Literature Review

2.1 General

This chapter reviews the background information on the selected area for the subject of “Performance Analysis of a Compression Ignition Engine using Biodiesel from different Tree-Borne oils”. It describes, summarises, evaluates and clarifies the literature of the problem. It helps us to get a theoretical base for the research and determine the nature of the research.

2.1.1 Vegetable Oil Resources

As per Indian oil Research and Development report, availability of some Tree Borne Oil seeds in India are given in TABLE - 2.1 as given in [95]. Oil content in seeds is shown in TABLE - 2.2 as per [95]-[99].

**TABLE - 2.1 Availability of some Tree Borne Oil Seeds in India**

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Common Name</th>
<th>Botanical Name</th>
<th>Sr. No</th>
<th>Common Name</th>
<th>Botanical Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bawachi</td>
<td><em>Psoralea Corylifolia</em></td>
<td>14</td>
<td>Kusum Seed</td>
<td><em>Carthamus Functorius</em></td>
</tr>
<tr>
<td>2</td>
<td>Ajmoda</td>
<td><em>Carrum Roxburghianum</em></td>
<td>15</td>
<td>Mahua seed</td>
<td><em>Madhuca Longifolia</em></td>
</tr>
<tr>
<td>3</td>
<td>Amla</td>
<td><em>Emblica Officinalis</em></td>
<td>16</td>
<td>Malkangani</td>
<td><em>Celestrus Berlerica</em></td>
</tr>
<tr>
<td>4</td>
<td>Babul</td>
<td><em>Acacia Nilotica</em></td>
<td>17</td>
<td>Mango Seed</td>
<td><em>Mangifera Indica</em></td>
</tr>
<tr>
<td>5</td>
<td>Ban Tulsi</td>
<td><em>Ocimum Cannum</em></td>
<td>18</td>
<td>Nagarmotha</td>
<td><em>Cyperus Rotundus</em></td>
</tr>
<tr>
<td>6</td>
<td>Beheda Seed</td>
<td><em>Terminalia Berlerica</em></td>
<td>19</td>
<td>Neem Seed</td>
<td><em>Azadirachta Indica</em></td>
</tr>
<tr>
<td>7</td>
<td>Bel Fruit</td>
<td><em>Aegle Mamelos</em></td>
<td>20</td>
<td>Polanga</td>
<td><em>Calophyllum inophyllum</em></td>
</tr>
<tr>
<td>8</td>
<td>Bhilawa</td>
<td><em>Semecarpur Occidentale</em></td>
<td>21</td>
<td>Ratan Jyot</td>
<td><em>Jatropha Curcas</em></td>
</tr>
<tr>
<td>9</td>
<td>Charota Beej</td>
<td><em>Cassia Tora</em></td>
<td>22</td>
<td>Saal Seed</td>
<td><em>Shorca Tobusta</em></td>
</tr>
<tr>
<td>10</td>
<td>Kaju Shell Oil</td>
<td><em>Anacardium Occidentale</em></td>
<td>23</td>
<td>Simarouba</td>
<td><em>Simaroubaceae Quasia.</em></td>
</tr>
<tr>
<td>11</td>
<td>Kala Dana</td>
<td><em>Impomoea Hederacea</em></td>
<td>24</td>
<td>Tamarind Seed</td>
<td><em>Tamarindus Indicus</em></td>
</tr>
<tr>
<td>12</td>
<td>Kantkari</td>
<td><em>Argmon Mexicana</em></td>
<td>25</td>
<td>Tesu Beej</td>
<td><em>Burea Frondosa</em></td>
</tr>
<tr>
<td>13</td>
<td>Karanj Seed</td>
<td><em>Pongamia Pinnata</em></td>
<td>26</td>
<td>Zaphara</td>
<td><em>Anatto Seed</em></td>
</tr>
</tbody>
</table>
### TABLE - 2.2 Oil Content in Seeds

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Seed Name</th>
<th>Botanical Name</th>
<th>Oil Content (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ajmoda</td>
<td><em>Carrum Roxburghianum</em></td>
<td>1.08</td>
</tr>
<tr>
<td>2</td>
<td>Amla</td>
<td><em>Emblica Officinalis</em></td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Bawachi</td>
<td><em>Psoralea Corylifolia</em></td>
<td>5.0</td>
</tr>
<tr>
<td>4</td>
<td>Beheda</td>
<td><em>Terminalia Berlerica</em></td>
<td>15.6</td>
</tr>
<tr>
<td>5</td>
<td>Bhilawa</td>
<td><em>Semecarpur Occidentale</em></td>
<td>19.0</td>
</tr>
<tr>
<td>6</td>
<td>Charota</td>
<td><em>Cassia Tora</em></td>
<td>1.42</td>
</tr>
<tr>
<td>7</td>
<td>Karanja</td>
<td><em>Pongamia Pinnata</em></td>
<td>34.0</td>
</tr>
<tr>
<td>8</td>
<td>Kusum</td>
<td><em>Carthamus Functorius</em></td>
<td>30.0</td>
</tr>
<tr>
<td>9</td>
<td>Mahua</td>
<td><em>Madhuca Indica</em></td>
<td>35.0</td>
</tr>
<tr>
<td>10</td>
<td>Neem</td>
<td><em>Azadirachta Indica</em></td>
<td>20-50</td>
</tr>
<tr>
<td>11</td>
<td>Polanga</td>
<td><em>Calophyllum inophyllum</em></td>
<td>50.0</td>
</tr>
<tr>
<td>12</td>
<td>Simarouba</td>
<td><em>Simarouba glauca</em></td>
<td>60.0</td>
</tr>
<tr>
<td>13</td>
<td>Tamarind</td>
<td><em>Tamarindus Indicus</em></td>
<td>0.87</td>
</tr>
</tbody>
</table>

Agro – climatic preferences of some promising tree-borne oil seeds stated in [94] is presented in TABLE – 2.3

### TABLE – 2.3 Agro – Climatic Preferences of some Promising Tree-Borne Oil Seeds

<table>
<thead>
<tr>
<th>Source</th>
<th>Rainfall (mm)</th>
<th>Temperature, °C</th>
<th>Soil preference</th>
<th>Tree height, m</th>
<th>Suitability for agro-forestry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatropha curcas L</td>
<td>480-2400</td>
<td>20-28</td>
<td>Any type</td>
<td>3-5</td>
<td>Fence, Alley, Sole</td>
</tr>
<tr>
<td>Karanja</td>
<td>500-2500</td>
<td>31-38</td>
<td>Wide range</td>
<td>8-10</td>
<td>Bunds Border</td>
</tr>
<tr>
<td>Neem</td>
<td>750-1000</td>
<td>15-45</td>
<td>Deep clay</td>
<td>20</td>
<td>Border, Sole</td>
</tr>
<tr>
<td>Mahua</td>
<td>550-1500</td>
<td>28-46</td>
<td>Deep clay</td>
<td>18-20</td>
<td>Border, Wastelands</td>
</tr>
<tr>
<td>Polanga</td>
<td>750-5000</td>
<td>31-48</td>
<td>Sand/loamy</td>
<td>10-25</td>
<td>Waste lands, Sea coast</td>
</tr>
<tr>
<td>Simarouba</td>
<td>1000-4000</td>
<td>25-45</td>
<td>Well drained</td>
<td>15</td>
<td>Bunds, Sole</td>
</tr>
</tbody>
</table>

### 2.1.2 Oil Extraction Techniques

There are two main methods that have been identified for commercial oil extraction: (1) Mechanical extraction and (ii) Solvent extraction. Before the oil extraction takes place, seeds have to be dried. Seed can be either dried in the oven or sun dried. Mechanical expellers or presses can be fed with either whole seeds or kernels or a mix of both, but common practice is of using whole seeds. However, for chemical extraction only kernels are used as feed also stated in [67], [73] and [100]. The chemical structure of vegetable oil is shown in Fig. 2.1.
2.1.3 Advantages of Biodiesel over SVO and Diesel

Overall the technical difficulties and challenges that are faced by the use of vegetable oil and its blends as CI engine fuels are:

- Kinematic viscosity is higher than biodiesel and diesel
- Calorific value is lower
- Flash point in blends is unreliable
- Compatibility with CI engine material is a major problem.
- Engine modification may be required
- Cold weather operation of the engine is difficult
- Acceptance by engine manufacturers is difficult
- Insufficient availability of the vegetable oil
- Effects on engine performance and its durability
- Emission profile
- Long term storage is difficult

Advantages of biodiesel

- Biodegradability and non-toxic
- Renewability
- Lower sulphur content
- Lower emission
- Safe to handle and transport

2.1.4 Biodiesel Standards and Characterisation

The quality of biodiesel can be influenced by various factors including: the quality of feed stock, fatty acid composition, techniques of production and post production parameters. Therefore a standard and characterisation of biodiesel is required. The establishment of standardization for biodiesel is to be wholly owned by several countries. All alternative biodiesel fuels should meet the international standard specification
of biodiesel. A standard specification of biodiesel in several countries around the world is given in Appendix-IV.

2.2 Literature Review

The main goal of this experiment was to investigate practical parameters through analysis and experiments that would increase the efficiency and effectiveness of biodiesel operated C.I. engine; ultimately resulting in quality end products. Therefore in this research, significant studies have been reviewed under the following main headings:

- Diesel engine performance with straight vegetable oil (SVO).
- Production and processing of biodiesel from vegetable oils.
- Fuel Properties.
- Chemical composition of fuels.
- Performance and exhaust emissions of diesel engine with Diesel and Biodiesel Blends.
- Energy and Exergy analysis of C.I. engine with Diesel and Biodiesel Blends.
- Optimal performance parameters.

2.2.1 Diesel Engine Performance with SVO

A number of research works have been carried out with SVO. Some of the related articles on SVO are given below. It was observed that SVO posed operational and durability problems when subjected to long term usage in CI engine. These problems can be attributed to high viscosity, low volatility and poly saturated characters of vegetable oil as reflected in [88], [89], [92] and [176].

Barsic et al. (1981) conducted experiments using 100% sunflower oil, 100% peanut oil, 50% peanut oil with diesel. A comparison of the engine performance of Sunflower oil and peanut oil results showed that there was an increase in power and emissions.

Tadashi and Young (1984) evaluated the feasibility of rapeseed oil and palm oil for diesel fuel in a naturally aspirated direct injection diesel engine. It was found that vegetable oil fuels gave an acceptable engine performance and exhaust emission levels for short-term operation. However, they caused carbon deposit build-ups and sticking of piston rings with extended operation.

Hammerlein et al. (1991) conducted experiments on naturally aspirated turbocharged air cooled and water cooled engines using rapeseed oils. Experiments were conducted using filtered rapeseed oil. It has been reported that the brake power and torque using rapeseed oil as fuel are 2% lower than that of diesel. The heat release rate is very similar for both fuels. With all the engines tested, maximum brake power was obtained with rapeseed oil. Lower mechanical stresses and lower combustion noise were observed. The emission of CO and HC are higher, whereas NOx and particulate emission are lower in comparison with diesel fuel.

Z. Mariusz and J. Goettler (1992) conducted experiments on sunflower oil and recommended incorporating dual fuel pre-heater for durability improvements of diesel engines. The durability of the engine increased through the prevention of engine operation at low load and low speed conditions, reduced exposure time of fuel injection system at very high temperature conditions during transition process from high to light loads and elimination of fuel injection of oil during shut down period.
S. Dhinagar and B. Nagalingam (1993) tested neem, rice bran and karanja oil with a low heat rejection engine. An electric heater and exhaust gas was utilised for heating the oil. He observed that 1 to 4% lower efficiency was compared to that of diesel in case of without heating. However with heating the efficiency was improved.

Forson et al. (2004) conducted experimental investigation on pure jatropha, pure diesel and blends of jatropha and diesel in a direct injection single-cylinder diesel engine. The results obtained suggested that the above said oil exhibited similar performance and broadly similar emission levels under comparable operating condition. It was also observed that introduction of jatropha oil into diesel fuel appears to be effective in reducing the exhaust gas temperature.

Ramadhas et al. (2004) conducted experimental work by using rubber seed oil. He concluded that cold weather operation of the engine in not easy with vegetable oils. Raw vegetable oil can be used as fuel in diesel engines with some minor modifications. Results showed that the thermal efficiency was comparable to that of diesel with small amount of power loss. The particulate emissions of vegetable oils are higher than that of diesel fuel with a reduction in NOx.

Agarwal et al. (2008) studied the performance and emission characteristics of linseed oil, mahua oil, and rice bran oil in a stationary single cylinder four stroke diesel engine and compare it with mineral diesel. Observed that straight vegetable oils posed operational and durability problems when subjected to long term usage in C.I. engine. These problems are attributed to high viscosity, low volatility and poly saturated character of vegetable oils.

