PRODUCTION OF BIODIESEL FROM THUMBA OIL AND ITS PERFORMANCE TESTING ON A CI ENGINE

A Major thesis submitted

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

Master of Engineering

In

Thermal Engineering

By

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STUDENT'S DECLARATION

I hereby certify that the work which is being presented in the major project entitled **"PRODUCTION OF BIODIESEL FROM THUMBA OIL AND ITS PERFORMANCE TESTING ON A CI ENGINE."** in partial fulfilment of the requirements for the award of the degree of Master of Engineering in Thermal Engineering, submitted to the Department of Mechanical Engineering, is an authentic record of my own work carried under the supervision of **Dr. Amit Pal** Asst. Professor of Mechanical Engineering Department, Faculty of Technology, University of Delhi, Delhi.

I have not submitted the matter embodied in this major project as whole or in part, for the award of any other degree.

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CERTIFICATE

Date: ___________

This is to certify that the dissertation entitled **"PRODUCTION OF BIODIESEL FROM THUMBA OIL AND ITS PERFORMANCE TESTING ON A CI ENGINE"** submitted by **Mr. Shashi Kumar (**14/THR/09), (University Roll. No.8581) in partial fulfilment for the award of the Degree of Master of Engineering in Thermal Engineering of University of Delhi, is an authentic record of student's own work carried out by him under my guidance and supervision.

This is also certified that this dissertation has not been submitted to any other Institute/University for the award of any degree or diploma.

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ABSTRACT

As the fossil fuels are depleting at a very faster rate, there is a need to find out an alternative fuel to fulfil the energy demand of the world. Biodiesel is one of the best available source to fulfil the energy demand of the world. The petroleum fuels play a very significant role in the development of industrial growth, transportation, agricultural sector and to meet many other basic human requirements. However, these fuels are limited and depleting day by day as the consumption is increasing very rapidly. Moreover, their use is alarming the environmental problems to society. Hence, there is a need of research for alternative fuels. There is a long list of trees, shrubs, and herbs available abundantly in India, which can be exploited for the production of biodiesel. Citrullus colocyntis (thumba non-edible oil), easily available in western Rajasthan can be efficiently used for production of biodiesel. In the present study, this thumba (citrullus colocyntis) oil was transesterified with methanol using potassium hydroxide as catalyst to obtain biodiesel by different production techniques and a comprehensive experimental investigation on single cylinder kiloskar engine running with biodiesel and its blends with diesel fuel was carried out for its performance and emission analysis. The results which obtained are significantly comparable to pure diesel. It show that biodiesel of thumba oil (citrullus colocyntis) can be used as alternative fuel with better performance and lower emissions compared with diesel and play a very vital role for the overall economic development of the country.

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LIST OF ABBREVIATIONS

CR	Compression ratio
MS	Magnetic stirring
UC	Ultrasonic cavitation
HC	Hydrodynamic cavitaion
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
BSEC	Brake specific energy consumption
BP	Brake power
EGT	Exhaust gas temperature
TB	Thumba biodiesel
WCO	Waste cooking oil
FP	Frictional power
IP	Indicated power
IThE	Indicated thermal efficiency
MechE	Mechanical efficiency
A/F	Air fuel ratio
BMEP	Brake mean effective pressure
PPM	Parts Per Million
EGR	Exhaust Gas Recirculation

CHAPTER-1
INTRODUCTION

1.1 INTRODUCTION

1.1.1 GENERAL

India is a country of more than 1.21 billion people which constitutes about 17.5% of the world's population. The population continues to grow at 1.64% per annum, which is well above the global average. The country's economy has also been growing rapidly in the last decade. The population of India has nearly tripled in the last 50 years, from 361 million in 1951 to 1.21 billion in 2011[1]. India has also developed rapidly during the past decades, reducing the percentage of the population living below the poverty line from 55 percent in 1973 to 21 percent in the late 1990s. However, millions of Indians still live in poverty and are dependent on continued development to raise their standard of living. In order to fight poverty and enhance livelihoods in developing countries the supply of food and energy must be secured; the population needs food for sustenance, and access to modern energy sources is necessary in order to achieve both economic growth and sufficient social and public services [2].

India depends on import of fossil fuels to its satisfy energy demand, and with population growth and economic development the demand will continue to increase in future [3]. Fossil fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world, and as the amount of new supplies found is decreasing, the resources will eventually be exhausted in the near future. Furthermore, rising petroleum prices, increasing threat to the environment from exhaust emissions and global warming have generated an intense international interest in developing alternative non-petroleum fuels for engines [4]. Increased fossil fuel use thus conflicts with the increasing global pressure to reduce environmental impact and mitigate climate change. (Planning Commission 2003).

In combination with the increasing global demand for renewable energy and bad effect of petroleum based fuels on environment, the need to secure energy supply in developing countries has created a demand for biomass energy, such as biofuels [3]. One of the most common biofuel energy system is production of biodiesel through transesterification of non-petroleum based oils. Biodiesel can be used in unmodified diesel engines, either alone or blended with conventional petro diesels [5]. For developing countries, production of biodiesels could represent a way to achieve economic growth by increasing and securing energy supply, and also by creating job opportunities enhancing source of income for the farmers involved.

1.1.2 GLOBAL ENERGY CRISIS

Energy is the lifeblood of modern era. Oil is necessary for almost all machines to move and we live in an era where oil is necessary to produce transport food, for movement of vehicles, airplanes etc. Oil is the most important ingredient for our lives, for industry, for economic development, for our prosperity but unfortunately, we are facing a global energy crisis with natural reserves being depleted fast due to over consumption.

Almost 90% of the world's energy needs are met by the non-renewable sources of energy like coal, oil and natural gas. This has resulted in an alarmingly increased rate of depletion of the natural resources. This is of concern globally as the future generations would definitely be at threat. Rapidly increasing oil prices are a threat to the economic growth of the nation, by way of increasing inflation and rising unemployment.

All countries of the world are united to tackle the global energy crisis. Certain countries who depend for oil on other countries find it difficult to exercise foreign policy options. This poses a security threat for the concerned nations. Global energy crisis is posing economic and security threat to almost all countries of the world [49].

1.1.3 ENERGY SCENARIO: INDIAN CONTEXT

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. India ranks sixth in the world in total energy consumption and needs to accelerate the development of the sector to meet its growth aspirations. The country, though rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy has very small hydrocarbon reserves (0.4% of the world's reserve). India, like many other developing countries, is a net importer of energy, more than 25 percent of primary energy needs being met through imports mainly in the form of crude oil and natural gas. The rising oil import bill has been the focus of serious concerns due to the pressure it has placed on scarce foreign exchange resources and is also largely responsible for energy supply shortages.

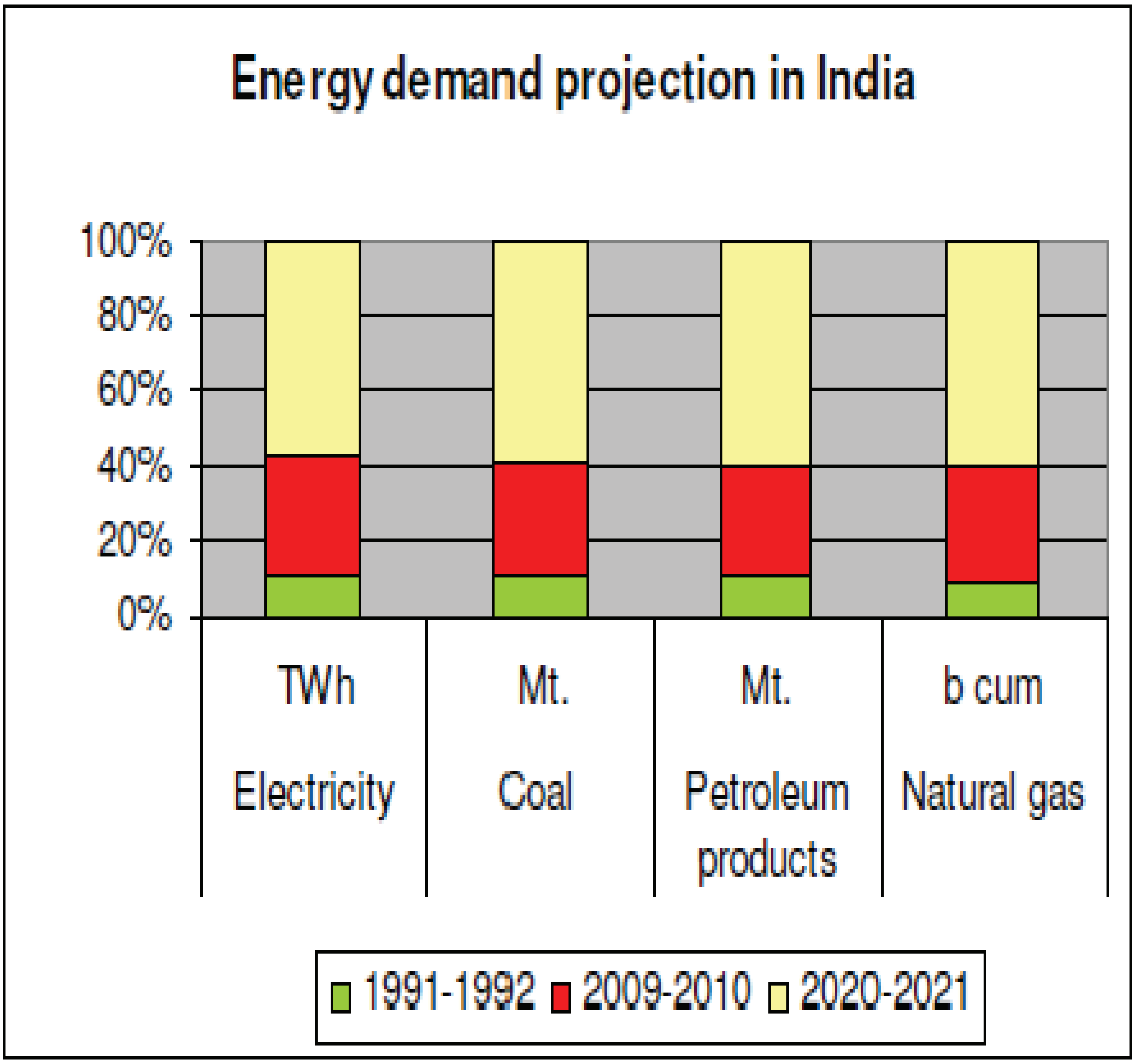


Fig 1.1: Energy demand projection in India

India had approximately 5.6 billion barrels of proven oil reserves as of January 2010, the second-largest amount in the Asia-Pacific region after China. India produced roughly 880 thousand barrels per day (bbl/d) of total oil in 2009 from over 3,600 operating oil wells. Approximately 680 thousand bbl/d was crude oil and the remainder was other liquids and refinery gain.

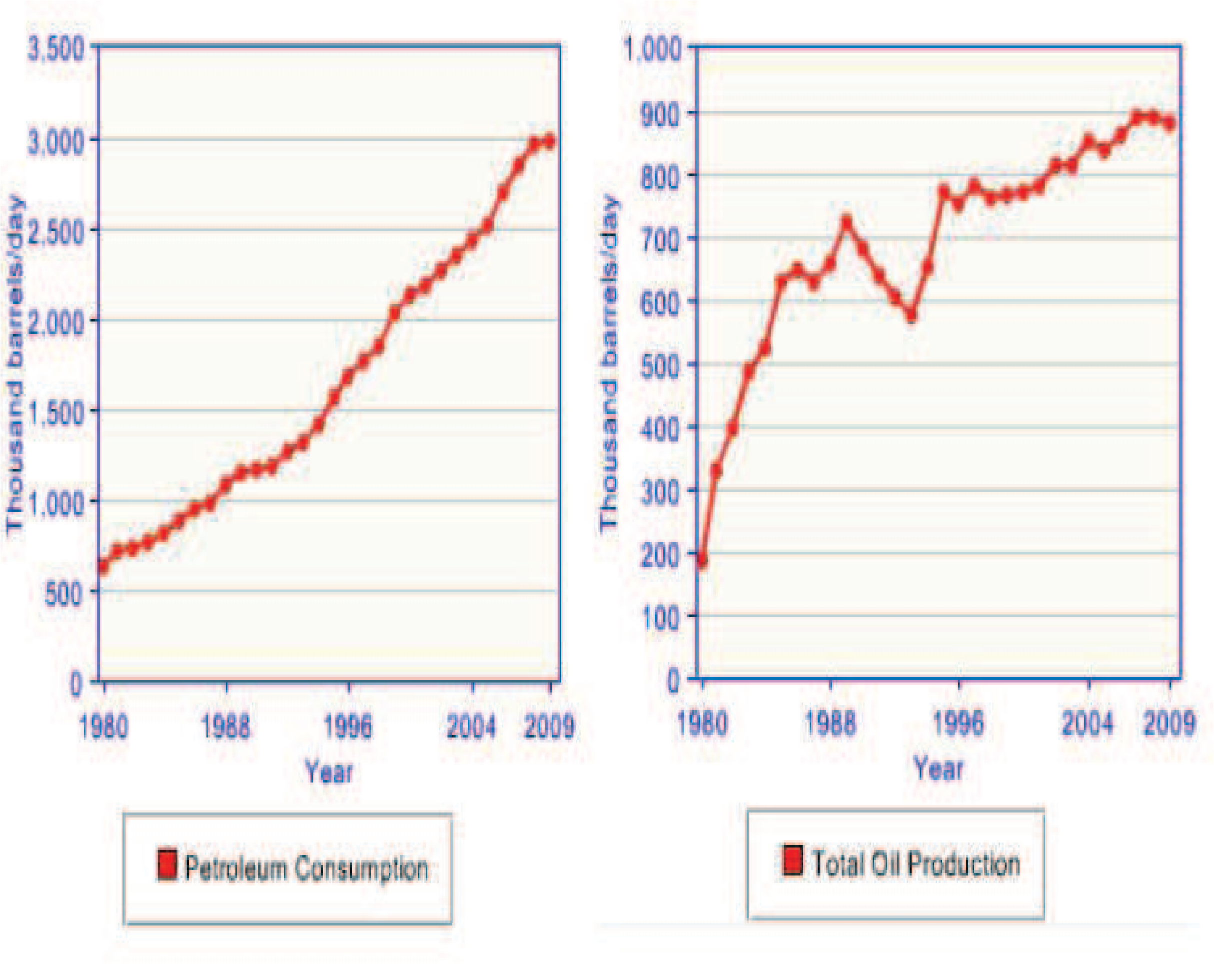


Fig 1.2: Petroleum Consumption and production in India

In 2009, India consumed nearly 3 million bbl/d (Fig. 4), making it the fourth largest consumer of oil in the world. EIA (Energy Information Administration) expects approximately 100 thousand bbl/d annual consumption growth through 2011. In 2009, India was the sixth largest net importer of oil in the world, importing, nearly 2.1 million bbl/d, or about 70 percent, of its oil needs. The EIA expects India to become the fourth largest net importer of oil in the world by 2025, behind the United States, China, and Japan. By seeing all parameters of production and consumptions of oils in India, it is necessary to look for some alternate energy resources to fulfill the demands of all the sectors of the country. And it is also necessary for better economic growth for our country [6].

1.3 BIODIESEL

1.3.1 Historical background

Developed in the 1890s by inventor Rudolph Diesel, the diesel engine has become the engine of choice for power, reliability, and high fuel economy, worldwide. Early experimenters on vegetable oil fuels included the French government and Dr. Diesel himself, who envisioned that pure vegetable oils could power early diesel engines for agriculture in remote areas of the world, where petroleum was not available at the time. Modern biodiesel fuel, which is made by converting vegetable oils into compounds called fatty acid methyl esters, has its roots in research conducted in the 1930s in Belgium, but today's biodiesel industry was not established in Europe until the late 1980s.

The diesel engine was developed out of a desire to improve upon inefficient, cumbersome and sometimes dangerous steam engines of the late 1800s. The diesel engine works on the principal of compression ignition, in which fuel is injected into the engine's cylinder after air has been compressed to a high pressure and temperature. As the fuel enters the cylinder it self-ignites and burns rapidly, forcing the piston back down and converting the chemical energy in the fuel into mechanical energy. Dr. Rudolph Diesel, after whom the engine is named, holds the first patent for the compression ignition engine, issued in 1893. Diesel became known worldwide for his innovative engine which could use a variety of fuels.

The concept of bio fuel dates back to 1885 when Dr. Rudolf Diesel built the first diesel engine with the full intention of running it on vegetative source. In 1912 he observed, "the use of vegetable oils for engine fuels may seem insignificant today. But such oils may in the course of time become as important as petroleum and coal tar product of present time."

In 1970, scientists discovered that the viscosity of vegetable oils could be reduced by a simple chemical process and that it could perform as diesel fuel in modern engine. Since then the technical developments have come a long way and the plant oil today has been highly established as biofuel, equivalent to diesel.

Recent environmental (e.g. Kyoto Protocol) and economic concerns have prompted resurgence in the use of biodiesel throughout the world. In 1991, the European Community proposed a 90% tax reduction for the use of bio fuels, including biodiesel. Today 21 countries worldwide produce biodiesel.

India is one of the largest petroleum consuming and importing countries. India imports about 70 % of its petroleum demands. The current yearly consumption of diesel oil in India is approximately 40 million tones constituting about 40% of the total petro-product consumption.

Biodiesel, derived from the oils and fats of plants like sunflower, rape seeds, Canola or Jatropha (Bhagveranda) can be used as a substitute or an additive to diesel. As an alternative fuel biodiesel can provide power similar to conventional diesel fuel and thus can be used in diesel engines. Biodiesel is a renewable liquid fuel that can be produced locally thus helping reduce the country’s dependence on imported crude petroleum diesel [7].

1.3.2 Definition

In general terms, biodiesel may be defined as a domestic, renewable fuel for diesel engines derived from natural oil that meets the specifications of ASTM D 6751. In technical terms (ASTM D 6751) biodiesel is a diesel engine fuel comprised of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated B100 and meeting the requirements of ASTM D 6751[8]. Biodiesel, also referred to as methyl ester or fatty acid methyl ester (FAME), in application as an extender for combustion in CIEs (diesel), possesses a number of promising characteristics, including reduction of exhaust emissions [9].

1.3.3 Indian Energy Scenario of Biodiesel

The government of India has formulated an ambitious National Biodiesel Mission to meet 20 per cent of the country’s diesel requirements by 2011-2012. 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. 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. The 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 cumulatively by Non Government Organizations (NGOs), public and private sectors. The Ministry of Forests and Environment (MEF) and the National Oilseed and Vegetable Oil Development Board (NOVODB) 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. Table-1.1 depicts the annual production of non-edible oil seeds in India. It can be seen that there is more than 1000 Metric Ton production capacity and it can further be increased with suitably planned plantation. 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 by 2011-12. Details of diesel and biodiesel requirements in near future are given in Table 1.2.

Table 1.1: Annual Production of Non-edible Oil Seeds in India [11].

Type	Production (MT)	Oil %	Type	Production (MT)	Oil %
Neem	500	30	Jaoba	-	50
Karanja	200	27-39	Bhikal	-	37
Kusum	80	34	Wild Walnut	-	60-70
Pilu	50	33	Undi	04	50-73
Ratanjot	-	30-40	Thumba	100	21

Table1.2: Demand for diesel and Biodiesel requirement [12].

year	Diesel demand (in metric ton)	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

There are many key challenges and market barriers for Biodiesel promotion in India. Information regarding the agro economic practices is 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 only 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 biodiesel 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 percentage 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 [10].

1.3.4 Resources of Biodiesel

There are various biodiesel sources: almond, andiroba (*Carapa guianensis*), babassu (*Orbignia sp.*), barley, camelina (*Camelina sativa*), coconut, copra, cumaru (*Dipteryx odorata*), *Cynara cardunculus*, fish oil, groundnut, *Jatropha curcas*, karanja (*Pongamia glabra*), laurel, *Lesquerella fendleri*, *Madhuca indica*, microalgae (*Chlorella vulgaris*), oat, piqui (*Caryocar sp.*), poppy seed, rice, rubber seed, sesame, sorghum, tobacco seed, and wheat (13).

Vegetable oils are renewable fuels. They have become more attractive recently because of their environmental benefits and the fact that they are made from renewable resources. Vegetable oils are a renewable and potentially inexhaustible source of energy, with energy content close to that of diesel fuel. Global vegetable oil production increased from 56 million tons in 1990 to 88 million tons in 2000, following a below-normal increase. The source of this gain was distributed among the various oils. Global consumption rose 56 million tons to 86 million tons, leaving world stocks comparatively tight.

A variety of biolipids can be used to produce biodiesel. These are (a) virgin vegetable oil feedstock; rapeseed and soybean oils are most commonly used, though other crops such as mustard, palm oil, sunflower, hemp, and even algae show promise; (b) waste vegetable oil; (c) animal fats including tallow, lard, and yellow grease; and (d) non-edible oils such as jatropha, neem oil, castor oil, tall oil, *etc.*

The widespread use of soybeans in the USA for food products has led to the emergence of soybean biodiesel as the primary source for biodiesel in that country. In Malaysia and Indonesia, palm oil is used as a significant biodiesel source. In Europe, rapeseed is the most common base oil used in biodiesel production. In India and Southeast Asia, the jatropha tree is used as a significant fuel source.

The production of vegetable oils globally given is shown in Table 1.3. In Table 1.4 top 10 countries biodiesel potential (Liter) and there production cost ($/Liter) is given.

Table1.3: Global productions of the major vegetable oils [14].

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**

Table1.4: Top 10 countries in terms of biodiesel potential [15].

Rank	**country**	**Volume potential (Litre)**	**Production cost ($/**
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	2496,000,000	$ 0.75
7	Germany	2024,000,000	$ 0.79
8	Philippines	1234,000,000	$ 0.53
9	Belgium	1213,000,000	$ 0.78
10	Spain	1073,000,000	$ 1.71

1.3.5 Thumba *(Citrullus colocyntis):*-an overview:

Present work is carried out by using thumba oil (Citrullus colocyntis) as raw material for biodiesel production. *Citrullus colocyntis* (thumba) oil, a non-edible vegetable oil considered as a potential alternative fuel for CI engines, has been chosen to explore its possibility for use as fuel oil. *Citrullus colocyntis* is known as *Indrayan* in Hindi or Bitter apple in English. It is native of Turkey and found in Asia and Africa. In India it mainly grows in rain fed parts of Rajasthan and Gujarat. The plant is in the form of creeper and grows well in sandy soil. The plant has annular and rough stems, rough leaves which are 3 to 7 lobed, 5-10 cm long in middle. Flowers are monolecious and have yellow round fruit. The fruit, seeds, raw oil and Biodiesel of thumba is shown in Figure 1. The flowering season is in between May (start of monsoon) and August. It grows along with main crop of Bajara and hence does not require special care. The oil of this plant is locally called as thumba oil. The plant is mainly used as cattle feed by farmers. It is also used as laxative and anti-inflammatory drug. Raw thumba oil is presently consumed in large quantities by the local soap industries. The small crop cycle and various uses of thumba plant are some of the salient features which can play a pivotal role for the progress of Indian rural economy [10].

