

CHAPTER – 1

INTRODUCTION

The status of a country whether developed, developing or under developed depends on the availability of fuel reserves and its consumption pattern. The consumption pattern also has some effect on pollution, greenhouse effect, desertification, carbon foot prints etc.. One third of the population in the developed nations consume two third of the total fuel available in the world. With rapid raise in population, increase in number of automobiles, lack of awareness etc the demand is growing more and more with limited availability of resources, which leads to a huge gap between supply and demand.

The high rate of economic growth in India has been fuelled by an increasing demand for oil. Consequently, the imports of crude oil are also increasing. In 2011-12, India was the world's fourth largest consumer of crude oil and natural gas, after the United States, China, and Russia. In 2012-13 the oil import of India (US \$ 155.57 billion) was 11.92% higher than its imports during the previous fiscal (US \$ 139.00 billion). [27]

1.1. Petroleum Sector in India at a Glance

After Coal, Oil is the largest energy source for the country with a share of about 30.5% in the primary energy consumption basket [8]. The indigenous production of crude oil has not been increasing in tandem with consumption. For an emerging economy like India, this gap is likely to increase over the coming years.

- Consumption of petroleum products during 2012-13 was 157.1 million metric tonnes (MMT), including sales through private imports, which is 6.0% higher than the 148.1 MMT consumed during 2011-12

- During 2012-13 the country imported 184.8 MMT of crude oil against 171.7 MMT during 2011-12.[36]

In view of the criticality of energy usage for economic growth and reduction in the degradation of environment, it is imperative for India to formulate appropriate policies and strategies that reduce our dependency on crude oil imports. [33]

1.2. Major Petroleum Dependent Sectors

In 2012-13 India was depending on foreign crude oil to meet 84.5% of its refinery requirement. However, in terms of domestic consumption of petroleum products, the dependency was significantly lower at 77.4% of the total consumption of all types of petroleum products in 2012-13, high speed diesel (HSD) accounted for 43.98%, followed by Petrol 10.02%, LPG 9.93% and Naphtha 7.82%.[33]

1.3. Diesel

The Figure 1 shows the trend in consumption of diesel in India over a period of 32 years. The total diesel sold during 2012-13 was 69,080 TMT and petrol was 15,744 TMT. While diesel constitutes about 44% of total consumption of petroleum products and petrol accounts for about 10%, in India. [33]

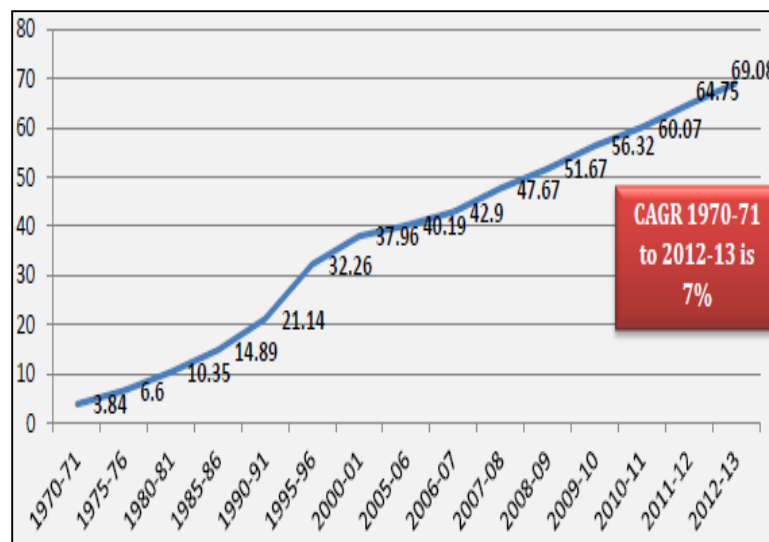


Figure 1: Trends in Consumption of Diesel in India

Diesel is mainly consumed in road transport, agriculture, industries and power generation sectors. Figure 2 shows the consumption of HSD in different sectors.

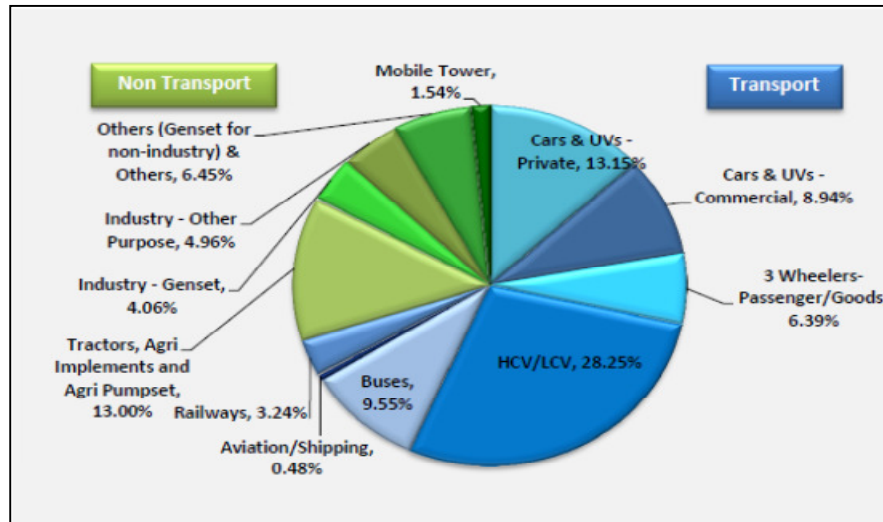


Figure 2: India's End-use Share (%) of Diesel in Retail and Direct Sales Combined

Hence, 'Bio fuels' seek to appendage conventional energy resources for meeting rapidly increasing requirement of transportation fuels and meeting energy needs and to diminish the reliance on import of fossil fuels. The aim is to provide a higher degree of national energy security in an eco-friendly, cost-effective and sustainable manner.

The term 'Bio fuels' can be defined as liquid or gaseous fuels produced from biomass resources and used in place of, or in addition to, diesel, petrol or other fossil fuels for transport, stationary, portable and other applications. Biomass resources can be defined as biodegradable fraction of products, wastes and residues from agriculture, forestry and related industries as well as the biodegradable fraction of industrial and municipal wastes.

The popular bio fuels are:

- Bio-ethanol, ethanol produced from biomass including sugar containing materials, like sugar cane, sugar beet, sweet sorghum, etc.; starch containing materials such as

corn, cassava, algae etc.; and, cellulosic materials such as wood waste, agricultural and forestry residues etc.

- Bio-Diesel and
- Other Bio fuels such as Bio-methanol, Bio-Synthetic fuels etc.

1.4. What is Biodiesel?

In the most general sense, biodiesel refers to any diesel fuel substitute derived from renewable biomass. More specifically, biodiesel can be defined as an oxygenated, sulphur free, biodegradable, nontoxic, and eco-friendly alternative diesel oil. Chemically, it can be defined as a fuel composed of mono alkyl esters of long chain fatty acids derived from renewable sources, such as vegetable oil (edible & non-edible), animal fat, and used cooking oil. Pure biodiesel is generally designated as B100, and also it should meet the standards or specifications of American Society for Testing of Materials (ASTM) and European Standards. One popular process for producing biodiesel is transesterification.

Biodiesel is receiving increased attention as an alternative, nontoxic, biodegradable, and renewable diesel fuel. Its properties vary somewhat depending on the oil feedstock and alcohol used but it can always be used as a direct substitute for diesel fuel (Mittelbach et al., 1992; Peterson et al., 1992; Peterson et al., 1994). Biodiesel has a higher cetane number(CN) than diesel fuel, no aromatics, almost no sulfur, and contains 10% to 11% oxygen by weight. These characteristics of biodiesel reduce the emissions of carbon monoxide (CO), hydrocarbon (HC), and particulate matter (PM) in the exhaust gases as compared to petrodiesel fuel. In spite of its properties to be used as a petrodiesel fuel substitute, biodiesel from food grade oil is not economically competitive with petrodiesel fuel. Lower cost feed stocks are needed. [9].

1.5. Problem Statement

Slow progress made towards jatropha plantation has resulted in lower availability of jatropha seeds to be used as feed-stock for biodiesel production and hence most of the biodiesel units operating in India need to be shifted to alternative feed-stocks such as kusum (*Schleichera Oleosa*), Thumba (*Citrullus colocynthis*), Karanja (*Pongamia pinnata*), and Neem (*Azadirachta indica*), edible oil waste (unusable oil fractions), animal fat and inedible oil. Hence, the objective of this study was to produce fuel quality biodiesel from low cost feedstock i.e. kusum, (*Schleichera Oleosa*) with high FFA and test the biodiesel blends for its performance and emissions characteristics on a four stroke, four cylinder, diesel engine.

1.6. Scope of Present Work

Nonedible oil from seeds such as kusum (*Schleichera Oleosa*), Ratanjyot (*Jatropha curcas*), Thumba (*Citrullus colocynthis*), Karanja (*Pongamia pinnata*), and Neem (*Azadirachta indica*), are being investigated for replacement of conventional, highly polluting mineral fuels and to provide employment for landless and marginal people. These plants can grow in low-rainfall areas and are usually rejected by browsing cattle and goats and contain about 10 to 50 per cent of oil that needs virtually no engine modification when esterified and blended with petrodiesel. Moreover, the residual oil cake is rich in minerals and organic residues, which constitutes an excellent fertilizer as well as serves as a good soil-binding material. In India there are varieties of feed stock which can give nonedible oil from their seeds. However, popularly available potential of tree-borne oilseeds (TBOs) in India are given in Table 1.

Table 1: Available Potential of Tree-Borne Oilseeds (TBO's) in India [10]

Sr. No.	TBOs	Seed yield (lakh tonnes)	Oil content (%)	Oil yield (lakh tonnes)
1.	Sal (<i>Shorea robusta</i>)	62.0	12	7.44
2.	Mahua (<i>Madhuca indica</i>)	5.2	35	1.82
3.	Neem (<i>Azadirachta indica</i>)	5.0	20	1.0
4.	Rubber (<i>Hevea brasiliensis</i>)	0.79	45	0.35
5.	Karanja (<i>Pongamia pinnata</i>)	1.11	27	0.30
6.	Kusum (<i>Schleichera Oleosa</i>)	0.45	33	0.15
7.	Khakan (<i>Salvadora oleoides</i>)	0.44	33	0.14
8.	Undi (<i>Calophyllum inophyllum</i>)	0.11	60	0.07
9.	Dhupa (<i>Vateria indica</i>)	0.13	19	0.02
10.	Other*	2.0		
Total		77.34		

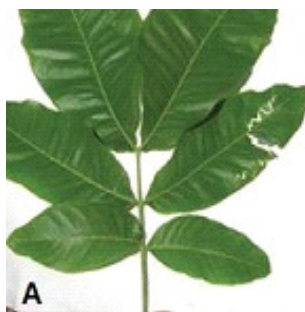
* **Other** : Maroti (*Hydnocarpus wightiana*), Palash (*Butea monosperma*), Pisa (*Actinodaphne angustifolia*), Ratanjyot (*Jatropha curcas*), Thumba (*Citrullus colocynthis*), Teak (*Tectona grandis*).

The generic name of Kusum, *Schleichera* is derived after the Swiss botanist J.C. Schleicher who first described the tree. The species name *Oleosa* derives from the Latin word *oleum* meaning oil, as the seed kernels are rich in oil. Synonymously the tree is also referred as *Schleichera trijuga* Willd, the word *trijuga* stands for 'three pairs', based on the presence of three pair of leaflets in a leaf. Kusum is a dicotyledonous, flowering and seed bearing vascular plant belonging to family Sapindaceae (soapberry), the same family to which the popular fruit 'Litchi' belongs. Kusum is a native of tropical Asian countries and is distributed throughout the foothills of Himalaya from the Sutlej to Chhota Nagpur regions covering the states of Jharkhand, Bihar, Chhattisgarh, Orissa, Madhya Pradesh and Andhra Pradesh.

Other than India the tree is distributed in countries like Nepal, Sri Lanka, Myanmar, Thailand, Indonesia and Malaysia. Though kusum trees are fire and frost resistant, they are best suited for 35–47°C temperature and 750–2500 mm annual

rainfall. Kusum is a large, deciduous tree approximately 20–30 m tall and a crown spread of approximately 2–4 m diameter. The bark of the tree is usually grey in colour with reddish wood inside it. The kusum tree sheds leaf during the month of December to February; remains leafless for a short period of time before the new purple to red coloured leaves emerge and gradually turns green with time. Kusum flowers are usually devoid of petals. The shape of the fruit is ellipsoid to sub-globular berry and the base of the fruit is narrowed and apex pointed. The fruits are hard crustaceous and smooth or slightly spiny.

Inside, the fruit contains one seed or sometimes two. The seeds are rich in oil. Seeds of one of the nonedible oilseed, kusum (*Schleichera Oleosa* f. *Sapindaceae*) is of great significance in Jharkhand area and its oil is used in burning lamps, varnishing, massage and medicine. Its oil-cake is good manure. The kusum trees generally flowers during the onset of dry season of January-February whereas fruiting takes place during the month of March-April. The fruits ripen in the months of July-August. The seeds are the major source of propagation and are viable mostly if sown freshly after collection. Proper drying and storage of seeds in airtight containers may allow germination of seeds up to 1–2 years. On prolonged storage the viability of seeds is lost drastically. Artificially kusum trees can be propagated through vegetative method of air-layering (artificial induction of roots from the wound on a shoot and detaching the explants from the mother plant to produce a plantlet). The estimated availability of kusum seed is about 25, 000 oil potential per tonnes per annum. In the past kusum oil was exported from India to Germany. In India average production of kusum seeds is 4000-5000 tonnes. Kusum seed kernels (0.45 lacks of tonnes of seed) contain about 33% of yellowish brown colored oil.