Agarwal et al. (2009b) experimented with preheated karanja oil and blends. Performance and emission characteristics were found to be very close to mineral diesel for lower blend concentration. However for higher blend concentration, performance and emission were observed to be marginally low.

Sidibe et al. (2010) reviewed the state of the art for SVO use as fuel in diesel engines, based on a bibliographic study (literature review). The 1st section of the document examines the type and quality of vegetable oils for fuel use in diesel engines. The second section discusses the advantages and disadvantages of two options recommended for SVO use in diesel engines: dual fuelling and blending with diesel fuel. He concluded that SVOs can be used as a replacement of diesel oil in the agricultural diesel engines. They can be directly produced locally in a short supply chain and offer the extra fuel needed to increase agricultural production. Their by-products can be used in agriculture and livestock production.

Acharya et al. (2011) conducted experiment on preheated SVO of karanja, kusum blends with diesel. Experiments were designed to study the effect of reducing kusum and karanja oil's viscosity by preheating the fuel, using a shell and tube heat exchanger. They concluded that, the engine performance with kusum and karanja oil (preheated), 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. The performance of karanja oil was found better than kusum oil in all respects. The viscosity of kusum and karanja oil was reduced by preheating to 100–130°C. It was found that in the above cases the viscosity was close to that of diesel—which would be suitable for the engines.

Masjuki et al. (2015) used preheated palm oil to run a C.I. engine. Preheating reduced the viscosity of fuel. Torque, Brake Power, Specific fuel consumption, exhaust emission and Brake Thermal Efficiency were found to be comparable to that of diesel.
2.2.2 Production of Biodiesel from Vegetable Oils

Many researchers have experimented the process of conversion of vegetable oil to biodiesel by using different oil seeds. Related articles are mentioned below.

Four techniques can be used to reduce the viscosity of vegetable oils for producing biodiesels. Brief summary of these technologies are described in [25], [48], [66]-[67] and [101]-[102]:

2.2.2.1 Pyrolysis (Thermal Cracking)

Cracking is the process of conversion of one substance into another by means of heat or with the aid of catalyst. It involves heating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules. The pyrolyzed material can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids.

2.2.2.2 Blending

Vegetable oil can be directly mixed with diesel fuel and used in diesel engine. This method does not require any chemical process. It has been observed that 100% vegetable oil in diesel engine is not practical. Therefore, blending of vegetable oil to diesel has been considered to give good results for diesel engines.

2.2.2.3 Micro-Emulsification

To solve the problem of high viscosity of vegetable oil, micro emulsions with solvents such as methanol, ethanol or butanol have been used. The formulation of hybrid diesel fuel by solubilisation of vegetable oil/alcohol mixtures through the addition of amphiphiles was initially known as micro emulsion. A micro emulsion is defined as a transparent, equilibrium thermodynamically stable colloidal dispersion of microstructure with diameter ranges from 100 A to 1000A.

2.2.2.4 Transesterification

The main reaction for converting oil to biodiesel is called transesterification. The transesterification process is the reaction of alcohol with triglyceride oils containing vegetable oils, animal fats or recycled greases, forming free fatty acid esters and glycerine. The reaction requires heat and a strong base catalyst, such as sodium hydroxide or potassium hydroxide.

Oil containing high free fatty acid (FFA) (>1.5%) is difficult to be converted into biodiesel because it will form soap with alkaline catalyst which reduces the amount of catalyst for transesterification. The soap can also prevent separation of the biodiesel from the glycerine fraction. All most all non edible oils contain high FFA, which is far beyond the 1.5% level. Few researchers have worked with feedstock having higher FFA levels using alternative processes. Pre-treatment is carried out to reduce the free fatty acids of this feedstock to less than 1.5% before transesterification reaction to produce biodiesel. Canakci and Gerpen [15] developed a two-stage process i.e. esterification shown in Fig. 2.2 and transesterification shown in Fig. 2.3, where the level of FFA could immediately be reduced to less than 1% using an acid catalyst (H2SO4) at the first stage and base catalyst (KOH) in the second stage. This process was also followed by many other researchers [16]-[26], [55], [60], [79] and [135].

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The methanol is removed after the biodiesel and glycerine have been separated, to prevent the reaction from reversing itself. The methanol is cleaned and recycled back to the beginning of the process. Once biodiesel is separated from the glycerine, it goes through a purification process to remove excess alcohol, residual catalyst and soaps. This consists of one or more washings with clean water. It is then dried and sent to storage. The glycerine by-product contains un-reacted catalyst and soaps that are neutralized with an acid. Water and alcohol are removed to produce 50% - 80% crude glycerine.

\[
\text{R}_1\text{COOH} + \text{ROH} \xrightarrow{\text{Catalyst}} \text{R}_1\text{COOR} + \text{H}_2\text{O}
\]

\[
\text{Fatty acid} \quad \text{Alcohol} \quad \text{Alkyl esters}
\]

Fig. 2.2 Esterification of Free Fatty Acids

\[
\text{O} \\
\text{CH}_2\text{O}\text{C}\text{R}_1 \\
\text{O} \\
\text{CH}_2\text{O}\text{C}\text{R}_2 + 3\text{CH}_3\text{OH} \xrightarrow{\text{KOH/NaOH}} \text{CH}_3\text{O}\text{C}\text{R}_2 + \text{CHOH} \\
\text{O} \\
\text{CH}_2\text{O}\text{C}\text{R}_3 \\
\text{O} \\
\text{CH}_2\text{O}\text{C}\text{R}_3
\]

Fig. 2.3 Transesterification of Triglycerides

Freedman et al. (1984) investigated the transesterification reaction variables that affect yield and purity of the product esters from Cottonseed, Peanut, Soybean and Sunflower oils include molar ratio of alcohol to vegetable oil, type of catalyst (alkaline vs. Acidic), temperature and degree of refinement of the vegetable oil. With alkaline catalysts (either sodium hydroxide or methoxide), temperatures of 60°C or higher molar ratios of at least 6 to 1 and with fully refined oils, conversion to methyl, ethyl and butyl esters was essentially complete in 1 hr. At moderate temperatures (32°C), vegetable oils were 99% transesterified in ca. 4 hr with an alkaline catalyst. Transesterification by acid catalysis was much slower than by alkali catalysis. Although the crude oils could be transesterified, ester yields were reduced because of gums and extraneous material present in the crude oils.

Vicente et al. (1998) studied the production of fatty acid methyl esters from refined sunflower oil. Different types of catalysts (NaOH, Amberlyst A26, Amberlyst A27, Amberlyst 15, Sulphate doped zirconium hydroxide MEL Cat XZO645/01, Titanium silicate, Titanium chelate, Lewis acid, MgO, Zeolite and Novozym 435) were tested and the experiments were conducted using methanol to triglyceride molar ration 6:1, catalyst concentration 1% wt., reaction temperature 60°C and reaction time 8 hr. It was found that sodium hydroxide as a catalyst led to largest conversion (100%). They also optimised the reaction temperature (levels were 25 and 65°C) and catalyst concentrations (levels were 0.5 and 1.5% et) by applying factorial design and response surface methodology. They found that temperature and catalyst concentration had a positive influence on conversion with effect on concentration larger than the effect of temperature. Temperature-
catalyst concentration effect was negative, probably due to side reactions, such as soap formation. High temperatures (more than 60°C) and catalyst concentrations (more than 1.5%) led to the production of large amount of soap. Therefore, these conditions were avoided. A second-order model was obtained to predict conversion levels as a function of temperature and catalyst concentration. Optimum conditions for the production of methyl esters were found to be mild temperatures (20-50°C) and large catalyst concentrations (1.3%).

Gryglewicz et al. (1999) compared catalytic activity of magnesium oxide, calcium hydroxide, calcium oxide, calcium methoxide, barium hydroxide and sodium hydroxide during the transesterification of rapeseed oil. The reactions were carried out by adding 0.225 mole of methanol and 0.0075 mole of the catalyst in the form of powder into a 100 ml capacity two-neck flask which was equipped with a stirrer and a reflux condenser. Then the flask with its content was heated up to the boiling point of methanol and the content was then stirred for 30 minutes. Then 50 gm of oil was poured in a thin stream, and co-solvent was added if necessary. The reaction was conducted for 2.5 hr. It was observed that the sodium hydroxide exhibited the highest catalytic activity in the process of alcoholysis. The degree to which substrates were reacted reached 85% after 30 min of the process and 95% after 1.5 hr. The barium hydroxide was slightly less active. The reaction degree was 75% after 30 minutes. Calcium methoxide was medially active and the degree to which the substrates were reacted reached 55, 80 and 93% after 30 minutes, 1 hr. and 2.5 hrs of the start of the process respectively. The rate of the reaction was lowest when CaO powder was used as the catalyst. But even in this case, a close to equilibrium state was reached after 2.5 hrs of reaction. This showed that transesterification of RSO by methyl alcohol can be catalyzed effectively by basic alkaline-earth metal compounds: CaO, Ca (MeO)\textsubscript{2} and Ba(OH)\textsubscript{2}. Calcium catalysts, due to their weak solubility in the reaction medium, are less active than sodium hydroxide. However, calcium catalysts are cheaper and need to decrease the number of technological stages and the amount of unwanted waste product. Magnesium oxide and calcium hydroxide showed no catalytic activity in the rapeseed oil methanolysis. It was found that the transesterification reaction rate can be enhanced by ultrasound as well as by introducing an appropriate regent into a reactor to promoted methanol solubility in the rapeseed oil. Tetra hydro furan was used as an additive to accelerate the process.

Ma et al. (1999) reviewed the use of vegetable oil as fuels. The uses of vegetable oil as fuel in diesel engine are direct use, blending, micro emulsions, thermal cracking and transesterification. Transesterification is the best method of making biodiesel from vegetable oil. Transesterification method is affected by molar ratio of triglyceride to alcohol, catalysts, reaction temperature, reaction time, free fatty acids and water content of oils and fats. Alkali-catalyzed transesterification was much faster than acid – catalysed transesterification. The commonly accepted molar ratio of alcohol to triglyceride was 6:1 and amount of base catalyst was 0.1 to 1% w/w of oil. Higher reaction temperature speeded up the reaction and shortened the reaction time. The reaction was slow at the beginning for a short time and proceeded quickly and then slowed down again. The oils or fats used in transesterification required to be substantially anhydrous with free fatty acids less than 0.5% w/w. Methanol was used most frequently among the alcohols because methanol could quickly react with triglycerides and its low cost.

Canakci and Gerpen (1999) studied the effects of process variables on acid-catalyzed transesterification of soybean oil (SBO). It was found that ester conversion efficiency was found to be strongly affected by the molar ratio of alcohol to oil. It was reported that ester conversion reached 98.4% at the molar ratio of 30:1 with 3% sulphuric acid catalyst at 60°C. When the acid catalyzed reaction occurred at room temperature, the reaction was very slow and poor ester conversion was obtained. The methyl ester conversions were 8.3, 57.2 and 87.8% at 25, 45 and 60°C, respectively. The specific gravity of ester decreased with increasing reaction temperature. The water formed by esterification was found to inhibit the reaction. Different amounts of distilled water was added to the vegetable oil to study the effect of water on transesterification and reported
that the addition of 5% water reduced the ester conversion by 5.6%. The FFA levels above 5% also lowered the ester conversion rate below 90%. It was concluded that amount of FFAs in vegetable oil had a significant effect on the transesterification reaction.

Canakci and Gerpen (2001) transesterified yellow grease and brown grease having FFA 12% and 33% respectively using two-step acid pre-treatment followed by alkali-transesterification. The yellow grease and brown grease were pre-treated using a 20:1 molar ratio of methanol to oil for first-step and 40:1 molar ratio of methanol to oil for second-step acid pre-treatment, respectively. The reactions were carried out using 5% H$_2$SO$_4$ and 10% H$_2$SO$_4$ for yellow grease and brown grease, respectively for both the steps for a period of 2hr (1 hr reaction time for each step) at 60°C. Following this procedure, the acid values for yellow grease after the first and second step were reduced to around 1.64 mg KOH/g and 0.74 mg KOH/g, respectively. Similarly, the reduction in acid values of brown grease was found to be around 5 mg KOH/g and 2 mg KOH/g after the first and second steps, respectively. The pre-treated oil obtained after two-step acid pre-treatment process of yellow grease was then transesterified with a 6:1 molar ratio methanol by using different base catalysts (KOH, NaOH, NaOCH$_3$ and Na). They investigated the effect of different amount of KOH (0.5% and 1%), NaOH (0.61%), NaOCH$_3$ (0.82%) and Na (0.35%) on the biodiesel yield. From this study, yield of biodiesel was found to be 74.8%, 74.3%, 81.2%, 80.5% and 82.2% while carrying out the reaction with 0.5% KOH, 1% KOH, 0.61% NaOH, 0.82% NaOCH$_3$ and 0.35% Na, respectively. Similarly, the investigation was carried out for base catalyzed transesterification for brown grease by using different amounts of KOH (0.5% and 0.24%) and NaOCH$_3$ (0.41% and 0.21%). The yield of biodiesel was obtained to be lower in case of 0.5% KOH (56.4%) as compared to NaOCH$_3$ i.e., 67% and 75.1%, respectively for 0.41% NaOCH$_3$ and 0.21% NaOCH$_3$. From this study, it was concluded that high FFA of oil should be reduced to less than 1% for the successful base catalyzed transesterification.

