



## PRODUCTION OF BIODIESEL FROM NON EDIBLE CEIBA PENTANDRA SEED OIL HAVING HIGH FFA CONTENT

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### ABSTRACT

Recently, most of the biodiesel is produced from edible oils using methanol and an alkaline catalyst. However, large amount of non edible oils are available in India. Often the non edible oil contain high amounts of free fatty acids(FFA), which quickly react with the alkaline catalyst to produce soap then slow down the separation of the ester and glycerin. In the present study, high free fatty acid (14.71%) *Ceiba pentandra* seed oil was used as a source for biodiesel production. A two-step transesterification process is developed to convert the high FFA oils to its mono-esters. The first step reduces the acid value of the oil to less than 2mg KOH/g of oil using the acid catalyst (H<sub>2</sub>SO<sub>4</sub>) and methanol. The second step, alkaline catalyzed transesterification process converts the products of the first step to its mono-esters and glycerol. The reaction parameters such as molar ratio, catalyst concentration, reaction temperature and reaction time were optimized for production of *Ceiba pentandra* oil methyl ester are analyzed. The two-step esterification procedure converts of crude *Ceiba pentandra* oil to its methyl esters. The yield of methyl esters from *Ceiba pentandra* oil under the optimal condition was 92-93%. The viscosity of biodiesel oil is nearer to that of diesel and the calorific value is less than that of diesel because of their oxygen content. The important properties of biodiesel such as density, flash point, fire point and cetane number are found out and compared with that of diesel. This study supports the biodiesel production from non-edible *Ceiba pentandra* seed oil as a viable alternative to the diesel fuel.

**Keywords:** biodiesel, *Ceiba pentandra* oil, transesterification, FFA.

### 1. INTRODUCTION

The majority of energy consumed worldwide comes from fossil sources like petroleum, coal and natural gas. However, these sources are limited and will be exhausted in the near future [1]. Thus looking for an alternating sources of new and renewable energy such as hydro, bio-mass, wind, solar, geothermal, hydrogen and nuclear is of vital importance [2]. Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic, and industrial sectors for the generation of power/ mechanical energy. From the point of view of protecting the global environment and concern for long term supplies of conventional diesel fuels, it becomes necessary to develop alternative comparable with conventional fuels. Of the alternative fuels, vegetable oils are becoming a promising alternative to diesel fuels because they are renewable in nature and can be produced locally and eco-friendly as well [3]. The substitution of even a small fraction of total consumption by alternative fuels will have a significant impact on the economy and the environment. Government of India has formulated a bio fuel policy in which it is expected to use 20% of biodiesel at the end of 2017 and this will require a total of 13.38MMT of biodiesel [4].

Biodiesel can be produced from both edible and non edible oils as well animal fats. However, in India, which is not self sufficient in edible oil production, the non edible oils will be the only source of feedstock for biodiesel production. Among the available non edible oils

Mahua, Karanja and Jatropha have been successfully proven as potential tree born oil for biodiesel production in India, but their availability is in specific region. Therefore, it is not possible to have sufficient amount of oil at one place to produce biodiesel to cope the exponentially increasing demand for energy in terms of diesel consumption. Hence, it is needed to carry out research on different tree born non edible oils, so that we can able to fulfill the biodiesel requirement of our country without depending on the specific oil and its availability. Moreover, vegetable oils yielding trees absorbs more carbon dioxide from the atmosphere during their photosynthesis than they add to the atmosphere on burning. Hence they essentially help to alleviate the increasing carbon dioxide content in the atmosphere. They have practically no sulfur content, offer no storage difficulty, and they have excellent lubrication properties [5, 6]. Several researchers [7-12] have been made systematic efforts in the recent years to use the various vegetable oils as fuel in compression ignition engines. The viscosity of vegetable oils is about 11-17 times higher than that of diesel. However, their use in direct injection diesel engines is restricted by some unfavorable physical properties, particularly their viscosity. The use of vegetable oil cause poor fuel atomization, incomplete combustion and carbon deposition on the injector and valve seats resulting in serious engine fouling.

This necessitates the reduction in viscosity of the vegetable oils for use as fuel in CI engines. The commonly



employed methods to reduce the viscosity of vegetable oils are blending with diesel, microemulsion, pyrolysis and transesterification [13]. Among the several methods for reducing the viscosity, transesterification is an extensive, commercial and most promising method of converting vegetable oil into biodiesel that can be used directly or as blends with diesel in diesel engines and also the byproduct (glycerol) has commercial value [14].