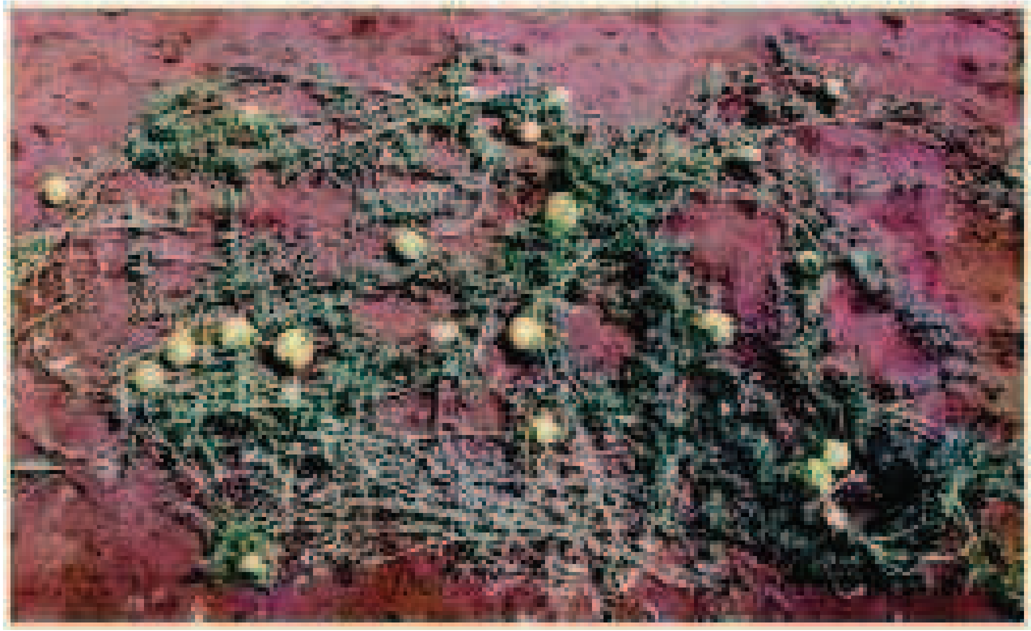
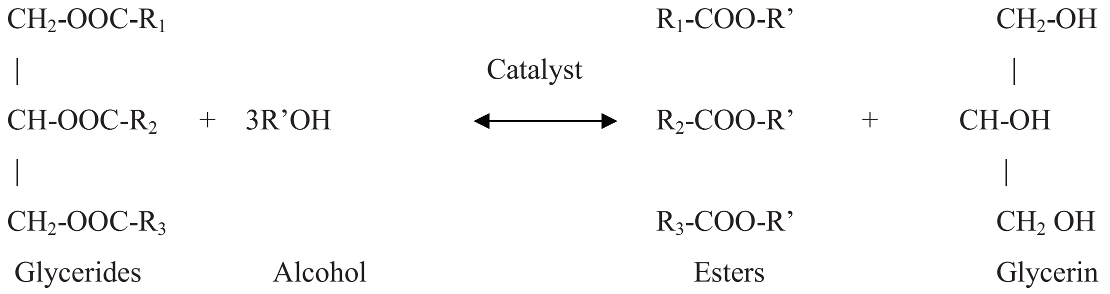


Figure 1.4(a): Thumba (Citrullus Colocynthis) plant

Figure 1.4(b): Thumba fruit and seeds

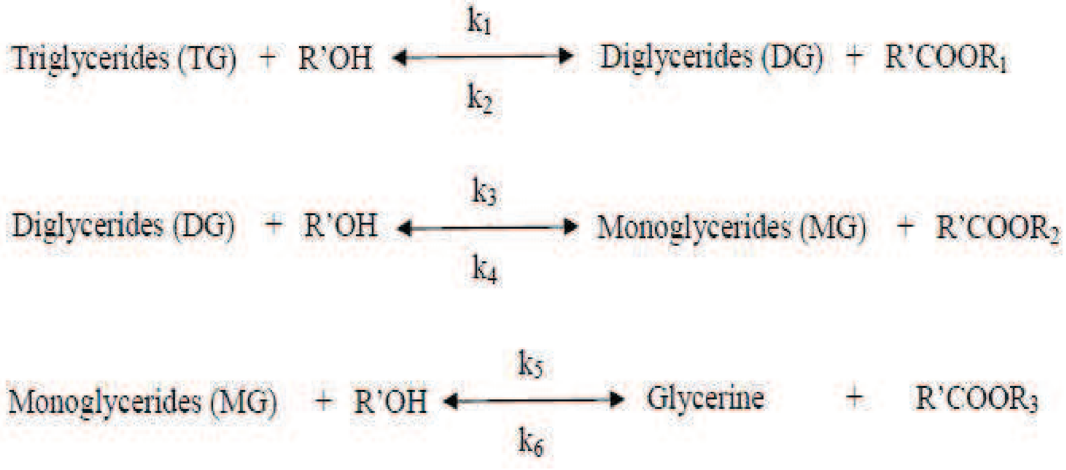
1.3.6 Chemistry of Biodiesel

In the transesterification of different types 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.



$$\begin{array}{lcccccc} CH_2\text{-}OOC\text{-}R_1 & & & & R_1\text{-}COO\text{-}R' & & CH_2\text{-}OH \\ | & & & \text{Catalyst} & & & | \\ CH\text{-}OOC\text{-}R_2 & + & 3R'OH & \longleftrightarrow & R_2\text{-}COO\text{-}R' & + & CH\text{-}OH \\ | & & & & & & | \\ CH_2\text{-}OOC\text{-}R_3 & & & & R_3\text{-}COO\text{-}R' & & CH_2\ OH \\ \text{Glycerides} & & \text{Alcohol} & & \text{Esters} & & \text{Glycerin} \end{array}$$

The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step, from triglycerides diglyceride is obtained, from diglyceride monoglyceride is produced and in the last step, from monoglycerides glycerin is obtained. In all these reactions esters are produced. The stochoimetric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product [16, 17]



$$\text{Triglycerides (TG)} + R'OH \underset{k_2}{\overset{k_1}{\longleftrightarrow}} \text{Diglycerides (DG)} + R'COOR_1$$

$$\text{Diglycerides (DG)} + R'OH \underset{k_4}{\overset{k_3}{\longleftrightarrow}} \text{Monoglycerides (MG)} + R'COOR_2$$

$$\text{Monoglycerides (MG)} + R'OH \underset{k_6}{\overset{k_5}{\longleftrightarrow}} \text{Glycerine} + R'COOR_3$$

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.

Alkali Catalyst

These catalysts 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).

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.

a. Sulfuric acid ($H2SO4$).
b. Sulfonic acid.

1.3.7 Properties of Biodiesel

Some of the important properties of biodiesel are as follows [8, 17]:

***Density/ Specific gravity*:**

Density is the mass per unit volume. The measurement was made at room temperature. The density was measured with the help of a U-Tube Oscillating True Density meter. Biodiesel is slightly heavier than conventional diesel fuel (specific gravity 0.88g/cm^3 compared to 0.84g/cm^3 for diesel fuel). This allows use of splash blending by adding biodiesel on top of diesel fuel for making biodiesel blends.

Viscosity:

When a fluid is subjected to external forces, it resists flow due to internal friction. Viscosity is a measure of internal friction. The viscosity of the fuel affects atomization and fuel delivery rates. It is an important property because if it is too low and too high then atomization and mixing of air and fuel in combustion chamber gets affected. 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:

It is defined as the "lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mm Hg), at which application of an ignition source causes the vapors of a specimen to ignite under the specified conditions of test." This test, in part, is a measure of residual alcohol in the B100. The flash point is also a determinant for flammability classification of materials. B100’s typical flash point is >200°C, classifying it as “non-flammable”. Water and sediment is a test that “determines the volume of free water and sediment in middle distillate fuels having viscosities at 40°C in the range 1.0 to 4.1 mm^2/s and densities in the range of 700 to 900 kg/m^3.” This test is a measure of cleanliness of the fuel. For B100 it is particularly important because water can react with the esters, making free fatty acids, and can support microbial growth in storage tanks. The flash point values of vegetable oil methyl esters are much lower than those of vegetable oils. An increase in density from 860 to 885 kg/m^3 for vegetable oil methyl esters or biodiesels increases the viscosity from 3.59 to 4.63 mm^2/s. There is high regression between the density and viscosity values of vegetable oil methyl esters. The relationships between viscosity and flash point for vegetable oil methyl esters are irregular.

Kinematic viscosity:

The resistance to flow of a fluid under gravity. The kinematic viscosity is a basic design specification for the fuel injectors used in diesel engines. Too high a viscosity and the injectors do not perform properly.

Dynamic viscosity:

Ratio between applied shear stress and rate of shear of a liquid.

Acid Value:

The quantity of base, expressed as milligrams of potassium hydroxide per gram of sample, required to titrate a sample to a specified end point. The acid number is a direct measure of free fatty acids in B100. The free fatty acids can lead to corrosion and may be a symptom of water in the fuel.

Cetane number:

A measure of the ignition performance of a diesel fuel obtained by comparing it to reference fuels in a standardized engine test. Cetane for diesel engines is analogous to the octane rating in a spark ignition engine. It is a measure of how the fuel will ignite in the engine. For B100, the cetane number can be very accurately predicted using the ester’s composition. It is unlikely that an individual producer will ever run cetane tests on-site. The cetane number (CN) is based on two compounds, hexadecane, with a CN of 100, and heptamethylnonane, with a CN of 15. The CN is a measure of the ignition quality of diesel fuels, and a high CN implies short ignition delay. The CN of biodiesel is generally higher than conventional diesel. The longer the fatty acid carbon chains and the more saturated the molecules, the higher the CN. The CN of biodiesel from animal fats is higher than those of vegetable oils.

Cloud point:

The temperature at which a cloud of wax crystals first appears in a liquid when it is cooled down under conditions prescribed in this test method. The cloud point is a critical factor in cold weather performance for all diesel fuels. The chemical composition of some biodiesel feedstock’s leads to a B100 that may have higher cloud points than desired. The cloud point, however, is another parameter that can be predicted accurately with knowledge of the esters composition, but producers are advised to be able to perform this test. The CP is the temperature at which wax first becomes visible when the fuel is cooled. Biodiesel has a higher cloud point compared to conventional diesel.

Pour Point:

The pour point is the temperature at which the amount of wax from a solution is sufficient to gel the fuel; thus it is the lowest temperature at which the fuel can flow. Biodiesel has a higher pour point compared to conventional diesel.

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.

Carbon residue:

In petroleum products, the part remaining after a sample has been subjected to thermal decomposition. The carbon residue is a measure of how much residual carbon remains after combustion. This is particularly important in diesel engines because of the possibility of carbon residues clogging the fuel injectors. The most common cause of excess carbon residues in B100 is an excessive level of total glycerin. Total glycerin is also measured directly using an additional procedure specified in this Standard.

Acid number:

The quantity of base, expressed as milligrams of potassium hydroxide per gram of sample required to titrate a sample to a specified end point. The acid number is a direct measure of free fatty acids in B100. The free fatty acids can lead to corrosion and may be a symptom of water in the fuel.

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.

Copper strip corrosion

Detection of the corrosiveness to copper of fuels and solvents. This test monitors the presence of acids in the fuel. For B100, the most likely source of a test failure would be excessive free fatty acids, which are determined in accordance with an additional specification

***Storage stability**:*

All fuels are subject to degradation over time when they are stored. This degradation may be due to microbial action, water intrusion, air oxidation, etc. The standard and the test methods for determining storage stability for B100 are still in the development stage within the ASTM process. This is due to the unsaturated fatty acid chains and the presence of the double bond in the molecule, which produce a high level of reactivity with the oxygen, especially when it placed in contact with air. The oxidation of fatty acid chains is a complex process that proceeds by a variety of mechanisms. The various other factors influence the oxidation process of biodiesel includes light, temperature, extraneous materials, peroxides, size of the surface area between biodiesel and air. One of the methods of improving biodiesel oxidative stability includes the deliberate addition of antioxidants or modification of the fatty ester profile [18].

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

Table1.5: Summary of proposed BIS (Bureau of Indian Standards) standards for biodiesel [8]

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	no.	>=51
Acid no	mg KOH/g	<=0.8
Methanol	%mass	<=0.02
Ester content	%mass	>=96.5
Triglyceride	%mass	<=0.2
Triglyceride	%mass	<=0.2
Free glycerol	%mass	<=0.02
Total glycerol	%mass	<=0.25
Iodine no	no.	<=115
Phosphorus	Ppm	<=10
Alkaline matter(Na,K)		<=10
Distillation, T 95%	°C	<=360

1.4 ADVANTAGES OF THE BIODIESEL OVER PETROLEUM BASED DIESEL FUEL

1. Biodiesel is a good lubricant about 66% better than petro diesel.
2. Biodiesel produce less smoke and particulates maters 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 sulphur or extremely low sulphur 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 [19].

1.5 ALTERNATIVE FUEL IMPUTES

There are some very important parameters which should be considered before adaptation of an alternative fuel in an existing engine. These include:

- No or minimum modification required in design of engine,
- Use of same storage and transportation infrastructure,
- Biodegradable and non-toxic assuring safe handling and transportation,

- Capability of being produced locally and low investment cost.

The economic benefits of the fuels like vegetable oils, compressed natural gas, ethanol, and methanol etc. compared to the traditional petroleum resources are marginal but the environmental benefits are enormous, thus public policies need to be revised to encourage the development of these resources for which:

- Land for production need to be explored.
- An efficient extraction of oil from oil seeds and transesterification plant would be required.
- Distribution and storage facilities constructed.
- Monitoring of major users for detection of problems
- Large scale use are needed before the technology can be recommended for general use
- The magnitude of our energy needs provides an inexhaustible market of our total agriculture production capacity at the highest possible level farm back to work providing for our food needs and also growing crops and livestock for energy.
- Energy is the only crop that we could never grow in surplus [20].

1.6 MOTIVATION FOR PRESENT WORK

Following reasons were compiling us for working on this project:

- The future energy availability is a serious global concern.
- Approximately half of the world's total resources would be exhausted by 2030
- Use of eco friendly fuels leads to the decrease in acid rain and greenhouse effect.
- Major global concern is environmental degradation
- Climate change such as global warming.

This present work hoped a positive way towards security of energy in future. The aim of this project to search suitable and effective method of biodiesel production, for its performance and emissions analysis on C.I. Engine.

1.7 OBJECTIVE OF THE PRESENT RESEARCH WORK

Objective of this research has two phases are as follows:

1. Production of biodiesel from thumba oil by following methods:

- Mechanical stirring
- Ultrasonic Cavitation .
- Hydrodynamic Cavitation.

2. Performance and emission testing of thumba biodiesel on CI 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 background and concept of biofuels, definition of biodiesel, need of biodiesel, Indian energy scenario, the resources of biodiesel, biodiesel properties according to the literatures, role of biodiesel production, performance and emission testing.

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

Third chapter deals with various biodiesel production techniques for the production of biodiesel from thumba oil. In this chapter conventional mechanical stirring, ultrasonic and hydrodynamic cavitation methods are used for biodiesel production. It also contains the yield analysis of all the methods with time.

Forth chapter is deals with performance and emission testing of biodiesel on VCR kirloskar engine. The testing is done on compression ratio 18 and 15.

Fifth chapter contains the result and discussion part. It represents the various of performance testing in graphical form in order to compare diesel and biodiesel performance and emissions.

CHAPTER-2

LITERATURE REVIEW

The literature review is classified into two major categories are as follows:

1). Biodiesel production techniques:-

  (a) Conventional mechanical stirring
  (b) Ultrasonic cavitation
  (c) Hydrodynamic cavitation

2). Performance and emissions

2.1 BIODIESEL PRODUCTION TECHNIQUES

Meher et al. [21] have studied the transesterification of Pongamia Pinnata oil by means of methanol and feasibility of methanolysis process by using KOH catalysts. The yield of biodiesel obtained was >97% by using oil/methanol molar ratio 12:1 KOH as catalyst at 65oC and stirring at 360 rpm in 3 hr. It was observed that the best yield was obtained with a catalytic concentration of 1% of KOH. For higher value of catalyst concentration, the yields were lower. There are very few studies reported on production of biodiesel by utilizing non-edible oils, among which Karanja is one of the most potential species to produce biodiesel in India which could offer opportunities for generation of rural employment increasing income and improving environment.

Meher et al. [22] have reported transesterification of karanja oil with methanol for the product of biodiesel. The reaction parameters such as catalyst concentration, alcohol/oil molar ratio, temperature and rate of mixing were optimized for production of karanja oil methyl ester (KOME). The yield of methyl esters from karanja oil under the optimal condition was 97-98%. Studies were carried out at molar ratio = 6:1, reaction temp = 650 C, rate of mixing = 360 rpm. Yield = above 85% in15 min. and Yield = 97-98% after 2 hrs. Molar ratio = 12:1, Reaction time = 1hr., Rate of mixing = 180 rpm and stirring at high rpm was a time efficient process.

Tomasevic et al. [23] have conducted an experimental investigation on methyl esters obtained on the basis of heated refined sunflower oil and used frying oils.

Transesterification reaction conditions that affect yield and purity of the esters including oil quality, molar ratio of methanol to vegetable oil, type and concentration of alkaline catalyst, temperature and reaction time were examined. The methanolysis of different oils at 250 C with 0.5%-1.5% potassium hydroxide or sodium hydroxide were studied. The effect of molar ratio 4.5:1, 6:1 and 9:1 on ester yield and its quality were investigated. By using 1% potassium hydroxide, temperature at 250 C, molar ratio 6:1 and 30 min, all investigated oils were sufficiently transesterified and could be used as fuel in diesel engines.

Math et al. [24] have explained use of two stage transesterification method for conversion of restaurant waste oil into biodiesel and optimization of experimental conditions for biodiesel production. Maximum yield (85.50%) of biodiesel (methyl ester of restaurant waste oil) was obtained at optimum amount of methanol, catalyst NaOH concentration temperature and reaction time. It studies different amounts of methanol (20, 25, 30, 35, 40 and 45%), catalyst concentration (0.3, 0.5, 0.7, 1.0, and 1.5% NaOH), reaction temperature (30, 45, and 55) and different reaction times (60, 90, and 120 min) were selected for transesterification of restaurant waste oil in order to optimize experimental conditions for maximum biodiesel yield. Methyl ester yield (65.50-85.50%) in the laboratory scale biodiesel reactor was obtained maximum (85.50%) at the optimized process parameters such as methanol (35% by volume), NaOH (0.3g), reaction temperature (55 oC) and reaction time (90 min).

Maeda et al. [25] has studied that the batch transesterification of vegetable oil with methanol, in the presence of potassium hydroxide as catalyst, by means of low frequency ultrasound (40 kHz) was studied with the aim of gaining more knowledge on intimate reaction mechanism. The concentration of fatty acid methyl esters, of mono-, di- and triglycerides of the actual reaction mixture were determined at short reaction time by HPLC. During ultrasonically driven transesterification, the first 3–10 min of reaction if not faster, making from this technique a unique one for FAME synthesis. Diglycerides were found in small amounts while monoglycerides were detected in high amount, indicating that the last step of transesterification is slower. The conversion of FAME at the end of 60 min of sonication was almost same regardless the type of oil, meaning that the reaction mixture was in steady state (i.e. equilibrium concentration was reached). We can conclude that the ultrasonically driven transesterification is a tool applicable to almost all types of vegetable oils. The saturated fatty acids were transesterified mostly at the beginning of the reaction, while the amount of unsaturated fatty acids esters increased as the reaction progressed.

Bhake et al. [26] has investigated that an ultrasonic reactor for biodiesel production drastically reduces the reaction time, reaction temperatures, and energy input. 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 was studied. 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). 28 kHz 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 transesterification process is affected by alcohol type, molar ratio of alcohol to oil, type and amount of catalyst, temperature and purity of the reactants, mixing efficiency. Ultrasounds could successfully replace the classical mixing –heating conditions.

Stavarache et al. [27] have investigated that 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 was studied. 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). 28 kHz give slightly better yields (98–99%), but longer reaction time, while higher frequencies are not useful at all for the transesterification of fatty acids.

Hanh et al. [28] investigates the production of fatty acid ethyl ester (FAEE) from oleic acid (FFA) with short-chain alcohols (ethanol, propanol, and butanol) under ultrasonic irradiation. Batch esterification of oleic acid was carried out to study the effect of: test temperatures of 10–60°C, molar ratios of alcohol to oleic acid of 1:1–10:1, quantity of catalysts of 0.5–10% (wt of sulfuric acid/wt of oleic acid) and irradiation times of 10 h. The optimum condition for the esterification process was molar ratio of alcohol to oleic acid at 3:1 with 5 wt% of H_2SO_4 at 60°C with an irradiation time of 2 h. The increase in the irradiation time, as well as molar ratio, contributes to high conversion and quality of esters. The esterification of fatty acid with ethanol under ultrasonic irradiation provides a possibility for producing cheap alternative fuels, which could reduce air pollution and protect the environment.

Parag et al. [29] carry out the 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 85W 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).

Pal et al. [30] described the details of development of a biodiesel production test rig based on hydrodynamic cavitation followed by results of experimental investigation carried out on a four cylinder, direct injection water cooled diesel engine operating on diesel and biodiesel blend of Citrullus Colocynthis (Thumba) oil. The experiment covers a wide range of engine speed. Results show that biodiesel of Thumba oil produced through hydrodynamic cavitation technique can be used as an alternative fuel with better performance and lower emissions compared to diesel. The most significant conclusions are that (i) Biodiesel production through hydrodynamic cavitation technique seems to be a simple, efficient, time saving, eco-friendly and industrially viable process. (ii) 30% biodiesel blend of Thumba oil shows relatively higher brake power, brake thermal efficiency, reduced bsfc and smoke opacity with favourable p–q diagram as compared to diesel.