A) Kusum leaf with three pairs of leaflets. B) An inflorescence racem



C) A male flower with anthers D) A hermaphrodite flower with fertilized ovule



E) Bunch of immature Kusum fruits. F) A mature seed with brown testa and cotyledon kernel

Figure 3: Mature kusum tree and different parts of a kusum Plant

The individual seed is almost round having about 1.5 cm diameter and weighing between 0.5 and 1.0g. The weight of 1000 seeds is 500-700 g. Figure 3 shows the mature kusum tree and different parts of a kusum plant. [39]

CHAPTER - 2

LITERATURE REVIEW

2.1 Production Related Reviews

- Canakci et al. (2001) studied that there are large amounts of low-cost oil and fats such as restaurant waste and animal fats that could be converted to biodiesel. The problem with processing these low cost oil and fats is that they often contain large amount of FFA that cannot be converted to biodiesel using an alkaline catalyst. In this study, a technique was described to reduce the FFA content of these feed stocks using an acid-catalyzed pretreatment to esterify the FFA before transesterifying the triglycerides with an alkaline catalyst to complete the reaction. Initial process development was performed with synthetic mixtures containing 20% and 40% free fatty acids, prepared using palmitic acid. Process parameters such as the molar ratio of alcohol, type of alcohol, acid catalyst amount, reaction time, and FFA level were investigated to determine the best strategy for converting the FFA to usable esters. The study showed that the acid level of the high FFA feed stocks can be reduced to less than 1% with a 2-step pretreatment reaction. The reaction mixture was allowed to settle between steps so that the water-containing alcohol phase could be removed. The 2-step pretreatment reaction was demonstrated with actual feed stocks, including yellow grease with 12% FFA and brown grease with 33% FFA. After reducing the acid levels of these feed stocks to less than 1%, the transesterification reaction was completed with an alkaline catalyst to produce fuel-grade biodiesel.[9]

- Math et al. (2007) found that the biodiesel may be cost effective if produced from low cost oil (animal fats, restaurant waste oil and frying oil), which, however, contain high amount of FFA. In their study, different amounts of methanol (20, 25, 30, 35, 40 and

45%), catalyst concentrations (0.3, 0.5, 0.7, 1.0 and 1.5 % NaOH), reaction temperature (30, 45 and 55°C) and different reaction times (60, 90 and 120 min) were selected for transesterification of restaurant waste oil in order to optimize experimental conditions for maximum biodiesel yield. Methyl ester yield (65.50-85.50 %) in the laboratory scale biodiesel reactor was obtained maximum (85.50 %) at the optimized process parameters such as methanol (35% by vol), NaOH (0.3 g), reaction temperature (55°C) and reaction time (90 minutes).[26]

- Singh et al. in their study reviewed the different source of biodiesel, their chemical composition, comparison with chemical composition of fuels such as diesel, different processes or method to produce biodiesel, various properties of alternative fuel or biodiesel, measurement of different parameters indicating performance of alternative fuel as a fuel, problems occurred and their solution during the use of alternative fuels and economic viability of biodiesel.[43]
- Mohanty et al. (2013) studied the annual production of different non edible seeds in India and it was concluded that kusum seed contains around 34% oil content in it and has a potential of 0.08 million metric tonne per year. Further all the important properties of transesterified products (bio-diesel) like specific gravity, kinematic viscosity, calorific value, carbon residue and flash point are compared with ASTM standards were determined and found to be within the specified parameters. Hence the biodiesel from non-edible oil like kusum, Karanja, Jatropha, Simarouba, Mahua and Polanga can be used as an alternative to diesel fuel.[28]
- Pali et al. (2013) studied about production and physio chemical characterisation of kusum oil methyl ester as an alternative fuel in diesel engine . In the present study, kusum oil methyl ester (KOME) was produced using a two-stage esterification cum transesterification process on account of the high FFA contents of the oil. In the

esterification stage, 0.85% by mass of catalyst (p-Toluenesulfonic acid), at 60°C temperature with constant agitation at 450 RPM led to less than 2% FFA in 45 min. Similarly, the transesterification stage led to 97.2% ester yield using 1.4% by mass of catalyst (potassium hydroxide/KOH), at 65°C temperature in 100 min under constant agitation at 450 RPM. Various physico-chemical properties of KOME, like density, viscosity, heating value, etc., were measured and found to be satisfactorily compliant with the corresponding ASTM / EN standards. The fatty acid profile suggested that KOME possessed 40% unsaturated fatty acids and around 53% saturated fatty acids. The results of oxidation stability indicated no substantial peroxide formations for six hours in the biodiesel rancimat, thus conforming to the EN standard. The cold flow plugging point of KOME was -1°C, as compared with -9°C indicated by the neat diesel. In the light of the above study, it was concluded that kusum oil is a promising feedstock for biodiesel production and efforts should be made to exploit the same for commercial-scale usage.[30]

- Sani et al. (2013) in their research study, a raw material of crude palm oil was used as the feedstock for biodiesel production. After pretreatment of crude palm oil, transesterification reactions of the feedstock with methanol are carried out in stages. This multi stage transesterification carried out in pilot scale with the capacity of 1 MT per batch results in a high conversion yield (> 96%) though the FFA level above 3%. Gas Chromatography was used to determine the methyl ester content following the EN 14103 testing methods to support the proposed multistage reactions towards a higher conversion. To assess the significance of the transesterification conducted in stages, various data showing the methyl ester profiles under different methanol to oil ratios were evaluated. Lowering the methanol to oil ratio in the first stage (2.5:1) and

proceeding with a higher constant ratio (1.5:1) each for the subsequent two stages got better results (more than 98% conversion) compared to 3:1 and 1.25: 1 ratios.[40]

- Sabariswaran et al.(2014) in their study observed difficulty of some oil in biodiesel production is that they had higher percentage of FFA. These FFA were major obstacle while reacting with the alkaline catalyst resulted in production of soaps that inhibit the production and separation of biodiesel. Based on this strategy, nonedible oil Karanja was chosen for this investigation. The maximum conversion efficiency of 90% of oil biodiesel yield was achieved under optimized conditions of 0.5 wt% acid catalyst concentration and 0.4% concentration of NaOH with respect to 6:1 oil to molar ratio and 60 minutes of reaction time with 60 ± 1 °C temperature.[38]

2.2 Factors Affecting the Production of Biodiesel/ Transesterification

A part from literature reviews discussed in preceding paragraphs, different researchers has also put their efforts to conclude the different factors affecting the transesterification were also overviewed and the findings are as discussed below:

2.2.1 The effect of Reaction Temperature

The pace of reaction is stoutly prejudiced by the reaction temperature. However, if sufficient time is given, the reaction will ensue to near conclusion at room temperature also. Generally, the reaction is conducted near to the boiling point of methanol (60°C –70°C) at atmospheric pressure. The maximum yield of esters occurs at temperatures ranging from 60°C to 80°C at a molar ratio (alcohol to oil) of 6:1. However, the case may be different for different oil.

2.2.2 The effect of Molar Ratio

Molar ratio of alcohol to vegetable oil is another important factor affecting the yield of ester. The stoichiometry of the transesterification reaction requires 3 mole of alcohol per mole of triglyceride to yield 3 mole of fatty esters and 1 mole of glycerol.

To shift the transesterification reaction to the right direction, it is necessary to use either a large amount of alcohol or remove one of the products from the reaction mixture continuously.

2.2.3 The effect of Catalyst

Catalysts are agents used in a chemical reaction to expedite the rate of reaction and they can be classified as alkali catalysts, acid catalysts, or enzymes. The rate of alkali catalyzed transesterification is much faster than acid catalyzed reaction. However, if a vegetable oil has FFA and water content, acid catalysts are preferred over alkali catalysts. Since the acid catalysts are corrosive in nature and due to their slower esterification than alkali catalysts, the latter found its use in most commercial transesterification reactions. However, increase in catalyst concentration may not increase the yield but it adds extra costs as it is compulsory to eliminate the catalyst from the reaction products at the end. Methanol can quickly react with triglycerides and NaOH does easily dissolve in it. The commonly used alkali catalysts are NaOH, KOH and carbonates. H_2SO_4 , sulfonic acids and hydrochloric acid are frequently used acid catalysts.

2.2.4 The effect of Reaction Time

The rate of exchange from oil to esters is not directly proportional to reaction time. Freedman et al. [11] transesterified peanut, cottonseed, sunflower and soybean oil under the condition of methanol to oil ratio of 6:1, 0.5% sodium methoxide catalyst and 60°C. An approximate yield of 80% was observed after one minute for soybean and sunflower oil. After an hour, the conversions were almost the same for all four oil (93%–98%). Hanna [16] studied the effect of reaction time on transesterification of beef tallow with methanol. The reaction was very slow during the first minute due to the mixing and dispersion of methanol into beef tallow. From 1

to 5 minutes, the reaction proceeded very fast. The apparent yield of beef tallow methyl esters surged from 1% to 38%.

2.2.5 The effect of Moisture and FFA

For an alkali-catalyzed transesterification, the glycerides and alcohol must be substantially anhydrous because water makes the reaction partially change to saponification, which produces soap. The soap lowers the yield of esters and renders the separation of ester and glycerol and water washing difficult. The glycerol is then removed by gravity separation and remaining ester is mixed with hot water for separation of catalyst. Moisture can be removed using silica gel. Saponification reaction also takes place simultaneously along with transesterification process but soap formation is not a major problem if presence of water is less than 1% [2, 3, 11, 16, 34, 41,]. The glycerol should have an acid value less than 1 and all reactants should be substantially anhydrous. If the acid value is greater than 1, more NaOH is required to neutralize the FFA. Freedman et al. found that ester yields were significantly reduced if the reactants did not meet these requirements. Sodium hydroxide or sodium methoxide reacted with moisture and carbon dioxide in the air, which diminished their effectiveness [11]. The effects of FFA and water on transesterification of beef tallow with methanol were investigated by Ma and Hanna. The results showed that the water content of beef tallow should be kept below 0.06 wt % and free fatty acid content of beef tallow should be kept below 0.5 wt % in order to get the best conversion. Water content was a more critical variable in the transesterification process than FFA [16].

2.3 Performance and Emission Related Reviews

- Liaquat et al.(2011) presented experimental results for the performance and exhaust emissions of a diesel engine operated on “Envo Diesel” which consists of 5% palm

diesel and 95% ordinary diesel fuel (also termed as P5) and C5 (5% coconut biodiesel and 95% ordinary diesel fuel). Experimental results showed that P5 and C5 reduced brake power compared to diesel fuel by 1.2% and 0.7% respectively. Emissions such as HC, smoke, CO and NO_x concentration were lesser for P5 and C5. The results of this investigation will be used to partial replacement of diesel fuel using low percentage of methyl ester (maximum 5%) obtained from waste vegetable oil. [23]

- Acharya et al.(2011), in their study concluded that the engine performance with kusum and karanja oil (preheatd) was found to be very close to that of diesel. The preheated oil's performances were found to be slightly inferior in efficiency due to low heating value.[1]
- Xue et al.(2011), reviewed that the use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NO_x emission on conventional diesel engines with no or fewer modification. And it favors to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel with small content in place of petroleum diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy. However it was also suggested that further researches about optimization and modification on engine, low temperature performances of engine, new instrumentation and methodology for measurements, etc., should be performed when petroleum diesel is substituted completely by biodiesel.[45]
- Patil et al. (2012 a) used the biodiesel from Karanja oil in a turbo charged, four stroke, four cylinder, and water cooled diesel engine in pure and blended form without any modification in engine design or fuel system. The performance characteristics of the engine were studied with different proportions of biodiesel and

petrodiesel .The power, torque, and brake thermal efficiency using biodiesel were found higher at various load conditions than the petrodiesel. The specific fuel consumption was found slightly high. The biodiesel blend KBD30 showed better performance than the diesel and other blends.[31]

- Patil et al. (2012 b) used biodiesel from jatropha oil in a turbo charged , four stroke, four cylinder, and water cooled diesel engine in pure and blended form without any modification in engine design or fuel system. The performance characteristics of an engine were studied with different proportions of biodiesel and petrodiesel .The power, torque, and brake thermal efficiency using biodiesel were found higher at various load conditions than the petrodiesel. The specific fuel consumption was observed slightly higher. The biodiesel blend JBD20 showed better performance than the diesel and other blends.[32]
- Palash et al. (2013) recorded impacts on engine performance and emission such as NO, HC, and CO fueled with Jatropha biodiesel blends (JB5, JB10, JB15 and JB20) in multi cylinder diesel engine at full throttle position were systematically investigated Performance parameters such as engine power and BSFC with respect to variable engine speed (1000~4000 RPM) were evaluated for all test fuels and were compared to diesel combustion under 100% throttle condition. It was concluded that the reason for the reduction in engine power and increase in BSFC are possibly due to slight reduction of cylinder pressure as well as lower heating value of biodiesel and higher NOx emissions were produced for biodiesel combustion. Lower HC and CO emissions were recorded.[29]
- Siju1 et al.(2013) In this review, before treatment as Exhaust Gas Recirculation and after treatment system as catalytic converter used with karanja biodiesel in CI, DI engine. This investigated the suitable use of karanja biodiesel in conventional diesel

engine and exhaust emissions like CO, HC, NO_x reduced simultaneously by the systems.[42]

