

CHAPTER 1

INTRODUCTION

1.1 Introduction

“Energy security” now a day is very important issue both for developed or developing countries. It has been on the top priority of every government because it can provide the much needed growth for any country. The production and distribution of energy need to be reliable so as to withstand ups and downs associated with its availability and price. The use of energy has been a key in the development of the human society by helping it to control and adapt to the environment. Managing the use of energy is inevitable in any functional society. Energy is one of the most significant inputs for growth of all sectors including agricultural, industrial services and transport sectors. Energy markets have combined crisis recovery and strong industry dynamism. Energy consumption soared by more than 5% in 2010. Energy has been at the centre stage of national & global economic development since several decades. The demand for energy, around the world is increasing exponentially, specifically the demand for petroleum-based energy. Petroleum derived fuels, actually, exceeds the demand of any other fuels or energy resources. The world consumption for petroleum and other liquid fuel will grow from 85 million barrels/day in 2006 to 107 million barrels/day in 2030 [1].

Under these growth assumptions, approximately half of the world’s total resources would be exhausted by 2030. Also, as per many studies, the world oil production would peak sometime between 2007 and 2030 [1]. Therefore, the future energy availability is a serious global concern. Another, major global concern is

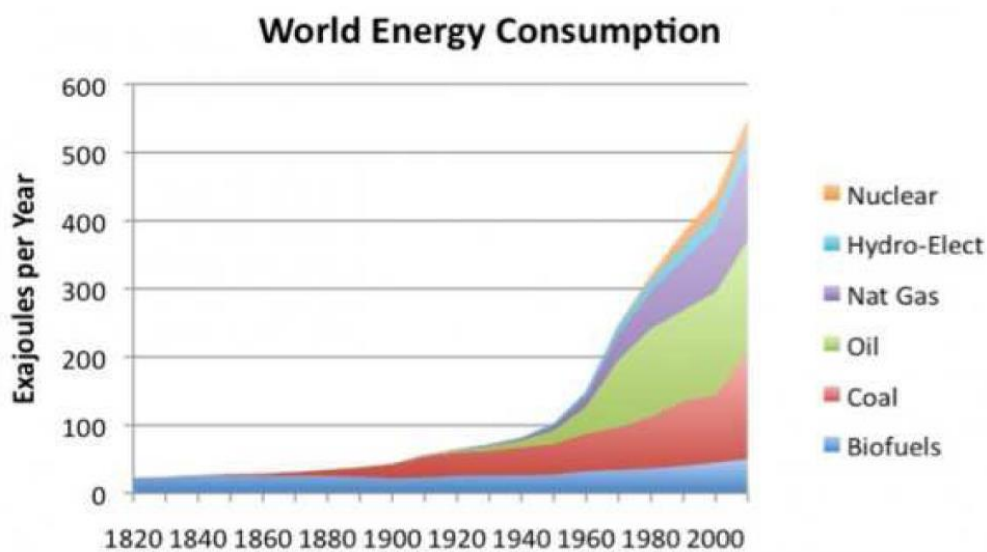
environmental degradation or climate change such as global warming. Global warming is related with the greenhouse gases which are mostly emitted from the combustion of petroleum fuels. In order to control the emissions of greenhouse gases, Kyoto Protocol targets to reduce the greenhouse gas emission by a collective average of 5% below 1990 level of respective countries. The Intergovernmental Panel on Climate Change (IPCC) concludes in the Climate Change 2007 that, because of global warming effect the global surface temperatures are likely to increase by 1.1°C to 6.4°C between 1990 and 2100 [2].

1.1.1 Energy Crisis

Adequate availability of inexpensive energy is the most important demand of today. Economic growth and industrialization both are dependent on the availability of energy. But today the problem is that world energy sources are fast depleting and this fast depleting energy resources have put the world in a grip of energy crisis so this is the time to take steps to conserve the non-renewable sources .Figure 1.1 shows the energy consumption of the world for past two centuries as well as shows the share of various energy sources in the total consumption of energy.

The growing demand for energy and gradual extinction of fossil fuels has lead to an energy crisis. Most of the power in industries and transportation is derived from oil and coal. Special mention is needed for automobiles where almost all of the fuels for combustion engine today are derived from petroleum, a non renewable source of energy, which is nearing its end at an unprecedented pace. Since then, several price hikes have taken place, upsetting economy of most of the nation. The globe today uses about 147 trillion kWh of energy which is expected to rise in the

coming future [3]. A major chunk of this rise will be due to the developing countries, which are bound to grow by leaps and bounds.



Source: - "<http://financialpress.com/2012/03/17/world-energy-consumption-since-1820-in-charts/>"

Figure1.1 World Energy Consumption (yearly)

1.1.2 World Primary Energy Consumption

Figure.1.2 depicts the primary energy consumption of world from 1970 to 2030. It is apparent that world energy is mainly dominated by fossil fuels.

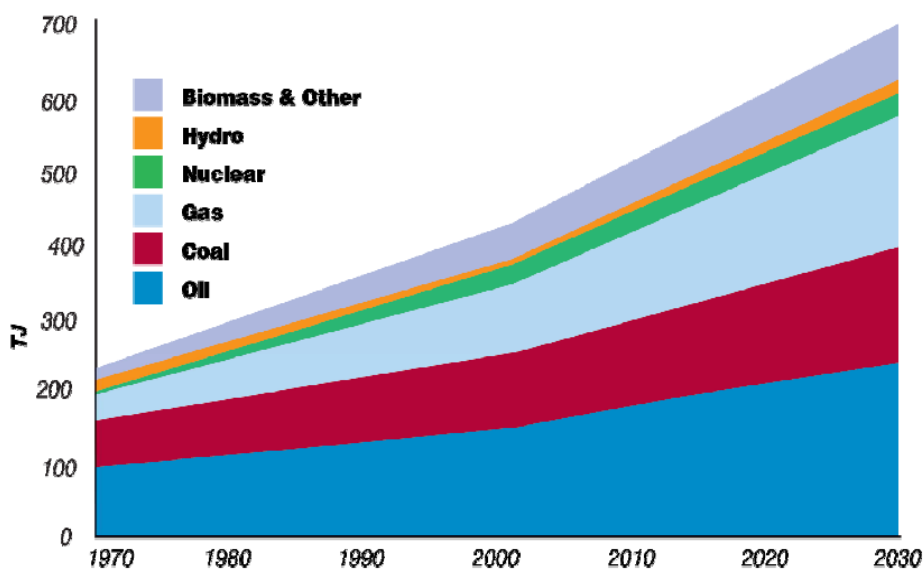


Figure 1.2: World primary energy consumption in Terajoules (yearly) [4]

Note: - Consumption of world primary energy is increasing sharply every year and this will lead to future energy crisis.

1.1.3 Energy Scenario: Indian Context

The energy policy of India is largely defined by the country's burgeoning energy deficit and increased focus on developing alternative sources of energy. Indian economy is mainly agriculture based and modern agriculture system is heavily dependent upon internal combustion engines for running farm machinery, irrigation pump sets, and other equipments. Indian growth is mainly based on energy, produced by “oil-burning” in IC engines. The energy needs of India are also rising to cope up the growth rate. Of the 156.1 million tonnes of crude oil that India consumed in 2007-08, it produced only 34.12 million tonnes [5]. According to Oil & Gas Journal (OGJ), India had approximately 5.7 billion barrels of proven oil reserves as of January 2011, the second-largest amount in the Asia-Pacific region after China. India's crude oil reserves tend to be light and sweet. From figure 1.3 it is observed that India produced roughly 950 thousand barrels per day (bbl/d) of total liquids in 2010, of which 750 bbl/d was crude oil. The country consumed 3.2 million barrels per day (bbl/d) in 2010 [6].

It is very difficult to find clear blue sky in Indian metropolis. Petroleum fuels are major contributor to ecological imbalance in India. As Indian economy is heavily based upon IC engines, it is not possible in any case to discard them and some other, easily available renewable fuels in India. These renewable fuels must be sought to lease new life to existing engines in order to curb the twin problems of fuel scarcity and air pollution. Various national emission standards have been set by the Government of India through which the fleets are facing greater pressures to

switch to cleaner alternative fuels. The alternative fuels are desirable from the fact that they are the only fuels used with recent engine developments, which can meet the stringent EURO-IV emission norms, which are expected to be enforced in India from 2010.

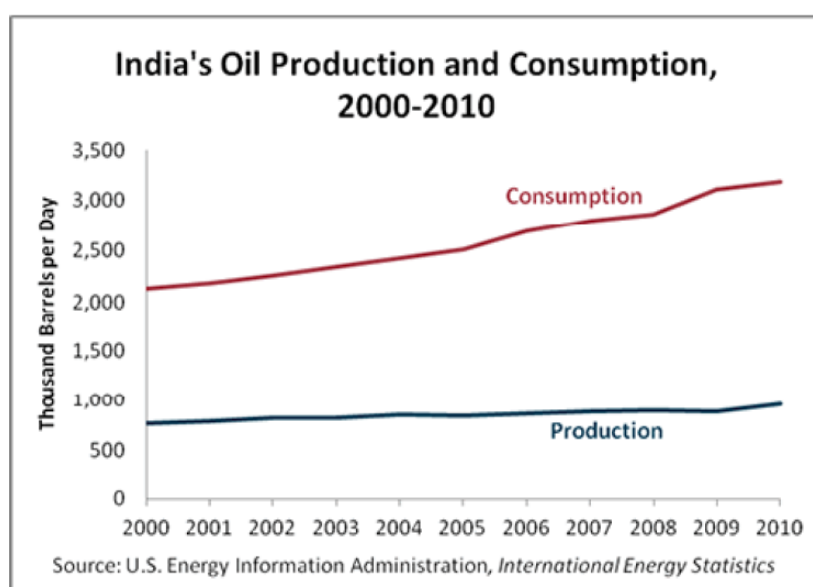


Figure 1.3 Differences between production and consumption of oil in India [6]

India being richer in flora and fauna can look forward to use fuels from bio origin as the suitable alternatives. The prominent bio fuels from Indian perspective are ethanol and biodiesel. India, the world's second most populous nation, has seen its population exploding from 300 million in 1947 to around 1.2 billion today. This rapidly growing population has placed a strain not only on India's infrastructure, but also on its environment. According to the World Health Organization, New Delhi is one of the top ten most polluted cities in the world.

Two primary sources of air pollution in India are vehicular emissions and untreated industrial smoke. The number of vehicles has registered a sharp increase more so, during the last decade. In Delhi alone, the vehicle number has crossed about 4.6 million. Today, the vehicular pollution contributes roughly 64 % of total

air pollution in Delhi, followed closely by Mumbai at 52% and somewhat controlled figure of 30% for Kolkata. About 50% of the total petroleum products consumed in the country go into the transport sector mainly in the form of high-speed diesel and gasoline [7]. India's per capita energy use and carbon emissions, while lower than the world average, result in a substantial percentage of world energy use and carbon emissions, due to the country's large population and heavy reliance on fossil fuels. Increased use of renewable energy is one means of reducing carbon emissions.

1.1.4 Environmental effects

The indiscriminate and inefficient energy utilization has also resulted in environmental degradation which needs to be adequately studied. The process of energy generation, transport and utilization leads to air pollutants. In-efficient use of energy has stretched the global environment to its limits as can be seen from the unprecedented and unpleasant responses of the nature in the past few years. Green house effect, global warming, acid rain, smog, deforestation, shift in climatic conditions etc. are some of the indications. Figure 1.4 represents the increase in carbon dioxide concentrations in last few thousand of years. It clearly represents that the CO₂ level has increased to an alarming level.

Environmental pollution from engine exhaust emissions has attracted worldwide attention. Besides vehicular pollution, the significance of engine exhaust emission from stationary utility engines, particularly genset for electrical energy applications, has also been realized. The emission norms for gensets in India have already been in force. However, further scope of reduction of emissions needs to be explored for these classes of engines as well as wide range of fuels like gasoline, diesel, kerosene, LPG and CNG. Faced with the huge challenge of meeting its

rapidly increasing energy demand, India is focusing sharply on both energy efficiency improvements as well as tying up energy resources at the global level – either through purchases on the international markets or through equity investments in global assets as also emphasized in the preceding section.

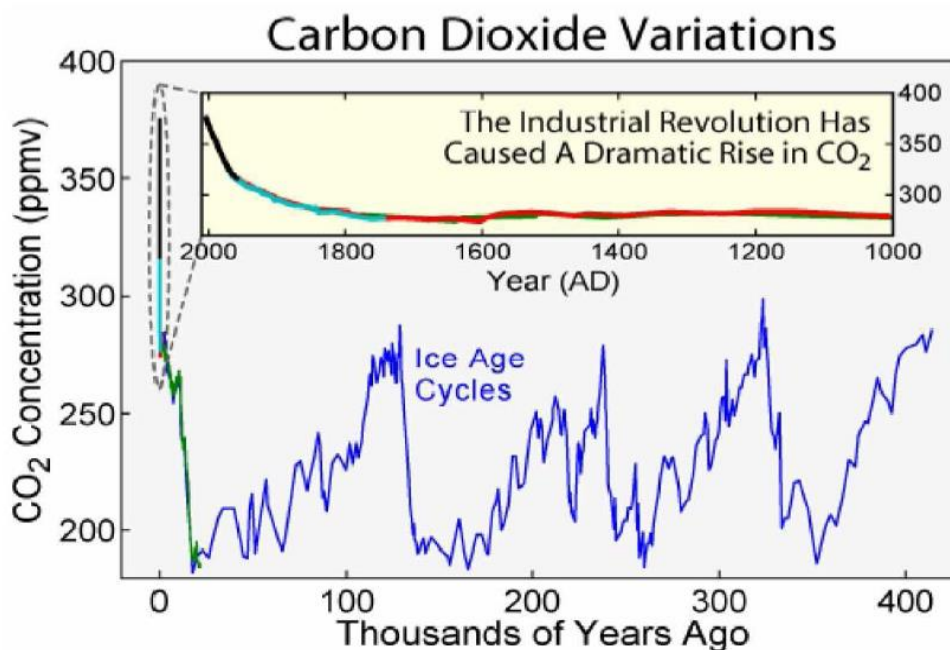


Figure 1.4 Increase in CO₂ Concentration [8]

1.1.5 Alternative Fuel Imputes

With gasoline skyrocketing to more than \$4 a gallon in 2011, dependence on imported oil and depleting resources worldwide, finding alternatives to petroleum-based fuel and fuel-related products is urgent. 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:

1. Land for production need to be explored.
2. An efficient extraction of oil from oil seeds and transesterification plant would be required.
3. Distribution and storage facilities constructed.
4. Monitoring of major users for detection of problems
5. Large scale uses are needed before the technology can be recommended for general use.
6. 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.
7. High consumption of diesel fuel and limited sources of others is the reason for enormous rise in the price of petrol. Developing fuel sources from agriculture that can make a significant impact on the large petroleum consumption. [9]

1.2 Biodiesel

1.2.1 General

Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, propyl or ethyl) esters. The idea of using vegetable oil as a substitute for diesel fuel was demonstrated by the inventor of the diesel engine,

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

ASTM International defines Biodiesel as the “mono alkyl esters of long chain fatty acids derived from renewable liquid feedstock’s, such as vegetable oils and animal fats, for use in compression ignition engines.” In the 1980s and 1990s significant R&D was conducted to evaluate a variety of biodiesel blending stocks, develop emissions data, assess engine/vehicle performance, and develop cost-effective manufacturing processes. The main commodity sources of biodiesel in India are non edible oils obtained from plant species such as Jatropha, Pongamia, Pinnata, Karanja etc [11]. Biodiesel can be blended at any level with petroleum diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition engine; which essentially require very little or no engine modifications because biodiesel has properties similar to petroleum diesel fuels. It can be stored just like petroleum diesel fuel and hence does not require separate infrastructure.