Zhang et al. (2003) showed that the alkali-catalyzed process using virgin vegetable oil as the raw material required the fewest and smallest process equipment units but a higher raw material cost than the other processes. The use of waste cooking oil to produce biodiesel reduced the raw material cost. The acid-catalyzed process using waste cooking oil proved to be technically feasible with less complexity than the alkali-catalyzed process using waste cooking oil, thereby making it a competitive alternative to commercial biodiesel production by the alkali-catalysed process.

Tomasevic et al. (2003) conducted experiment on heated refined sunflower and used frying oils, to obtain biodiesel. Transesterification reaction condition, that effect yield and purity of the esters including oil quality, type & concentration of alkaline catalyst, molar ratio of methanol to vegetable oil, reaction time and temperature were examined. The methanolsysis of different oils at 25°C with 0.5% to 1.5% KOH or sodium hydroxide were studied. The effect of molar ration 4.5: 1, 6:1, and 9:1 on ester yield and its quality were investigated. By using 1% potassium hydroxide, temperature at 25°C, molar ratio 6:1 and time 30 minutes transesterification is done. The transesterified oil could be used in diesel engine.

Canakci et al. (2003) developed a pilot plant and produced methyl ester from yellow grease, brown grease and soybean oil. Tests were for the confirmation of the laboratory process preparation scaled up for biodiesel production. For soybean biodiesel, 1% KOH was used as the catalyst with methanol at a 6:1 molar ratio. For yellow grease and brown grease, a two step acid catalysed pre-treatment reaction was used to reduce their acid value to less than 2 mg KOH/gm. The transesterification reaction was then continued with 0.21 % sodium methoxide as the alkaline catalyst. After decreasing the acid value of the feed stock, alkaline catalysed transesterification gave good ester conversion and the biodiesel met the total and free glycerine specification. Separation of glycerine was problematic for yellow grease and brown grease and it required addition of water.
The number of washing cycles is very important and it affected the free glycerine amount in the ester produced from pre-treated feed stock with high FFAs.

Dorado et al. (2004) revealed the optimization of the parameters involved in the transesterification process of Brassica carinata oil. It was found that the free fatty acid content determined by Gas chromatography is a notorious parameter to determine the viability of the vegetable oil transesterification process. In this sense, it was not possible to perform basic transesterification process. In this sense, it was not possible to perform basic transesterification using Brassica carinata oil with high erucic acid content. The transesterification process of Brassica carinata without erucic acid required 1.4% KOH and 16% methanol, in the range of 20-45°C, after 30 minutes of stirring. It was suggested that if the presence of KOH or methanol is lower or higher than the optimal values, the reaction either does not fully occur or leads the soap production, respectively. Based in this field trial, biodiesel from Brassica carinata oil could be recommended as a diesel fuel candidate if long term engine performance tests provide satisfactory results.

Ghadge and Raheman (2005) prepared biodiesel from mahua oil having 19% FFA by using two-step process i.e. acid pre-treatment process followed by base transesterification process. Pre-treatment process was carried out using 0.30 to 0.35 v/v methanols to oil ratio, 1% v/v H₂SO₄ to oil ratio and the reaction was carried out for 1 hr. The pre-treated product obtained after separation of methanol and water suspension was treated for the input for base catalyzed transesterification and the process was conducted using 0.25 v/v of methanol to oil ratio, 0.7 % w/v KOH and the reaction was carried out for 1 hr. All the reactions were carried out maintaining the reaction temperature at 60 degree Centigrade. The average biodiesel obtained was around 98%.

Karmee et al. (2005) conducted an experiment on crude Pongamia oil and transesterified using KOH as catalyst and methanol to form biodiesel. The conversion was found to be 92% at 60°C with 1:10 molar ratio (oil: methanol) for KOH (1% by weight) catalyzed transesterification. The fuel properties especially viscosity and flash point of the transesterified product compare well with accepted biodiesel standards such as ASTM and German biodiesel standards.

Bouaid et al. (2005) reported the process of biodiesel production for pilot plant using Brassica carinata oil as raw material with methanol and using KOH as catalyst. Methyl or ethyl esters are the products of transesterification of vegetable oils with alcohol (methanol/ethanol) using an alkaline catalyst. The factorial design of experiments procedure has been followed to optimize the variables that determine the yield of ester. According to this study, the maximum yield of ester (98%) can be obtained, working with an initial catalyst concentration (1.5%), an operating temperature of 25 degree centigrade and with an alcohol/oil molar ratio of 6:1. The Factorial design of experiments methodology allows to develop and to optimize the process. The quality of biodiesel satisfied the European specification defined as EN 14214.

Veljkovic et al. (2006) studied the production of fatty acid methyl esters from crude tobacco seed oil (TSO) having high free fatty acids (FFA) content, the TSO was processed in two steps i.e. the acid pre-treatment was followed by the base-catalysed methanolysis (BCM). The first step reduced the FFA level to less than 2% in 25 minutes for the molar ratio of 18:1. The second step converted the product of the first step into FAME and glycerol. The maximum yield of FAME was about 91% in about 30 minutes. The tobacco biodiesel obtained had the fuel properties within the limits prescribed by the latest American (ASTM D 6751-02) and European (DIN EN 14214) standards., except a somewhat higher acid value than that prescribed by the latter standard (<0.5). He concluded that the tobacco seeds as agricultural wastes might be a valuable renewable raw material for the biodiesel production.

Math et al. (2007) conducted experiment on restaurant waste oil into biodiesel by applying two stage transesterification method, also conducted optimization condition for biodiesel production. Maximum yield up
to 85.50% of biodiesel from restaurant waste oil can be obtained. Experiments were carried out for transesterification in order to optimize experimental condition for maximum biodiesel yields at different levels. The different levels are: amounts of methanol i.e. 20, 25, 30, 35, 40 and 45%, catalyst concentration of 0.3, 0.5, 0.7, 1.0 and 1.5% NaOH, reaction temperature at 30, 45 and 55°C and different reaction time i.e. 60, 90 and 120 minutes. The optimise process parameters obtained for 85.50% yields are methanol at 35% by volume, NaOH 0.3 gm., reaction temperature at 55°C and reaction time at 90 minutes.

Berchmans et al. (2008) applied alkali base catalyzed transesterification technique to produce biodiesel from crude Jatropha curcus seed oil having high free fatty acids (1.5% FFA). The high FFA level was reduced to less than 1% by a two-step pre-treatment process. The first step was carried out with 0.60 w/w methanol to oil ratio in the presence of 1% w/w H₂SO₄ as an acid catalyst in 1 hr reaction at 50°C. After the reaction, the mixture was allowed to settle for 2 hr and the methanol-water mixture separated at the top layer was removed. The second step was transesterification using 0.24 w/w methanol to oil and 1.4% w/w NaOH to oil as alkaline catalyst to produce biodiesel at 65°C. The final yield for methyl esters of fatty acids was achieved is 90% in 2 hrs.

Balat et al. (2008) described the methods of reducing the viscosity of vegetable oils, when used as diesel fuels. They concluded that transesterification is the most common method and leads to mono alkyl esters of vegetable oils and fats, called bio-diesel when used for fuel purposes. They also described the factors affecting the transesterification process.

Sahoo et al. (2009) produced biodiesel from jatropha, karanja and polanga oil by using methanol as reagent and H₂SO₄ and KOH as catalyst for acid and base reactions, respectively. It has been conclusively observed that biodiesel production from feed stocks with high FFA is extremely difficult using alkaline catalyzed transesterification process. This is because the alkaline catalysts react with FFAs to form soap that prevents the separation of the glycerine and ester. A twostep transesterification for jatropha and karanja: and a triple stage transesterification for polanga oil are developed to convert the high FFA oils to its ester. The first step reduces the FFA content of the oil to less than 2% for jatropha and karanja oils. The second step reduces the FFA content of polanga oil to less than 2%. The alkaline catalyzed transesterification process converts the products of the first step for jatropha and karanja and products of second step for polanga oil to its mono-esters and glycerol. The effects of alcohol to oil volume, catalyst amount and reaction duration are analyzed in each step. Excess addition of sulphuric acid darkens the product. It has also been found that the conversion efficiency is strongly affected by the amount of alcohol. The volumetric ratio of 11:1, 11.5:1 and 12:1 of alcohol favours the completion of alkaline catalyzed transesterification process within 2 hr for the formation of JOME, KOME and POME, which is sufficient to give 93%, 91% and 85% yield of ester, respectively. The viscosity of biodiesel is nearer to that of diesel. The flash point of biodiesel is greater than that of diesel and calorific value is slightly lower than that of diesel.

Sekhar et al. (2009) reported the production of biodiesel from Neem oil through transesterification process. Factors effecting the biodiesel production are; catalyst, reaction temperature and reaction rate were analyzed. The important properties of the biodiesel oil such as flash point, viscosity, calorific value, density is comparable with the diesel. The viscosity of biodiesel is nearer to that of diesel and the calorific value is about 16% less than that of diesel.

Saravanan et al. (2010) investigated about the transesterification of Mahua oil having 14% free fatty acid. If the material possesses high free fatty acid then acid catalyst gives better results. In this investigation, the oil was transesterified to obtain biodiesel using acid catalysts with different alcohols. The alcohols used were methanol, ethanol and butanol. It was seen that transesterification with butanol gives a better yield compared
to methanol and ethanol. The best process condition with butanol was found to be 6% volume of sulphuric acid with 150% excess butanol, which gave a yield of around 95.4% in a reaction time of 5 hours. The prepared biodiesels were tested as per the standard and were found to be satisfactory.

Singh et al. (2010) reported that non-edible oils can also be utilized for making biodiesel fuel. For the production of biodiesel fuel, an alkali-catalysis process has been established that gives high conversion levels of oils to methyl esters. Enzymatic processes using both extra cellular and intracellular lipases have recently been developed. The cost of lipase production is the main hurdle to commercialization of the lipase-catalyzed process; several attempts have been made to develop cost-effective systems. In terms of production cost, there are two aspects, the transesterification process and by-product glycerol recovery. A continuous transesterification process is to lower the production cost, shorter reaction time, and greater production capacity. The recovery of high-quality glycerol is another way to lower production cost. Land may be a cost increasing factor for biodiesel production, because of more and more land required to live the growing population. To overcome the land problem, they suggested that the high yielding biodiesel plants (non edible producing plants) should be grown in marginal and waste land.

Sharma et al. (2010a) obtained biodiesel from kusum (Schleichera riguga) oil by two step transesterification process and optimized the process variables to get a high yield of biodiesel. The acid value was 21.30 mg KOH/g. Various parameter were applied to optimize the process for biodiesel production. These are methanol to oil molar ratio (6:1-12:1 mole) in 2:1 mole step, amount of H$_2$SO$_4$ (0.5 -1.25 % v/v) in steps of 0.25% v/v, KOH (0.5- 1.1 % w/w) in 0.2% w/w steps, reaction temp (40- 64°C) in 5°C steps and reaction time (0.50 to 1hr) in 0.5 h steps were varied to optimize the process. The acid value reduced to 0.94 mg KOH/g by esterification using H$_2$SO$_4$ as catalyst. Thereafter alkaline transesterification method was carried out by using KOH as catalyst for conversion of kusum oil to its methyl ester. The optimum combinations are; molar ratio 10:1 for acid esterification and 8:1 for alkaline transesterification. The amount of H$_2$SO$_4$ is 1 % v/v and KOH is 0.7 % w/w. The time duration is 1 hr for acid esterification followed by another 1 hr for alkaline transesterification. The yield of biodiesel obtained to be 95%.

Conceicao et al. (2011) studied the viability of biodiesel production from the oil of Raphia taedigera Mart., commonly known as jupati. The acid catalysts and ethanolic route are recognized as unfavourable conditions to produce biodiesel with high yield and purity. However, the production of high-quality biodiesel from low quality oil derived from naturally occurring oil seeds can be feasible. Biodiesel is obtained by using an ethylic route with a methane sulphuric acid reaction catalyst. The alcohol: oil molar ratio was 9:1, and the catalyst concentration was 2% of the oil mass. The yield of the process was 92% by mass and the oil conversion into jupati ethylic biodiesel was 99.6%. The physical and chemical parameters of jupati ethylic biodiesel were within the limits set by the National Agency of Petroleum, Natural Gas and Bio fuels.

