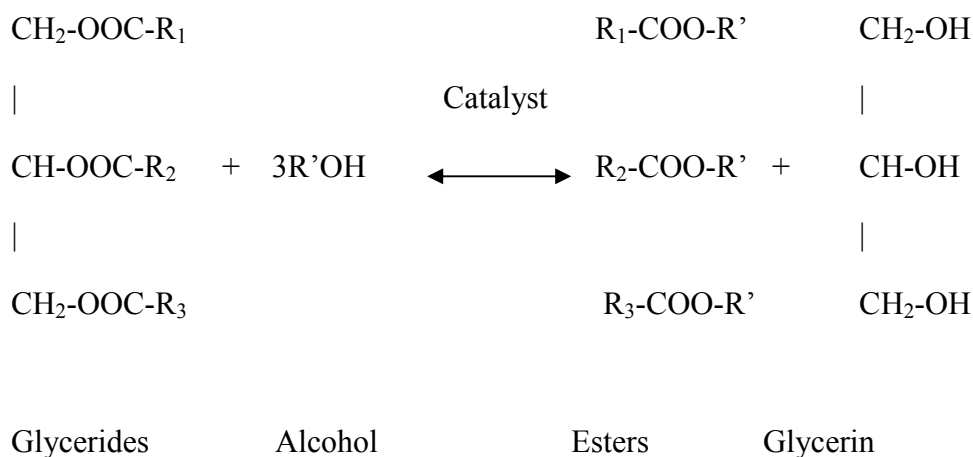
2.3 Conclusions

1. Ultrasonic cavitation and Hydrodynamic cavitation technique are much better than conventional techniques of biodiesel production. They take less time and consume very less power than mechanical stirring technique.
2. Supercritical methanol is less time consuming process then other methods but due to its high temperature and pressure it is difficult for commercial production
3. Transesterification with alkali catalyst (KOH & NaOH) is more economical then acid catalyst and enzyme catalyst.
4. Supercritical methanol process using CO₂ as a co-solvent is more convenient for industrial purpose then conventional supercritical methanol process.
5. Biodiesel blends has shows less power than diesel at low load condition but at higher load shows slightly more power due to better combustion with excess air. Thermal efficiency is higher for biodiesel blends. Specific fuel consumption (SFC) is higher for biodiesel because of lower heating value.
6. Main advantage analyzed biodiesel over diesel is lower emission. Carbon monoxide and unburned hydrocarbon has lower value in case of biodiesel due to complete combustion. Carbon dioxide from biodiesel can recycle.NO_x slightly increases for biodiesel.

3. BIODIESEL PRODUCTION METHODOLOGIES

3.1 Transesterification

Transesterification is the reaction of vegetable oil or animal fat with an alcohol, in most cases methanol, to form esters and glycerol. The transesterification reaction is affected by alcohol type, molar ratio of glycerides to alcohol, type and amount of catalyst, reaction temperature, reaction time and free fatty acids and water content of vegetable oils or animal fats. The transesterification reaction proceeds with or without a catalyst by using primary or secondary monohydric aliphatic alcohols having 1–8 carbon atoms as follows:



Where, term R represents to different alkyl groups.

Triglycerides + Monohydric alcohol = Glycerin + Mono-alkyl esters

Generally, the reaction temperature is near the boiling point of the alcohol is recommended. Nevertheless, the reaction may be carried out at room temperature. The reactions take place at low temperatures (45⁰C) and at modest pressures (2 atm, 1 atm = 101.325 kPa). Bio-diesel is further purified by washing and evaporation to remove any remaining methanol and catalyst. Generally oil to alcohol ratio is 1:6 or 1:4.5 and catalyst used is 1% of the oil is taken. As the molar ratio increases the reaction take less time to occur. The alcohols employed in the transesterification are generally short chain alcohols such as methanol, ethanol, propanol, and butanol. It was reported that when transesterification of soybean oil using methanol, ethanol and butanol was performed, 96–98% of ester could be obtained after 1 h of reaction. Catalysts used for the transesterification of triglycerides are classified as alkali, acid, Enzyme heterogeneous catalysts, among which alkali catalysts like

sodium hydroxide, potassium hydroxide are more effective. Sulphuric acid, hydrochloric acid and sulfonic acid are usually preferred as acid catalysts. Usually, industries use sodium or potassium hydroxide as catalyst, since they are relatively cheap and quite active for this reaction. The lipases is Enzyme catalyst, which is generally not use because it is costly and take more time in reaction[26] .

Alkali-catalyzed transesterification

The alkaline catalysts show high performance for obtaining vegetable oils with high quality; these free fatty acids react with the alkaline catalyst to produce soaps that inhibit the separation of the bio-diesel and glycerin at atmospheric pressure and a temperature of approximately 60–70 °C with an excess of methanol. It often takes at least several hours to ensure the alkalis (NaOH or KOH) catalytic transesterification reaction is complete. Moreover, removal of these catalysts is technically difficult and brings extra cost to the final product. Since they give very high yields (>98%) in short reaction times (30 min) The important thing about this transesterification process is that some of the methanol can be recovered and that glycerin (that issued in pharmaceuticals and other applications) is also a by-product.

Acid catalyzed transesterification

The transesterification process is catalyzed by sulfuric, hydrochloric, and organic sulfonic acids. In general, acid catalyzed reactions are performed at high alcohol-to-oil molar ratios, low-to moderate temperatures and pressures, and high acid catalyst concentrations. Acid-catalyzed reactions require the use of high alcohol-to-oil molar ratios in order to obtain good product yields in practical reaction times. However, ester yields do not proportionally increase with molar ratio. Higher molar ratios showed only moderate improvement until reaching a maximum value at a 30:1 ratio (98.4%). Despite its insensitivity to free fatty acids in the feedstock, acid-catalyzed transesterification has been largely ignored mainly because of its relatively slower reaction rate.

Enzyme catalyzed transesterification

The enzymatic alcoholysis of soybean oil with methanol and ethanol was investigated using a commercial, immobilized lipase. In this study the best conditions were obtained in a solvent-free system with ethanol/oil molar ratio of 3.0, temperature of 50 °C, and enzyme

concentration of 7.0% (w/w) and obtained yield 60% after 1 h of reaction. As for the enzyme-catalyzed system, it requires a much longer reaction time than the other two systems. The main problem of the lipase-catalyzed process is the high cost of the lipases used as catalyst. The enzyme reactions are highly specific and chemically clean. Because the alcohol can be inhibitory to the enzyme, a typical strategy is to feed the alcohol into the reactor in three steps of 1:1 mole ratio each [27]. The reactions are very slow, with a three step requiring from 4 to 40 h, or more. The reaction conditions are modest, from 35 to 45⁰C. Block diagram of general transesterification reaction is shown in figure 3.1

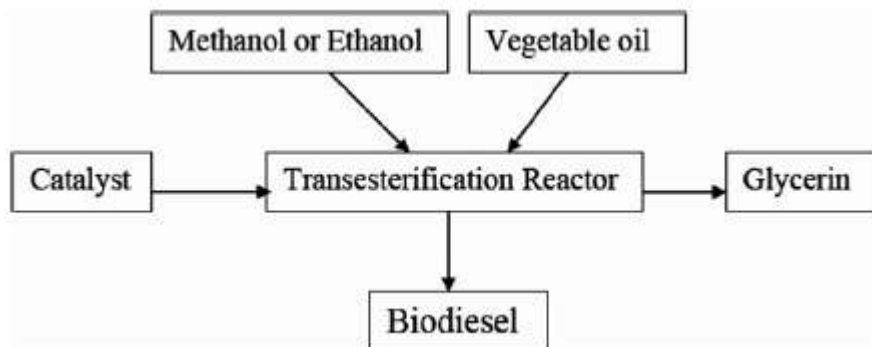


Figure 3.1: Catalytic bio-diesel production diagram [27]

3.2 Supercritical Methanol

The transesterification of triglycerides by supercritical methanol (SCM) has proved to be the most promising process. Supercritical methanol is believed to solve the problem associated with the two phase nature of normal methanol/oil mixture by forming a single phase as a result of lower value of dielectric constant of methanol in supercritical state. As a result reaction is completed in very short reaction time. For reaction in supercritical methanol and ethanol no catalyst is required and no need to remove catalyst from bio-diesel and better yielding are obtained and nearly complete conversion is taking place in very short reaction time. Transesterification of triglycerides can also be achieved by supercritical ethanol, propanol and butanol [27]. The critical temperatures and critical pressures of the various alcohols are shown in Table 3.1

Table 3.1 Critical pressure and critical temperature of various alcohols [27]

Alcohol	critical temperature ($^{\circ}\text{C}$)	critical pressure (MPa)
Methanol	239.2	8.1
Ethanol	243.2	6.4
1-Propanol	264.2	5.1
1-Butanol	287.2	4.9

Figure 3.2 shows supercritical ethanol transesterification system. All the process are performed in cylindrical autoclave made of 316 stainless steel in which the pressure and temperature are monitored in real time covering up to 100MPa and 850K respectively in the process autoclave is charged with given amount of vegetable oil and liquid methanol with charged molar ratio. Higher methanol to oil molar ratio (41 to 42) is used in this technology. After each process gas is vented and autoclave is poured in collecting vessel. All the content is removed from the autoclave by washing with methanol. Compared with catalytic process purification of product is much simpler and more environment friendly. However the reaction required temperature of 350-400 $^{\circ}\text{C}$ and pressure 45-65 MPa, which are not viable in practice in industry. Furthermore, high temperature and pressure lead to high production cost and energy consumption.

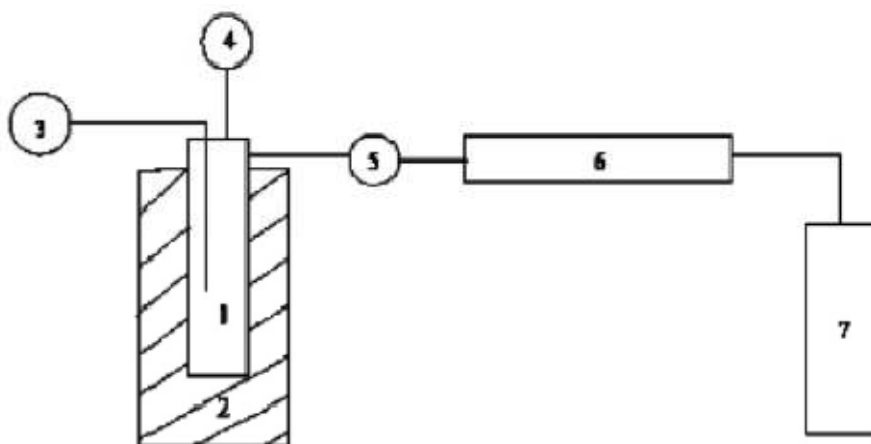


Figure 3.2: Supercritical ethanol transesterification system 1. Autoclave 2. Electric furnace 3. Temperature control monitor 4 pressure control monitor 5. Product exit valve 6. Condenser 7. Product collecting vessel [27]

Transesterification using CO_2 as a co-solvent

A co-solvent was added to reaction mixture in order to decrease the operating temperature, pressure and molar ratio of alcohol to vegetable oil. With CO_2 as a co-solvent in reaction system, there is significant decrease in the severity of condition required for

supercritical reaction. It was demonstrated that, with an optimum reaction temperature of 280 °C, methanol to oil ratio of 24 and CO₂ to methanol ratio of 0.1, a 98% yield of methyl ester viable as an industrial process[15]. Features of supercritical methanol process with co-solvent process are given below:

1. Solubility of vegetable oil in methanol increase at a rate of 2±3% (w/w) per 10⁰C as reaction temperature increase is increased.
2. The use of co-solvent increases the mutual solubility of methanol and vegetable oil at low reaction temperature.
3. Addition of an appropriate co-solvent decreases the critical point of methanol and allows the supercritical reaction to be carried out under mild condition.
4. Superior to the conventional supercritical methanol method.
5. Supercritical CO₂ is a good solvent for small and moderate organic molecule and it is low cost and fecile material .The CO₂ is both easy to add and remove from the mixture when reaction is complete.
6. Much lower pressure and temperature is required which makes the process safer and lowers the production cost.
7. Co-solvent has no effect on reaction mechanism.
8. In the absence of catalyst the purification after transesterification is much simpler and more environmental friendly.
9. The relatively mild reaction condition and high yield of methyl ester using this environmental friendly method make it practical use in industry.

The supercritical methanol /co-solvent reaction system employed in this work shown in Figure 3.3. A 250 ml cylinder autoclave made of stainless steel equipped with a magnatic stirrer and internal cooling was used. The temperature and pressure monitored in real time up to maximum value of 100 MPa and 450⁰C, respectively. The reaction vessel are charged with a given amount of oil and liquor methanol with different molar ratio, and known amount of CO₂ was then added to the autoclave as co-solvant.The reaction vessel was heated with external heater. The desired temperature can be reached in 13-15 min. The mixture was then transferred to ice-water bath to quench the reaction.

After process gas was vented and the content of the autoclave were poured into a collecting vessel. The remaining of the contents of autoclave was removed by washing with methanol .The treated oil than allow to settle down for about 60 min in order to allow two

phase to separate. The upper and lower phases were evaporated at 70⁰C for 30 min in order to remove methanol.

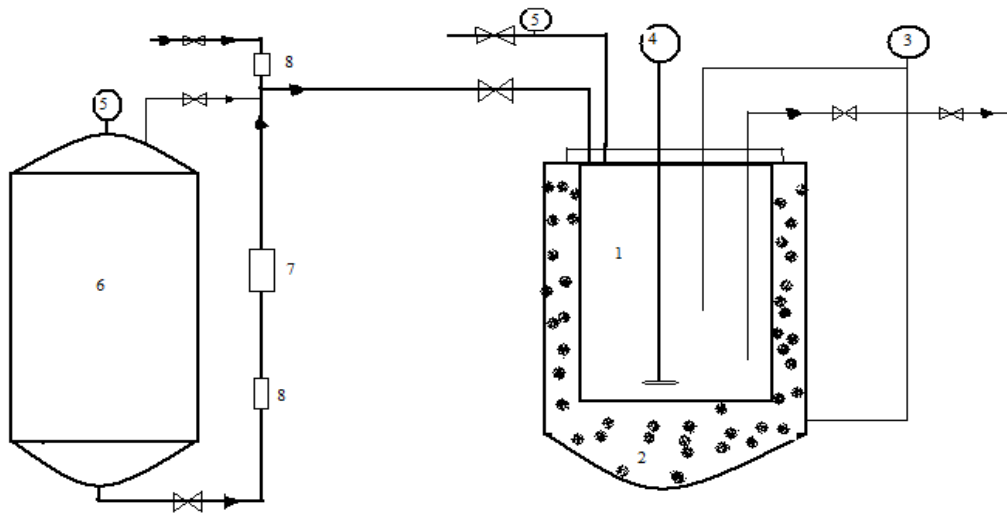


Figure 3.3: Supercritical methanol and co-solvent transesterification system 1. Autoclave 2.Electric furnace 3.Temperature control monitor 4.Magnetic stirrer 5.Pressure control monitor 6.Co-solvent tank 7. Co-solvent flow meter 8.Filter [15]

Reaction by supercritical methanol has some advantages:-

- (1) Glycerides and free fatty acids are reacted with equivalent rates
- (2) The homogeneous phase eliminates diffusive problems
- (3) The process tolerates great percentages of water in the feedstock catalytic process require the periodical removal of water in the feedstock or in intermediate stage to prevent catalyst deactivation.
- (4) The catalyst removal step is eliminated
- (5) If high methanol: oil ratios are used, total conversion of the oil can be achieved in a few minutes.

Some disadvantages of the one-stage supercritical method are clear: -

- (1) It operates at very high pressures (25–40 MPa),
- (2) The high temperatures bring along proportionally high heating and cooling costs
- (3) High methanol: oil ratios (usually set at 42) involve high costs for the evaporation of the untreated methanol
- (4) The process as posed to date does not explain how to reduce free glycerol to less than 0.02% as established in the ASTM D6584 or other equivalent international standards.

4. BIODIESEL PRODUCTION THROUGH CAVITATION TECHNIQUE

This chapter contains the details of biodiesel production methodology. In this present work biodiesel is produced from hydrodynamic cavitation, ultrasonic cavitation and conventional magnetic stirring method and results of these methods are relatively compared.

4.1 Hydrodynamic Cavitation

4.1.1 Principle of Hydrodynamic Cavitation

Hydrodynamic cavitation can simply be generated by the passage of the liquid through a constriction such as throttling valve, orifice plate, venturi etc. When the liquid passes through the orifice plates, the velocities at the orifice increase due to the sudden reduction in the area offered for the flow, resulting in a decrease in the pressure. If the velocities are such that their increase is sufficient to allow the local pressure to go below the medium vapour pressure under operating conditions, cavities are formed. Such cavities are formed at a number of locations in the reactor, which also depends strongly on the number of holes in the orifice plates. At the downstream of the orifice, however, due to an increase in the area of cross-section, the velocities decrease giving rise to increasing pressures and pressure fluctuations, which control the different stages of cavitation, namely *formation, growth and collapse*. This process generates conditions of very high temperatures and pressures locally. As a result, micro fine bubbles are formed. The asymmetric collapse of the cavitation bubbles disrupts the phase boundary and impinging of the liquids create micro jets, leading to intensive emulsification of the system [28], which result in increase of reaction rate at much faster rate. Now this mixture is circulated through orifice hole again and again until all the mixture is converted into bio diesel.

