1. INTRODUCTION

1.1 General

Various products derived from vegetable oils have been proposed as an alternative fuel for diesel engines. Today ‘‘biodiesel’’ is the term applied to the esters of simple alkyl fatty acids used as an alternative to petroleum based diesel fuels. Importance of biodiesel in the recent context increases due to increasing petroleum prices; limited fossil fuel reserves and environmental benefits of biodiesel viz. decrease in acid rain, decrease in emission of CO_2, SO_X and un-burnt hydrocarbons during the combustion process. Beside these factors, its easy biodegradability, production of biodiesel is considered as an advantage over that of fossil fuels.

The main commodity sources of biodiesel in India are non edible oils obtained from plant species such as Jatropha, Pongamia pinnata etc. Biodiesel contains no petroleum, but it 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, carbon monoxide and particulate matters. 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 cetain number improves the ignition quality even when blended in the petroleum diesel.

Presently various techniques have developed for producing biodiesel. Some of them are Mechanical stirring, ultrasonic cavitation, and 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. [1]. 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 vapor 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 creates micro jets, leading to intensive emulsification of the system. 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.

1.2 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.

$$\begin{array}{lcccccl}
CH_2\text{-}OOC\text{-}R_1 & & & & R_1\text{-}COO\text{-}R' & & CH_2\text{-}OH \\
| & & & \text{catalyst} & & & | \\
CH\text{-}OOC\text{-}R_2 & + & 3R'OH & \longleftrightarrow & R_2\text{-}COO\text{-}R' & + & CH\text{-}OH \quad \text{-------} \quad (1.1) \\
| & & & & & & | \\
CH_2\text{-}OOC\text{-}R_3 & & & & R_3\text{-}COO\text{-}R' & & CH_2\text{-}OH \\
\text{Glycerides} & & \text{Alcohol} & & \text{Esters} & & \text{Glycerin}
\end{array}$$

where, the 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 stecheometric 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 [2, 3].

$$\textbf{Triglycerides (TG) + R'OH} \underset{k_2}{\overset{k_1}{\longleftrightarrow}} \textbf{Diglycerides (DG) + R'COOR}_1 \text{ ------- } (1.2)$$

$$\textbf{Diglycerides (DG) + R'OH} \underset{k_4}{\overset{k_3}{\longleftrightarrow}} \textbf{Monoglycerides (MG) + R'COOR}_2 \text{ ----- } (1.3)$$

$$\textbf{Monoglycerides (MG) + R'OH} \underset{k_6}{\overset{k_5}{\longleftrightarrow}} \textbf{Glycerin (GL) + R'COOR}_3 \text{ ------- } (1.4)$$

Where k_1, k_2, k_3, k_4, k_5, k_6 are the catalyst used which may be acidic catalyst, alkali catalyst or lipase as a catalyst. These are described below.

<u>Alkali Catalyst</u>

These catalyst can be used with methanol or ethanol as well as any kind of oils, refine, crude or frying. The main alkali catalysts are.

a. Sodium hydroxide (NaOH).
b. Potassium hydroxide (KOH).

<u>Acidic Catalyst</u>

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

a. Sulfuric acid (H_2SO_4).
b. Sulfonic acid.

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 [4].

The productions of vegetable oil globally and in India are given in Table 1.1 and Table 1.2.

Table 1.1 Global production of the major vegetable oils [4]

Oil	**Production (million tonnes)**
Soybean	27.8
Rapeseed	13.7
Cottonseed	4.0
Sunflower	8.2
Peanut	5.1
Coconut	3.5
Linseeds	0.6
Palm	23.4
Palm kernel	2.9
Olive	2.7
Corn	2.0
Castor	0.5
Seasame	0.8
Total	**95.2**

Table 1.2 Vegetable oil production in India [4]

Oil	**Production (million tonnes)**
Groundnut	1.40
Soya	0.82
Rape / Mustard	1.55
Sunflower	0.30
Sesame	0.26
Castor	0.25
Niger	0.03
Safflower	0.09
Linseeds	0.10
Cottonseed	0.44
Coconut	0.55
Rice Bran	0.55
Oil from expelled cakes	0.28
Minor oilseeds	0.05
Total	**6.67**

1.4 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 [4].

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 ^{0}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 whether 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 no. and stability.

There are three types of stability criteria:

- Oxidation stability
- Storage stability
- 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. SO 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 1.3. And properties of the biodiesel from different oil are given in Table 1.4.

Table 1.3 summary of proposed BIS(Bureau of Indian Standards) standards for biodiesel [4]

Standard / specification		**Proposed BIS**
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

Table 1.4 Properties of biodiesel from different oils [5]

Vegetable oil methyl esters (biodiesel)	Kinematic viscosity (mm^2/s)	Cetane no.	Lower heating value (MJ/kg)	Cloud point (^oC)	Pour point (^oC)	Flash point (^oC)	Density (kg/l)
Peanut	4.9	54	33.6	5	–	176	0.883
Soya bean	4.5	45	33.5	1	-7	178	0.885
Babassu	3.6	63	31.8	4	–	127	0.875
Palm	5.7	62	33.5	13	–	164	0.880
Sunflower	4.6	49	33.5	1	–	183	0.860
Tallow	–	–	–	12	9	96	–
Diesel	3.06	50	43.8	–	-16	76	0.855
20% biodiesel blend	3.2	51	43.2	–	-16		0.859

1.5 Objective of Present Project

The objective of present work include two parts

Development of Test Rig

In present work a set of hydrodynamic cavitation technique for biodiesel production is prepared. In which cavitation is generated by passing the mixture of vegetable oil and alcohol through an orifice hole. The biodiesel is prepared using thumba oil, methanol and sodium hydroxide as a catalyst. The reaction is carried out in oil to alcohol molar ratio of 1:4.5 and 1:6.

Performance Testing

After preparing biodiesel from thumba oil its blends with petroleum diesel (pure diesel, B-10, B-20, B-30) are tested on a four cylinder four stroke diesel engine (make: Indica). And similar blends of biodiesel from jatropha oil are also tested on this engine and there performence characteristics are compared. Also the heat balance analysis is done in these experiments.

2. LITERATURE OVERVIEW

The literature review has been classified into two broad categories.

- Biodiesel production techniques through cavitation process.
- Performance characteristics.

2.1 Biodiesel Production Techniques

Jianli Wang [6] performs experiments on Power Ultrasonic (PU), 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 with a jacket, as shown in Fig. 2.1. The horn of the transducer was submerged 2 cm in the reactive mixture. The temperature of the reaction mixture was controlled by a water bath. Vegetable oil (100 g) was poured into the reactor at the beginning of each reaction for warm-up. The reaction started when a quantitative amount of methanol liquor dissolved in NaOH was poured into the heated reactor. Orthogonality experiments were designed with 4 factors and 3 levels, which are listed in Table 2.1.

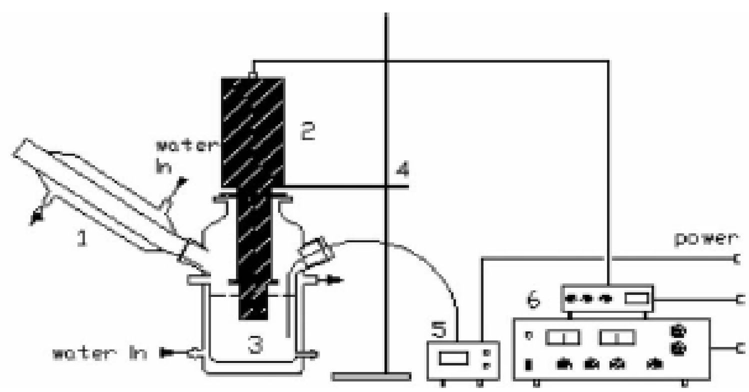


Figure 2.1 Schematic diagram of ultrasonic system setup [6]

Where 1– condensator; 2 – transducer; 3 –ultrasonic reactor; 4 – stand support; 5 – thermometer; 6 – ultrasonic generator.

Table 2.1 Orthogonality experiments design [6]

factor	A, Power (W)	B, molar ratio	C, pulse frequency	D, temperature (^{0}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 2.2. 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

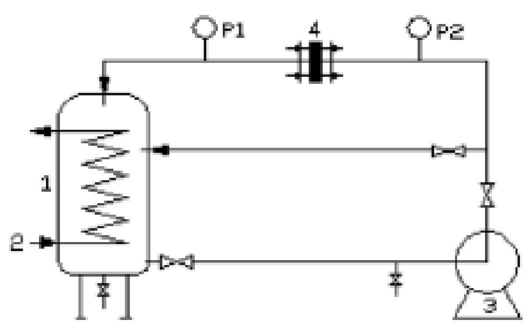


Figure 2.2 Schematic diagram of hydrodynamic system setup [6]

Where “1– tank; 2 – cold water; 3 –pump; 4 – orifice plate”

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 Fig. 2.3.

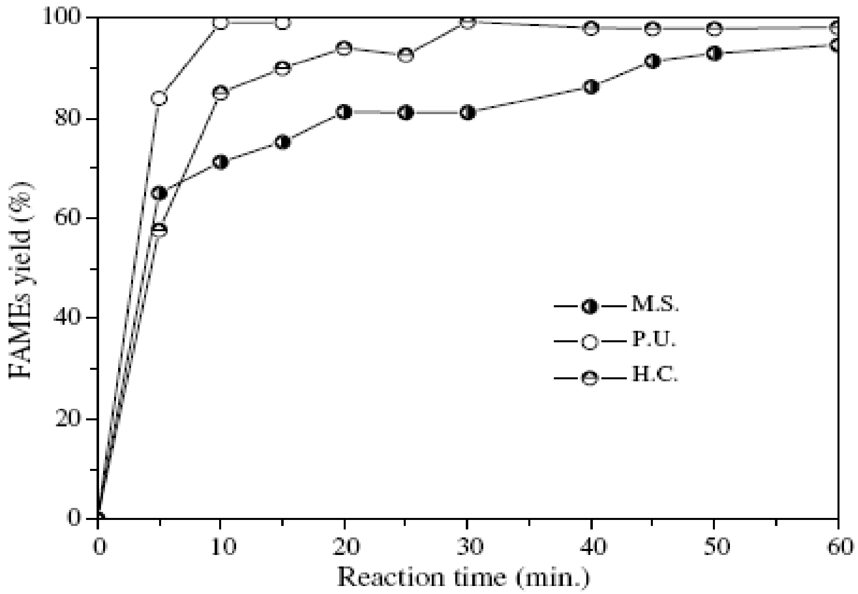


Fig. 2.3 Effect of different methods on FAMEs yield [6]. [Reaction Conditions: substrate molar ratio 6:1; temperature 45 ^{o}C; KOH amount 1 wt.%; MS: speed 900 rpm; PU: frequency 19.7 kHz; power 150 W; HC: operation pressure 0.7 MPa; single orifice.]

Table 2.2 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 2.2, 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.

Gogate and Pandit [7] also perform the similar 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 (H_2SO_4) 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. Calorimetric studies indicated that about 65% of the supplied energy is actually dissipated in the system and available for generation of cavitation events. 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 ^{0}C with accuracy of ±2 ^{0}C.

Gogate and Parag [8] perform the similar experiment on hydrodynamic cavitation, ultrasonic cavitation and mechanical stirring techniqe 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/cm^2. 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

Mohan Raj [9] use biodiesel from rubber seed oil for blending with diesel and performed test on a 4 stroke single cylinder CI engine and compare their operational characteristics with diesel fuel. In his experiment the engine is coupled with an eddy current dynamometer. Rubber seed oil was injected in to the engine through the existing conventional injection system. Two separate fuel tanks were used, one for diesel fuel and other for Rubber seed oil. Both the fuels were injected at the room temperature only. A fuel changing arrangement was provided to change one fuel mode to another fuel. The test rig is a computerized engine test rig, all the observations were carried out by the respective sensors. The engine speed was measured by the crank angle encoder. The cylinder pressure and fuel injection pressure were measured by the piezo electric sensors. The signals that were obtained from various sensors are fed to the engine indicator for storing the data and interfacing with computer. From his experiments he has drawn conclusion that:- The performance and the combustion characteristics of diesel engine and biodiesel almost match. Biodiesel is very effective and can be used as an alternative fuel without any engine modifications. Rubber seed oil as biodiesel is considered as cost effective when produced in large quantity.

Muammer ¨O ZKAN, ERGENC, DENIZ [10] perform there experiment on A single cylinder Lombardini LDA 450 Diesel engine, whose characteristics are listed in Table 2.3, was used for the experimental analysis. Fuel was supplied to the engine from an outside tank. All runs started with a 10-min warm-up period prior to data collection. The data measured during the tests included engine speed, brake torque, and fuel consumption. The fuel consumption was determined by measuring the time for the consumption of a fixed mass (10 g). During all tests, the injection timing (25^0 BTDC) was not altered and the rack position was maintained at full. The engine speed was varied by adjusting the load knob on the control panel of the test rig while maintaining the full rack position. The tests were performed with traditional Diesel fuel, biodiesel without glycerine and biodiesel with glycerine.

Table 2.3 Technical specifications of LDA 450 [10].

Total displacement	454 cm3
Number of cylinders	1
Injection timing	25^0 BTDC
Stroke	80 mm
Bore	85 mm
Compression ratio	17.5/1
Max. torque at 1700 rpm	28.5 Nm
Max. power	5.5 kW

Prof S C Pathak [11] perform there experiments on a constant speed Kirloskar engine (AV1) using Blends of biodiesel from neem with pure diesel. Various aspects of engine performance using neem-diesel blend (B-20) as fuel were studied through extensive experimentation at different injection pressure. Data thus obtained were analyzed and compared with those of pure diesel. Significant reduction in emissions was observed as compared to that with pure diesel. They drawn following conclusion from there experiments:- The properties of neem-diesel blend are comparable with those of pure diesel. Neem-diesel blends produced lower exhaust emissions. There is significant effect of injection pressure on engine performance. For both pure diesel and neem-diesel blend 160 kgf/cm2 is the optimum injection pressure, as highest BTE and lowest BSFC was observed over the entire load range at this injection pressure.