- Jawre et al. (2014) in their study presented effects of diethyl ether (DEE) as additive to biodiesel of kusum (*Schliechera Oleosa*) on the performance and emission of diesel engine at different load and constant speed and two different injection pressure (170 and 190 bar). The fuels and its blends used were 100% diesel, B100 (100% KME), BD-1 (95% KME, 5% DEE), BD-2 (90% KME, 10% DEE), BD-3 (85% KME, 15% DEE) respectively. It was observed that the performance of the engine increases at high injection pressure. The results indicated that lower B_{sf}c was observed with BD-3 as compared to B100, BD-1 and BD-2. Brake thermal efficiency of BD-3 decreased at 170 bar injection pressure, but it increased at 190 bars. Drastic reduction in smoke was observed with all blends at higher engine loads. DEE addition to biodiesel reflects better engine performance compared to neat biodiesel.[18]
- Islam et al. (2014) in their paper presented the result of investigations carried out in studying the emission and performance of diesel engine using the castor biodiesel produced by using acid based catalyzed transesterification system and its blend with diesel from 0% to 40% by volume. The highest yield of 82.5% was obtained under the optimized condition. The smoke emission test revealed that B40 had the least black smoke compared to the conventional diesel. Diesel engine performance test indicated that the specific fuel consumption of biodiesel blend was increased sufficiently when the blending ratio was optimized. Thus, the reduction in exhaust emissions and reduction in brake-specific fuel consumption made the blends of castor seed oil B20 a suitable alternative fuel for diesel and could help in controlling air pollution. [17]
- The dilution of Sunflower oil with diesel fuels in the ratio of 1:3 by volume has been studied and engine tests were carried out by Ziejewski et al. (1983). They concluded

that the blend could not be recommended for long term use in the direct injection diesel engines due to density difference.[46]

- Pryor et al. (1983) had conducted the short term and long term performance tests with blends of vegetable oil with diesel. In short term performance test, crude, degummed Soybean oil and Soybean ethyl ester were found suitable substitutes for diesel fuel. A longer term evaluation of the engine when using 100% crude soybean oil was prematurely terminated severe injector chock led to decreases in power output and thermal efficiency. [35]
- Parmanik (2003) studied the properties and use of Jatropha oil and diesel fuel blends in CI engine. The heating value of the vegetable oil was comparable with ordinary diesel fuel and CN was slightly lower than diesel oil. Significant improvement in engine performance was observed as compared to pure vegetable oil. The exhaust gas temperature was reduced due to reduced viscosity of the vegetable oil diesel blends. It was found that the fuel consumption was increased with a higher proportion of the Jatropha oil in the blends. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50% (by volume) of Jatropha oil. The tests were conducted on a single-cylinder direct-injection operated on diesel fuel, Jatropha oil and blends of diesel and Jatropha oil in proportions of 97.4%/ 2.6%; 80%/ 20%; and 50%/ 50% by volume test results showed that Jatropha oil can be conveniently used as a diesel substitute in a diesel engine. The test results further showed increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for oil and its blends with diesel. [34]

Table 2 gives the summary of proposed BIS (Bureau of Indian Standards) standards for biodiesel.

Table 2: Summary of Proposed Standards for Biodiesel by Bureau of Indian Standards
[44]

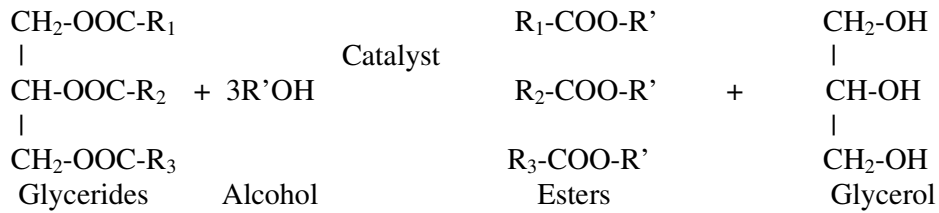
S.No.	Standard / specification	Unit	Proposed BIS
1	Density @ 15°C	g/cm ³	0.87 – 0.90
2	Viscosity @ 40°C	mm ² /s	3.5 - 5.0
3	Flash point	°C	>=100
4	Sulphur, max.	%mass	0.035
5	Sulphated ash,max,	%mass	0.02
6	Water.max	mg/kg	500
7	Total contamination, max.	mg/kg	20
8	Cetane no		>=51
9	Acid no	mg KOH/g	<=0.8
10	Methanol	%mass	<=0.02
11	Ester content	%mass	>=96.5
12	Diglyceride	%mass	<=0.2
13	Triglyceride	%mass	<=0.2
14	Free glycerol	%mass	<=0.02
15	Total glycerol	%mass	<=0.25
16	Iodine no		<=115
17	Phosphorus	ppm	<=10
18	Alkaline matter(Na,K)		<=10
19	Distillation, T 95%	°C	<=360

CHAPTER-3

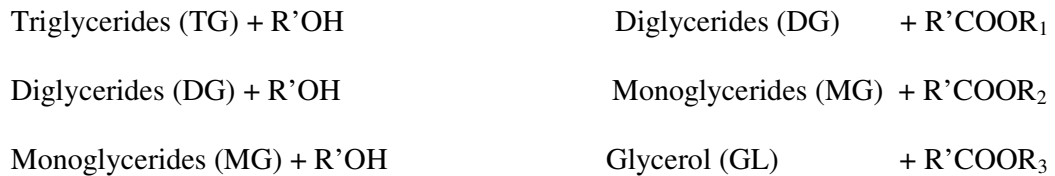
BIODIESEL CHARACTERISTICS & PRODUCTION TECHNIQUES

3.1 Chemistry of Biodiesel

In the transesterification of different types of oil, triglycerides react with an alcohol, generally methanol or ethanol, to produce esters and glycerol. To make it possible, a catalyst is added to the reaction. [12, 20, 24, 25, 37]



The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step, from triglycerides diglyceride is obtained, from diglyceride monoglyceride is produced and in the last step, from monoglycerides glycerol is obtained. In all these reactions esters are produced. The stoichiometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product [12, 25]:



Transesterification is the most common method and leads conversion of vegetable oil and fats into mono alkyl esters, called biodiesel. The methyl ester produced by transesterification of vegetable oil has a high CN, low viscosity and improved heating

value compared to those of pure vegetable oil which results in shorter ignition delay and longer combustion duration and hence low particulate emissions.

3.2 Biodiesel Characteristics

3.2.1 Calorific Value or Heat of Combustion

Heating value or heat of combustion is the amount of heating energy released by the combustion of a unit value of fuels. One of the most important determinants of heating value is moisture content. Air-dried biomass typically has about 15-20% moisture, whereas the moisture content for oven-dried biomass is negligible. Moisture content in coals varies in the range 2-30%. However, the bulk density of most biomass feed stocks is generally low, even after densification between about 10 and 40% of the bulk density of most fossil fuels. Liquid bio fuels however have bulk densities comparable to those for fossil fuels.

3.2.2 Pour Point

Melt or pour point refers to the temperature at which the oil in solid form starts to melt or pour. In cases where the temperatures fall below the melt point, the entire fuel system including all fuel lines and fuel tank will need to be heated.

3.2.3 Cloud Point

The temperature at which oil starts to solidify is known as the cloud point. While operating an engine at temperatures below oil's cloud point, heating will be necessary in order to avoid waxing of the fuel.

3.2.4 Flash Point

The flash point temperature of a fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Flash point varies inversely with the fuel's volatility. The flash point of biodiesel is higher than the petrodiesel fuel.

3.2.5 Iodine Value

The iodine value is the measure of degree of unsaturation in oil. The IV is determined by measuring the number of double bonds in the mixture of fatty acid chains in the fuel by introducing iodine into 100 grams of the sample under test and measuring how many grams of that iodine are absorbed. Iodine absorption occurs at double bond positions thus a higher IV number indicates a higher quantity of double bonds in the sample, greater potential to polymerize and hence lesser stability.

3.2.6 Viscosity

Viscosity refers to the thickness of the oil, and is determined by measuring the amount of time taken for a given measure of oil to pass through an orifice of a specified size. Viscosity affects injector lubrication and fuel atomization. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, resulting in leakage or increased wear. Fuel atomization is also affected by fuel viscosity. Diesel fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion, increased exhaust smoke and emissions.

3.2.7 Cetane Number

It is a relative measure of the interval between the beginning of injection and auto ignition of the fuel. The higher the CN the shorter the ignition delay period and the greater its combustibility. Fuels with low CN will result in difficult starting, noise and exhaust smoke. In general, diesel engines will operate better on fuels with CN above 50. CN test provide information on the ignition quality of a diesel fuel.

3.2.8 Density

It is the weight per unit volume. Oil that is denser contains more energy. For example, petrol and diesel fuels give comparable energy by weight, but diesel is denser and hence gives more energy per liter.

3.2.9 Ash Percentage

Ash is a measure of the amount of metals contained in the fuel. High concentrations of these materials can cause injector tip plugging, carbon deposits and injection system wear. The ash content is important for the heating value, as heating value decreases with increasing ash content. Ash content for bio-fuels is typically lower than for most coals, and sulphur content is much lower than for many fossil fuels. Unlike coal ash, which may contain toxic metals and other trace contaminants, biomass ash may be used as a soil amendment to help replenish nutrients removed by harvest.

3.3 Processes Overview

There are several accepted ways to make biodiesel. Some common methods are blending, transesterification and recently developed method like reaction with supercritical methanol etc. are discussed below:

- 1) Direct use and blending,
- 2) Microemulsions with simple alcohol,
- 3) Thermal cracking or Pyrolysis
- 4) Transesterification or alcoholysis which consists of the following sub categories
 - i) Alkali Catalyzed Transesterification
 - ii) Acid Catalyzed Pretreatment
 - iii) Lipase as Catalyst

5) Other forms of catalysis

- i) Biocatalyst
- ii) Reaction with Supercritical Methanol
- iii) Catalyst Free

3.3.1 Direct use and blending

The direct use of vegetable oil in diesel engine is problematic and has many inherent failings. Although some diesel engines can run on pure vegetable oil where as engines that are turbocharged, direct injection engines such as of trucks are prone to many problems. For short term use energy consumption with the use of pure vegetable Oil was found to be similar to that of diesel. [20]

3.3.2 Microemulsions

Microemulsions can be defined as a colloidal equilibrium dispersion of optical isotropic fluid structures, with dimensions generally in the 1-150 nm range. These are formed spontaneously from two normally immiscible liquids and one or more ionic or non ionic amphophiles. A microemulsion is designed to tackle the problem of high viscosity of pure vegetable Oil by reducing the viscosity of these oil with solvents such as simple alcohols. The performances of ionic or non ionic microemulsion were found to be similar to diesel fuel, over short term testing. In longer term testing no significant deterioration in performance was observed, however significant injector needle sticking, carbon deposits, incomplete combustion and increasing viscosity of lubricating oil was recorded [5, 20].

3.3.3 Thermal Cracking Or Pyrolysis

Pyrolysis is the conversion of one substance into another by means of applying heat i.e. heating in the absence of air or oxygen with temperatures ranging from 450°C -850°C . In some situations this is with the aid of a catalyst leading to the cleavage of chemical bonds to yield smaller molecules. The pyrolysis of fats has been successful

to produce many smaller chain compounds. Typical catalysts that can be employed in pyrolysis are SiO_2 and Al_2O_3 . The ratios of light to heavier compounds are dependent on temperature and time. Although the products are chemically similar to petrodiesel, oxygen removal from the process decreases the products benefits of being an oxygenated fuel. This generally decreases its environmental benefits and produces fuel, similar in properties of gasoline than diesel, with the addition of some low value materials [5, 20].

3.3.4 Transesterification

Some transesterification phenomena are discussed below:

(A) Alkali-catalyzed Transesterification

Figure 4 shows a schematic diagram of the processes involved in biodiesel production from feedstocks containing low levels of free fatty acids (FFA). This includes soybean oil, canola (rapeseed) oil, and the higher grades of waste restaurant oil. Alcohol, catalyst, and oil are combined in a reactor and agitated for approximately an hour at 60°C . Smaller plants often use batch reactors [21] but most of the larger plants (> 4 million liters/yr) use continuous flow processes involving continuous stirred-tank reactors (CSTR) or plug flow reactors [22]. The reaction is sometimes done in two steps where approximately 80% of the alcohol and catalyst is added to the oil in a first stage CSTR. Then, the product stream from this reactor goes through a glycerol removal step before entering a second stage CSTR. The remaining 20% of the alcohol and catalyst are added in this second reactor. This system provides a very complete reaction with the potential of using less alcohol than single step systems. Following the reaction, the glycerol is removed from the methylesters. Due to the low solubility of glycerol in the esters, this separation generally occurs quickly and may be accomplished with either a settling tank or a centrifuge. The excess methanol tends

to act as a solubilizer and can slow the separation. However, this excess methanol is usually not removed from the reaction stream until after the glycerol and methyl esters are separated due to concern about reversing the transesterification reaction. Water may be added to the reaction mixture after the transesterification is complete to improve the separation of glycerol [12, 13].