At present *Ceiba pentandra* seed oil does not find any major applications and hence even the natural production of seeds itself remains unidentified. In this study, typically non-edible, high FFA content, ceiba pentandra seed oil is considered as a potential feed stock for biodiesel production.

## 2. CHARACTERISATION OF CEIBA PETANTRA OIL

### 2.1. Crop pattern and yield assessments

*Ceiba pentandra* L. Gaertn or locally known as ilavampanju, silk cotton or kapok belongs to the Malvaceae family [15]. It was native to Southeast Asia and cultivated in Southeast Asia, India, Sri Lanka and tropical America [16, 17]. The tree grows to 60-70m tall and has a very substantial trunk up to 3m in diameter with buttresses. The trunk and many of the larger branches are densely crowded with very large, robust simple thorns. The leaves are compound of 5 to 9 leaflets, each up to 20cm and palm like. *Ceiba pentandra* was grown naturally in humid and sub humid tropical region, generally drought-resistant tree yields about 300 to 1,000 seed pods per year. Pods are ellipsoid capsule of 10-25cm long, and 3-6cm diameter. Capsules split open into 5 valves, having cotton-like woolly floss, yellowish grey and lustrous fiber in which 120-175 seeds are embedded as given in Figure-1(a). Seeds are round and black in colour as shown in Figure-1(b) the oil seed yield was producing on average 1280kg/ha. Air dried seeds have typically 58.0 % kernel, 3.4 % moisture, 28.7 % oil, and 23.0 % protein. It is cultivated for two purposes, first one its fibre is short natured, traditionally it is used as a filling materials for mattresses, pillows, cushions, and stuffed toys and second is its seeds produce pale yellow, bitter, non-drying, non-edible oil used locally in soap, illuminating oil and oil cake can be used as cattle feed and fertilizer. Ceiba pentandra is one of the most effective CO<sub>2</sub> absorbers which produce seeds containing about 25-28% (w/w) of oil in each fruit [18, 19].



Figure-1(a). *Ceiba pentandra* pods split open.



Figure-1(b). Ceiba Pentandra seeds.

### 2.2. Extraction of crude *Ceiba pentandra* oil

The oil extraction was carried out with mechanical expeller having high pressure continuous screw press and containing a stainless steel helical screw. The extracted oil was kept at atmospheric temperature for few hours in order for solids to settle down. The extracted crude *Ceiba pentandra* oil was filtered and heated to remove unwanted particles in the oil. After filtration, to remove any water content in the oil, the crude *Ceiba pentandra* oil was heated to 120°C.

### 2.3. Measurement of free fatty acid (FFA)

The titration method was used to determine the acid value or Free Fatty Acid (FFA) content in the crude ceiba pentandra oil. At first, 10mL of 95% ethanol and 10mL of diethyl ether were prepared and poured into the 250mL conical flask with 5 drops of phenolphthalein indicator. And then, 50g of sample oil was taken into the conical flask and finally titrated with KOH solution with continuous stirring to the end point of the indicator where the pink colour persisted [20].

### 2.4. Physicochemical and fatty acid properties of ceiba pentandra oil

Mechanically extracted *Ceiba pentandra* oil was pale yellow in color. The physical and chemical properties of *Ceiba pentandra* oil are given in Table-1. The saponification value of 197 clearly suggests that the oil consist mainly of medium-chain fatty acids (i.e. C16 and



C18). The free fatty acid content of unrefined *Ceiba pentandra* seed oil was about 14.71% i.e. acid value of 29.42 mg KOH/g. Unsaponification matter present in the extracted oil was 1.89%, which includes tocopherols, sterols, triterpenic alcohols, hydrocarbons, aliphatic alcohols and waxes [21]. The iodine value of the oil is 100.6 which was quite high and it lies within the values of semi-drying.

The fatty acid compositions of the *Ceiba pentandra* oil are given in Table-2, which shows the principal fatty acid profile of linoleic (35.11%), oleic (29.69%), palmitic (23.20) and stearic (5.68%) acids [22]. The level of total mono unsaturated, polyunsaturated and saturated fatty acid of the extracted oil was 52.89%, 35.11% and 9.44% respectively. The high content of unsaturated fatty acid makes it a stable liquid at room temperature.