The use of biodiesel in conventional diesel engines results in substantial reduction of un-burnt hydrocarbons (HC), carbon monoxide (CO) and particulate matters for example Karanja oil blends with diesel up to 50% v/v give lower emissions[12]. But uses of biodiesel slightly increase nitrogen oxide (NO_x) which can be reduced by incorporating EGR system. Biodiesel is considered as a clean fuel since it has almost no sulphur, no aromatics and has about 10% built in oxygen, which helps it to burn fully. Its higher cetane number improves the ignition quality

even when blended in the petroleum diesel. Due to the fact that vegetable oils are produced from plants, their burning leads to a complete recyclable CO₂ (green house gas).

There are also some drawbacks in the bio diesel fuel as compared to petroleum fuels which includes high cost of biodiesel which is around 1.5 times to that of petroleum diesel, unavailability at large scale, and requirement of large area of land. Now a day's various techniques have been developed for producing biodiesel. Some of them are mechanical stirring, ultrasonic cavitation, hydrodynamic cavitation and supercritical methanol

1.2.2 Advantages of the Biodiesel over Petroleum based Diesel Fuel

- Biodiesel is a good lubricant about 66% better than petro diesel
- Biodiesel produce less smoke and particulates matters as it is free of sulphur and aromatics.
- Biodiesel have higher cetane number having good anti knocking property.
- Produce lower carbon monoxide and hydrocarbon emissions.
- 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 [13].

1.2.3 Indian scenario in biodiesel

The country's energy demand is expected to grow at an annual rate of 6.8 percent over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels – coal, petroleum based products and natural gas. Past and projected increased demand is shown in Table 1.1. Domestic production of crude oil can only fulfil 25-30 per cent of national consumption rest we are importing from other countries. In these circumstances bio fuels are going to play an important role in meeting India's growing energy needs. Bio fuels offer an attractive alternative to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize the positive and minimize the negative aspects of bio fuels.

Table 1.1 Demand of energy for consumption in India

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

Source: Planning commission report, 2003

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

Table 1.2 Demand for diesel and biodiesel requirement

Year	Diesel demand (Million 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

Source: Planning commission report, 2003

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

the cultivation in the forest and non-forest areas, respectively by providing the necessary information and financial assistance.

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

There are many key challenges and market barriers for biodiesel promotion in India. Information regarding the agro economic practices are limited, which often discourages the risk-averse small and marginal farmers from growing non-edible oil seeds. Still there is uncertainty about the potential yields and reliability of seeds. Further cultivation of such crops having relatively longer gestation period such as *Jatropha* (3years) & *Pongamia* (5years). At present the country is relying on imported technology, which is extremely expensive and is also proven for edible oil as feedstock. There are risks associated with the technology for its costs and compatibility. Though indigenous technologies are available at low costs and in smaller plant sizes with lower levels of performance regarding conversion of oil to

diesel. Finance of biodiesel projects are a major constraint but few venture capital firms and banking institutions are coming forward to finance biodiesel-manufacturing plants. The production costs of bio-diesel are currently higher than conventional fuels, so it will be very difficult to gain market share without Government intervention in terms of favourable duty and taxation levels. At present wide and uncertain price band ranging from Rs 17-45 per litre of biodiesel discourage the seller & distributor to set up separate distribution channels.

1.2.4 Resources of Biodiesel

Biodiesel - the fuel of the future is still not a practicable fuel like other resources. The reason for that is that we still unable to produce enough vegetable oil to produce the amount of fuel required. The 3 future alternatives for biodiesel source are:

[1] **Algae** is one of the most promising sources for renewable energy. Algae is a primitive photosynthetic creature that can efficiently convert carbon dioxide to sugars and fats, Since it is easy to grow and harvest it, and its growth rate is very high, It promises a great foundation for developing a biodiesel factory that can produce an enormous amount of biofuel with low cost, and without jeopardising our food.

[2] Another promising source of renewable energy is **agriculture waste**. A vast amount of organic waste is being produced all the time. We use to throw this waste away since we are unable to reuse it, because it is mostly made of cellulose which is hard to break with normal means. But there are bacteria which are able to digest and bread cellulose easily. Most of these bacteria live in symbiosis with cellulose eating animals like cows or termites.

[3] Third, the future of biofuels might be held in the hands of genetic engineers.

The major advances in the fields of **genetic manipulation of plants**, promises the ability to manipulate plants and bacteria in the future to produce much more oil, in a more efficient way, to solve the insufficient production of the present. Biodiesel and biofuels in general, don't only raise concerns about the production capacity but also originated fear about the possibility that we will found ourselves with a nutrition shortage, if we will use our crops for fuel instead of food.

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



Figure 1.5 Cotton seeds

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

In Table 1.4 Top 10 countries in terms of biodiesel potential (Litters) and there production cost (\$/Litter) is given.

Table 1.3 Global productions of the major vegetable oils [14]

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

Table 1.4 Top 10 countries in terms of biodiesel potential [15]

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

1.2.5 Vegetable Oil Utilization as Engine Fuel

Neat vegetable oils are not suitable as fuel for diesel engines; hence they have to be modified to bring their combustion-related properties closer to those of

mineral diesel. This fuel modification is mainly aimed at reducing the viscosity to get rid of flow and combustion-related problems. Considerable efforts have been made to develop vegetable oil derivatives that approximate the properties and performance of HC-based fuels. Vegetable oils can be used through at least four ways:

- ✓ Direct use and blending.
- ✓ Micro-emulsion.
- ✓ Pyrolysis (thermal cracking).
- ✓ Transesterification.

1.2.5.1 Direct Use and Blending

Caterpillar (Brazil) in 1980 used pre-combustion chamber engines with a mixture of 10% vegetable oil to maintain total power without any alterations or adjustments to the engine. At that point, it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% mineral diesel was successful. Some short-term experiments used up to a 50/50 ratio [16]. Pramanik et al. [17] found that 50% blend of Jatropha oil can be used in diesel engine without any major operational difficulties but further study is required for the long-term durability of the engine. Direct use of vegetable oils and/or the use of blends of the oils have generally been considered to be not satisfactory and impractical for both direct and indirect diesel engines. The high viscosity, acid composition, free fatty acid content, as well as gum formation due to oxidation, polymerization during storage and combustion, carbon deposits and lubricating oil hickening are obvious problems. The probable reasons for the problems and the potential solutions are shown in [16, 18].

1.2.5.2 Micro-Emulsions

To solve the problem of the high viscosity of vegetable oils, micro-emulsions with solvents such as methanol, ethanol and 1-butanol have been investigated. A micro-emulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimension generally in the 1–150 nm range, formed spontaneously from two normally immiscible liquids. They can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. Short term performance of micro-emulsions of aqueous ethanol in soybean oil was nearly as good as that of no. 2 diesel, in spite of the lower cetane number and energy content [19].

1.2.5.3. Pyrolysis (thermal cracking)

Pyrolysis is the conversion of one substance into another by means of heat or by heat in presence of a catalyst. The paralyzed material can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids. The pyrolysis of fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum. Many investigators have studied the pyrolysis of triglycerides to obtain products suitable for diesel engine. Thermal decomposition of triglycerides produces alkanes, alkenes, alkanes, aromatics and carboxylic acids [17, 20].

1.2.6 Properties of biodiesel

- a. **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.

- b. **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.
- c. **Cetane Number:** Biodiesel has higher cetane number than conventional diesel fuel, these results in higher combustion efficiency and smoother combustion. Biodiesel has cetane number more than 51.
- d. **Flash and Fire point:** Flash point is the minimum temperature at which the oil vapour, which when mixed with air forms an ignitable mixture and gives a momentary flash on application of a small pilot flame. The flash point of biodiesel is higher than the petroleum based diesel fuel. The flash point of biodiesel is around 160°C . Fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for at least for 5 seconds. Fire point is generally higher than the flash point by $5\text{-}8^{\circ}\text{C}$.

- e. **Cloud and Pour Point:** Cloud and Pour points are important for determining the feasibility of using the fuel in engine at lower ambient temperatures. Fuels with high pour points give flow problems at lower temperature, therefore it cannot be recommended for use in engine at low temperatures. Pour point for fuel oils, lubricating oils and diesel fuels is used as criteria in cold surroundings. The cloud and pour point of the fuel were measured as per the specification given of ASTM D2500 and ASTM D97 respectively .Biodiesel generally has higher cloud point than diesel fuels. The pour point is the lowest temperature at which the liquid will flow in a specific way when cooled under controlled conditions. The cessation of flow results from an increase in viscosity or from the crystallization of wax from the oil. Fuel oils of wax bearing crude oils have much higher pour point than those derived from crude oils of low wax content. A low pour point is a desired property of oil in respect of handling in cold atmosphere.
- f. **Cold filter plugging point (CFPP):** At low operating temperature fuel may thicken and not flow properly affecting then 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.
- g. **Aromatics:** Biodiesel does not contain any aromatics so aromatic limit not specified.
- h. **Stability:** Biodiesel age more quickly than fossil diesel fuel due to the chemical structure of fatty acids and methyl esters present in biodiesel. Typically there are up to 14 types of fatty acid methyl esters in the biodiesel.

The individual proportion of presence of these esters in the fuel affects the final properties of biodiesel. There are three types of stability criteria namely Oxidation stability, Storage stability and Thermal stability.

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

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

Table 1.5 Summary of proposed BIS (Bureau of Indian Standards) standards for biodiesel [11]

Property	Unit	Proposed BIS specification
Density @ 15 ⁰ C	g/cm ³	.87-0.9
Viscosity @ 40 ⁰ C	mm ² /s	3.5-5
Flash point	⁰ C	>=100
Sulphur content	% mass	0.035
CRR , 100% distillation residual max.	% mass	0.05
Sulphated ash, max	% mass	0.02
Water.max	mg/kg	500
Total contamination, max	mg/kg	20
Cetane no		>=51
Acid no	mg HOH/g	<=0.8
Methanol	% mass	<=0.02
Ester content	% mass	>=96.5
Triglyceride	% mass	<=0.2
Free glycerol	% mass	<=0.02

Total glycerol	%mass	≤ 0.25
Iodine no		≤ 115
Phosphorus	Ppm	≤ 10
Alkaline matter (Na,K)		≤ 10
Distillation, T 95%	$^{\circ}\text{C}$	≤ 360

1.2.7 Storage, Handling and Distribution

Biodiesel is significantly safer than diesel. The storage and handling procedures for petroleum diesel can also be used for biodiesel. The fuel is best stored in a dark, dry and clean environment, in storage tanks, preferably steel, aluminium, Teflon, fluorinated polyethylene or polypropylene. Materials which should be avoided include lead, copper, brass, tin and zinc. Biodiesel has a flash point higher than diesel. Many diesel fuel suppliers recommend storing diesel for no more than three to six months unless using a stabilizing additive. The current industry recommendation is that biodiesel or biodiesel blends also be used within six months. A longer safe life is possible and storage enhancing additives can provide additional benefits. Acid numbers in biodiesel and biodiesel blends will become elevated if the fuel ages, or if it was not properly manufactured. Raised acid numbers have been associated with fuel system deposits and reduce the life of fuel pumps and filters. Pure biodiesel and biodiesel blends should be stored at temperatures higher than the pour point of the fuel. Biodiesel blends will not separate in the presence of water however it is recommended that good 'housekeeping' be maintained. This is in respect to tank and fuel maintenance, to ensure water in storage systems is monitored and minimised [9].

1.2.8 Additives for oxidative stability of biodiesel

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

Long-term storage in the presence of diesel fuel, diesel additives, water, sediments, heat, and air has not been adequately documented in the field. Biodiesel and blends of biodiesel and diesel fuel should not be stored for longer than 6 months in either storage tanks or vehicles until better field data is available. If it becomes necessary to store biodiesel longer than 6 months, or the storage conditions are poor, use antioxidants. The common antioxidants that work with biodiesel are TBHQ (t-butyl hydroquinone), Tenox 21, and Tocopherol (Vitamin E). Most of these are sold by food additive firms. Powdered antioxidants are difficult to mix into biodiesel. A trick used is to heat a small amount of biodiesel (1 gal or so) up to 37.7

C or until all the powdered antioxidant is dissolved then mixed the treated biodiesel into the bulk biodiesel fuel [10].