Sundarapandian and Devaradjane[12] perform the experiment on a single cylinder, four strokes naturally aspirated, and water-cooled kirloskar computerized diesel engine test rig. In this investigation the engine performance and emission while using three vegetable oil esters namely Jatropha, Mahua & Neem oil esters in C.1 engine are evaluated. The present analysis is focused towards the formulation and development of a four zone combustion model for the prediction of combustion, pressure, temperature, heat release, heat transfer, work done, thermal efficiency, power, specific fuel consumption and harmful pollutants such as HC, CO, NO_x and smoke. The four zones of the model are fuel zone, stoichiometric burning zone, product / Air zone and a non-burning zone outside the spray. The computer model and experimental findings are demonstrated. From the experimental findings, it is found that the results are very good and the model is highly efficient.

Deshmukh [13] perform his experiment on a single cylinder two stroke D.I. diesel engine, Make: Kirloskar Oil Engine Ltd. India with Rated Power of 3.60 kw using Rope brake dynamometer as Loading device. He uses pure diesel, pure bio diesel & blends of diesel & bio-diesel as fuels and obtained characteristic curve of brake thermal efficiency, specific fuel consumption and torque produced with respect to brake power. The results thus obtained were encouraging & signifies that cotton seed Methyl ester (Bio-diesel) can easily replace the conventional diesel without any modification in existing diesel engine.

Alam, Song, Acharya and Boehman [14] from Pennsylvania state university also performs similar type of experiments. There experiments were conducted with a comercially available six-cylinder, 4-valve per cylinder, turbocharged, direct injection (DI) diesel engine. The engine was operated with low sulfur diesel fuel, ultra low sulfur diesel fuel and two other blends, low sulfur diesel fuel with 20 wt % biodiesel and ultra low sulfur diesel fuel with 20 wt % biodiesel, to investigate the effect of the base fuels and there blends on combustion and emissions. Combustion analysis, particulate matter emissions and exhaust gas composition (CO, NO_X, and total hydrocarbons) were determined at 8 steady state operating conditions according to AVL 8-mode test protocol. Combustion analysis showed at high load conditions a retarded start of injection, an earlier start of combustion and a lower premixed burn peak with ultra low sulfur diesel fuel. Mode averaged NO_X emissions decreased with ultra low sulfur diesel fuel and biodiesel blends compared to low sulfur diesel fuel. A 20 % PM reduction was observed with low sulfur (15 PPM) diesel fuel compared to low sulfur (325 PPM) diesel fuel.

Christopher Sharp and Ryan III [15] also work on emission characteristics of biodiesel fuel. In there experiments, A 2003 heavy-duty diesel engine (2002 emission level) was used to test a representative biodiesel fuel as well as the methyl esters of several different fatty acids. The fuel variable included degree of saturation, the oxygen content, and carbon chain length. In addition, two pure normal paraffins with the corresponding chain lengths of two of methyl esters were also tested to determine the impact of chain length. The dependent variables were the NO_X and the particulate emissions (PM). The result indicated that the primary fuel variable affecting the emissions is the oxygen content. The emission results showed that the higher oxygen content test fuel had the lowest emission of both NO_X and PM. As compared to baseline diesel fuel the NO_X emissions were reduced by 5 % and the PM emissions were reduced by 83 %.

Choudhury & Bose [16] perform similar type of experiment on a kirloskar make single silinder engine. In there study biodiesel is produced from Jatropha by transesterification. Plant indigenously developed by the authors and there properties were measured to compare with diesel fuel. The blends of varying properties of this biodiesel with diesel were prepared, analyzed and compared with diesel oil. The engine performance and emission characteristics were evaluated in a single cylinder C.I. engine and a comparison was made to suggest the better option among the biodiesel under study.

2.3 Conclusion

1. Hydrodynamic cavitation and ultrasonic 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. Biodiesel- diesel blends are found to be an environmental friendly fuel. The cause less opacity as compared to petroleum diesel fuel.
3. Biodiesel- diesel blends have high thermal efficiency, less specific fuel consumption as compared to pure diesel fuel.

3. DEVELOPMENT OF A BIODIESEL PRODUCTION TEST RIG BASED ON HYDRODYNAMIC CAVITATION

3.1 Principal Of Hydrodynamic Cavitation

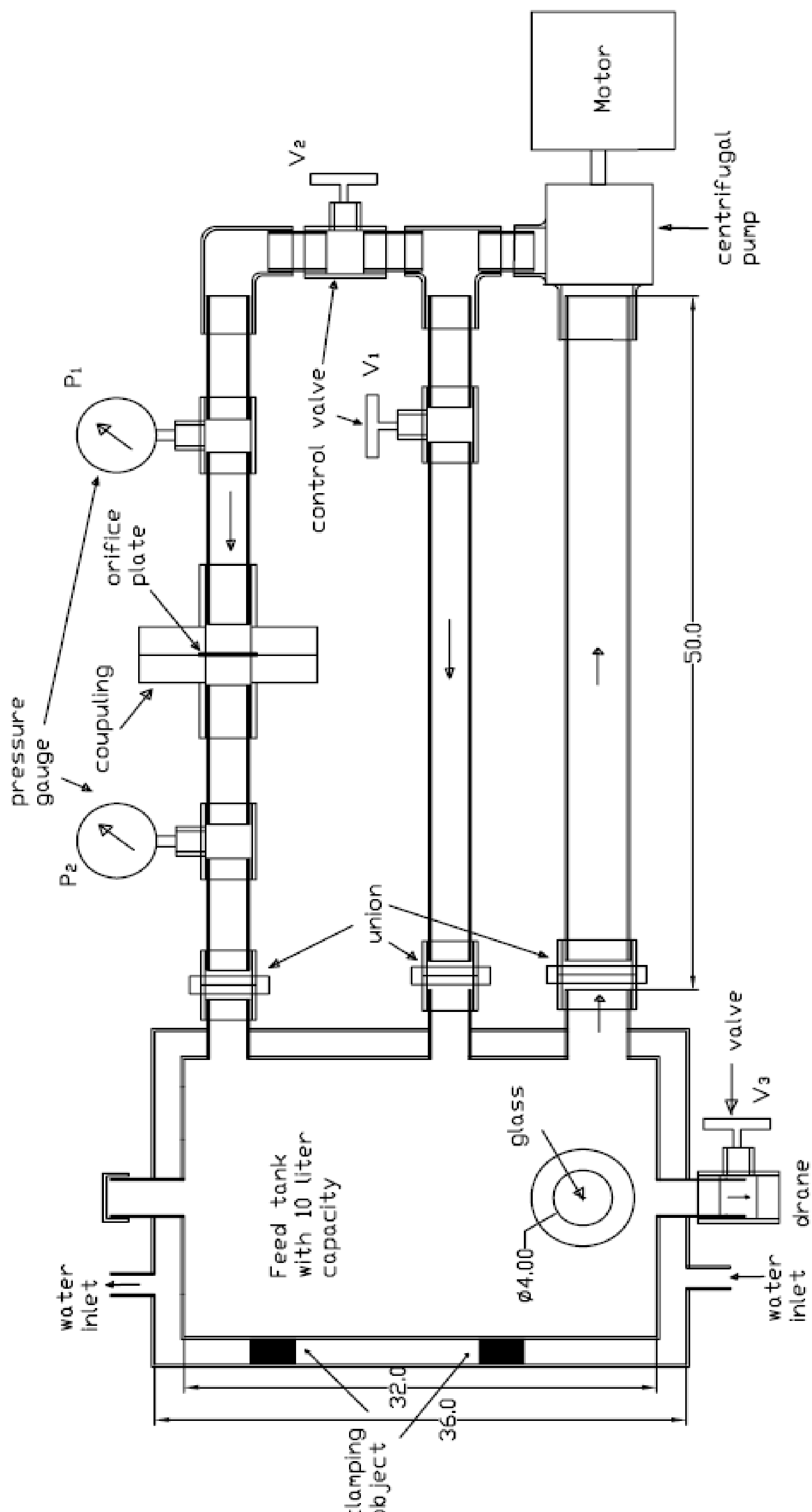
Hydrodynamic cavitation can simply be generated by the passage of the liquid through a constriction such as throttling valve, orifice plate, venturi etc. When the liquid passes through the orifice plates, the velocities at the orifice increase due to the sudden reduction in the area offered for the flow, 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 vapor 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 creates micro jets, leading to intensive emulsification of the system. 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.

3.2 Description of Test Rig

Schematic of test rig is shown in Figure 3.1. 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 3.2, and schematic of feed tank is shown in Figure 3.3. 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 (Fig. 3.4) to accommodate the orifice plates (single or multiple holes, different configurations of the orifice plates have been shown in Figure 3.5). 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 descriptions of component specification are given in Table 3.1.

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 all the component (pressure gauge, valve, pump, tank and coupuling) 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.



All dimensions are in cm

Figure 3.1 schematic diagram of hydrodynamic cavitation setup

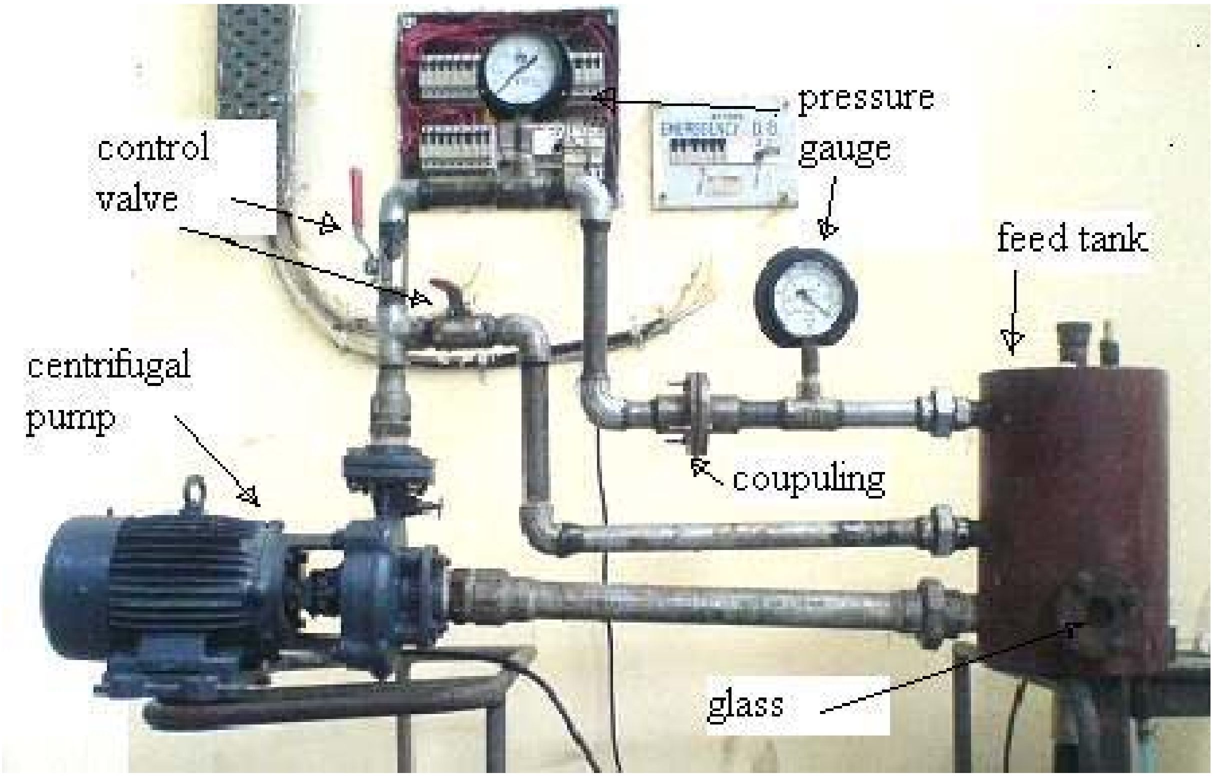
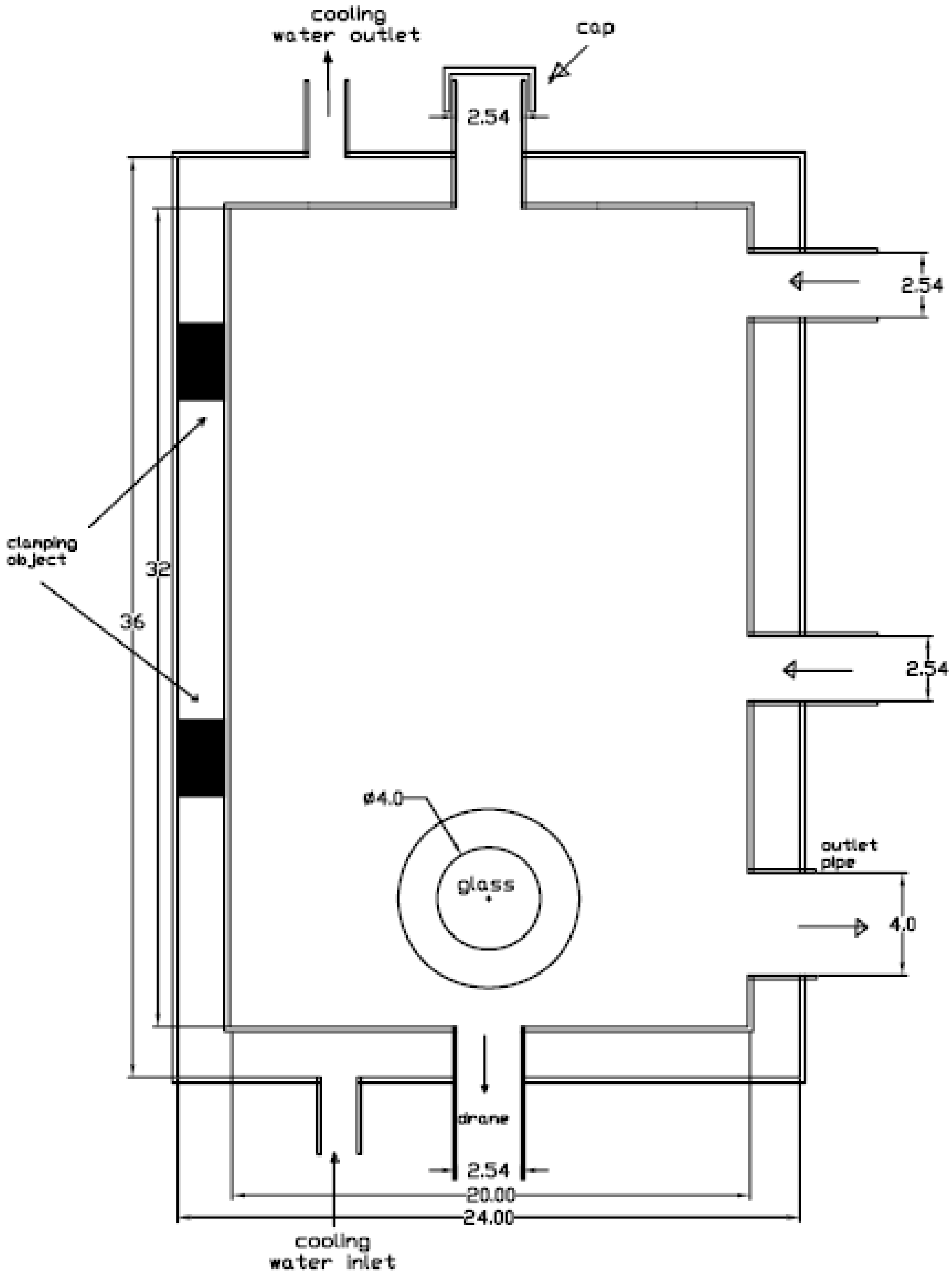