Kelkar et al. [31] have presented the effectiveness of cavitation as a novel tool for process intensification of synthesis of bio-diesel which has been looked at an affordable alternative to conventional petroleum based fuels. The different reaction operating parameters such as molar ratio of acid to alcohol, catalyst quantity have been optimized under acoustic as well as hydrodynamic cavitating conditions in addition to the optimization of the geometry of the orifice plate in the case of hydrodynamic cavitation reactors. It has been observed that ambient operating conditions of temperature and pressure and reaction times of less than 3 hours, for all the different combinations of acid/alcohol studied in the present work, was sufficient for giving more than 90% conversion. Comparison of energy efficiencies of hydrodynamic cavitation reactors with sonochemical reactors indicated that hydrodynamic cavitation is more energy efficient as compared to acoustic cavitation. Depending on the type of acid/alcohol combination used in the present work the energy efficiency for hydrodynamic cavitation varied in the range of 1×10^{-4} to 2×10^{-4} g/J whereas for acoustic cavitation it was order of magnitude lower i.e. in the range of 5×10^{-6} to 2×10^{-5} g/J.

Lu et al. [32] have carried out two step process consisting of pre-esterification and transesterification process to produce biodiesel from crude Jatropha curcas L. oil. The effects of the methanol/oleic acid molar ratio, reaction time, temperature and catalyst amount on the conversion of the pre-esterification reaction were investigated. Temperature is found to influence the reaction rate. Higher yield was obtained at a higher temperature between 35 and 65oC. The conversion increased with reaction time. The first 15 minutes is the fastest period of the reaction, in which a conversion of 90% is possible. The yield of biodiesel by transesterification was higher than 98% in 20 minutes of reaction time using 1.3% KOH as catalyst, and a molar ratio of methanol to oil of 6:1 at 64oC.

Gupta and Vivek [33] have investigated the feasibility of Karanja oil for the production of biodiesel optimization of different parameters for high yield conversion. The optimum parameters for high conversions are: pressure one atmosphere, temperature 68-70oC, reactant ratio 8-10 (Moles of MeOH: Moles of oil), reaction time 30-40 min, catalyst (KOH) 1.5% w/w.

Kumar et al. [34] have produced biodiesel from non-edible vegetable oil using ultrasonication, calls for an efficient solid catalyst to make the process fully ecologically and economically friendly. The methodology allows for the reaction to be run under atmospheric conditions. Solid catalyst and ultrasonication reduced the reaction time comparing to the conventional batch processes and we found 98.53% biodiesel yield. The optimal conditions for biodiesel production is the molar ratio oil to methanol 1:9, Catalyst conc. 3 wt. % of oil and 15 min reaction time.

Karnwal et al. [35] have investigated the transesterification process for production of Thumba oil methyl ester has been analyzed and the various process variables like temperature, catalyst concentration, amount of methanol and reaction time have been optimized with the objective to maximize yield. The optimum conditions for transesterification of Thumba oil with methanol and KOH as catalyst were found to be 60°C reaction temperature, 6:1 molar ratio of Thumba oil to methanol, 0.75% catalyst (w/w) and 1 hour reaction time

2.2 PERFORMANCE AND EMISSIONS STUDIES

Sundarapandian and Devaradjane et al. [36] carry out the experiment by developing the a theoretical model to evaluate the performance characteristics, combustion parameters and emissions of vegetable oil esters like Jatropha, Mahua and Neem Oil esters. The predicted results of these fuels are compared with Experimental result of diesel fuel. From the results, it is found that the heat release and work done are reduced by about 4% for Jatropha, 5% for Mahua and 8% for Neem oil esters when compared to diesel. The harmful pollutants such as HC, CO, NO_X and smoke are reduced in the vegetable oil esters compared to diesel fuel. From the investigation, it is concluded that the performance of vegetable oil esters are good. Thus the developed model is highly compatible for simulation work with bio diesel as an alternative fuel.

Hariharan et al. [37] were conducted the experiments to study the performance, emission and combustion characteristics of a DI diesel engine using sea lemon oil-based fuels. In the present work, sea lemon oil and sea lemon oil methyl ester are tested as diesel fuels in diesel engine in neat form. The reduction in NOx emission and an increase in smoke, hydrocarbon and CO emissions were observed for Neat sea lemon oil compared to those of standard diesel. From the combustion analysis it was found that ignition delay was slightly more for both the fuels tested compared to that of standard diesel. The combustion characteristics of sea lemon oil and its methyl ester closely followed those of standard diesel.

Rao et al. [38] have investigated the combustion, performance and emission characteristics of Used Cooking oil Methyl Ester (UCME) and its blends with diesel oil are analyzed in a direct injection C.I. engine. The fuel properties and the combustion characteristics of UCME are found to be similar to those of diesel. A minor decrease in thermal efficiency with significant improvement in reduction of particulates, carbon monoxide and unburnt hydrocarbons is observed compared to diesel. The use of transesterified used cooking oil and its blends as fuel for diesel engines will reduce dependence on fossil fuels and also decrease considerably the environmental pollution.

Banapurmath et al. [39] were carried out the investigations on a single-cylinder, fourstroke, and direct-injection, CI engine operated with methyl esters of Honge oil, Jatropha oil and sesame oil. Comparative measures of brake thermal efficiency, smoke opacity, HC, CO, NOX, ignition delay, combustion duration and heat release rates have been presented and discussed. Engine performance in terms of higher brake thermal efficiency and lower emissions (HC, CO, NOX) with sesame oil methyl ester operation was observed compared to methyl esters of Honge and Jatropha oil operation.Compared to neat diesel operation, methyl esters of Honge oil, Jatropha and sesame oils result in poor performance associated with higher emissions. The brake thermal efficiency with HOME, SOME and JOME is 29.51%, 30.4% and 29%, respectively, at 80% load and 31.25% with diesel. The HC and CO emissions with SOME, HOME and JOME are found to be slightly more than the diesel operation. All the esters result in slightly higher smoke emissions than diesel, and it is attributed to the incomplete combustion because of their lower volatility and higher viscosity. All the esters show increased ignition delay and combustion duration as compared to neat diesel. SOME and HOME resulted in an improved heat-release rate as compared to

JOME, which results in better brake thermal efficiency. On the whole it is seen that operation of the engine is smooth on SOME, HOME and JOME. All the esters tested result in a slightly reduced thermal efficiency and increased smoke, HC and CO levels. The existing engine could be operated on the esters tested without any major modification.

Qi et al. [40] have studied to characterize the effect of biodiesel produced from soybean crude oil on the combustion characteristics, performance and exhaust emissions of a diesel engine. The properties, performance, emissions and combustion characteristics of the engine fueled with biodiesel and diesel were compared. Based on the experimental results, it was found that the fuel properties of biodiesel are slightly different from those of diesel. The viscosity of biodiesel is evidently higher than that of diesel, especially at low temperatures. The specific gravity of the biodiesel is approximately 6.1% higher than that of diesel. The LHV of the biodiesel is approximately 10.2% lower than that of diesel. The flash point is higher than that of diesel. The acid value of biodiesel is 1.8 mg KOH/g. The biodiesel has a narrow boiling range, 95% of which is boiled off between 310 and 360 ^{o}C. Due to the different properties of biodiesel and diesel, both fuels exhibit different combustion characteristics with the variation of engine loads. At lower engine loads, the peak cylinder pressure, the peak rate of pressure rise and the peak heat release rate are slightly higher for biodiesel. At higher engine loads, the peak cylinder pressures for both fuels are almost same, but the peak rate of pressure rise and peak heat release rate are lower for biodiesel. The crank angles at which the peak values occur are in advance for biodiesel. Combustion for biodiesel starts earlier owing to a shorter ignition delay and advanced injection time at all engine loads. The power output for biodiesel is almost the same as that for diesel under speed characteristic at full load. The BSFC for biodiesel is higher than that for diesel. The higher fuel consumption reflects its lower heating value. Both fuels give nearly identical BSEC. The emission of carbon monoxide, hydrocarbon, nitrogen oxides and smoke are averagely decreased under speed characteristic at full load. The study tacitly suggests that biodiesel from soybean crude oil can be used as a substitute for diesel in diesel engine.

Nabi et al. [41] investigated the production of biodiesel from nonedible Cotton Seed Oil (CSO) and performance study of diesel engine with diesel fuel and biodiesel mixtures. Biodiesel was prepared from CSO by transesterification process. A maximum of 77% BD production was found at 20% methanol and 0.5% NaOH at 55 _C reaction temperature.

Biodiesel mixtures showed less CO, PM, smoke emissions than those of neat diesel fuel. NOx emission with biodiesel mixtures showed higher values when compared with neat diesel fuel. Compared to the neat diesel fuel, 10% biodiesel mixtures reduced PM, smoke emissions by 24% and 14%, respectively. Biodiesel mixtures (30%) reduced CO emissions by 24%, while 10% increase in the NOx emission was experienced with the same blend. The reason for reducing three emissions (PM, smoke and CO) and increasing NOx emission with biodiesel mixtures was mainly due to the presence of oxygen in their molecular structure. Also low aromatics in the biodiesel mixtures may be an additional reason for reducing these emissions. Thermal efficiency with biodiesel mixtures was slightly lower than that of neat diesel fuel due to lower heating value of the mixtures. However, volatility, higher viscosity, higher density may be additional reasons for efficiency reduction with biodiesel mixtures.

Ghai et al. [42] in this research study 'Methyl ester of Sunflower oil' which is also popularly known as biodiesel, was prepared by employing transesterification of sunflower vegetable oil with methanol and catalyst KOH. Various blends of Sunflower methyl ester (SFME) were tested in 4-S, C.I. engine and engine performance results obtained were compared with data obtained from pure diesel (HSD). Study reported 1.5 to 4% increase in brake thermal efficiency (BTE) with SFME blends. The brake power (BP) values were comparable to those obtained from HSD. With biodiesel blends, significant reduction in emissions of hydrocarbons as well as smoke/ (particulates) was noticed. NO_x emissions with SFME blends were observed to be somewhat higher as compared to diesel. Since biodiesel is sulphur free fuel, no SO_x emissions were produced.

Nagarhalli et al. [43] investigation of experimental work has been carried out to analyze the emission and performance characteristics of a single cylinder 3.67 kW, compression ignition engine fuelled with mineral diesel and diesel-biodiesel blends at an injection pressure of 200 bars. The performance parameters evaluated were break thermal efficiency, break specific energy consumption (BSEC) and the emissions measured were carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), and oxides of nitrogen (NO_x). The results of experimental investigation with biodiesel blends were compared with that of baseline diesel. The results indicate that the CO emissions were slightly higher, HC emissions decreased from 12.8 % for B20 and 2.85 % for B40, NO_x emissions decreased up to 39 % for B20 and 28 % for B40. The efficiency decreased slightly for blends in comparison with diesel. The BSEC was slightly more for B20 and B40. From the investigation it can be concluded that biodiesel can be used as an alternative to diesel in a compression ignition engine without any engine modifications.

Sureshkumar et al. [44] conducted the performance and emission analyses carried out in an unmodified diesel engine fueled 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, NOx to evaluate the behaviour of PPME and diesel in varying proportions. It is found that there is slight increase in NOx emissions due to high temperature in the combustion chamber for biodiesel. The results reveal that blends of PPME with diesel up to 40% by volume (B40) provide better engine performance (BSFC and BSEC) and improved emission characteristics.

Labeckas and Slavinskas [45] investigated the comparative bench testing results of a four stroke, four cylinder, direct injection, unmodified, naturally aspirated Diesel engine when operating on neat RME and its 5%, 10%, 20% and 35% blends with Diesel fuel. The purpose of this research is to examine the effects of RME 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 (273.5 g/kW h) and rated power (281 g/kW h) for RME is higher by 18.7% and 23.2% relative to Diesel fuel. It is difficult to determine the RME concentration in Diesel fuel that could be recognized as equally good for all loads and speeds. The maximum brake thermal efficiency varies from 0.356 to 0.398 for RME and from 0.373 to 0.383 for Diesel fuel. The highest fuel energy content based economy (9.36– 9.61 MJ/kW h) is achieved during operation on blend B10, whereas the lowest ones belong to B35 and neat RME. The maximum NOx emissions increase proportionally with the mass percent of oxygen in the biofuel and engine speed, reaching the highest values at the speed of 2000 min^{-}1, the highest being 2132 ppm value for the B35 blend and 2107 ppm for RME. 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, emissions along with the fuel consumption and gas temperature, are slightly higher for the B20 and B35 blends and neat RME. The emissions of unburned hydrocarbons, HC, for all biofuels are low, ranging at 5–21 ppm levels.

Karnwal et al. [50] were carried out investigations on assessing potential of biodiesel derived from Thumba oil and its blends with mineral diesel (B10, B20, B40, B60, B80, B100) in a medium capacity, single cylinder, direct injection, water-cooled diesel engine. The performance test was carried out at different loads and brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) were evaluated. The exhaust gas temperature and exhaust emissions (CO, CO_2, HC, NO_x, and Smoke Opacity) were also recorded. The highest BTE was achieved in case of B10. As the concentration of biodiesel was increased in biodiesel-diesel blends, a reduction in BTE was observed. It is may be due high low calorific value and high viscosity of biodiesel. The exhaust gas temperature was found minimum in case of B10 and maximum for B100. The CO, HC and Smoke opacity were found lower for biodiesel based fuels than neat diesel. The CO_2 and NO_x emissions were found higher in case of biodiesel based fuels. The results suggest that Thumba biodiesel can be used as an extender to diesel fuel, which would results in better performance and improved emission characteristics.

2.3 CONCLUSION FROM LITERATURE REVIEW

Following conclusions has been made from literature survey:

1. Ultrasonic cavitation and hydrodynamic cavitation techniques are better than conventional techniques of biodiesel production. They take less time and consume very less power than mechanical stirring technique.
2. Transestrification with alkali (KOH and NaOH) is more economical than acid catalyst and enzyme catalyst.
3. Biodiesel blends has shows less power than diesel at low load condition but at higher loads shows slightly more power due to better combustion as biodiesel contains oxygen. Thermal efficiency and specific fuel consumption is higher for biodiesel of low heating value.
4. Main advantage of biodiesel over diesel is lower emissions. Carbon monoxide and unburnt hydrocarbons has lower value in case of biodiesel due to complete combustion. Carbon dioxide from biodiesel can be recycled.
5. There is slight increase in NOx emissions due high temperature of cylinder while using biodiesel.

CHAPTER-3

BIODIESEL PRODUCTION

This chapter contains the details of biodiesel production by using Thumba (citrullus colocynthis) oil, by different techniques like conventional mechanical stirring method, ultrasonic cavitation and hydrodynamic cavitation method.

3.1 BIODIESEL PRODUCTION PROCESSES

3.1.1 Process flow chart [46]

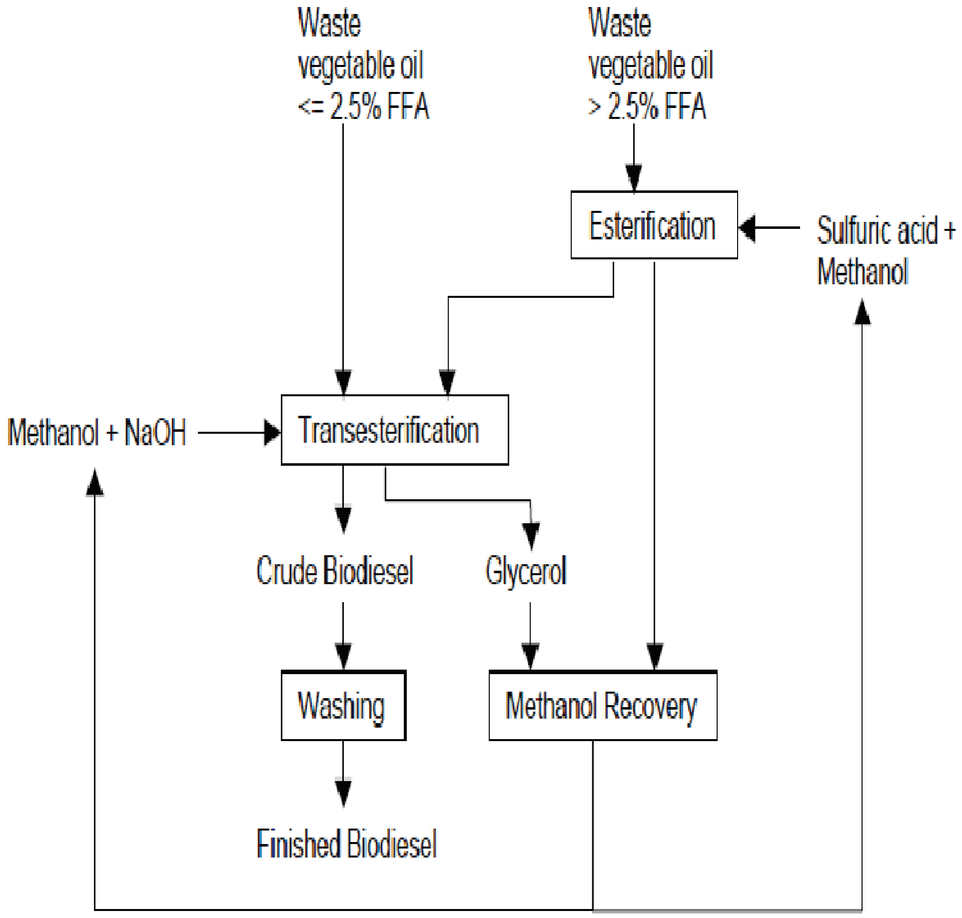


Figure 3.1: Process flow for Biodiesel process.

This process has two separate starting points. If vegetable oils can be obtained that are below 2.5% FFA, the esterification step is not necessary.

3.1.2 Process Details

The processes described here are used by WMRC in a controlled lab environment. We strongly recommend that you read and understand handling requirements of all chemicals used in this report. Take time to do additional research and obtain a thorough understanding of the processes involved before proceeding.

A. Heating of Oil

In order to speed up the reaction, the oil must be heated. The ideal temperature range is 120deg F to 140deg F. The reaction can take days at room temperature and will be inhibited above 140deg F. Heating with electric elements is usually the easiest way to bring the oil up to temperature. Equation 1 will give an estimate for the amount of time it takes to heat the oil.

$$Heatingtime(Hours) \cong \frac{\left[oil(gallons) * temperatureincrease(\deg F) * 2.3432 \frac{Wh}{gallon \bullet \deg F} \right]}{Heaterpower(Watts)}$$

Equation 1. Estimated heating time in hours

It is important to stir the oil as it is heated. This will result in a more even heating and reduce the temperature of oil exposed directly to the heating element.

B. Titration

In order to determine the percent of FFA in the oil, a process called titration is used. The vegetable oil is first mixed with methanol. Next, a mixture of Sodium Hydroxide (NaOH) and water is added until all of the FFA has been reacted. This is confirmed by checking the pH of the mixture. A pH of about 9 signifies all of the FFA has been reacted. Virgin vegetable oil from the same feed stock will usually titrate at approximately the same level, so checking every batch is not necessary. Waste Vegetable oil feed stocks will vary greatly. Every batch must be titrated.

The following items are needed to perform an accurate titration.

- Two 50mL flasks
- One 5mL graduated pipette
- A 1mL dropper

- A 10mL dropper
- A mixture of NaOH and water in 0.1% concentration
- pH solution and color chart

The NaOH water mixture can be prepared by adding 1 gram of NaOH to 1000ml distilled water. The mixture will be more accurate if it is first made as a 1% solution (10grams NaOH to 1000ml water). Next, add 100mL of the 1% solution to 900ml of distilled water. This will make a 0.1% NaOH solution.

The process for titration is as follows:

1) Place 10mL of Methanol in a 50ml flask
2) Add 1mL of vegetable oil (mix the oil thoroughly prior to drawing 1ml)
3) Mix the oil with the Methanol using the squirting action of the dropper
4) Add the ph indicator solution (usually 3 drops, check instructions)
5) Place 15ml 0.1% NaOH (know as titrant) solution in a 50ml flask
6) Draw exactly 5ml of the NaOH solution into the graduated pipette
7) Add the 0.1% NaOH to the methanol/oil mixture one drop at a time. Mix the solution using a swirling action between the drops. Using the eyedropper to mix the solution may help if the oil forms drops in the bottom of the flask.
8) Continue to add 0.1% NaOH until a pH of 9 (blue-green color) is reached. This may require more than 5ml. Refill the pipette and continue. Note the amount in ml that was required.
9) Look up the corresponding amount of NaOH required for the entire batch in table 3.1. Multiply the same amount by the number of gallons oil to obtain the required amount.

Table 3.1: Titration information

ml titration	%FFA	NaOH (grams) per gallon
0	0	13.25
0.5	0.3578222	15.15
1	0.7156445	17.025
1.5	1.0734667	18.925
2	1.431289	20.825
2.5	1.7891112	22.7
3	2.1469334	24.6
3.5	2.5047557	26.5
4	2.8625779	28.3875
4.5	3.2204002	30.28
5	3.5782224	32.1725

C. Mixing of Methanol and Catalyst

The purpose of mixing methanol and the catalyst (NaOH) is to react the two substances to form Methoxide. The amount of Methanol used should be 20% of the volume of the oil. Methanol and NaOH are dangerous chemicals by themselves, with Methoxide even more so. None of these substances should ever touch skin. Vapors should **NOT** be inhaled. Gloves, goggles and ventilation are required at **ALL TIMES** when working with these substances.

NaOH does not readily dissolve into Methanol. It is best to turn on the mixer to begin agitating the Methanol and slowly pour the NaOH in. When particles of NaOH cannot be seen, the Methoxide is ready to be added to the oil. This can usually be achieved in 20 –30 minutes.

D. Draining of Glycerol

After the transesterification reaction, one must wait for the glycerol to settle to the bottom of the container. This happens because Glycerol is heavier then biodiesel. The settling will begin immediately, but the mixture should be left a minimum of eight hours (preferably 12) to make sure all of the Glycerol has settled out. The Glycerol volume should be approximately 20% of the original oil volume.

Figure 3.2 and Figure 3.3 show the difference in viscosity and color between the two liquids. The object is to remove only the Glycerol and stop when the biodiesel is reached. Glycerol looks very dark compared to the yellow biodiesel. The viscosity difference is large enough between the two liquids that the difference in flow from the drain can be seen.

Figure 3.2: Draining Glycerol layer.

Figure 3.3: Draining biodiesel layer.

E. Washing of Fuel

The washing of raw biodiesel fuel is one of the most discussed subjects among do it yourselfers. The purpose is to wash out the remnants of the catalyst and other impurities. There are three main methods:

- Water wash only (a misting of water over the fuel, draining water off the bottom)
- Air bubble wash (slow bubbling of air through the fuel)
- Air/water bubble wash (with water in the bottom of the tank, bubbling air through water and then the fuel)

Which method works the best is dependent on the quality of the fuel. The method used at WMRC for all fuel is a combination of water washing and air bubble washing. Water is misted above the fuel at a rate of 5 gallons/hour. (The rate really depends on the diameter of the tank. The water should not break the surface of the biodiesel). The amount of wash water should equal the amount of oil, and can be drained throughout the washing process.