1.2.9 Material compatibility

Brass, bronze, copper, lead, tin, and zinc will oxidize diesel and biodiesel fuels and create sediments. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change colour and sediments may form, resulting in plugged fuel filters. Affected equipment should be replaced with stainless steel or aluminium. Acceptable storage tank materials include aluminium, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. The effect of B20 on vulnerable materials is diluted compared to higher blends. Some slow oxidation can occur, although it may take longer to materialize. Biodiesel can also affect some seals, gaskets, and adhesives, particularly those made before 1993 made from natural or nitrile rubber. It is primarily for these reasons that vehicle and storage equipment are modified. Most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant. Earlier engine models or rebuilds may use older gasket and seal materials and present a risk of swelling, leaking, or failure. Fuel pumps may contain rubber valves that may fail. The typical approach is to create a maintenance schedule that checks for potential failures. Users can also contact engine manufacturers for more information [10].

1.3 Motivation for present work

The decrease of world petroleum reserves and high energy demand in the power industries and transport sector has necessitated the need for an alternative source of energy. Due to harmful emission and green house gas from fossil fuel, environment is continuously degrading .Therefore there is an also need of alternative fuel which improve the environmental condition. Biodiesel obtained from vegetable oil can be alternative source of energy because its property is similar to petroleum derived diesel oil and produces favourable effects on the environment, such as a decrease in acid rain and greenhouse effect. Due to these factors, the use of biodiesel is considered an advantage to that of fossil fuels.

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

1.4 Objective of the present research work

- 1) Production of CSO (Cotton Seed Oil) biodiesel by Hybrid Reactor.
- 2) Performance and emission testing of CSO biodiesel on single cylinder VCR diesel engine.

1.5 Organization of the report

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

storage, handling and distribution of biodiesel and last one is biodiesel properties according to BIS standards. Second chapter is literature review in which literatures available on biodiesel performance and emission testing are summarized. Third chapter describe the biodiesel production techniques. Fourth chapter describe the experimental setup of a single cylinder Kirloskar engine and result and discussion of performance studies of biodiesel derived from CSO (cotton seed oil). Performance parameters are torque, brake power, brake thermal efficiency, specific fuel consumption, specific energy consumption and smoke opacity.

CHAPTER 2

LITERATURE REVIEW

2.1 About Cottonseed Oil

Cottonseed oil is cooking oil extracted from the seeds of cotton plant of various species, mainly *Gossypium hirsutum* and *Gossypium herbaceum*. Cotton grown for oil extraction is one of the big four genetically modified crops grown around the world, next to soy, corn, and rapeseed (canola), mostly Monsanto products. The scientific and technical advances developed to process cottonseed oil became the cornerstones of the edible fats and oils industry as it is known today [21].

2.1.1 Composition

Its fatty acid profile generally consists of 70% unsaturated fatty acids (18% monounsaturated, and 52% polyunsaturated) and 26% saturated fat. When it is fully hydrogenated, its profile is 94% saturated fat and 2% unsaturated fatty (1.5% monounsaturated, and 0.5% polyunsaturated) [22].

Gossypol is a toxic yellow polyphenolic compound produced by cotton and other members of the order Malvaceae, such as okra [23]. This coloured compound is found in tiny glands in the seeds, leaf, stem, tap root bark, and root of the cotton plant. The adaptive function of the compound is believed to be one of facilitating insect resistance.

2.1.2 Physical Properties

Once processed, cottonseed oil has a mild taste and appears generally clear with a light golden colour, the amount of colour depending on the amount of refining [24]. Cottonseed oil has a relatively high smoke point as a frying medium. Like other long chain fatty acid oils, cottonseed oil has a smoke point of about 450 °F (232 °C) [23]. Cottonseed oil is high in tocopherols which also contribute its stability giving products that contain it a long shelf life, hence manufacturers' proclivity to use it in packaged goods.

2.1.3 Uses of Cottonseed Oil

Since cotton seed oil was first extracted from cotton seeds in the 1860s, there have been a variety of uses discovered. According to researchers at the National Cottonseed Products Association, cotton seed has a bland taste that does not mask the flavour of foods in which it's cooked [25]. Cotton seed oil is cholesterol-free and high in antioxidants.

Cooking

Since cotton seed oil is flavourless, it makes an ideal option for frying. The oil is used in stir-fry dishes, for frying snack foods and seafood, vegetables and Asian food. Cotton seed oil produces full-flavored potato chips that are not masked with oily residue. Cotton seed oil can be used in place of any vegetable oil in recipes as well. Consumers use it in commercial applications as well as in the home.

Spreads

Cotton seed oil is used to make margarine, mayonnaise, sauces, salad dressing and marinades. In its hardened form as margarine or shortening, cotton seed oil can be

used for baked goods as well as for spreads on those same baked goods such as bread and muffins. When heavily refined, cotton seed oil is nearly clear and provides very little taste, serving mainly as a catalyst for holding ingredients together. Less refining can leave a light, nutty taste to the oil, often preferred for salad dressings. Many products aimed at health-conscious consumers are made with cotton seed oil because it contains fewer saturated fats. Cotton seed oil ranks high among healthier oils, including corn, sunflower and soybean oil.

Soap

Cotton seed oil provides a lasting, thick lather when used in soap, report soap makers at Saratoga Scents. Cotton seed oil also has emollient properties that can smooth and soften rough skin. Soap-makers recommend using soap that contains no more than 25 percent cotton seed oil because of its tendency to spoil. Like other oils used in soaps, cotton seed oil can leave skin soft and silky, report cosmeticians at Skin Care Tips. Cotton seed is an inexpensive additive that can be added to soap to provide lather and oil, so it often provides a good option for those looking for inexpensive beauty products. Cotton seed, however, can contain high levels of pesticides if not treated sufficiently, and can cause skin irritation. Cotton seed oil often is found in all-natural products at health food stores and should not be used by people with sensitive skin.

2.2 Performance and Emissions studies of Cottonseed Oil

Different parameters for the optimization of biodiesel production were investigated in the first phase of the study conducted by Md. Narun Nabi [26], while in the next phase of the study performance test of a diesel engine with neat diesel

fuel and biodiesel mixtures were carried out. Biodiesel was made by the well-known transesterification process. Cottonseed oil (CSO) was selected for biodiesel production. Cottonseed is non-edible oil, thus food versus fuel conflict will not arise if this is used for biodiesel production. The transesterification results showed that with the variation of catalyst, methanol or ethanol, variation of biodiesel production was realized. However, the optimum conditions for biodiesel production are suggested in this paper. A maximum of 77% biodiesel was produced with 20% methanol in presence of 0.5% sodium hydroxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NO_x) emission was experienced for biodiesel mixtures.

The usability of cotton oil soapstock biodiesel–diesel fuel blends as an alternative fuel for diesel engines were studied by Ali Keskin [27]. Biodiesel was produced by reacting cotton oil soapstock with methyl alcohol at determined optimum condition. The cotton oil biodiesel diesel fuel blends were tested in a single cylinder direct injection diesel engine. Engine performances and smoke value were measured at full load condition. Torque and power output of the engine with cotton oil soapstock biodiesel–diesel fuel blends decreased by 5.8% and 6.2%, respectively. Specific fuel consumption of engine with cotton oil soapstock–diesel fuel blends increased up to 10.5%. At maximum torque speeds, smoke level of engine with blend fuels decreased up to 46.6%, depending on the amount of biodiesel. These results were compared with diesel fuel values.

A 4-stroke 5hp diesel engine was tested with Diesel oil plus cottonseed oil blends in a study carried out by Mohd. Yousuf Ali [28], Amit Pal, Ashish Verma,

S.S Kachhwaha, S.Maji and M K G Babu [29, 30]. The blends in different proportions (10 to 50 percent by volume) were tested at constant speed of 1500 rpm. The said engine is operated at different loads and characteristics like Brake power, Brake thermal efficiency, specific fuel consumption etc. Engine performance for blends resulted in lower brake thermal efficiency. Smoke is also found to increase with the blends. The results of the present experimental investigations reveal that the performance of the blends is comparable with that of diesel. Hence blends can profitably be employed in an existing CI engine without major engine modifications, further it can be an immediate solution for the development of rural areas, and for the emergency use in the event of severe diesel fuel shortage.

In an investigation by S. Naga Sarada [31] short term tests were conducted with the use of untreated cotton seed oil in a single cylinder, four stroke, and direct injection diesel engine. Tests were conducted with cotton seed oil and diesel. The major problem with the direct use of vegetable oils as fuel into CI engines is their higher viscosity. It interferes the fuel injection and atomization and contributes to incomplete combustion, nozzle clogging, excessive engine deposits, ring sticking, producing thick smoke, etc. The problem of higher viscosity of vegetable oils can be overcome to a greater extent by various techniques, such as heating of fuel lines, trans-esterification, modification of injection system, etc. To improve the combustion characteristics of cotton seed oil in an unmodified engine, effect of increase in injection pressure was studied. The injection pressure was increased from 180 bar to 240 bar (in steps of 15 bar). The investigation revealed that the optimum pressure for cottonseed oil as 210 bar and comparison of the performance of the engine was studied in terms of brake specific fuel consumption, brake thermal

efficiency, indicated thermal efficiency, mechanical efficiency and exhaust emissions.

Two cottonseed oil biodiesel samples (cottonseed oil methyl esters, COME) produced in Clemson lab, together with other two commercial cottonseed oil biodiesels were evaluated on their engine performance with the No. 2 diesel fuel as a reference by Xiaohu Fan [32]. The results revealed that emission of CO, CO₂ and NO_x from cottonseed oil biodiesels was lower than that of the No. 2 diesel fuel. CO decreased by 13.8%, CO₂ by 11.1% and NO_x by 10%, though there was no significantly statistical difference at $p < 0.05$. The engine test also showed a slightly higher amount of consumption and less tendency of coke formation from COME than the No. 2 diesel fuel. The oxidative stability study showed COME with acceptable stability. COME exhibited friendly environmental benefits and acceptable stability, demonstrating its feasibility as an alternative fuel.

Comparison of the performance of single cylinder diesel engine with direct use of cotton seed oil methyl ester and preheated condition at variable temperature such as 50°C, 70°C and 90°C by P.B.Ingle [33]. The properties such as viscosity, flash point, pour point were experimentally measured of COME, thus obtained are comparable with ASM biodiesel standards. The COME has been tested in single cylinder four stroke diesel engine coupled with rope brake dynamometer, such as BSFC, BTE, BSEC are calculated and exhaust gas temperature were measured. The experiment was carried out varying load at constant speed. The results revealed that preheating COME up to 90°C at higher load lead to increase in brake thermal efficiency is 2 % as compared to diesel fuel and brake specific fuel consumption increases at higher load as compared to diesel fuel. There is no significant change found in brake power whereas exhaust gas temperature of all preheated biodiesel

COME is high and break specific energy consumption required to preheat COME is high as compared to diesel. However, the optimum conditions for biodiesel production are suggested in this paper. A maximum of 76% biodiesel was produced with 20% methanol in presence of 0.5% potassium hydroxide.

The effect of orange peel oil addition on the performance of cottonseed oil fuelled DI diesel engine was studied by Leenus Jesu Martin. M [34]. The world petroleum situation due to rapid depletion of fossil fuels and the degradation of the environment due to the combustion of fossil fuels have caused a resurgence of interest in finding alternative fuel. Vegetable oil based fuels are biodegradable, non-toxic and significantly reduce pollution. Cottonseed oil, which is considered, is not suitable as a fuel for diesel engines straight because of its high viscosity. Addition of a small quantity of another light vegetable oil, Orange Peel oil reduces the viscosity and improves the performance of the engine largely. Blends of varying proportions of cottonseed oil and orange peel oil were prepared, analysed and their properties were calculated. The performance of the engine using diesel, the blends and cottonseed oil were evaluated using a single cylinder, four stroke, direct injection and compression ignition engine. The results obtained were compared with baseline data generated with raw cottonseed oil and diesel. 15% of Orange peel oil by volume addition to cottonseed oil exhibited the best performance and smooth engine operation without any problem.

2.3 Performance and Emissions studies of other oils

In the investigation done by K. Pramanik [35], the high viscosity of the *Jatropha curcas* oil which has been considered as a potential alternative fuel for the compression ignition (C.I.) engine was decreased by blending with diesel. The

blends of varying proportions of jatropha curcas oil and diesel were prepared, analysed and compared with diesel fuel. The effect of temperature on the viscosity of biodiesel and jatropha oil was also studied. The performance of the engine using blends and jatropha oil was evaluated in a single cylinder C.I. engine and compared with the performance obtained with diesel. Significant improvement in engine performance was observed compared to vegetable oil alone. The specific fuel consumption and the exhaust gas temperature were reduced due to decrease in viscosity of the vegetable oil. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50% volume of jatropha oil. From the properties and engine test results it has been established that 40–50% of jatropha oil can be substituted for diesel without any engine modification and preheating of the blends.

There is a need for innovative thinking to stabilize the fuel consumption pattern as well as depletion rate of crude oil and natural gas resources. Also, there are concerns ranging from environmental degradation as a result of tremendous noxious tail pipe emissions (CO, SO_x, NO_x, HC, SPM, aromatic compounds etc.) to global warming due to emission of GHG (i.e. CO₂) from petrol & diesel driven vehicles. Thus there are strong incentives to adopt renewable energy in the form of biofuels- alcohols and biodiesels both, in transport sector in the service of the nation. In the research study ‘Methyl ester of Sunflower oil’ which is also popularly known as biodiesel, by Sudhir Ghai [36], was prepared by employing transesterification of sunflower vegetable oil with methanol and catalyst NaOH. 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.