Figure3.2 Hydrodynamic cavitation setup



All dimensions are in cm

Figure 3.3 Schematic of Feed Tank

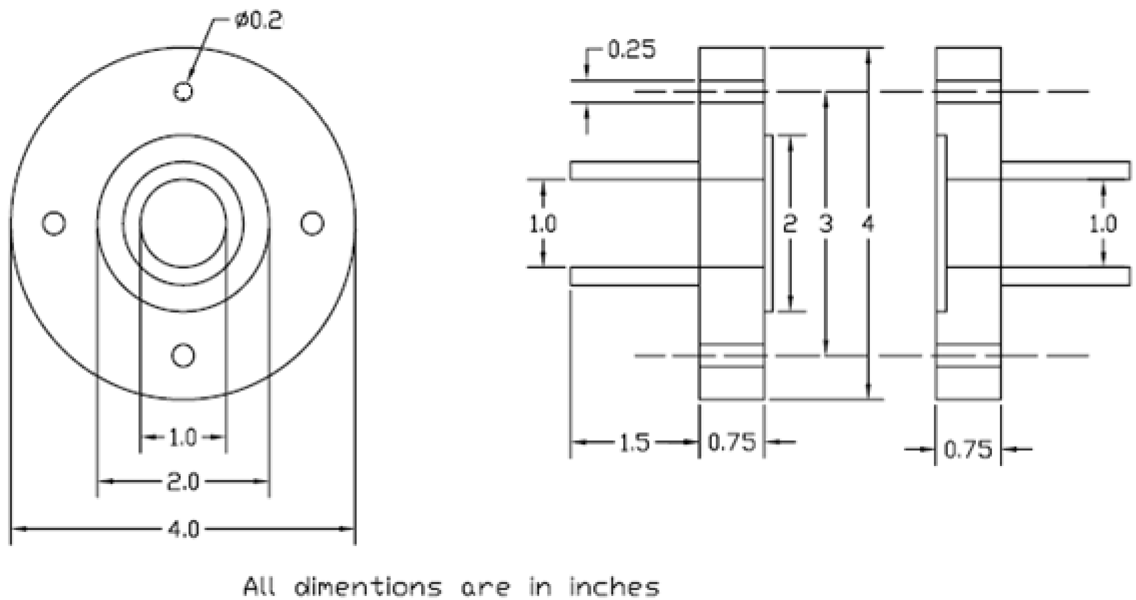


Figure 3.4 Coupling for holding orifice plate

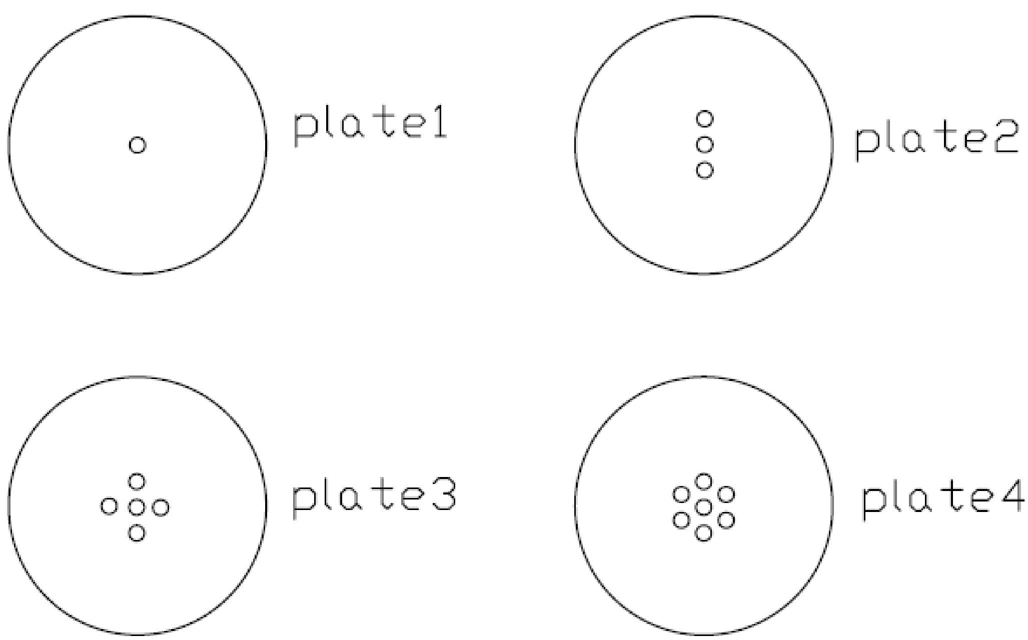


Figure 3.5 Multiple-hole orifice plates.

Table 3.1 specification of component

Serial no.	Name of component	specification
1	Centrifugal pump	Make: Crompton Greaves, Type: Centrifugal moonset pump, Head: 27 m, Power: 2.2 kW, Speed: 2850 rpm, Supply: 3 phase, 415 V, 5 Amp.
2	Feed tank	Material: mild steel, provided with cooling jacket, Inner tank volume: 10 L, Height: 32 cm, Diameter 20 cm. Volume of cooling jacket: 6.2 L. Thickness: 2 cm.
3	Coupling	Material: M S, Outer dia: 4 inch, Diameter of pipe 1 inch, Thickness of plates: 0.75 inch.
4	Orifice plate	Material: stainless steel, 4 pieces with number of holes 1, 3, 5, 7, Diameter of hole: 3 mm.
5	Pressure gauge	Type: Borden tube type, 1. Range: 10.6 kg/cm^2, Least count: 0.2 kg/cm^2. 2. Range: 760 mmHg, Least count: 760 47.5 mmHg.
6	Control valve	Material: stainless steel, Type: ball valve type.

3.3 Selection of thumba vegetable oil

In this experiment thumba oil is used as a vegetable oil for production of biodiesel. Thumba oil is thick viscous liquid of dark Yellowish colour. It is obtained from seeds of thumba plant.

3.4 Experimental Procedure

Following steps has been followed during the experiment.

The vegetable Thumba oil of (3.5 to 5.5kg) is filtered to remove impurities. It is heated up to 110^0 C in order to remove water content of oil to avoid soap formation. Then this oil is allowed to cool upto 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 the temperature of mixture is kept between 40-55^0 C. The temperature of mixture is controlled by circulation of cooling water in the jacket of 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 40^0 C) is mixed and the mixture is stirred for I minute and then left for settling of water with impurities. After complete settling water of with impurities at the bottom of separating funnel it is removed by opening the tab provided at the bottom of separating funnel. The Figure 3.6 shows the settling process in the laboratory funnel.

Figure 3.6 washing process of biodiesel

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

3.5 Experiment Results

The experiments are performed with oil to alcohol molar ratio as 1:6 and 1:4.5. The amount of vegetable oil, alcohol and catalyst taken is given in Table 3.2.

Table 3.2, Vegetable oil, alcohol and catalyst during the experimentation

Molar ratio	**Vegetable oil (Kg)**	**Methanol (Kg)**	**Catalyst (NaOH)**
1:6	3.8 Kg	0.84 Kg	38 gm
1:4.5	3.8 Kg	0.63 Kg	38 gm

For calculation of molar ratio following data are used.

Molecular weight of triglycerides from thumba oil = 870

Molecular weight of methanol = 32

Hence, 1 gm mole of thumba oil = 870 gm

And 1 gm mole of methanol = 32 gm

Catalyst (NaOH) = 1% by weight of oil

Amount of methanol for 3.8 kg of vegetable oil

- For 1:6 molar ratio = (32 / 870) ×3.8 × 6 × 1000 = 0.84 kg
- 1:4.5 molar ratio = (32 / 870) ×3.8 × 4.5 × 1000 = 0.63 kg

During experimentation samples of 100 ml were collected at the interval of 5 min. These samples were allowed to settling for 15 minutes. After 15 minutes glycerin settle down at the bottom And rest of sample float over it. The volume of sample discarding glycerin per 100 ml of mixture is shown in tables 3.3 and table 3.4.

During the experiment the flow rate of cooling water was 3.2 L/min. Temperature difference of water at inlet and outlet of jacket was 4 ^{0}C. And the amount of heat released by water was found to be 0.89 KJ /sec.

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

Observation for 1:6 molar ratio is given below

Temperature of mixture = 52 ^{0}C

Orifice hole diameter = 3 mm.

Operating pressure = 2.4 kg/cm^2.

Oil to alcohol Molar ratio = 1:6.

Table 3.3, Amount of transesterification for 1:6 molar ratio of oil to alcohol

Time in minutes		10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min
Volume of biodiesel for	Single hole	--	Nil	--	--	73	--	--	77
	3 holes	58	60	73	74	75.5	76.5	77	77
	5 holes	58	67	72	75	76	77	78	78
	7 hole	57	71	72.5	75	76.5	78	78	78

From the above table we can observe that transesterification starts after 10 minutes of process and increases continuously with time. But for single hole process it takes more time for start. It gains its optimum value after 35 minutes of process. Also with increase in no of holes in orifice plate the saturation state reaches earlier and also more amount of transesterification is obtained.

Observation for 1:4.5 molar ratio is given below

Temperature of mixture = 52 ^{0}C

Orifice hole diameter = 3mm.

Operating pressure = 2.4 kg/cm^2.

Oil to alcohol Molar ratio = 1:4.5

Table 3.4, Amount of transesterification for 1:4.5 molar ratio of oil to alcohol

Time in minutes		10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min
Volume of biodiesel for	Single hole	Nil	Nil	68	70	74	75	76	76
	3 holes	56	59	68	72	75	76	77	77
	5 holes	57	65	70	73	76	76.5	77	77
	7 hole	58	69	72	73	76.5	77	78	78

From the above table we can observe that transesterification starts after 10 minutes of process and increases continuously with time. But for single hole process it starts after 20 minutes of process. It gains its optimum value after 40 minutes of process. Also with increase in no of holes in orifice plate the saturation state reaches earlier.

It is observed that saturation state also reaches earlier with increase in oil to alcohol molar ratio.

The produced biodiesel is shown in Figure 3.7 and its properties (which are checked in laboratory) are listed in Table 3.5

Figure 3.7 Biodiesel prepared from thumba oil.

Table 3.5 Properties of biodiesel from thumba oil as per BIS: 2796

property	**Value for thumba biodiesel**
Appearance	Clear
Color	Yellowish liquid
Density at 15 ^{0}C	0.89 kg/l
Kinematic viscosity at 40 ^{0}C	5.86 centistokes
Flash point	>66 ^{0}C
Sulphur contents	<100 ppm
Water content	≈ 500 ppm
ASTM distillation	Can't be detected as per P:18

Kinematic viscosity of this fuel is 5.86 centistokes which is better than biodiesel from Jatropha oil (7.2 centistokes). Its density (0.89 kg/l) is also in desirable range (0.87 – 0.90 kg /l) for biodiesel and it is slightly greater than Jatropha biodiesel (0.88). Its sulphur content is <100 ppm which is also under desirable range. So this fuel is suitable for blending and can be used in CI engines.

4. PERFORMANCE STUDIES

4.1 Engine Test Setup

The engine test setup consists of four cylinder, four stroke, diesel engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments (Table 4.1) for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for P-θ and P-V 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 (Figure 4.1 & 4.2). Smoke meter (AVL make) is used for measurement of opacity at different speed, which is shown in Figure 4.3.