After the water is drained, the air washing process can start. At this point, the biodiesel is usually a pale yellow color. Air should be bubbled through the biodiesel mixture for approximately 8 hours. The bubbling should be just enough to agitate the biodiesel surface. A final drain of accumulated contaminants is done immediately after the air bubble wash is finished. The fuel is now ready for use [46].

3.2 BIODIESEL PRODUCTION BY MECHANICAL STIRRING

3.2.1 Principle

Conventional mechanical stirring machine consist of temperature controller to control temperature within the range of 0-100^{o}C and speed controller is for controlling speed of stirrer in terms of revolution per minute (rpm). In this machine hot plate functions as a heating source to maintain the temperature of the solution. The beaker is placed on the hot plate then vegetable oil as per the requirement was poured into it at the beginning. The reaction started when a quantitative amount of methanol liquor dissolved in catalyst was poured into the beaker and then immediately drops the magnetic stirrer so that through its stirring action at a particular rpm, dilution of mixture can take place by switching the button on.

3.2.2 Experimental Set-up

The transesterification reactions were carried by conventional mechanical stirring method, photograph is shown in Figure 3.4. Conventional mechanical stirring machine consist of temperature controller to control temperature within the range of 0-100°C and speed controller is for controlling speed of stirrer. In this machine hot plate functions as a heating source to maintain the temperature of the solution. The beaker (500 ml) is placed on the hot plate and Thumba oil (400 g) was poured into it at the beginning. The reaction started when a quantitative amount of methanol as per molar ratio is dissolved with KOH was poured into the beaker. The magnetic stirrer due to its stirring action enhances the transesterification reaction.

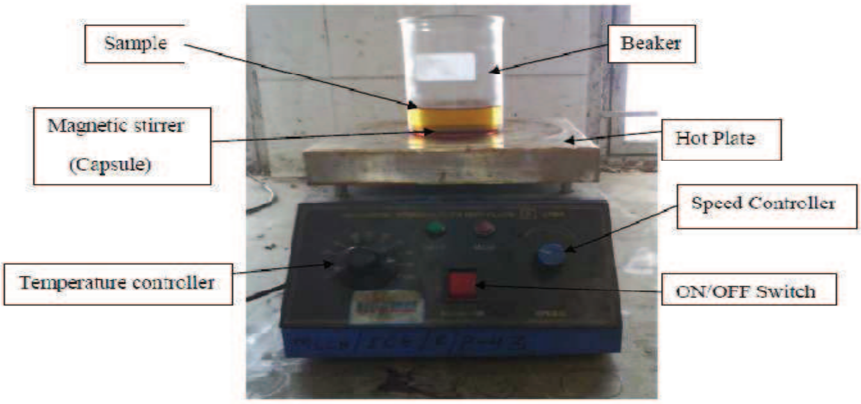


Figure 3.4: Photograph of Mechanical stirrer

3.2.3 Reagents and Material used

1. Thumba oil, 400g/sample for preparing experimental biodiesel sample.
2. Methyl alcohol (CH_3OH) (99% pure) as per molar ratio.
3. Base catalyst (KOH) (85% pure) for accelerating the reaction mixture.

3.2.4 Experimental Procedure

This experiment has been performed to evaluate performance of mechanical stirring method of biodiesel production in terms of yield (%) and time.

Experiment has been performed with the following steps:

1. Thumba oil (400g) is taken in a beaker and filtered it to remove impurities. The raw oil is heated up to 110^0C in order to remove water content of oil to

avoid soap formation. This oil is allowed to cool up to 55^0C temperature for the reaction to 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).The mixer of methyl alcohol and KOH stirred until KOH dissolve in methyl alcohol.
3. This mixture is mixed with thumba oil. The methanol is immiscible with the oil.
4. A magnetic capsule is dipped in the mixture of oil, methanol and catalyst and rotated with the help of magnetic stirrer.
5. During the reaction the temperature of mixture is kept between 55-60^0C.
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 at the bottom.
8. Bio-diesel is separated from beaker for purification process. The catalyst present in the methyl ester is impurity.
9. Excess methanol present in biodiesel has been removed by vaporization process.
10. To remove the catalyst, water at around 40^0C 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 3.5.
11. Excess water is removed by heating the biodiesel.

Figure 3.5: Photograph of washing process of biodiesel

3.2.5 Experimental 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 3.2.

Table 3.2 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	400 g	88 g	2.0 g	3.0 g	4.0 g
4.5:1	400 g	66.24 g	2.0 g	3.0 g	4.0 g

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

Amount of methanol for 100 g of vegetable oil

- For 1:6 molar ratio = (32 / 870) ×400 × 6 = 88 g
- 1:4.5 molar ratio = (32 / 870) ×100 × 4.5 = 66.24 g
-

Sample Calculation for yield

Quantity of thumba oil taken = 400 gm

Quantity of alcohol = 88 gm (For molar ratio 6:1)

Quantity of KOH = 4 gm (For 1% KOH)

Quantity of biodiesel produced = 372.43 gm (say)

Yield % = (Quantity of biodiesel produced/Quantity of oil taken)*100

= (372.43 /400)*100

= 93.11%

Time and yield produced for waste cooking oil

Main aim of this experiment is to calculate time, catalyst percentage and molar ratio (alcohol/oil) for biodiesel production with maximum yield. The results obtained from magnetic stirring experiment are shown below in tabular form.

Experimental Data for Magnetic Stirring Method

Time and yield of methyl ester for thumba oil and catalyst (%) of oil is shown in the table 3.3.

Table 3.3: Time and yield (%) of thumba oil for different molar ratio and catalyst percentage

Percentage of catalyst (%)	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield (%)	Time (min)	Yield (%)
0.5	20	84.15	20	81.76
	30	85.45	30	83.31
	40	87.78	40	85.56
	50	89.61	50	86.52
	60	90.20	60	87.11
0.75	20	87.88	20	84.77
	30	91.98	30	88.82
	40	93.17	40	91.50
	50	94.24	50	93.23
	60	95.43	60	93.89
1	20	89.26	20	87.12
	30	92.06	30	91.54
	40	93.11	40	93.03
	50	94.86	50	94.48
	60	96.32	60	94.26

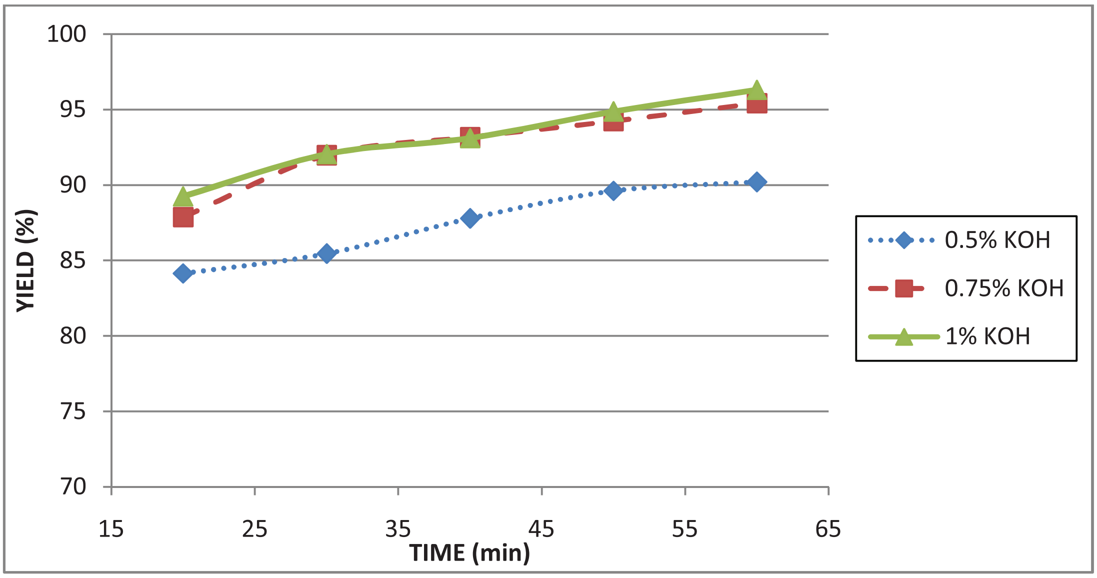


Figure3.6: Time Vs Yield graph at 6:1 molar ratio for different KOH percentage

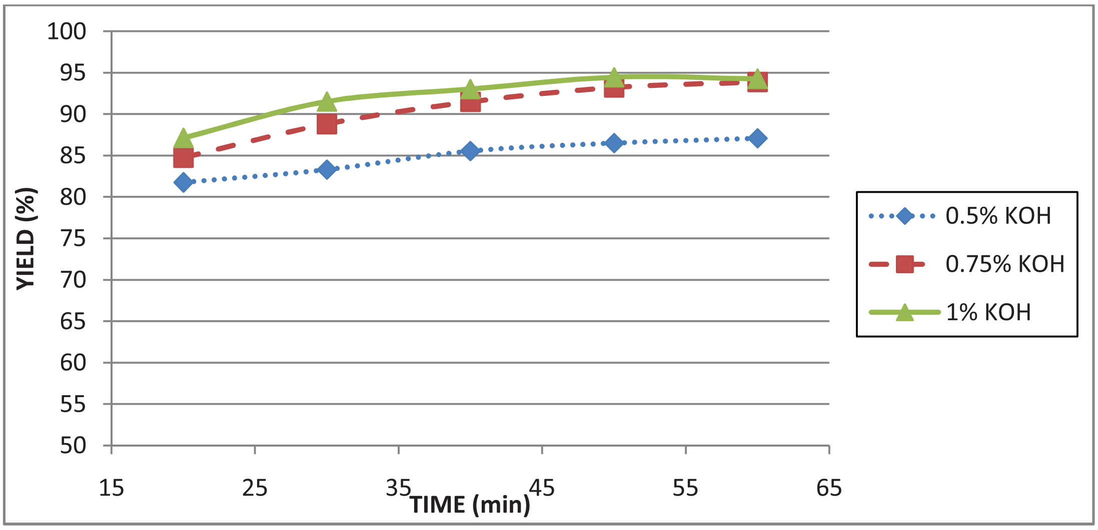


Figure3.7: Time Vs Yield graph at 4.5:1 molar ratio for different KOH percentage

Figure 3.6 and 3.7 shows the graphical representation of Biodiesel yield with respect to time for 6:1 and 4.5:1 molar ratio respectively at different percentage of catalyst (KOH). It has been observed that there is higher yield in case of 6:1 molar ratio as compared to 4.5:1 molar ratio. It may be because of alcohol using for 6:1 molar ratio is more than that of 4.5:1 molar ratio. The yield for 0.5% KOH is less as compare to 0.75% and 1% KOH in both the cases. It may be because of 0.5% KOH is not sufficient to enhance the reaction. The maximum yield obtained is 96.32 at 1% KOH for 6:1 molar ratio.

3.3 BIODIESEL PRODUCTION BY ULTRASONIC CAVITATION

3.3.1 Principle

Principal of ultrasonic cavitation method is the process of creating cavities 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. In the cavitation process small bubbles are formed in liquids at mechanically weak points, usually at phase boundaries, as a result of intense sanitations. These bubbles increase in size due to resonance in areas of under pressure. Small gas bubbles present in the liquid initiate the process. This process is directly related to oscillatory velocity which is directly related to vibration amplitude at given frequency [15]. More the oscillatory velocity the reaction time will be short. On the other hand oscillating velocity of ultrasonic transducer is insufficient for the sonochemical 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. Low frequency ultrasonic irradiation is a useful tool for emulsification of immiscible liquids. The collapse of the cavitation bubbles disrupts the phase boundary and causes emulsification, by ultrasonic jets that impinge one liquid to another.

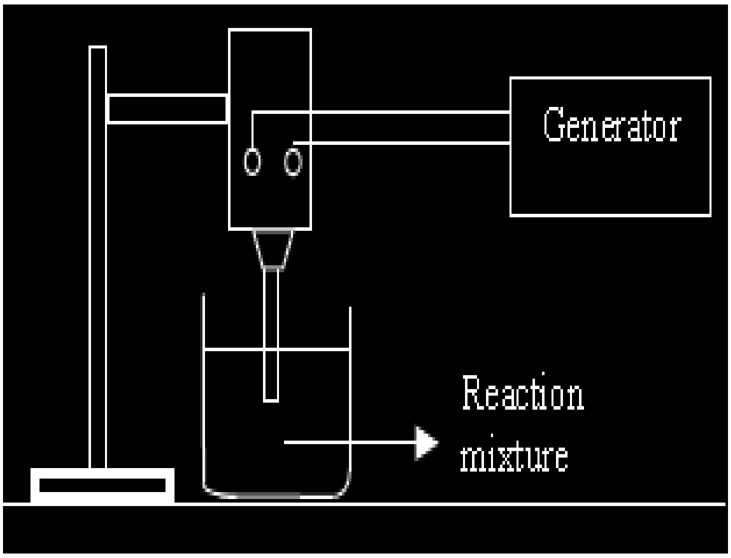


Fig3.8: Ultrasonic Processor

3.3.2 Experimental Set-up

The transesterification reactions were carried out in an ultrasonic reactor. Schematic diagram of its front view, side view and photograph of ultrasonic horn type processor is shown in figure 3.9(a), 3.9(b) and 3.9(c), respectively. In horn type reactor, horn is attached with the transducer which produces ultrasonic irradiation in the mixture. Horn type reactor has been used for this experiment. The ultrasonic cavitation generates ultrasonic processor frequency of 20 KHz. The transducer horn is clamped in a separate stand having jack type table to support the beaker and for its proper adjustment so that sufficient length of horn is dipped in the sample without touching the boundaries of the beaker. Heated thumba oil (400 g) was poured into the beaker at the beginning. Now mixing the proper quantity of methanol and KOH solution as per molar ratio in the heated thumba oil. After mixing the solution of oil, methanol and KOH is kept under ultrasonic horn with sufficient probe tip dipped in the solution without touching the boundaries of the beaker. Now the reaction started, 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.

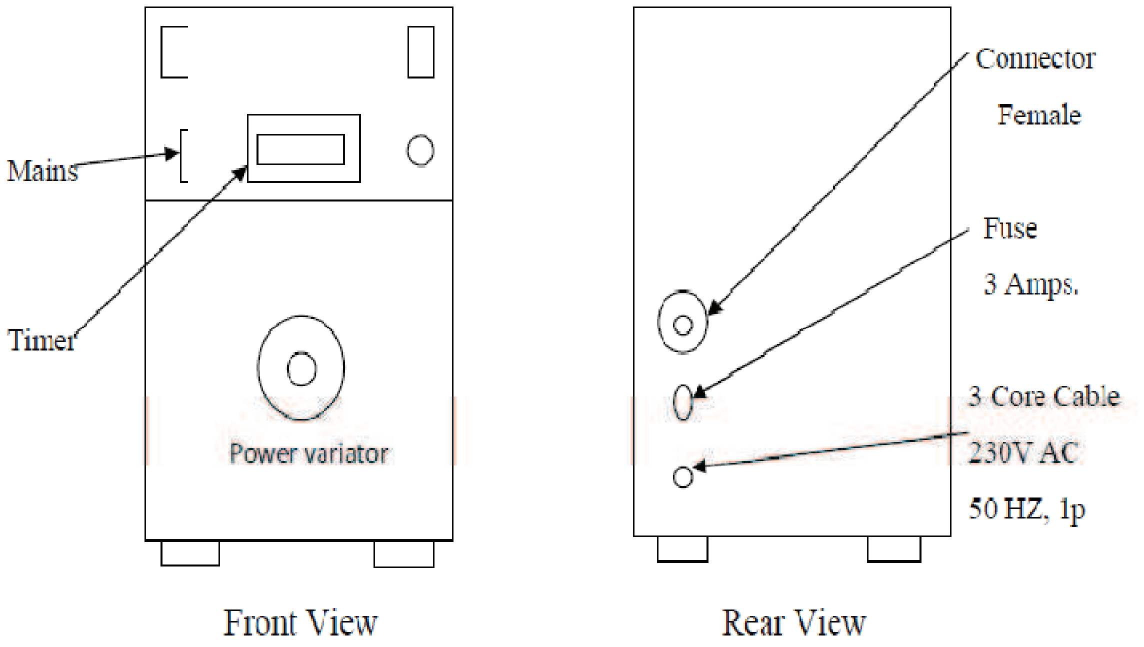


Fig3.9 (a): Ultrasonic Generator

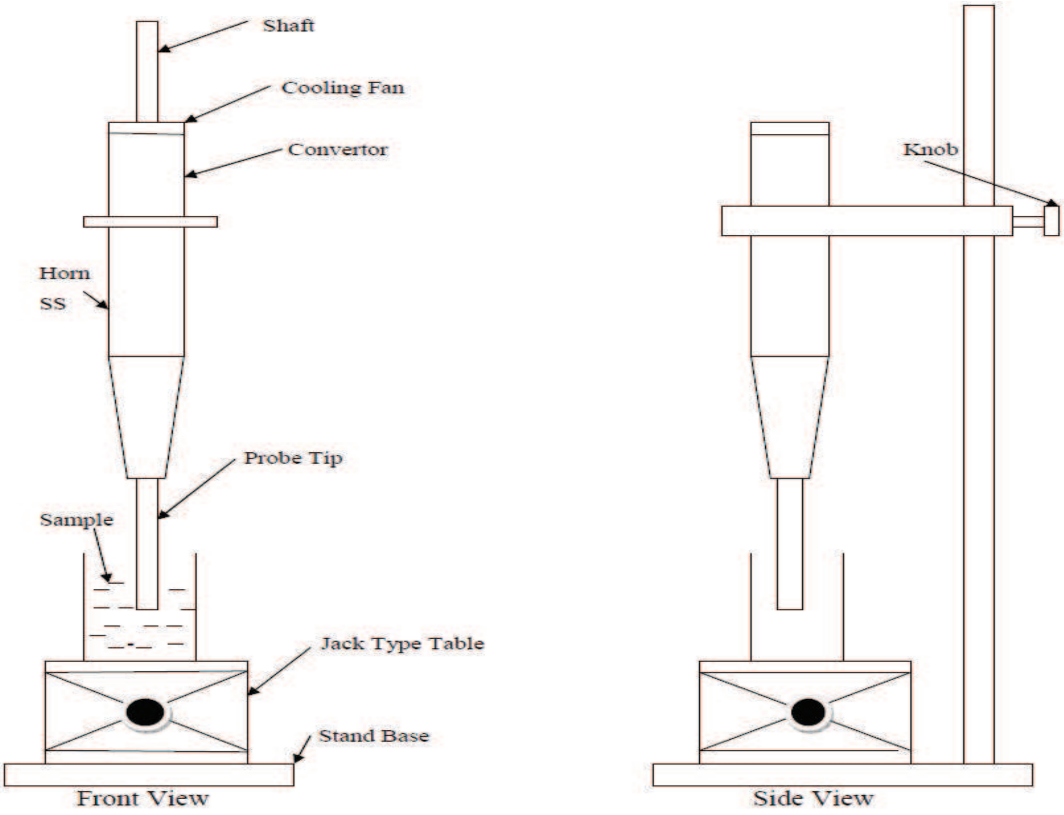


Fig3.9 (b): Ultrasonic Processor Horn mounted on stand with Jack type table.

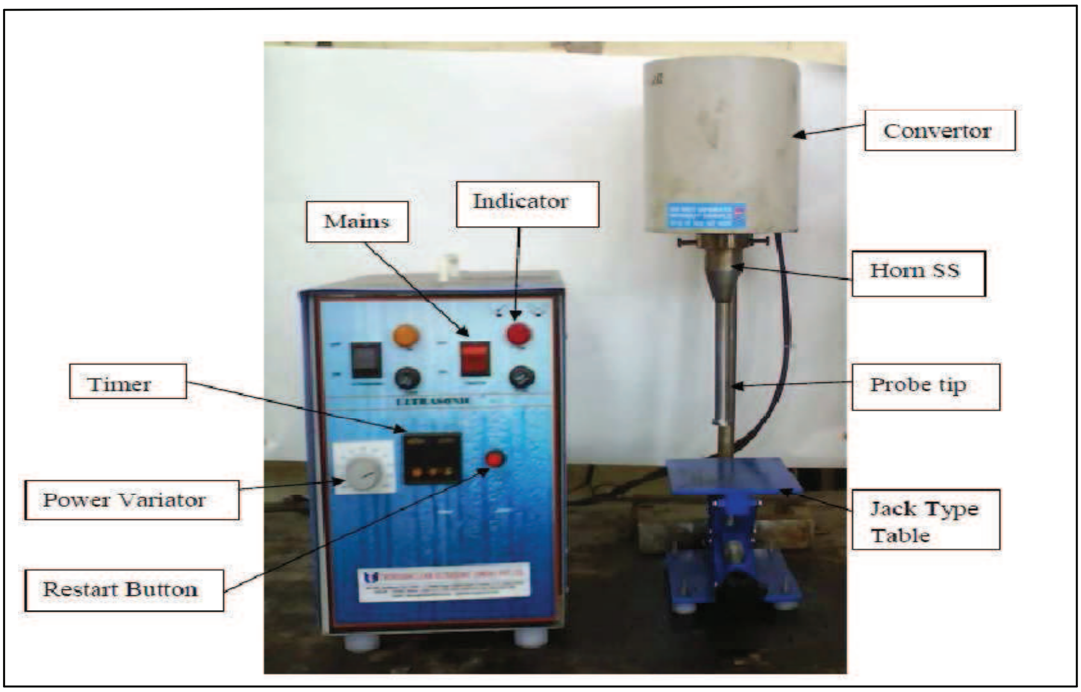


Figure 3.9(c): Photograph of ultrasonic horn type processor

3.3.3 Reagents and Materials used

1. Thumba oil 400g/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.

3.3.4 Experimental Procedure

There are following steps:

1. Thumba oil (400g) is taken in a beaker and filtered it to remove impurities. Than it is heated through a heating device up to 110°C in order to remove water content of oil to avoid soap formation. This oil is allowed to cool up to 55°C temperature so as to reaction can take place.
2. Now methyl alcohol (CH_3OH) 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 is stirred until KOH is completely dissolved in methyl alcohol.
3. This solution of methyl alcohol and KOH is now mixed with vegetable oil. Initially the methanol is immiscible with the oil.
4. The mixture of oil, methanol and catalyst is kept inside the ultrasonic processor transducer.
5. Adjust the beaker so that ultrasonic horn sufficiently dips in the solution.
6. When reaction is completed the beaker is kept for the separation of glycerol and biodiesel. Glycerol 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 at the bottom.
8. Bio-diesel is separated and collected for purification process
9. To remove the catalyst, water should be 33% wt. of biodiesel at around 40-45°C is mixed with the methyl ester and left for settling down will take 12-24 hrs. Water due to its higher specific gravity collected at bottom.
10. Excess methanol present in biodiesel has been removed by distillation process. This methanol can be again used for transesterification process.