Kaur et al. (2011) used lithium ion impregnated calcium oxide, is prepared by wet impregnation method in a nano particle form as supported by powder X-ray diffraction and transmission electron microscopy. Calcium oxide impregnated with 1.75 wt % of lithium was used as solid catalyst for the transesterification of karanja and jatropha oil, containing 3.4 and 8.3 wt % of free fatty acids respectively. The reaction parameters, viz., reaction temperature, alcohol to oil molar ratio, free fatty acid contents, amount of catalyst and amount of impregnated lithium ion in calcium oxide support. The complete transesterification of karanja and jatropha oils was achieved in 1 and 2 hr respectively at 65°C, utilising 12:1 ratio of methanol to oil and 5 wt% of catalyst. The result obtained is more than 99% conversion of oils to fatty acid methyl esters. The major drawback of the catalyst reported was its non-recyclability.
Nigam et al. (2011) reviewed the literature available on the subject of liquid bio-fuels. The four major research challenges need to be considered for process optimization to produce a sustainable biofuels. The four major research challenges are: (1) The purpose of enzymatic hydrolysis of agricultural substrates needs to be improved, which can be approached with the use of cheaper and of higher specific activity crude enzymes, by synthesis of enzyme in a process of reduced production cost and by novel technology for the handling of large amounts of solids. (2) The development of such microbial strains which are not only robust fermenting organisms, but also are at the same time more tolerant to inhibitors present in substrate-hydrolysates. These specially developed strains should be able to ferment all sugars available from the raw material in concentrated hydrolysates, giving high productivity of alcohols and with standing high alcohol concentration in the medium. (3) A well thought strategy for the process integration to reduce the number of steps involved in overall production process. (4) Working on 3-R strategy: Re-cycling, reduction and reuses of any by products and wastes generated in the process to reduce the energy demand and protect the environment.

Mishra et al. (2012) studied the optimum reaction conditions for alcoholysis of Simarouba oil is 8% of catalyst in oil, methanol to oil molar ratio 12:1, reaction temperature 65°C for a period of 180 minutes. The yield of methyl ester is more than 95%. The conversion of transesterification of oil is 90 –95% and almost complete at higher molar ratio of methanol to oil within 150 minutes.

Mishra et al. (2012) conducted the experiment with the transesterification of Simarouba glauca oil by means of methanol in presence of Potassium hydroxide catalyst at less than 65°C. The viscosity of biodiesel is nearer to that of the diesel. The biodiesel is characterized by TLC and the important properties of biodiesel such as density, flash point, cloud point, pour point, carbon residue and ash content are found out and compared with that of diesel.

Lohan et al. (2013) produced from non-edible oil like jatropha, neem, karanja, mahua, simarouba oil. This brief presents the current status, discusses the future prospects and examines the critical constraints and impediments in India to the path of development of biodiesel program. It also offers suggestions and alternative policy options so as to enable the program to achieve its objectives. The effects of biodiesel on engine performance i.e. brake power, brake thermal efficiency, specific fuel consumption and substantial reduction in particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO) and oxide of nitrogen (NOₓ) were also reviewed.

Mishra et al. (2013) prepared biodiesel from the crude oil of simarouba glauca by transesterification with methanol in the presence of KOH as a catalyst. The reaction parameters such as catalyst concentration, alcohol to oil molar ration, temperature and rate of mixing were optimised for the production of simarouba oil methyl ester. The yield of methyl esters from simarouba oil under the optimal condition was 94-95%. Important fuel properties of methyl esters of simarouba oil (biodiesel) was compared with ASTM and DIN EN 13214. The viscosity was found to be 4.68 cSt at 40°C and the flash point was 165°C.

2.2.3 Fuel Properties

Researchers have shown that the properties of biodiesel fuel may vary significantly depending on their chemical compositions and fatty acid compositions, which have an obvious effect on engine performance and emissions. Related research articles are given below.

Iwuoha et al. (1996) concluded that the degummed local, edible vegetable oils compared well with the commercially available brands in their physical and chemical quality parameters. The type and strength of degummed, as well as type of oil, affected these measured characteristics. There was a general improvement
in the quality of the oils due to the degumming treatment. Study has demonstrated that the characteristics of vegetable oils can be controlled by manipulating the type and strength of the degumming reagent during the process of refining.

Korbitz (1997) produced biodiesel from rapeseed oil. It has been observed that the reduction of kinematic viscosity of rapeseed biodiesel decreases to about 1/6th that of respective parent oil. The viscosity of the rapeseed biodiesel was about 1.28 -2.16 times that of diesel. The flash point of the said biodiesel is quite high compared to diesel. However, the said biodiesel has a little lower gross heating value and higher distillation temperature as compared to diesel.

Allen et al. (1999) presented a method, which has been verified experimentally and predicted the viscosities of biodiesel fuels from the knowledge of the fatty acid composition. The viscosity of biodiesel fuels reduce considerably with increase in un-saturation.

Abigor et al. (2000) studied the fuel properties of palm kernel oil, coconut oil and their biodiesel. They have reported that the viscosity, cloud point and pour point of palm kernel oil as 32.40 cSt, 28°C and 22°C respectively. However the above said properties of palm kernel biodiesel were reduced to 9.33 cSt, 12°C and 8°C. Similar reduction was observed for coconut biodiesel.

Sangha et al. (2000) studied the fuel properties of four selected plant oils, viz., linseed, jatropha, sunflower and rice bran and their esters. It was observed that methyl esters exhibited lower values of viscosity, flash point and density as compared to their un-etherified plant oils in all cases. However, no significant variation was noticed in the gross heat values of these oils.

Chitra et al. (2005) prepared biodiesel from crude jatropha oil by transesterification process and characterized the fuel properties of jatropha biodiesel. At 40°C the kinematic viscosity was reduced from 29.36 cSt to 4.78 cSt, which was 8.4 times higher than that of diesel fuel. The specific gravity of jatropha biodiesel was also reduced from 0.910 to 0.860 as compared to 0.810-0.860 for diesel. The free fatty acid value has also been reduced from 6.16 to 0.49. The quality of biodiesel satisfied the BIS biodiesel standard specifications.

Demirbas A (2005) described the biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. Biodiesel (BD) fuel is a renewable substitute fuel for petroleum diesel or petro diesel fuel made from vegetable or animal fats. The viscosity values of vegetable oils vary between 27.2 and 53.6 mm²/s whereas those of vegetable oil methyl esters between 3.59 and 4.63 mm²/s. The viscosity values of vegetable oil methyl esters highly decreases after transesterification process. The flash point values of vegetable oil methyl esters are highly lower than those of vegetable oils. An increase in density from 860 to 885 kg/m³ for vegetable oil methyl esters or biodiesels increases the viscosity from 3.59 to 4.63 mm²/s.

Puhan et al. (2005) prepared to produce mahua oil methyl ester (MOME) by transesterification process. They have studied the fuel properties of mahua oil and their biodiesel. They have concluded that MOME possessed lower calorific value around 12% than that of diesel. The specific gravity of MOME possessed a little variation with that of diesel. The kinematic viscosity was slightly higher than that of diesel. Cetane number is higher by 10% than that of diesel which is favourable for combustion. Flash point and fire point is reported to be higher of MOME than that of diesel. Cloud point was higher than that of diesel which is not favourable for cold temperature regions.
Tate et al. (2006) studied the densities of three biodiesel fuels, viz., canola methyl ester (COME), soybean oil methyl ester (SBOME) and fish oil ethyl ester (FOEE) at temperature up to 300°C. The kinematic viscosity of COME, SBOME and FOEE were found to be 4.47, 4.2 and 3.98 cSt respectively as compared to diesel of 2.07 cSt at 40°C. The densities of biodiesel fuels were observed to be decreased linearly with temperature by 1.23 kg/m³ per °C. For this temperature range and the predicted values in the literature for density beyond 100°C was found to be deviating from the experimental values of density obtained in this work. The specific gravity at 15°C was measured to be 0.888, 0.885 and 0.878 for COME, SBOME and FOEE respectively as compared to 0.833 for diesel. The water content, sulphur content and copper-strip corrosion were found to be much lesser than diesel. However, the cetane index, distillation range and flash point temperature of the said biodiesel were found higher than that of diesel.

Tiwari et al. (2007) produced biodiesel from high free fatty acid (FFA) jatropha oil by a two-steps i.e. esterification process followed by transesterification method. The above said biodiesel fuel properties were studied. The viscosity of biodiesel so obtained was found to be 4.8 cSt, which was very close to diesel. The calorific value of biodiesel was 39.29 MJ/kg, which was 6.59 % less than diesel. The specific gravity is found to be 0.880 and pour point is 2°C was found comparable with diesel. However, the flash point of the said biodiesel is found to be 135°C, which is quite higher than that of diesel.

Radwan et al. (2007) investigated esterification method which is used to produce JOJOBA methyl ester (JME) from crude jojoba oil. This method is optimized to produce the highest amount of fuel using a minimum amount of methyl alcohol. The chemical and physical properties were obtained by taking 0.25 JME and 0.10 JME. The 0.25 JME fuel gave highest cetane number with lower yield ration and 0.1 JME fuel gave lowest cetane number with highest yield ratio.

Kalbande et al. (2008) studied biodiesel productions of jatropha and karanja oils by using biodiesel Processor and evaluated fuel properties of biodiesel such as kinematic viscosity and specific gravity. The important factor that effects the transesterification reaction is the amount of methanol and sodium or potassium hydroxide, reaction temperature and reaction time. A molar ratio of 6:1 is normally used in industrial processes to obtain methyl ester. Yield is found to be 98% by weight.

El-Mashad et al. (2008) used salmon oil as a feed stock for biodiesel production via transesterification in a two-step process. Optimal amounts of chemicals required to give the highest biodiesel yield from each oils were determined using batch production procedures. It was found that due to the high acid value of salmon oil, alkaline-catalysed transesterification was not an effective method for producing biodiesel from the salmon oil. Therefore a two-step process was applied, in which a sulphuric acid –catalysed pre-treatment was used in the first step to produce the acid value from 12.0 to 3 mg [KOH][g[oil]]⁻¹ and then, in the second step. KOH-catalysed transesterification was applied. Al experiments were performed with a mixing intensity of 600 rpm. Based on the total weight of salmon oil used, the maximum biodiesel yield of 99% was achieved using a total methanol/molar ratio of 9.3% and 0.5 % (w/w) KOH. Ester loss due to the formation of emulsion during the washing and drying steps was 15% maximum. This loss could be reduced in practical applications by better design of washing and drying techniques. A preliminary economic analysis showed that the cost of biodiesel production from salmon oil was almost twice that produced from soybean oil.

Santos et al. (2008) studied the Terminalia catappa l. (TC) oil characteristics. Prepared biodiesel from crude oil, obtained from the kernels. The yield is of 49%, allowing the possibility of economical exploitation and its fatty acid composition and is compared with that of some conventional oils. The crude oil was transesterified using conventional catalysts and methanol to form biodiesel. Based on the result obtained the fuel properties
are calculated. It is concluded that the material may be used as pure biodiesel or blends. The fuel properties are compared with that of palm and soybean oil and it lies in the ASTM and EN specifications.

Saydut et al. (2008) investigated sesame seed oil for the production of biodiesel fuel. Biodiesel was prepared from crude sesame oil by transesterification method with methanol in the presence of NaOH as catalyst. Properties of sesame oil and biodiesel meet the requirement of ASTM and EN standards. Sesame seed oil has 7.5% less heating value than that of diesel due to more oxygen content in the molecule of biodiesel. Viscosity and density of sesame biodiesel are very close to that of diesel. The calorific value of sesame biodiesel is found slightly lower than that of biodiesel.

Demiribas (2009) reported that biodiesel fuel comprises lower alkyl fatty acid (chain length (C_{14}-C_{22}), esters of short-chain alcohols, primarily, methanol or ethanol. Among various methods of production transesterification is an attractive technique. The purpose of transesterification is to lower the viscosity of the oil. The most important variables affecting methyl ester yield during the transesterification reaction are the molar ratio of alcohol to vegetable oil and the reaction temperature. Methanol is the commonly used alcohol in this process, due in part to its low cost. Methyl esters of vegetable oils have several outstanding advantages over other new-renewable and clean engine fuel alternatives. Biodiesel can be used in any mixture with petro diesel fuel, as it has very similar characteristics, but it has lower exhaust emissions. Biodiesel has better properties than petro diesel fuel; it is renewable, biodegradable, non-toxic, and essentially free of sulphur and aromatics.