**Table-1.** Physical and chemical properties of in crude *Ceiba pentandra* oil.

Property	Value
Density	916 kg/m <sup>3</sup>
Viscosity@40°C	30.42 mm <sup>2</sup> /s
Acid value	29.42mg KOH/g
Water content	0.04 wt. %
FFA	14.71% as oleic acid
Flash point	297°C
Saponification value	197
Iodine value	100.6

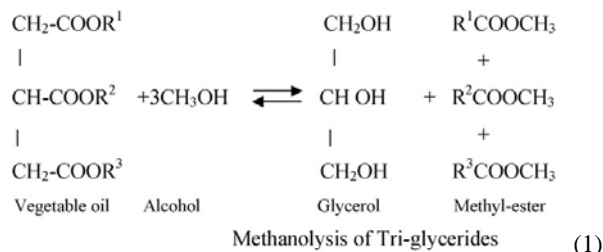
**Table-2.** Fatty acid compositions of *Ceiba pentandra* oil.

Fatty acids	Structure	Formula	Systematic name	Composition
Myristic	14:0	C <sub>14</sub> H <sub>28</sub> O <sub>2</sub>	Tetradecanoic	0.10
Palmitic	16:0	C <sub>16</sub> H <sub>32</sub> O <sub>2</sub>	Hexadecanoic	22.60
Stearic	18:0	C <sub>18</sub> H <sub>36</sub> O <sub>2</sub>	Octadecanoic	5.19
Oleic	18:1	C <sub>18</sub> H <sub>34</sub> O <sub>2</sub>	Cis-9-Octadecanoic	30.14
Linoleic	18:2	C <sub>18</sub> H <sub>32</sub> O <sub>2</sub>	Cis-9,cis-12-octadecadienoic	37.45
Arachidic	20:0	C <sub>20</sub> H <sub>40</sub> O <sub>2</sub>	Eicosanoic	1.68
Behenic	22:0	C <sub>22</sub> H <sub>44</sub> O <sub>2</sub>	Docosanoic	0.27
Lignoceric	24:0	C <sub>24</sub> H <sub>48</sub> O <sub>2</sub>	Tetracosanoic	1.47

### 3. BIO-DIESEL PRODUCTION PROCESS

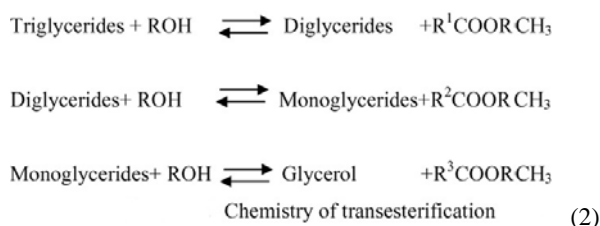
#### 3.1. Chemistry of transesterification reaction

Transesterification is the chemical reaction between triglycerides and short chain alcohol in the presence of catalyst to produce mono-ester. The long and branched-chain triglyceride molecules are transformed to mono-esters and glycerin [23]. The overall transesterification reaction can be shown by the following reaction in Equation (1).



where R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup> are long-chain hydrocarbons, sometimes called fatty acid chains. Normally, there are five main types of chains in vegetable oils and animal oils: palmitic,

stearic, oleic, linoleic, and linolenic. However, three consecutive and reversible reactions are supposed to occur. These reactions are represented in Equation (2).



The initial step in the conversion is triglycerides to diglycerides followed by the conversion of diglycerides to mono-glycerides and of monoglycerides to glycerol yielding one methyl ester molecule from each glycerides at every step [24]. Stoichiometrically, three moles of alcohol are required for each mole of triglyceride, but in practice a higher molar ratio is employed in order to displace the equilibrium for getting greater ester production. Though esters are the desired products of the transesterification reactions, glycerin recovery also is important due to its numerous applications in different industrial processes. Commonly used short chain alcohols



are methanol, ethanol, propanol and butanol. The yield of esterification is independent of the type of alcohol used. Therefore, the eventual selection of one of these three alcohols will be based on cost and performance considerations. The methanol is used commercially because of its low price. Alkaline hydroxides are the most effective transesterification catalysts as compared to acid catalysts. Potassium hydroxide and sodium hydroxide are the commonly used alkaline catalysts. Alkaline catalyzed transesterification of vegetable oils is possible only if the acid value of oil is less than 4. Higher percentage of FFA in the oil reduces the yield of the esterification process. The feed stocks with high FFAs could not be transesterified with the commercially available alkaline catalyst transesterification process. The reason is alkaline catalysts react with the FFAs to form soap that prevents the separation of the glycerin and ester [5].

### 3.2. Esterification procedure

A two-step transesterification process is developed to convert the high FFA oils to its esters. The process consists of two steps namely, acid esterification and alkali esterification.