11. Finally separated biodiesel is heated to remove moisture present in it due to washing

3.3.4 Experimental Results

The calculations will remain same as given in the section 3.2.5. For the comparison purpose similar experiment has also been performed in Ultrasonic cavitation using the same amount of sample. Time and yield of methyl ester for Thumba oil and catalyst (%) of oil is shown in tables 4.4 and 4.5 for molar ratio 4.5:1 and 6:1 is given below.

Table 3.4 Time and yield (%) of thumba oil for different molar ratio and catalyst percentage

Percentage of catalyst (%)	Molar ratio 6:1		Molar ratio 4.5:1	
	Time (min)	Yield (%)	Time (min)	Yield (%)
0.5	20	81.59	20	80.54
	30	83.86	30	83.62
	40	85.621	40	85.14
	50	88.63	50	87.78
	60	90.03	60	88.23
0.75	20	81.93	20	85.56
	30	90.25	30	91.61
	40	95.32	40	93.33
	50	96.34	50	93.35
	60	97.15	60	95.12
1	20	88.63	20	88.76
	30	92.63	30	92.70
	40	95.29	40	93.87
	50	96.82	50	95.04
	60	97.62	60	96.23

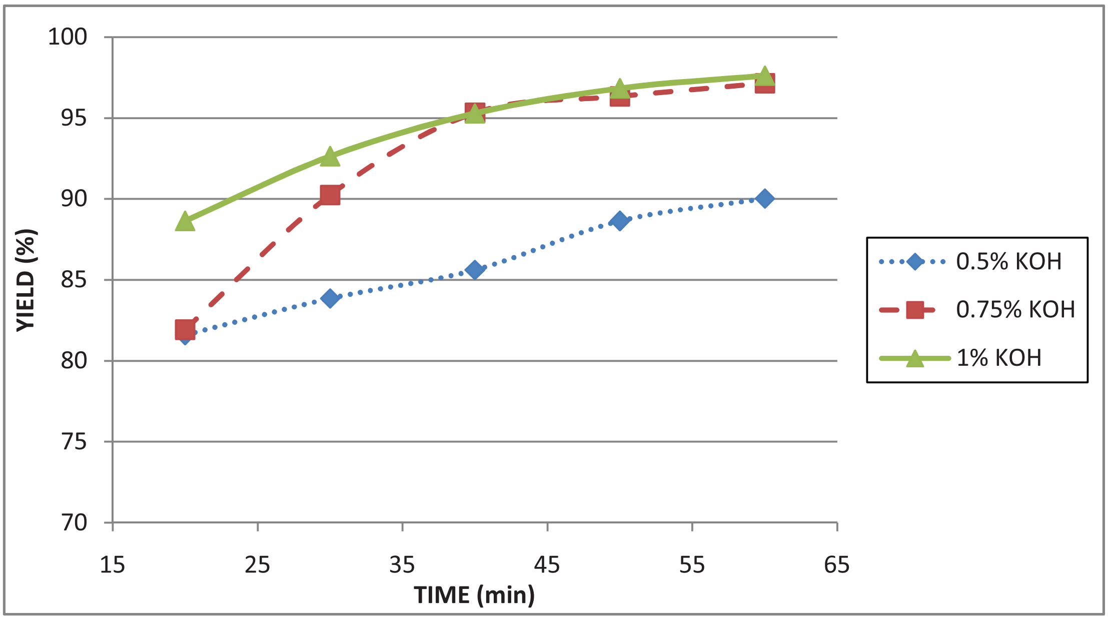


Figure3.10: Time Vs Yield graph at 6:1 molar ratio for different KOH percentage

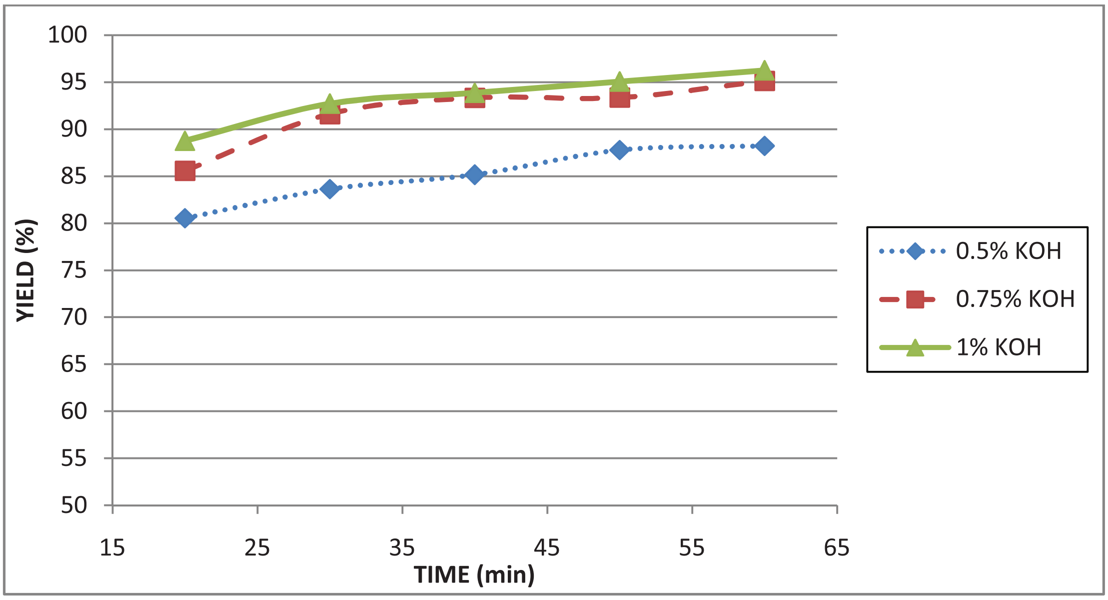


Figure3.11: Time Vs Yield graph at 4.5:1 molar ratio for different KOH percentage

Figure 3.10 and 3.11 shows the graphical representation of Biodiesel yield with respect to time for 6:1 and 4.5:1 molar ratio respectively at different percentage of catalyst (KOH). Similar to magnetic stirring method here also it is found that there is higher yield in case of 6:1 molar ratio as compared to 4.5:1 molar ratio. It may be because of alcohol using for 6:1 molar ratio is more than that of 4.5:1 molar ratio. The yield for 0.5% KOH is less as compare to 0.75% and 1% KOH in both the cases. It may be because of 0.5%

KOH is not sufficient to enhance the reaction But the maximum yield is 97.62% at 1% KOH for 6:1 molar ratio in 60 minutes.

3.4 BIODIESEL PRODUCTION BY HYDRODYNAMIC CAVITATION

3.4.1 Principle

The principle of hydrodynamic cavitation machine resembles the ultrasonic cavitation method as the fundamental of working is cavitation phenomena. In the cavitation process small bubbles are formed in liquids at mechanically weak points, usually at phase boundaries, as a result of intense sonication. These bubbles increase in size due to resonance in areas of under pressure. Small gas bubbles present in the liquid initiate the process. This process is directly related to oscillatory velocity which is directly related to vibration amplitude at given frequency. The series of working is bubble formation, growth and when it collapses, due to the rapid kinetic motions of molecules due to high generation of pressure inside. Using cavitation as an alternative technique for the synthesis of biodiesel results in conditions of very high local temperatures and pressures at the same time releasing free radicals which intensifies many chemical reactions [31, 47].

3.4.2 Experimental Set-up

The developed set up of hydrodynamic cavitation machine consist of an A.C. induction motor, pressure pumps, flow meter, nozzle spray gun, pressure gauge, temperature indicator, control valves, throttle valve, couplings, provided with water cooling jacket. In this experiment we have used orifice plate made of stainless steel 304, containing one hole of 1.90 mm diameter fixed in a nozzle spray gun. An A.C. induction motor is a single phase motor of 1 horse power(hp) having voltage of 220 V and current of 8A with a specified value of speed 1440 rpm (revolution per minute). Reciprocating pressure pump of model AV3 PS 18 is being used in modeling of hydrodynamic cavitation machine with plunger diameter 3*18 mm, working pressure 15.25 $kgcm^2$ required motor of range 5 to 1.5 hp having speed range 800 to 1000 rpm. Its weight is 7 kg. A rotameter is fitted in between two couplings to measure fluid in terms of LPM (litre per minute) which ranges from 0 to 20. The Pressure gauge is attached at the top of the model to control the pressure inside the cylindrical tank of range 0 to 350 Psi or 0 to 20 bars. The model consists of one temperature indicator too, to maintain the temperature of the mixture (catalyzed alcohol and Thumba oil) which ranges from 0 to 150°C. The cylindrical tank is prepared by rolling process using 304 SS having the capacity of 10 litres. 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 304 SS pipe of 1.5" and 1" diameter.

The cavitating conditions are generated just after the orifice plates 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.

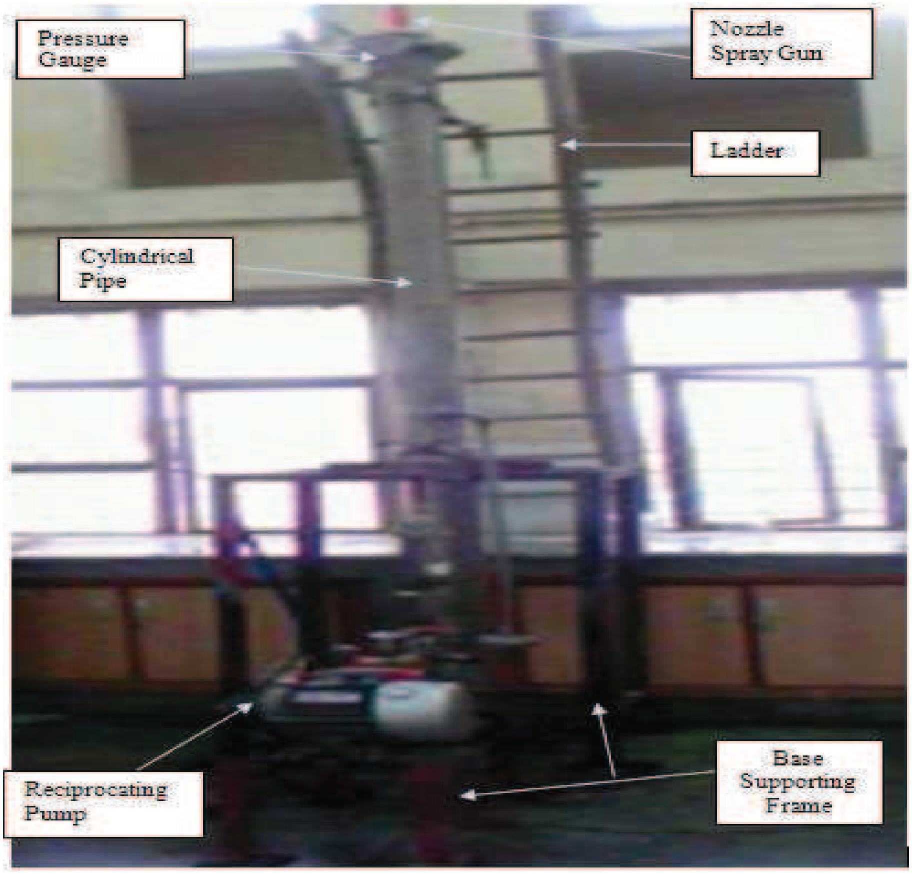


Figure 3.12(a): Hydrodynamic cavitation setup

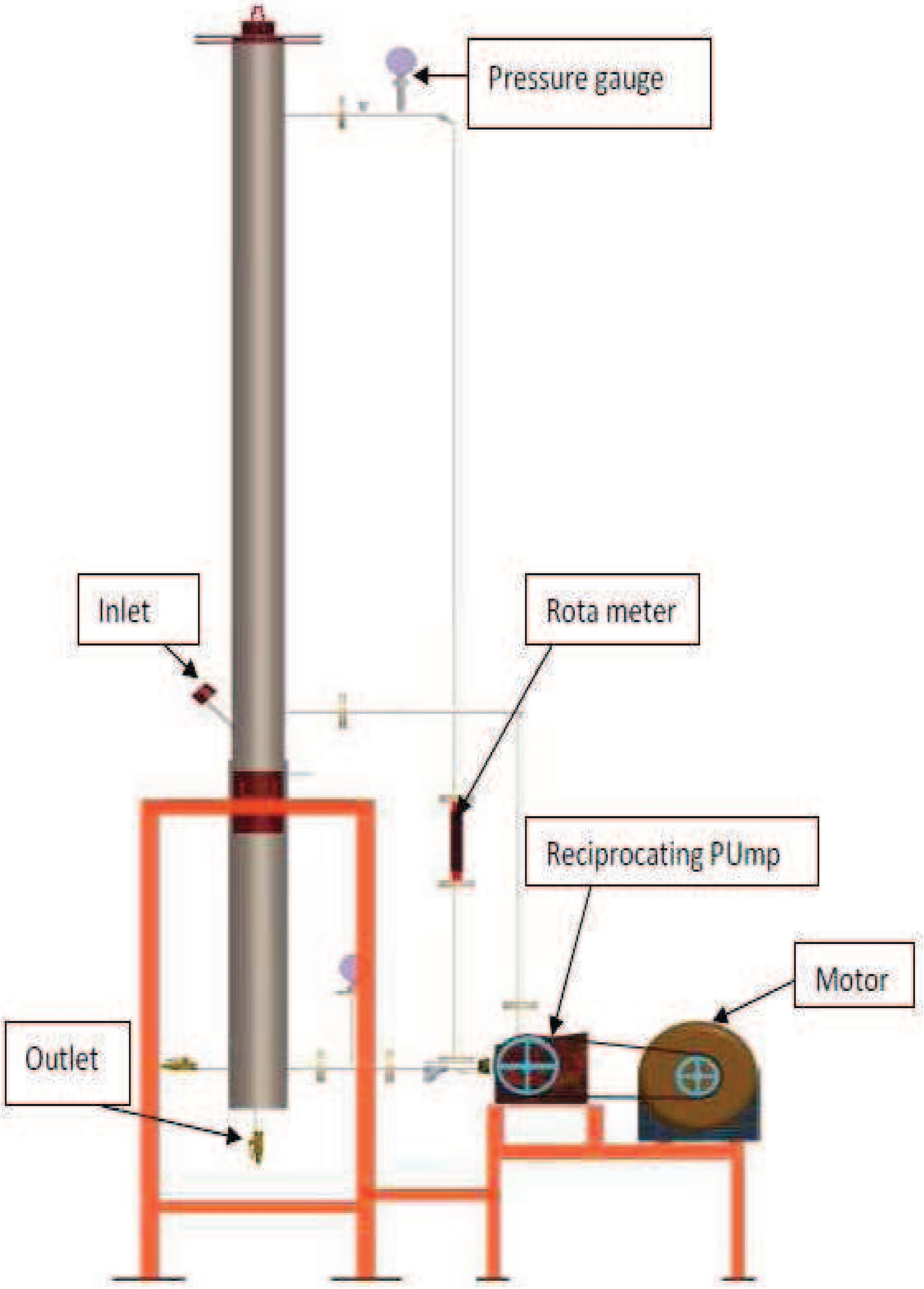


Figure 3.12(b): Front view of the experimental set up

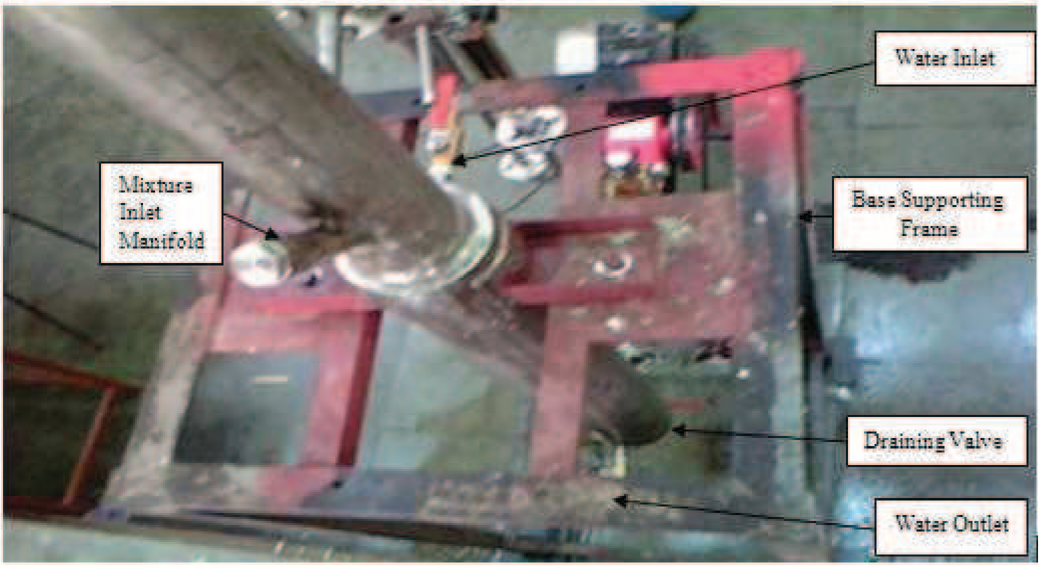


Figure 3.13: Top view of Base supporting frame

3.4.3 Reagents and Materials used

1. Thumba oil.
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.

3.4.4 Experimental procedure

1. Thumba oil (2500g) is taken in a beaker and filtered it to remove impurities. Than repeat the same methods from step 1 to 3 as given in section 3.2.4.

4. Open fully bypass valve (as shown in Figure 3.14) before starting.

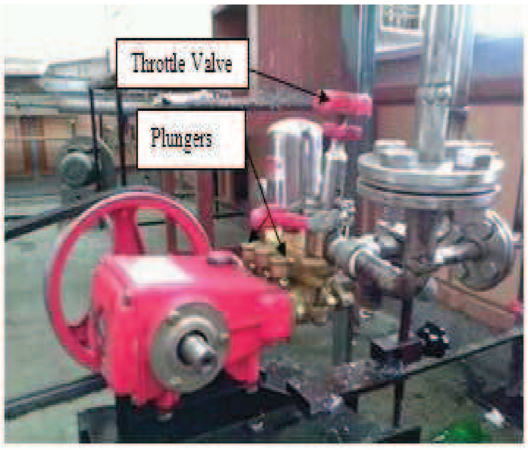


Figure 3.14: Throttle valve and plungers

5. Check out that all the line valves should be open and drain valve should be closed.

6. Pour the solution prepared through inlet manifold as shown in Figure 3.14.

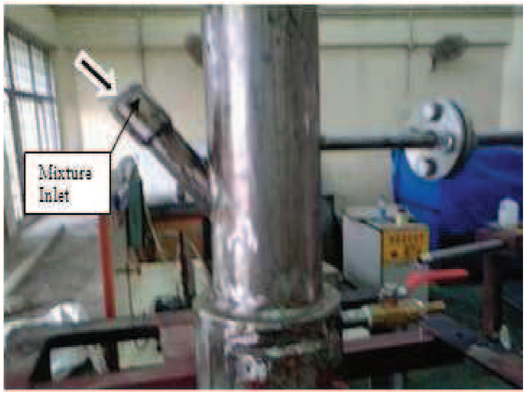


Figure 3.15: Mixture inlet manifold

7. Switch on the plug for voltage supply.

8. Maintain the pressure up to 10 bar in the pressure gauge and flow rate 8.5 lpm (liter per minute) in the rotameter as shown in the Figure 5.9 and 5.10, respectively. Reciprocating pressure pump (Figure 3.17) is responsible to generate high pressure inside the chamber.