Ragit S.S et al. (2010) prepared biodiesel from crude neem oil by base catalyzed transesterification process and studied its major fuel properties. Studied the, performance, and emission evaluation of a diesel engine by using NOME.

Valente et al. (2011) studied to calculate the physical & chemical properties of fuel blends of waste cooking oil biodiesel or castor oil biodiesel with diesel oil. The properties evaluated were fuel density, kinematic viscosity, cetane index, distillation temperatures and sulphur content, measured according to standard test methods. The results were analysed based on present specifications for biodiesel fuel in Brazil, Europe and USA. Fuel density and viscosity were increased with increasing biodiesel concentration, while fuel sulphur content was reduced. Cetane index is decreased with high biodiesel content in diesel oil. The biodiesel blends distillation temperatures T_{20} and T_{50} are higher than those of diesel oil. While the distillation temperature T_{90} is lower. Finally, the use of waste cooking oil biodiesel or castor oil biodiesel blended to N.2 diesel fuel can substantially reduce the fuel sulphur content at an equivalent rate for a given concentration. The fuel blends containing over 83% waste cooking oil biodiesel in N.2 diesel fuel reduce the fuel sulphur content below 50 ppm.

Ragit et al. (2011) observed that the ester recovery and kinematic viscosity, it was found that filtered neem oil at 6:1 molar ration (methanol to oil) preheated at 55^\circ C temperature and maintaining 60^\circ C reaction temperature for 60 minutes in the presence of 2 percent KOH and then allowed to settle for 24 hr. gave lowest kinematic viscosity (2.7 cSt) with ester recovery (83.36%). The lowest viscosity is considered better for engine performance in IC engine. The density, flash and fire points of neem methyl ester gave good results but calorific value was slightly less as compared to diesel.

Jesikha M (2012) described the fatty acid methyl ester characteristics and esterification of some vegetable oils for production of biodiesel. In this study oil sources were obtained from the seeds of Ricinus commonis, Cocos nucifera, Brassica juncea, Arecaceae elaeels, Helianthus annus Linn, Madhuca longifolia and Pongamia pinnata oils. Biofuel Characteristics such as free fatty acid content, Iodine value, saponification value, cetane
number, energy value and density were studied. The highest acid value in this study was 16.92% in Arecaceae Elaeels and the lowest was 1.41% in Pongamia pinnata. Energy values have been reported in other samples such as Rapseed oil - 35000k/j/kg, Linseed - 39307k/j/kg, soybean - 39623k/j/kg, Tallow - 40054k/j/kg. The maximum Saponification value in this study was 252 in Cocos nucifera and the lowest was 172.504 in Brassica juncea (Fig no: 3). Saponification value of Ximenia americana Linn oil is 169.2, Momordica dioica Rox 189.5, Balanites roxburghii planch 188.9 and Mimusops hexendra 202.0. In this study showed CN value between 52 and 66.

Mohanty et al. (2012) developed a small-scale decentralised biodiesel production unit for non-edible oils and the performance has been evaluated for the production of biodiesel from high-FFA oils like Karanja, Jatropha, Mahua, Simarouba and Polanga. Biodiesel production was more than 90% from all the above mentioned non-edible oils. All the important properties of transesterified products (biodiesel) like specific gravity, calorific value, carbon residue, ash content, flash point and kinematic viscosity are compared with ASTM and BIS standards and found to be within the specified parameters. Therefore, the biodiesel from non-edible oils like Karanja, Jatropha, Mahua, Simarouba and Polanga can be used as a blend constituent of an alternative diesel fuel.

Singh et al. (2012) reviewed the effects of corrosion on the engine parts that come in contact with biodiesel fuel and its petro diesel blend. Copper, aluminium, copper alloys (bronze), and elastomers caused significant levels of corrosiveness in biodiesel and biodiesel blend as opposed to low corrosion with petro diesel. Specimens of stainless steel showed significant resistance to corrosion in biodiesel samples as compared to copper, aluminium and copper alloys, but the level or corrosion was still higher than that in petro diesel. Common methods adopted for measurement of corrosion include weight loss through static emersion tests and electro chemical techniques by electrochemical impedance spectroscopy or on Potentiostat/Galvanostat. The surfaces of the specific metal strips were analysed by optical, scanning electron, and atomic force microscopy, revealing the nature and extent of corrosion. Fourier Transform Infrared Spectroscopy revealed formation of secondary product due to degradation, and X-ray diffract meter revealed formation of a new phase in the metal strips exposed to biodiesel and its blend with mineral diesel. Biodiesel seemed to degrade due to auto-oxidation and presence of moisture to secondary products that enhanced the corrosion rate. The problem related to the use of non-compatible materials as engine parts for biodiesel-run vehicles is dual in nature. The engine part in contact with the fuel is corroded as a result of fuel degradation, causing the fuel to go further off-specification.

Mishra et al. (2013) prepared biodiesel from crude simarouba glauca oils by transesterification process with methanol in the presence of KOH as catalyst. A maximum conversion was achieved using a 1:6 molar ratio of oil to methanol at 65°C, i.e. 92% (oil to methyl ester). Otherwise addition of 8% solid base catalyst CaO using 1:6 molar ratio of oil to methanol at 65°C was also used as catalyst for this transesterification and conversion exceeds 95%. Important fuel properties of methyl esters of simarouba oil (biodiesel) was compared with ASTM and DIN EN 14214. The viscosity was found to be 4.68 cSt at 40°C and the flash point was 165°C.

2.2.4 Chemical Composition of fuels

Fatty acid composition is an important property for any biodiesel feed stock as it determines the efficiency process to produce biodiesel. The percentage and type of fatty acid composition relies mainly on the plant species and their growth conditions. The fatty acid composition and distribution of some oils are generally aliphatic compounds with a carboxyl group at the end of a straight-chain. The most common fatty acids are C16 and C18 acids. However, some feed stocks contain significant amounts of fatty acids other than
the typical C16 and C18 acids. Chemical structures of some common fatty acids oils are shown in TABLE – 2.4 revealed from [67], [68], [93] and [95].

<table>
<thead>
<tr>
<th>Name of Fatty acid</th>
<th>Chemical name</th>
<th>Chemical formula</th>
<th>Number of carbons</th>
<th>Number of double bonds</th>
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</thead>
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<tr>
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</table>

Brindi (1987) showed the fatty acid composition of non-edible oil like neem seed oil, karanja seed oil, kusum seed oil, mahua seed oil, polanga seed oil.

Azam et al. (2005) described the prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. He shows the chemical structures of common fatty acid.

Sahoo et al (2007) showed the chemical compositions of fatty acid of polanga oil in percentage. Three step transesterification i.e. zero catalyzed, acid catalyzed and base catalyzed is applied to produce biodiesel from non-edible filtered high viscous (72 cSt at 40°C) and high acid value (44 mg KOH/gm) polanga (Calophyllum inophyllum L.) oil. This biodiesel and blended with high speed diesel were tested for their use as a substitute fuel on diesel in a single cylinder diesel engine. Diesel and polanga oil methyl ester (POME) fuel blends (0%, 20%, 40%, 60%, 80% and 100%) were used for conducting the short-term engine performance tests at varying loads. Tests were carried out over entire range of engine operation at varying conditions of speed and load. The brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) were calculated from the recorded data. The engine performance parameters such as fuel consumption, thermal efficiency, exhaust gas temperature and exhaust emissions (CO, CO₂, HC, NOₓ and O₂) were recorded. The optimum engine operating condition based on lower brake specific fuel consumption and higher brake thermal efficiency was observed at 100% load for neat biodiesel. Concluded that, from emission point of view the neat POME was found to be the best fuel as it showed lesser exhaust emission as compared to diesel.
Navindgi et al. (2012) showed the fatty acids and chemical composition of mahua oil.

Abhani et al. (2013) showed the chemical structures of common fatty acids of non-edible oils. Also show the fatty acid composition of various non-edible oils that were found suitable for production of biodiesel.

### 2.2.5 Performance and Exhaust Emission of Diesel Engine with Diesel and Biodiesel Blends

Srivastava et al. (2000) reviewed the triglycerides (vegetable oils/animal fats) as alternative fuel for diesel engines. To improve the fuel properties of triglycerides in the catalytic transesterification of triglycerides with alcohols to form mono-alkyl esters of long chain fatty acids, known as biodiesel with is quite similar to hydrocarbon based diesel fuels in its main characteristics and provides similar engine performance with attractive emission levels.

Silva et al. (2003) carried out tests in a 180 kW, 6-cylinders, turbocharged VOLVO engine fuelled with diesel and sunflower oil methyl esters (SFOME) blends (B5 and B30). The CO and NOx concentration in exhaust gas were found to be similar in all cases. The CO concentration was however slightly lower at higher loads with SFOME was incorporated into the fuel. It was also observed that the addition of higher SFOME content in diesel in the blends led to an increase of NOx concentration in exhaust gas at higher loads and the opacity of the exhaust smoke was found to be decreasing with increasing SFOME content in diesel.

Puhan et al. (2005) prepared Mahua Oil Ethyl Ester by transesterification by using sulphuric acid (H2SO4) as catalyst and tested in a 4-stroke direct injection natural aspirated diesel engine. Tests were carried out at constant speed of 1500 rev/min at different brake mean effective pressure. Results showed that brake thermal efficiency of Mahua Oil Ethyl Ester (MOEE) was comparable with diesel and it was observed that 26.36% of diesel whereas 26.42% of MOEE. Emissions of carbon monoxide, hydrocarbons, oxides of nitrogen and Bosch smoke number were reduced around 58, 63, 12 and 70% respectively, in case of MOEE compared to diesel. Concluded on the base of this study that, MOEE can be used a substitute for diesel in diesel engine.

Puhan et al. (2005b) tested a 3.7 kW, 4-stroke, constant speed (1500 rpm), vertical, water cooled, direct injection compression ignition engine fuelled with mahua oil ethyl ester (MOEE) and reported lower emissions of CO, HC, NOx and Bosch smoke number to the tune of around 58%, 63%, 12% and 70% respectively and higher CO2 emission as compared to diesel. They conclude that MOEE could be used as a substitute for diesel engine.

Ramadhas et al. (2005b) evaluated emissions of a 5.5 kW, single cylinder, four stroke, direct injection, diesel engine when fuelled with diesel, rubber seed methyl ester (RSME) and their blends (B10, B20, B50 and B75). The exhaust gas emissions were found to be reduced with increase in biodiesel concentration in the fuel blends. The engine emitted more CO using diesel as compared to that of biodiesel blends under all loading conditions, with increasing biodiesel percentage, CO emission level decreased. The CO2 increased with increase in biodiesel concentration in the blend. The smoke density of B20 is lowest i.e. 28% compared to that of diesel 45%. Concluded that rubber seed methyl ester can be a substitute for diesel engine.

Nabi et al. (2006) presented comparative results for exhaust emission viz.; CO, NOx and smoke density from a single cylinder, 9.8 kW water cooled, direct injection running at 2000 rpm. Experiments were conducted with diesel fuel and diesel-neem oil methyl ester (NOME) blends of 5-15%. The experiments were conducted at different brake mean effective pressure conditions. The rpm was set at optimum speed of 1000 rpm with injection timing 13° ATDC. Concluded that, the exhaust emissions i.e. the CO and smoke is observed to be
decreased with the increase in volumetric percentages in NOME fuelled. They reported that, 4% decrease in CO and smoke emissions and 5% increase in NOx when fuelled with 15% NOME as compared to diesel.

Agarwal et al. (2007) conducted performance and emissions tests with diesel, pre heated jatropha oil, unheated Jatropha oil and blends of jatropha oil at different loads at constant speed with 1500 rpm. Experimental results showed that, jatropha oil is found to be a promising alternative fuel for compression ignition engines. It can be directly used as straight vegetable oil as a replacement for diesel fuel and do not require any major modification in the engine. BSFC and exhaust gas temperatures for unheated jatropha oil were found to be higher compared to diesel and heated jatropha oil. Thermal efficiency was lower for unheated jatropha oil compared to heated jatropha oil and diesel. CO2, CO, HC and smoke opacity were higher for jatropha oil compared to that of diesel. These emissions were found to be close to diesel for preheated jatropha oil. For blends BSFC and exhaust gas temperature were found higher compared to diesel. Thermal efficiency was also found to be close to diesel for jatropha oil blends. While operating the engine on jatropha blends it was found that the emission parameter such as smoke opacity, CO2, CO and HC were found to have increased with increasing proportion of Jatropha oil in the blends compared to diesel. They have concluded that blending the jatropha oil can be used in CI engines in rural areas for agriculture, irrigation and electricity generation. Modified maintenance schedule may however be adopted to control carbon deposits formed during long term usage of vegetable oils/blends.