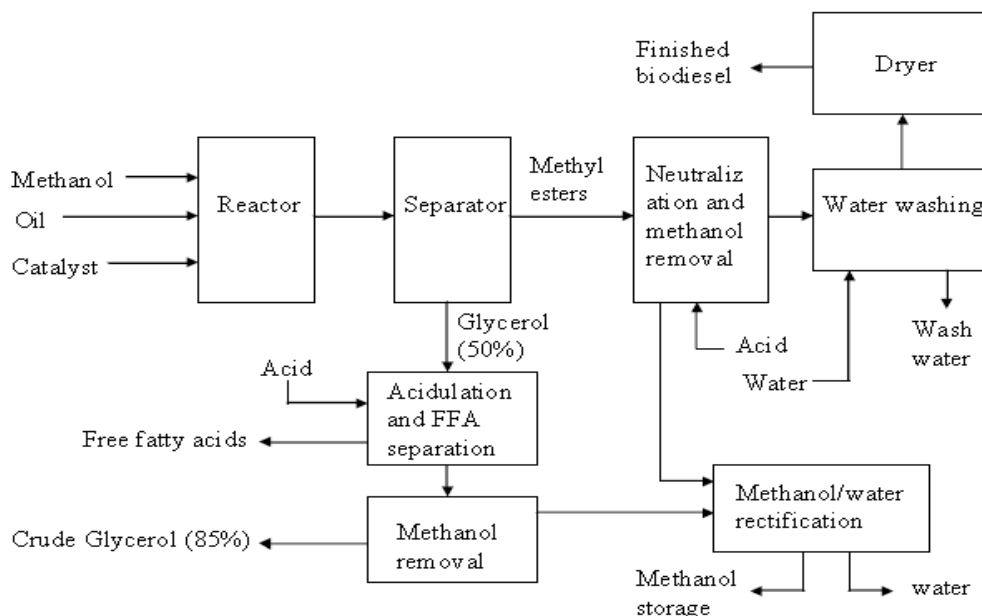
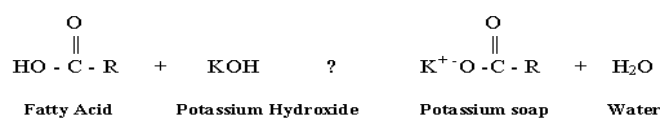


Figure 4: Process Flow Schematic for Biodiesel Production [12]

(B) Acid Catalyzed Pretreatment

Special processes are required if the oil or fat contains significant amounts of FFAs. Used cooking oil typically contains 2% to 7% FFA and animal fats contain from 5% to 30% FFA. Some very low quality feedstocks, such as trap grease, can approach 100% FFA. When an alkali catalyst is added to these feedstocks, the free fatty acids react with the catalyst to form soap and water as shown in the reaction below:



Up to about 5% FFA, the reaction can still be catalyzed with an alkali catalyst but additional catalyst must be added to compensate for that lost to soap. The soap created during the reaction is either removed with the glycerol or is washed out during the water wash. When the FFA level is above 5%, the soap inhibits separation of the glycerol from the methyl esters and contributes to emulsion formation during the water wash. For these cases, an acid catalyst such as sulfuric acid can be used to esterify the FFA to methyl esters in the following reactions. [12, 13]

(C) Lipase as Catalyst

Lipases are enzymes used to catalyze some reaction such as hydrolysis of glycerol, alcoholysis and acidolysis, but it has been discovered that they can be used as catalyst for transesterification and esterification reactions too. Biocompatibility, biodegradability and environmental acceptability of the biotechnical procedure are the desired properties in agricultural and medical applications. The extra cellular and the intracellular lipases are also able to catalyze the transesterification of triglycerides effectively [25].

3.4 Conventional Mechanical Stirring Method

Conventional mechanical stirring machine consist of temperature controlling mechanism to control the temperature within the range of 0-100°C and speed controller is for controlling speed of stirrer in terms of 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 starts when quantitative amount of methanol liquid with dissolved catalyst is poured into the beaker and then immediately but gently drop the magnetic stirrer piece so that the stirring action begin at particular RPM.

3.5 Cavitation Methods

Cavitations can be defined as the generation, subsequent growth and collapse of cavities resulting in very high energy densities of the order of 1 to 1018 kW/m³. Cavitation can occur at millions of locations in a reactor simultaneously and generate conditions of very high temperature and pressure in the order of few thousand atmospheric pressure and few thousand Kelvin temperature locally, with the overall environment being that of ambient conditions. Thus, chemical reactions requiring stringent conditions can be effectively carried out using cavitation at ambient conditions. Moreover, free radicals are generated in the process due to the dissociation of vapors trapped in the cavitating bubbles, which results in either intensification of the chemical reactions or in the propagation of certain unexpected reactions. Cavitation also results in the generation of local turbulence and liquid micro-circulation (acoustic streaming) in the reactor, enhancing the rates of transport processes. The four principle types of cavitation and their causes can be summarized as follows [15]:

- 1) Acoustic cavitation- In this case, pressure variations in the liquid are effected using sound waves, usually ultrasound (16 kHz–100 MHz). The chemical changes associated with the cavitation induced by the passage of sound waves are commonly termed as sonochemistry.
- 2) Hydrodynamic cavitation- This type of cavitation is produced by pressure variations, which is obtained by using the geometry of the system creating velocity variation. For example, based on the geometry of the system, the interchange of pressure and kinetic energy can be achieved resulting in the generation of cavities as in the case of flow through orifice, venturi, etc.

3) Optic cavitation- This is produced by photons of high intensity light (laser) rupturing the liquid continuum.

4) Particle cavitation- This is produced by a beam of elementary particles, e.g. a neutron beam rupturing a liquid, as in the case of a bubble chamber.

3.5.1 Ultrasonic Cavitation Method

Principal of ultrasonic or acoustic cavitation method is the process of creating cavities by the irradiation of power ultrasonic with sufficient energy in immiscible liquid (oil and alcohol are not miscible with each other) as a result micro fine bubbles are formed and these bubbles are collapsing at various place of the reactor and disturb the phase boundary between two immiscible liquid and resulted emulsification of mixture. In this 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 [14]. More the oscillatory velocity, shorter will be the reaction time. On the other hand, if oscillating velocity of ultrasonic transducer is insufficient for the sonochemical reaction in the mixture, an acoustic rod horn is connected to the transducer which is used to amplify the vibration amplitude. This rod permits achieving higher velocity and less reaction time. Low frequency ultrasonic irradiation is a useful tool for emulsification of immiscible liquids. The collapse of the cavitation bubbles disrupts the phase boundary and causes emulsification, by ultrasonic jets that impinge one liquid to another.

3.5.2 Hydrodynamic Cavitation Method

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 synthesising biodiesel result in conditions of very high local temperature and pressure at the same time releasing free radicals which intensifies chemical reactions. [15, 7]

3.5.3 Supercritical & Co-solvent Method

There are two methods of transesterification reaction. One method is by using a catalyst and the other is without a catalyst. However, there are at least two problems associated with the former process; the process is relatively time consuming and purification of the product for catalyst and saponified products are necessary. The first problem is due to the two phase nature of vegetable oil and methanol mixture requires vigorous stirring to proceed in the transesterification reaction. To resolve it the use of simple ether such as tetrahydrofuran can make this two phase nature into one phase of its mixture and that methyl esters can be produced in less than 15 minutes depending on the catalyst concentration. Yet, the catalyst problem cannot be solved for purification. Therefore, this conventional process still requires a high production cost and energy. The overall process, thus, includes transesterification reaction, recovery

of unreacted methanol, purification of methyl esters from catalyst and separation of glycerol as a co-product from saponified products.

The latter method involves uncatalyzed transesterification of vegetable oil in supercritical methanol. The supercritical state of methanol is believed to solve the two phase nature of oil and methanol mixture to form a single phase due to a decrease in dielectric constant of methanol in supercritical state. As a result, the reaction will be completed in a very short time of 2-4 minutes. In addition, because of non-catalytic process, the purification of products after transesterification reaction is much simpler and ecofriendly, as compared to the conventional commercial method in which all the catalyst and saponified products have to be removed for biodiesel fuel [21].

CHAPTER-4

PRESENT WORK

4.1 Experimental Setup for Biodiesel Production from Kusum Seed Oil

4.1.1 Mechanical Stirring Method

Conventional mechanical stirring machine consist of a controller to control temperature within the range of 0°C-100°C and speed controller is for controlling speed of stirrer in terms of 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 is poured into it at the beginning. The reaction starts when a quantitative amount of methanol liquid with dissolved catalyst is poured into the beaker and then immediately but gently drop the magnetic stirrer piece so that the stirring action begin at a particular RPM.



Figure 5: Conventional Mechanical Stirring Setup

4.1.2 Acid Catalyzed Transesterification Process

1 kg of kusum oil (FFA>2%<7%) was taken in an open, stainless steel container. The moisture content of the oil was removed by heating this oil up to 110°C with the help of an electric hot plate. After cooling down the same oil to a temperature

of 50°C the beaker is placed over the magnetic stirrer and a solution comprising 220gm of methanol (molar ratio of 6:1) and 10g (1%) sulphuric acid (H_2SO_4) is added to it. In order to get the homogeneous mixing it must be added only with the oil in stirring state. It was continuously stirred for an hour under controlled temperature conditions (50°C-55°C) at 350 RPM. This mixture was allowed for gravity separation in a separating funnel for a period of an hour. After gravity separation, top layer consisting of acid esterified oil and bottom layer, called as pretreatment oil, were separated as shown in Figure 6. The bottom residue was taken out from acid esterified oil in a different beaker and further processed for biodiesel production.



Figure 6: Acid Catalyzed Transesterification Process

4.1.3 Alkali Catalyzed Transesterification Process

The pretreatment oil obtained from acid transesterification was heated to remove moisture content before starting the reaction. The beaker is placed over the magnetic stirrer and a solution comprising the alkali methanol solution is added to preheated pretreatment oil. In order to get the homogeneous mixing it must be added only with the pretreatment oil in stirring state. It was continuously stirred for an hour under controlled temperature conditions (50°C-55°C) at 350 RPM. This mixture was

allowed for gravity separation in a separating funnel for a period of an hour. After gravity separation, top layer consisting of raw biodiesel and at bottom the glycerol were separated, as shown in Figure 7. The bottom layer of glycerol was taken out and the raw biodiesel is further processed for water washing and purification.



Figure 7: Alkali Catalyzed Esterification Process

4.1.4 Purification

The raw biodiesel was washed with warm distilled water to remove the unreacted alcohol, catalyst and traces of glycerol in the biodiesel. Further the water washed fuel was heated to 110°C in an open container until there was no more steam in the fuel. The resultant fuel should be a clear liquid as shown in Figure 8.



Figure 8: Kusum Biodiesel after Purification Process

4.2 Experimental Results of Kusum Biodiesel Production

The stoichiometric requirement for transesterification is 3 mole of the alcohol per mole of the triglyceride to yield 3 mole of the fatty esters and 1 mole of the glycerol. However, in practice an excess amount of alcohol is taken to drive the reaction close to completion in a forward direction.

Table 3 shows the amount of kusum oil, methanol, and catalyst used during experiment. However, the amount of acid catalyst (H_2SO_4) consumed was kept at 1.0% of the weight of the specimen during the first step of transesterification. Table(s) 4-12 shows experimental results for the kusum seed oil transesterification reaction performed in the laboratory for molar ratios 9:1, 6:1 and 4.5:1 respectively. Further for each molar ratio, catalyst quantity has been taken as 0.5%, 0.75% and 1.0% (by weight of oil) respectively.