4.1.2 Description of Test Rig

Schematic of test rig developed at I.C. Engine laboratory of Delhi College Engineering is shown in Figure 4.2. The set-up consists of a closed loop fluid circuit comprising a holding tank with 10 liter capacity (with water jacket), centrifugal pump (2.2 kW), control valve (V_1 , V_2 and V_3) and a coupling to accommodate the orifice plate. The photograph of test rig is

shown in Figure 4.1. The suction side of the pump is connected to the bottom of the tank. Discharge from the pump branches into two lines, which help in the control of inlet pressure and inlet flow rate into the main line housing of the orifice with the help of valves V_1 and V_2 . The main line consists of a coupling to accommodate the orifice plates (single or multiple holes, different configurations of the orifice plates have been shown in Figure 4.3). In this experiment we have used orifice plate made of stainless steel and contain holes of 3 mm diameter. The numbers of holes used in the plate are 1, 3, 5 and 7. The diameter of each plate is 2 inch.

The tank is prepared by rolling process using M.S. sheet of 2 mm thickness. And its joints are welded using gas welding. It consists of two coaxial cylinders. Inner cylinder is for holding mixture of vegetable oil and methanol and outer cylinder for cooling water circulation. The coupling is made by turning process on lath machine. After that the entire component (pressure gauge, valve, pump, tank and coupling) are assembled using mild steel pipe of 1.5" and 1" diameter.

The cavitating conditions are generated just after the orifice plates in the main line and hence the intensity of the cavitating conditions strongly depends on the geometry of the orifice plate. The pressures in the main line before the orifice plate and after the orifice plate at vena contracta are measured with the help of pressure gauge p_1 and p_2 . The holding tank is provided with a cooling jacket to control the temperature of the circulating liquid.

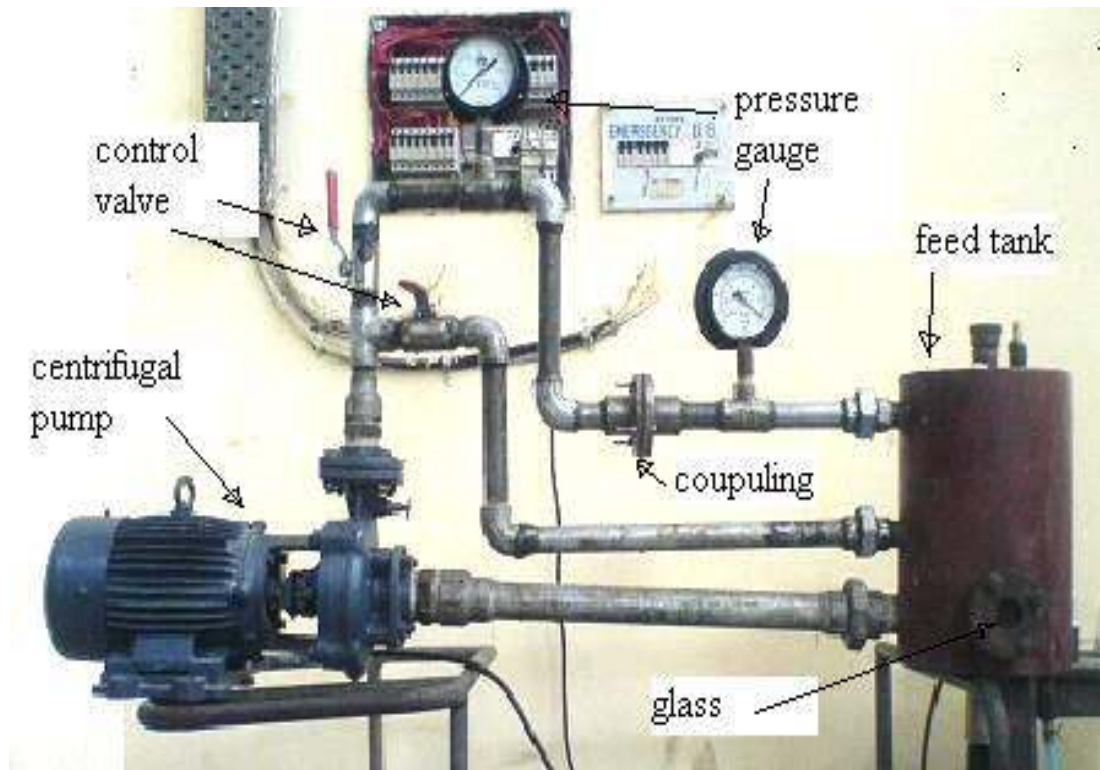


Figure 4.1: Setup for hydrodynamic cavitation reactor

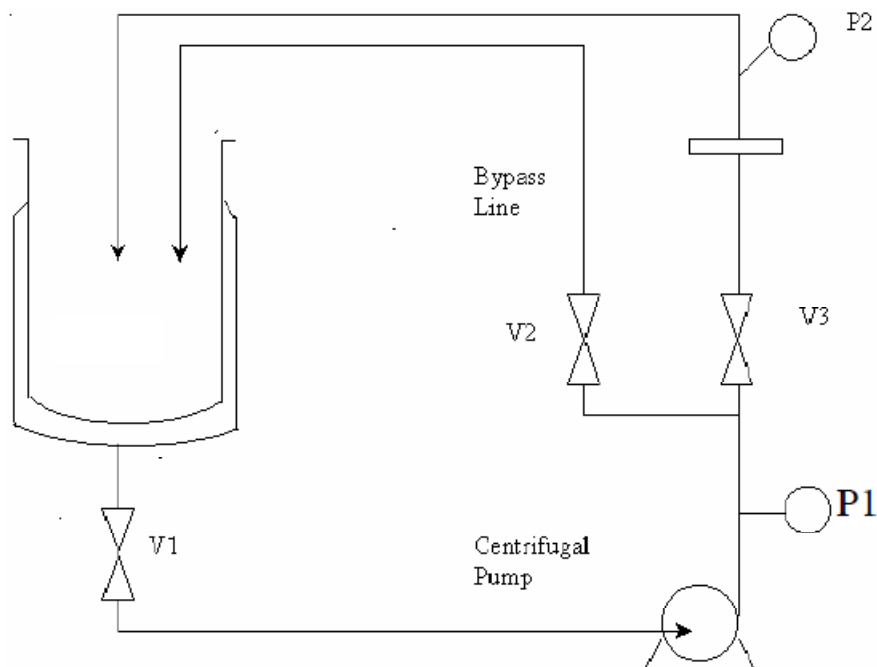


Figure 4.2: Schematic representation of the experimental

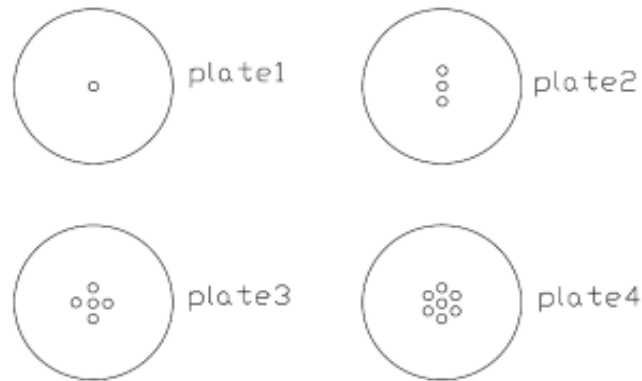


Figure 4.3: Multiple-hole orifice plates

4.1.3 Experimental Procedure

Following steps has been performed during the experiment

The vegetable thumba oil of (3.5 to 5.5kg) is filtered to remove impurities. It is heated up to 110°C in order to remove water content of oil to avoid soap formation. Then this oil is allowed to cool up to room temperature. Now methyl alcohol (CH_3OH) is taken with a molar ratio of (1:4.5 & 1:6). Catalyst Sodium hydroxide is taken (1% by weight of oil), and mixed in methanol and stirred till sodium hydroxide is dissolve in alcohol. This mixture is mixed with vegetable oil and supplied to hydrodynamic cavitation reactor test rig. The pump of Hydrodynamic cavitation reactor is started and whole mixture is allowed to pass through orifice hole to generate the favorable cavitation condition during the reaction and the temperature of mixture is kept between $40\text{-}55^{\circ}\text{C}$. The temperature of mixture is controlled by circulation of cooling water in the jacket of the reactor.

After 30 to 45 minutes process is stopped and the mixture is collected in a bucket. The glycerin is allowed to settle down in the mixture as it has higher density than methyl esters. A layer of Glycerin and methyl esters will be visible in 10 minutes of settling while complete settling takes place in 2 to 3 hours. After the separation of the glycerin and methyl esters, the methyl esters has been washed to remove residual catalyst or soaps. The methyl esters are washed with the water. For washing, first methyl esters is kept in separating funnel and water up to 30% of methyl esters (at a temperature of 40°C) is mixed and the mixture is stirred for 1 minute and then left for settling of water with impurities. After complete settling of water of with impurities at the bottom of separating funnel it is removed by opening the tap provided at the bottom of separating funnel.

4.1.4 Experiment result

The experiment has been performed with alcohol to oil molar ratio as 6:1 and 4.5:1 and catalyst percentage of 0.5 and 1% using Thumba oil. The amount of oil, alcohol and catalyst taken are shown in Table 4.1.

Table 4.1 Oil, alcohol and catalyst during the experimentation

Molar ratio (alcohol/oil)	Quantity of non-edible oil (g)	Quantity of methanol (g)	Catalyst (KOH)	
			0.5%	1.0%
6:1	5 kg	1103.5 g	25 g	50 g
4.5:1	5 kg	827.6 g	25 g	50 g

Total energy consumed by electric motor

Power of motor used = 2.2 kW

Time of experiment = 45 minutes = 2700 sec.

Total energy consumed = 2.2×2700 kJ
= 5940 kJ

According to the above Table 4.1 the sample of oil is experimented in hydrodynamic cavitation set up. According to Verma [29] the experiment has been performed for 7 hole system. During the experiment sample of methyl ester formed is taken in the interval of 15 min but the highest yield has obtained at the reaction time between 40 to 45 min. The result obtained is shown in Table 4.2.

Table 4.2 Time and yield of thumba oil for different molar ratio and catalyst %

Catalyst %	Molar ratio 6:1		Molar ratio 4.5:1	
	Time(min)	Yield (%)	Time(min)	Yield (%)
0.5%	42	76	45	72
1%	40	78	42	75

4.2 Ultrasonic cavitation

4.2.1 Principle of Ultrasonic Cavitation

Principal of ultrasonic cavitation method is same as the hydrodynamic cavitation technology. In this process cavities are created by the irradiation of power 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. This process is directly related to oscillatory velocity which is directly related to vibration amplitude at given frequency. More the oscillatory velocity the reaction time will be short. On the other hand oscillating velocity of ultrasonic transducer is insufficient for the sono-chemical reaction in the mixture so acoustic rod horn connected to the transducer are used to amplify the vibration amplitude this rod permit achieving higher velocity and less reaction time.

4.2.2 Experimental set-up

The transesterification reactions were carried out in an ultrasonic reactor. Schematic diagram shown in Figure 4.4 and photograph of ultrasonic processor in Figure 4.5. There is a two type of ultrasonic reactor one is bath type and other is horn type. In bath type reactor three transducer are attached at the bottom of the reactor, and in horn type reactor horn is attached with the transducer which produce ultrasonic irradiation in the mixture. Horn type reactor has been used for this experiment. In this ultrasonic processor frequency is ranging from 25 kHz to 30 kHz and time limit is ranging from 3 min to 30 min. There is an integrated arrangement for supporting the beaker (100 ml) so as the transducer horn should be at the separating boundary. The horn of the transducer was submerged 2 cm in the reactive mixture of methanol and fatty acid oil. The temperature of the reaction mixture was controlled by a water bath. Heated fatty acid oil (50 g) was poured into the reactor at the beginning. The reaction started when a quantitative amount of methanol liquor dissolved in KOH was poured into the heated reactor. The reaction is carried out by ultrasonic irradiation produced by ultrasonic generator through the transducer incorporated with acoustic rod horn. There is a temperature measurement device which indicates the temperature of mixture and provides a measure to control it.

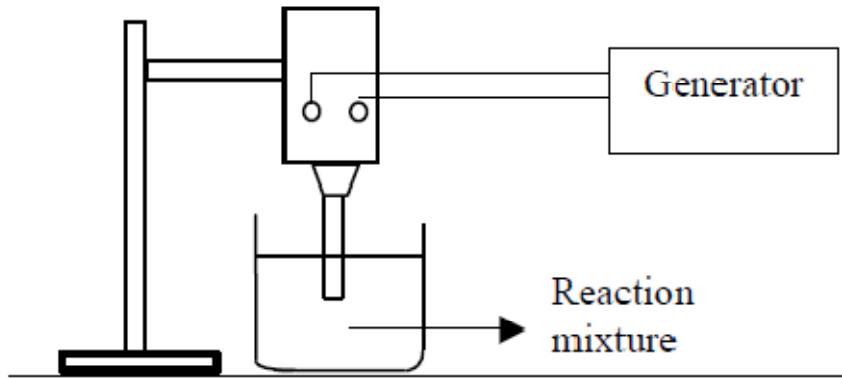


Figure 4.4: Schematic diagram of ultrasonic horn type reactor



Figure 4.5: Photograph of ultrasonic horn type processor (TU-50)

4.2.3 Experimental Procedure

Reagents and materials used for experiment

1. Thumba (originated from the Thumba seeds), Jatropha oil and waste cooking oil (50g/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 or NaOH) (85% pure) for accelerating the reaction mixture.

Design of Experiment

This experiment has been performed to evaluate performance of ultrasonic cavitation method of biodiesel production in terms of yield (%) and time. Same amount of sample (50g)

has been taken of raw vegetable oil for both ultrasonic cavitation method and conventional method. Followed by comparison.

Experiment has been performed with the following steps:

1. Thumba oil (50g) is taken in a 100 ml beaker and filtered it to remove impurities. Than it is heated up to 110 °C in order to remove water content of oil to avoid soap formation. This oil is allowed to cool up to 40 °C temperature so as to reaction can take place.
2. Now methyl alcohol (CH₃OH) is taken with a molar ratio of (1:4.5 & 1:6) and Catalyst (KOH) is taken as (0.5%, 0.75% and 1% by weight of oil).Then mixer of methyl alcohol and KOH stirred until KOH dissolve in methyl alcohol.
3. This mixture is mixed with vegetable oil. The methanol is immiscible with the oil.
4. The mixture of oil, methanol and catalyst come in contact with ultrasonic processor transducer (model TU-50) which is shown in Figure 4.6.



Figure 4.6: Ultrasonic processor with mixture

5. Test is performed for the ultrasonic frequency (28.5 kHz). During the reaction the temperature of mixture is kept between 40-55 °C.
6. When reaction is completed the beaker is kept for the separation. Fatty acid has higher specific weight therefore it will settle at bottom. Separation of methyl ester and glycerol will take 2 to 3 hr duration.
7. After complete separation bio-diesel (methyl Ester) is visible in the upper layer and glycerol.
8. Bio-diesel is separated from beaker for purification process. The catalyst present in the methyl ester is impurity.

9. To remove the catalyst, water at around 40 °C is mixed with the methyl ester and left for settling down. Water due to its higher specific gravity collected at bottom. This is shown in Figure 4.7.



Figure 4.7: Photograph of washing process of biodiesel

10. Excess methanol present in biodiesel has been removed by distillation process. This methanol can be again used for transesterification process.

4.2.4 Experiment Results

The experiments are performed with alcohol to oil molar ratio as 6:1 and 4.5:1. The amount of oil, alcohol and catalyst taken is shown in Table 4.3.

Table 4.3 Oil, alcohol and catalyst during the experimentation

Molar ratio (alcohol/oil)	Quantity of non-edible oil (g)	Quantity of methanol (g)	Catalyst (KOH)		
			0.5%	0.75%	1.0%
6:1	50 g	11 g	0.25 g	0.375 g	0.5 g
4.5:1	50 g	8.28 g	0.25 g	0.375 g	0.5 g

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

and 1 gm mole of methanol = 32 gm

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

Amount of methanol for 50 g of vegetable oil

- For 1:6 molar ratio = $(32 / 870) \times 50 \times 6 = 11 \text{ g}$
- 1:4.5 molar ratio = $(32 / 870) \times 50 \times 4.5 = 8.28 \text{ g}$

Total energy consumed by ultrasonic processor

Power consumption/sample

Power of motor used = 50 W

Time of experiment = 20 minutes = 1200 sec.

Total energy consumed = $50 \times 1200 \text{ J}$
= 60 kJ

Time and yield produced for three different vegetable oil

Experiments have been performed to prepare biodiesel from three different vegetable oil (Thumba, Jatropha and waste cooking oil) by ultrasonic cavitation method and conventional magnetic stirring method. Main aim of this experiment to calculate time, catalyst percentage and molar ratio (alcohol/oil) for biodiesel production with maximum yield and comparison with the conventional method. Our main emphasis on this project is to reduce the use of catalyst (KOH) and alcohol because catalyst (KOH) is pollutant for the water and land. If biodiesel produce on industrial scale than large amount of catalyst will be discharged in river or land and this will be harmful for environment and local area. The results obtained from experiment are shown below in tabular form.

Experimental Data for Ultrasonic Cavitation Method

Here data is generated by performing ultrasonic cavitation on the sample which is a mixture of vegetable oil (jatropha, thumba and waste cooking oil), methanol (CH_3OH) and catalyst (KOH). For every sample reaction time required for biodiesel production and yield of methyl ester is calculated. Time and yield for every sample is shown in tabular form given below.