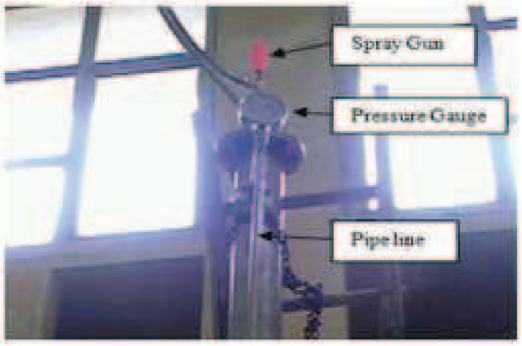


Figure 3.16: Pressure gauge and spray gun

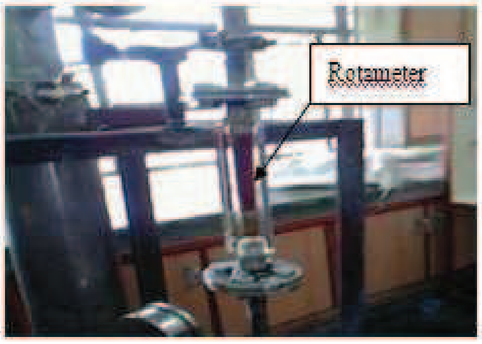


Figure 3.17: Rotameter

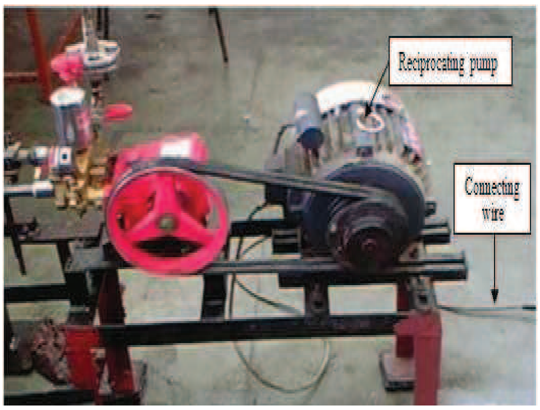


Figure 3.18: Reciprocating pressure pump

3.4.4 Experimental procedure

Table 3.5: Yield observed at various reaction times for molar ratio of 6:1

Thumba oil (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)
2.5	550	0.5 w/w% (i.e.12.5 gm)	20	90.16
			30	92.52
			40	93.77
			50	94.98
			60	94.47

Table 3.6: Yield observed at various reaction times for molar ratio of 4.5:1

Thumba oil (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)
2.5	414	0.5 w/w% (i.e.12.5 gm)	20	83.64
			30	84.47
			40	86.12
			50	87.56
			60	89.04

Table 3.7: Yield observed at various reaction times for molar ratio of 6:1

Thumba oil (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)
2.5	550	0.75 w/w% (i.e.18.75 gm)	20	92.16
			30	94.52
			40	96.77
			50	97.98
			60	98.24

Table 3.8: Yield observed at various reaction times for molar ratio of 4.5:1

Thumba oil (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)
2.5	414	0.75 w/w% (i.e.18.75 gm)	20	93.13
			30	95.49
			40	95.92
			50	96.28
			60	96.27

Table 3.9: Yield observed at various reaction times for molar ratio of 6:1

Thumba oil (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)
2.5	550	1.0 w/w% (i.e.25 gm)	20	91.23
			30	93.15
			40	94.56
			50	96.12
			60	96.72

Table 3.10: Yield observed at various reaction times for molar ratio of 4.5:1

Thumba oil (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)
2.5	414	1.0 w/w% (i.e.25 gm)	20	90.21
			30	91.08
			40	92.12
			50	93.81
			60	96.35

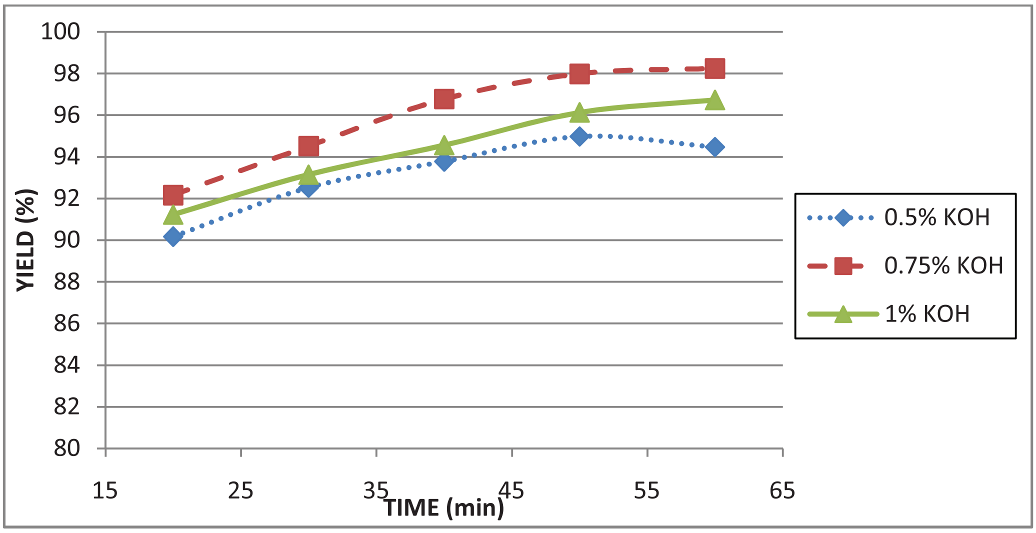


Figure3.19: Time Vs Yield graph at 6:1 molar ratio for different KOH percentage

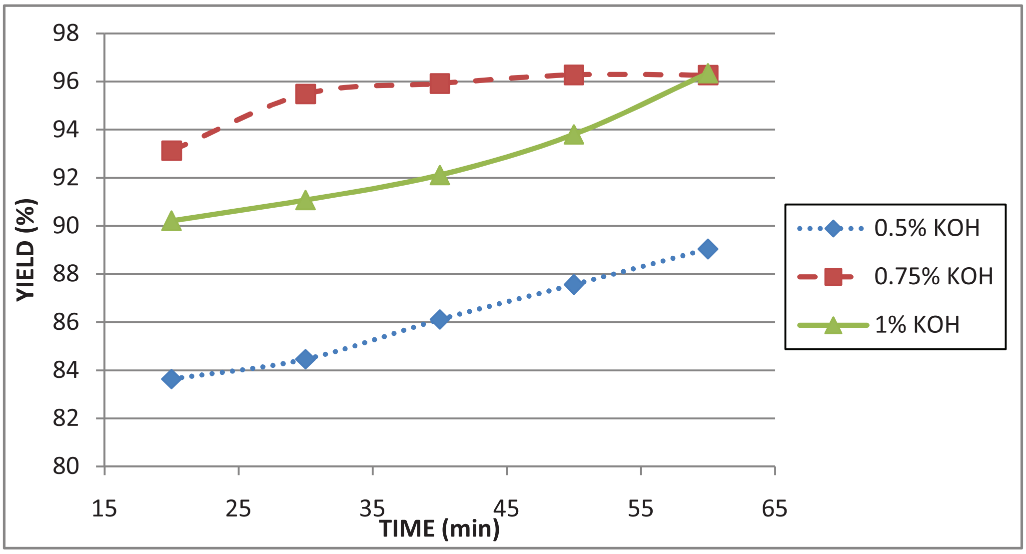


Figure3.20: Time Vs Yield graph at 4.5:1 molar ratio for different KOH percentage

Figure 3.19 and 3.20 shows the variation of biodiesel yield with respect time for 6:1 and 4.5:1 molar ratio respectively for different percentage of catalyst (KOH). It has been observed that the yield for 0.75% KOH is higher in both the cases. Similar to magnetic stirring and ultra sonic cavitation the yield with 0.5% KOH is less as compare to 6:1 and 4.5:1 molar ratio. Maximum yield is 98.24% in case of 6:1 molar ratio at 0.75% of KOH.

3.5 COMPARISON

3.5.1 Comparison for 6:1 molar ratio

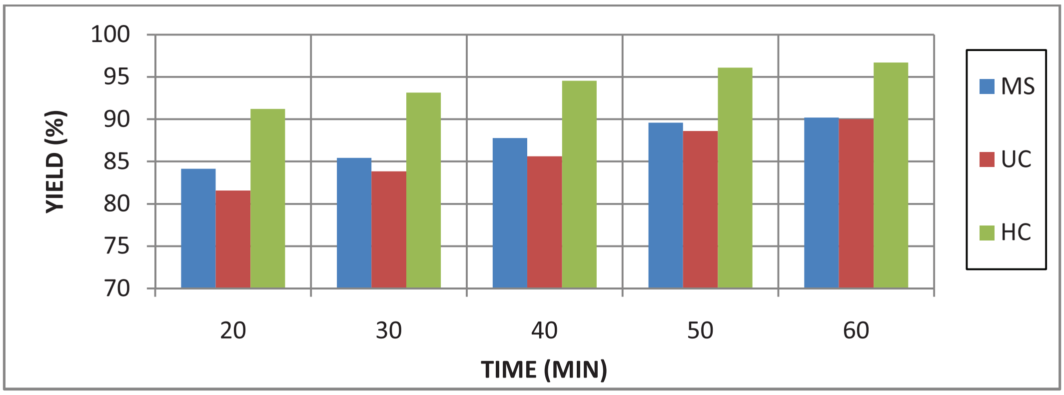


Figure 3.21: Comparison of yield with time for MS. UC, HC technique at 0.5% of KOH

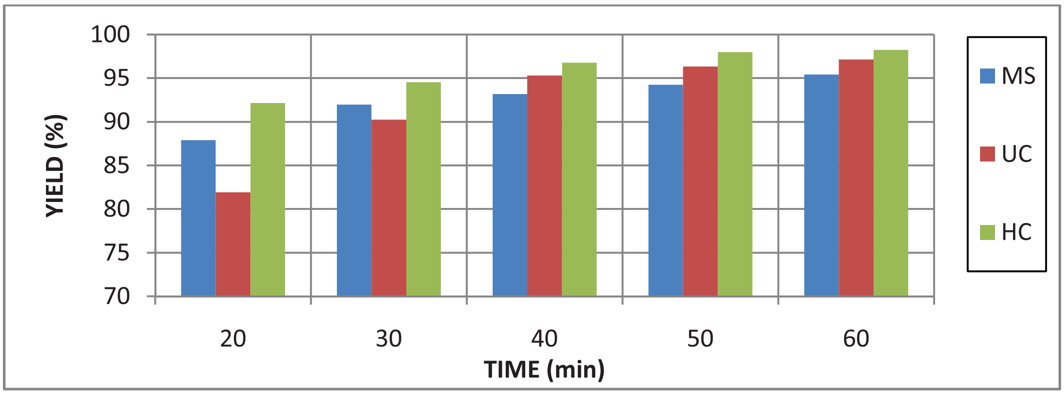


Figure 3.22: Comparison of yield with time for MS. UC, HC technique at 0.75% of KOH

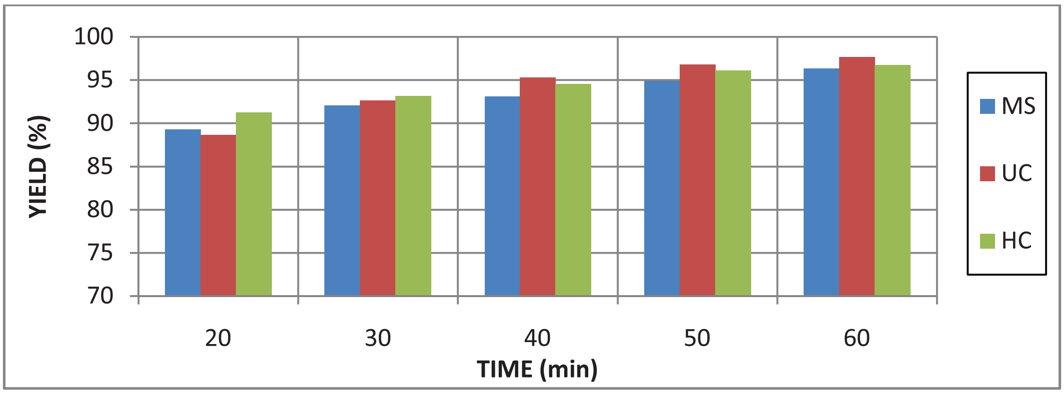


Figure 3.23: Comparison of yield with time for MS. UC, HC technique at 1% of KOH

3.5.2 Comparison for 4.5:1 molar ratio

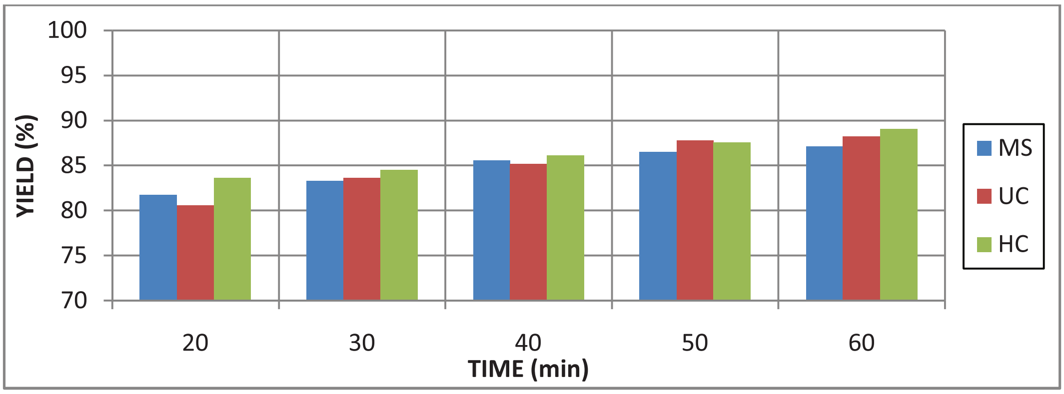


Figure 3.24: Comparison of yield with time for MS, UC, and HC technique at 0.5% of KOH

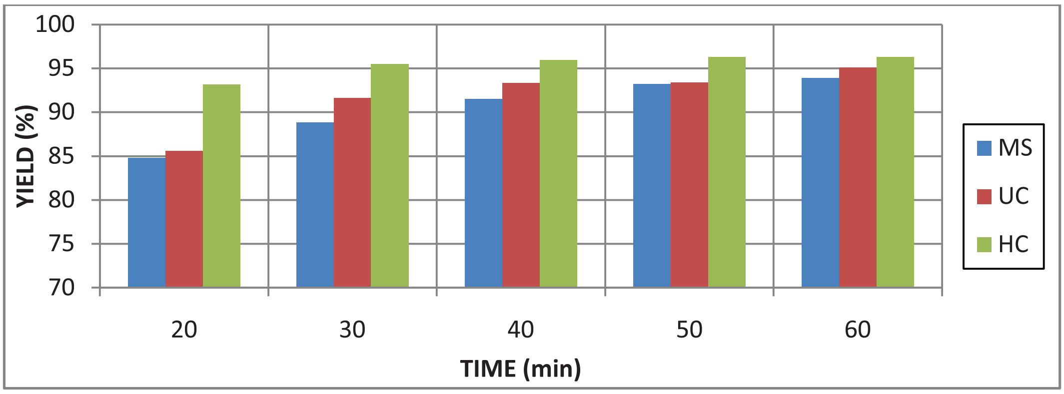


Figure 3.24: Comparison of yield with time for MS. UC, HC technique at 0.75% of KOH

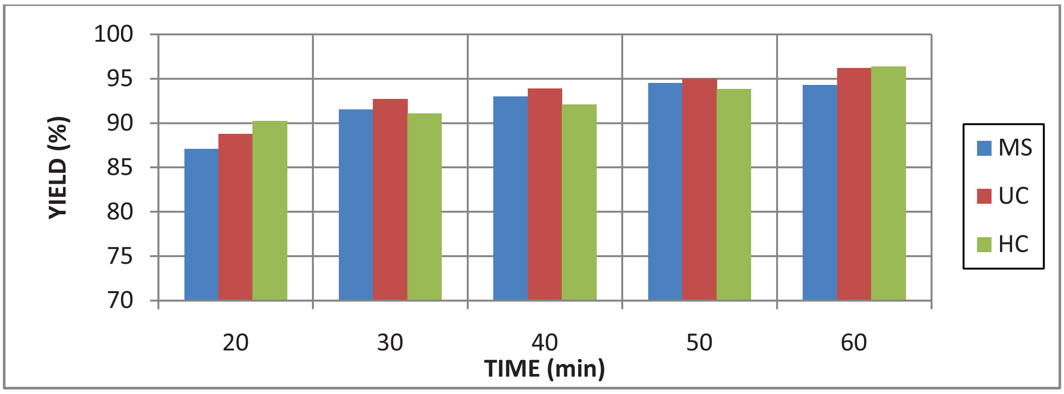


Figure 3.24: Comparison of yield with time for MS. UC, HC technique at 1% of KOH

CHAPTER-4

PERFORMANCE AND EMISSION TESTING

This chapter contains the performance and emission testing of biodiesel extracted from Thumba oil by applying various biodiesel production techniques, as discussed in the previous chapters 3. The chapter also contains the details of experiment setup performance test, procedure followed by various performance and emission parameters observed.

4.1 ENGINE TEST SETUP

The setup consists of single cylinder, four stroke, and VCR (Variable Compression Ratio) Diesel engine connected to the eddy current type dynamometer for loading. The compression ratio of the engine can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed ***tilting cylinder block*** arrangement. Setup is attached with a piezosenser angle encoder instruments for combustion pressure and crank-angle measurements. These signals are interfaced to the computer through engine indicator for obtaining Pθ−PV diagrams. Setup is also capable for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for the measurement of cooling water and calorimeter water flow..

The setup enables study of VCR 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.

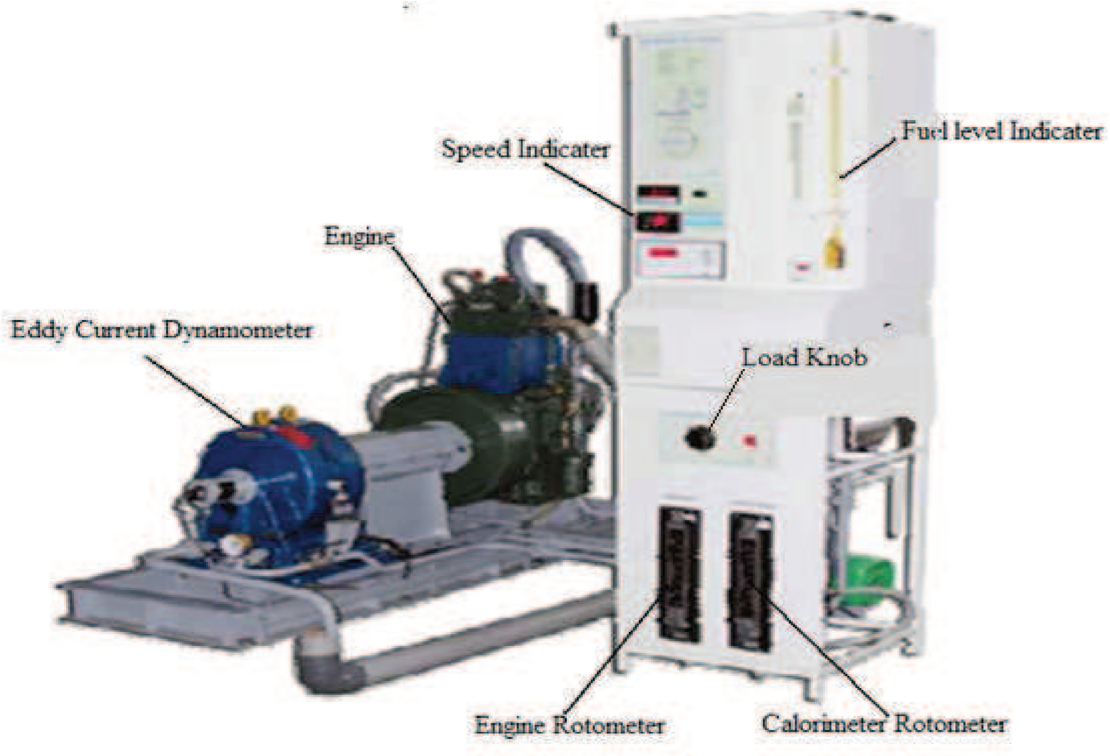


Figure 4.1(a): Actual experimental set-up of Kirloskar diesel engine

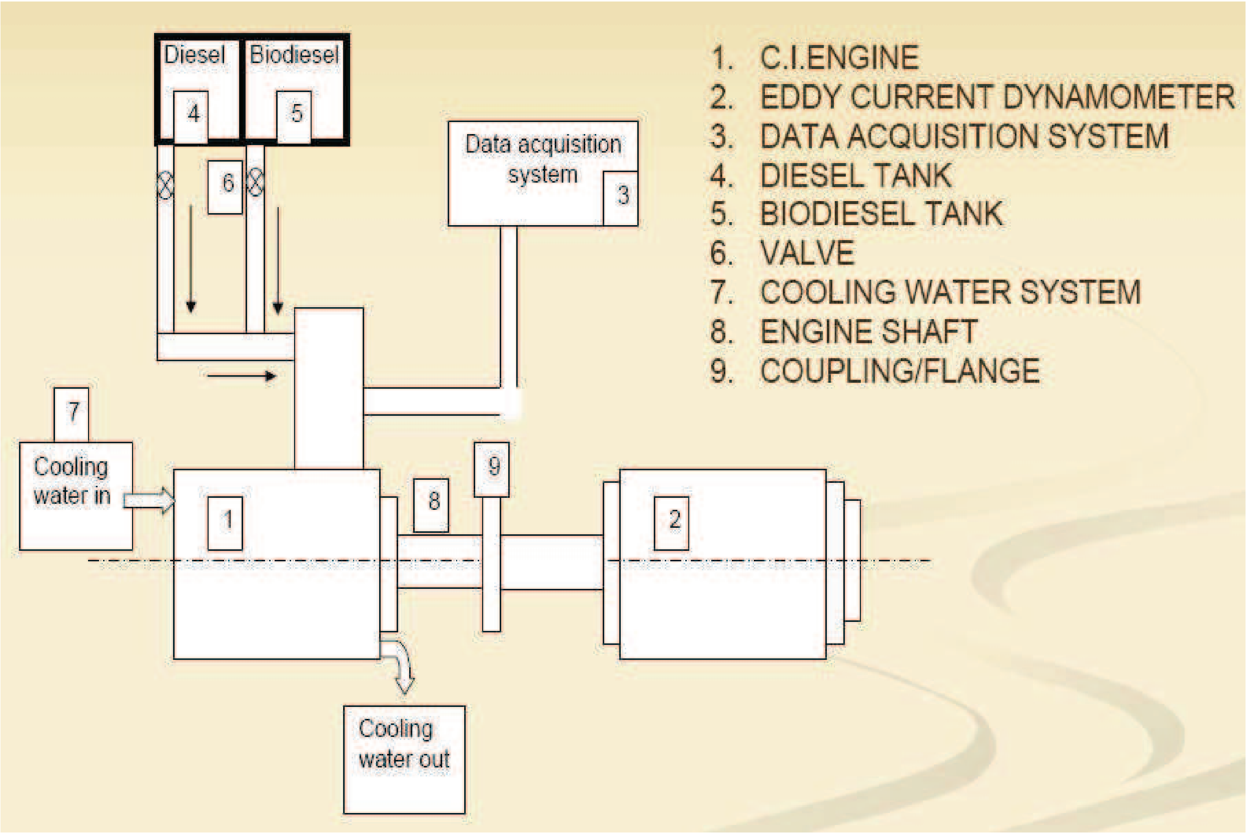


Figure 4.1(b): Schematic Diagram of the Experimental set-up

Table 4.1: Specifications.

Component	**Specifications**
Product	VCR Engine test setup 1 cylinder, 4 stroke, Diesel (Computerized)
Engine	Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18
Dynamometer	Type eddy current, water cooled, with loading unit
Propeller shaft	With universal joints
Air box	M S fabricated with orifice meter and manometer
Calorimeter	Type Pipe in pipe
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse
Data acquisition device	NI USB-6210, 16-bit, 250kS/s.
Piezo powering unit	Make-Cuadra, Model AX-409
Digital milivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Type two wire, Input RTD PT100, Range 0–100 Deg C, Output 4–20 mA and Type

	two wire, Input Thermocouple, Range 0–1200 Deg 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
Software	"EnginesoftLV" Engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Pump	Type Monoblock
Overall dimensions	W 2000 x D 2500 x H 1500 mm

AVL smoker meter

AVL smoker meter works on the light extinction principle, shown in Figure 6.1(d). A continuously taken exhaust sample is passed through a tube of about 46 cm length which has a light source at one end and photocell or solar cell at the other end. The amount of light passed through this smoke column is used as an indication of smoke level. This smoke density is defined as the ratio of electric output from the photocell or solar cell when sample is passed through this smoke column to the electric output when clean air is passed through it. The fraction of the light transmitted through the smoke (T) and the length of the light path (L) are related by the Beer-Lambert law.

$$T = e^{-KL}$$

$$K = n\,A\,\theta$$

Where K is the optional absorption coefficient of the obscuring matter per unit length, n the number of soot particles per unit volume; 'A' is the average projected area for each particles; and 'θ' is the specific absorbance per particle.