Table 3: Amount of Kusum Oil, Methanol, Catalyst Used During Experiment and Acid @1.0%

Molar Ratio	Kusum Oil (gm)	Methanol Consumed (gm)	Pre-treatment oil (gm)	Catalyst Consumed (gm)		
				0.5wt%	0.75wt%	1.0wt%
4.5:1	500	85	421	2.1	3.1	4.2
6:1	500	110	450	2.25	3.3	4.5
9:1	500	166	465	2.32	3.4	4.65

Table 4: Yield Observed at Different Reaction Times for Molar Ratio of 4.5:1 (Catalyst 0.5 wt %)

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
500	85	5	2.1	30	57.97
				45	61.45
				60	65.63

**Table 5: Yield Observed at Different Reaction Times for Molar Ratio of 4.5:1
(Catalyst 0.75 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
500	85	5	3.2	30	58.62
				45	62.39
				60	66.89

**Table 6: Yield Observed at Different Reaction Times for Molar Ratio of 4.5:1
(Catalyst 1.0 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
500	85	5	4.2	30	59.56
				45	63.52
				60	68.09

**Table 7: Yield Observed at Different Reaction Times for Molar Ratio of 6:1
(Catalyst 0.5 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
1000	220	10	4.5	30	63.16
				45	68.52
				60	71.77

**Table 8: Yield Observed at Different Reaction Times for Molar Ratio of 6:1
(Catalyst 0.75 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
1000	220	10	6.75	30	64.16
				45	69.52
				60	72.77

**Table 9: Yield Observed at Different Reaction Times for Molar Ratio of 6:1
(Catalyst 1.0 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
1000	220	10	9.1	30	66.12
				45	71.61
				60	73.7

**Table 10: Yield Observed at Different Reaction Times for Molar Ratio of 9:1
(Catalyst 0.5 Wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
500	166	5	2.32	30	77.82
				45	80.19
				60	84.37

**Table 11: Yield Observed at Different Reaction Times for Molar Ratio of 9:1
(Catalyst 0.75 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
500	166	5	3.5	30	79.52
				45	82.76
				60	88.53

**Table12: Yield Observed at Various Reaction Times for Molar Ratio of 9:1
(Catalyst 1.0 wt %)**

Kusum oil (gm)	Methanol Consumed (gm)	Acid Consumed (gm)	Catalyst Consumed (gm)	Reaction Time (in minutes)	Yield (%)
500	166	5	4.65	30	83.07
				45	85.26
				60	91.25

The comparison of physico-chemical properties of neat petrodiesel, kusum oil and kusum biodiesel is tabulated as under:

Table13: Comparison of Physico-Chemical Properties of Neat Petrodiesel, Kusum Oil and Kusum Biodiesel

Sl.No.	Property	Petro Diesel	Kusum Oil	Kusum Biodiesel	Unit	Limit
1	Appearance	Clear	Clear	Clear	----	----
2	Color	----	Golden Brown	Brownish	----	----
3	Density at 15°C	823.9	890	870	kg/m ³	860-900
4	Kinematic viscosity at 40°C	4.86 x 10 ⁻⁶	41.51	4.9 x 10 ⁻⁶	m ² /s	3.5-5 x 10 ⁻⁶
5	Flash point	51	-	>66	°C	Min 100
6	Sulphur content	0.35-0.55	-	0.01	Wt %	Max 0.05
7	Water content	0.005	-	0.05	Wt %	0.02-0.05
8	Calorific Value	45.49	38.50	41.60	MJ/kg	----

While comparing the properties, it is found that the density of kusum biodiesel is slightly less than the neat kusum oil. However, kusum biodiesel's density is around 5.5% higher than petrodiesel and it was compatible with ISO 12185 standard limit of 0.86-0.89 g/cc. Kinematic viscosity of the kusum oil was reduced by a large amount from 41.51 m²/s to nearly 4.9x10⁻⁶ m²/s after transesterification process. The viscosity of the produced biodiesel sample was compatible with the ASTM D6751. The heating value shown by the kusum biodiesel sample was very much comparable with petrodiesel.

4.3 Performance Testing on a Multi Cylinder CI Engine

4.3.1 Preparation of Biodiesel Blends

Biodiesel blends of kusum biodiesel with petrodiesel have been prepared for the conduct of performance testing. From the literature overview it is evident that the dilution or blending of nonedible oil with petrodiesel fuel would bring the viscosity

close to a specified range. In this experimental study experiments are performed with pure petrodiesel and with different blends of biodiesel B5 (95% petrodiesel, 5% kusun biodiesel), B10 (90% petrodiesel, 10% kusun biodiesel), B15 (85% petrodiesel, 15% kusun biodiesel), and B20 (80% petrodiesel, 20% kusun biodiesel).

4.3.2 Experimental Setup for Performance Testing

The schematic diagram of the experiment setup is shown in Figure 9. The actual setup consists of four stroke, four cylinder, Tata Indica, diesel engine connected to eddy current type dynamometer for loading, as shown in Figure 10. It is attached with necessary instruments for combustion pressure and crank-angle measurements. The signals are interfaced to computer through engine indicator for $p-\theta$ diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up also consists of an air box, dual fuel tank, manometer, fuel measuring unit and transmitters for air and fuel flow measurements as shown in Figure 11. Windows based engine performance analysis software package “Enginesoft” is used for on-line performance evaluation. The main aim of engine performance tests is to investigate the suitability and effect on performance of blending of biodiesel in comparison to the petrodiesel fuel. Table 14 gives specifications of the experimental set-up used to compute the performance parameters.

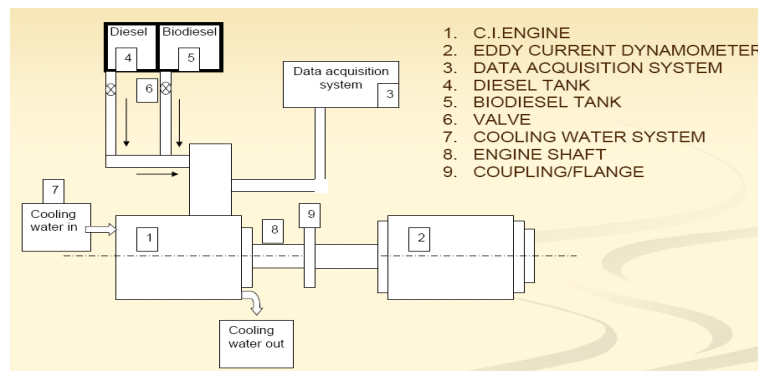


Figure 9: Schematic Diagram of the Experimental Set-up



Figure 10: Actual Experimental Setup for Performance Testing (ENGINE)



Figure 11: Actual Experimental Setup for Performance Testing (with Air and Fuel Flow Measurements)

Table 14: Specifications of the Experimental Set-Up

S.No.	Parameter	Specification
1.	Make	TELCO
2.	Model	TATA Indica
3.	Type	4-stroke, Four cylinder, inline, diesel engine indirect injection
4.	Maximum power (kW)	39 kW @ 5000 RPM
5.	Maximum Torque (N-m)	85 Nm @ 2500 RPM
6.	Cylinder bore (mm)	75mm
7.	Stroke (mm)	79.5mm
8.	Compression ratio	22:1
9.	Maximum engine speed (RPM)	5000 RPM
10.	Total Volume	1405 cc
11.	Fuel system	Rotary FI pump (Indirect Injection)
12.	Lubrication system	Pressure feed
13.	Combustion chamber	Swirl type
14.	Cooling system	Water cooling System
15.	Dynamometer	Type: eddy current, water cooled, with loading unit
16.	Piezo sensor	Range 5000 PSI, with low noise cable
17.	Crank angle sensor	Resolution 1 Deg, Speed 5000 RPM with TDC pulse
18.	Data acquisition device	NI USB-6210, 16-bit, 250kS/s.
19.	Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
20.	Load indicator	Digital, Range 0-50 kg, Supply 230V AC
21.	Load sensor	Load cell, type strain gauge, range 0-50 kg
22.	Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
23.	Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
24.	Software	“Enginesoft” Engine performance analysis software
25.	Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH

4.4 Emission Measuring Equipments

There are two basic types of emission measuring equipments which are used to measure emission:

- (i) Smoke Meter
- (ii) Exhaust Gas Analyser

4.4.1 Smoke Meter

There are two basic types of smoke meters which are used to measure smoke density:

- (i) Filter darkening type
- (ii) Light extinction type

The light extinction type of meters can measure both white and black smoke whereas the filter paper darkening type meters can give only black smoke. The light extinction meter can be used for continuous measurements while the filter type can be used only under steady state conditions.

AVL smoke meter also work 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 at the other end. The amount of light passed through this smoke column is used as an indication of smoke level. This smoke density is defined as the ratio of electric output from the photocell when sample is passed through this smoke column to the electric output when clean air is passed through it. The fraction of the light transmitted through the smoke (T) and the length of the light path (L) are related by the Beer-Lambert law.

$$T = e^{-KL}$$
$$K = n A \theta$$

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



Figure 12: AVL Smoker Meter

Table 15: General Specification of AVL 437 Smoke Meter

Accuracy and Reproducibility	$\pm 1\%$ full scale reading
Measuring range	0 – 100 % capacity in %
Heating Time	Approx. 20 minutes
Light source	Halogen bulb 12 V / 5W

4.4.2 Exhaust Gas Analyser

AVL Di gas analyser is being used to measure the amount of CO, HC, CO₂, NO_x and O₂. AVL Di gas analyser is a non dispersive infrared type analyser. The infrared energy of a particular wavelength or frequency is peculiar to a certain gas; the gas will absorb the infrared energy of this wavelength and transmit the infrared energy of other wavelength.



Figure 13: AVL Exhaust Gas Analyser

Table 16: General Specifications of AVL Di-Gas Analyser

Measurement principle	CO, HC, CO ₂ : Infrared measurement O ₂ : Electrochemical measurement NO _x : Electrochemical measurement
Dimensions	432 x 230 x 470 mm (w x h x l)

Table 17: Measurement Ranges of AVL Di-Gas Analyser

S.No.	Parameter	Measurement Range	Resolution
1	CO	0-10% vol	0.01% vol
2	CO ₂	0-20% vol	0.1% vol
3	HC	0-20000 ppm vol	1 ppm
4	NO _x	0-5000 ppm vol	1 ppm
5	O ₂	0-25% vol	0.01% vol

4.5 Formulation Used for Calculation of Various Parameters

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

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

$$\text{Brake Thermal Efficiency (\%)} = \frac{\text{Brake power (kW)} \times 3600 \times 100}{\text{Fuel flow(kg/h)} \times \text{Calorific value(kJ/kg)}}$$

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

$$\text{Brake specific energy consumption (MJ/kWh)} = \frac{\text{BSFC (kg/kW-h)} \times \text{Calorific value(kJ/kg)}}{1000}$$

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

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

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

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

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

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

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

$$\text{Heat in Exhaust (calculate } C_{pex} \text{ value): } C_{pex} = \frac{F_4 \times C_p \times (T_4 - T_3)}{(F_1 + F_2) \times (T_5 - T_6)}$$

Where,

C_{pex} Specific heat of exhaust gas (kJ/kg °C).

C_{pW} Specific heat of water (kJ/kg °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 (°C).

T_1 Engine water inlet temperature (°C).

T_2 Engine water outlet temperature (°C).

T_3 Calorimeter water inlet temperature (°C).

T_4 Calorimeter water outlet temperature (°C).

T_5 Exhaust gas to calorimeter inlet temp (°C).

T_6 Exhaust gas from calorimeter outlet temp (°C)

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

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

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

4.6 Experimental Procedure for Measuring Biodiesel Performance

As described in earlier section 4.3.2 the experimental setup consists of four stroke, four cylinder, Tata Indica, Diesel Engine connected to eddy current type dynamometer for loading. Ensure that the cooling water circulation for eddy current dynamometer, piezo sensor, engine cooling and calorimeter is in proper order. Start the set up and run the engine at no load for 4-5 minutes till the operating temperature is achieved. Gradually increase throttle to full open condition and load the engine simultaneously maintaining engine speed at 4000 RPM. Waited for approximately 3 minutes as the engine achieve steady state and collect the reading as per observations provided. Gradually increased the load to decrease the speed in steps of 500 RPM up to 4000 RPM and repeat the observations. The fuel is shifted from petrodiesel to the blend of biodiesel and after every 5 minutes interval and three consecutive reading were taken at selected RPM. The data for each set of time is compared with the petrodiesel's observation and average variation is taken as the difference in the performance parameters. The same series of proceeding is followed with different speed ranges and a different blend of biodiesel and observation tables are prepared.

Table 18: Observation Table for B0

R.P.M.	Brake Power (kW)	Bsfc (g/kWh)	BSEC (MJ/kW-hr)	CO (% by vol)	HC (ppm)	NOx (ppm)	Smoke Opacity(%)
1000	12.78	335.1	14.20824	0.894	23	121	14
1500	20.53	331	14.0344	0.562	16	178	20
2000	26.47	333	14.1192	0.356	10	193	30
2500	31.15	354	15.0096	0.31	7	210	57
3000	37.89	390	16.536	0.462	7	238	70
3500	36.14	432	18.3168	0.723	6	215	79
4000	33.93	488	20.6912	0.811	6	240	93

Table 19: Observation Table for B5

R.P.M.	Brake Power (kW)	Bsfc (g/kWh)	BSEC (MJ/kW-hr)	CO (% by vol)	HC (ppm)	NOx (ppm)	Smoke Opacity(%)
1000	12.68159	353.8321	14.50712	0.71815	16.9556	136.04	10
1500	20.37192	349.5029	14.32962	0.451455	11.7952	200.125	16
2000	26.26618	351.6147	14.4162	0.285975	7.372	216.99	24
2500	30.91015	373.7886	15.32533	0.249023	5.1604	236.103	45
3000	37.59825	411.801	16.88384	0.371125	5.1604	267.583	55
3500	35.86172	456.1488	18.7021	0.580786	4.4232	264.211	63
4000	33.66874	515.2792	21.12645	0.723818	4.4232	269.832	80

Table 20: Observation Table for B10

R.P.M.	Brake Power (kW)	Bsfc (g/kWh)	BSEC (MJ/kW-hr)	CO (% by vol)	HC (ppm)	NOx (ppm)	Smoke Opacity(%)
1000	12.57296	354.6698	14.3302	0.535327	15.9413	134.8545	10
1500	20.19741	350.3304	14.15487	0.336526	11.0896	198.381	15
2000	26.04119	352.4472	14.2404	0.213173	6.931	215.0985	23
2500	30.64537	374.6736	15.13844	0.185628	4.8517	234.045	43
3000	37.27618	412.776	16.67794	0.276646	4.8517	265.251	52
3500	35.55453	457.2288	18.47403	0.432932	4.1586	239.6175	60
4000	33.38033	516.4992	20.86881	0.485627	4.1586	267.48	75