Table 4.4 Time (Min) and yield (%) of jatropha oil for different molar ratio and catalyst (%)

% of Catalyst	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield %	Time (min)	Yield %
0.5%	16	73.4	18	76.9
0.75%	15	66.1	18	71.5
1%	12	70	15	74.2

Table 4.5 Time (Min) and yield (%) of thumba oil for different molar ratio and catalyst (%)

% of Catalyst	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield %	Time (min)	Yield %
0.5%	20	80	21	82.1
0.75%	14	80.5	18	78.2
1%	9	82.8	15	75.6

Table 4.6 Time (Min) and yield (%) of waste cooking oil for different molar ratio and catalyst (%)

% of Catalyst	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield %	Time (min)	Yield %
0.5%	16	76.3	18	80.2
0.75%	15	73.8	16	79.3
1%	15	69.8	10	74.5

Experimental Data for Magnetic Stirring Method

For the comparison purpose similar experiment has also been performed in magnetic stirrer using the same amount of sample. Time and yield of methyl ester for three different oil and catalyst (%) of oil is shown in tabular form below.

Table 4.7 Time (Min) and yield (%) of jatropha oil for different molar ratio and catalyst (%)

% of Catalyst	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield %	Time (min)	Yield %
0.5%	42	70.5	45	72
0.75%	38	68.8	40	65.2
1%	34	66	36	64

Table 4.8 Time (Min) and yield (%) of thumba oil for different molar ratio and catalyst (%)

% of Catalyst	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield %	Time (min)	Yield %
0.5%	38	71	42	72.4
0.75%	34	70.5	39	68.6
1%	30	68.3	36	64.8

Table 4.9 Time (Min) and yield (%) of waste cooking oil for different molar ratio and catalyst (%)

% of Catalyst	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield %	Time (min)	Yield %
0.5%	38	77.5	42	75.2
0.75%	36	75.2	37	74
1%	30	73.1	35	76.1

4.2.5 Discussion on experiment data

From the above mentioned table graphs have been plotted to compare between various oils and methods. Comparisons of ultrasonic and magnetic stirrer methods for different vegetable oils are plotted separately.

Comparison of ultrasonic method with magnetic stirring method for different biodiesel in terms of yield % and time

Comparison with jatropha oil

Comparison of ultrasonic and magnetic stirring method of biodiesel yield and time for molar ratio 6:1 (alcohol and oil) for three different catalyst (%) is shown in Figure 4.8(a) and 4.8(b). Here U-jat and MS-jat indicate ultrasonic and magnetic stirring method for jatropha biodiesel. It can be seen from Figure 4.8(a) and 4.8(b) yeild is slightly more in case of ultrasonic method and reaction time is much lower for ultrasonic method.

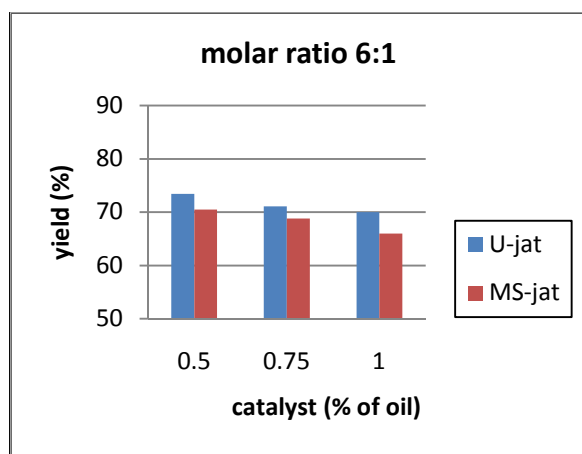


Figure 4.8(a): Comparison of yield for jatropha biodiesel and molar ratio 6:1

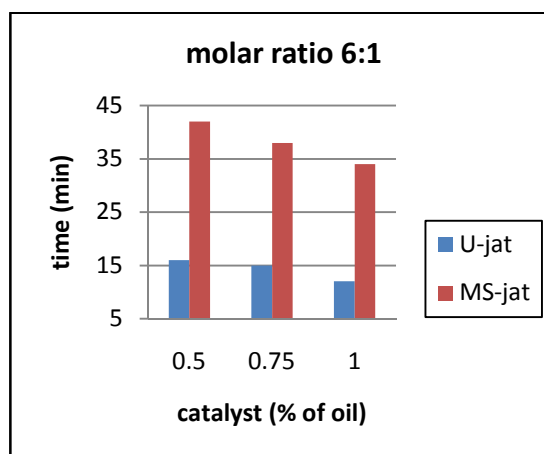


Figure 4.8(b): Comparison of time for jatropha biodiesel and molar ratio 6:1

The similar comparison for jatropha biodiesel for molar ratio 4.5:1 with catalyst (%) are shown in Figure 4.8(c) and 4.8(d). From this Fig it can be evaluate that the yield of ultrasonic method is higher for all catalyst (%) and time is also much lower in this case.

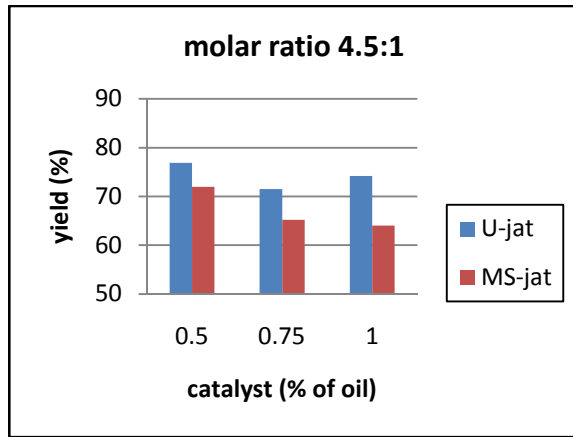


Figure 4.8(c): Comparison of yield for jatropha biodiesel and molar ratio 4.5:1

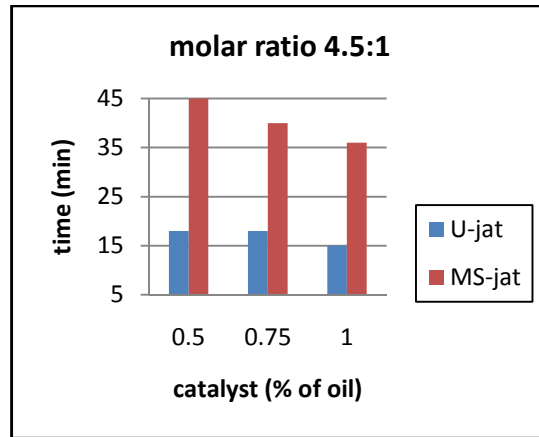


Figure 4.8(d): Comparison of time for jatropha biodiesel and molar ratio 4.5:1

Comparison with thumba oil

Comparison of ultrasonic and mechanical stirring method for molar ratio 6:1 (alcohol and oil) for different catalyst (%) is shown in Figure 4.9(a) and 4.9(b). As shown in Fig thumba biodiesel also exhibit lower reaction time and more yield than conventional method. Maximum yield in case of ultrasonic method for thumba biodiesel is 82.5% and lower reaction time is 9 min.

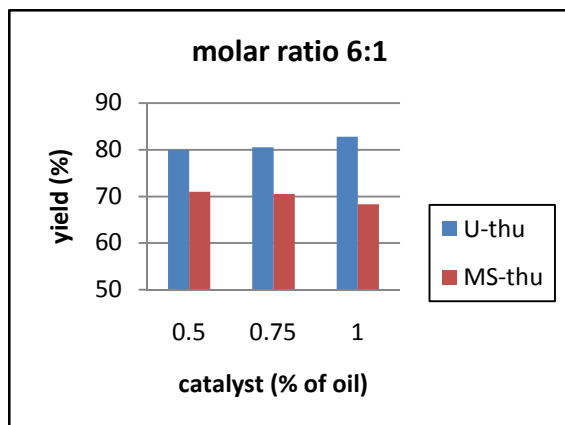


Figure 4.9(a): Comparison of yield for thumba biodiesel and molar ratio 6:1

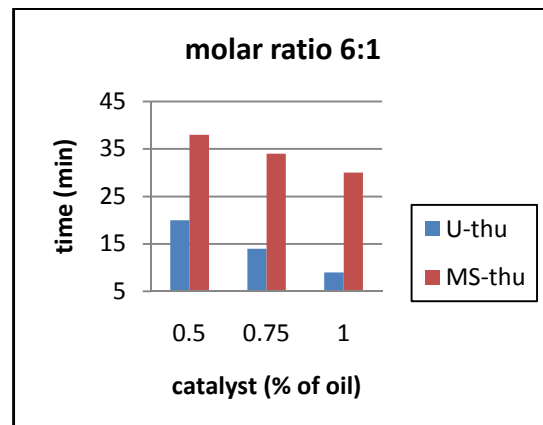


Figure 4.9(b): Comparison of time for thumba biodiesel and molar ratio 6:1

Comparison of above method for molar ratio 4.5:1 is shown in Figure 4.9(c) and 4.9(d). For this molar ratio and same catalyst (%) yield and reaction time is optimum for the ultrasonic cavitation method. It can be seen that using ultrasonic method reaction time is almost half compare to conventional method which is beneficial for industrial purpose.

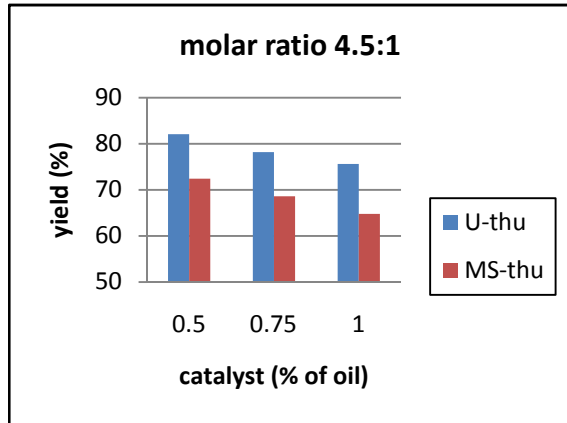


Figure 4.9(c): Comparison of yield for thumba biodiesel and molar ratio 4.5:1

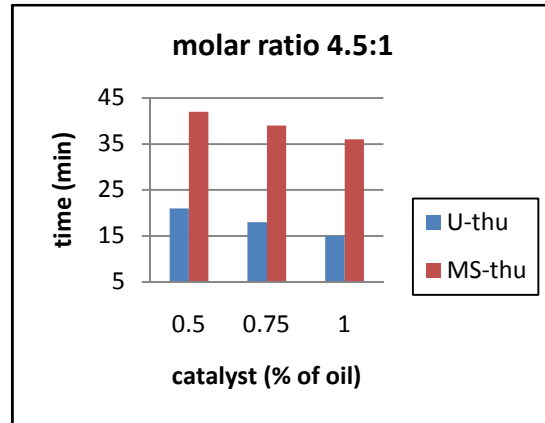


Figure 4.9(d): Comparison of time for thumba biodiesel and molar ratio 4.5:1

Comparison with waste cooking oil (WCO)

Similar comparison has also been performed for the waste cooking oil for molar ratio 6:1 and different catalyst (%) which is shown in Figure 4.10(a) and 4.10(b). Yield is almost same for both method for all catalyst (%) but time is much lower in case of ultrasonic cavitation method.

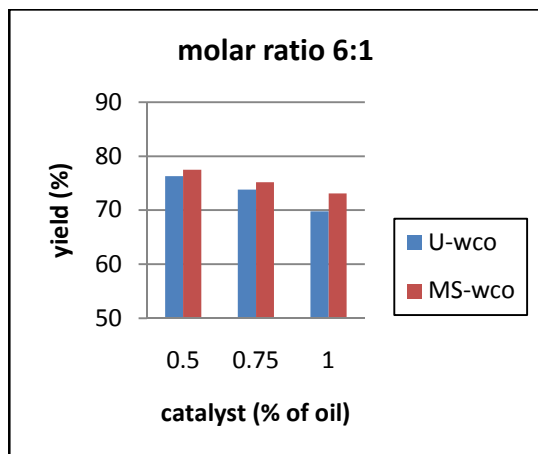


Figure 4.10(a): Comparison of yield for WCO biodiesel and molar ratio 6:1

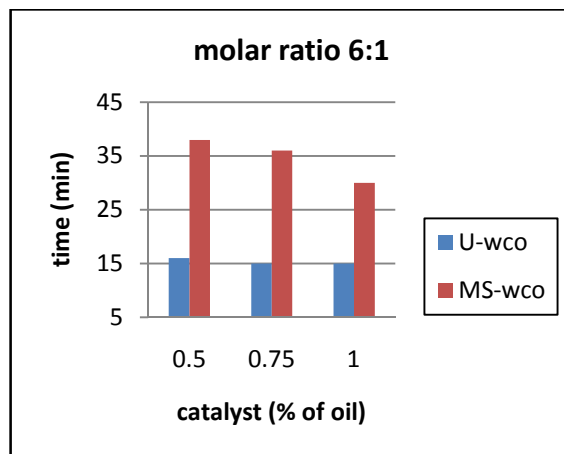


Figure 4.10(b): Comparison of time for WCO biodiesel and molar ratio 6:1

For molar ratio 4.5:1 (alcohol to oil) comparison between ultrasonic and magnetic stirring method is shown in Figure 4.10(c) and 4.10 (d) .Yield in case of ultrasonic method higher for

0.5 and 0.75% catalyst of oil and it is lower for 1% compared to conventional method. Reaction time show similar pattern as above.

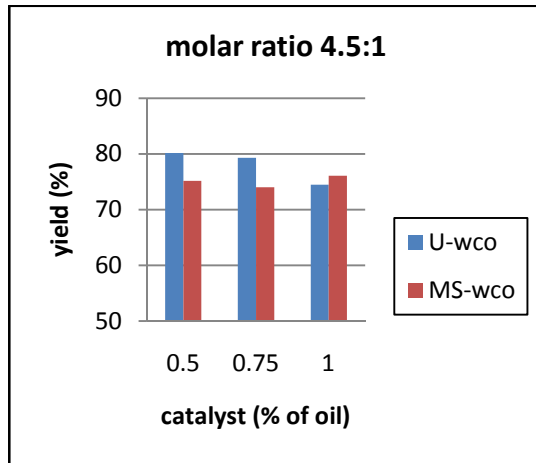


Figure 4.10(c): Comparison of yield for WCO biodiesel and molar ratio 4.5:1

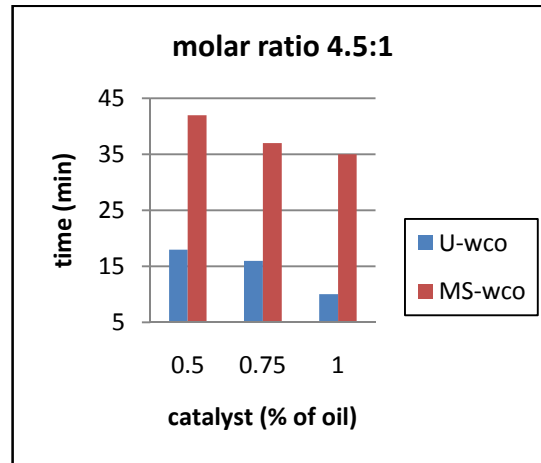


Figure 4.10(d): Comparison of time for WCO biodiesel and molar ratio 4.5:1

Comparison of various oils for two different methods in terms of yield (%) and time

On the basis of data collected for three different oil (thumba, jatropha and waste cooking oil) with two different methods ultrasonic cavitation and conventional magnetic stirring method. The main emphasis of this work is to evaluate the performance of ultrasonic cavitation over conventional method for different oils.

Yield v/s catalyst (%) for molar ratio 6:1

Here yield of three different oil (thumba, jatropha and waste cooking oil) for ultrasonic and magnetic stirring method shown in Figure 4.11. Here U stand for ultrasonic method and MS stand for conventional magnetic stirring method. It can be seen from Fig that ultrasonic method have higher yield for all biodiesel but not with much difference with conventional method. Thumba biodiesel have highest yield for ultrasonic method at 0.5% catalyst.

Reaction time v/s catalyst (%) for molar ratio 6:1

Here comparison for different oil has been made in terms of reaction time to prepare biodiesel for molar ratio 6:1 which is shown in Figure 4.12. It can be easily concluded from Fig that for ultrasonic method reaction time is much low compare to magnetic stirring method for all condition. Lowest reaction time for thumba oil with ultrasonic method at 1% catalyst of oil.

Yield v/s catalyst (%) for molar ratio 4.5:1

Comparison of yield for three oils for molar ratio 4.5:1 and different catalyst percentage is shown in Figure 4.13. Similar to molar ratio 6:1 yield is almost same but by ultrasonic method

yield has slightly increased. Maximum yield has obtained at 0.5% catalyst for thumba oil with ultrasonic cavitation method which is 80%.

Time v/s catalyst (%) for molar ratio 4.5:1

Reaction time required for different oil to prepare biodiesel by ultrasonic cavitation and magnetic stirring method is shown in Figure 4.14. Reaction time is almost half for ultrasonic cavitation method compare to conventional method.