Altiparmak et al. (2007) measured the tall oil methyl ester (TOME) as fuel for diesel engine. The blends of tall oil methyl ester were tested in a direct injection diesel engine at full load conditions. Fuel blend of TOME on the engine performance and exhaust emission were studied. It was observed that the engine torque and power output with tall oil methyl ester-diesel fuel blends increased up to 6.1% and 5.9% respectively. It was also seen that CO emissions decreased to 38.9 % and NOx emissions increased up to 30 % with the new fuel blends. The smoke opacity did not vary significantly.

Balusamy et al. (2007) investigated methyl ester of thevetia peruviana seed oil (TPSO) and blended with diesel fuel, has been tested in naturally aspirated single cylinder diesel engine at a speed of 1500rpm. Brake Thermal Efficiency increases with increasing in brake power for all fuels. At maximum load, BSFC of B20 (3.4%) and B100 (10.3%) are higher than that of diesel due to higher density and viscosity of the fuel blends. Mechanical efficiency increases with increasing brake power for all fuels. The performance and emission parameters like brake thermal efficiency, brake specific fuel consumption, CO, HC, NOx, CO2, O2, smoke and exhaust gas temperature are measured, analysed, and compared with that of diesel. Engine performance with TPSO has been found comparable to that of diesel and CO, HC emissions are less but NOx and smoke are slightly higher than that of diesel.

Rao et al. (2007) carried out transesterification process of used cooking oil using an alkaline catalyst. The combustion, performance and emission characteristics of used cooking oil methyl and its blends with diesel oil are analyzed in a direct injection CI engine and compared with the base line diesel fuel. Performance and emission results have shown that the specific fuel consumption increase with increase in percentage of used cooking oil methyl ester (UCME) in the blend due to the lower CV of UCME. The brake thermal efficiency decreases with increases in percentage of UCME in the fuel. Increase in oxygen content in the UCME-diesel blends as compared to diesel results in better combustion chamber temperature. This leads to increase in NOx. UCME recoded higher values of NOx compared to diesel at rated load. Emissions of CO and HC decrease with increase in percentage of USME in the blend. It is observed that, a significant reduction in smoke density at higher loads.
Raheman et al. (2007) concluded that the B100 could be safely blended with DIESEL up to 20% without significantly affecting the engine performance, emission and this could be a suitable alternative fuel for diesel.

Stalin et al. (2007) prepared karanja biodiesel by alkali catalysed transesterification process. Performance of IC engine using Karanja biodiesel blending with diesel and with various blending ratios has been evaluated. Brake power, brake specific fuel consumption and brake thermal efficiency are calculated. It is observed that as the load increases, brake thermal efficiency increases up to 70% load and then decreases for all the fuel samples tested. The low brake thermal efficiency for B60, B80 and B100 may be due to the lower HHV and the increase in fuel consumption.

Sundarapandian et al. (2007) developed a theoretical model to evaluate the emissions of Jatropha (JB), Mahua (MB) and Neem oil esters (NB). For conforming the predicted results, a set of experiments were conducted on a single cylinder, four strokes, naturally aspirated, water cooled, 5.2 kW kirloskar diesel engines at the engine speed of 1500 rpm. All the experiments were conducted at the injection timing of 140° BTDC and 200 bar at various loads by using the above said biodiesels and diesels. It was observed that the CO, HC and NO\textsubscript{x} with JB, MB and NB were reduced by an amount of 19%, 16% and 16%; 18,16 and 15%; 1.8, 2.5 and 3%, respectively when compared to those of diesel.

Banapurmath et al. (2008) reported that, the results of investigations carried out on a single-cylinder, four stroke, direct injection, CI engine operated with methyl esters of Honge oil, Jatropha oil and sesame oil. Comparative measures of brake thermal efficiency, smoke opacity, HC, CO, NO\textsubscript{x}, ignition delay, combustion duration and heat release rates have been presented and discussed. Engine performance in terms of higher brake thermal efficiency and lower emissions (HC, CO, NO\textsubscript{x}) with sesame oil methyl ester operation was observed compared with methyl esters of Honge and Jatropha operation.

Silvico et al. (2008) pure palm oil was employed in diesel engines as an alternative fuel. Engine performance and emissions were influenced by basic differences between diesel fuel and palm oils such as mass based heating values, viscosity, density and molecular oxygen content. The high viscosity of palm oil resulted in poor atomisation, carbon deposits, clogging of fuel lines and starting difficulties in low temperatures. When heated at 100 °C palm oil presented lower viscosity, better combustion and less deposits. Tests were conducted in a naturally aspirated MWM 229 direct injection four-stroke 70 kW diesel-generator fuelled with 100% palm oil.

Sahoo et al. (2009) produced non-edible jatropha(Jatropha curcas), Karanja (Pongamia pinnata) and polanga (Calophyllum inophyllum) oil based methyl esters were produced and blended with conventional diesel having sulphur content less than 10 mg/kg. Ten fuel blends (Diesel, B20, B40, and B100) were tested for their use as substitute fuel for a water-cooled three cylinder tractor engine. Test data were generated under full/part throttle position for different engine speeds (1200, 1800, and 2200 rev/min). Change in exhaust emissions (Smoke, CO, HC, NO\textsubscript{x} and PM) were also analysed for determining the optimum test fuel at various operating conditions. The maximum increase in power is observed for 50% jatropha biodiesel and diesel blend at rated speed. Brake specific fuel consumptions for all the biodiesel blends with diesel increases with blends and decreases with speed. There is a reduction in smoke for all the biodiesel and their blends when compared with diesel. Smoke emission reduces with blends and speeds during full throttle performance test.

Bora (2009) have analysed the performance and emission characteristics of a single cylinder diesel engine by using Karabi seed biodiesel as fuel. BSFC increased and BTE decreased with increase in proportion of
biodiesel in blends. Smoke level, un-burnt hydrocarbons and carbon monoxide in exhaust emission reduced, whereas NO\textsubscript{x} increased with increase in percentage of Karabi biodiesel in blends.

**Devan et al. (2009)** analysed the bio fuels namely, methyl ester of paradise oil and eucalyptus as fuel in the form of blends. Various proportions of paradise oil and eucalyptus oil are prepared on a volume basis and used as fuels in a single cylinder, four-stroke DI diesel engine, to study the performance and emission characteristics of these fuels in the present investigation a methyl ester derived from paradise oil is considered as an ignition improver. The results show a 49% reduction in smoke, 34.5% reduction in HC emission and a 37% reduction in CO emissions for the ME50-Eu60 blend with a 2.7% increase in NO\textsubscript{x} emission at full load. There was a 2.4% increase in brake thermal efficiency for the Me60-Eu50 blend at full load. The combustion characteristics of Me50-Eu60 blend are comparable with those of diesel.

**Kandasamy et al. (2009)** discussed the performance characteristics of a single cylinder diesel engine using rice bran and pungamia oil blended with diesel fuel. Experiments are carried out for the various blends i.e. B20, B40, B60, B80 and the results were compared with the neat diesel. They have reported that preheating ensures the enhancement of combustion efficiency and the overall performance of the engine. The temperature is varied from 27°C to 80°C. Continuous heating is required in order to reduce the viscosity of the blended oil so that the engine performance will improve. Performance of the engine is found to be good for the B40 blend. However, the overall performance of the engine is found to be good when the oil and diesel blend is supplied to the cylinder after preheating.

**Elango et al. (2010)** carried out experimental investigation on neem biodiesel. Reported that the variation in the peak pressures is not significant but an increase in the ignition delay of about 6 to 8 degree in crank angle was observed for the blends when compared to diesel. The specific fuel consumption is slightly higher for B20 but is closer to diesel among all the blends. When the concentration of neem oil in the blend is more than 30% by volume, there is an appreciable increase in the specific fuel consumption. The smoke opacity is found to be higher than diesel for all blends. Blends up to 20% substantially reduce CO\textsubscript{2} emissions with a marginal decrease in brake thermal efficiency. The brake thermal efficiency decrease as the concentration of neem oil in the blend increases. A maximum brake thermal efficiency of 30.4% was achieved for B20 while for diesel it was 30.9% at full load.

**Sarvanan et al. (2010)** conducted experiments on a single cylinder, four stroke, air cooled, direct injection, compression ignition engine using mahua oil methyl ester and diesel as fuel. Based on the finding they concluded that the energy consumption is found to be similar to that of diesel at full load. There is a significant variation at par load and due to higher fuel consumption of mahua oil (lower calorific value) it will require higher fuel storage volume which might be a disadvantage for automotive applications.

But this can be offset by injecting fuel at higher pressures it increase the specific output of the engine. The thermal efficiency is found to be at par with diesel. There is a significant drop in specific emissions of hydrocarbon, carbon monoxide and smoke emissions. These would attract biodiesel as a suitable substitute for diesel fuel. As mahua is a renewable fuel with its performance similar to that of diesel and lower emissions it can be promoted as an alternative fuel.

**Xue et al. (2011)** reviewed about the biodiesel engine performances and emissions, published by highly rated journals in cited scientific indexes. Reported the effect of biodiesel on engine power, economy, durability and emissions including regulated and non-regulated emissions, and the corresponding effect factors are surveyed and analyzed in detail. 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\textsubscript{x}.
emission on conventional diesel engines with no or fewer modification. And it favours to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel with small content in place of diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy. However, many further researches about optimization and modification on engine, low temperature performances of engine, new instrumentation and methodology for measurements, etc., should be performed when diesel is substituted completely by biodiesel.

**Dhar et al. (2012)** produced biodiesel from high free fatty acid neem oil using a two step process i.e. esterification followed by transesterification. The biodiesel was characterized for its physical, chemical and thermal properties. Performance, emission and combustion characteristics of the biodiesel and its various blends with mineral diesel were compared with baseline data in a direct injection diesel engine. Brake specific fuel consumption for biodiesel and its blends was higher than mineral diesel and brake thermal efficiency of all biodiesel blends was found to be higher than mineral diesel. Brake specific CO and HC emissions for biodiesel fuelled engine were lower than mineral diesel but NOx emissions were higher for biodiesel blends. Detailed combustion characterisation revealed that combustion starts earlier for higher biodiesel blends however start of combustion was slightly delayed for lower blends of diesel in comparison with mineral diesel. Rate of heat release for all biodiesel blends were almost identical to mineral diesel. Combustion duration for biodiesel blends was found to be shorter than diesel. Finally concluded that, biodiesel produced from high FFA neem oil is found to be marginally inferior compared to mineral diesel.

**Yamin et al. (2013)** studied the use of new as well as waste oil as biodiesel fuel for CI engine. The engine performance and emission characteristics were studied and compared with pure diesel fuel. The result showed that there was a loss in the fuel calorific value of about 13.43% for wasted oil biodiesel and 7.24% for unused oil biodiesel. Further, the density of the fuel was found to increase by about 4.75% with respect to pure reference fuel. As for the performance, biodiesel showed improvement in the torque, power and thermal efficiency and reduction in specific fuel consumption. This was achieved both as full load and low load.

**Atabani et al. (2013)** reported that production of biodiesel from non-edible oil resources. Reviewed, numerous aspects linked to non-edible oil feed stocks such as non-edible oil resources, advantages of non-edible oils, problems in exploitation on non-edible oils, fatty acid composition profiles of various non-edible oils, oil extraction techniques, technologies of biodiesel production, properties and characteristic on non-edible biodiesel and engine performance and emission characteristics have been studied. The determined properties beside the engine performance and emission characteristics of non-edible biodiesel covered in this review indicated that there is a huge chance to produce biodiesel from non-edible sources in the future.

**Raheman et al. (2013)** conducted test on a 103 kW single cylinder water cooled direct injection diesel engine using blends of biodiesel (B10 and B20) obtained from a mixture of mahua and simarouba oils (50-50) with high speed diesel in terms of brake specific fuel consumption, brake thermal efficiency, and exhaust gas temperature and emissions such as CO, HC and NOx. Based on performance and emissions, blend B10 was selected for long-term use. Experiments were also conduction to assess soot deposits on engine components, such as cylinder head, piston crown and fuel injector tip, and addition of wear metal in the lubricating oil of diesel engine when operated with the biodiesel blend (B10) for 100 hr. The amount of soot deposits on the engine components was found to be, on average, 21% lesser for B10 fuelled engine as compared with diesel fuelled engine due to better combustion. The addition of wear metals such as copper, zinc, iron, nickel, lead, magnesium and aluminium, except for manganese, in the lubricating oil of B10. Fuelled engine after 100 h of engine operation was found to be 11% to 50% lesser than those of the DIESEL fuelled engine due to additional lubricates.
2.2.6 Energy and Exergy Analysis of CI engine with Diesel and Biodiesel Blends

Al-Najem et al. (1992) analysed energy-exergy for a diesel engine. Both first and second laws of thermodynamics are employed to take into account the quantity and quality of energy. The availability of exergy analysis based on the second law is utilized to identify the source of losses in useful energy within the components of diesel engines. They observed that 50% of the chemical availability of the fuel is destroyed due to unaccounted factors and about 15% is lost in the cooling water or exhaust gases. On the other hand, the energy analysis shows 50% is wasted in the cooling water and exhaust gases and 15% is lost due to unaccounted factors.