Fuel crisis because of dramatic increase in vehicular population and environmental concerns have renewed interest of scientific community to look for alternative fuels of bio-origin such as vegetable oils. Vegetable oils can be produced from forests, vegetable oil crops, and oil bearing biomass materials. Non-edible vegetable oils such as linseed oil, mahua oil, rice bran oil, etc. are potentially effective diesel substitute. Vegetable oils have high-energy content. This study was carried out by Deepak Agarwal [37], to investigate the performance and emission characteristics of linseed oil, mahua oil, rice bran oil and linseed oil methyl ester (LOME), in a stationary single cylinder, four stroke diesel engine and compares it with mineral diesel. The linseed oil, mahua oil, rice bran oil and LOME were blended with diesel in different proportions. Baseline data for diesel fuel was collected. Engine tests were performed using all these blends of linseed, mahua, rice bran, and LOME. Straight vegetable oils posed operational and durability problems when subjected to long-term usage in CI engine. These problems are attributed to high viscosity, low volatility and polyunsaturated character of vegetable oils. However, these problems were not observed for LOME blends. Hence, process of transesterification is found to be an effective method of reducing vegetable oil viscosity and eliminating operational and durability problems. Economic analysis was also done in this study and it is found that use of vegetable oil and its derivative as diesel fuel substitutes has almost similar cost as that of mineral diesel.

An artificial neural network (ANN) modelling of a diesel engine using waste cooking biodiesel fuel to predict the brake power, torque, specific fuel consumption and exhaust emissions of the engine was studied by Ghobadian et al. [38]. To acquire data for training and testing the proposed ANN, two cylinders, four-stroke diesel engine was fuelled with waste vegetable cooking biodiesel and diesel fuel blends and operated at different engine speeds. The properties of biodiesel produced from waste vegetable oil was measured based on ASTM standards. The experimental results revealed that blends of waste vegetable oil methyl ester with diesel fuel provide better engine performance and improved emission characteristics. It can be concluded that R values are very close to one for torque, SFC, CO and HC, while the MSE error was 0.0004. Analysis of the experimental data by the ANN revealed that there is a good correlation between the predicted data resulted from the ANN and measured ones.

Gonzalez Gomez et al.[39] evaluated the exhaust emission and performance characteristics in a Toyota van, powered by a 2l indirect injection (IDI) naturally aspirated diesel engine, operating on vegetable based waste cooking oil methyl ester (WCOME). Exhaust emission results showed that lower levels of CO, CO₂, smoke (approximately 64%, 7.5% and 48% respectively) and SO₂ can be attained with WCOME. On the other hand, NO_x emissions were higher (approximately 20%) for WCOME. Engine performance was satisfactory for WCOME. The power developed by WCOME was higher (approximately 9%) than that for mineral diesel fuel at low speeds although it was lower at higher speeds. It seems that WCOME had better performance characteristics than mineral diesel fuel at low speeds. Polymerization of the lubricating oil did not occur. The viscosity was still in grade at the end of the trial. The wear metals were higher when the trial finished. WCOME is a good

option as alternative fuel due to the similarities with mineral diesel fuel and its improvement in exhaust emission levels. However, it is certain that further research into the reduction of NO emissions is needed.

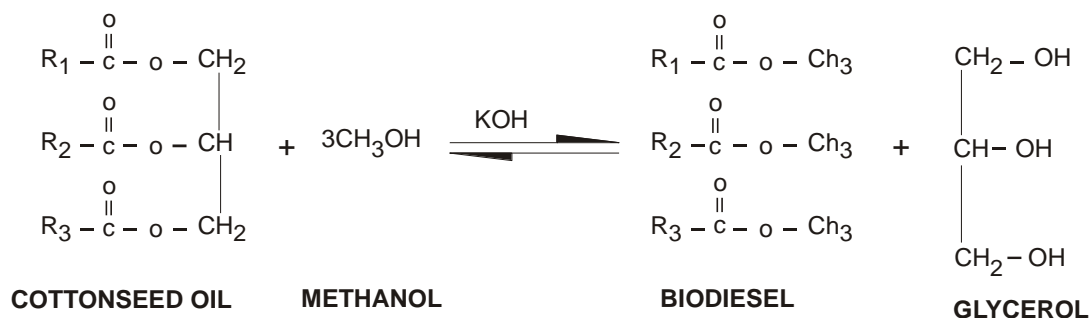
Biomass derived fuels are preferred as alternate fuels for I.C Engines due to their abundant availability and renewable nature. Fuels such as methanol and ethanol have proved to be suitable alternate fuels in the transport sector. In the present work the performance, emission and combustion characteristics of a single cylinder, constant speed, and direct injection diesel engine using orange oil as an alternate fuel were studied by K.Purushothaman [40] and the results are compared with the standard diesel fuel operation. Results indicated that the brake thermal efficiency was higher compared to diesel throughout the load spectra. Carbon monoxide (CO) and hydrocarbon (HC) emissions were lower and oxides of nitrogen (NO_x) were higher compared to diesel operation. Peak pressure and heat release rate were found to be higher for orange oil compared to diesel fuel operation

CHAPTER 3

BIODIESEL PRODUCTION

Biodiesel production is the process of producing the biofuels (biodiesel) through the chemical reactions and transesterification. This involves vegetable or animal fats and oils being reacted with short-chain alcohols (typically methanol or ethanol). Biodiesel is derived from vegetable oils or animal fats through transesterification[41]. Transesterification is also called alcoholysis, which uses alcohols in the presence of catalyst (e.g., base, acid or enzyme depending on the free fatty acid content of the raw material) that chemically breaks the molecules of triglycerides into alkyl esters as biodiesel fuels and glycerol as a by-product. The commonly used alcohols for the transesterification include methanol, ethanol, propanol, butanol, and amyl alcohol. Methanol and ethanol are adopted most frequently, particularly the former due to its low cost.

Commonly used vegetable oil for transesterification includes soybean oil, rapeseed oil, etc. In recent years, there exist active researches on biodiesel production from cotton seed oil [42], of which the conversion between 72% and 94% was obtained by enzyme catalyzed transesterification when the refined cottonseed oil reacted with short-chain primary and secondary alcohols. The application of solid acid catalysts on cottonseed oil transesterification was investigated by He *et al.* Chemical equation is given below:-



This chapter contains the details of biodiesel production methodology. In the present work biodiesel is produced from ultrasonic cavitation, conventional magnetic stirring, hydrodynamic cavitation and multi process reactor.

3.1 BIODIESEL PRODUCTION BY MECHANICAL STIRRING

Conventional mechanical stirring machine consist of temperature controller to control temperature within the range of 50-60°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.

3.1.1 Experimental Set-up

The transesterification reactions were carried by conventional mechanical stirring method, photograph is shown in Figure 3.1 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 CSO (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 NAOH was poured into the beaker. The magnetic stirrer due to its stirring action enhances the transesterification reaction.

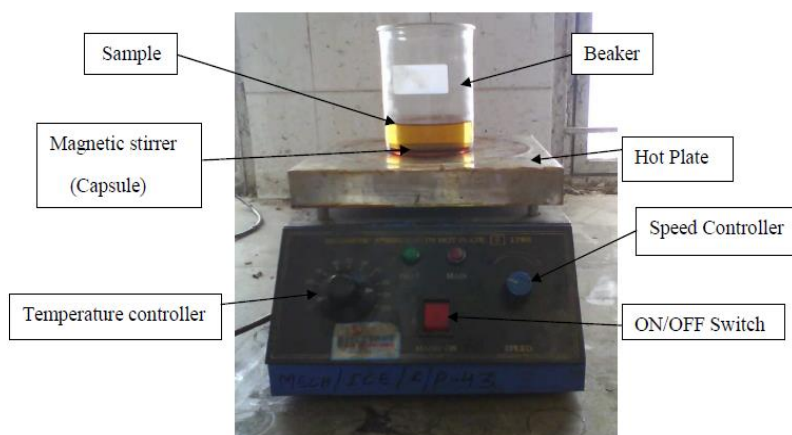


Figure 3.1 Mechanical stirrer

3.1.2 Reagents and Material used

1. CSO, 400g
2. Methyl alcohol (CH_3OH) (99% pure).
3. Base catalyst (NAOH) (85% pure) for accelerating the reaction mixture.

3.1.3 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. CSO (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 60⁰C temperature for the next step.

2. Now methyl alcohol (CH₃OH) is taken with a molar ratio of (1:4.5 & 1:6) and Catalyst (NAOH) is taken as (0.5%, 0.75% and 1% by weight of oil).The mixer of methyl alcohol and NAOH stirred until NAOH dissolve in methyl alcohol.
3. This mixture is poured in CSO. 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 within 55-60⁰C.
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 hour 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 50⁰C is mixed with the methyl ester and left for settling down. Water due to its higher specific gravity collected at bottom, which is drained out and remaining is removed by heating the biodiesel.



Figure 3.2: Washing process of biodiesel

3.1.4 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 3.1.

Table 3.1 Oil, alcohol and catalyst during the experimentation

Molar ratio (alcohol/ oil)	Quantity of CSO (g)	Quantity of methanol (g)	Catalyst (NAOH)		
			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 oil = 870

Molecular weight of methanol = 32

Hence, 1 gm mole of oil = 870 gm

And 1 gm mole of methanol = 32 gm

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

Amount of methanol for 100 g of vegetable oil

- For 1:6 molar ratio = $(32 / 870) \times 400 \times 6 = 88 \text{ g}$
- For 1:4.5 molar ratio = $(32 / 870) \times 100 \times 4.5 = 66.24 \text{ g}$

Sample Calculation for yield

Quantity of CSO oil taken = 400 gm

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

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

Quantity of biodiesel produced = 372.43 gm (say)

Yield % = (Quantity of biodiesel produced/Quantity of oil taken)*100
 = $(372.43 / 400) \times 100$
 = 93.11%

Time and yield produced for CSO

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 for time and yield of methyl ester for waste cooking oil and catalyst (%) of oil is shown in the table 3.2

Table 3.2 Time and yield (%) of CSO (Magnetic Stirring)

Percentage catalyst (%)	Time (min)	Molar ratio 6:1	Molar ratio 4.5:1
		Yield (%)	Yield (%)
0.5	30	84.5	82.45
	45	85.95	84.63
	60	88.18	85.95

	75	92.61	82.45
0.75	30	88.28	84.63
	45	92.64	85.95
	60	94.58	88.42
	75	95.5	84.5
1	30	89.46	89.92
	45	93.12	92.50
	60	94.95	93.2
	75	95.90	88.2

3.2 BIODIESEL PRODUCTION BY ULTRASONIC CAVITATION

3.2.1 Principle

Principle 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 immiscible 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 results in emulsification of mixture. In cavitation process small bubbles are formed in liquids at mechanically weak points, usually at phase boundaries, as a result of intense vibrations. 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. 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.

3.2.2 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 3.3, 3.4 and 3.5, 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 CSO (400 g) was poured into the beaker at the beginning. Now the proper quantity of methanol and NAOH solution is mixed as per molar ratio in the heated CSO. After mixing the solution of oil, methanol and NAOH is kept under ultrasonic horn with sufficient probe tip dipped in the solution without touching the boundaries of the beaker. Now the reaction is carried out by ultrasonic irradiation produced by ultrasonic generator through the transducer incorporated with acoustic rod horn.

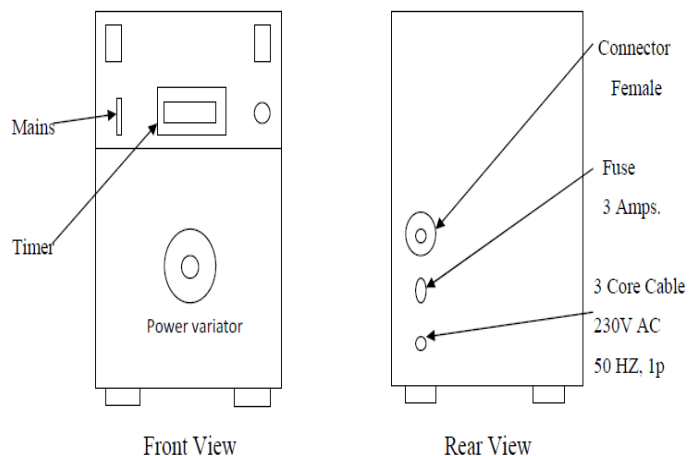


Fig3.3 Ultrasonic Generator

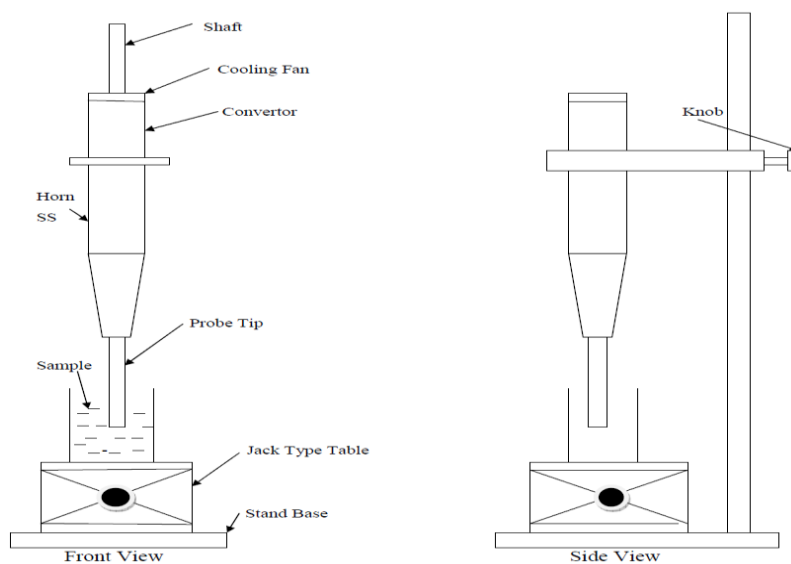


Fig3.4 Ultrasonic Processor Horn mounted on stand with Jack type table.