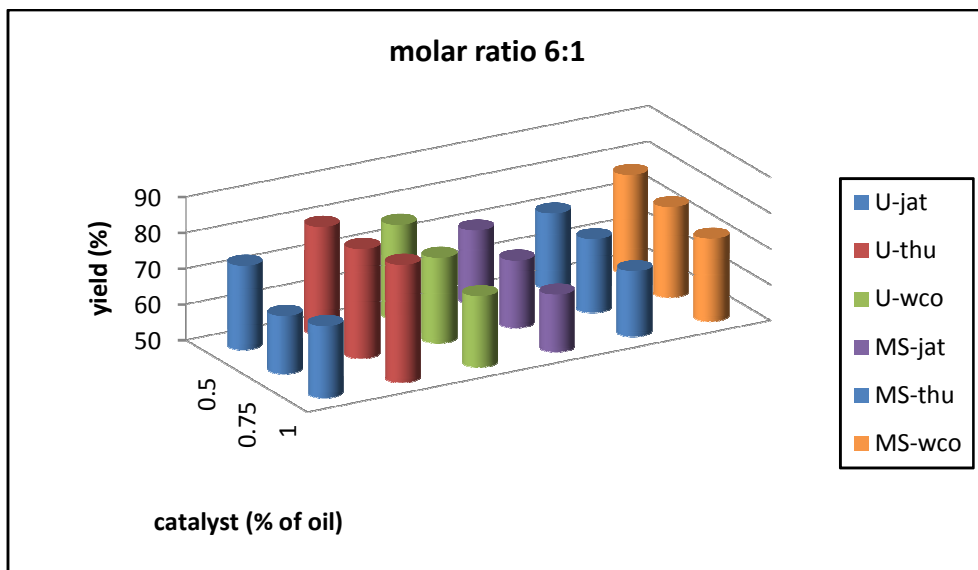


Figure 4.11: Comparison of yield for three different oil by two methods for molar ratio 6:1

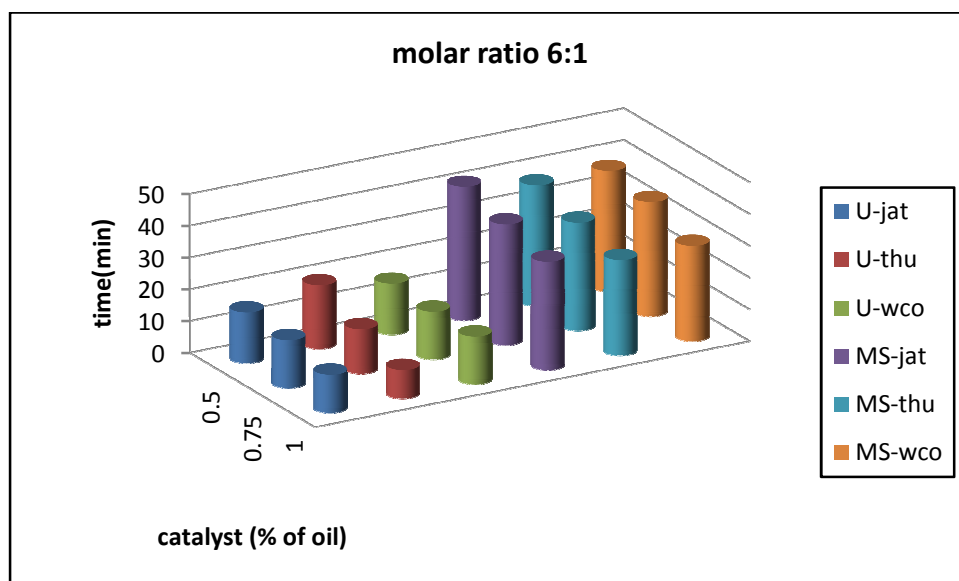


Figure 4.12: Comparison of time for three different oil by two methods for molar ratio 6:1

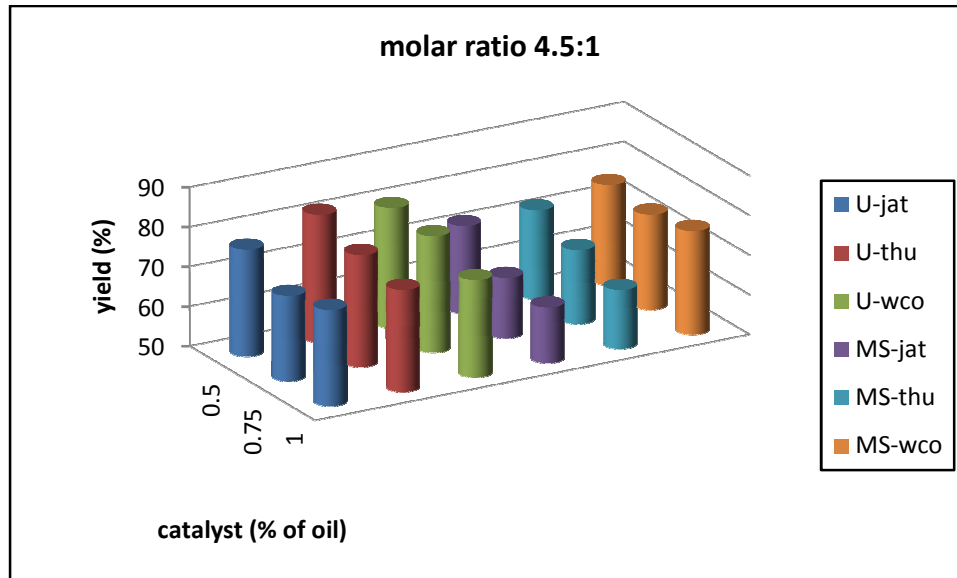


Figure 4.13: Comparison of yield for three different oil by two methods for molar ratio 4.5:1

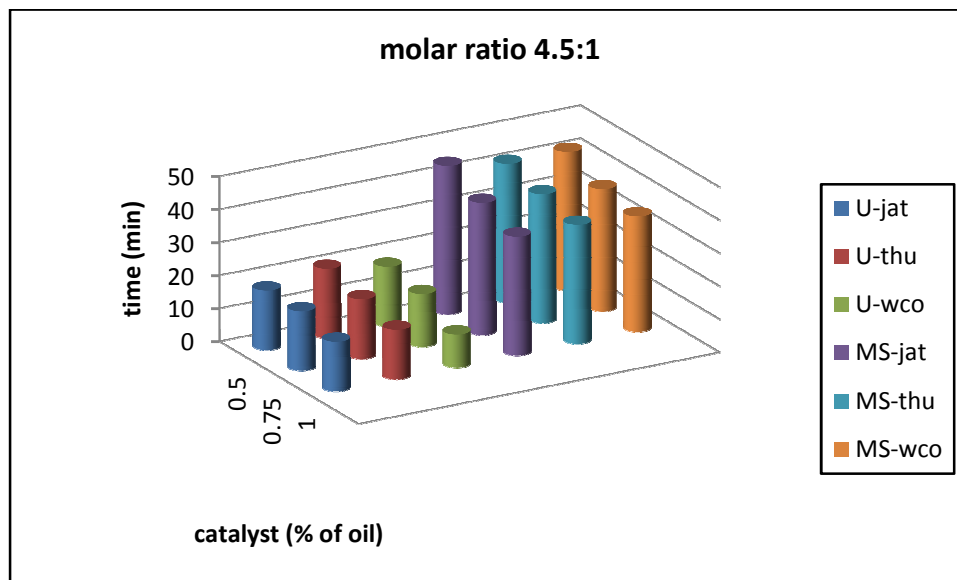


Figure 4.14: Comparison of time for three different oil by two methods for molar ratio 4.5:1

4.2.6 Comparison of biodiesel property with diesel fuel

Some properties of diesel and biodiesel are tabulated below. Some property show advantage over diesel and other are disadvantage for biodiesel. These properties are shown in Table 4.10.

Table 4.10 Comparison of the property of biodiesel and diesel as per BIS: 2796

Property	Biodiesel from			Unit	Limit	Diesel
	Thumba oil	WCO	Jatropha oil			
Appearance	clear	clear	clear	----	----	clear
Color	Brownish	Yellowish	Brownish	----	----	----
Density at 15 °C	890	886	880	kg/m ³	860-900	840
Kinematic viscosity at 40 °C	5.86×10^{-6}	4.3×10^{-6}	5.37×10^{-6}	m ² /se c	$3.5-5 \times 10^{-6}$	4.86×10^{-6}
Flash point	>66	>110	>162	°C	Min 100	51
Sulphur contents	0.01	>0.012	.0036	w/w %	Max 0.05	0.35- 0.55
Water content	0.05	>0.04	.09	w/w %	0.02- 0.05	0.005

Density is almost same for the thumba, WCO and jatropha biodiesel but higher from the diesel density. Kinematic viscosity of thumba and jatropha biodiesel is higher than WCO and diesel, diesel have lowest kinematic viscosity. Flash point of jatropha and WCO biodiesel is much higher from the thumba oil and diesel, jatropha have highest flash point. Water content (0.005 w/w %) is much lower in case of diesel oil. Sulphur content in all biodiesel is lower than diesel.

5. PERFORMANCE STUDIES

5.1 Engine Test Setup

The setup consists of four cylinder, four stroke, Diesel engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for P θ –PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, fuel tank, 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. Photograph of engine setup, schematic diagram of engine and photograph of smoke meter is shown in Figure 5.1, 5.2 and 5.3

The setup enables study of engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Windows based Engine Performance Analysis software package “Engine soft” is provided for on line performance evaluation.

The main aim of this experiment is to investigate the effects on performance of blending of biodiesel with diesel fuel in Tata Indica engine.

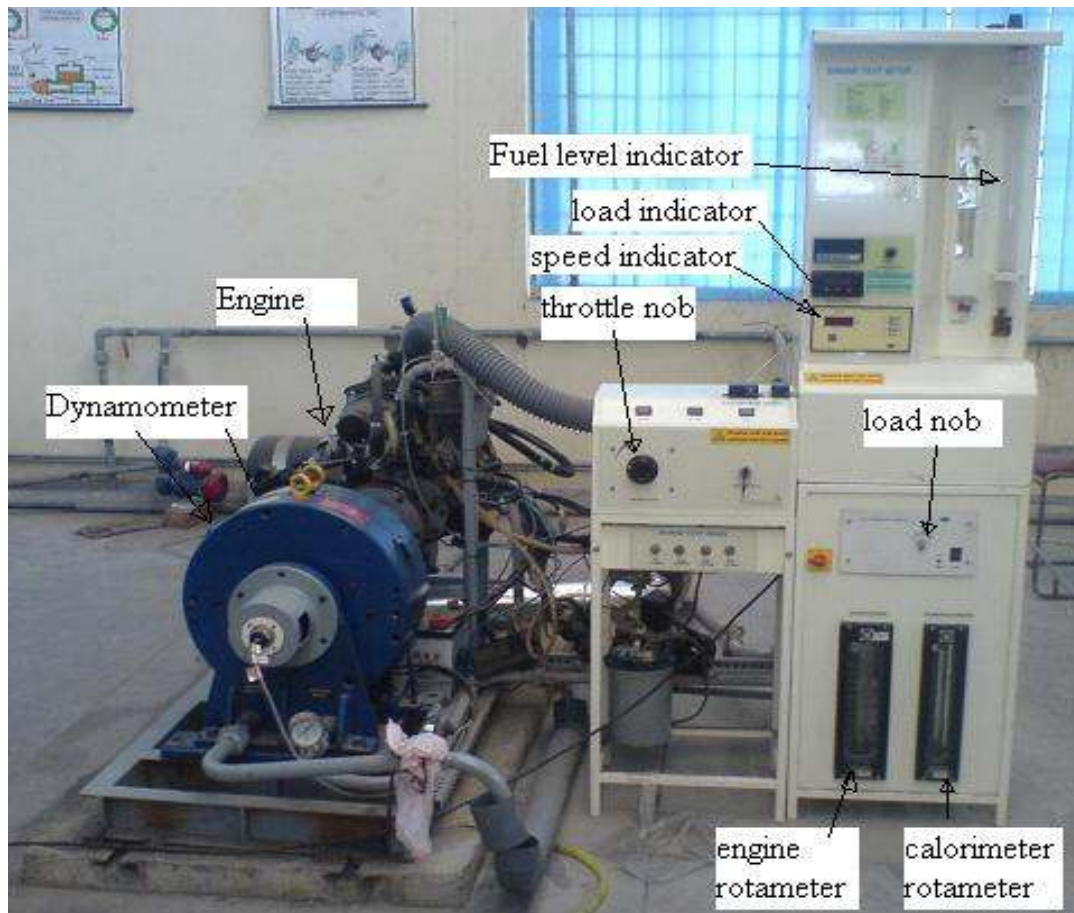


Figure 5.1: Experimental setup.

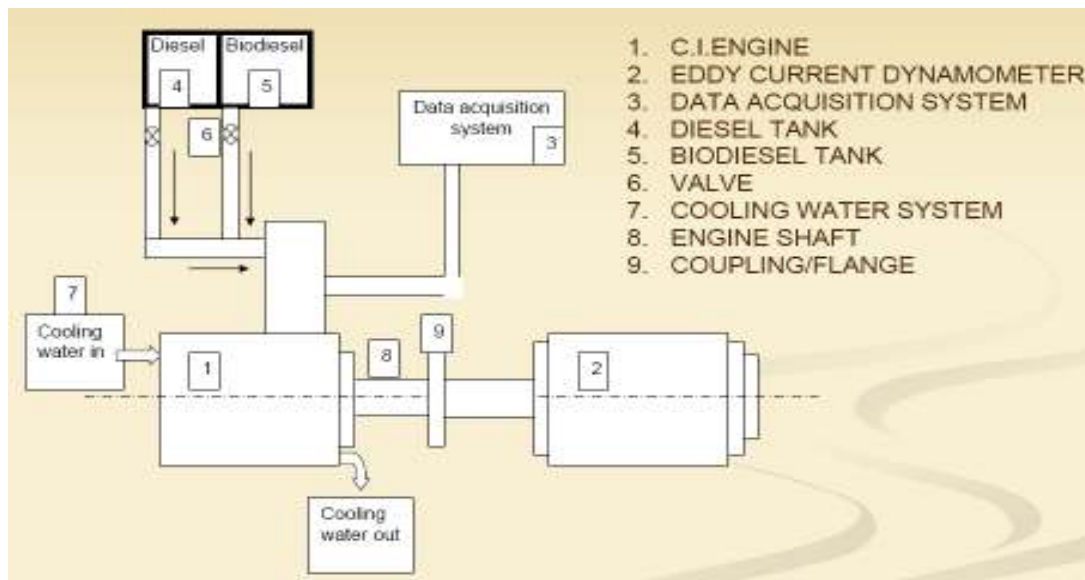


Figure 5.2: Schematic Diagram of the Experimental set-up



Figure 5.3: Smoke meter

Specifications

Product	Engine test setup 4 cylinder, 4 stroke, Diesel (Computerized)
Engine	Make Telco, Model Tata Indica, Type 4 Cylinder, 4 Stroke, Diesel water cooled, Power 39Kw at 5000 rpm, Torque 85 NM at 2500 rpm, stroke 79.5mm, bore 75mm, 1405 cc, CR22
Dynamometer	Type eddy current, water cooled, with loading unit
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 lit 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 550 RPM
Engine indicator	Input Piezo sensor, crank angle sensor, No of channels 2, Communication RS232
Digital millivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K

Temperature transmitter	Input RTD PT100, Range 0–100 °C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 °C, Output 4–20 mA
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Rota meter	Engine cooling 100-1000 LPH; Calorimeter 25-250 LPH
Data acquisition card	Resolution 12 bit, 8/16 input, mounting PCI slot
Software	“Enginesoft” performance analysis software
Overall dimensions	W 2000 x D 2750 x H 1750 mm
Smoke meter	Make AVL, for opacity measurement

5.2 Preparation of biodiesel blends

On this engine experiments are performed with different blends of biodiesel (pure diesel, B-10, B-20, and B-30). These blends are prepared in quantity of 2 liter each by mixing required quantity of biodiesel in petroleum diesel. Their description is shown in Table 5.1.

Calorific value of petroleum diesel = 42000 kJ/kg.

Calorific value of biodiesel = 37000 kJ/kg.

Density of petroleum diesel = 800 kg/m³.

Density of biodiesel = 891 kg/m³.

Table 5.1 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	2000	0	42000	800
B-10	1800	200	41500	809
B-20	1600	400	41000	818
B-30	1500	600	40500	827

5.3 Performance data

Experimental data for performance study are given below:

5.3.1 Pure diesel

Engine performance parameters obtained from performance testing in 4 cylinder CI engine against different speeds for pure diesel are given below in Table 5.2

Table 5.2 Performance parameters for pure diesel against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThe %	MechE %	SFC kg/kwhr	Opacity
4975	6.24	31.88	20.2	52.08	19.76	32.28	61.21	0.434	58.2
4501	5.99	27.72	21.39	49.11	22.1	39.16	56.44	0.388	57.7
4035	7.27	30.14	13.95	44.09	22.27	32.58	68.35	0.385	56.4
3581	7.28	26.79	13.29	40.09	22.34	33.43	66.84	0.384	54.7
3996	7.51	23.13	8	31.13	22.03	29.65	74.29	0.389	49.3
2445	6.96	17.49	8.02	25.5	21.92	31.95	68.57	0.391	41.2
2077	5.9	12.59	5.68	18.27	22.53	32.69	68.89	0.381	22
1503	2.72	4.2	4.7	8.9	19.77	41.92	47.16	0.434	7.4

5.3.2 Biodiesel blends from Thumba Oil

Experiment has been performed by taking thumba biodiesel (TB) blends with diesel in proportion of 10%, 20% and 30% respectively as a diesel engine fuel and following parameters has been obtained.