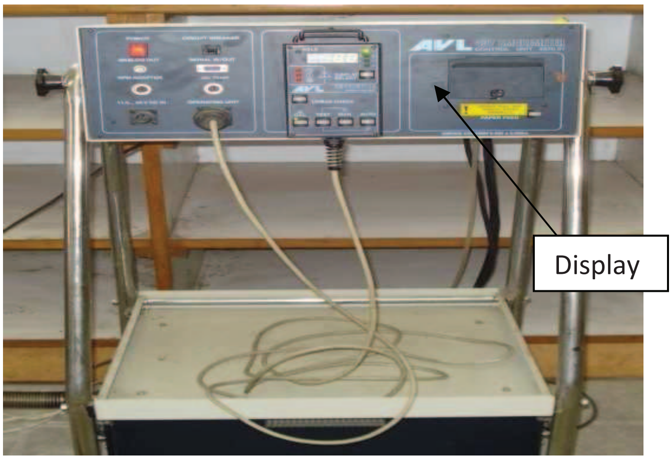


Figure 4.1(c): AVL smoke meter

4.2 PREPARATION OF BIODIESEL BLENDS

Five different Thumba blends B20 (20 % biodiesel + 80 % diesel v/v), B40 (40 % biodiesel + 60 % diesel v/v), B60 (60 % biodiesel + 40 % diesel v/v), B80 (80 % biodiesel + 20 % diesel v/v) and B100 (100 % biodiesel + 0 % diesel v/v) were prepared. The total quantity of each Thumba blend is equal to one liter. These blends were prepared for Thumba biodiesel.

- Calorific value of petroleum diesel = 42000 kJ/kg.
- Calorific value of biodiesel = 3700 kJ/kg
- Density of petroleum diesel = 821 kg/m^3.
- Density of biodiesel = 870 kg/m^3 [tested in laboratory]

The calorific value and densities of biodiesel blends have been calculated by volume fraction and are shown in Table 4.2.

Table 4.2: Calorific values and Densities of Biodiesel blends

Type of blend	Amount diesel (ml)	Amount of biodiesel(ml)	Resultant calorific value (kj/kg)	Resultant density (kg/m^3)
Diesel	1000	0	42000	821
B-20	800	200	40952.8	830.8
B-40	700	300	39930.05	840.6
B-60	600	400	38930.85	850.4
B-80	400	600	37954.42	860.2
B-100	0	1000	37000	870

4.3 PERFORMANCE EVALUATION

A single 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. During the test engine load was varied from 0 to 12 kg by adjusting the load knob provided on the control panel of the test rig while maintaining a constant engine speed of about 1550 rpm. The tests were performed with pure diesel fuel and biodiesel blends (B20, B40, B60, B80, and B100).

Formulation used for calculation of various parameters is described below:

Torque (kg m) = Load × Arm length

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

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

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

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

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

$$\text{Percentage change (\%)} = \frac{\text{Biodiesel} - \text{Diesel}}{\text{Diesel}} \text{ X } 100$$

Heat balance (kJ/h):

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

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

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

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

Heat carried in jacket cooling water (%)

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

Heat in Exhaust (calculate $C_p$ex value):

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

Where,

$C_p$ex	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) = $(F_1 + F_2) \times C_p\text{ex} \times (T_3 - T_{amb})$

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

Heat to Radiation and unaccounted (%)= Heat Supplied By Fuel (%) - { (Heat In Jacket Cooling Water (%)+ Heat To Exhaust (%) + Heat Equivalent To Useful Work (%)}

4.4 EXPERIMENTAL OBSERVATIONS

4.4.1 Pure diesel

Engine performance and emission parameters obtained from performance testing in single cylinder CI engine at 18 and 15 compression ratio against different loads for pure diesel are given below in Table 4.3 and 4.4

4.4.2 Biodiesel blends from thumba oil

Experiment has been performed by taking thumba biodiesel (TB) blends with diesel in proportion of 20%, 40%,60%,80% and 100% respectively as a diesel engine fuel and following parameters at 18 and 15 compression ratio has been obtained . The performance and emission parameter of thumba (B20, B40, B60, B80, and B100) is given below tables from 4.5 to 4.14. Exhaust gas temperature and Air fuel ratio parameters for pure diesel and different blends of thumba biodiesel are given in table 4.15 and 4.16.

Table 4.3: Performance and emission parameters for pure diesel at CR18.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity
1569	0.39	0.0	2.05	2.11	0.07	1.44	46.95	3.06	5.97	250.74	8
1563	3.24	0.5	1.93	2.46	0.62	9.90	45.86	21.59	0.87	36.54	13.6
1556	6.13	1.0	1.86	2.94	1.16	15.93	46.92	33.95	0.54	22.68	18.3
1546	9.35	1.5	1.94	3.38	1.78	20.99	46.84	44.82	0.41	17.22	24.9
1533	12.60	2.0	1.80	3.83	2.39	24.78	46.89	52.85	0.35	14.70	35.6
1518	15.83	2.5	1.80	4.31	3.01	27.53	47.26	58.33	0.31	13.02	44
1504	19.08	3.0	1.69	4.68	3.62	29.71	46.24	64.24	0.29	12.18	60.5
1493	22.50	3.5	1.65	5.17	4.27	31.39	46.16	68.01	0.27	11.34	81.6

Table 4.4: Performance and emission parameters for pure diesel at CR15.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1519	0.38	0.0	2.02	2.08	0.07	1.29	44.39	2.91	6.64	278.88	19.2
1515	3.39	0.5	1.96	2.50	0.64	9.67	45.03	21.48	0.89	37.38	21.0
1503	6.28	1.0	1.90	2.89	1.19	15.78	46.11	34.23	0.54	22.68	38.0
1491	9.52	1.5	1.90	3.39	1.81	20.56	46.84	43.89	0.42	17.64	48.7
1473	12.76	2.0	1.84	3.81	2.42	24.09	46.61	51.70	0.36	15.12	64.7
1458	16.35	2.5	1.84	4.34	3.11	26.58	46.23	57.51	0.32	13.44	73.5
1451	19.24	3.0	1.82	4.75	3.66	28.31	45.98	61.58	0.30	12.60	88.8
1442	23.07	3.5	1.80	5.28	4.38	29.49	44.71	65.96	0.29	12.18	105.6

Table 4.5: Performance and emission parameters for B20 blend of thumba biodiesel at CR18.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1578	0.21	0.0	2.16	2.20	0.04	0.77	49.49	1.56	11.09	454.17	9.2
1570	2.75	0.5	2.03	2.48	0.52	8.80	48.43	18.18	0.97	39.72	12.9
1548	6.48	1.0	2.01	3.06	1.23	16.74	48.74	34.35	0.51	20.89	16.7
1546	9.18	1.5	1.87	3.36	1.74	20.87	47.13	44.29	0.41	16.79	25.4
1529	12.59	2.0	1.81	3.82	2.39	24.85	47.12	52.73	0.34	13.92	32.1
1515	16.01	2.5	1.70	4.24	3.04	27.54	45.99	59.89	0.31	12.66	42.3
1506	18.90	3.0	1.67	4.65	3.59	29.21	45.54	64.14	0.29	11.88	56.2
1493	22.36	3.5	1.61	5.11	4.25	30.84	45.03	68.49	0.28	11.47	76.8

Table 4.6: Performance and emission parameters for B20 blend of thumba biodiesel at CR15.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1516	0.19	0.03	2.18	2.21	0.04	0.68	49.93	1.37	12.87	527.06	18.5
1507	3.04	0.5	2.09	2.57	0.58	8.76	46.79	18.71	1.00	40.95	18.2
1495	0.51	1.0	2.05	3.07	1.24	15.61	46.95	33.24	0.56	22.93	32.6
1483	9.68	1.5	2.03	3.54	1.84	19.81	46.63	42.49	0.44	18.02	44.6
1469	12.92	2.0	2.07	4.05	2.45	22.50	45.89	49.02	0.39	15.97	58.8
1458	16.54	2.5	2.02	4.55	3.14	25.06	45.15	55.51	0.35	14.33	66.4
1449	19.77	3.0	2.02	5.02	3.76	26.50	44.35	59.77	0.33	13.51	78.1
1440	23.25	3.5	1.94	5.45	4.42	28.04	43.56	64.37	0.31	12.69	90.8

Table 4.7: Performance and emission parameters for B40 blend of thumba biodiesel at CR18.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1573	0.22	0.0	2.27	2.31	0.04	0.87	56.11	1.55	10.34	412.88	8.6
1566	3.22	0.5	2.09	2.62	0.61	10.78	53.51	20.15	0.84	33.54	12.1
1554	5.95	1.0	2.00	2.97	1.13	17.19	52.65	32.66	0.52	20.76	14.4
1543	9.54	1.5	1.83	3.37	1.81	22.95	50.21	45.70	0.39	15.57	22.7
1527	12.07	2.0	1.91	3.83	2.29	24.37	48.43	50.32	0.37	14.77	30.3
1515	16.50	2.5	1.59	4.20	3.13	29.07	46.70	62.26	0.31	12.38	39.8
1506	18.93	3.0	1.65	4.64	3.60	30.06	46.68	64.40	0.30	11.98	53.9
1490	22.63	3.5	1.59	5.12	4.30	31.38	45.51	68.94	0.29	11.58	72.5

Table 4.8: Performance and emission parameters for B40 blend of thumba biodiesel at CR15.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1532	0.20	0.0	2.08	2.11	0.04	0.68	45.50	1.50	13.21	527.47	20.4
1508	3.06	0.5	2.11	2.59	0.58	9.07	48.63	18.64	0.99	39.53	17.9
1496	6.43	1.0	2.01	3.01	1.22	16.21	48.48	33.43	0.56	22.36	28.6
1486	9.62	1.5	2.04	3.54	1.83	20.62	48.75	42.29	0.44	17.57	40.3
1466	13.29	2.0	1.94	3.96	2.53	24.25	47.07	51.53	0.37	14.77	55.0
1460	16.55	2.5	1.88	4.41	3.15	27.03	47.06	57.43	0.33	13.18	64.8
1446	19.61	3.0	1.74	4.71	3.73	28.19	44.72	63.03	0.32	12.78	72.5
1438	23.09	3.5	1.59	5.07	4.39	29.77	43.41	68.58	0.30	11.98	87.7

Table 4.9: Performance and emission parameters for B60 blend of thumba biodiesel at CR18.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1573	0.41	0.0	2.14	2.21	0.08	1.65	54.30	3.04	5.60	218.01	7.3
1562	3.01	0.5	1.94	2.43	0.58	10.12	49.58	20.40	0.91	35.43	13
1545	5.99	1.0	2.08	3.01	1.10	15.31	49.37	31.00	0.60	23.36	16.2
1544	9.17	1.5	1.92	3.40	1.74	21.49	49.32	43.58	0.43	16.74	23.6
1529	12.41	2.0	1.82	3.83	2.36	25.60	49.39	51.83	0.36	14.02	27.8
1513	15.85	2.5	1.77	4.28	3.01	28.45	48.50	58.65	0.33	12.85	36.7
1505	18.99	3.0	1.73	4.72	3.61	30.30	47.81	63.37	0.31	12.07	52.1
1492	22.37	3.5	1.65	5.14	4.25	31.67	47.06	67.98	0.29	11.29	60.2

Table 4.10: Performance and emission parameters for B60 blend of thumba biodiesel at CR15.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1523	0.38	0.0	1.92	1.98	0.07	1.21	39.57	3.67	7.62	296.65	15.2
1511	3.27	0.5	1.91	2.43	0.62	8.24	41.51	21.31	1.05	40.88	17.5
1501	6.43	1.0	1.87	2.88	1.22	15.53	44.26	35.09	0.60	23.36	32.2
1458	9.34	1.5	1.88	3.34	1.70	19.92	45.68	43.60	0.46	17.91	38.6
1470	13.29	2.0	1.85	3.90	2.52	23.92	45.57	52.49	0.39	15.18	52.8
1461	16.35	2.5	1.85	4.35	3.11	25.87	45.03	57.44	0.36	14.01	60.1
1451	18.88	3.0	1.86	4.73	3.59	27.39	45.16	60.65	0.34	13.24	67.7
1440	23.05	3.5	1.77	5.24	4.38	29.43	44.40	66.30	0.31	12.07	75.6

Table 4.11: Performance and emission parameters for B80 blend of thumba biodiesel at CR18.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1570	0.38	0.0	2.05	2.12	0.07	1.49	50.44	2.96	6.35	241.01	7.1
1559	3.04	0.5	1.95	2.45	0.58	10.03	49.42	20.29	0.95	36.06	9.4
1555	5.95	1.0	1.93	2.90	1.13	16.45	49.21	33.44	0.58	22.01	13.6
1541	9.52	1.5	1.80	3.34	1.81	22.19	48..21	46.03	0.43	16.32	20.5
1529	12.04	2.0	1.84	3.83	2.36	25.19	48.59	51.85	0.38	14.42	31.1
1516	15.65	2.5	1.73	4.22	2.97	28.16	47.82	58.89	0.34	12.90	35.4
1505	19.06	3.0	1.71	4.71	2.62	30.23	47.43	63.73	0.31	11.77	48.3
1495	22.15	3.5	1.69	5.16	4.21	31.72	47.17	67.25	0.30	11.39	65.4

Table 4.12: Performance and emission parameters for B80 blend of thumba biodiesel at CR15.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1514	0.38	0.0	1.94	2.00	0.07	1.15	38.23	3.00	8.28	314.26	19.5
1502	3.41	0.5	1.80	2.33	0.65	9.01	39.17	23.00	1.05	39.85	16.4
1494	6.34	1.0	1.81	2.80	1.21	14.77	41.73	35.39	0.64	24.29	24.0
1481	9.51	1.5	1.89	3.36	1.81	19.03	44.00	43.87	0.49	18.60	40.2
1470	12.93	2.0	1.79	3.79	2.46	22.78	43.32	52.59	0.42	15.94	56.8
1458	16.00	2.5			3.04	24.90			0.38	14.42	52.1
1446	19.80	3.0	1.79	4.79	3.76	26.77	42.77	62.60	0.35	13.28	70.5
1438	23.31	3.5	1.69	5.20	4.43	28.32	41.91	67.56	0.33	12.52	80.3

Table 4.13: Performance and emission parameters for B100 blend of thumba biodiesel at CR18.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1573	0.38	0.0	1.98	2.05	0.07	1.47	47.96	3.06	6.62	244.94	10.2
1568	3.39	0.5	1.93	2.49	0.64	10.69	47.77	22.37	0.91	33.67	10.0
1559	6.12	1.0	1.85	2.85	1.16	16.21	46.26	35.04	0.60	22.20	15.4
1546	9.53	1.5	1.81	3.35	1.81	21.34	46.34	46.05	0.46	17.02	22.0
1537	12.23	2.0	1.73	3.70	2.32	24.37	45.81	53.20	0.40	14.80	32.8
1520	15.82	2.5	1.64	4.16	3.01	27.63	45.67	60.51	0.35	12.95	40.5
1514	19.08	3.0	1.64	1.66	3.62	29.81	45.94	64.89	0.33	12.21	54.3
1501	23.34	3.5	1.61	5.12	4.24	31.18	45.50	66.52	0.31	11.47	68.2

Table 4.14: Performance and emission parameters for B100 blend of thumba biodiesel at CR15.

SPEED (rpm)	TORQUE (Nm)	BP (kw)	FP (kw)	IP (kw)	BMEP (bar)	BThE (%)	IThE (%)	MechE (%)	BSFC (kg/kwhr)	BSEC (MJ/kW-h)	Opacity (%)
1528	0.19	0.0	2.02	2.05	0.04	0.69	45.90	1.50	14.15	523.55	17.3
1509	3.14	0.5	1.87	2.41	0.65	9.43	42.20	22.35	1.03	38.11	15.0
1500	6.09	1.0	1.90	2.86	1.16	14.93	44.54	33.52	0.65	24.05	30.0
1485	9.86	1.5	1.92	3.46	1.87	20.26	45.68	44.36	0.48	17.76	35.1
1471	13.10	2.0	1.83	3.85	2.49	24.13	45.99	52.47	0.40	14.80	45.9
1461	16.35	2.5	1.75	4.25	3.11	26.83	45.57	58.88	0.36	13.32	52.4
1449	19.60	3.0	1.77	4.75	3.72	28.22	45.06	62.63	0.34	12.58	61.1
1438	23.40	3.5	1.76	5.29	4.45	29.80	44.71	66.65	0.33	12.21	71.4

Table 4.15: Observation data of Exhaust gas temperature (EGT) and air/fuel (A/F) ratio at CR18.

BP (kW)	DIESEL		B20		B40		B60		B80		B100	
	EGT (°C)	A/F ratio	EGT. (°C)	A/F ratio	EGT. (°C)	A/F ratio	EGT. (°C)	A/F ratio	EGT. (°C)	A/F ratio	EGT (°C)	A/F ratio
0	171.01	76.67	163.50	80.09	161.96	78.59	149.79	77.97	195.98	74.91	167.02	73.59
0.5	176.52	65.96	174.90	68.14	176.94	67.15	166.17	64.45	185.70	62.82	174.79	57.35
1	194.08	53.76	200.56	54.70	193.56	56.73	196.55	51.05	197.46	51.20	191.83	49.39
1.5	214.70	45.89	222.34	47.12	218.34	48.53	211.27	45.49	217.19	43.99	215.10	42.43
2	239.87	41.24	251.27	39.94	249.35	38.48	238.59	38.50	238.97	38.39	237.54	36.52
2.5	267.36	37.56	278.82	35.87	277.87	33.89	265.96	34.72	261.85	32.98	262.58	31.59
3	294.53	31.62	304.88	32.30	304.67	30.94	290.83	30.06	289.61	29.92	290.40	28.39
3.5	325.98	28.73	337.40	27.93	343.50	27.67	322.39	25.93	316.16	26.67	320.17	24.68

Table 4.16: Observation data of Exhaust gas temperature (EGT) and Air/Fuel (A/F) ratio at CR15.

BP (kW)	DIESEL		B20		B40		B60		B80		B100	
	EGT (^{o}C)	A/F ratio	EGT (^{o}C)	A/F ratio	EGT (^{o}C)	A/F ratio	EGT (^{o}C)	A/F ratio	EGT (^{o}C)	A/F ratio	EGT. (^{o}C)	A/F ratio
0	175.43	73.77	183.87	74.17	162.28	69.33	193.15	62.82	166.28	57.74	170.34	68.03
0.5	186.74	60.96	179.96	60.91	174.28	58.78	191.46	54.28	180.08	51.04	187.52	50.61
1	207.49	51.25	202.97	50.84	197.03	52.43	209.77	47.49	199.04	46.41	206.21	43.85
1.5	236.64	44.37	229.53	43.79	226.41	41.34	226.41	41.43	229.00	39.37	234.05	38.14
2	266.20	35.36	261.28	36.10	259.43	353.58	271.32	35.91	261.40	33.47	257.91	34.85
2.5	303.98	32.95	293.63	30.90	293.49	31.92	302.56	29.89	295.58	29.14	288.81	28.87
3	339.22	30.21	329.18	26.20	328.71	27.38	328.15	27.34	321.41	23.80	312.78	26.54
3.5	387.30	26.21	373.16	22.88	365.57	25.31	375.54	23.72	373.95	22.90	359.92	22.13

CHAPATER-5

RESULT AND DISCUSSION

5.1 RESULT AND DISCUSSION

Variation of brake thermal efficiency w.r.t brake power

Figure 5.1(a) shows the variation of brake thermal efficiency with brake power for various thumba biodiesel blends like B20, B40, B60, B80 and B100 respectively compared with pure diesel at compression ratio 18. Brake thermal efficiency is increasing with increasing loads for all blends of biodiesel and diesel. It may be due to reduction in heat loss and increase in power with increase in load. At rated power of 3.5kW almost all the blends have higher efficiency than diesel in which B60 have maximum thermal efficiency (31.99%) as compared to diesel (31.39%). It may be because of the presence of oxygen in biodiesel which enhance the combustion as compared to diesel and biodiesel is more lubricant than diesel that provides additional lubrication. Thumba oil biodiesel has higher viscosity, density and lower calorific value than diesel. Higher viscosity leads to decreased atomization, fuel vaporization and combustion. These may be the possible reasons of B100 have lowest brake thermal efficiency for all loads. Figure 5.1(b) shows the percentage change graph of all biodiesel blends with diesel as reference at compression ratio 18. It shows how much percent change is occurs in brake thermal efficiency of pure diesel and biodiesel blends.

Figure 5.2(a) shows the variation of brake thermal efficiency with brake power at compression ratio 15. It has been observed that at starting up to 3.5kW of BP the thermal efficiency of diesel is higher as compared to all thumba biodiesel blends. At 15 compression ratio B40has higher brake thermal efficiency as compared to all Biodiesel blends and diesel. At rated load of 3.5kW B40 have higher efficiency (29.77%) as compared to diesel (29.49). Figure5.2 (b) shows percent change graph of brake thermal efficiency with brake power with diesel as baseline.

Variation of brake specific fuel consumption w.r.t. brake power

The Variation in BSFC(Brake Specific Fuel Consumption) with brake power for different fuel samples at different compression ratios of 18 and 15 and their percent change graph with refence to diesel is shown in figure 5.3(a), 5.3(b), 5.4.(a), and 5.4.(b) respectively. The specific fuel consumption when using biodiesel fuel is expected to increase as compared to the consumption of diesel fuel. BSFC decreased sharply with increase in load for all fuel samples at both the compression ratio. The main reason for this may be that the percent increased in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads. As the BSFC is calculated on weight basis, so higher densities resulted in higher values of BSFC. BSFC for all the thumba biodiesel blends is higher comapred to diesel but among them B20 has lower values of BSFC at both the compression ratios of 18 and 15.From the graph it has been seen that the B100 has the maximum value of BSFC at CR18 but at CR15 B80 has the maximum values.

Variation of brake specific energy consumption w.r.t. brake power

The variation of BSEC (Brake Specific Energy Consumption) with BP (Brake Power) for different fuels at 18 and 15 compression ratios are shown in figure 5.5(a) and 5.6(a) respectively. Their percentage change graphs are shown in figure 5.5(b) and 5.6(b) respectively. BSEC decreases with increase in load which is because of higher percentage in brake power with load as compared to fuel consumption. It has been also observed that BSEC for B20 is high for all load conditions at compression ratio 18.