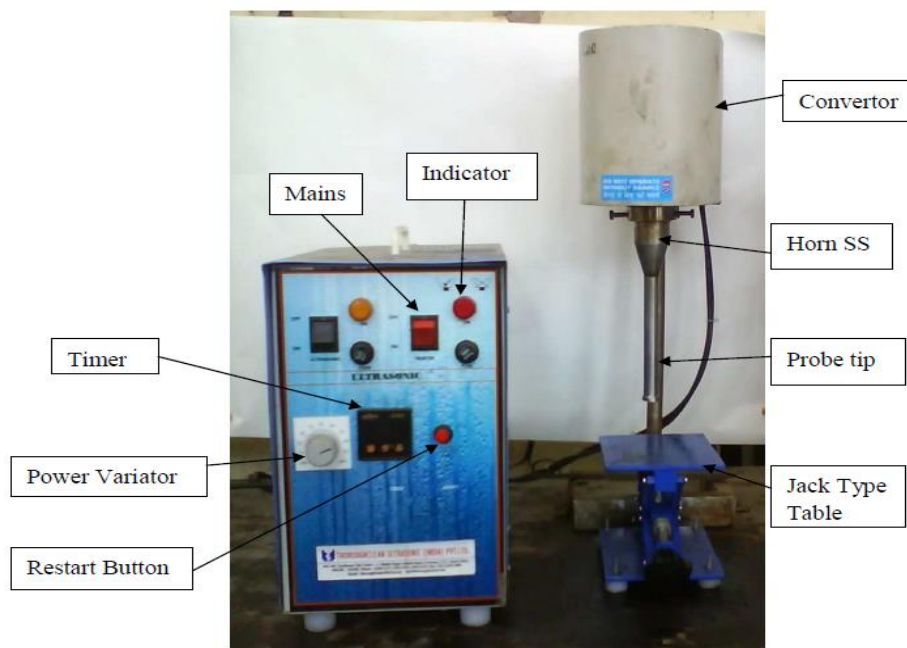


Fig3.5 Ultrasonic horn type processor

3.2.3 Reagents and Materials used

1. CSO 400g/sample for preparing experimental biodiesel sample.
2. Methyl alcohol (CH_3OH) (99% pure).
3. Base catalyst (NaOH) (85% pure) for accelerating the reaction mixture.

3.2.4 Experimental Procedure

There are following steps:

1. CSO (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 60°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 (NaOH) is taken as 0.5%, 0.75% and 1% by weight of oil. Then

mixer of methyl alcohol and NaOH is stirred until NaOH is completely dissolved in methyl alcohol.

3. This solution of methyl alcohol and NaOH 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 50°C is mixed with the methyl ester and left for settling down will take 2-4 hrs. Water due to its higher specific gravity collected at bottom.
10. Excess methanol present in biodiesel can be removed by distillation process. This methanol can be again reused for transesterification process.
11. Finally separated biodiesel is water washed and heated to remove moisture present in it due to washing

3.2.5 Experimental Results

Time and yield of methyl ester for CSO and catalyst (%) of oil is shown in tables 3.3 for molar ratio 4.5:1 and 6:1 is given below.

Table 3.3 Time and yield (%) of CSO for Ultrasonic cavitation

Percentage catalyst (%)	Time (min)	Molar ratio 6:1	Molar ratio 4.5:1
		Yield (%)	Yield (%)
0.5	30	82.45	80.69
	45	84.26	84.26
	60	86.21	86.32
	75	89.26	89.63
0.75	30	82.43	86.93
	45	90.86	91.25
	60	95.82	95.32
	75	97.04	96.34
1	30	89.06	88.93
	45	93.64	93.63
	60	96.29	95.24
	75	97.82	96.32

Similar to magnetic stirring method 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 97.82% at 1% KOH for 6:1 molar ratio in 75 minutes.

3.3 BIODIESEL PRODUCTION BY HYDRODYNAMIC CAVITATION

3.3.1 Principle

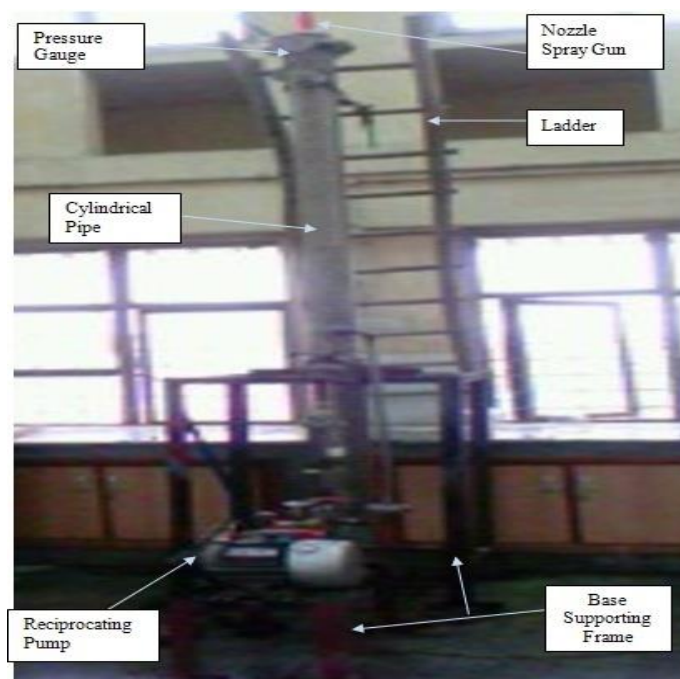
The principle of hydrodynamic cavitation machine resembles the ultrasonic cavitation method as the fundamental of working is cavitation phenomena. In the cavitation process small bubbles are formed in liquids at mechanically weak points, usually at phase boundaries, as a result of intense sonication. 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.

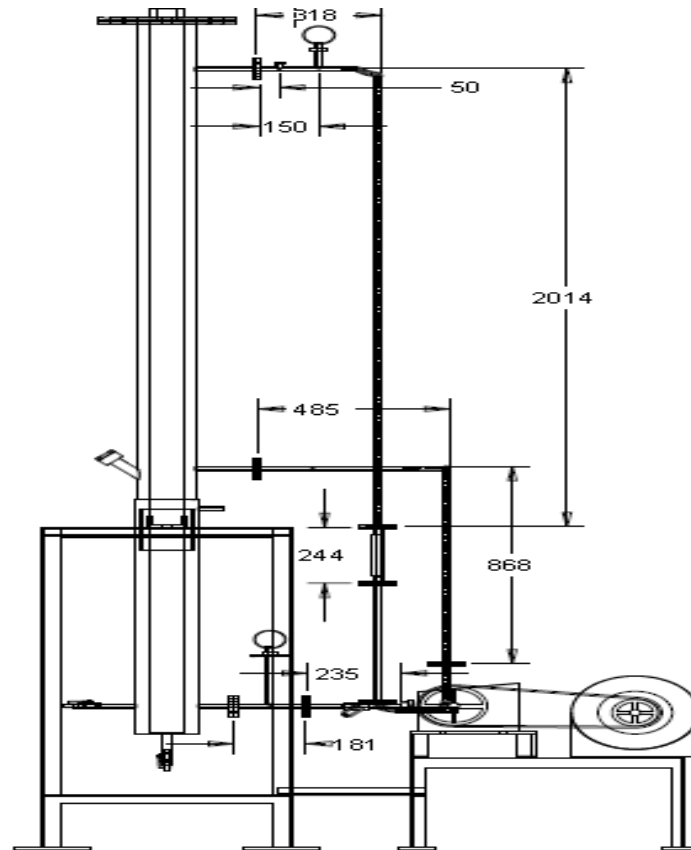
3.3.2 Experimental Set-up

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. A reciprocating pressure pump is being used in modeling of hydrodynamic cavitation machine with plunger diameter 3*18 mm, working pressure 15.25 kgcm² required motor of range 5 to 1.5 hp having speed range 800 to 1000 rpm. 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 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 apparatus is shown in Fig. 3.6.

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.





*All dimensions are in mm

Figure 3.6 Hydrodynamic cavitation experimental set up (2-10 kg)

3.3.3 Reagents and Materials used

1. CSO
2. Methyl alcohol (CH_3OH) (99% pure).
3. Base catalyst (NaOH) (85% pure) for accelerating the reaction mixture.

3.3.4 Experimental procedure

1. CSO (2500g) is taken in a beaker and filtered it to remove impurities.
2. Then repeat the same methods from step 1 to 3 as given in previous section.
3. Open fully bypass valve before starting.
4. Check out that all the line valves should be open and drain valve should be closed.

5. Pour the solution prepared through inlet manifold.
6. Maintain the pressure up to 10 bar in the pressure gauge and flow rate 8.5 LPM. Reciprocating pressure pump is responsible to generate high pressure inside the chamber.

3.3.5 Experimental Results

Time and yield of methyl ester for CSO and catalyst (%) of oil is shown in tables 3.3 for molar ratio 4.5:1 and 6:1 is given below.

Table 3.4: Time and Yield (%) of CSO for Hydrodynamic cavitation

Percentage of catalyst	Time (min)	Molar ratio 6:1	Molar ratio 4.5:1
		Yield	Yield
0.5	30	93.06	84.24
	45	93.42	85.28
	60	95.27	86.84
	75	97.98	87.88
0.75	30	93.42	93.61
	45	95.82	96.26
	60	97.37	96.96
	75	98.38	97.16
1	30	94.22	93.81
	45	96.35	96.40
	60	97.51	96.45
	75	98	97.21

3.4 Biodiesel Production by Hybrid Reactor

In this work an approach has been proposed to make the biodiesel through all three processes described in previous sections 3.1, 3.2 and 3.3. It is designed to enhance the reliability of the system, so that all these process can be simultaneously used to make the biodiesel from non-edible oils. In proposed set up research data for all the three process, operating each one at a time can be generated and further data for their parallel processing in different combinations i.e. process MS+HDC, process MS+UC, process UC+HDC, process MS+HDC+UC can be generated.

In first installment of the project proposed reactor has been made for the Mechanical Stirring and Hydrodynamic Cavitation processes. The reactor is capable of processing the biodiesel from 15-100 kg non-edible oils. Actual reactor and its drawing is shown in Figure 3.7. The same reactor has the provision of up gradation by attaching the unit for Ultrasonic Cavitation. Biodiesel samples have been made with CSO using 6:1 and 4.5:1 molar ratio and 0.5, 0.75 and 1 % KOH catalyst. The set-up consists of a closed loop circuit comprising a oil heating tank, mechanical stirring tank, reciprocating pump (maximum pressure 600 psi, 3HP, 950 RPM), a control valve and a coupling to accommodate the orifice plate. The suction side of the pump is connected to the bottom of the mechanical stirring tank. Discharge from the pump branches into two lines, which helps in the control of inlet pressure and inlet flow rate into the main line housing and the orifice with the help of valves. The main line consists of a coupling to accommodate the orifice plate. The diameter of orifice hole was 1 mm. The liquid in the main line after undergoing cavitation process is feedback to the mechanical stirring tank where mechanical stirring of rest of the liquid is going on. The liquid again goes to the reciprocating pump and continuous circulation of liquid takes place in a closed loop circuit. The test rig also serves the purpose of individual mechanical stirring and hydrodynamic cavitation. In case of individual mechanical stirring the mixture is not allowed to pass through

reciprocating pump by closing the valve between mechanical stirring tank and reciprocating pump. In case of individual hydrodynamic cavitation reactor the motor operating mechanical stirrer is switched

There is a appreciable increase by parallel processing. The results are shown in table 3.11, 3.12 and 3.13. production yield for CSO is graphically represented in Fig 3.9, Fig. 3.10 and Fig 3.11.

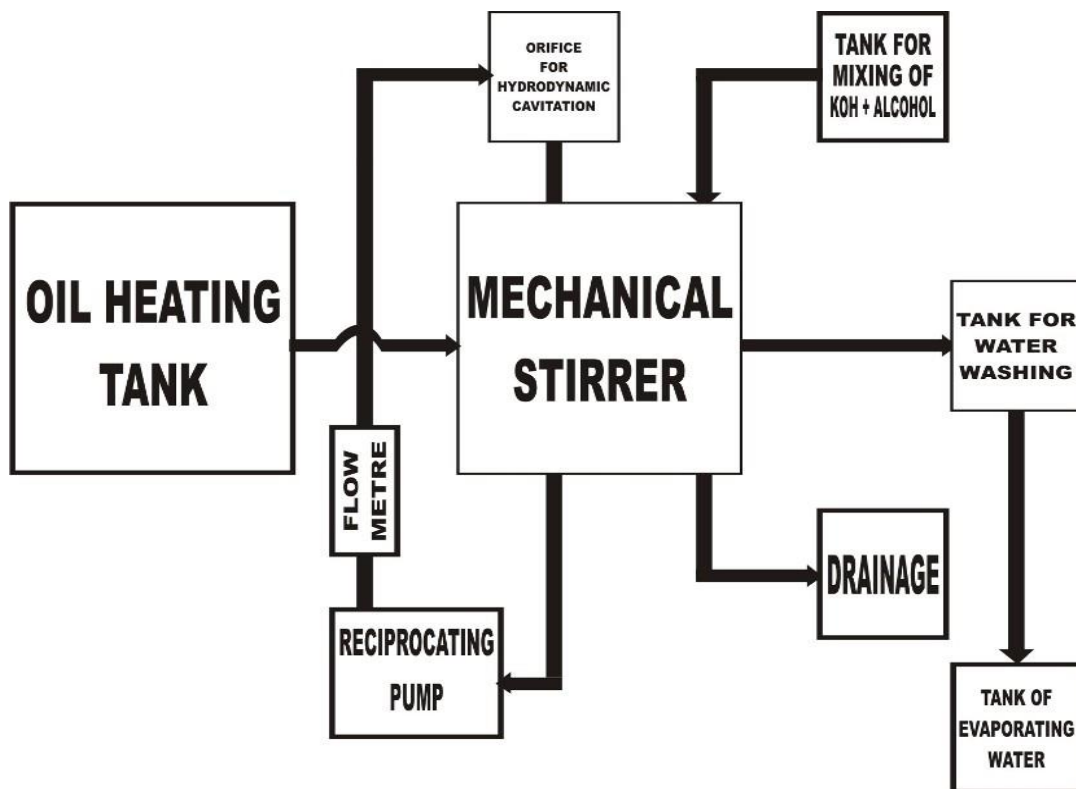


Figure 3.7 Block diagram for Hybrid Reactor



Figure 3.8 Hybrid Reactor (15-100Kg capacity)

Table 3.5 CSO BD Yield observed at various reaction times for molar ratio of 6:1 and 0.5% catalyst