Rakopoulos et al. (1997) analysed first- and second law of thermodynamics on a single cylinder, naturally aspirated, indirect injection diesel engine to study the energy and exergy performance of engine subsystems during various transient operating schedules comprising changes in speed and load. They concluded that combustion irreversibility decreases after a ramp increase in load, whereas the intensity of the heat lost to the walls has a minimal effect on the combustion irreversibility. The indicated work decreases after both speed or load increases. The exergy terms for the heat losses to the walls increase after an increase in load, which indicates that, the greater the heat loss to the walls increase after an increase in load. However, an increase in speed under a constant load reduces the relative value of the exergy terms for heat losses. The exergy terms for the exhaust gases from the cylinder and for the exhaust-manifold gas to the ambient increase with increasing load or speed and also with decreasing heat loss to the walls. The exhaust manifold irreversibility varies strongly during a load or speed change, while the inlet manifold irreversibility are insignificant.

Parlak et al. (2003) analysed the exhaust energy exergy loss in a low heat rejection diesel engine to that of standard diesel engine. In this study, the effects of reducing the compression ratio on the performance and exhaust emissions in a low heat rejection (LHR) indirect injection Diesel engine have been experimentally compared to those obtained from a standard Diesel engine (SDE) with fixed compression ratio. Reducing the compression ratio in a SDE without making any modification in the combustion chamber geometry and improvements in fuel properties cause the ignition delay time to be unduly long, and consequently, an unacceptable pressure rise is experienced. By means of high temperature increases in the combustion chamber of the LHR Diesel engine, the compression ratio was lowered from 18.20 to 16.10 in 0.7 intervals. Satisfactory performance was obtained at compression ratios of 17.50 and 16.80 in the LHR engine. In comparison to the SDE, at these compression ratios, the specific fuel consumption and NOx emissions are, respectively, decreased about 2.9% and 15%.

Canakci et al. (2006) analysed comparative energy and exergy of a four-cylinder turbocharged diesel engine using two different biodiesel fuels viz.; diesel fuel and blends of the biodiesel with diesel. Utilizing the experimental data obtained from steady-state tests, balance of energy and exergy rates for the engine were determined. Various performance parameters of the engine were evaluated for each fuel operation. They concluded that, the tested biodiesel offered almost the same energetic performance as diesel fuel, while the exergetic performance parameters usually follow similar trends with the corresponding energetic ones.

Sayin et al. (2007) presented comparative energy exergy analysis of a four-cylinder, four stroke spark ignition engine using gasoline fuels of three different research octane numbers (RONs), namely 91,93 and 95.3. Each fuel test was performed by varying the engine speed between 1200 and 2400 rpm while keeping the engine torque at 20 and 40 Nm. Then, using the steady-state data along with energy and exergy rate balance equations, various performance parameters of the engine were evaluated for each fuel. It was observed that the gasoline of 91-RON, the design octane rating of the test engine, yielded better energetic and exergetic
performance, while the exergetic performance parameters were slightly lower than the corresponding energetic ones. The combustion was the main contributor to the system inefficiency, and almost all performance parameters increased with increasing the engine speed. The exergy losses due to the exhaust gas and heat flow from the control volume are other contributors to inefficiency.

Abusoglu et al. (2009) studied the energy, exergy and exergo economic analysis of diesel powered cogeneration (DEPC). The first part presented, the formulation developed for such a comprehensive analysis while the second part is an application of the developed formulation that considers an actual cogeneration power plant. Compression ignition engine powered cogeneration application is among the most efficient simple cycle power generation plants where the efficiency is around 50%. The DEPC plant is considered with all associated components. Mass, energy and exergy balances are applied to each system component and subsystem. Exergy balance formulation is aimed to yield exergy destructions. Various efficiencies based on both energy and exergy methods and the performance parameters are defined for both the system components and the entire cogeneration plant. The formulations for the cost of products, and cost formation and allocation within the system are developed on basis of both energy and exergy.

Caliskan et al. (2009) carried out energy and exergy analysis of a John Deere 4045T diesel engine run with no.2 diesel fuel, Soybean oil methyl ester (SME) and High-Oleic soybean oil methyl ester (HOME) at 1400 rpm. It was aimed at determining energy and exergy efficiencies, energy losses and exergy destructions of the combustion process and comparing energetically the fuels used. The specific exergy of the fuels was calculated to be in the order of diesel > HOME>SME, while thermal energy and exergy efficiencies were 40.5% and 37.8% respectively.

Mukul et al. (2009) analysed the energy and exergy of a hybrid gas turbine cycle. The thermodynamic characteristics of Brayton-diesel cycle is considered in order to establish its importance to future power generation. Based on mathematical modelling, a computer code has been developed and the configuration has been subjected to thermodynamic analysis. Results showed that, at any turbine inlet temperature the plant specific work initially increases with increase of pressure ratio, and but a very high values of pressure ratio, it starts decreasing. For a specific work both increases. The cycle is best suited for applications where power requirement ranges between 700-900 kJ/kg. The exergy analysis shows that maximum exergy loss of around 27% occurs in during combustion in the plant. Finally concluded that, the Brayton-Diesel cycle provides the maximum available energy (about 60%) and the cycle gives maximum work output between 840-875 kJ/kg. Thus the cycle is found to be useful as energy conversion cycle.

Gopal et al (2010) analysed a diesel engine integrated with a PCM based energy storage system. Using actual system data, the assessments of energy and exergy saved, the energy and exergy efficiencies are done. It is observed that, 6.13% of the total energy of the fuel is saved using thermal energy storage system. From the exergy analysis, it is identified that only 0.47% of the chemical availability of the fuel is saved. The energy efficiency of the integrated system is found to be varying between 3.19% and 34.15%. In contrast, the exergy efficiency, which incorporates the second law of thermodynamics, ranges from 0.25% to 27.41%.

Ciniviz (2010) investigated the effect of ceramic coating on a turbocharged diesel engine performance and energy balance. The engines were tested at full load. The heating value, engine power, torques and specific fuel consumption (SFC) of ethanol is lower than that of diesel. Compare to engine power of diesel engine, low heat rejection of the engine (LHRe) has increased about 2%. Low heat rejection engine with ethanol (LHReth) has decreased about 22% at all engine speed. Compare to engine torque of diesel engine, LHRe has increased about 2.5%. LHReth has decreased about 23% at all engine speeds. Compare to specific fuel consumption of diesel engine, LHRe has decreased about 1.1%, and LHReth has increased about 54% at all engine speeds.
Compare to exhaust turbine (inlet temperature of diesel), LHRe has increased about 15%, LHReθ has decreased about 17% at all engine speeds.

Jaimes et al. (2010) concluded that the exergy analysis is a powerful tool for evaluation of efficiency and sustainability of biodiesel production processes. With the application of exergy analysis the irreversibility of the overall process was estimated (106,739 MJ/h) with impact of separation and purification system about 42% of total losses. The exergy analysis also shows that energy integration is needed to reduce energy losses and to make the process more sustainable.

Sorguven et al. (2010) conducted the thermodynamic assessment of algal biodiesel utilization. They observed that the algae biodiesel carbon dioxide cycle provides a positive amount of useful work. The renewability indicator is found to be 0.27. This means that nearly three fourth of the work potential of algal biodiesel is used for its production and to restore the environment. Thus, the net available work gain from this process is about one fourth of work produced by the algal biodiesel. The renewability can be increased, if electricity from renewable sources is used, or the lipid content of the algae is enhanced.

Sahoo et al. (2011) performed second law analysis of syngas with a mixture of hydrogen (H₂) and carbon monoxide (CO), in a 5.2 kW engine for various loads. The results indicate that, compared to the 100% CO dual fuel mode, increasing the H₂ content in syngas from 50% to 100%, increased second law efficiency from 8 to 51%. This is due to better combustion process and increased the work output with the presence of added H₂.

Sekmen et al. (2011) performed energy and exergy balances to the engine using soybean biodiesel as fuel. The energetic and exergetic performance parameters of the engine computed and compared with each other. They observed that using exergy as a measure of quality; the diesel is better quality fuel than biodiesel. They also observed that specific fuel consumption of biodiesel is more than that of diesel. The biodiesel fuel shows the similar energetic performance value with diesel fuel. Regarding exergy part, the use of biodiesel develops similar exergetic performance value with diesel. The system inefficiency is the destructive of exergy by irreversible process occurred by the combustion. Exergy losses due to the exhaust gas and heat transfer are other contributors in decreasing order. Finally they concluded that, a combined energy and exergy analysis provides much better and more realistic information about the engine performance.

Sorathia et al. (2012) analysed the quantity and quality of energy by applying 1st law and 2nd law of Thermodynamics in a single-cylinder, direct injection diesel engine using diesel and biogas as fuel. The experimental data studied by various investigators using steady-state tests which enable accurate measurements of air, fuel, engine load, and all the relevant temperatures. Balance of energy and exergy rates for the engine were determined and then various performance parameters and energy and exergy efficiencies were calculated for diesel oil and diesel – biogas duel fuel. The results of tested diesel – biogas duel fuel offer similar energetic performance as diesel fuel. In addition to this, the exergetic performance parameters usually follow similar trends according to the energetic performance parameters.

Avdin et al. (2013) carried out energetic and exergetic performance assessment of a turboprop engine at various loads. They studied a thermodynamic analysis of a turboprop engine at full and partial load condition. Objective of this study is to understand the mechanisms that have enabled improvements of performance parameters such as thermodynamic efficiencies, thrust or power, specific fuel consumption and specific power in aero engines, thus reducing environmental impact. They observed the maximum overall and exergy efficiency of the turboprop are found to be 30.7 and 29.2% respectively. The minimum specific fuel consumption and maximum shaft power are found to be 0.2704 kg (kWh)^{-1} and 1948 bhp at maximum load.
respectively. The optimum functional load conditions of the engine are observed at higher loads. The results from this study are expected to assist propeller aero-engine design work, where the first and second laws provide a more comprehensive assessment of performance.

Debnath et al (2013) explored the effect of compression ratio and injection timing on energy and exergy potential of a palm oil methyl ester (POME) run diesel engine. Experiments were carried out in a single cylinder, direct injection, water cooled variable compression ratio diesel engine at a constant speed of 1500 rpm under a full load of 4.4 bar brake mean effective pressure. The study involves four different CRs of 16, 17, 17.5 and 18; and three different Injection timing of 20, 23 and 28 BTDC. The energy analysis performed for the experimental data includes shaft power, energy input through fuel, output by cooling water and exhaust, unaccounted loss per unit time. The exergy analysis is carried out for availability input, shaft, cooling water and exhaust availability, availability destruction and entropy generation. It shows that higher values of CR increase the shaft availability and cooling water availability, however, they decrease the exhaust flow availability. The retardation and advancement of IT give similar results. The exergy analysis also shows that with the increase of CR, the injection retardation and advancement increase the shaft availability and exergy efficiency, while it reduces the exergy destruction. They also concluded that the entropy generation is also reduced for the similar CR and IT modifications.

Gogoi et al. (2013) analysed the performance of a single-cylinder four stroke direct injection diesel engine in the light of first law of thermodynamics. An energy balance study is carried out to quantify the various losses associated with diesel engine process on the basis of experimental performance and emission data. The engine was fuelled with diesel and jatropha methyl ester (JME) in order to obtain experimental results corresponding to steady state engine operations at full load. The energetic performance parameters of the engine were evaluated at full load. The results showed lower brake thermal efficiency (BTE) and higher fuel consumption in respect of JME. From the energy analysis, it was observed that, the fuel energy input was more with JME due to higher fuel consumption. The indicated power produced by the engine with JME was comparatively higher. The energy loss with the exhaust gases was marginally higher and the loss of energy due to cooling was slightly lower for JME. However the un accounted heat losses were significantly higher and this was the reason of lower BTE with JME. The viscosity of JME was higher compared to diesel as a result the JME fuel did not atomize properly resulting in poor combustion. The combustion efficiency was found to be less with JME and higher losses of energy due to combustion inefficiency resulted in higher un accounted losses and hence lower BTE with JME.