The setup enables study of engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, Brake specific fuel consumption and heat balance. Windows based Engine Performance Analysis software package “Engine soft” is provided for on line performance evaluation. The detailed specification of various component are given in Table 4.1.

The main aim of this experiment is to investigate the effects on performance of blending of biodiesel with gasoline diesel fuel in Tata Indica engine for wide range of operating parameters.

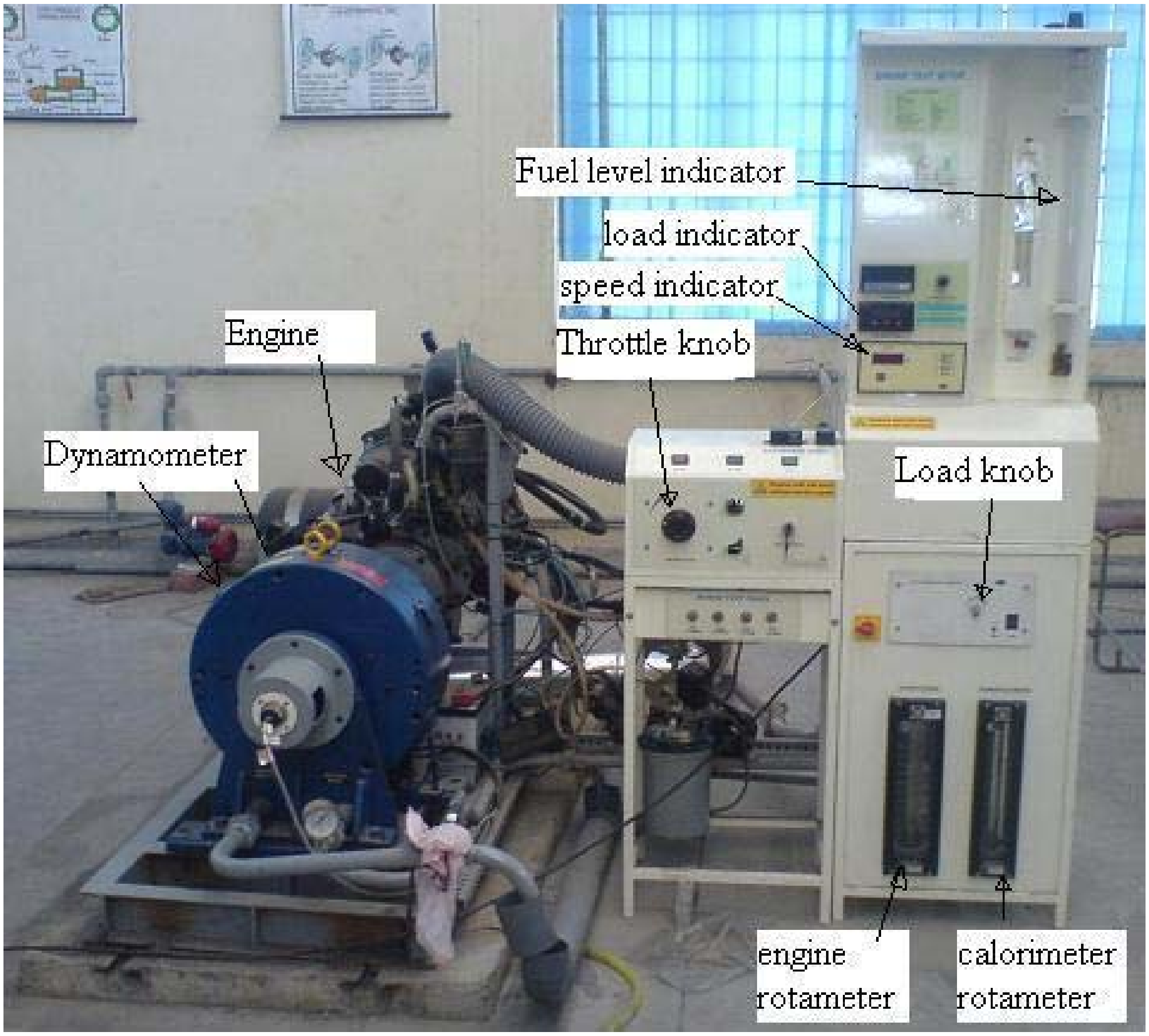


Figure 4.1 Experimental setup

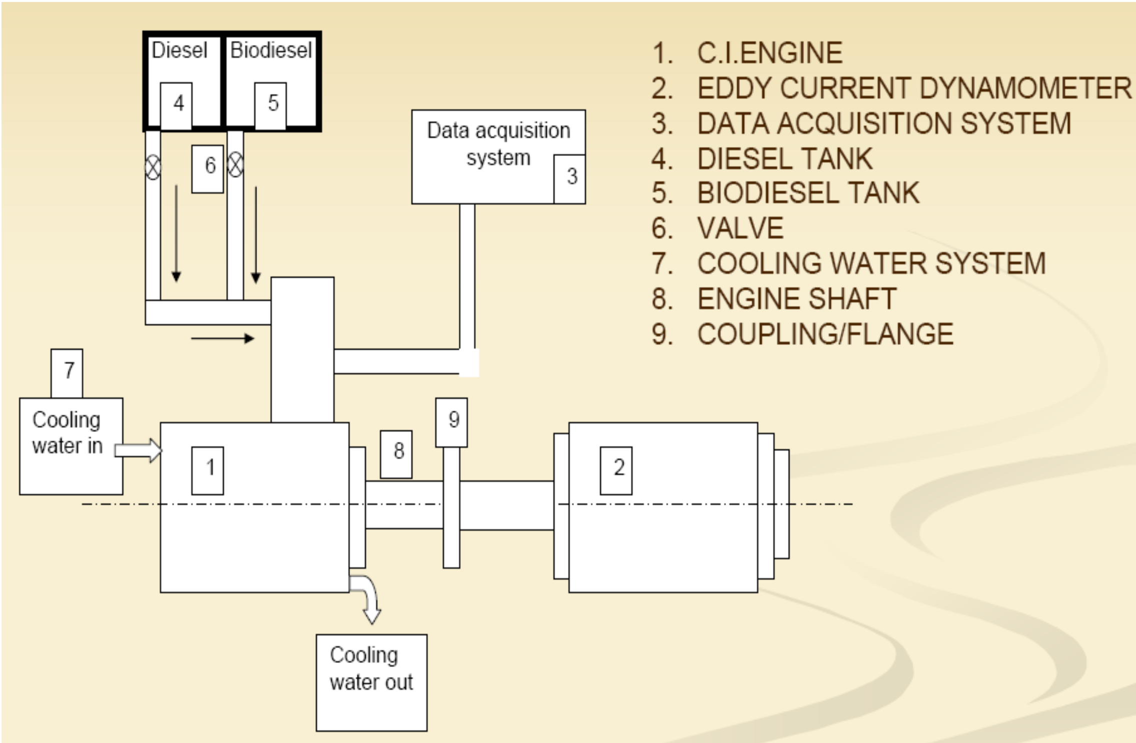


Figure 4.2 Schematic Diagram of the Experimental set-up

Figure 4.3 Smoke meter

Table 4.1 Specifications of component used

Component	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, CR 22
Dynamometer	Type eddy current, water cooled, with loading unit
Propeller shaft	With universal joints
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 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 5500 RPM with TDC pulse..
Engine indicator	Input Piezo sensor, crank angle sensor, No of channels 2, Communication RS232
Digital milivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Type two wire, Input RTD PT100, Range 0–100 ^{0}C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 ^{0}C, Output 4–20 mA
Load indicator	Digital, Range 0-50 Kg, Supply 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	Presure transmitter, Range (-) 250 mm WC
Rotameter	Engine cooling 100-1000 LPH; Calorimeter 25-250 LPH
Pump	Type Monoblock
Add on card	Resolution12 bit, 8/16 input, Mounting PCI slot
Software	“Enginesoft” Engine performance analysis software
Smoke meter	Make AVL, for opacity measurement

4.2 Preparation of biodiesel blends

Three different blends B-10 (10 % biodiesel + 90 % diesel), B-20 (20 % biodiesel + 80 % diesel), B-30 (30 % biodiesel + 70 % diesel) in addition to pure diesel has been prepared and tested on engine. The total quantity of each blend is two liters. These blends are prepared for Jatropha and Thumba biodiesel.

Calorific value of petroleum diesel [10] = 42000 kJ/kg.
Calorific value of biodiesel = 37000 kJ/kg.
Density of petroleum diesel = 820 kg/m^3.
Density of biodiesel = 891 kg/m^3 [tested in laboratory].

The biodiesel blends calorific value and densities have been calculated by volume fraction and are shown in table 4.1.

Table 4.2 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	820
B-10	1800	200	41500	827
B-20	1600	400	41000	834
B-30	1500	500	40500	841

4.3 Performance Evaluation

A multi cylinder Diesel engine was used for the experimental analysis. Fuel was supplied to the engine from an outside tank. All runs started with a 5-min warm-up period prior to data collection. The gap of 3 to 4 minutes was provided between the two consecutive runs. The data measured during the tests included engine speed, brake power, torque, and fuel consumption, SFC, opacity, heat balence. During the test engine speed was varied by adjusting the load knob provided on the control panel of the test rig while maintaining the full throttle position. The tests were performed with pure diesel fuel and biodiesel blends (B-10, B-20, B-30). Biodiesel blends of thumba and Jatropha were used. The observations were taken at engine speed of 5000, 4500, 4000, 3500, 3000, 2500, 2000, 1500 rpm. In order to maintain 1500 rpm engine throttle was slightly reduced.

Formulation used for calculation of various parameters are described below

i. Torque (kg m) = Load × Arm length

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

iii. Brake Thermal Efficiency (%) = $\frac{\text{Brake power (kW)} \times 3600 \times 100}{\text{Fuel flow in } \frac{kg}{hr} \times \text{calorific value (kJ/kg)}}$

iv. Specific fuel consumption (Kg/kwh) = $\frac{\text{Fuel flow in } \frac{kg}{hr}}{\text{Brake power (kW)}}$

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

vi. Heat balance (kJ/h):

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

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

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

c) Heat carried in jacket cooling water = $F_3 \times C_{pw} \times (T_2 - T_1)$

$$\text{Heat carried in jacket cooling water (\%)} = \frac{\text{Heat carried in jacket cooling water} \times 100}{\text{Heat supplied by fuel}}$$

d) Heat in Exhaust (calculate C_{pex} value):

$$C_p ex = \frac{F4 \times C_p W \times (T4 - T3)}{(F1 + F2) \times (T5 - T6)}$$

Where,

C_{pex}	Specific heat of exhaust gas (kJ/kg ^{0}C).
C_{pw}	Specific heat of water (kJ/kg ^{0}C).
F_1	Fuel consumption (kg/hr).
F_2	Air consumption (kg/hr).
F_3	Engine water flow rate (kg/hr).
F_4	Calorimeter water flow rate (kg/hr).
T_{amb}	ambient temperature (^{0}C).
T_1	Engine water inlet temperature (^{0}C).
T_2	Engine water outlet temperature (^{0}C).
T_3	Calorimeter water inlet temperature (^{0}C).
T_4	Calorimeter water outlet temperature (^{0}C).
T_5	Exhaust gas to calorimeter inlet temp (^{0}C).
T_6	Exhaust gas from calorimeter outlet temp (^{0}C).

Heat in Exhaust (kJ / h) = $(F_1 + F_2) \times C_{pex} \times (T_3 - T_{amb})$

$$\text{Heat in Exhaust (\%)} = \frac{\text{Heat in Exhaust} \times 100}{\text{Heat supplied by fuel}}$$

e) Heat to Radiation and unaccounted (%)

= Heat Supplied By Fuel (%) - { (Heat In Jacket Cooling Water (%)

+ Heat To Exhaust (%)

+ Heat Equivalent To Useful Work (%)}

4.3.1 Observations for load test

Table 4.3 to 4.9 shows the observations for load test for pure diesel, B-10, B-20, B-30 blends of Thumba and Jatropha biodiesel.

For pure diesel and thumba biodiesel blends all observations are taken in speed range of 1500 to 5000 rpm at interval of 500 rpm each. While for Jatropha biodiesel blends for comparison purpose all observation are taken in speed range of 2000 to 5000 rpm at interval of 1000 rpm each. Following are the observations for load test and there range for pure diesel. LOAD (12-36 kg), Air inlet temp (30-31 ^{0}C), Water to engine and calorimeter inlet temp (33-38 ^{0}C), Water from engine outlet temp (48-88 ^{0}C), Water from C. M. outlet temp (42-80 ^{0}C), Exhaust gas to C. M. inlet temp (245-636 ^{0}C), Exhaust gas from C. M. outlet temp (205- 499 ^{0}C), Opacity (7-59 %), Fuel Mass flow rate (1.82-13.83 kg/hr), Air mass flow rate (265 kg/hr), Water to engine flow rate (589 lph), Water to calorimeter flow rate (131 lph).

Table 4.3 Observation of load test for pure diesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
D-1	4975	29.7	31	37.18	87.85	37.18	79.49	632.97	498.17	58.2	13.83	265.06	589	131
D-2	4501	28.54	30	33.82	62.94	33.82	63	537.73	445.42	57.7	10.75	265.06	589	131
D-3	4035	34.62	31	37.12	82.48	37.12	74.11	635.16	498.17	56.4	11.6	265	589	131
D-4	3581	34.68	30	34	63.19	34	64.59	596.34	473.26	54.7	10.28	265.03	589	131
D-5	3996	35.78	31	37.12	72.47	37.12	62.82	591.94	452.01	49.3	9	265.09	589	131
D-6	2445	33.15	30	34.8	58.73	34.8	54.82	529.67	415.38	41.2	6.84	265.07	589	131
D-7	2077	28.08	31	37.12	61.9	37.12	53.05	421.98	333.33	22	4.79	265.06	589	131
D-8	1503	12.94	30	35.35	48.6	35.35	42.43	245.42	205.13	7.4	1.82	265.07	589	131

Where C. M. refers to Calorimeter.