Table 5.3 Performance parameters for TB10 against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThe %	MechE %	SFC kg/kwhr	Opacity
5001	6.67	34.26	22.87	57.13	20.23	33.74	59.95	0.429	54.3
4488	6.54	30.18	18.73	48.91	21.41	34.7	61.7	0.405	55.5
4038	7.46	30.96	15.88	46.84	22.31	33.75	66.09	0.389	53.6
3577	7.24	26.62	11.39	38.01	22.89	32.68	70.03	0.379	54
3010	7.41	22.92	8.76	31.67	22.65	31.29	72.35	0.383	46.2
2485	7.13	18.2	6.57	23.1	22.52	28.59	78.8	0.385	36.4
1999	5.61	11.52	7.83	19.35	23.29	39.13	59.52	0.372	19.3
1526	3.07	4.81	5.91	10.72	20.55	45.18	44.89	0.421	9.2

Table 5.4 Performance parameters for TB20 against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThE %	MechE %	SFC kg/kwhr	Opacity
4987	5.99	30.71	23.52	54.23	19.87	35.09	56.63	0.442	54.1
4511	6.45	29.89	20.87	50.76	22.37	38	58.87	0.392	56.3
3990	7.33	30.06	14.13	44.2	23.17	34.07	68.02	0.379	53.7
3559	7.18	26.25	12.62	38.87	23.62	34.97	67.54	0.372	52.1
2981	7.56	23.15	6.87	30.02	23.42	30.37	77.11	0.375	44.9
2493	7.4	18.96	7.61	26.58	23.28	32.64	71.32	0.377	34.1
2026	5.7	11.86	5.93	17.79	24.22	36.33	66.66	0.362	16.8
1512	2.96	4.6	3.62	8.22	20.5	36.64	55.95	0.428	10.7

Table 5.5 Performance parameters for TB30 against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThE %	MechE %	SFC kg/kwhr	Opacity
4990	6.1	31.25	26.97	58.23	20.5	38.2	53.67	0.434	55.2
4522	6.56	30.5	21.09	51.58	22.78	38.53	59.12	0.39	53.7
4033	7.16	29.67	15.51	45.18	24.8	37.77	65.67	0.358	54.2
3545	7.28	26.52	12.35	38.87	25.26	37.03	68.23	0.352	51.9
3021	7.37	22.88	8.53	31.41	25.54	35.05	72.85	0.348	44.8
2425	7.18	17.89	7.22	25.11	25.33	35.55	71.24	0.351	36.1
2021	5.54	11.5	6.82	18.32	26.26	41.82	62.78	0.339	17.2
1553	3.55	5.67	4.7	10.37	19.53	35.74	54.66	0.455	8.6

5.3.3 Biodiesel blends from Jatropha oil

Experiment has been performed by taking jatropha biodiesel (JB) blends with diesel in proportion of 10%, 20% and 30% respectively as a diesel engine fuel and following parameters has been obtained.

Table 5.6 Performance parameters for JB10 against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThE %	MechE %	SFC kg/kwhr	Opacity
5012	5.99	30.86	25.86	56.72	20.22	37.16	54.41	0.429	55.1
4501	6.1	30.52	21.91	52.43	22.4	36	58.21	0.401	53.1
4027	7.43	30.74	15.94	46.68	23.18	35.21	65.85	0.374	51.3
3581	7.2	27	15.76	42.76	22.82	31.87	68.91	0.376	53.8
3015	7.6	23.55	6.76	30.31	23.01	29.62	77.71	0.377	44.6
2445	6.3	18.4	8.25	26.65	22.8	30.42	72.53	0.382	38.1
1980	5.77	11.74	5.12	16.86	23.09	33.17	69.62	0.376	18.1
1495	3.2	4.9	3.31	8.21	20.2	19.89	64.23	0.442	9.05

Table 5.7 Performance parameters for JB20 against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThE %	MechE %	SFC kg/kwhr	Opacity
5010	6.24	32.14	23.83	55.97	22.43	39.07	57.41	0.391	56.8
4503	6	29.2	18.7	48.2	24.3	37.5	62.8	0.374	52.3
4016	7.37	30.42	13.1	43.52	24.24	34.68	69.9	0.362	50.9
3581	7.1	26.89	11.32	38.21	24.01	33.68	72.38	0.358	53.2
3055	7.55	23.7	7.47	31.18	24.74	32.55	76.01	0.355	45.9
2445	7.21	18.1	8.6	26.7	22.43	34.6	73.34	0.36	36.3
1997	5.76	11.81	5.51	17.33	24.75	36.32	68.14	0.355	17.9
1503	2.82	4.8	11.54	16.34	20.6	30.4	65.04	0.424	10.2

Table 5.8 Performance parameters for JB30 against speed

SPEED (rpm)	TORQUE kgm	BP kw	FP kw	IP kw	BThE %	IThE %	MechE %	SFC kg/kwhr	Opacity
4986	6.43	32.94	23.4	56.33	21.35	36.51	58.47	0.416	57.6
4480	6.5	30.4	20.01	50.42	23.2	34.42	55.67	0.384	50.1
3992	7.41	30.39	15.02	45.42	24.01	35.88	66.92	0.37	49.4
3552	7.21	26.8	10.6	37.6	25.1	32.9	71.6	0.361	48.5
2994	7.44	22.89	8.1	30.99	23.26	31.49	73.88	0.382	44.1
2492	7.2	17.7	6.3	24.2	26	36.1	71	0.349	35.2
1989	5.49	11.21	5.29	16.51	27	39.74	67.94	0.329	17.5
1445	3.3	5.8	5.63	11.51	20.15	30.6	69.4	0.4	8.8

The discussion of various calculated parameters are given below:

Variation of Torque w.r.t. Engine Speed

Figure 5.4(a) to 5.6(a) shows the variation of torque with speed for pure diesel and biodiesel blends of thumba and jatropha biodiesel. Variation of torque for different blends and pure diesel at a particular engine speed is within a very narrow range. In case of both biodiesel blends and pure diesel, initially the torque rises sharply with increase in engine speed up to 2500 rpm. Between speed 2500 to 4000 rpm the variation or torque with speed remain almost constant. Further increase in speed causes decrease in torque. The pattern is almost same for all blends. The maximum torque achieved in case of thumba biodiesel blend (TB-20) is 7.5 kg-m at 2500 rpm.

Figure 5.4(b) to 5.6(b) shows the percentage change in torque of biodiesels against speed, considering diesel oil as a reference. At initial speed biodiesels have more torque for all percentage of blends. Maximum torque is obtained for thumba oil at a blend of TB30 which is 30% more than diesel oil. Minimum torque is obtained for jatropha biodiesel at 10% blend and at a 2500 rpm. With increasing speed there is not much difference in torque with diesel oil. For the entire rpm range percentage change in torque is positive for all the three blends of thumba oil. The percentage increase in torque for thumba oil varies between 0 to 17%.

Variation of Brake Power w.r.t. Speed

The variation of brake power vs. speed for both blends in comparison to pure diesel is shown in Figure 5.7(a) to 5.9(a). The Brake Power increases proportionally to engine speed in the range of 2000 to 4000 rpm. In this speed range variation of brake power is between 6-32 kW. For more than 4000 rpm there is fluctuating variation in brake power among the biodiesel blends. The maximum brake power achieved for thumba biodiesel blend (TB-10) is 35 kW at 5000 rpm. The variation of brake power is almost negligible for all types of blends and pure diesel for upto 4000 engine rpm. Between 4000 to 5000 rpm biodiesel blends are having slightly higher brake power as compared to pure diesel.

The percentage change of brake power of biodiesels with speed considering diesel oil at baseline is shown in figure 5.7(a) to 5.9(b). At initial speed brake power obtained is more in case of biodiesel for all percentage of blends. Maximum percentage increase in brake power has obtained for jatropha biodiesel at TB30 blend and at 1500 rpm which is 37.5% more.

Thumba and jatropha biodiesel shows similar pattern. At the speed range of 2500 to 4000 brake power of biodiesel is almost constant with diesel oil for all blends. At 2000 rpm biodiesel shows slightly less power than diesel oil.

Variation of brake specific fuel consumption w.r.t. engine speed

The variations of brake specific fuel consumption vs. speed are shown in Figure 5.10(a) to 5.12(a) for biodiesel blends and pure diesel. For all cases the bsfc initially decreases sharply with increase in rpm upto 2000 and afterward between the rpm 2000-4000 bsfc remains approximately constant. For more than 4000 rpm range bsfc increases sharply with speed. The bsfc for all blends and pure diesel is least at 2000 rpm. The bsfc for JB-30 of jatropha oil is lowest between the rpm range of 2000 to 4500. In this speed range the bsfc varies between 0.32 kg/kWh to 0.44kg/kWh. In case of all thumba and jatropha biodiesel blends bsfc values are significantly lower as compared to pure diesel for a wide range of engine speed. This trend encourages the possibility of further increase in percentage of biodiesel blending during experimentation.

Change in percentage of sfc of biodiesel with speed considering diesel oil as a reference line shown in figure 5.10(b) to 5.12(b). At 10% blend of biodiesels, percentage change of sfc is within $\pm 4\%$ with diesel oil and for TB20 and JB20 reduction in sfc are within 5% and 10% respectively. At the speed range of 2000 rpm to 3500 rpm much reduction in sfc has obtained for biodiesel than diesel oil. Maximum reduction in sfc has obtained at 2000 rpm and at JB30 blend of jatropha biodiesel. As shown in figure 5.12(b) the maximum percentage reduction of sfc for biodiesel blends (TB30 and JB30) is 11% and 13% respectively.

Brake Thermal Efficiency vs Speed

Figure 5.13(a) to 5.15(a) shows comparison of Brake thermal efficiency vs. speed for different biodiesel blends of thumba and jatropha oil in comparison to diesel respectively. The maximum value of brake thermal efficiency for all blends & pure diesel is at 2000 rpm. For all blends of both oil variation of brake thermal efficiency is higher as compared to pure diesel for wide range of engine speed. The maximum thermal efficiency is achieved by using JB-30 blend is around 26.9 % at 2000 rpm which is 5 % higher as compared to pure diesel. The brake thermal efficiency is almost constant between rpm range of 2000 to 4000, and it decreases sharply with further increase in rpm and with increase in percentage of biodiesel blending the brake thermal efficiency increase for wide range of engine rpm. Both jatropha

and thumba oil exhibit comparatively higher efficiency for all speed range than pure diesel with all blends. Biodiesel blend of 30% shows much higher efficiency than diesel fuel.

The percentage change in brake thermal efficiency of biodiesel at various speeds compare to diesel is shown in figure 5.13(b) to 5.15(b). For all percentage of blends and speed, biodiesels shows higher brake thermal efficiency than diesel engine. For 10% of blend % increase in brake thermal efficiency for biodiesel is less than 5% for all speeds. At 30% of blend maximum brake thermal efficiency increased is 19.8% for jatropha biodiesel and except initial speed efficiency of biodiesel is higher than diesel oil.

Opacity vs. Speed

To understand the pollution aspect of biodiesel the variation of opacity vs. speed are shown in Figure 5.16(a) to 5.18(a) for biodiesel blends in comparison to pure diesel. The opacity value for pure diesel is slightly higher as compared to all type of blends for wide range of engine rpm. For all biodiesel blends the opacity value increases from 10 to 60 % between the speed ranges of 2000 to 3500 rpm. There is no significant change in opacity value for above 4000 rpm engine speed. The trend regarding variation of opacity with respect to speed is almost similar for all type of blends and further the variation of opacity value of different blend at a particular rpm is almost negligible.

Percentage change in opacity at various speeds shown in figure 5.16(b) to 5.18(b). Except initial speed of 1500 rpm opacity of all biodiesel blends have less value than diesel oil. At around 3500 rpm percentage change in opacity is not much for biodiesel than diesel oil. At speed range of 2000 rpm to 3000 rpm opacity has much reduced for biodiesel than diesel oil. Maximum reduction in opacity has obtained at 2000 rpm which is 22.2% for thumba biodiesel.

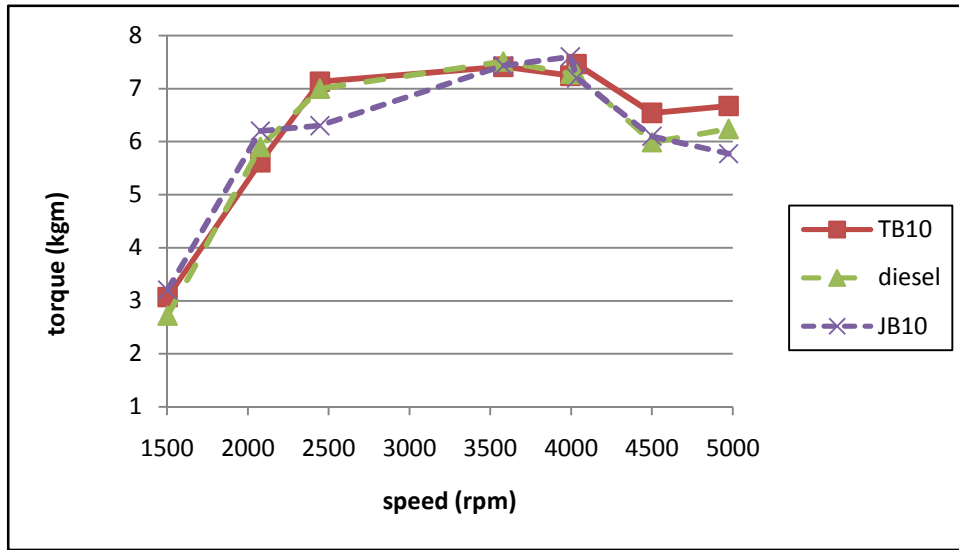


Figure 5.4(a) Comparison of Torque Vs Speed for 10% biodiesel blends of Jatropha & Thumba oil

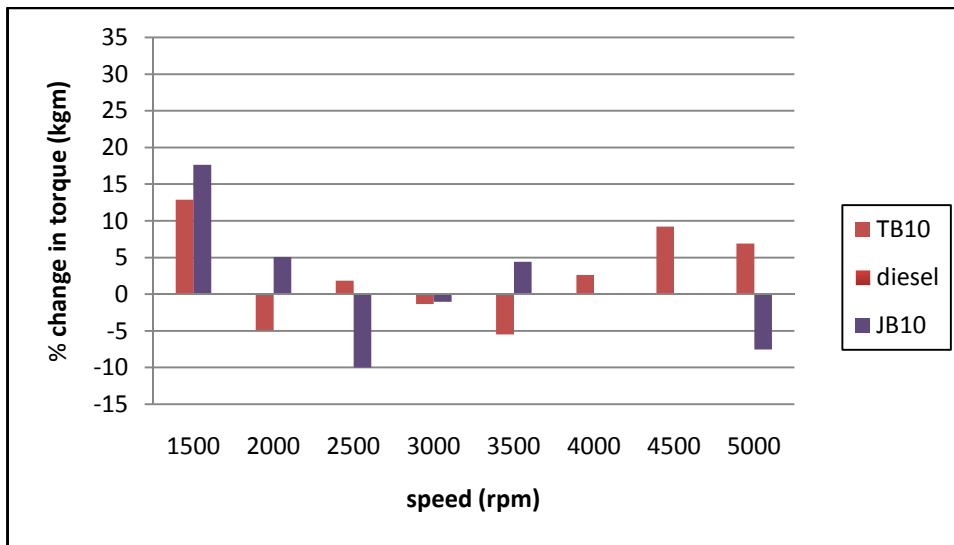


Figure 5.4(b) Change in torque with the biodiesels blend of 10% compared to diesel fuel as baseline

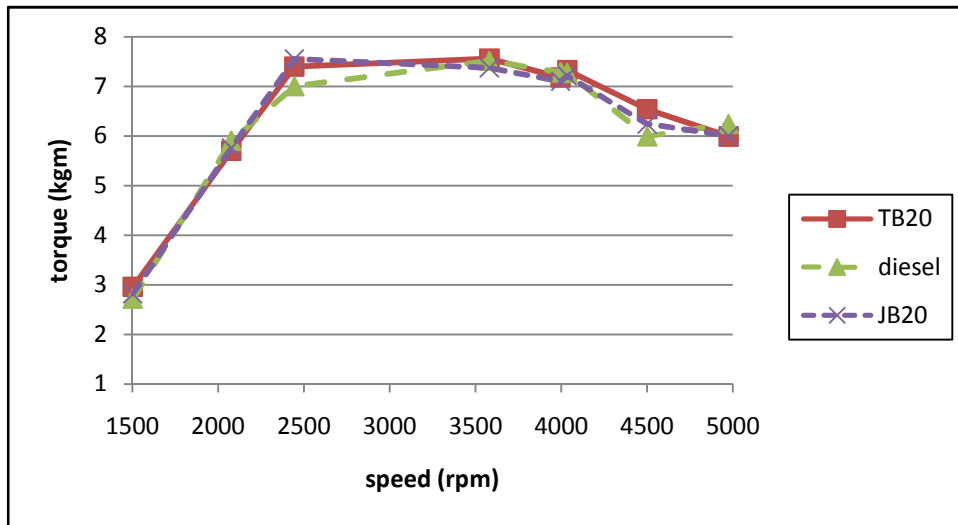


Figure 5.5(a) Comparison of Torque Vs Speed for 20% biodiesel blends of Jatropha & Thumba oil

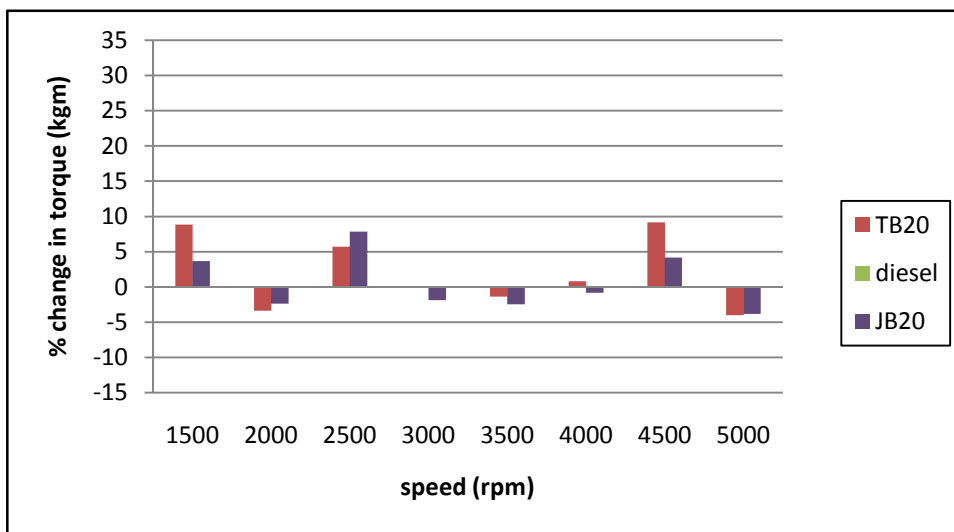


Figure 5.5(b) Change in torque with the biodiesels blend of 20% compared to diesel fuel as baseline