CSO (kg)	Methanol Consumed (gm)	Catalyst consumed (i.e. 0.5 w/w% (i.e. 75 gm))	Reaction time (in min)	Yield (%) MS	Yield (%) HDC	Yield (%) MS + HDC
15	3312	0.5 w/w% (i.e. 75 gm)	30	75.3	80.1	83.5
			45	78.1	83.3	90.8
			60	84.3	90.7	94.6
			75	91.3	94.7	95.8

Table 3.6 CSO BD Yield observed at various reaction times for molar ratio of 6:1 and 0.75% catalyst

CSO (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time (in min)	Yield (%)	Yield (%)	Yield (%)
				MS	HDC	MS+HDC
15	3312	0.75 w/w% (i.e.112.5 gm)	30	78.2	82.8	85.4
			45	80.8	87.8	94
			60	86.84	93.2	95.8
			75	94.68	96.1	97.6

Table 3.7 CSO BD Yield observed at various reaction times for molar ratio of 6:1 and 1% catalyst

CSO (kg)	Methanol Consumed (gm)	Catalyst consumed	Reaction time	Yield (%)	Yield (%)	Yield (%)
			(in min)	MS	HDC	MS+HDC
15	3312	1 w/w% (i.e.150 gm)	30	80	84.6	87.1
			45	82.4	89.1	94.6
			60	87.9	95.3	97.5
			75	95.2	96.9	98.3

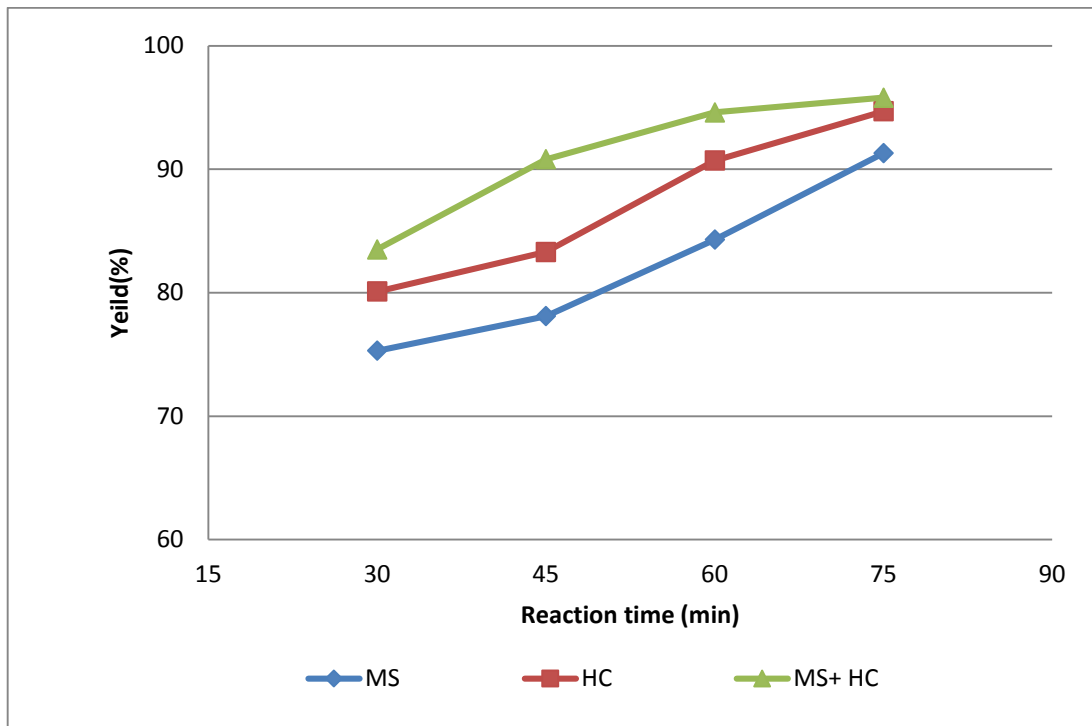


Fig. 3.9 Biodiesel conversion yield at 0.5% NaOH by weight of oil.

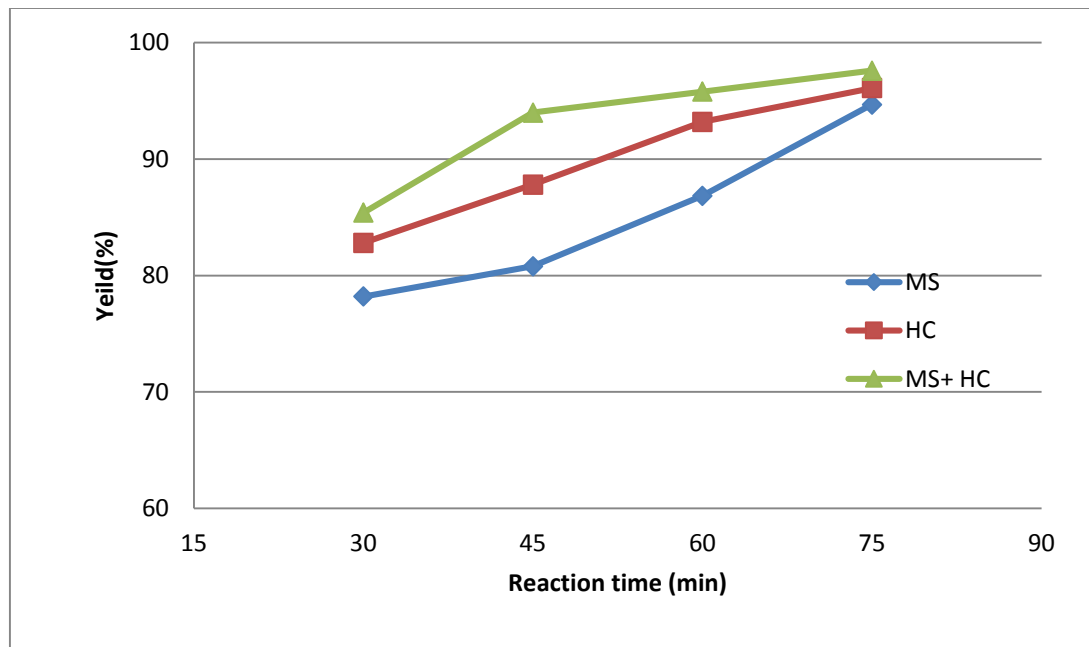


Fig. 3.10 Biodiesel conversion yield at 0.75% NaOH by weight of oil.

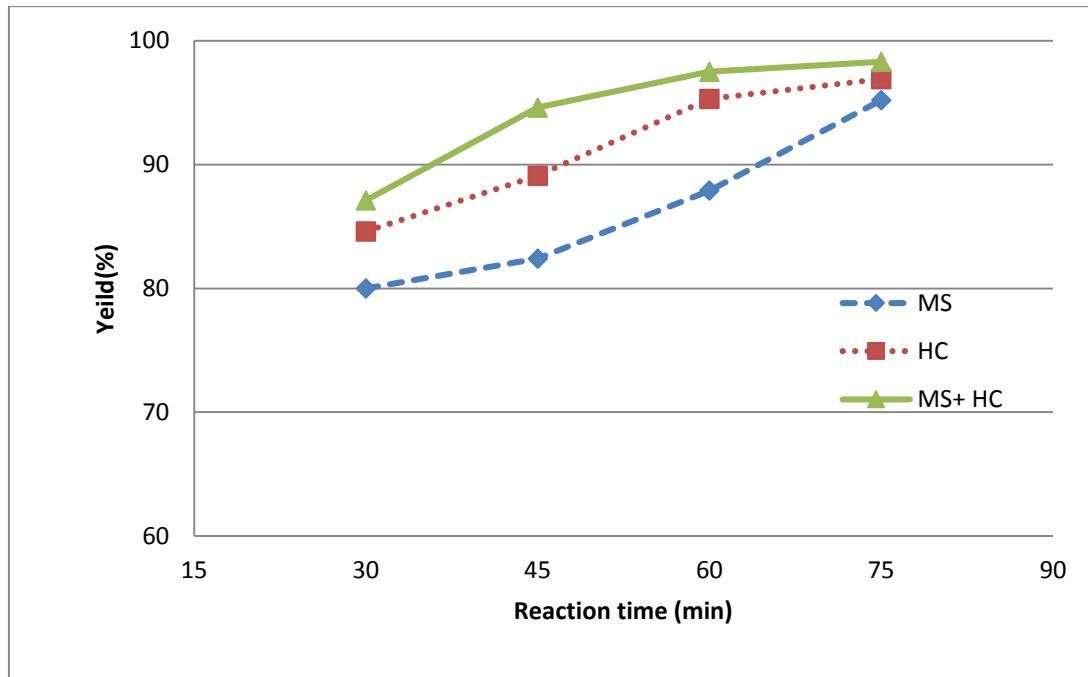


Fig. 3.11 Biodiesel conversion yield at 1% NaOH by weight of oil.

- Higher yield was obtained for combined hydrodynamic cavitation and mechanical stirring process as compared to hydrodynamic cavitation or mechanical stirring alone.
- Percentage increase in yield was maximum for 45 minutes sample for all the concentrations of catalyst.
- Considerable improvement of biodiesel yield is observed when increasing the percentage of catalyst from 0.5% to 0.75% for all the processes. However a small improvement of biodiesel yield is observed when increasing the percentage of catalyst from 0.75% to 1% for all the processes. This may be attributed to low FFA content of CSO.

CHAPTER 4

ECONOMIC ANALYSIS OF BIODIESEL PRODUCTION

4.1 ECONOMICS OF BIO-DIESEL

The term ‘‘Life Cycle Assessment’’ is used to assess the total environmental performance of a product all along its lifetime, often referred as from ‘cradle to grave’. Other terms, such as life cycle analysis and eco-balance, are also used. When talking about fuels, the proper term in use is ‘‘Well-to-Wheel (WTW) Analysis’’. Similarly in case of minerals, ‘‘Mine-to-Mill Analysis’’ is carried out. In order to be able to examine the complete cycle of a transport fuel, the analysis is often divided into following five stages:

- Feedstock production.
- Feedstock transportation.
- Fuel production.
- Fuel distribution.
- Vehicle use.

These stages can be divided even further into a Well-to-Tank (WTT) and Tank-to-Wheel (TTW) portions of the WTW analysis. The WTT analysis considers the fuel from resource recovery to the delivery to the vehicle tank, i.e., the feedstock production, transportation, fuel production and fuel distribution. The TTW analysis

considers the fuel economy, i.e., the vehicular use of the fuel. This way, the WTW analysis integrates WTT and TTW into a complete fuel history.

4.2 COST ESTIMATION OF BIODIESEL PRODUCTION

COST OF RAW MATERIALS

Cost of CSO

Assuming the market Price of CSO = Approx. 40 / Kg

Requirement of CSO per day = 800 Kg

Requirement of CSO for a month = $800 * 25 = 20000$ Kg

Cost of CSO for a month = Rs. $40 * 25 * 800 = 800,000$ Rs

Cost of Methanol

Price of 1Kg of Methanol is Rs. 40

Daily requirement of Methanol = 176 Kg

Cost of Methanol for a month = $176 * 25 * 40 = 176,000$ Rs

Cost of KOH

Price of 1Kg of KOH = Rs. 300 / Kg

Daily requirement of KOH = 8 Kg

Cost of KOH for a month = $8 * 25 * 300 = 60,000$ Rs

Cost of Water

Monthly requirement of water for water washing = $0.3 * 20000 = 6000$ Kg

Cost of water for a month = $6000 * 0.25 = 1500$ Rs

Total raw material cost for a month = 10,37,500 Rs

ELECTRICITY COST

Assumptions:

- 1KWh of electricity = Rs. 7/-(for industrial uses)
 - Specific heat of CSO is 1.97 KJ/Kg K
 - Specific heat of water is 4.2 KJ/Kg K
 - Heat loss due to radiation, convection = 10%
 - Power of heater is 40 KW.
 - 25 Working day in a month.
 -
- 1) Electricity cost for heating oil from 20⁰ C to about 120⁰ C.

$$Q = m \cdot C_p \cdot \Delta T / \text{efficiency}$$

$$= 100 \text{ kg} \cdot 1.97 \cdot (120-20) / 0.9$$

$$= 21888.89 \text{ KJ}$$

$$\text{Heating duration} = 21888.89 / 40$$

$$= 547.22 \text{ sec or } 10 \text{ min (approx.) required to reach } 120 \text{ }^\circ\text{C.}$$

$$\text{Electricity cost} = 1/6 \text{ h} \cdot 40 \text{ KW} \cdot 7$$

$$= 46.67 \text{ Rs / batch of } 100 \text{ Kg oil}$$

$$= 46.67 \cdot 8 \cdot 25 \text{ per month}$$

$$= 9334 \text{ Rs / month}$$

2) Electricity cost for stirring alcohol and catalyst

Assumptions

- Power of motor is 7.2 KW
- We stir the solution for 10 minutes in 7 batches of 25 Kg each

Electricity cost per batch = $7.2 \text{ KW} * 1/6 \text{ hr} * 7 = 8.4 \text{ Rs}$

Electricity cost per month = $8.4 * 7 * 25 = 1470 \text{ Rs}$

3) Electricity cost for stirring alcohol and catalyst mixture with CSO for 30 minutes

Assumption

- Power of motor is 10 KW
- We stir the solution for 30 minutes

Electricity cost per batch of $(100+22+1=123) \text{ Kg}$ of mixture

$$= 10 \text{ KW} * \frac{1}{2} \text{ hr} * 7 = 35 \text{Rs}$$

Electricity cost per month = $35 * 8 * 25 = 7000 \text{ Rs}$

4) Maintenance of temperature during mechanical stirring

Tank in which mechanical stirring is taking place is insulated but still radiation losses takes place and even convection losses cannot be neglected.

Cost of maintaining temperature of about 60°C is assumed to be 900 Rs per month.