- a) **Acid esterification:** The first step (acid catalyzed transesterification) reduces the FFA content of the ceiba pentandra oil to less than 2% using acid catalyst.
- b) **Alkaline esterification:** After removing the impurities from the first step, the alkaline catalyst transesterification process converts the low FFA ceiba pentandra oil to its mono-esters and glycerol. The parameters affecting the process such as alcohol to oil molar ratio, catalyst amount, reaction temperature and duration are analyzed.

### 3.3. Reaction setup

The transesterification reaction was carried out in a laboratory scale reactor as shown in Figure-2. The apparatus used for the experiment consists of 1000 ml three necked flat bottom glass flask and electrical heater with magnetic stirrer arrangement to achieve a perfect contact among the reactants. One side neck of the reactor is plugged with air tight rubber stopper which holds the thermometer used to measure the reaction temperature. The other side neck is used to draw the sample oil and alcohol catalyst mixture. The water cooled condenser was inserted through the main neck of the reactor to recover the escaping methanol which has a boiling point of 65°C and vaporizes at the elevated temperature during the reaction. The condenser also helps in maintaining atmospheric pressure inside the reactor.

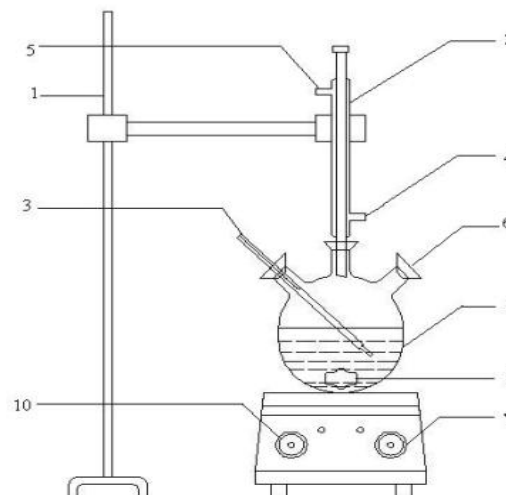


Figure-2. Schematic diagram of reaction setup.

- |                                |                            |
|--------------------------------|----------------------------|
| 1. Iron Stand                  | 2. Condenser               |
| 3. Thermometer                 | 4. Coolant in              |
| 5. Coolant out                 | 6. Closed Neck             |
| 7. Three Neck Flask            | 8. Magnetic Stirrer        |
| 9. Magnetic Stirrer Controller | 10. Temperature Controller |

### 4. ACID ESTERIFICATION

The first step reduces the FFA value of *Ceiba pentandra* oil to about 2% using acid catalyst. The crude ceiba pentandra oil had an initial acid value of 29.42 mg KOH/gm, corresponding to a FFA level of 14.71 %, which is for above the 1% limit for satisfactory transesterification reaction using alkaline catalyst. The process of transesterification is complicated, if oil contains large amount of FFA content that will form soap with alkaline catalyst. The soap can prevent the separation of the biodiesel from the glycerine fraction [25]. Therefore FFAs were first converted to esters in a pretreatment process using an acid catalyst ( $H_2SO_4$ ) to reduce the acid value of *Ceiba pentandra* oil to below 2mg KOH/gm and completed transesterification with an alkaline catalyst to produce biodiesel [26].

In this process, *Ceiba pentandra* oil feedstock, methanol and concentrated sulphuric acid were used in amounts established for each experiment. A known quantity of *Ceiba pentandra* oil was poured into the reaction flask and heated to the desired temperature. The methanol and sulphuric acid ( $H_2SO_4$ ) was added with the preheated *Ceiba pentandra* oil and maintained at the temperature of 60°C. During the reaction, the mixture was stirred constantly using a magnetic stirrer at a speed of 500-600 rpm. The product was poured into a separating funnel and left for 2 hours. The excess methanol with sulphuric acid and impurities moved to the top surface and was removed. The lower layer was low free fatty acid oil content as shown in Figure-3. The oil sample was heated to 70°C to remove the extra methanol and washed with distilled water in a separating funnel. Finally the acid value of the product separated at the bottom was





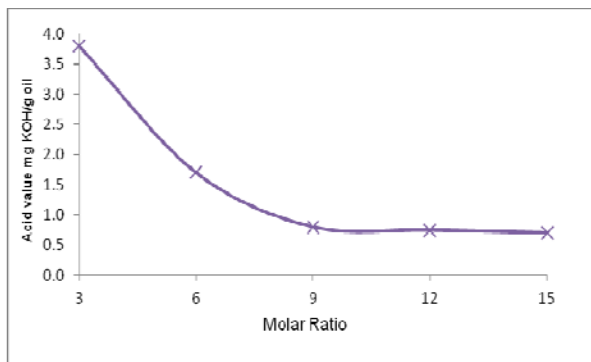
determined. After each parameter's optimum value was attained, this value was kept to be constant during the optimization of the next parameter was determined.