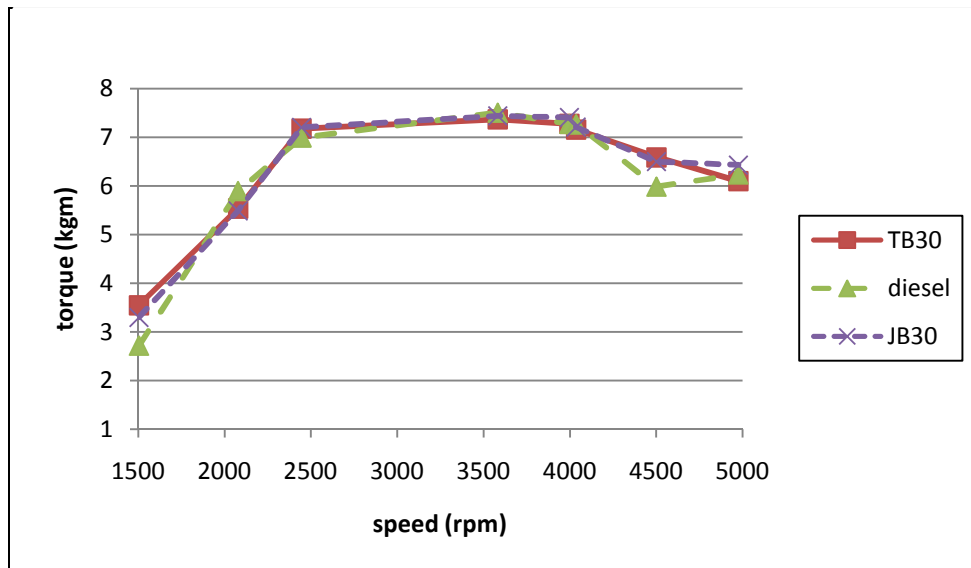


Figure 5.6(a) Comparison of Torque Vs Speed for 30% biodiesel blends of Jatropha & Thumba oil

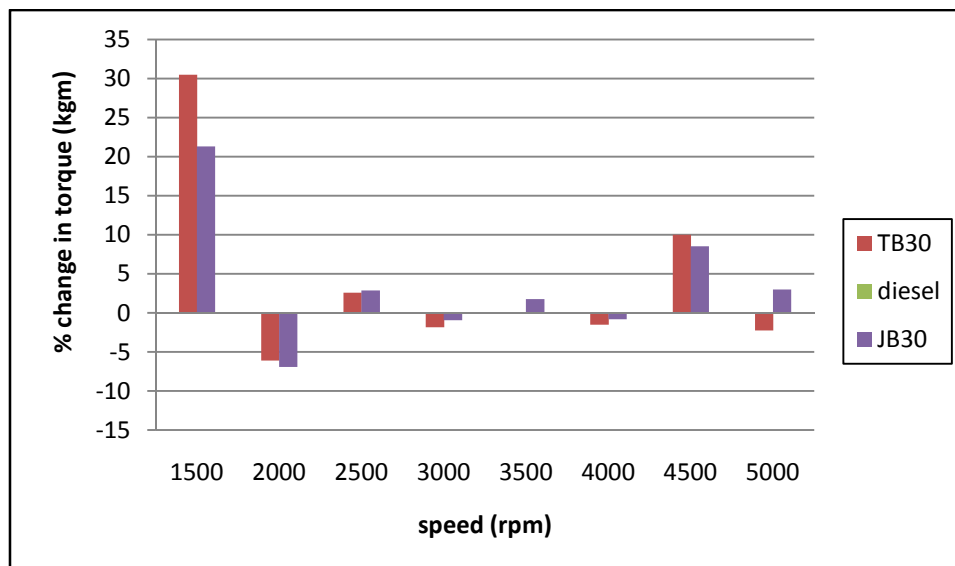


Figure 5.6(b) Change in torque with the biodiesels blend of 30% compared to diesel fuel as baseline.

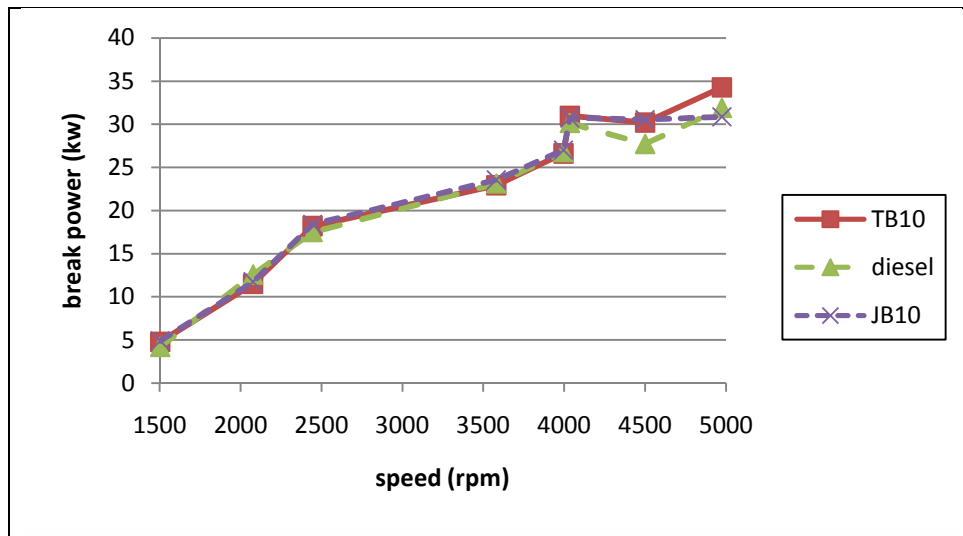


Figure 5.7(a) Comparison of Brake Power Vs Speed for 10% biodiesel blends of Jatropha & Thumba oil

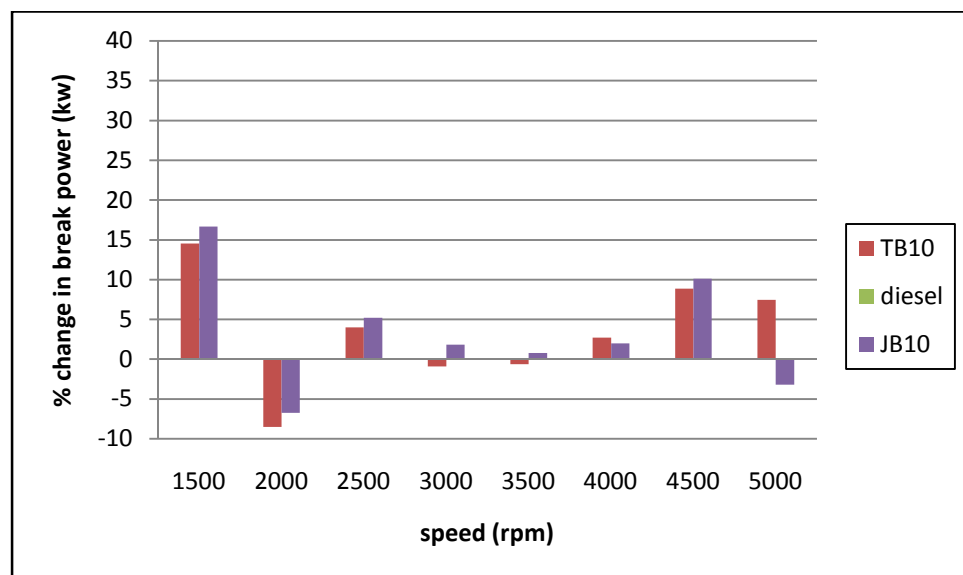


Figure 5.7(b) Change in brake power with the biodiesels blend of 10% compared to diesel fuel as baseline.

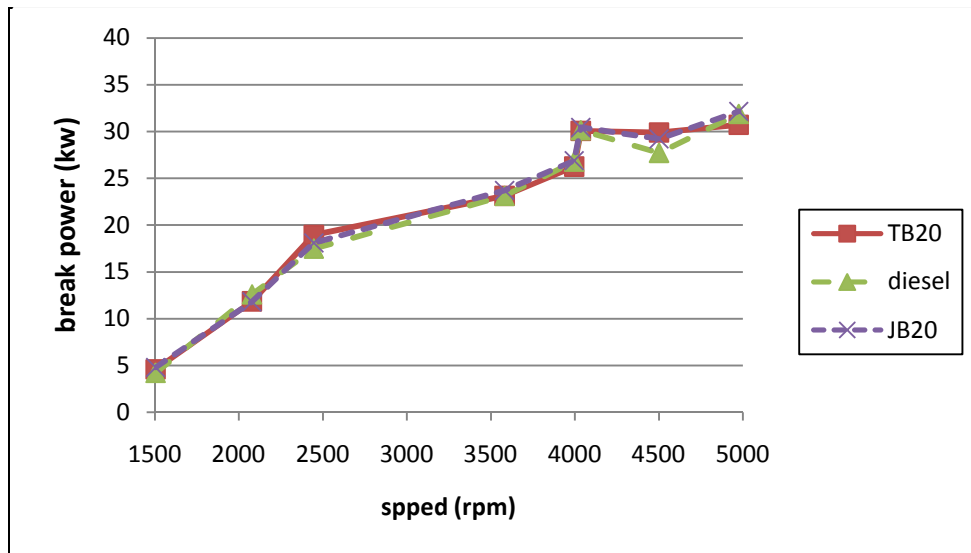


Figure 5.8(a) Comparison of Brake Power Vs Speed for 20% biodiesel blends of Jatropha & Thumba oil

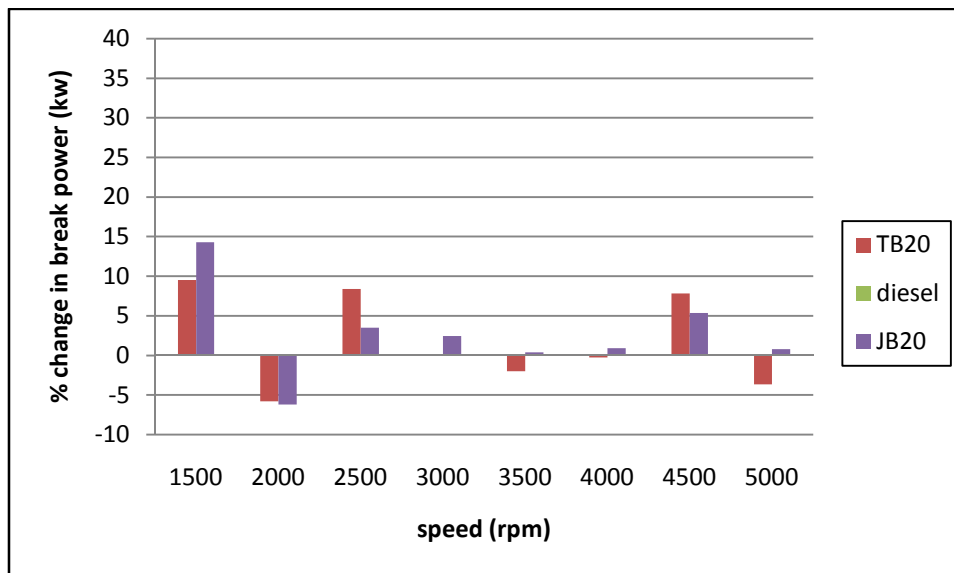


Figure 5.8(b) Change in brake power with the biodiesels blend of 20% compared to diesel fuel as baseline

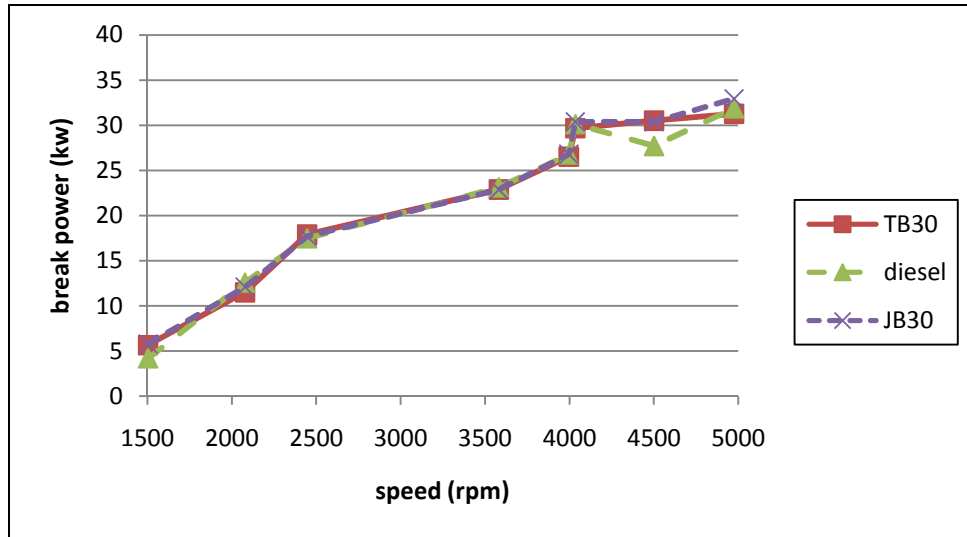


Figure 5.9(a) Comparison of Brake Power Vs Speed for 30% biodiesel blends of Jatropha & Thumba oil

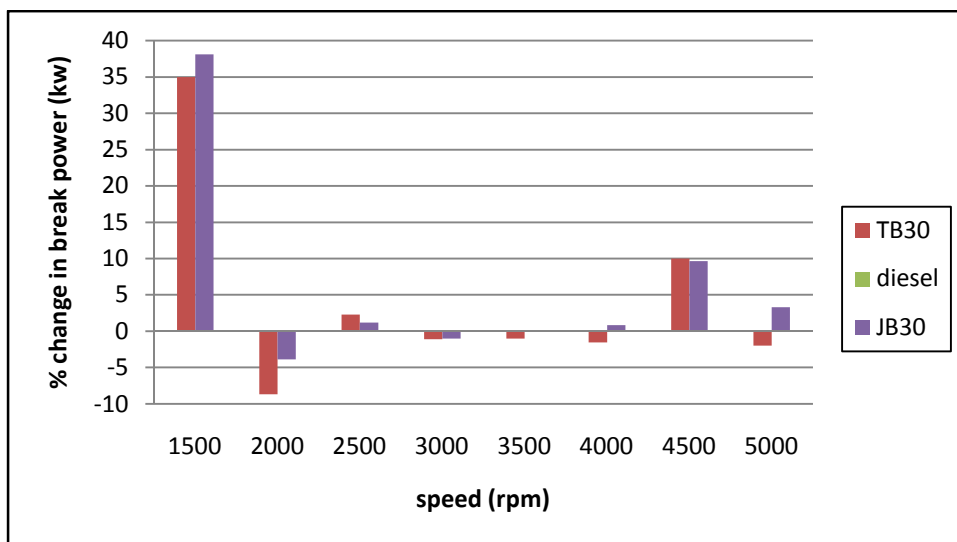


Figure 5.9(b) Change in brake power with the biodiesels blend of 30% compared to diesel fuel as baseline

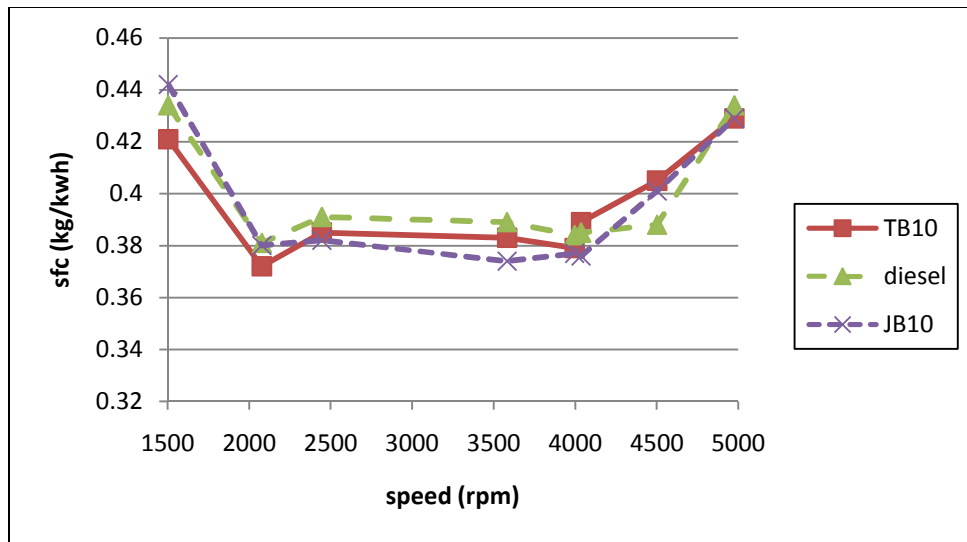


Figure 5.10(a) Comparison sfc Vs Speed for 10% biodiesel blends of Jatropa & Thumba oil