5) Electricity cost for heating water 20°C to 80°C for water washing

$$Q \text{ (for 30 Kg batch)} = m \cdot C_p \cdot \Delta T / \text{efficiency}$$
$$= 30 * 4.2 * 60 / 0.9 = 8400 \text{ KJ}$$

Power of heater is 10 KW

Heating duration = $8400 / 10 = 840 \text{ sec}$ or 0.233 hr

Electricity Cost per batch = $\text{Rs. } 0.233 * 10 * 7 = \text{Rs. } 16.33$

Electricity Cost per month = $16.33 * 8 * 25$

$$= 3267 \text{ Rs}$$

- 6) Electricity cost for final heating of sample to 120°C for removing water if present

Assume this cost to be 9000 Rs.

Total electricity cost involved is

$$= \text{Rs. } (9334 + 1470 + 7000 + 900 + 3267 + 9000) = \text{Rs. } 30,971$$

APPARATUS COST

Total cost of apparatus and equipments is about 200000 Rs

Assuming these equipments works for 10 yrs and taking 6% interest rate

Equipment cost for a month Rs. 2670 (approx.)

MISCELLANEOUS COST

Miscellaneous cost is as shown in Table 4.1

Table 4.1 Miscellaneous cost in biodiesel production

Purpose	Cost per month (Rs.)
Transportation Cost	8,000
Labour Cost	20,000
Rent Cost	2,000
Maintenance Cost	1,000
Manufacturing Unit Establishment Cost	2,500

Net Miscellaneous Cost = Rs. 33,500 for a month.

RECOVERABLE COST

- From the stoichiometry of the chemical reaction, we know that methanol is required in the ratio of 3:1. However, to shift the equilibrium of the chemical reaction towards the product (biodiesel) side, we used methanol in the ratio of 6:1.
- The extra methanol used can't be recovered 100% mainly due to evaporation.
- We take 3.75:1 as the consumed ratio of alcohol.
- So, in a reaction 37.5% methanol is recovered
- Methanol recovered = 1650 Kg
- Therefore, net recoverable cost of methanol

$$= 1650 * 40 = \text{Rs. } 66000/ \text{ month.}$$
- Glycerol obtained after completion of reaction is about 10% of oil (20,000Kg), and cost of 1Kg of glycerol is Rs. 40.
- Therefore, **net cost of glycerol = 2,000 * 40 = Rs. 80,000 / month.**

Table 4.2 Total Production Cost of Bio-Diesel

S. No.	Purpose of Expenses	Total Cost per Month (Rs.)
1.	Raw material cost	1,037,500
2.	Electricity Cost	30,971
3.	Apparatus & Equipment Cost	2670
4.	Miscellaneous Cost	33,500
5.	Recoverable Cost	144,000
	Total Cost	Rs. 960,641/-

Cost of Bio-Diesel for One Unit

For 90% yield of biodiesel from the CSO

Cost of Biodiesel for 1Kg. = Rs. 960,641 / 18,000 Kg = Rs. 53.37

Net Bio-Diesel Cost = Rs. 53.37/Kg.

Cost of CSO = Rs. 40/Kg.

Therefore net processing Cost = Rs. 13.37/Kg.

Assume 15% distribution cost, dealer commission etc.

Therefore, **Total Cost of Bio-Diesel of 1Kg. = Rs. 61.4/-**

CHAPTER 5

PERFORMANCE AND EMISSION STUDIES

5.1 Experimental Setup of single cylinder Kirloskar Engine

The setup consists of single cylinder, four strokes, Diesel engine connected to eddy current type dynamometer for loading is used with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for P- θ & P-V diagrams. Sensors are used interfacing airflow, fuel flow, temperatures and load measurement. The setup has standalone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables varying the compression ratio for measurement of engine performance parameters like 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. Lab view based Engine performance Analysis software package “Engine soft LV” is used for on line performance evaluation. A computerized diesel injection pressure sensor is used for the measurement of combustion chamber pressure.

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

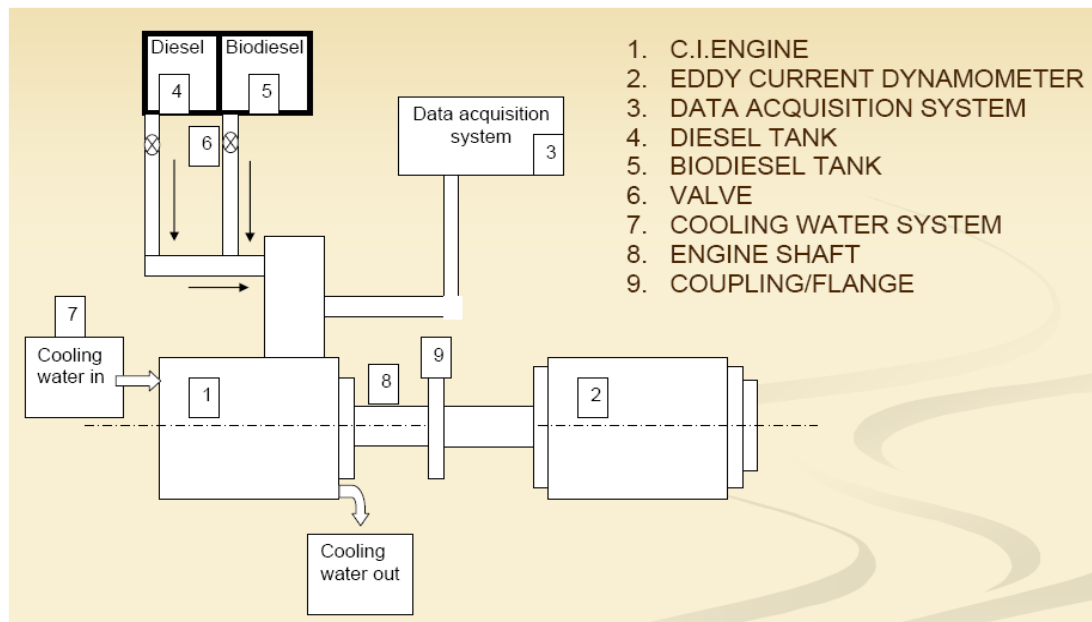


Figure 5.1 Schematic Layout of Single Cylinder Engine Setup



Figure 5.2 Actual Engine Setup

Setup 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,
Dynamometer	Type eddy current, water cooled, with loading unit

Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 lit with glass fuel metering column
Calorimeter	Type Pipe in pipe
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 550 RPM with TDC pulse
Digital milivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Input RTD PT100, Range 0–100 °C, Output 4– 20 mA and Type two wire, Input Thermocouple, Range 0–1200 °C,
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Rota meter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Software	“Engines of tLV” engine performance analysis software
Overall dimensions	W 2000 x D 2500 x H 1500 mm
Smoke meter	Make AVL, for opacity measuremet

Smoke Meter

This smoke meter works on the light extinction principle. 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. The 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 the average projected area of each particles; and θ the specific absorbance per particle.



Figure 5.3 An AVL Smoke meter

5.2 Preparation of biodiesel blends

On this engine experiments are performed with different blends of biodiesel (pure diesel, B-20, B-40, and B-60). These blends are prepared in quantity of 1 litre

each by mixing required quantity of biodiesel in petroleum diesel. There description is shown in Table 4.1

Calorific value of petroleum diesel = 43000 kJ/kg.

Calorific value of biodiesel = 41680 kJ/kg.

Density of petroleum diesel = 821 kg/m³.

Density of biodiesel = 850 kg/m³.

Table 5.1 Details of different blends of biodiesel

Type of blend	Amount of biodiesel (ml)	Amount of diesel(ml)	Resultant calorific value (kJ/kg)	Resultant density (kg/m ³)
Diesel	1000	0	43000	821
B-20	800	200	42736	826.8
B-40	600	400	42472	832.6
B-60	400	600	42208	838.4

5.3 Performance Evaluations

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, BSFC, heat balance. During the test engine load was varied from 0 to 14 kg by adjusting the load knob provided on the control panel of the test rig while maintaining a constant engine speed of about 1500 rpm. The tests CSO biodiesel production, performance, and emissions study on C.I engine were performed with pure diesel fuel and biodiesel blends (B-20, B-40,B-60). Biodiesel blends of CSOME (cottonseed oil methyl ester) were used.

Formulation used for calculation of various parameters are described below

$$\text{Torque (kg m)} = \text{Load} \times \text{Arm length}$$

$$\text{Brake power (kW)} = (2 \times \pi \times \text{Speed} \times \text{Torque} \times 9.81) / (60 \times 1000)$$

$$\text{Brake Thermal Efficiency(\%)} = \frac{\text{Brake Power} \times 3600 \times 100}{\text{fuel flow} \left(\frac{\text{kg}}{\text{hr}} \right) \times \text{calorific value} \left(\frac{\text{kJ}}{\text{kg}} \right)}$$

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

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

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

Heat balance (kJ/h):

$$\text{Heat supplied by fuel (kJ/h)} = \text{fuel flow (kg/h)} \times \text{Calorific value (kJ/kg)}$$

$$\text{Heat equivalent to useful work (kJ/h)} = \text{Break power (kW)} \times 3600$$

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

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

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

Heat in Exhaust (calculate C_p ex value):

$$C_{p \text{ ex}} = \frac{F_4 \times C_p \times (T_4 - T_3)}{(F_1 + F_2) \times (T_5 - T_6)}$$

Where,

$C_{p \text{ ex}}$ Specific heat of exhaust gas (kJ/kg $^{\circ}\text{C}$).

C_{pw} Specific heat of water (kJ/kg $^{\circ}\text{C}$).

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 ($^{\circ}C$).
T_1	Engine water inlet temperature ($^{\circ}C$).
T_2	Engine water outlet temperature ($^{\circ}C$).
T_3	Calorimeter water inlet temp ($^{\circ}C$).
T_4	Calorimeter water outlet temp ($^{\circ}C$).
T_5	Exhaust gas to calorimeter inlet temp ($^{\circ}C$).
T_6	Exhaust gas from calorimeter outlet temp ($^{\circ}C$)

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

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

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

5.4 Results of the performance testing

Fig. 5.4 to 5.9 shows performance characteristics at variable load conditions at different compression ratios for neat diesel and diesel-CSOME blends (B-20, B-40 and B-60).

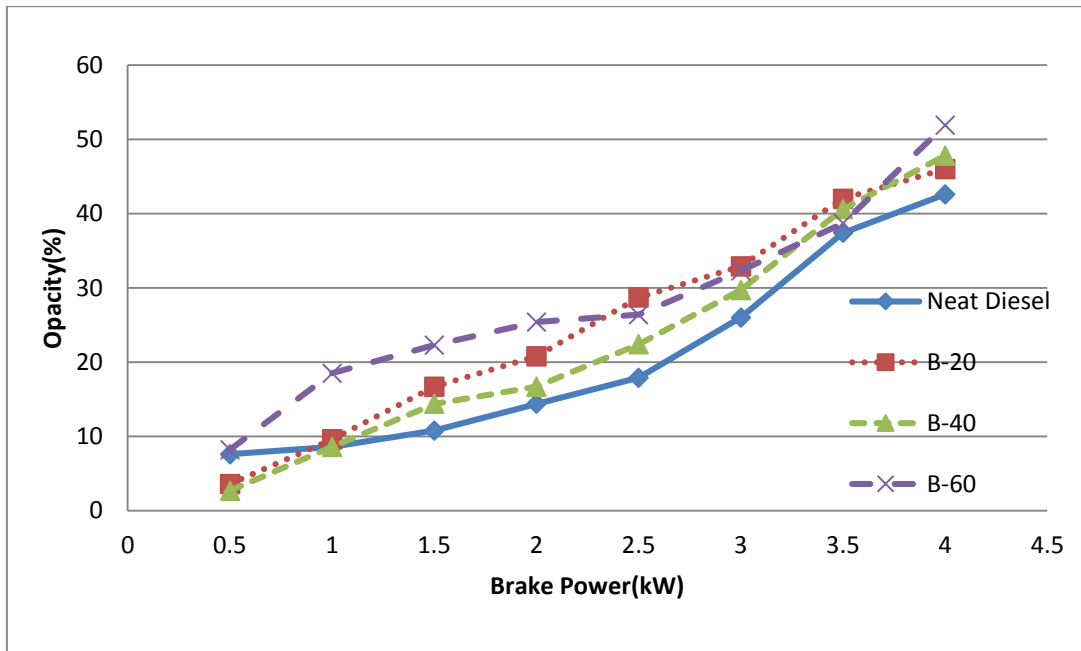


Figure 5.4 Comparison of Opacity v/s Brake Power for diesel and CSO biodiesel at 16 compression ratio

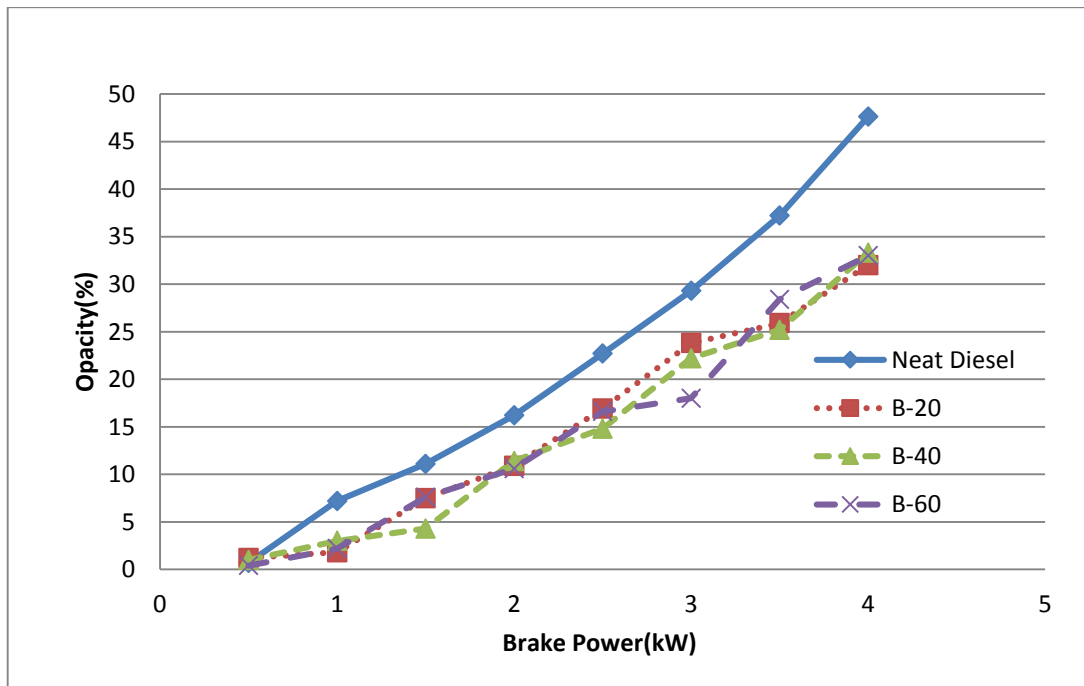


Figure 5.5 Comparison of Opacity v/s Brake Power for diesel and CSO biodiesel blends at 18 compression ratio