**Figure-3.** Acid esterification: Low FFA oil at bottom layer and excess methanol with sulphuric acid at top layer.

#### 4.1. Influence of molar ratio on reduction of acid value

The methanol to oil ratio is one of the most important factors that influences the reaction process. Therefore, suitable amount of added methanol should be chosen cautiously. The acid value reduction at different molar ratios is shown in Figure-4. It was found that the acid catalyst esterification rate increases with increasing in methanol value. The acid value reduced quickly during the initial phase and after that it reduced slowly. This might be due to the effect of water formation during the esterification of FFAs, which prevented further reaction [27]. The methanol to oil ratio 9:1 was the lowest ratio which gives the acid value of oil less than 2mg KOH/g oil, so it was selected as the optimum methanol to oil ratio.

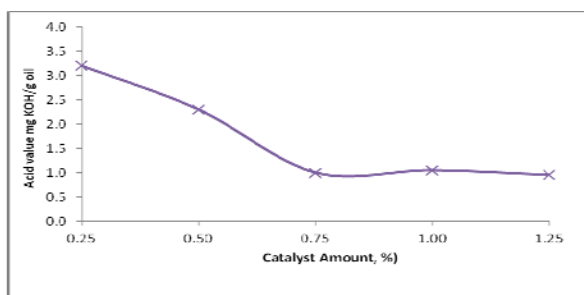


**Figure-4.** Influence of molar ratio on reduction of acid value.

Catalyst amount 0.75% v/v, reaction temperature 60°C, reaction time 45 min.

#### 4.2. Influence of acid catalyst amount on acid value

Another parameter that influences the acid value of oil in the acid catalyzed esterification is the catalyst concentration. The catalyst amount is varied in the range of 0.25-1.25% for five different values (0.25, 0.5, 0.75, 1.0 and 1.25% v/v of sulphuric acid). These percentages are volume fractions of the oil supplied for the reaction. The effect of the acid catalyst amount on the acid value reduction is shown in Figure-5. At lower catalyst concentration acid value could not be reduced below 2mg KOH/g oil. In accordance with the results of other researchers [28, 29] the ester formation rate increased with increasing catalyst concentration. However, 0.75% v/v of oil was selected as the optimum catalyst concentration because it was the lowest catalyst concentration which provides the acid value less than 2mg KOH/g oil. It is noted that during the present experiments, that excess addition of  $H_2SO_4$ , darken the color of the product and lower amount of addition affects the yield of the subsequent step.

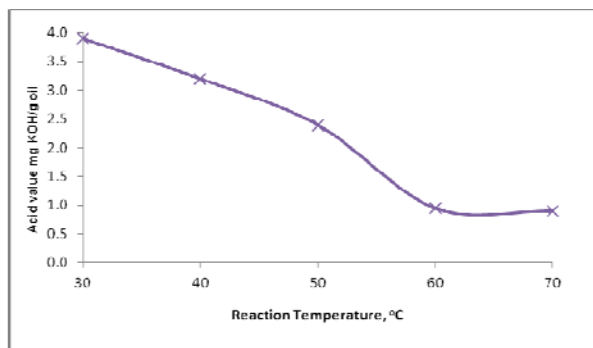


**Figure-5.** Influence of acid catalyst amount on reduction of acid value.

Molar ratio 9:1, reaction temperature 60°C, reaction time 45 min.

#### 4.3. Influence of reaction temperature on acid value

The acid value of oil versus reaction temperature was plotted as shown in Figure-6. Studies were carried out at different temperatures (30, 40, 50, 60 and 70°C) while methanol to oil ratio and catalyst concentration were 9:1 and 0.75% v/v of oil respectively. The result shows that the reaction temperature had an important role in the acid catalyzed esterification. The rate of reaction is increased by increasing the reaction temperature. This result was in accordance with the outcome obtained from earlier reports (14, 29). However, it was observed that the acid catalyzed esterification could occur at room temperature but the acid value of oil could not be reduced to less than 2mg KOH/g oil. The highest reaction rate was obtained at 60°C and the acid value reduced from 29.42 to 1.05mg KOH/g oil within 60 min. Hence the reaction temperature 60°C was considered to be the optimum temperature for this reaction.