Table 21: Observation Table for B15

R.P.M.	Brake Power (kW)	Bsfc (g/kWh)	BSEC (MJ/kW-hr)	CO (% by vol)	HC (ppm)	NOx (ppm)	Smoke Opacity (%)
1000	12.38765	358.3559	14.26256	0.459516	14.8511	133.705	10
1500	19.89973	353.9714	14.08806	0.288868	10.3312	196.69	17
2000	25.65737	356.1102	14.17319	0.182984	6.457	213.265	24
2500	30.1937	378.5676	15.06699	0.15934	4.5199	232.05	45
3000	36.72678	417.066	16.59923	0.237468	4.5199	262.99	55
3500	35.0305	461.9808	18.38684	0.371622	3.8742	237.575	63
4000	32.88835	521.8672	20.77031	0.416854	3.8742	265.2	79

Table 22: Observation Table for B20

R.P.M.	Brake Power (kW)	Bsfc (g/kWh)	BSEC (MJ/kW-hr)	CO (% by vol)	HC (ppm)	NOx (ppm)	Smoke Opacity(%)
1000	12.32375	359.6628	14.17071	0.409631	12.3027	138.593	9
1500	19.79708	355.2623	13.99733	0.257508	8.5584	203.881	15
2000	25.52502	357.4089	14.08191	0.163119	5.349	221.062	22
2500	30.03795	379.9482	14.96996	0.142042	3.7443	240.534	41
3000	36.53733	418.587	16.49233	0.211688	3.7443	272.605	50
3500	34.8498	463.6656	18.26842	0.331279	3.2094	269.169	57
4000	32.7187	523.7704	20.63655	0.3716	3.2094	274.896	72

CHAPTER - 5

RESULT and DISCUSSION

5.1 Result of the Kusum Biodiesel Production

The resultant yield obtained from the experimental work of kusum biodiesel production with different reaction time(s), molar ratio(s) & percentage(s) of catalyst is shown in Table 23.

Table 23: Yield Vs Reaction Time at Different Molar Ratio(s) & Catalyst (KOH) Percentage

Percentage Catalyst	Molar ratio 4.5:1		Molar ratio 6:1		Molar ratio 9:1	
	Reaction Time (in minutes)	Yield %	Reaction Time (in minutes)	Yield %	Reaction Time (in minutes)	Yield %
0.5wt%	30	57.97	30	63.16	30	77.82
	45	61.45	45	68.52	45	80.19
	60	65.63	60	71.77	60	84.37
0.75wt%	30	58.62	30	64.16	30	79.52
	45	62.39	45	69.52	45	82.76
	60	66.89	60	72.77	60	88.53
1.0wt%	30	59.56	30	66.12	30	83.07
	45	63.52	45	71.61	45	85.26
	60	68.09	60	73.7	60	91.25

From Figure 14 (a) it is observed that during the reaction with a molar ratio of 4.5:1 maximum yield of 68.09% was obtained with reaction time of 60 minutes and 1% of catalyst was used. However for the same time period the yield obtained was 66.89% and 65.63% for 0.75% & 0.5% catalysts respectively.

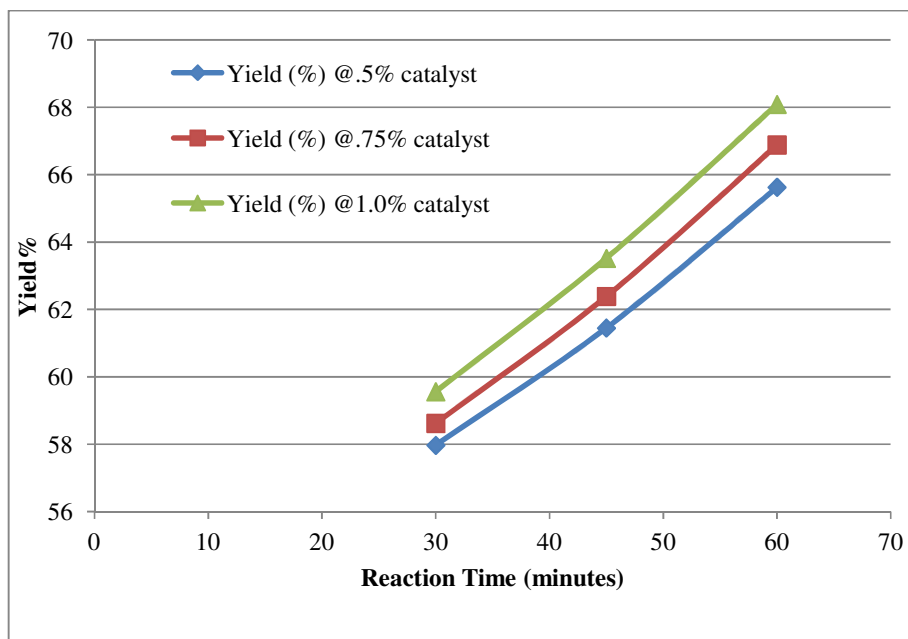


Figure: 14 (a) Yield Vs Reaction Time at 4.5:1 Molar Ratio

When a molar ratio of 6:1 was used it was observed that the maximum yield of 73.70% was obtained for 60 minutes reaction time and 1% of catalyst. However for the same time period the yield obtained was 72.77% and 71.77% with 0.75% & 0.5% catalyst respectively as shown in Figure14 (b). Though it has been observed by the different researchers that the molar ratio of 6:1 or higher generally gives the maximum yield (higher than 98% by weight) and lower molar ratios take a longer time to complete the reaction. However the case may be different for high FFA oil.

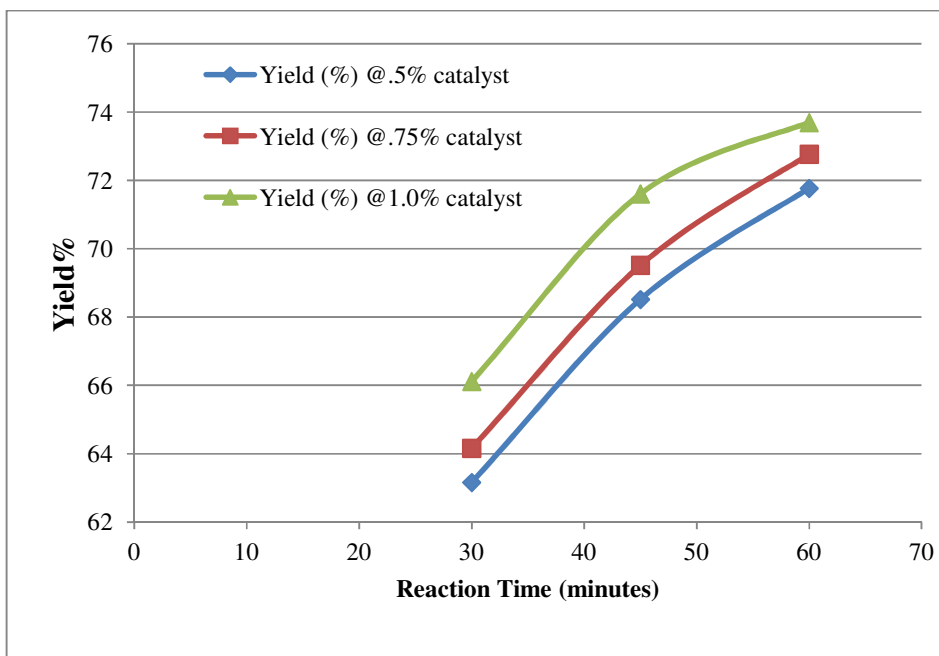


Figure: 14 (b) Yield Vs Reaction Time at 6:1 Molar Ratio

While working with the molar ratio of 9:1 it was observed that the maximum yield of 91.25% was obtained for 60 minutes reaction time and 1% of catalyst. However for the same time period the yield obtained was 88.53% and 84.37% with 0.75% & 0.5% catalyst respectively as shown in Figure14 (c).

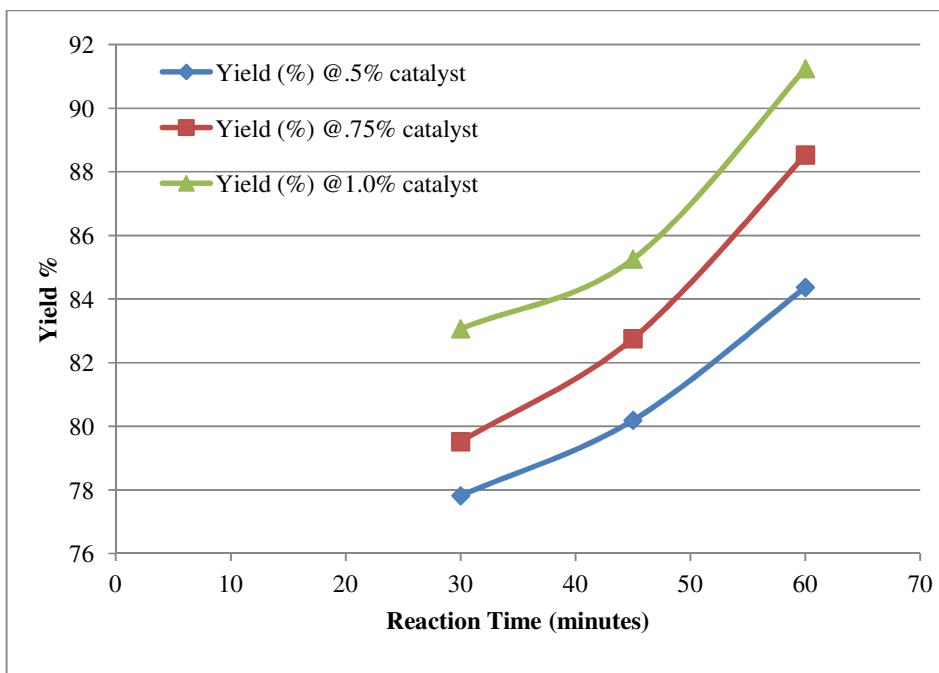


Figure14(c): Yield Vs Reaction Time at 9:1 Molar Ratio

Figure 14(d) represents the comparison for yield obtained at different reaction time, molar ratios and catalyst percentages. It is worth to mention here that the excess molar ratios increase the conversion rate but leads to difficulties in the separation of the glycerol which was observed when a molar ratio of 12:1 was tried. So at optimum molar ratio only the process gives higher yield and easier separation of the glycerol. Hence it can be stated that the optimum molar ratios can be different for different type and quality of the vegetable oil as in the case of kusum oil specimen the maximum yield of 91.25% was obtained for 60 minutes reaction time and 1% of catalyst.

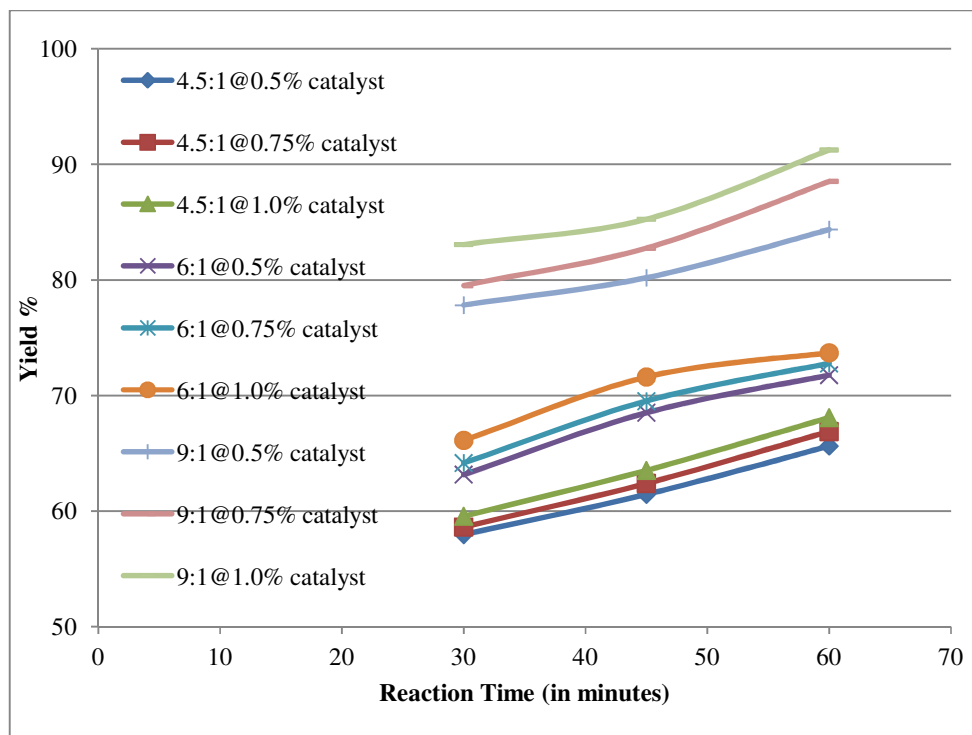


Figure14 (d): Comparison for Yield Vs Reaction Time at Different Molar Ratio(s) & Catalyst (KOH) Percentage

5.2 Result of the Performance Testing

Figure(s) 15 to 22 show(s) the performance and emission parameters with respect to speed (engine RPM) considering diesel and B5, B10, B15 and B20 blends

of kusum biodiesel and petrodiesel. The performance parameters include brake power, brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency, whereas the emission parameters include % of carbon dioxide, carbon monoxide, hydrocarbon, oxides of nitrogen and smoke opacity. All observations are taken in the speed range of 1000 to 4000 RPM at an increment of 500 RPM. The discussion on various calculated engine performance parameters is given below:

5.2.1 Brake Power Vs Engine RPM

The variation of brake power of biodiesel blends w. r. t. speed is shown in Figure 15. It is observed that at all speed ranges the brakepower of the petrodiesel fuel is slightly higher than the biodiesel blends. At all speed ranges the brake power observed is higher for B5 blend as compared to other biodiesel blends. This could be due to the properties like viscosity, CN and calorific value of B5 are very close to the petrodiesel and are least affected as compared to other test fuel samples. It is observed that in comparison to petrodiesel there was a reduction in the brake power by 0.77%, 1.62%, 3.07% and 3.57% for B5, B10, B15, and B20 blends respectively. Hence it can be concluded that as the biodiesel has lower heating value (10% lower than petrodiesel), because of substantial amount of oxygen in the fuel it is quiet possible but at the same time the biodiesel has higher specific gravity (0.87) as compared to petrodiesel (0.85) so overall impact is approximately 5% lower energy content per unit volume.