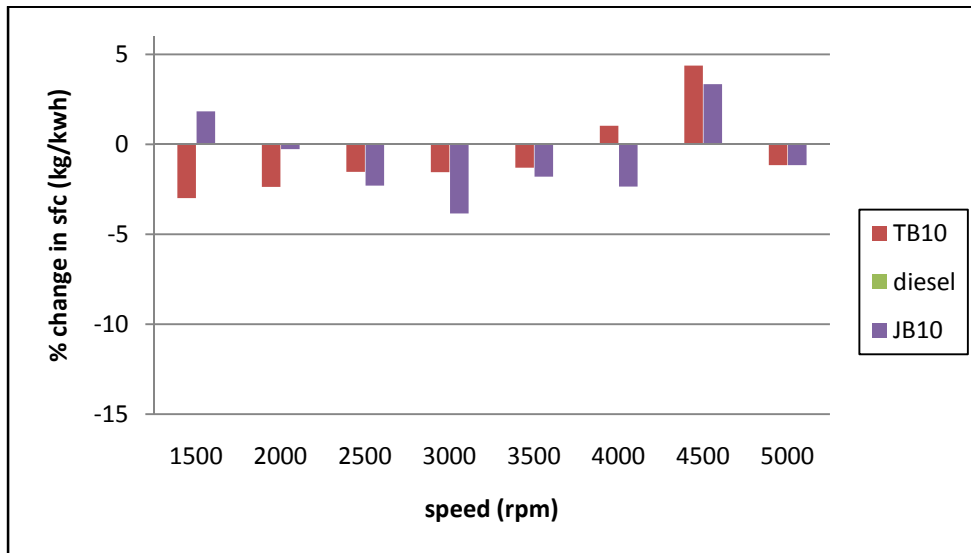


Figure 5.10(b) Change specific fuel consumption with the biodiesels blend of 10% compared to diesel fuel as baseline

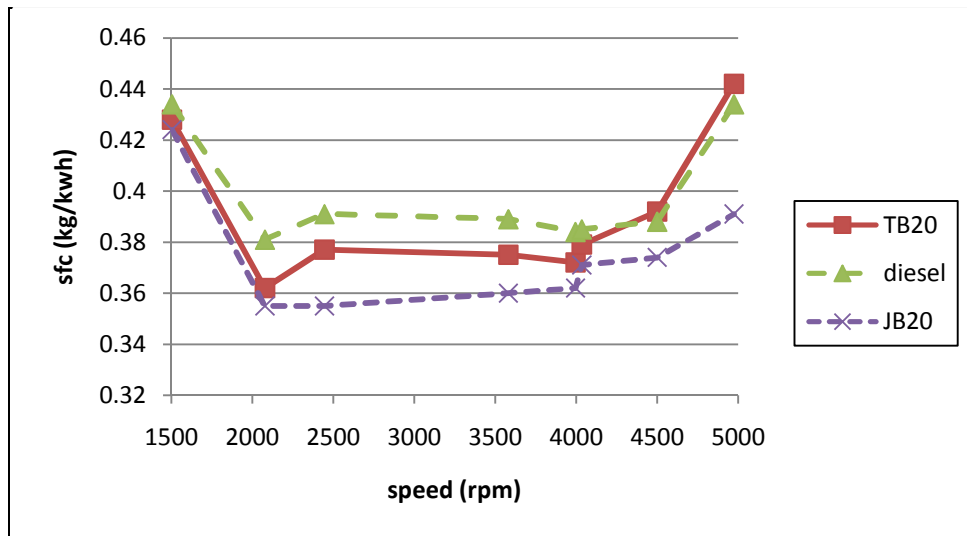


Figure 5.11(a) Comparison sfc Vs Speed for 20% biodiesel blends of Jatropha & Thumba oil

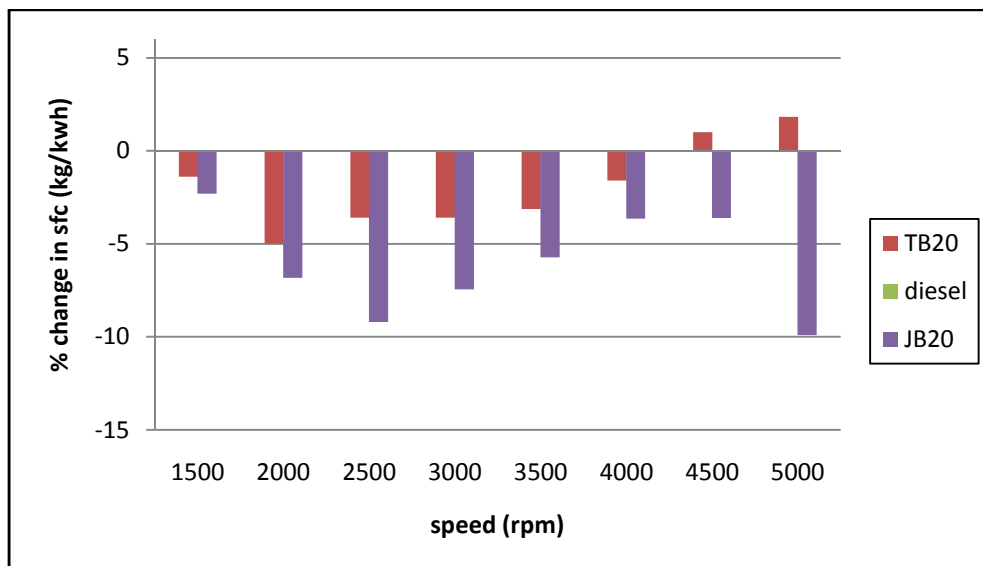


Figure 5.11(b) Change in specific fuel consumption with the biodiesels blend of 20% compared to diesel fuel as baseline

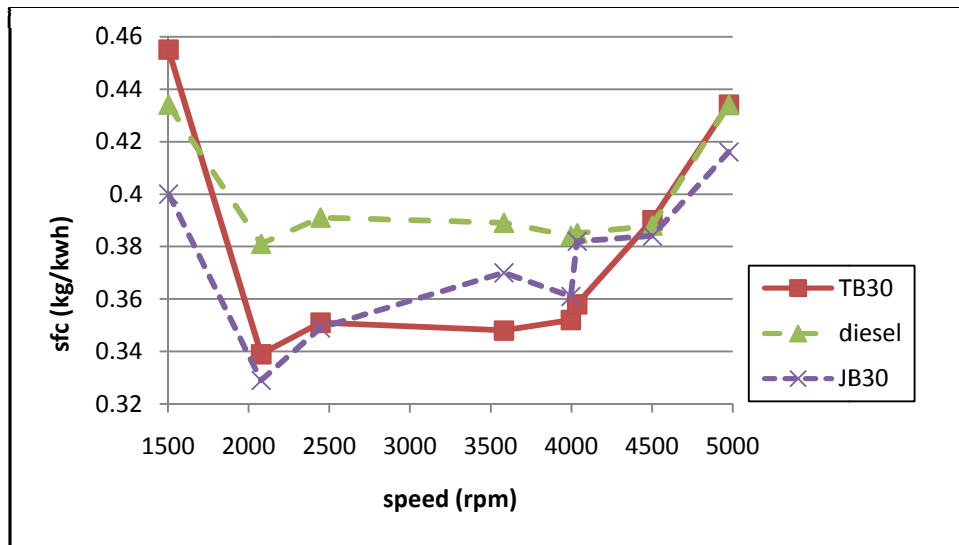


Figure 5.12(a) Comparison sfc Vs Speed for 30% biodiesel blends of Jatropha & Thumba oil

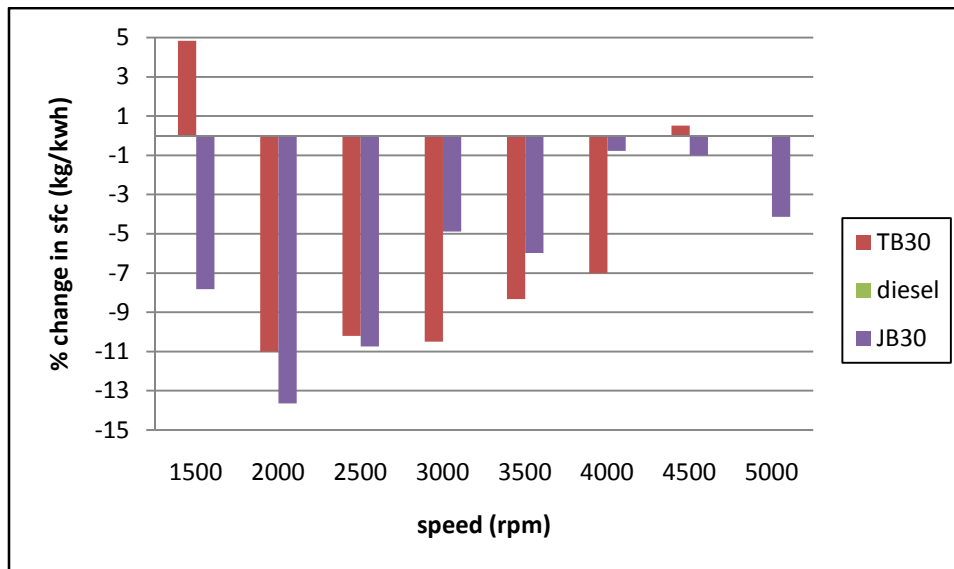


Figure 5.12(b) Change in specific fuel consumption with the biodiesels blend of 30% compared to diesel fuel as baseline

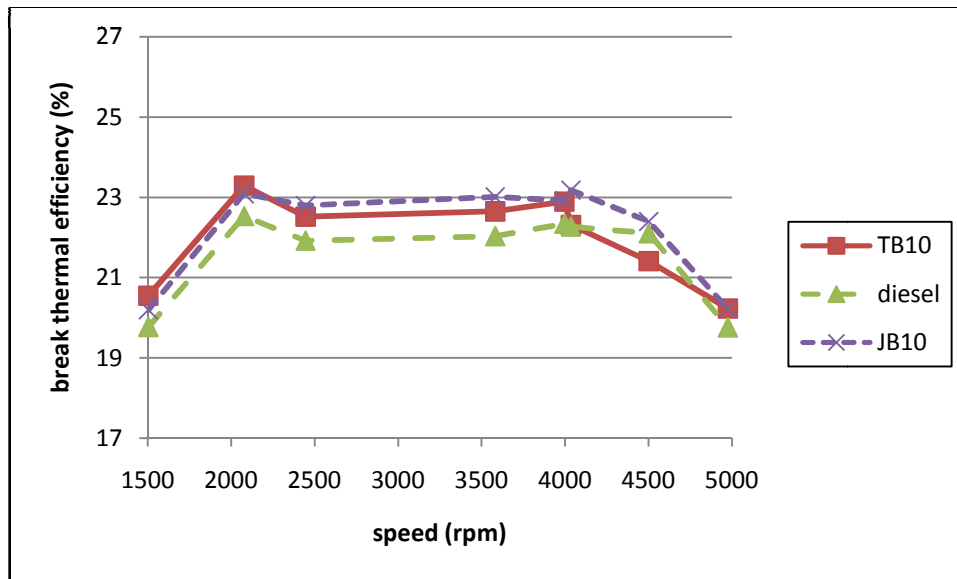


Figure 5.13(a) Brake Thermal Efficiency Vs Speed for 10% biodiesel blends of Jatropa & Thumba oil

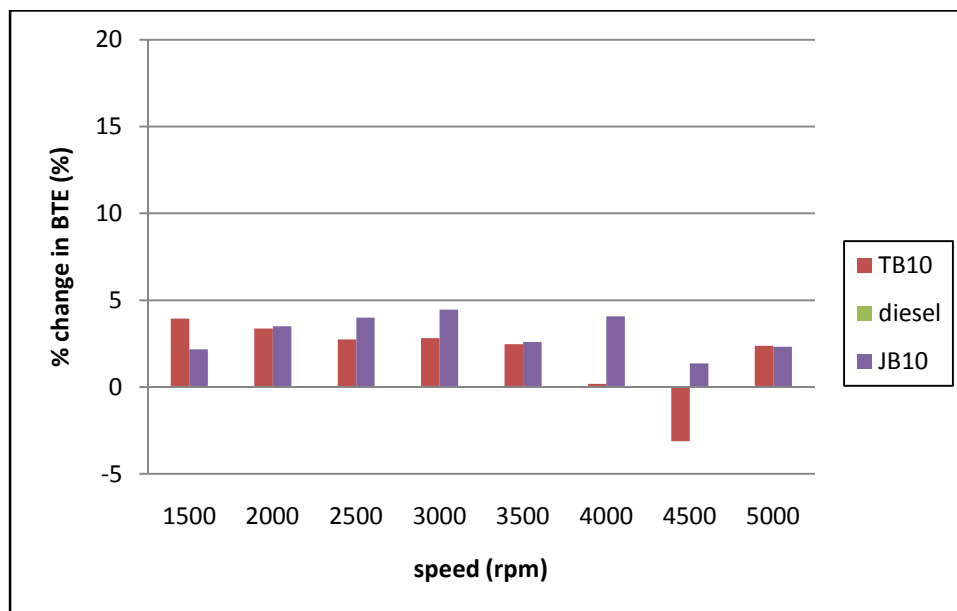


Figure 5.13(b) Change in brake thermal efficiency with the biodiesels blend of 10% compared to diesel fuel as baseline

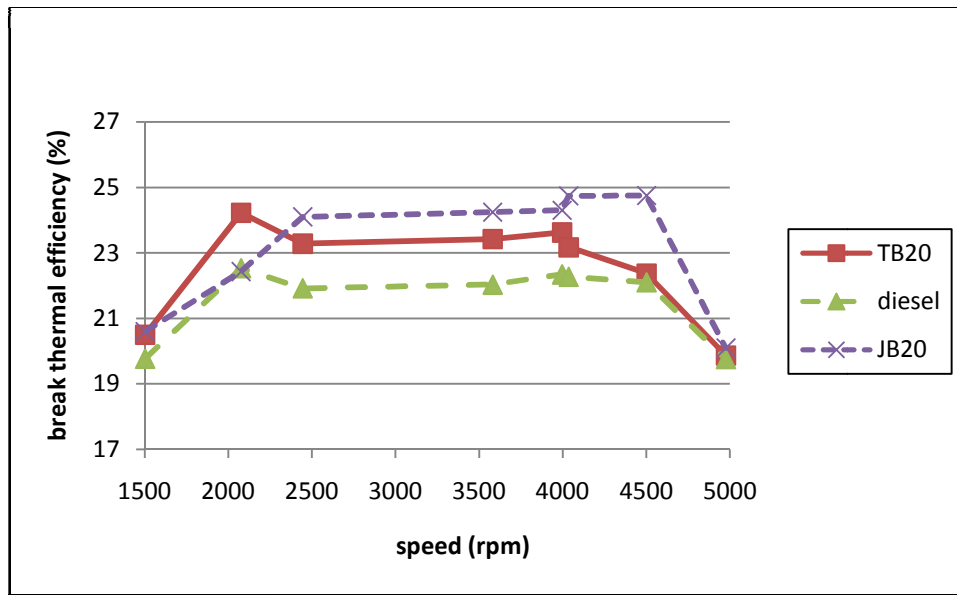


Figure 5.14(a) Brake Thermal Efficiency Vs Speed for 20% biodiesel blends of Jatropha & Thumba oil

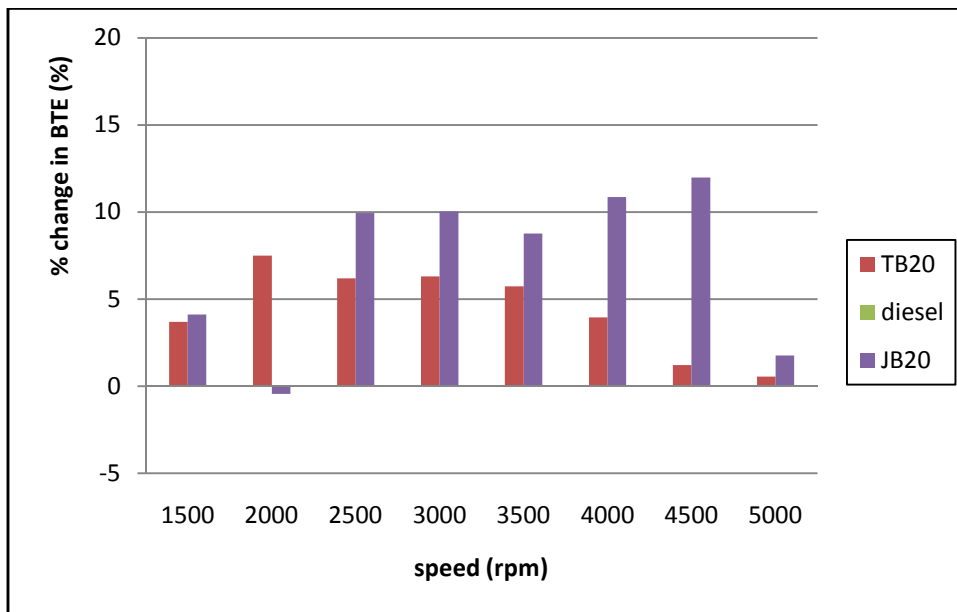


Figure 5.14(b) Change in brake thermal efficiency with the biodiesels blend of 20% compared to diesel fuel as baseline