Table 4.4 Observation of load test for B-10 blend of thumba biodiesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
T-B10-1	5001	31.75	29	30.59	71.12	30.59	71.92	603.66	474.73	54.3	14.69	191.07	589	131
T-B10-2	4488	31.17	29	30.22	76.98	30.22	52.32	550.92	427.11	55.5	12.23	265	589	131
T-B10-3	4038	35.53	29	30.16	63.19	30.16	67.7	569.96	440.29	53.6	12.04	152.33	589	131
T-B10-4	3577	34.49	29	30.46	77.53	30.46	55.01	631.5	488.64	54	10.09	265.02	589	131
T-B10-5	3010	35.29	29	30.16	73.38	30.16	52.93	616.85	471.79	46.2	8.78	265.06	589	131
T-B10-6	2485	33.94	29	33.7	58.97	33.7	63.98	515.02	378.02	36.4	7.01	265	589	131
T-B10-7	1999	26.71	29	32.3	49.33	32.3	47.92	384.62	301.83	19.3	4.29	265.11	589	131
T-B10-8	1526	14.62	29	32.36	44.14	32.36	40.84	246.15	211.72	9.2	2.03	265.09	589	131

Table 4.5 Observation of load test for B-20 blend of thumba biodiesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
T-B20-1	4987	28.54	30	37.12	81.93	37.12	76.25	574.36	443.22	54.1	10.47	265.07	589	131
T-B20-2	4511	30.71	29	34.49	60.99	34.49	67.58	537.73	426.37	56.3	11.73	265.51	589	131
T-B20-3	3990	34.92	30	37.24	82.6	37.24	85.16	596.34	462.27	53.7	10.29	265.21	589	131
T-B20-4	3559	34.19	29	34.43	60.26	34.43	67.46	561.17	441.03	52.1	9.76	265.55	589	131
T-B20-5	2981	35.99	30	37.24	74.6	37.24	74.54	571.43	437.36	44.9	3.27	265.06	589	131
T-B20-6	2493	35.26	29	34.74	57.51	34.74	62.15	542.86	419.78	34.1	7.15	265.47	589	131
T-B20-7	2026	27.14	30	34.86	52.69	34.86	50.61	397.07	315.02	16.8	4.3	265.6	589	131
T-B20-8	1512	14.1	29	35.04	47.19	35.04	42.92	241.76	201.47	10.7	1.97	265.52	589	131

Table 4.6 Observation of load test for B-30 blend of thumba biodiesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
T-B30-1	4990	29.03	30	32.66	64.41	32.66	71.67	596.34	483.52	55.2	13.55	265.39	589	131
T-B30-2	4522	31.26	30	33.39	71.73	33.39	60.68	569.96	446.89	53.7	11.9	265.13	589	131
T-B30-3	4033	34.1	30	33.52	72.41	33.52	63.55	606.59	476.19	54.2	10.63	265.03	589	131
T-B30-4	3545	34.68	30	33.64	71	33.64	62.58	614.65	474.73	51.9	9.33	265.04	589	131
T-B30-5	3021	35.1	30	33.46	69.29	33.46	56.17	600	460.81	44.8	7.96	265.08	589	131
T-B30-6	2425	34.19	30	33.76	65.81	33.76	53.36	558.24	422.71	36.1	6.28	265.08	589	131
T-B30-7	2021	26.37	30	33.33	55.25	33.33	46.46	402.93	326.01	17.2	3.89	265	589	131
T-B30-8	1553	16.91	30	32.84	47.31	32.84	41.21	254.21	206.59	8.6	2.58	265.51	589	131

Table 4.7 Observation of load test for B-10 blend of Jatropha biodiesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
J-B30-1	5012	28.54	30	35.35	74.73	35.35	62.64	594.87	476.19	55.1	13.24	265.13	589	131
J-B30-2	4027	35.38	30	35.53	71.79	35.53	66.06	621.25	494.51	51.3	11.5	265.06	589	131
J-B30-3	3015	36.2	30	36.08	66.36	36.08	59.95	616.85	476.19	44.6	8.88	265.08	589	131
J-B30-4	1980	27.47	30	36.26	56.11	36.26	51.28	416.12	334.07	18.1	4.41	265.06	589	131

Table 4.8 Observation of load test for B-20 blend of Jatropha biodiesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
J-B30-1	5010	29.73	31	35.96	81.75	35.96	71.18	626.37	507.69	56.8	12.58	264.62	589	131
J-B30-2	4016	35.1	31	36.32	77.05	36.32	75.76	635.16	504.76	50.9	11.02	264.65	589	131
J-B30-3	3055	35.96	31	36.26	71.25	36.26	70.45	617.58	485.71	45.9	8.41	264.67	589	131
J-B30-4	1997	27.41	31	36.63	56.53	36.63	51.53	413.19	326.74	17.9	4.19	264.58	589	131

Table 4.9 Observation of load test for B-30 blend of Jatropha biodiesel

Run	SPEED (rpm)	LOAD (Kg)	Air inlet temp. (^0C)	Water to engine inlet temp. (^0C)	Water from engine outlet temp. (^0C)	Water to C.M. inlet temp. (^0C)	Water from C. M. outlet temp. (^0C)	Exhaust gas to C. M. inlet temp. (^0C)	Exhaust gas from C. M. outlet temp. (^0C)	Opacity (%)	Fuel Mass flow rate (kg/hr)	Air mass flow rate (kg/hr)	Water to engine flow rate (lph)	Water to C. M. flow rate (lph)
J-B30-1	4986	30.62	31	38.22	81.56	38.22	72.89	668.13	537.73	57.6	13.71	264.66	589	131
J-B30-2	3992	35.29	31	38.34	75.52	38.34	68.8	646.15	515.75	49.4	11.25	264.59	589	131
J-B30-3	2994	35.44	31	38.77	67.03	38.77	61.17	574.36	439.56	44.1	8.75	264.58	589	131
J-B30-4	1989	26.13	31	39.26	59.4	39.26	54.15	420.51	345.05	17.5	3.69	264.67	589	131

4.3.2 Results and discussion

Table 4.10 to 4.16 shows the calculated parameters of load test for pure diesel, B-10, B-20, B-30 blends of Thumba and Jatropha biodiesel. These parameters include Torque (kg-m), Brake Power (kW), Friction Power (kW), Indicated Power (kW), Brake Thermal Efficiency (%), Indicated Thermal Efficiency (%), Mechanical Efficiency (%), SFC (kg/kwhr), and heat balance.

Table 4.10 Calculated parameters of load test for pure diesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC (kg/kWhr)	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
D-1	6.24	31.88	20.2	52.08	19.76	32.28	61.21	0.434	19.76	17.68	21.51	41.05
D-2	5.99	27.72	21.39	49.11	22.1	39.16	56.44	0.388	22.1	19.47	15.9	42.53
D-3	7.27	30.14	13.95	44.09	22.27	32.58	68.35	0.385	22.27	27.23	22.96	27.54
D-4	7.28	26.79	13.29	40.09	22.34	33.43	66.84	0.384	22.34	27.87	16.67	33.12
D-5	7.51	23.13	8	31.13	22.03	29.65	74.29	0.389	22.03	14.92	23.06	39.91
D-6	6.96	17.49	8.02	25.5	21.92	31.95	68.57	0.391	21.92	16.62	20.54	40.92
D-7	5.9	12.59	5.68	18.27	22.53	32.69	68.89	0.381	22.53	19.14	30.37	27.96
D-8	2.72	4.2	4.7	8.9	19.77	41.92	47.16	0.434	19.77	27.15	42.73	10.35

Table 4.11 Calculated parameters of load test for B-10 blend of thumba biodiesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC kg/kWhr	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
T-B10-1	6.67	34.26	22.87	57.13	20.23	33.74	59.95	0.429	20.23	16.57	19.74	43.46
T-B10-2	6.54	30.18	18.73	48.91	21.41	34.7	61.7	0.405	21.41	10	22.71	45.88
T-B10-3	7.46	30.96	15.88	46.84	22.31	33.75	66.09	0.389	22.31	17.19	20.13	40.37
T-B10-4	7.24	26.62	11.39	38.01	22.89	32.68	70.03	0.379	22.89	13.58	27.71	35.82
T-B10-5	7.41	22.92	8.76	31.67	22.65	31.29	72.35	0.383	22.65	13.91	29.23	34.21
T-B10-6	7.13	18.2	6.57	23.1	22.52	28.59	78.8	0.385	22.52	20.27	21.53	35.68
T-B10-7	5.61	11.52	7.83	19.35	23.29	39.13	59.52	0.372	23.29	20.65	23.59	32.47
T-B10-8	3.07	4.81	5.91	10.72	20.55	45.18	44.89	0.421	20.55	34.76	34.56	10.13

Table 4.12 Calculated parameters of load test for B-20 blend of thumba biodiesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC kg/kWhr	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
T-B20-1	5.99	30.71	23.52	54.23	19.87	35.09	56.63	0.442	19.87	16	19.85	44.28
T-B20-2	6.45	29.89	20.87	50.76	22.37	38	58.87	0.392	22.37	17.27	13.55	46.81
T-B20-3	7.33	30.06	14.13	44.2	23.17	34.07	68.02	0.379	23.17	23.78	23.96	29.09
T-B20-4	7.18	26.25	12.62	38.87	23.62	34.97	67.54	0.372	23.62	20.08	15.91	40.39
T-B20-5	7.56	23.15	6.87	30.02	23.42	30.37	77.11	0.375	23.42	23.2	25.88	27.5
T-B20-6	7.4	18.96	7.61	26.58	23.28	32.64	71.32	0.377	23.28	21.42	19.14	36.16
T-B20-7	5.7	11.86	5.93	17.79	24.22	36.33	66.66	0.362	24.22	21.98	24.96	28.84
T-B20-8	2.96	4.6	3.62	8.22	20.5	36.64	55.95	0.428	20.5	28.29	37.1	14.11

Table 4.13 Calculated parameters of load test for B-30 blend of thumba biodiesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC kg/kWhr	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
T-B30-1	6.1	31.25	26.97	58.23	20.5	38.2	53.67	0.434	20.5	19.61	14.26	45.63
T-B30-2	6.56	30.5	21.09	51.58	22.78	38.53	59.12	0.39	22.78	13.62	19.61	43.99
T-B30-3	7.16	29.67	15.51	45.18	24.8	37.77	65.67	0.358	24.8	16.9	22.26	36.04
T-B30-4	7.28	26.52	12.35	38.87	25.26	37.03	68.23	0.352	25.26	17.53	24.36	32.85
T-B30-5	7.37	22.88	8.53	31.41	25.54	35.05	72.85	0.348	25.54	15.82	27.39	31.25
T-B30-6	7.18	17.89	7.22	25.11	25.33	35.55	71.24	0.351	25.33	16.46	31.08	27.13
T-B30-7	5.54	11.5	6.82	18.32	26.26	41.82	62.78	0.339	26.26	22.13	34.27	17.34
T-B30-8	3.55	5.67	4.7	10.37	19.53	35.74	54.66	0.455	19.53	20.81	34.15	25.51

Table 4.14 Calculated parameters of load test for B-10 blend of Jatropha biodiesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC kg/kWhr	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
J-B10-1	5.99	30.86	25.86	56.72	20.22	37.16	54.41	0.429	20.22	12.96	17.31	49.51
J-B10-2	7.43	30.74	15.94	46.68	23.18	35.21	65.85	0.374	23.18	16.37	18.36	42.09
J-B10-3	7.6	23.55	6.76	30.31	23.01	29.62	77.71	0.377	23.01	14.79	19.87	42.33
J-B10-4	5.77	11.74	5.12	16.86	23.09	33.17	69.62	0.376	23.09	21.21	26.21	29.49

Table 4.15 Calculated parameters of load test for B-20 blend of Jatropha biodiesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC kg/kWhr	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
J-B20-1	6.24	32.14	23.83	55.97	22.43	39.07	57.41	0.391	22.43	18.75	21.87	36.95
J-B20-2	7.37	30.42	13.1	43.52	24.24	34.68	69.9	0.362	24.24	22.13	22.23	31.4
J-B20-3	7.55	23.7	7.47	31.18	24.74	32.55	76.01	0.355	24.74	24.16	25.03	26.07
J-B20-4	5.76	11.81	5.51	17.33	24.75	36.32	68.14	0.355	24.75	20.97	32.1	22.18

Table 4.16 Calculated parameters of load test for B-30 blend of Jatropha biodiesel

Run	TORQUE (kg-m)	Brake Power (kW)	Friction Power (kW)	Indicated Power (kW)	Brake Thermal Eff. (%)	Indicated Thermal Eff. (%)	Mech. Eff. (%)	SFC kg/kWhr	Heat Brake Power (%)	Heat Exhaust GAS (%)	Heat Jacket Water (%)	Radiation (%)
J-B30-1	6.43	32.94	23.4	56.33	21.35	36.51	58.47	0.416	21.35	16.71	21.64	40.3
J-B30-2	7.41	30.39	15.02	45.42	24.01	35.88	66.92	0.37	24.01	17.28	22.62	36.09
J-B30-3	7.44	22.89	8.1	30.99	23.26	31.49	73.88	0.382	25.11	17.99	22.96	33.94
J-B30-4	5.49	11.21	5.29	16.51	27	39.74	67.94	0.329	27	28.09	37.37	7.54