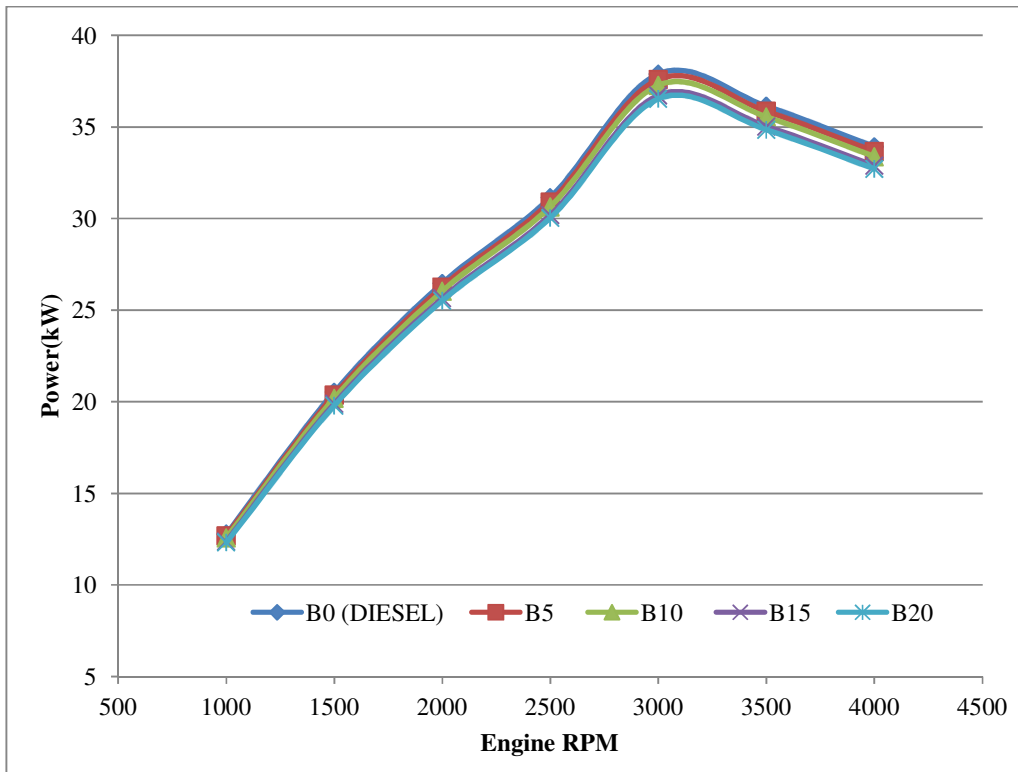


Figure15: Brake Power Vs Engine RPM

5.2.2 Brake Specific Fuel Consumption (Bsf) Vs Engine RPM

The variation of brake specific fuel consumption of biodiesel blends with speed is shown in Figure 16. The Bsf can be defined as the ratio of mass of the fuel consumed to the brake power. The specific fuel consumption gets increased when the kusum biodiesel blending percentage increased. The increment in the specific consumption of B5, B10, B15 and B20 blends as compared to petrodiesel is approximately 5.59%, 5.84%, 6.94%, and 7.33%, respectively. From the increment percentage, it can be stated that the B20 blend has the highest specific fuel consumption value and it consumes more fuel to produce 1kW of power as compared to the petrodiesel . The higher SFC with higher percentage blends is mainly due to the fact that the biodiesel has lower calorific value than the petrodiesel.

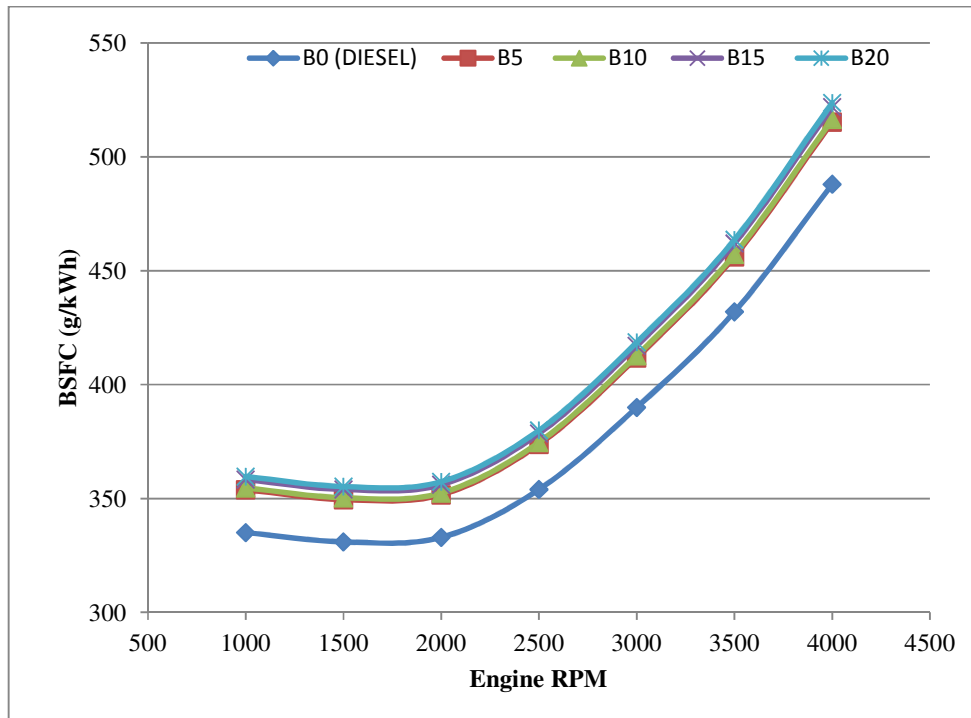


Figure16: Brake Specific Fuel Consumption (Bsfc) Vs Engine RPM

5.2.3 Brake Specific Energy Consumption (BSEC) Vs Engine RPM

Brake-specific energy consumption (BSEC) is a more suitable criterion as compared to brake specific fuel consumption (Bsfc) for comparing the fuels having different calorific values and densities. Several experimental investigations have been carried out by researchers around the world to evaluate the engine performance of different biodiesel blends [4]. For all test blends BSEC increases with increase in speed, but this increase in BSEC is relatively lower than the increase in BSFC, this may be attributed to the better combustion quality of the test blends. The B20 blend has lowest value of BSEC for all loading conditions after petrodiesel. This is because of lower calorific value of fuel.

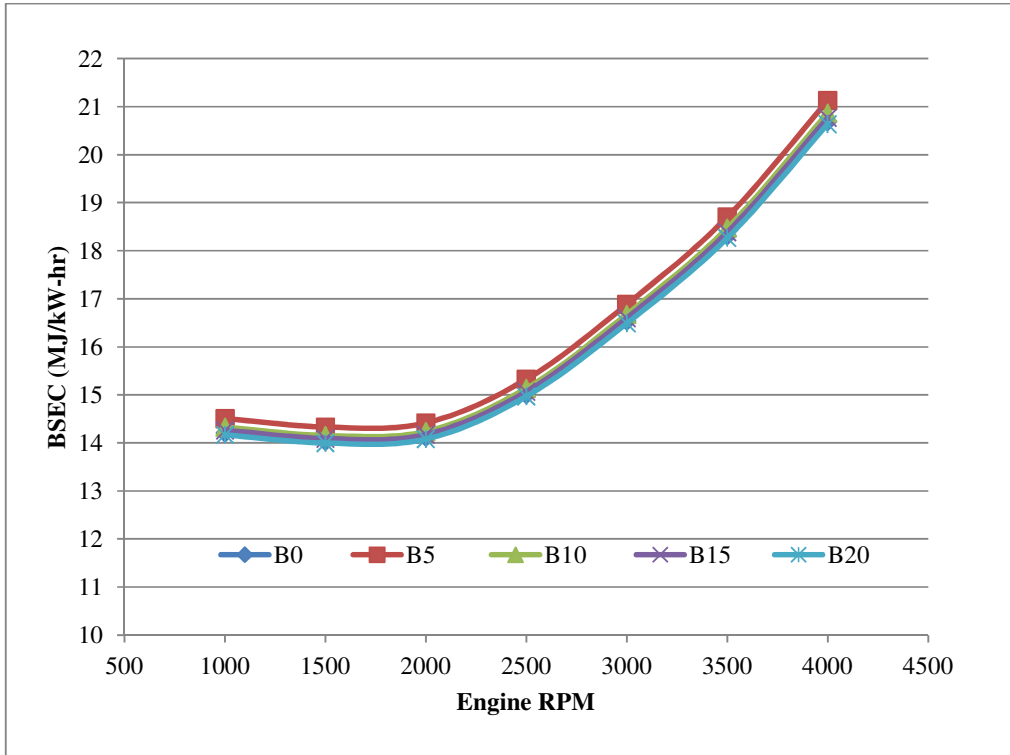


Figure17: Brake Specific Energy Consumption Vs Engine RPM

5.2.4 Brake Thermal Efficiency Vs Engine RPM

The percentage variation in the brake thermal efficiency of biodiesel at various speeds w. r. t. petrodiesel is shown in Figure 18.

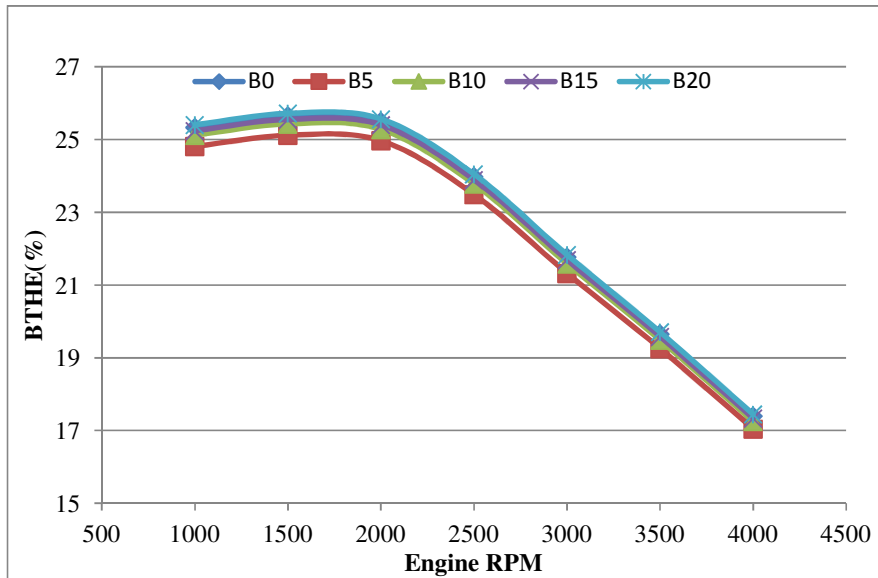


Figure18: Brake Thermal Efficiency Vs Engine RPM

For most of the speed ranges B20 blend shows increase in brake thermal efficiency than petrodiesel which can be attributed to the better combustion due to higher oxygen content of the blend and additional lubricity provided by the biodiesel. Further it can be concluded from the graph that at higher speeds the thermal efficiency decreases for all fuels. The methyl ester or biodiesel of kusum oil has higher viscosity, higher density and lower calorific value than petrodiesel. Higher viscosity and higher density leads to decreased atomization and fuel vaporization which deteriorates the combustion. Based on the results it can be concluded that the performance of the engine with biodiesel blends is compare able to petrodiesel, in terms of brake thermal efficiency.

5.3 Result of the Emission Testing

5.3.1 Carbon Monoxide Vs Engine RPM

Carbon monoxide is formed during the combustion process with rich fuel-air mixture when there is insufficient or scarcity of oxygen to completely burn the whole amount of carbon present in the fuel. From the observations and Figure 19 it can be stated that the reduction in the % of CO is maximum in case of B20 blend and at 2500 RPM. This could be due to some of the CO produced during combustion of biodiesel might have converted into CO₂ by taking up the extra oxygen molecules present in the biodiesel. However, after 2500 RPM it start increasing, which may be due to the increased fuel- air ratio at such higher loads when larger quantities of fuel is injected in to the combustion chamber, which results in lowering A/F ratio.