Jing-ping et al. (2013) conducted the exergy analysis on a gasoline engine. The exergy balance model was built according to the thermodynamic theory of IC engine. The working processes of gasoline engine were simulated by using the GT-power. The required parameters were calculated and then gasoline engine exergy balance was obtained by programming on computer. On this basis, the influences of various parameters on exergy balance were analysed. Result showed that, the proportions of various forms of exergy in gasoline engine from high to low are irreversible loss, effective work, exhaust gas exergy and heat transfer exergy. They observed that effective exergy proportion fluctuates with cylinder volumetric efficiency at full load, while it always increases with break mean effective pressure at part load. The lower proportion of heat transfer exergy appears at high speed and high load. Irreversible loss is mainly influenced by load. At part load, higher BMEP results in lower proportion of irreversible loss; at full load, the proportion of irreversible loss changes at highest speed.

Mishra et al. (2013) carried out energy and exergy analysis in a single-cylinder, 4-stroke, 7 bhp, water cooled diesel engine fuelled with palm biodiesel based on experimental data. Used exergy analysis to understand and improve the actual efficiencies of the whole system. Energy analysis identified the energy
losses but could neither identify the irreversible losses nor their location. These are, however, could be clearly explained with the application of exergy analysis. The objective of the analyses is to determine whether the fuel made any significant difference on the efficiencies of the engine. The fuel exergy, exergy loss due to exhaust gasses, exergy loss due to cooling water, exergy destruction and exergetic efficiency of the engine were obtained by using the experimental data at steady-state condition. The results of tested biodiesel showed a similar type energetic performance as petro diesel fuel.

**Jibanandana et al. (2014)** analysed the exergetic performance of a CI engine in terms of irreversibility components and its emission when operated at steady-state fuelled with Palm and Karanja biodiesels. They evaluated the energy and exergy balances for the engine using the experimental performance and emission data for the three selected fuels, namely petro diesel (PD), Palm biodiesel (PB), and Karanja biodiesel (KB), then the energetic and exergetic performance parameters of the engine are evaluated and compared with each other. They observed that the petro diesel is a better quality fuel than biodiesel, because of its higher net calorific value. The brake specific fuel consumption of biodiesel is higher than that of petro diesel for the same work output. The same has been found out through the exergy analysis. The magnitudes of the various entropy generations, exergy losses, exergy destructions, exergy loss ratios and exergy destruction ratios have been evaluated. It is found that exergy destroyed due to both combustion and fluid flow irreversibility for PB is minimum, whereas evaluation of Irreversibility components of a CI engine fuelled separately with palm and karanja biodiesels the brake thermal efficiency and exergetic efficiency is maximum. The irreversibility found with the petro diesel is higher than that of biodiesels. Palm biodiesel is found to be better than karanja biodiesel in terms of both energetic and exergetic performance. The comparative assessment of the fuels reveals that with the increase in oxygen content in the fuel, the combustion on one hand is found to be better and reversibility get reduced on the other.

**Reddy et al. (2014)** carried out energy and exergy analysis of the biogas run dual fuelled diesel engine. They analysed the study by coupling 1st law and 2nd law of thermodynamics to have a clear idea on fuel consumption, brake thermal efficiency, exergy efficiency and different availabilities with the varying load and compared to the corresponding diesel values. They concluded that the presence of CO₂ in the biogas reduced the burning velocity, and there by resulted incomplete combustion that increases the brake specific energy consumption and exhaust gas temperature of dual fuel modes, including the ignition delay and high self-ignition temperature of biogas helped delaying the dual fuel combustion process more into the expansion stroke. All these factors lowered the thermal efficiency. Also concluded that the increase in load result an increase in exergy efficiency for all the tested fuel mode condition. For the dual fuel operation beyond 20% load, exergy efficiency was increased significantly due to improved combustion of biogas at high temperature zones. However, due to presence of about 41% CO₂ volume in biogas, the work output of the dual fuel modes have been lower, and hence, resulted in lower exergy efficiency. Finally they conclude that, the dual fuel mode require higher fuel exergy for producing the same amount of shaft output compared to its diesel mode. The destroyed availability decreases as the load increases due to the presence of availability decreases as the load increases due to the presence of CO₂ in biogas.

**2.2.7 Optimal Performance Parameter**

**Irusta et al. (1994)** described a statistical criterion for evaluation and selection of different testing methods for solid bio fuels taking into consideration accuracy, precision, sensitivity, re productivity, repeatability, testing costs and testing time. The signal-to-noise ratio suggested by Taguchi has been used in a way similar to a traditional method (analysis of variance, ANOVA) used for this purpose. Some simulated examples are described to illustrate the development of the proposed technique. Application to real situations can be made by treating experimental data in a similar way.
Kim et al. (2010) studied the optimization of experimental parameters, such as catalyst type, catalyst concentration, and molar ratio of alcohol to oil and reaction temperature on the transesterification for the production of rapeseed methyl ester. The Taguchi approach was adopted as the experimental design methodology, which was adequate for understanding the effects of the control parameters and to optimize the experimental conditions from a limited number of experiments. The optimal experimental conditions obtained from this study were potassium hydroxide as the catalyst, at a concentration of 1.5 wt % and a reaction temperature of 60°C. Concluded that according to Taguchi method, the catalyst concentration played the most important role in the yield of rapeseed methyl ester. Finally, the yield of rapeseed methyl ester was improved to 96.7% with the by optimal conditions of the control parameters which were obtained by Taguchi method.

Karnwal et al. (2011) presented an experimental study that involved an application of the Taguchi method and grey relational analysis to determine the optimum factor level to obtain optimum multiple-performance characteristics of a diesel engine run with different low-percentage thumba biodiesel-diesel blends. Four factors namely, low-percentage thumba biodiesel-diesel blend, compression ratio, nozzle opening pressure and injection timing were each considered as three levels. An L9 orthogonal array was used to collect data for various engine performance-and emission-related responses under different engine loads. The signal-to-noise (S/N) ratio and grey relational analysis were used for data analysis. The results of the study revealed that the combination of a blend consisting of 30% thumba biodiesel (B30), a compression ratio of 14, a nozzle opening pressure of 250 bar and an injection timing of 20° produces maximum multiple performance of a diesel engine with minimum multiple emissions from the engine.

Sivaramakrishnan et al. (2012) optimized the direct injection single cylinder diesel engine with respect to brake power, fuel economy and emissions through experimental investigations and DOE methods. A single cylinder 5.2 kW diesel engine was selected for test. Five parameters, Power (P), static injection pressure (IP), injection timing (IT), fuel fraction (B) and compression ratio (CR) was varied at four levels and the responses brake power, fuel economy and emissions were investigated. The optimum n values of the response could be predicted using Signal-Noise ratio(S/N ratio) and optimum combination of control parameters were specified. The best results for brake specific fuel consumption, brake thermal efficiency were observed at increased CR, IP and IT. The emissions CO, HC were reduced while NOx emission increases.

Kawade et al. (2013) concluded that, the blends of biodiesel with small content by volume could replace diesel in order to help in controlling air pollution and improving engine performance of power and economy of engine when using biodiesel blending with diesel fuel. They have also concluded that, the Optimization of CI engine performance and operating parameters through different software is most suitable, more accurate and less time consuming technique as compared to experimental method. Use of Artificial Neural Networks (ANN) for optimizing the C.I. engine parameters is most suitable techniques. Therefore ANN will be a very good tool to optimize engines parameters in the future. Also they observed that, Taguchi method can be effectively used for the investigation of multiple performance characteristics of a diesel engine.

Kaliamoorthy et al. (2013) investigated the effects of engine parameters on the performance and emission characteristics of a single cylinder 5.2 kW diesel engine. The experiments were designed using a statistical tool known as design of experiments based on Taguchi. Five parameters, namely, power, static injection pressure, injection timing, fuel fraction, and compression ratio were varied at four levels and the responses brake power, fuel economy and emissions were investigated. The optimum values of the response could be predicted using signal-noise ratio and optimum combination of control parameters were specified. Results of confirmation tests showed good agreement with predicted quantities. A compression ratio of 17.7, blend of 20% karanja biodiesel, an injection pressure of 230 bar, injection timing of 270 before top dead centre and a
70% load were found to be optimal values for the karanja biodiesel blended diesel fuel operation in the test engine.

**Naik et al. (2013)** studied the optimum of effective parameters of Pongamia pinnata biodiesel using Taguchi Method. The optimum parameter for high percentage yield was selected by varying parameters through Taguchi method. With an orthogonal array (L-9) a total set of nine experiments having three parameters each at three levels indicated that the Taguchi method was a efficient method of determining the optimum parameters for high percentage yield of karanja oil methyl ester (KOME). ANNOVA helped to estimate the contribution of each noise factor.

**Dhote et al. (2013)** studied the most commonly used method for biodiesel preparation method via transesterification of vegetable oil using alkaline catalysts. The optimization of experimental parameters, such as catalyst type, catalyst concentration, oil to alcohol molar ratio and reaction time, on the transesterification for the production of Mahua oil methyl ester has also been studied. The Taguchi approach was adopted as the experimental design methodology, which was adequate for interpreting the effects of the control parameters and to optimise the experimental conditions from a limited number of experiments. The optimal experimental conditions obtained from this study were oil to the alcohol molar ratio 1:15, sodium hydroxide as the catalyst, as a catalyst concentration of 0.4 wt% and a reaction time of 5 min. According to Taguchi method, the catalyst type played the most important role in the yield of Mahua oil methyl ester.

**Gorle et al. (2013)** carried out experiments on biodiesel blends and compared it with diesel fuel characteristics. Studied the optimization of experimental parameters such as catalyst type, catalyst concentration, molar ratio of alcohol to oil and reaction temperature. The Taguchi method helped to understand the effect of control parameter and to optimize experimental conditions from a limited number of experiments and contribution of each noise factor calculated by ANOVA. Finally the yield of jatropha methyl ester could be improved using control parameter which was obtained by Taguchi method. The acquired data were analyzed for various parameters such as brake thermal efficiency (BTE), brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT). The blends of BJ-10 and BJ-20 have superior emission characteristics than other blends and closer to diesel value.

**Siju et al. (2013)** investigated the combine effect of EGR and Injection Pressure for the performance of DICI engine by using Karanja biodiesel. To reduce number of experiments, Taguchi method of DOE has been carried out. Optimum parameters from Taguchi method were validated by experiments and compared the results.

### 2.3 Lead Points for Taking the Present Work

#### 2.3.1 Learning variances

- A very few reports are available for the energy and exergy analysis of neem, mahua, polanga and simarouba biodiesel.
- The detailed energy and exergy analysis of neem and simarouba biodiesel has not yet been studied.
- Few reports are available for molecular formula and chemical composition of neem, mahua, polanga and simarouba biodiesels and its blends.
- Few analyses have been done for the emission characteristics in diesel engines of simarouba oil methyl esters.
• Few reports are available for optimal performance analysis of neem, mahua, polanga and simarouba biodiesel.

Taking into account the present day need for alternative fuels and the easy compatibility of biodiesel in C.I. engines the study was conducted to analyse the performance of biodiesel fuelled C.I. engine. In addition to that, the abundant availability of tree-borne seeds in Odisha influenced the study. Neem, mahua, polanga and simarouba seeds were selected for the experiment because of their high oil content. Also, these oils are mostly not considered as cooking oil and therefore are likely to be wasted if not used efficiently. The energy and exergy analysis of the biodiesel fuels signifies the utilisation of energy (indicating the losses) in C.I. engine and thus plays an essential role in the performance analysis.

2.4 Scope of Present Investigation

• The ever increasing demand for fossil fuels, uncertainty in their availability along with growing environmental degradation due to their combustion generated pollutants, it is important on the part of researchers to seek for renewable and non-polluting alternative energy sources.
• In rural and remote areas of Odisha, where grid power is not available in many parts, the abundant availability of tree borne oil like neem, mahua, polanga and simarouba can play a vital role in power generation for irrigation and electrification.
• There exists an ample scope in the transport sector which can curb some major problems like environmental pollution and health hazards.
• Biodiesel can be used as a substitute for diesel in diesel generators.
• The common by- products produced while processing the biodiesel is oil seed cake. During oil expelling, about 65-70% of the seed kernel is obtained as de-oiled cake. The residue of biodiesel production can be used as organic manure in agricultural fields. Oil cake contains nitrogen, phosphorous and potassium; it can be used as organic manure. After extraction of oil from seed the detoxification of the seed cake is necessary so that the seed cake can be used as cattle feed.
• Glycerol is a by- product of transesterification process from biodiesel industry, which is generated in large amounts during the production of biodiesel from SVO. The crude glycerol, the low-priced by-product of biodiesel industry, can be efficiently used for the production of additional value-added products.

2.5 Definition of the Problem

The definition of the problem is described briefly as:

• Selection and extraction of vegetable oils.
• Biodiesel production and processing.
• Preparation of biodiesel blends.
• Determination of fuel properties.
• Fatty acid profile
• Engine performance and exhaust emissions.
• Energy and exergy analysis of compression ignition engine.