The discussion of various calculated parameters of Table 4.10 to 4.16 are given below

a. Torque Vs Speed

Figure 4.4 and 4.5 shows the variation of torque with speed for biodiesel blends of thumba & Jatropha respectively and compared with pure diesel. Variation of torque for different blends and pure diesel at a particular engine speed is with in a very narrow range. In case of thumba oil initially the torque rises sharply with increase in engine speed upto 3000 rpm. Between speed 3000-4000 rpm the variation or torque with speed remain almost constant. Further increase in speed causes decrease in torque. The variation in torque at high range of speed is smoother in jatropha blends as compared to thumba biodiesel blends. Between the range of 2000 to 5000 rpm the torque value is always more than 6 kg-m for all the blends and pure diesel. The maximum torque achieved in the case of thumba biodiesel blend (B-20) is 7.6 kg-m at 2500 rpm. Where as the maximum torque for all the Jatropha blends is 7.8 kg-m at 3500 rpm. The overall variation of torque Vs speed for all the blends is quit comparable with pure diesel.

b. Brake Power Vs Speed

The variation of Brake Power Vs speed for thumba and Jatropha biodiesel blend in comparison to pure diesel is shown in fig 4.6 and 4.7 respectively. The Brake Power increases proportionally to engine speed in the range of 2000 to 4000 rpm. In this speed range variation of torque is between 10-30 kW. For more than 4000 rpm there is fluctuating variation of Brake Power among the thumba biodiesel blends. Where as the variation of Brake Power in Jatropha biodiesel blends is relatively smooth. The maximum B.P achieved for thumba biodiesel blends (B-10) is 35 kW whereas value of maximum Brake Power for Jatropha biodiesel blend (B-30) is 33 kW at 5000 rpm. The variation of B.P at a particular speed is almost negligible for all types of blends and pure diesel.

c. Specific Fuel Consumption Vs Speed

The variation of Specific Fuel Consumption Vs Speed are shown in Fig 4.8 and 4.9 for thumba biodiesel blend and Jatropha biodiesel blend respectively in comparison to pure diesel. As shown in fig 4.8. The SFC decreases with increase in rpm upto 2000 initially and afterward between the rpm 2000-4000 SFC remains almost constant. For more than 4000 rpm range SFC increases sharply with speed. The SFC for all blends and pure diesel is minimum at 2000 rpm. The SFC for B-30 of thumba oil is minimum between the rpm range of 2000 to 4500. In this speed range the SFC varies between 0.33 kg/kWh to 0.38 kg/kWh. In the case of all thumba biodiesel blends SFC value is lower as compared to diesel for a wide range of engine speed. As shown in Fig 4.9 the variation of SFC is almost constant between the rpm range 2000 to 4000 and afterwards it increases significantly with further increase in engine speed. At a particular speed all the biodiesel blends of Jatropha is having the lower SFC value as compared to diesel. The lowest value of SFC is 0.33 kg/kWh for B-30 of Jatropha at 2000 rpm.

d. Brake Thermal Efficiency Vs Speed

Figure 4.10 and 4.11 shows comparison of Brake thermal efficiency Vs speed for different biodiesel blends of thumba & Jatropha in comparison to diesel respectively. The maximum value of Brake thermal efficiency for all blends & pure diesel is at 2000 rpm. For all blends 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 B-30 blend (Jatropha and thumba) is around 27 % at 2000 rpm which is 5 % higher as compared to pure diesel. The brake thermal efficiency remains constant between rpm range of 2000 to 4000, and it decreases with further increase in rpm.

e. Opacity Vs Speed

To understand the pollution aspect of biodiesel the variation of opacity Vs speed are shown in Figure 4.12 & 4.13 for thumba and Jatropha respectively in comparison to pure diesel. At a particular speed the opacity value for pure diesel is slightly higher as compared to all type of blends. For all biodiesel blends the opacity value increases from 20 to 50 % between the speed range 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.

f. P-θ diagram

Figure 4.14 and 4.15 shows the P-θ diagram for thumba biodiesel and Jatropha biodiesel respectively with pure diesel. On comparing P-θ diagram of pure diesel and various blends of thumba & Jatropha biodiesel it can be stated that the peak cylinder pressure in pure diesel is slightly higher (around 5 %) than all blends of thumba and Jatropha biodiesel. The peak pressure in case of pure diesel and blends of thumba and Jatropha biodiesel is around 60 bar at crank angle of 360^0.

In case of pure diesel the peak pressure is for a shorter duration, while in case of various biodiesel blends the peak pressure is available for a slightly higher duration. This is the reason for higher thermal efficiency obtained in case of biodiesel blends. The sharp peak obtained in pure diesel mode may be due to spontaneous combustion. While in case of biodiesel blends the combustion process takes substantial time. Thus the peak pressure is available for longer duration but with slight fluctuation.

g.

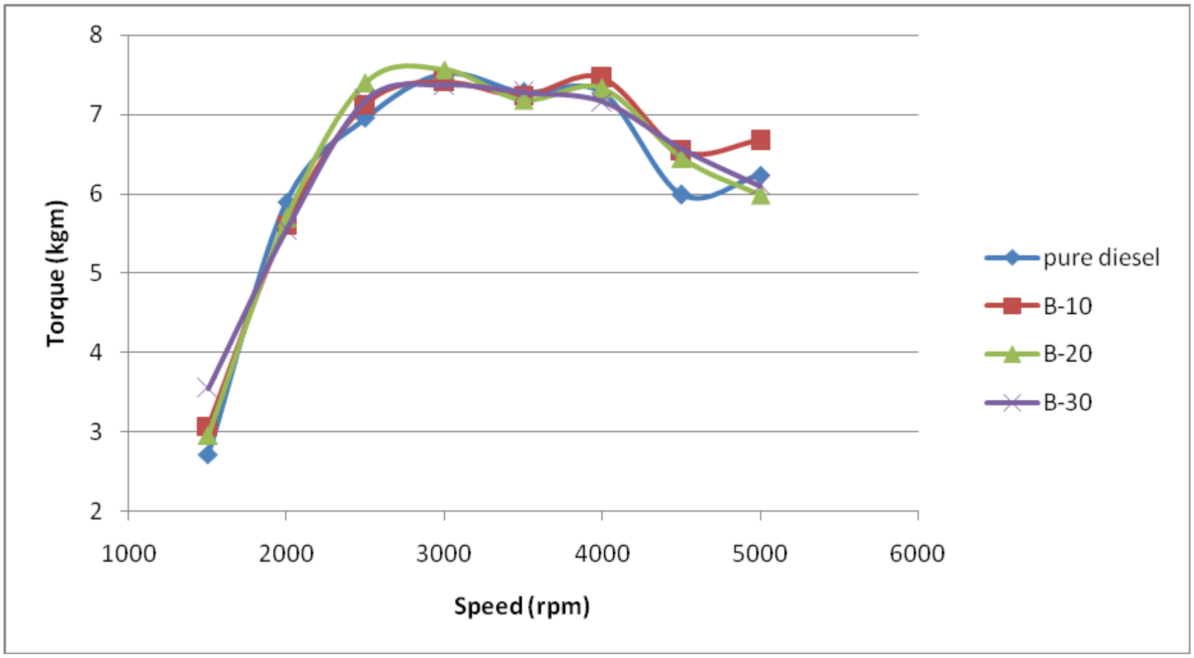


Figure 4.4 Comparison of Torque Vs Speed for different biodiesel blends from thumba oil

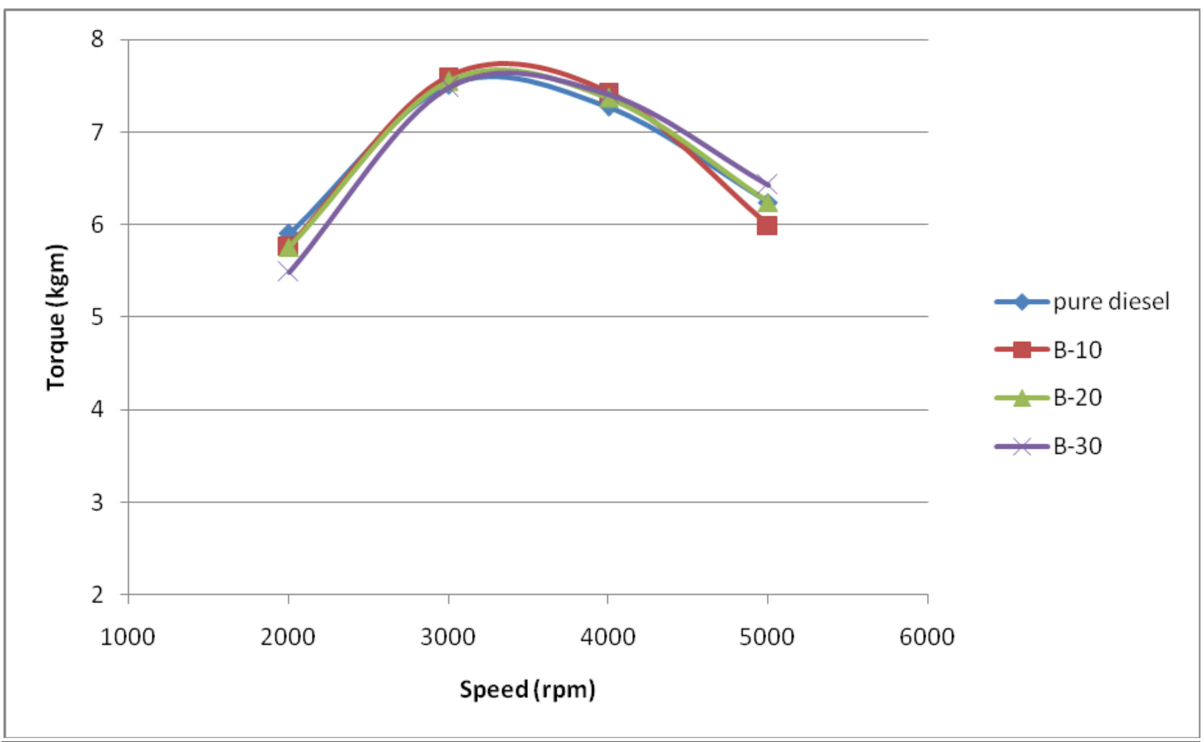


Figure 4.5 Comparison of Torque Vs Speed for different biodiesel blends from Jatropha oil

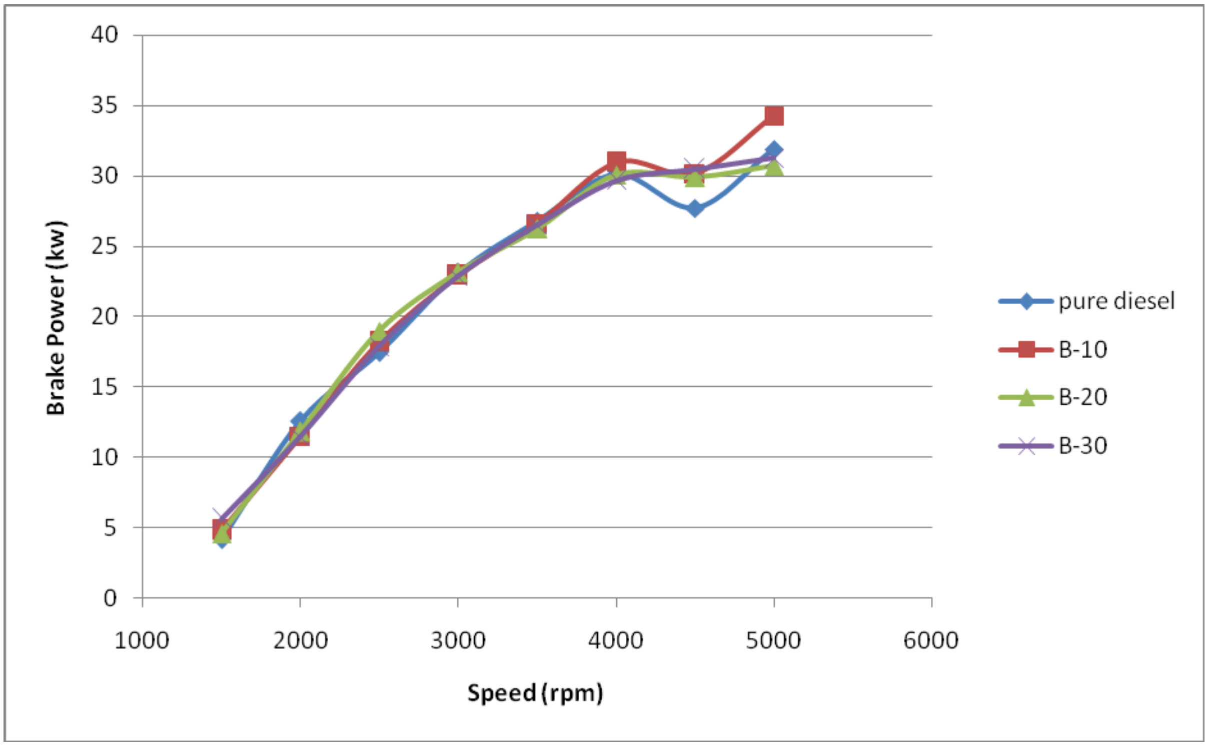


Figure 4.6 Comparison of Brake Power Vs Speed for different biodiesel blends from thumba oil