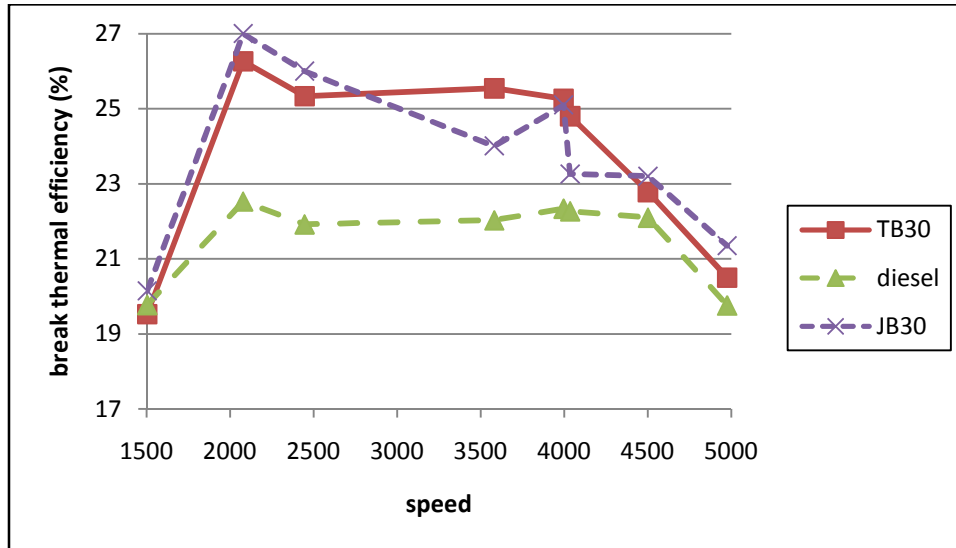


Figure 5.15(a) Brake Thermal Efficiency Vs Speed for 30% biodiesel blends of Jatropha & Thumba oil

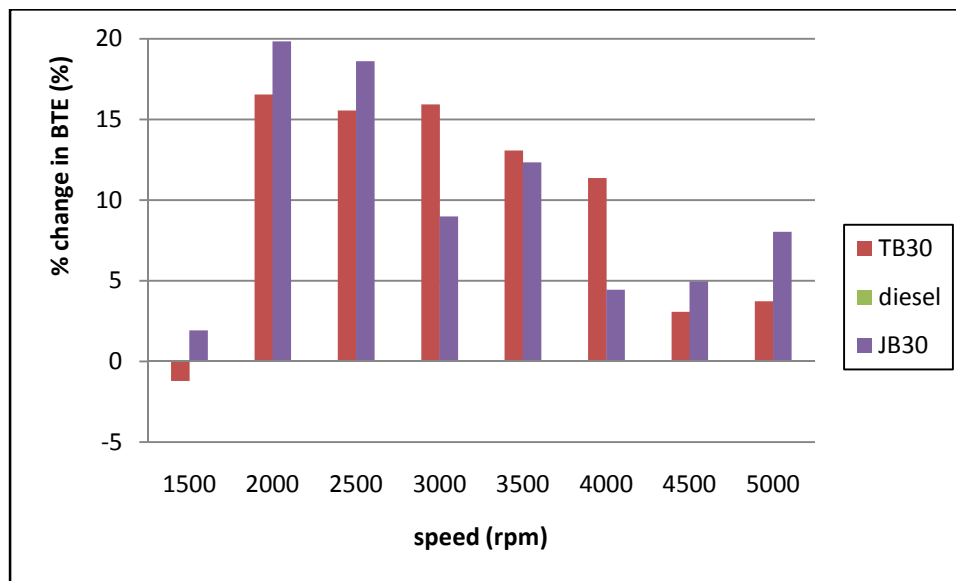


Figure 5.15(b) Change in brake thermal efficiency with the biodiesels blend of 30% compared to diesel fuel as baseline

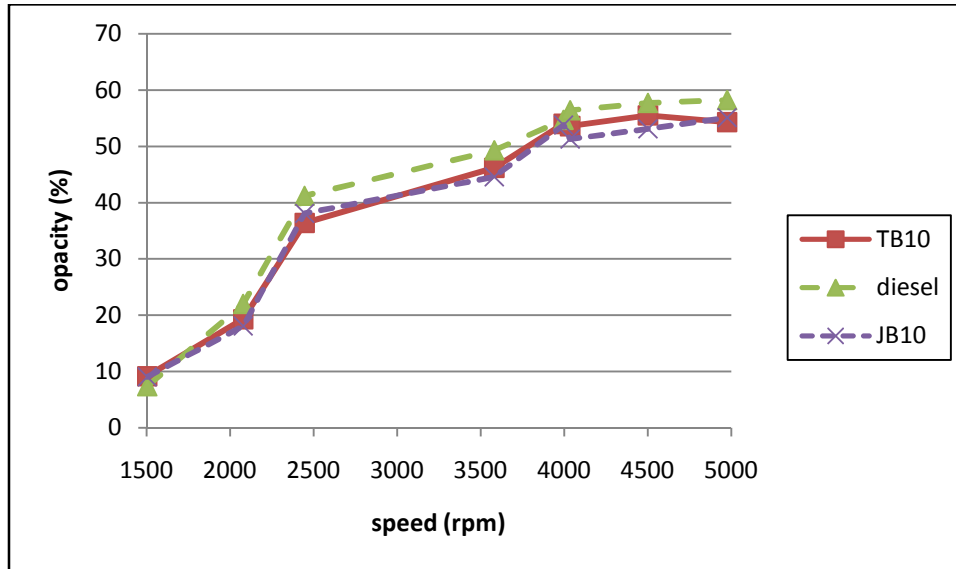


Figure 5.16(a) Comparison of Opacity Vs Speed for 10% biodiesel blends of Jatropha & Thumba oil

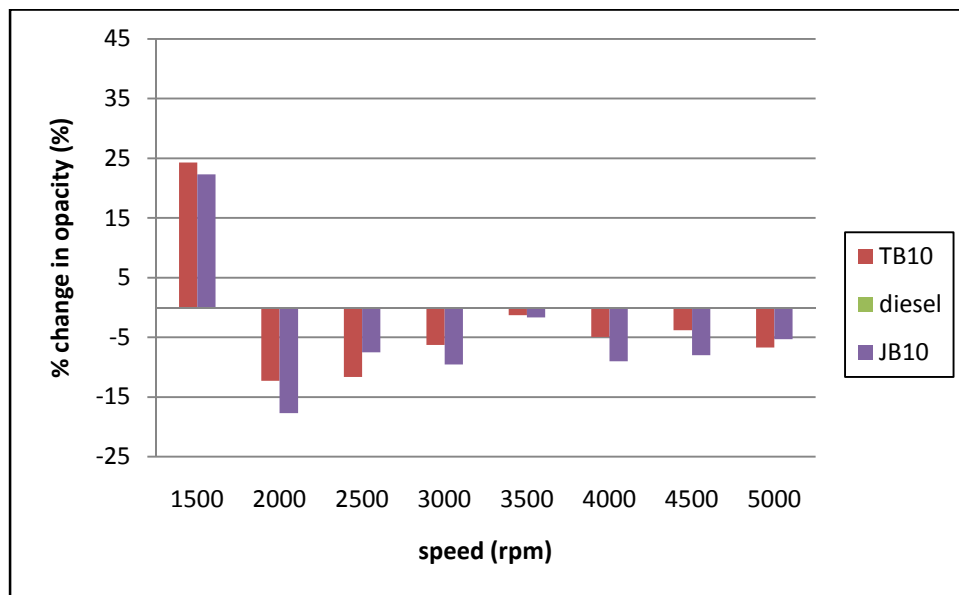


Figure 5.16(b) Change in opacity with the biodiesels blend of 10% compared to diesel fuel as baseline

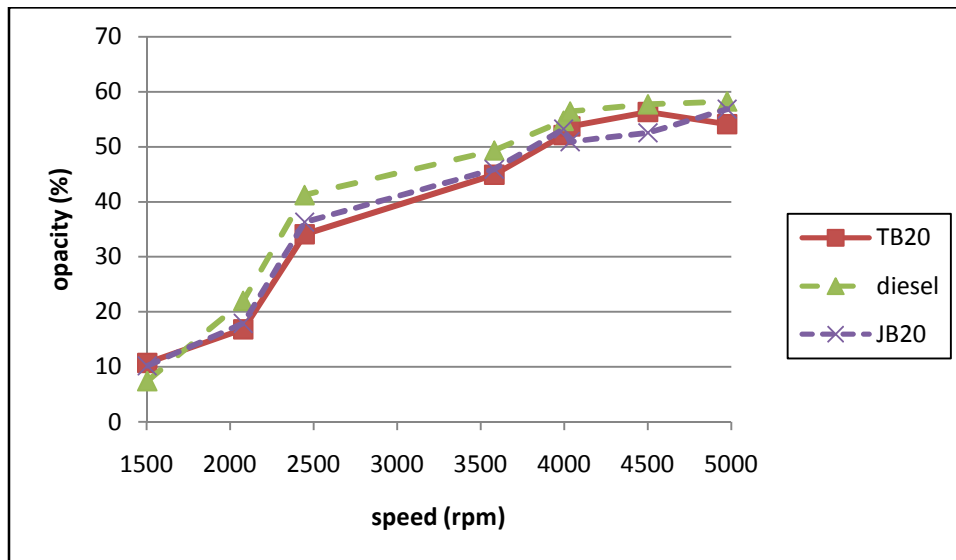


Figure 5.17(a) Comparison of Opacity Vs Speed for 20% biodiesel blends of Jatropha & Thumba oil

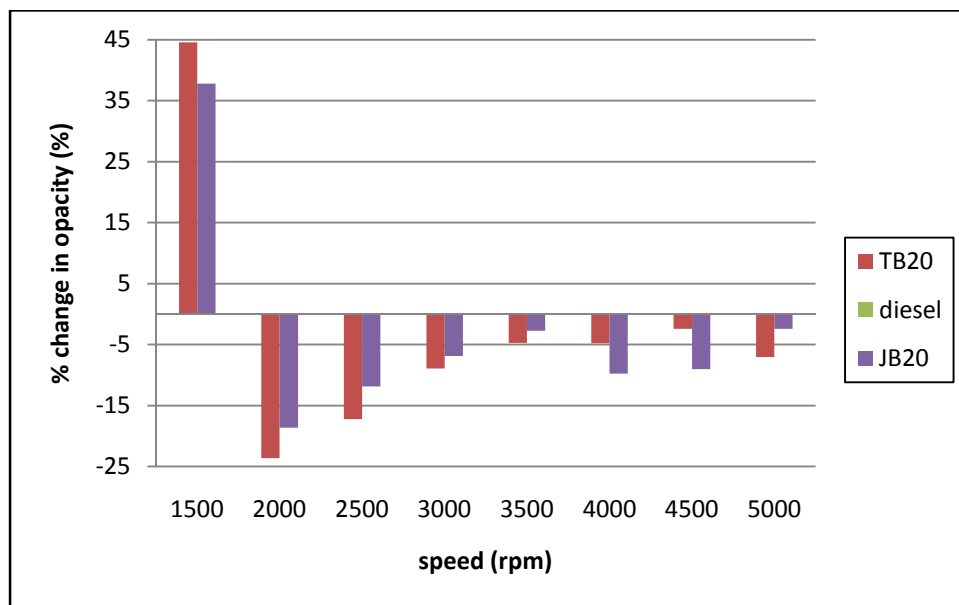


Figure 5.17(b) Change in opacity with the biodiesels blend of 20% compared to diesel fuel as baseline

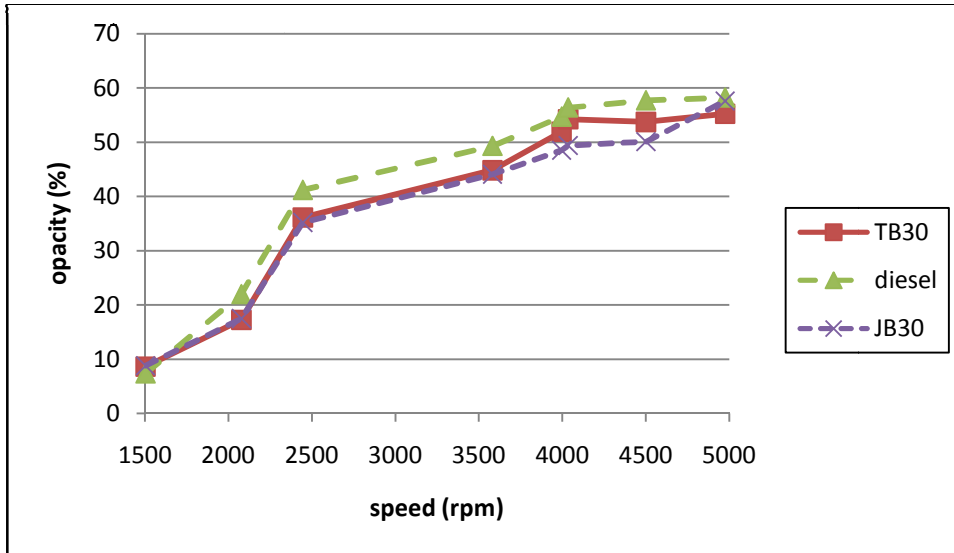


Figure 5.18(a) Comparison of Opacity Vs Speed for 30% biodiesel blends of Jatropha & Thumba oil

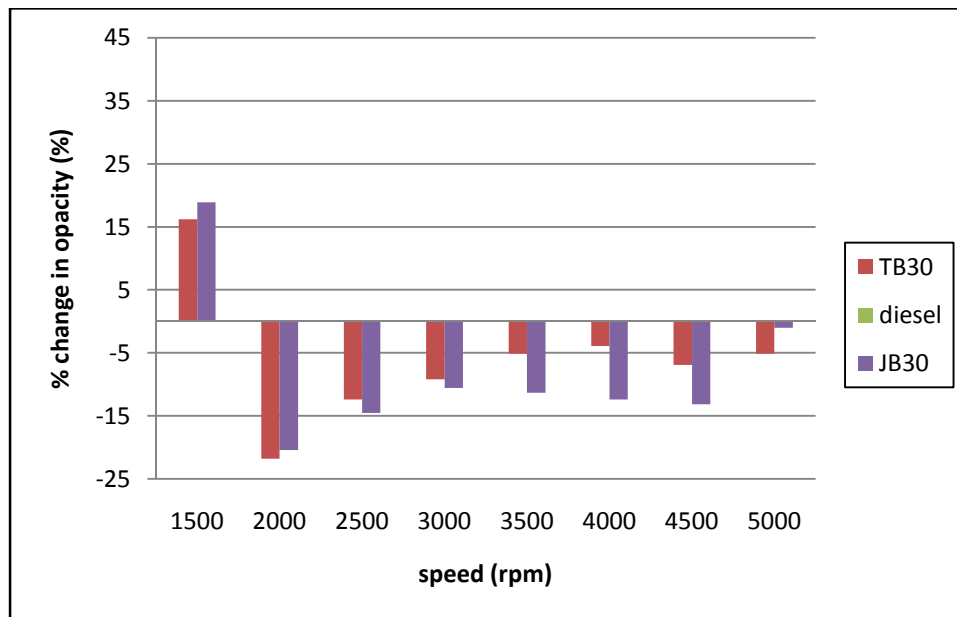


Figure 5.18(b) Change in opacity with the biodiesels blend of 30% compared to diesel fuel as baseline

6. CONCLUSION

Ultrasonic cavitation method and hydrodynamic cavitation method are good alternative for the biodiesel production. It is observed that in ultrasonic cavitation method the reaction time for the methyl ester formation is less than the other conventional process such as magnetic stirrer of biodiesel production and satisfactory yield from methyl ester is obtained. Thumba oil is a new source of biodiesel production in this experiment. It is observed that for thumba oil reaction time required for biodiesel production and yield are almost similar to the jatropha oil.

Following conclusion has been made from the experiments:

1. The reaction time required for methyl ester formation is much shorter for ultrasonic cavitation method compare to conventional magnetic stirring method.
2. Slightly more yield (70-80%) has obtained by ultrasonic cavitation technique compare to convention method of biodiesel production.
3. It is observed from the experimental result that there is not much difference in yield (%) and reaction time by taking catalyst 0.5%, 0.75% and 1% of oil with the ultrasonic cavitation method and therefore 0.5% catalyst is optimum catalyst to be used because catalyst is an impurity and its use should be low as much as possible.

From the engine performance testing it can be concluded that the performance parameter and emission characteristics for both biodiesel (thumba and jatropha) have better results than the diesel oil. In this project performance of biodiesel is compared by the parameters like brake power, torque, brake thermal efficiency, specific fuel consumption and emission is characterized by opacity measurement. Some advantages obtained for biodiesel are:

1. At low speed more torque is obtained for biodiesel and torque almost constant for wide range of speed for both diesel and biodiesel blends. Maximum torque obtained for thumba oil is 7.5 kg-m at 2500 rpm and maximum percentage increase in torque is 30% more than the diesel oil which is obtained for 30% blend of thumba oil and at 1500 rpm.
2. More brake power has obtained at initial speed and it is nearly constant for 2500 to 4000 rpm. The maximum brake power achieved is 35 kW at 5000 rpm for thumba biodiesel a blend of 10%. Maximum percentage increase obtained for jatropha biodiesel of 30% blend is 37.5% at 1500 rpm.

3. Except at starting speed more brake thermal efficiency has obtained for higher speeds. For 10% blend of biodiesel there is not much difference in diesel and biodiesel. For higher blend biodiesel has much better efficiency than diesel oil.
maximum brake thermal efficiency increased is 19.8% for jatropha biodiesel at 2000 rpm.
4. Biodiesel blends reduce the specific fuel consumption for higher load. For the blend 10% there is not much difference in sfc but at higher % if blend sfc reduced considerably. Maximum reduction in sfc has obtained for 30% blend of jatropha biodiesel at 2000 rpm.
5. Lower value of opacity has obtained for biodiesel than diesel oil at higher speeds. Maximum reduction in opacity has obtained is 22.2% for thumba biodiesel.

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