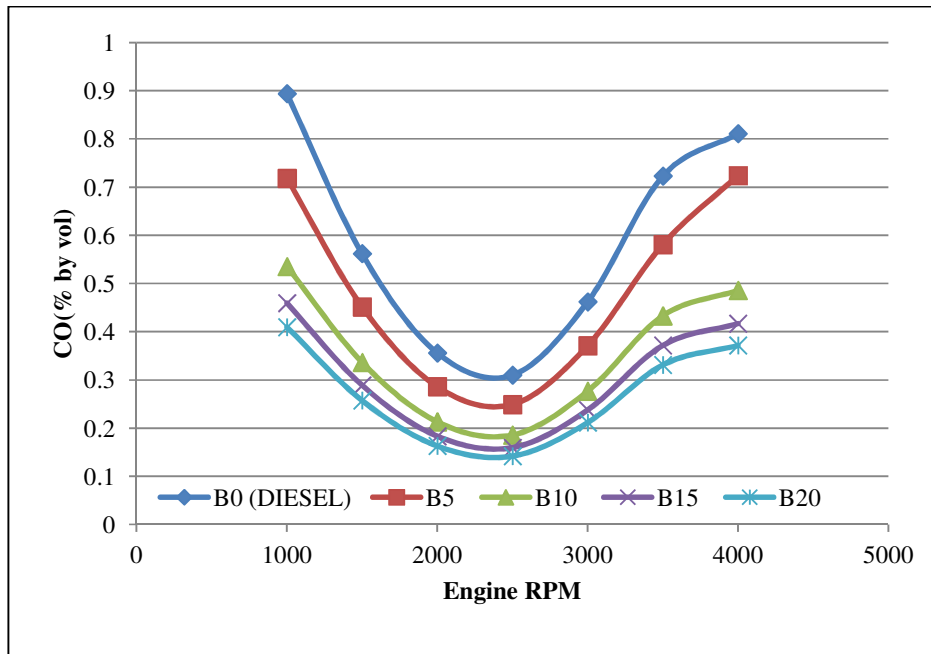


Figure19: Carbon Monoxide Vs Engine RPM

5.3.2 Unburnt Hydrocarbon Vs Engine RPM

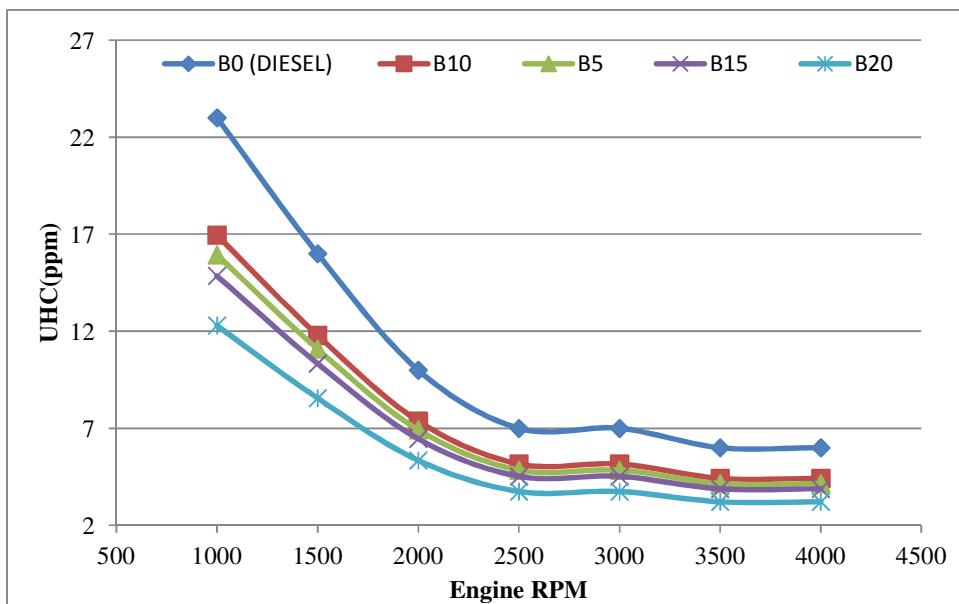


Figure20: Unburnt Hydrocarbon Vs Engine RPM

A sample of diesel exhaust may be free from unburnt hydrocarbons and at the same time can have its heavy concentration because of the effect of engine type.

Figure 20 shows the UHC emissions for all the blended and petrodiesel fuel. The B20 blend produced the lowest UHC emission (3 ppm) at 4000 RPM, followed by the B15 blend (4 ppm) and petrodiesel (6 ppm). The reduction in UHC is mainly the result of complete combustion of the B20 blend fuel within the combustion period as confirmed by combustion characteristics (for palm oil diesel and other biological fuels) such as net heat release rate and mass burn fraction (Masjuki et al. 1997; Masjuki, Kalam, and Maleque 2000). Hence, it could be stated that the B20 blend fuel with the conventional petrodiesel could be effective as an alternative fuel for diesel engines because it reduced the emission levels of UHC.

5.3.3 Oxides of Nitrogen Vs Engine RPM

High peak temperature and availability of oxygen are two main reasons for the formation of NO_x . The effect of the biodiesel blended fuel on NO_x emission is shown in Figure 21. At high combustion temperature in the cylinder, the long chain hydrocarbons break into short chain hydrocarbons which contain high energy in the polarized form and promotes to NO_x formation. Gong et al. (2007) observed that the NO_x concentration gets increased with oxygenate additive and decrease with antioxidant additives [15]. It may also be noted that emission of NO_x also varies with the different family of feed-stocks for biodiesel. Moreover, the problem of increased NO_x emission can be effectively tackled by retarding the fuel injection timing.

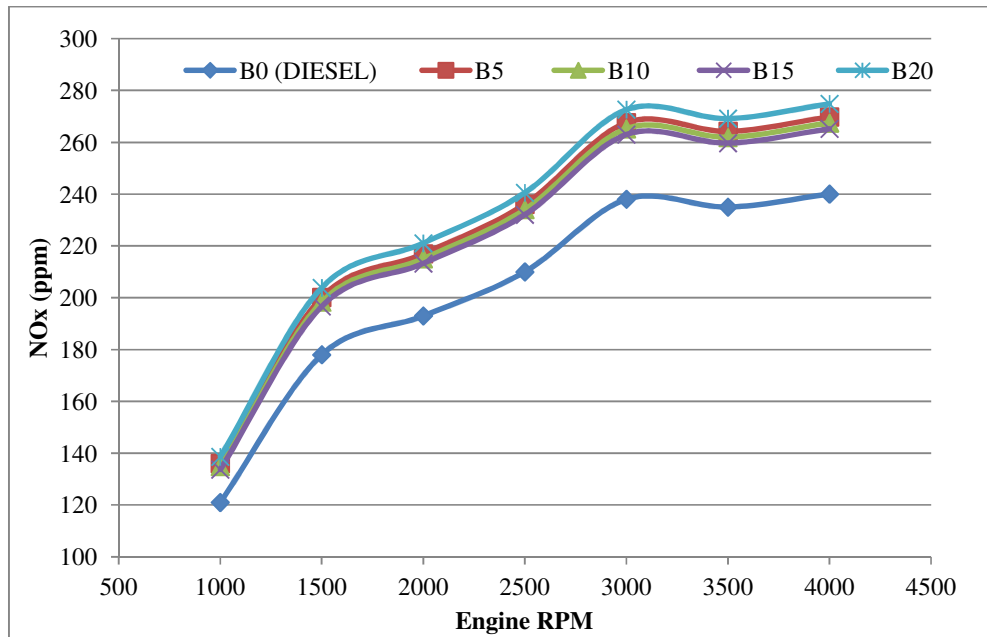


Figure 21: Oxides of Nitrogen Vs Engine RPM

5.3.4 Smoke Opacity Vs Engine RPM

Smoke opacity is a direct measure of smoke and soot. To understand the pollution aspect of biodiesel, the percentage variation in the smoke opacity percentage

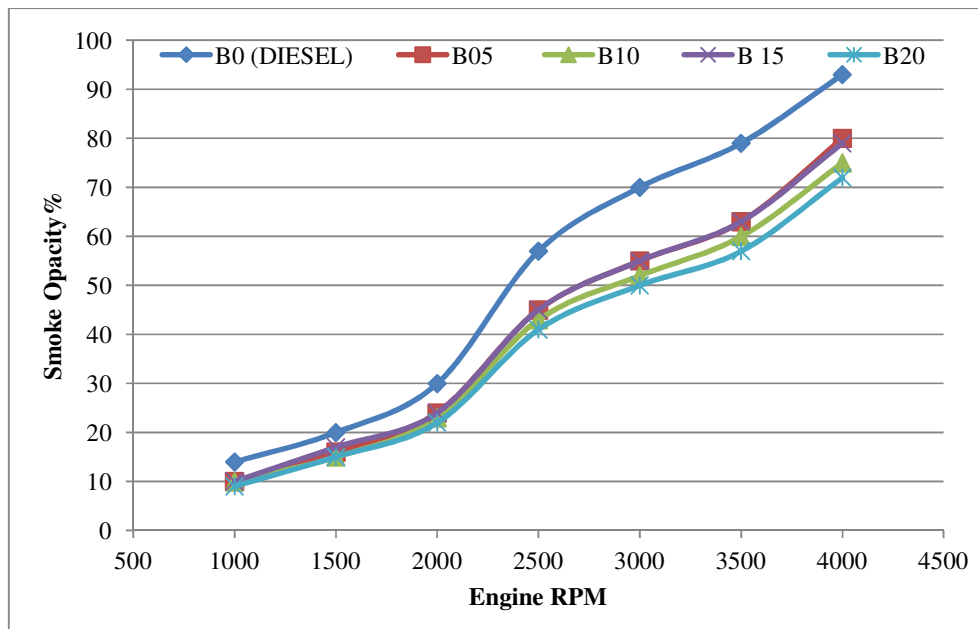


Figure 22: Smoke Opacity Vs Engine RPM

of biodiesel at various speeds compared to petrodiesel is shown in Figure 22. It is observed that biodiesel and its blends with petrodiesel produced less smoke than the petrodiesel. This could be due to the basic difference in their chemical structure, absence of sulphur content and the presence of oxygen in the molecule of the biodiesel. The oxygen content helps in its complete burning as compared to petrodiesel. It can also be interpreted that smoke level increased sharply with increase in speed beyond 2000 RPM for all fuels tested. It was mainly due to the decreased air–fuel ratio at such higher loads when larger quantities of fuel is injected in to the combustion chamber, much of it goes unburnt into the exhaust.

CHAPTER - 6

CONCLUSIONS

In present work a biodiesel production study has been completed using conventional mechanical stirring method with kusum oil. Following conclusion has been made from the present study:

- In this experimental study the optimum reaction time for methylester formation is 120 minutes in total at a molar ratio of 9:1 and 1% catalyst level with conventional mechanical stirring method.

The variation of the engine performance and exhaust emission parameters of a four cylinder, four stroke, indirect injection, diesel engine using 5, 10, 15, and 20 % blends of kusum oil biodiesel with petrodiesel were investigated and compared with the petrodiesel. Performance of biodiesel is compared for the parameters like brake power, brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency, and emission are characterized by CO, HC, NO_x, and smoke opacity measurement. Based on experimental results, following conclusions can be drawn:

- Biodiesel gets mixed completely with petrodiesel and homogeneous blends were achieved, and no phase separation was observed in any of the blends.
- At intermediate engine speeds (2500-3000 RPM) higher percentage of variation of brake power are obtained for biodiesel blends relative to petrodiesel.
- The brake specific fuel consumption gets marginally increased when the biodiesel blending percentage increased.
- Except at starting speed, the variation of brake thermal efficiency improves with increase in both engine speed and blending percentage.

- Smoke opacity reduces with increase in biodiesel blending percentage and for intermediate speed range the values observed are the lowest.
- In this experimental study B20 blend was found to be the optimum biodiesel blend giving maximum increase in thermal efficiency, lowest BSEC and advantage in terms of lowering emissions.
- The trends for variations of performance parameters using kusum oil biodiesel blends do not show any sign of deterioration as compared to petrodiesel.

CHAPTER - 7

SCOPE FOR THE FUTURE WORK

From the previous chapters it can be easily recalled that the biodiesel produced from the kusum oil is a promising alternative fuel for diesel engines. Integrated economic value assessment of all kusum products is important in order to develop sustainable management plans that benefit local people in the long term.

There are a lot of scopes in this field which are discussed below:

- Cultivation of kusum plants may be promoted in the areas having 35–47°C temperature and 750–2500 mm annual rainfall, as this species grows in marginal lands and produces a range of forest products,
- Introduction of alternating catalysts such as heterogeneous catalysts may reduce the time consumed in two step transesterification,
- Introduction of different production techniques like ultrasonic and hydrodynamic cavitation may definitely help in reducing the time required for giving yield.
- Effects of higher or different fuel injection pressure on various performance parameters may be investigated.
- Compression ratios play an effective role in performance of an internal combustion engine. Hence, performance parameters may be investigated on various compression ratios.
- Effectiveness of kusum biodiesel blend may be studied with common rail direct injection system.
- Methodology to reduce the reversibility of biodiesel production with the time may be studied.

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