Variation of exhaust gas temperature w.r.t. brake power

Exhaust gas temperature (EGT) for different blends with respect to brake power at 18 and 15 compression ratios with their percent change graph in reference with diesel are represented in figure 5.7(a), 5.7(b), 5.8(a), 5.8(b) respectively. The exhaust gas temperature for all fuel samples increase with increase in the load. It is because of increase in the amount of fuel injected with increase in engine load and in order to maintain increased power output, exhaust temperature increases. Exhausted gas temperature is an indication of good combustion in the combustion chamber. It has been observed that the value of exhaust gas temperature is low for diesel and small blends like B20 and B40 at both the compression ratios. But when concentration of biodiesel increased, the exhaust gas temperature also increased. It has also observed that at lower compression ratio of 15 the exhaust gas temperature of biodiesel blends is less as compared to diesel. As EGT at CR15 is less which can be leads to reduction in NOx emissions as they are highly dependent on temperature. It can be recommended that is better to run engine at lower compression ratio in order to have low emissions, but it should be further investigated properly at various engines.

Variation of smoke opacity w.r.t. brake power

Variation in smoke opacity with respect to brake power for different fuels at 18 and 15 compression ratios is shown in figure 5.9(a) and 5.10(a) respectively. The major finding is that biodiesel and its blends with diesel produce less smoke as compared to pure diesel. This is may be due to basic difference in chemical structure of biodiesel and diesel and the presence of oxygen in the molecule of the biodiesel, which enhanced its complete burning as compared to diesel. It can also be observed from the graph that smoke level increased sharply with increase in load for all fuels tested at both the compression ratios. It was mainly due to the decreased air-fuel as such higher loads when larger quantities of fuel are injected in to the combustion chamber. It has been also observed that at lower compression ratio of 15 the smoke opacity in higher as compared to higher compression ratio of 18. Figure 5.9(b) and 5.10(b) shows the percent change in smoke opacity for all blends with reference to the smoke opacity of diesel at CR 15 & 18.

Variation of Pressure with respect to Crank Angle (P-ϴ curve)

The variation of cylinder pressure with respect to crank angle of all biodiesel blend and diesel is shown in figure 5.11 to 5.12. Figure 5.11(a) and 5.11(b) shows the P-θ diagram of idling and maximum load condition at compression ratio 18 where as figure 5.12(a) and 5.12(b) shows the P-θ diagram of idling and maximum load condition at compression ratio 15 respectively. It is observed from the graph that at CR18 the maximum pressure attained during idling is around 56 bars by B60 whereas at maximum load maximum pressure (68 bars) is attained by B100. At compression ratio 15 the maximum pressure (49 bars) in idling condition is attained by B60 whereas at maximum load condition the maximum pressure (66 bars) is attained by B100. It is noticed that at CR15 the pressure less in both the conditions as compared toCR18.

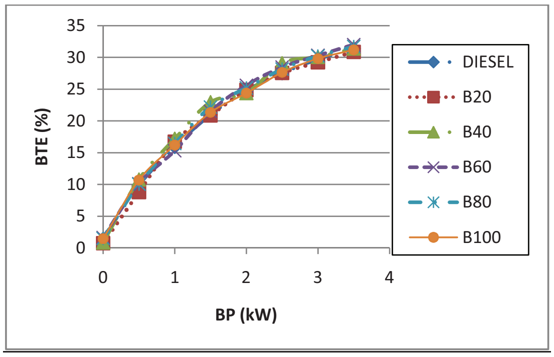


Figure 5.1(a): Variation of brake thermal efficiency w.r.t brake power at CR18

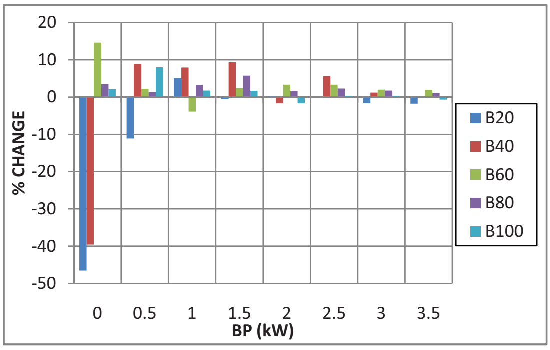


Figure 5.1(b): Percent Change in BTE of all blends with reference to diesel at CR18

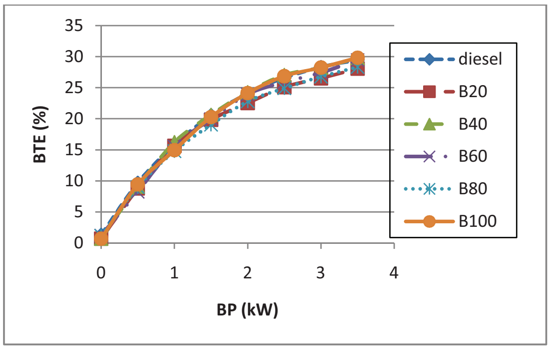


Figure 5.2(a): Variation of brake thermal efficiency w.r.t. brake power at CR15.

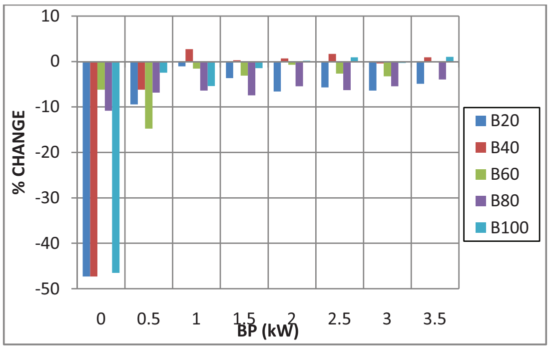
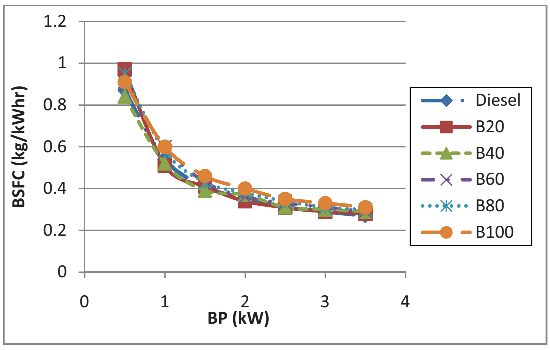


Figure 5.2(b): Percent Change in BTE of all blends with reference to diesel at CR15



Figures 5.3(a): Variation of BSFC w.r.t. brake power at CR 18

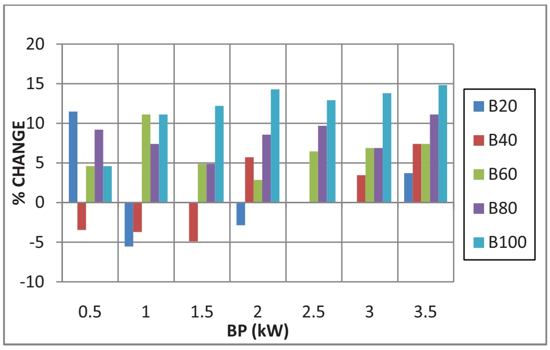
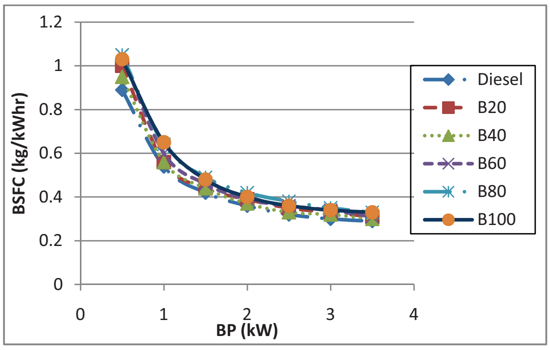


Figure 5.3(b): Percent Change in BSFC of all blends with reference to diesel at CR18



Figures 5.4(a): Variation of BSFC w.r.t. brake power at CR 15

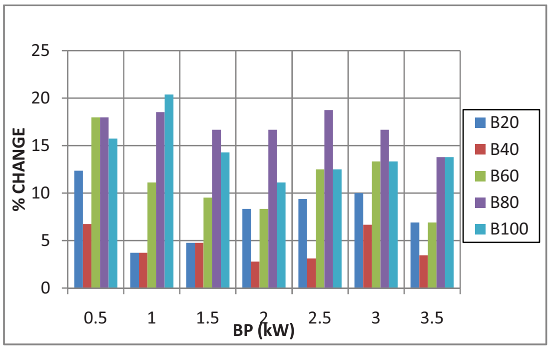
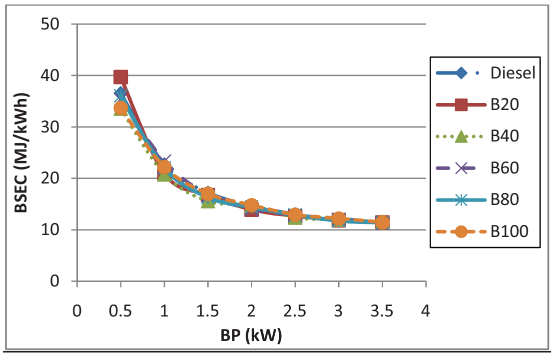
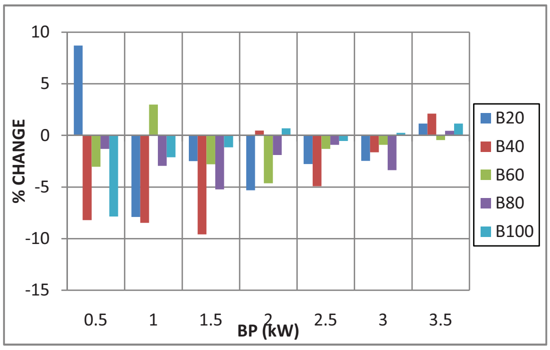


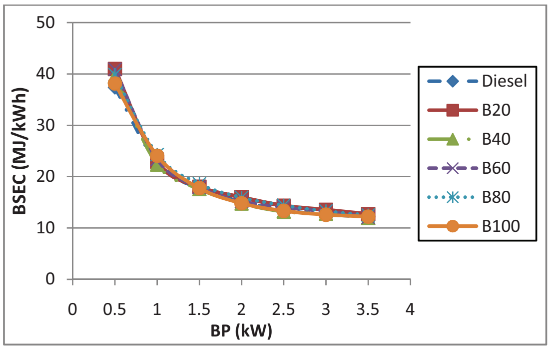
Figure 5.4(b): Percent Change in BSFC of all blends with reference to diesel at CR15

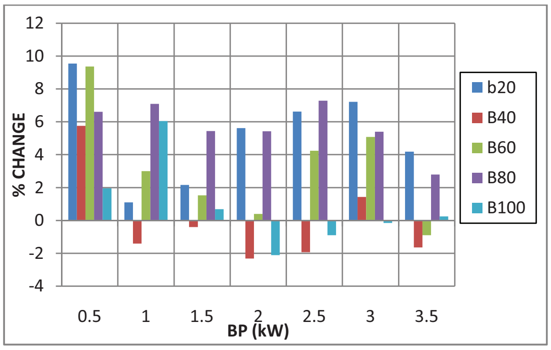




Figures 4.5(a): Variation of brake specific energy consumption w.r.t. brake power at CR 18

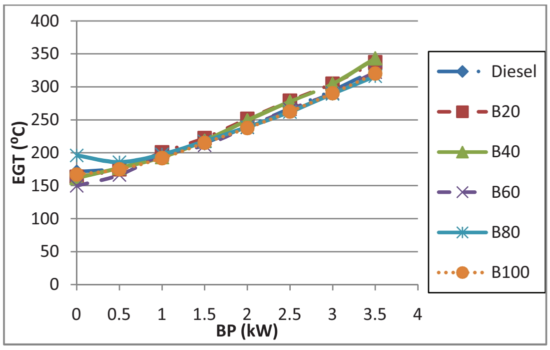
Figure 5.5(b): Percent Change in BSEC of all blends with reference to diesel at CR18





Figures 5.6(a): Variation of brake specific energy consumption w.r.t. brake power at CR 15

Figure 5.6(b): Percent Change in BSEC of all blends with reference to diesel at CR15



Figures 5.7(a): Variation of Exhaust gas temperature w.r.t. brake power at CR 18

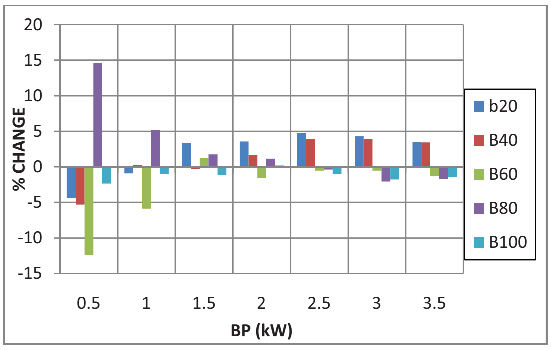
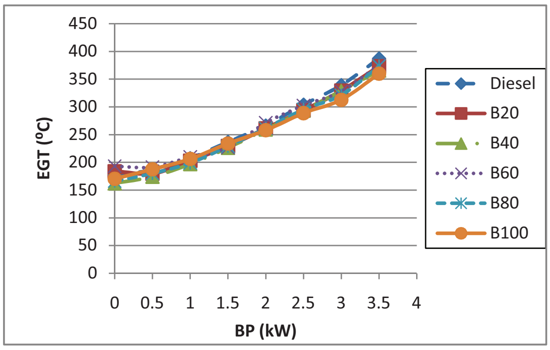


Figure 5.7(b): Percent Change in EGT of all blends with reference to diesel at CR18



Figures 5.8(a): Variation of Exhaust gas temperature w.r.t. brake power at CR 15

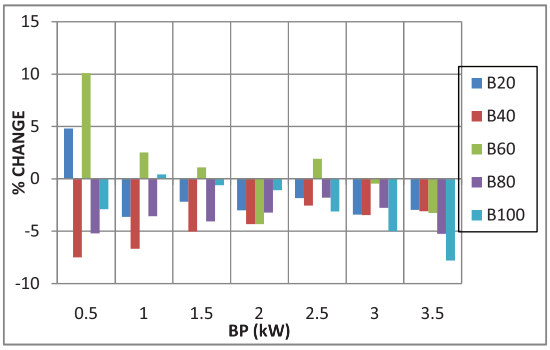
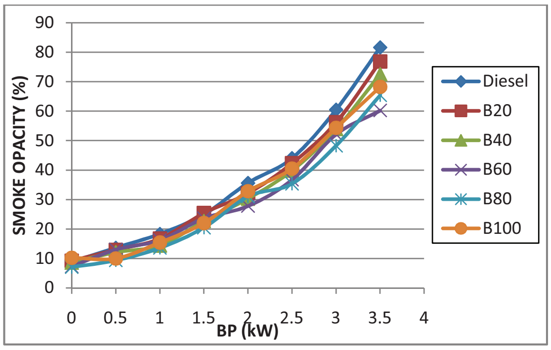


Figure 5.8(b): Percent Change in EGT of all blends with reference to diesel at CR15



Figures 5.9(a): Variation of Smoke opacity w.r.t. brake power at CR 18

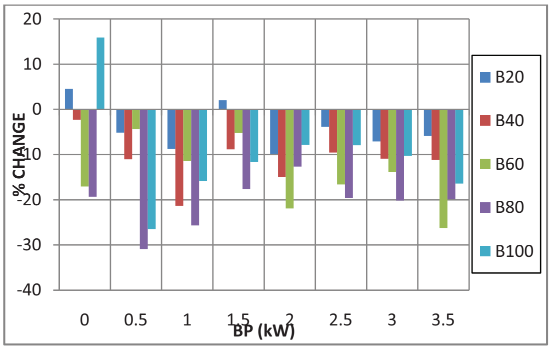
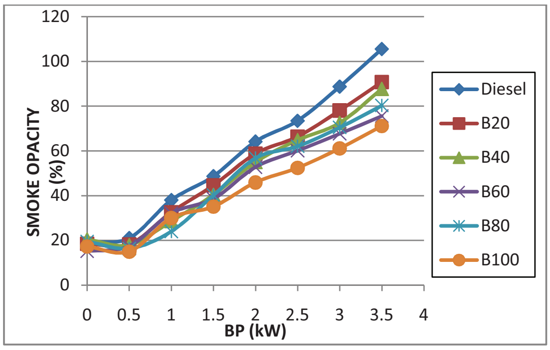


Figure 5.9(b): Percent Change in Smoke opacity of all blends with reference to diesel at CR18



Figures 5.10(a): Variation of Smoke opacity w.r.t. brake power at CR 15

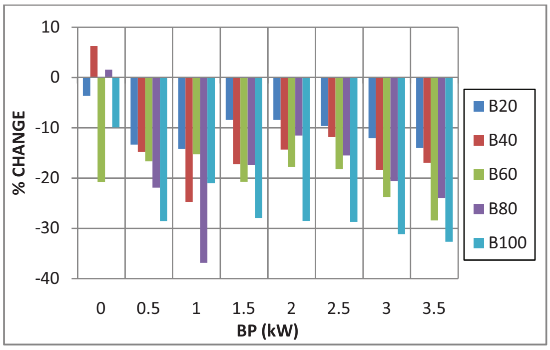


Figure 5.10(b): Percent Change in Smoke opacity of all blends with reference to diesel at CR15

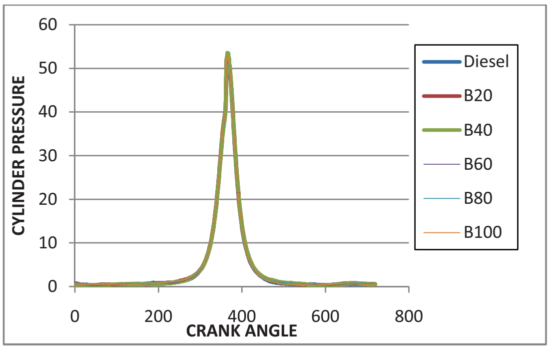


Figure5.11 (a): P-θ diagram of idling at CR18

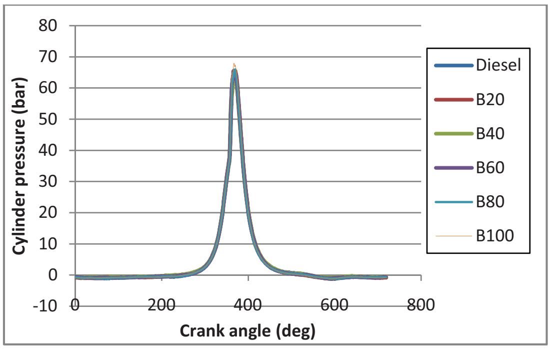


Figure 5.11(b): P-θ diagram of maximum load at CR

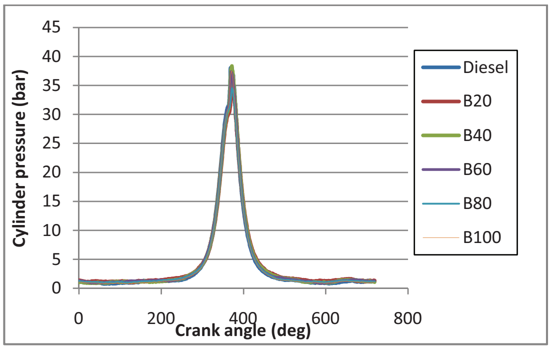


Figure 5.12(a): P-θ diagram of idling at CR15

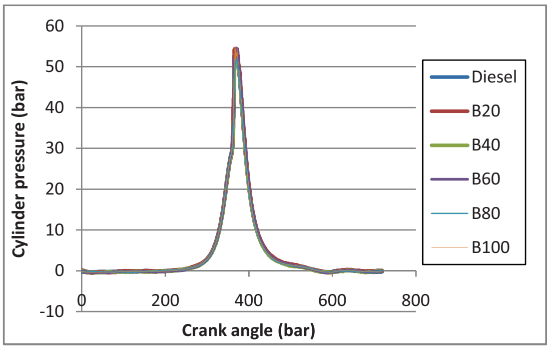


Figure 5.12(b): P-θ diagram of maximum, load at CR15

CHAPTER-6

CONCLUSION & FUTURE SCOPE

7.1 CONCLUSION

Thumba (Citrullus colocyntis) has enormous potential for biodiesel production. The salient feature of this plant is that it grows in the form of creeper in sandy soil with in a six month crop cycle. It is very clear that economics of the product is controlled by the availability of the raw materials. So, the plantation of the trees and their usage should be properly managed to explore the benefits from this neglected plant. The important conclusions are as follows:-:

1. Ultrasonic cavitation and hydrodynamic cavitation techniques are better than conventional techniques of biodiesel production. They give higher yields by taking lesser time as compare to mechanical stirring technique.
2. It can be concluded that for Hydrodynamic cavitation techniques the optimum value of KOH will be 0.75% because it gives higher yield than 1% KOH
3. It is found that in mechanical stirring and ultrasonic the yield obtained at 1% KOH is higher whereas in hydrodynamic cavitation higher yield obtained at 0.75% KOH.
4. Maximum Yield up to 98% is obtained by using thumba oil.
5. Slightly higher yield is obtained by Ultrasonic and hydrodynamic cavitation technique as compare to MS method of biodiesel production.
6. Engine testing experiment at different compression ratios results suggests that trends for variation of performance parameters for wide range of engine loads are similar for biodiesel blends and pure diesel and do not show any sign of deterioration as compared to pure diesel.
7. The presence of oxygen in the molecular structure of Biodiesel intensifies the complete combustion phenomenon.
8. The calorific value of the blends decreases as the percentage of biodiesel is increased, which affects the performance of high percentage blends.

9. The performance parameter like brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption, torque have similar result at wide range of power output.

10. It is observed that the Exhaust gas temperature for biodiesel blends is low for CR15 as compared to CR18 than diesel.

11. The smoke emissions of biodiesel blends are considerably less as compare to diesel due to complete combustion of the fuel. The results confirm the potential of these blends have in reducing the overburdening imports of diesel fuel.

7.2 FUTURE SCOPE & RECOMMENDATIONS

Biodiesel has distinct advantage as an automotive fuel. Initial cost may be higher but feedstock diversity and multi-feedstock production technologies will play a critical role in reductions in production cost and making the fuel economically viable. The following points may be considered before introducing the fuel in India:

1. Hydrodynamic cavitation process should be further investigated at higher pressure in order to get maximum yield in minimum time.
2. The blends prepared for this project work were utilized within short time span. Thus, long term stability of blends was not studied. So there is scope for study of long term stability of blends.
3. As there no problem occurred during the testing in the lab but for long term use of biodiesel in an engine, high maintenance required. So there is a scope of further investigation for long term use of biodiesel.
4. Government may consider providing support to the activities related to collection of seeds, production of oil from non-edible sources, production of bio-fuels and its utilization for cleaner environment.
5. The technique of transesterification can be extended to various non-edible vegetable oils. Further investigation can be carried out to prepare ethyl ester from various non-edible vegetable oils and to conduct various engine tests.

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