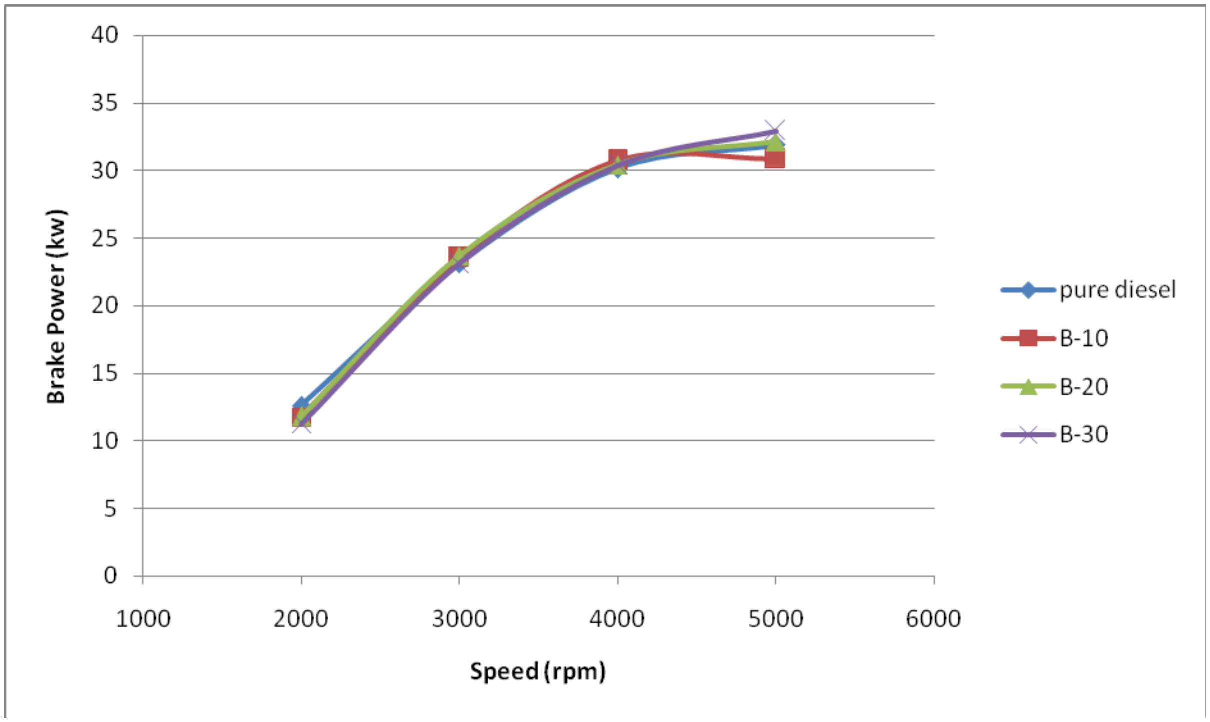


Figure 4.7 Comparison of Brake Power Vs Speed for different biodiesel blends from Jatropha oil

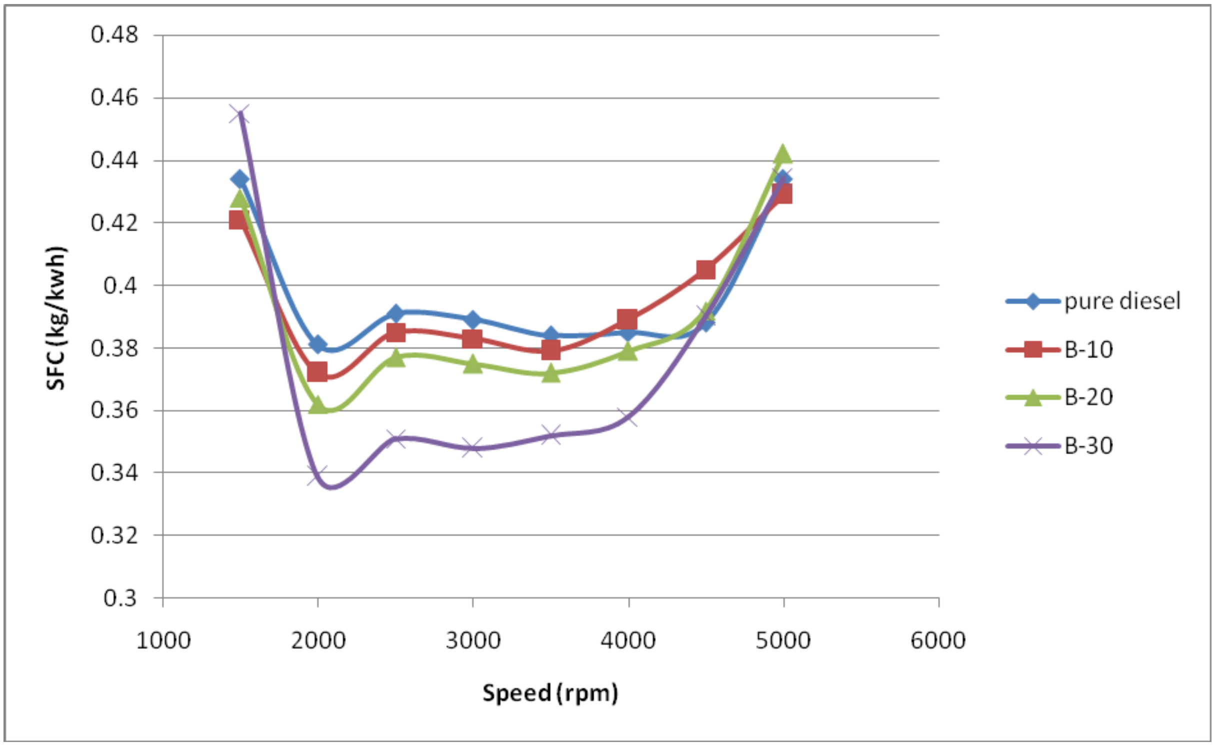


Figure 4.8 Comparison of SFC Vs Speed for different biodiesel blends from thumba oil

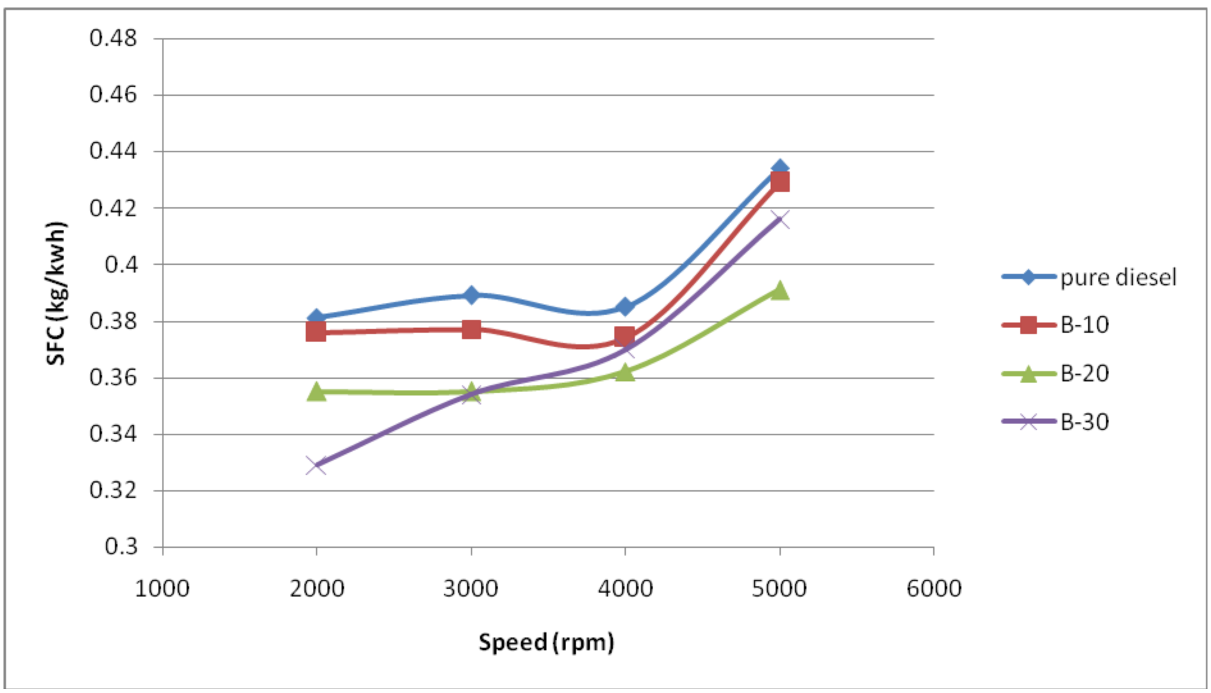


Figure 4.9 Comparison of SFC Vs Speed for different biodiesel blends from Jatropha oil

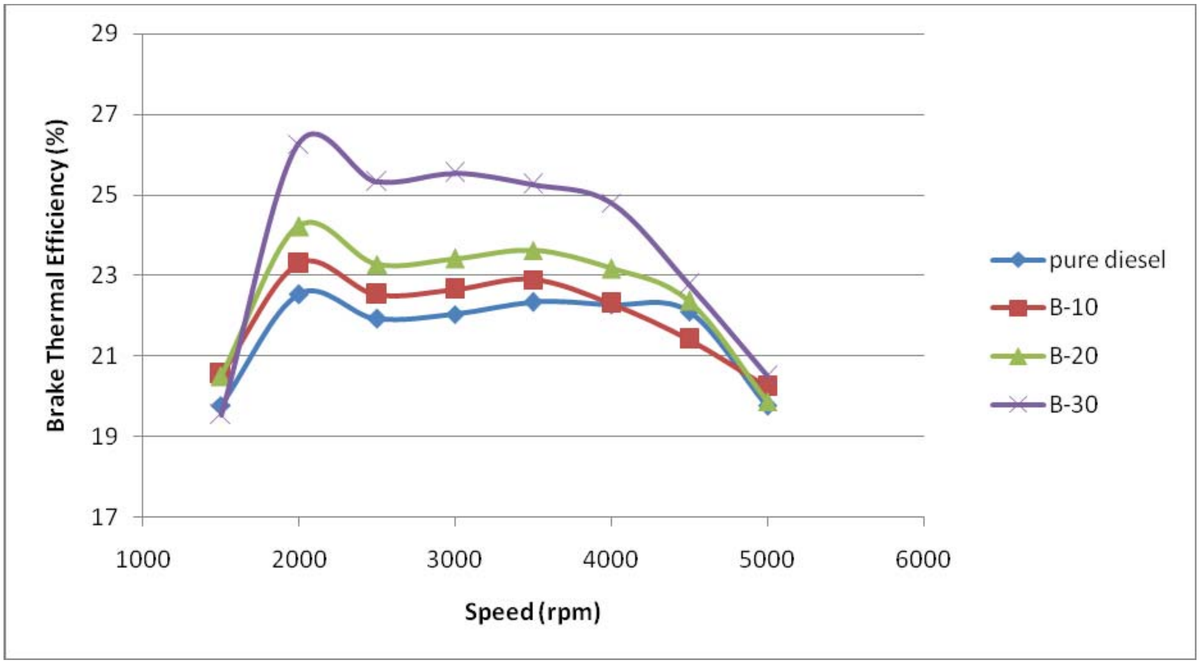


Figure 4.10 Comparison of Brake Thermal Efficiency Vs Speed for different biodiesel blends from thumba oil

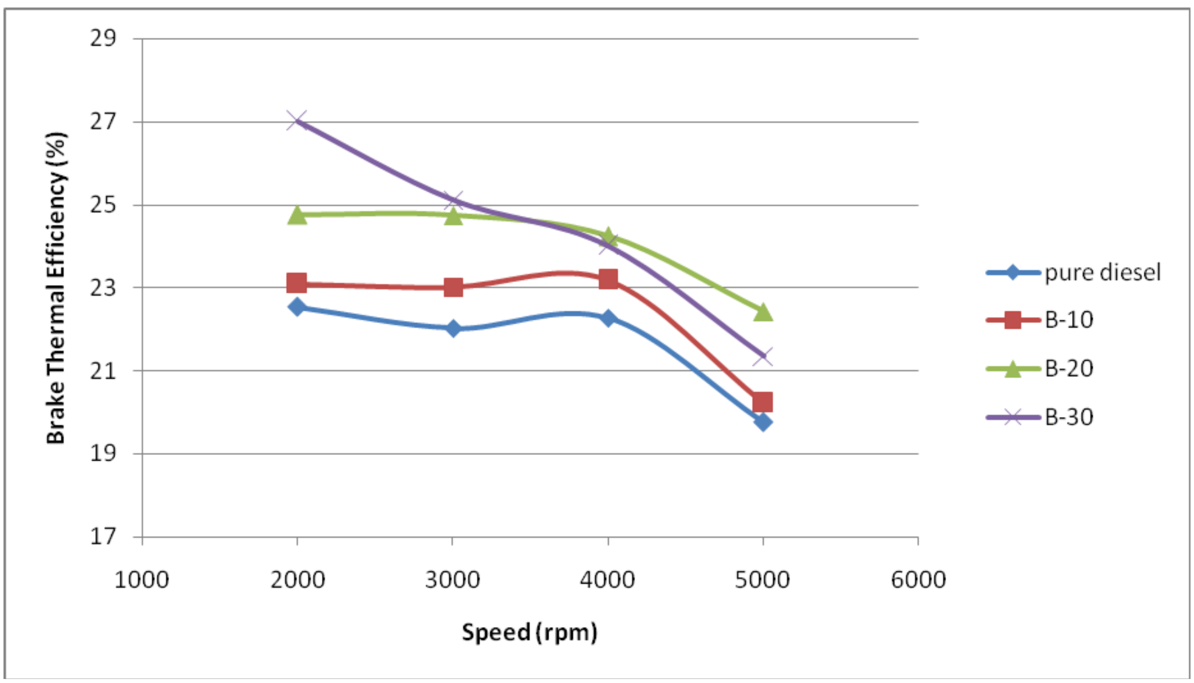


Figure 4.11, Comparison of Brake Thermal Efficiency Vs Speed for different biodiesel blends from Jatropha oil