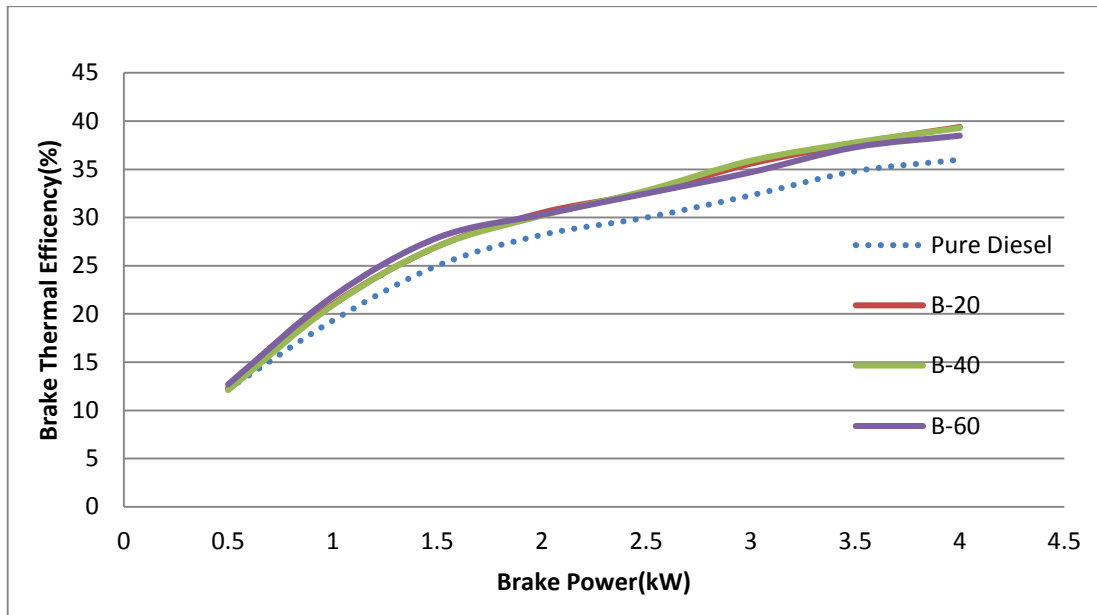


Figure 5.6 Comparison of BTE v/s Brake Power for diesel and CSO biodiesel blends at 18 compression ratio

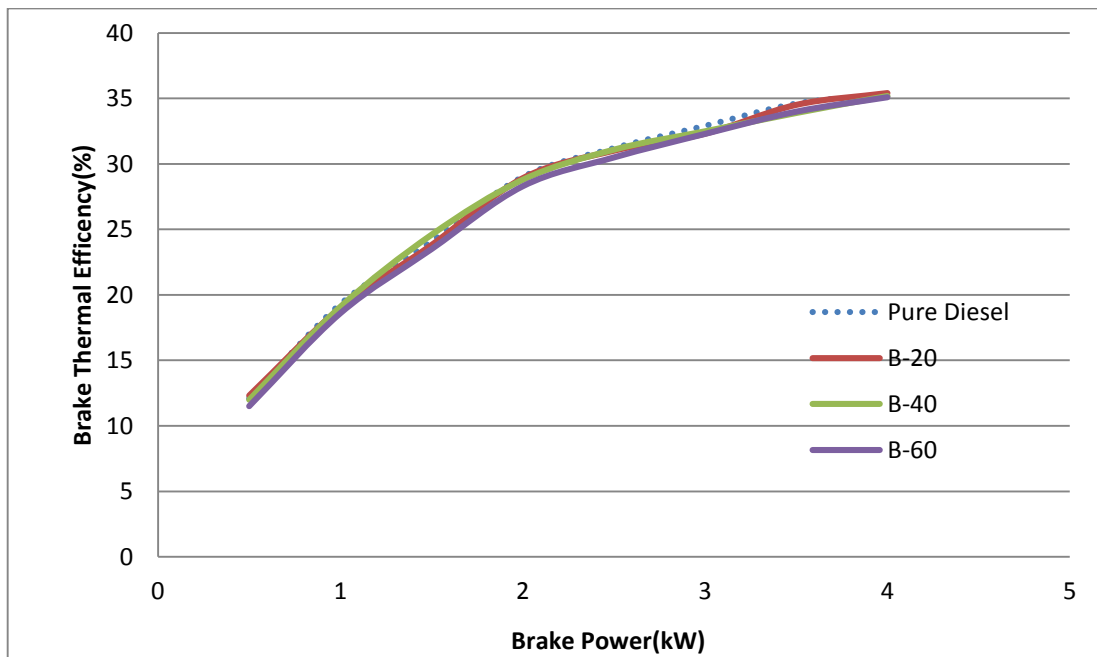


Figure 5.7 Comparison of BTE v/s Brake Power for neat diesel and CSO biodiesel blends of at 16 compression ratio

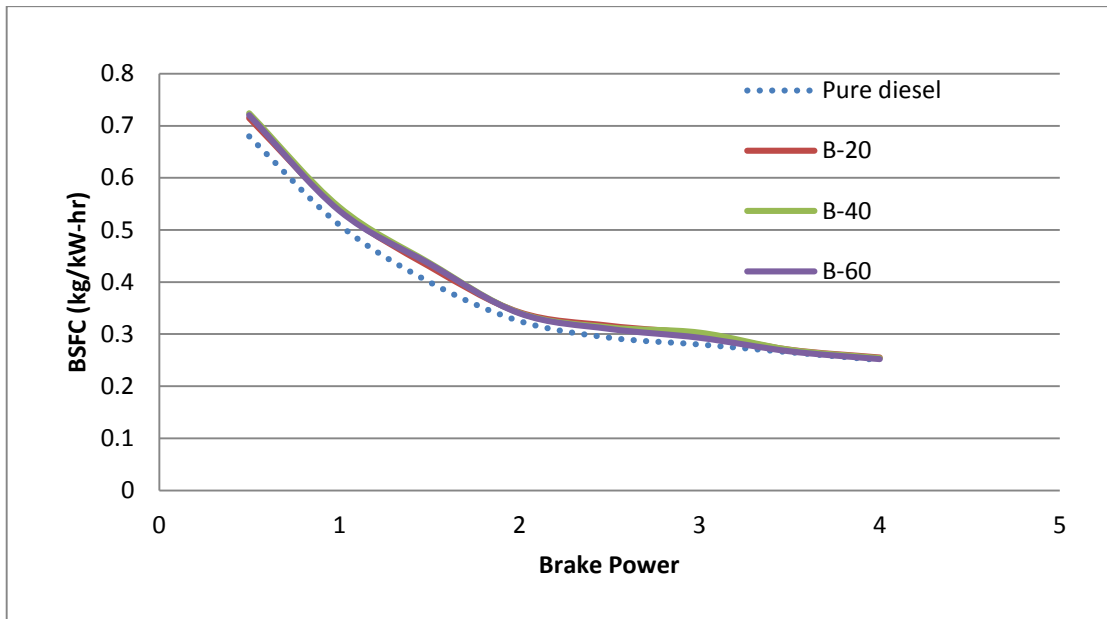


Figure 5.8 Comparison of BSFC v/s Brake Power for diesel and CSO biodiesel blends at 18 compression ratio

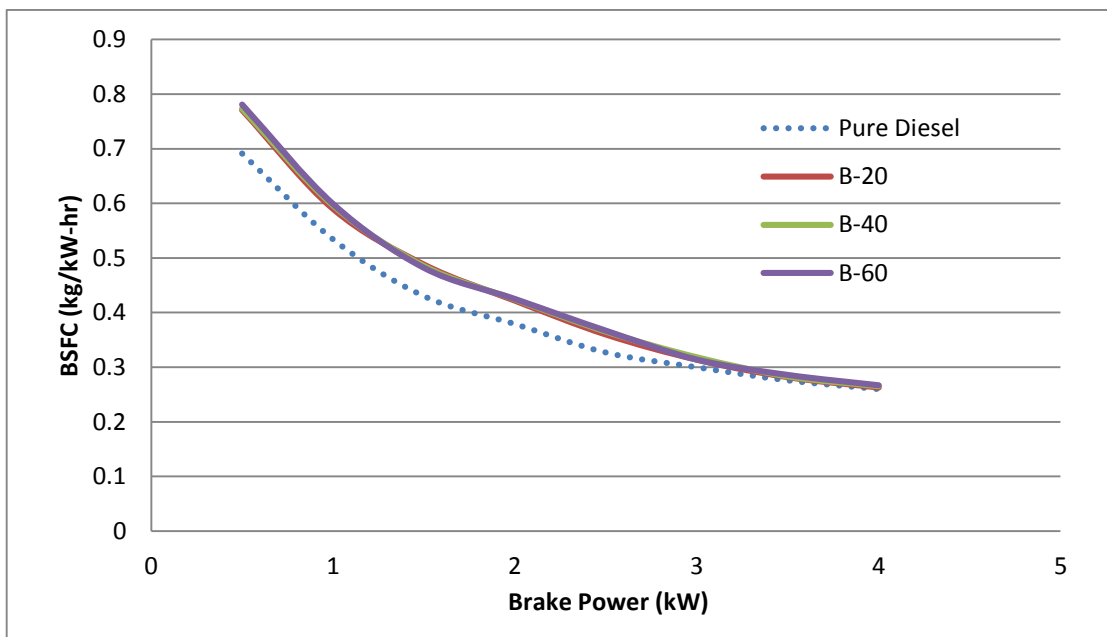


Figure 5.9 Comparison of BSFC v/s Brake Power for neat diesel and CSO biodiesel blends at compression ratio 16

5.4.1 Variation of opacity w.r.t. brake power at 16 compression ratio

Fig.5.4 shows that opacity value for neat diesel is slightly lower as compared to all types of diesel-CSOME blends. Biodiesel has about 10% oxygen by weight which results in decrease of opacity. However its higher viscosity results in increase in opacity. At lower compression ratio (16) effect of volatility dominates the effect of oxygen content. Probably vaporization and atomization of high viscosity fuel becomes difficult at lower compression ratios.

5.4.2 Variation of opacity w.r.t. brake power at 18 compression ratio

Fig.5.5 shows opacity value for all diesel-CSOME blends increases from 1% to 33% between the brake power ranges of 0.5 and 4kW brake power. The trend regarding the variation of opacity values w.r.t. brake power is almost similar for all types of blends. The opacity value for neat diesel is slightly higher as compared to all type of blends. Addition of CSOME to neat diesel increases the viscosity and oxygen content of fuel. The effect of latter dominates at 18 compression ratio and thus decrease in opacity is noticed for all diesel-CSOME blends.

5.4.3 Variation of BTE w.r.t. brake power at 18 compression ratio

Fig. 5.6 shows the variation of BTE v/s brake power for diesel-CSOME blends in comparison to neat diesel. For all selected blends BTE increases with brake power output and the trend is almost similar to diesel. This small gain in BTE as compared to diesel is due to presence of oxygen in biodiesel molecules and its higher lubricity, which results in better combustion and lower frictional losses.

5.4.4 Variation of BTE w.r.t. brake power at 16 compression ratio

Fig. 5.7 shows the variation of BTE v/s brake power for diesel-CSOME blends in comparison to neat diesel. For all selected blends BTE increases with brake power output and the trend is almost similar to diesel. No significant change in BTE as seen when using diesel-CSOME blends when compared to diesel. Diesel-CSOME blends shows poor vaporization and atomization characteristics at lower compression ratios due to higher viscosity and lower volatility. This counteracts the effect of increase in BTE due to presence of oxygen in biodiesel molecules and higher lubricity.

5.4.5 Variation of BSFC w.r.t. brake power at 18 compression ratio

Fig. 5.8 shows the variation of BTE v/s brake power for diesel-CSOME blends in comparison to neat diesel at 18 compression ratio. BSFC is the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to BTE. BSFC values were determined to be slightly higher than those of neat diesel in spite of increase in BTE with diesel-CSOME blends. This is due to lower heating values of diesel-CSOME blends and thus more fuel was required for maintenance of constant power output. An indicator of the loss of heating value and thus the expected fuel consumption is the oxygen content of fuel.

5.4.6 Variation of BSFC w.r.t. brake power at 16 compression ratio

Fig. 5.9 shows the variation of BTE v/s brake power for diesel- CSOME blends in comparison to neat diesel at 18 compression ratio is shown in. Percentage increase

in BSFC with biodiesel blends as compared to diesel at 16 compression ratio is more as compared to the corresponding increase at 18 compression ratio. This is due to negligible rise in BTE with biodiesel blends at 16 compression ratio.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

- High yield is obtained for combined (hydrodynamic cavitation and mechanical stirring) process as compared to hydrodynamic cavitation or mechanical stirring alone
- Higher percentage of catalyst does not have much impact on biodiesel production
- Opacity values were lower for diesel-CSOME blends as compared to neat diesel when engine is operated at 18 compression ratio.
- Brake Thermal Efficiency for diesel- CSOME blends was higher as compared to neat diesel when engine is operated at 18 compression ratio.
- Brake specific fuel consumption for diesel- CSOME blends was higher as compared to neat diesel in spite of increase in Brake Thermal Efficiency.

6.2 Scope for future work

Future study can also be carried for biodiesel production in a hybrid reactor which combines ultrasonic cavitation along with hydrodynamic cavitation and mechanical stirring

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