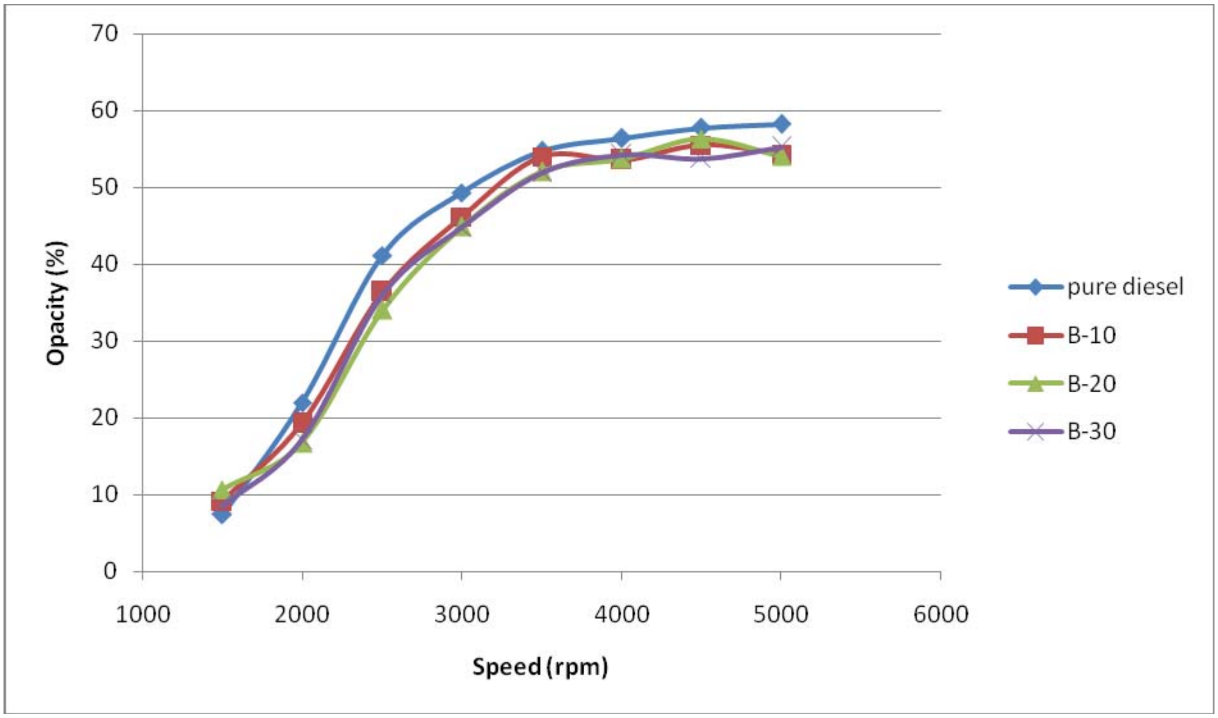


Figure 4.12 Comparison of Opacity Vs Speed for different biodiesel blends from thumba oil

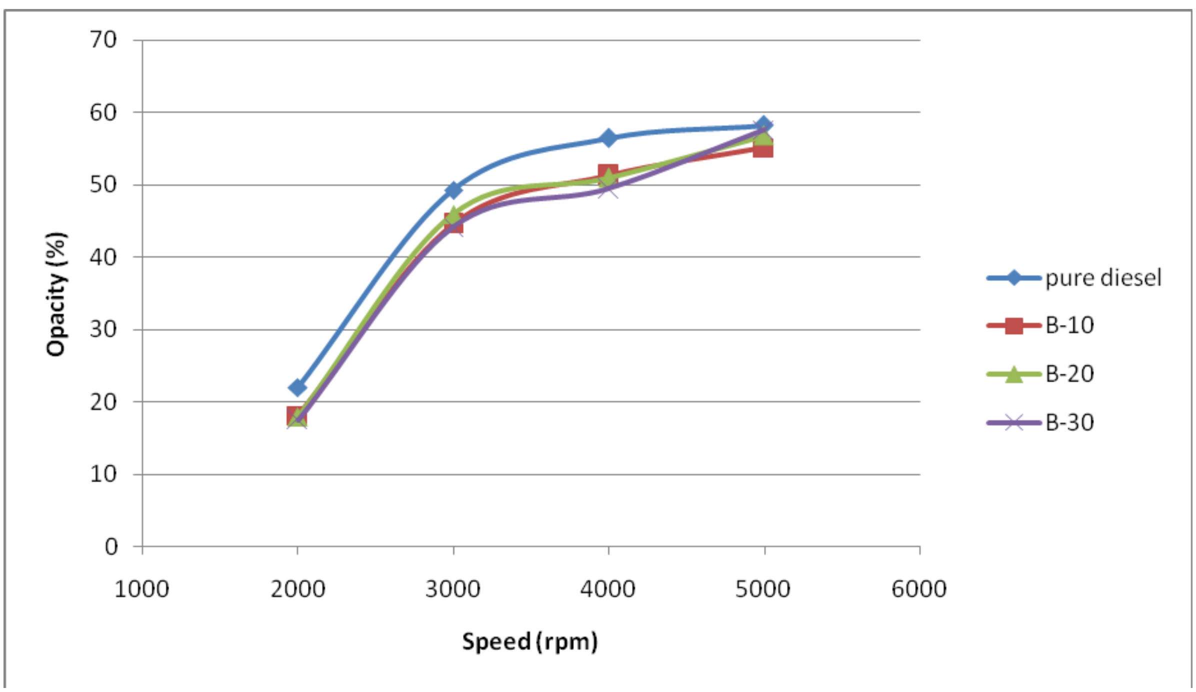
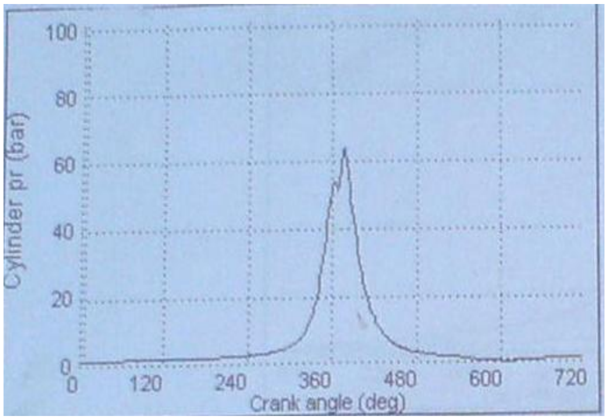
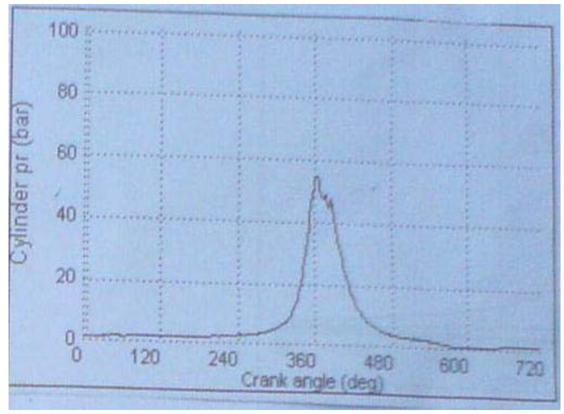


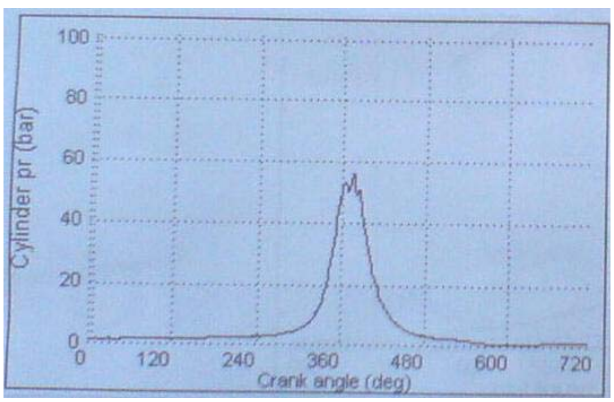
Figure 4.13 Comparison of Opacity Vs Speed for different biodiesel blends from Jatropha oil



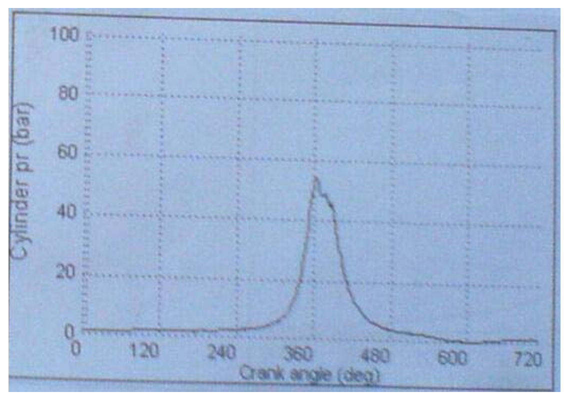
a) Pure diesel



b) B- 10

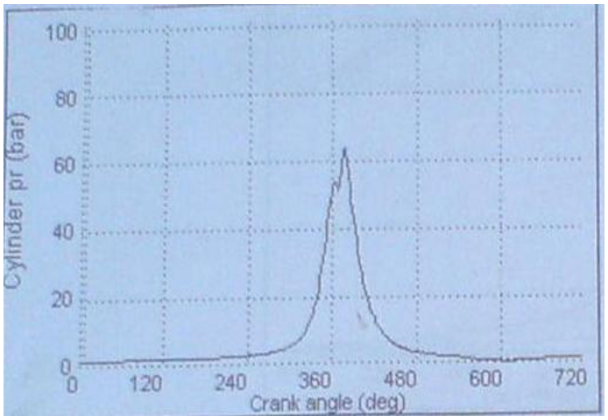


c) B- 20

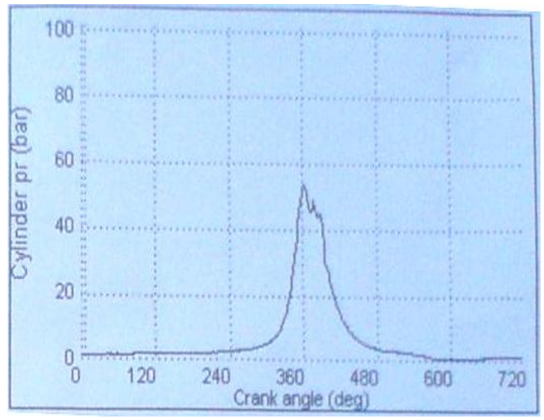


d) B- 30

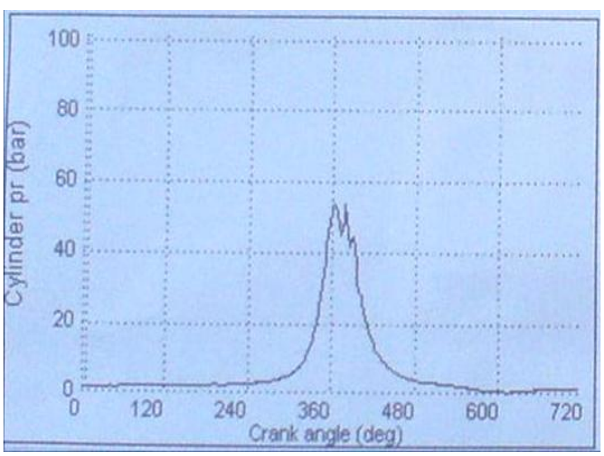
Figure 4.14 P-θ diagrams of pure diesel and thumba biodiesel blends at 3000 rpm.



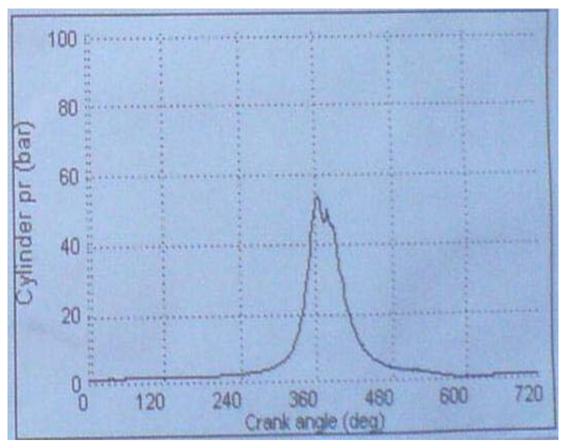
a) Pure diesel



b) B- 10



c) B- 20



d) B- 30

Figure 4.15 P-θ diagrams of pure diesel and Jatropha biodiesel blends at 3000 rpm.

5. CONCLUSION

Hydrodynamic cavitation is found to be an efficient method for bio diesel production. It is found to be efficient and less time taking technique. In this technique transesterification process starts after 10 minutes. And gain optimum value of 77 after 35 minutes of process. Transesterification rate increases and also it gain optimum value by increasing alcohol to oil molar ratio and increase in no of holes in orifice plate. So it can be concluded that hydrodynamic cavitation technique is a potential method for biodiesel production and further development of this technique is required.

In general the biodiesel blends displayed performance characteristics very similar to pure diesel. Biodiesel blends especially B-30 has shown better performance in terms of specific fuel consumption and brake thermal efficiency. Also biodiesel blends causes less opacity as compared to pure diesel. Overall, biodiesel blends can be successfully used for partial substitution of petroleum diesel. It can readily be adopted as an alternative fuel in the existing C. I. engines without any major modification in the engine hardware.

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