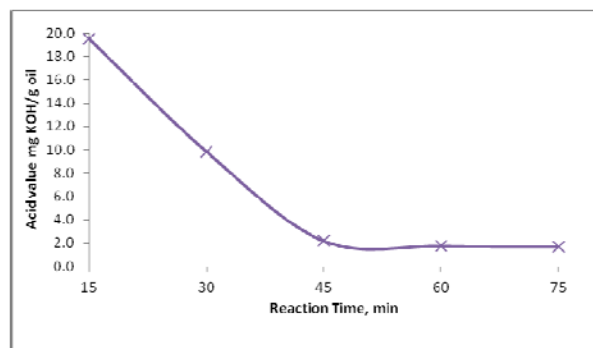


**Figure-6.** Influence of reaction temperature on reduction of acid value.

Molar ratio 9:1, catalyst amount 0.75% v/v, reaction time 45 min.

#### 4.4. Influence of reaction time on acid value

Influence of reaction time on acid catalyst esterification is shown in Figure-7. From the Figure it was very clearly evident that the pretreatment stage considerably reduced the acid value from 29.42 to below 2mg KOH/g. The rate of reaction was fast in the first 45min, for which the acid value dropped down from 29.42 to 3.85 (86.91%). The reaction slows down after 45min up to 60min, acid value reduction is from 3.85 to 1.76 (94.01%). The esterification reached the equilibrium in the stationary stage after 60min. For economical reasons, the best process is the one that reaches the acid value less than 2mg KOH/g oil in the shortest period of time.



**Figure-7.** Influence of reaction time on acid catalyst esterification.

Molar ratio 9:1, catalyst amount 0.75% v/v, reaction temperature 60°C.

## 5. ALKALINE ESTERIFICATION

After removing the impurities of the first step product, it is transesterified to mono-esters of fatty acids using alkaline catalyst. The parameters affecting the process such as alcohol to oil molar ratio, catalyst amount, reaction temperature and duration are analyzed. In this process, the low free fatty acid content ceiba pentandra oil was poured into the reaction flask were kept on the electrical magnetic stirrer just below the boiling point of methanol. The potassium hydroxide-methanol solution was

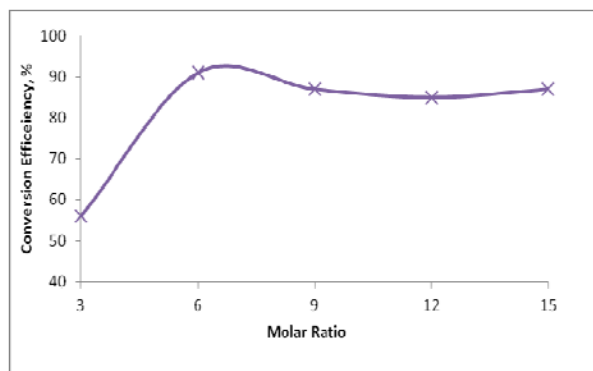
prepared freshly by stirring in a small flask in order to maintain the catalytic activity and to prevent the moisture absorbance. When the temperature reached 60°C in the reactor, the recently prepared potassium methoxide was added to ceiba pentandra oil in reaction flask rapidly under stirred condition and the measurement of time was started at this point. Then the final mixture was agitated for 45 min at 60°C. The mixing is necessary to improve the mass transfer across the boundary between the two faces.



**Figure-8.** Alkaline transesterification: Biodiesel at top layer and Glycerol at bottom layer.

After the esterification process, the product was transferred to separating funnel and allowed to settle under gravity for overnight to enhance the separation at room temperature. Two distinct liquid phases were formed during the separation with the methyl ester at the top layer and the glycerol was settled down at the bottom layer as shown in Figure-8. The glycerol layer at the bottom was separated out as a byproduct and it is used in pharmaceutical, cosmetic and other industries. The separated methyl ester was mixed with some warm water by using a sprinkler which slowly sprinkled water. After the mixture had got settled down the water was drained out and washed repeatedly to remove any traces of glycerol at room temperature until the water became clear. After the final washing, the excess methanol and water in the ester phase was then removed by heating the product to 110°C and maintain this temperature for a while for some water bubbles. Then it is allowed to cool at room temperature.

### 5.1. Influence of molar ratio on biodiesel conversion efficiency



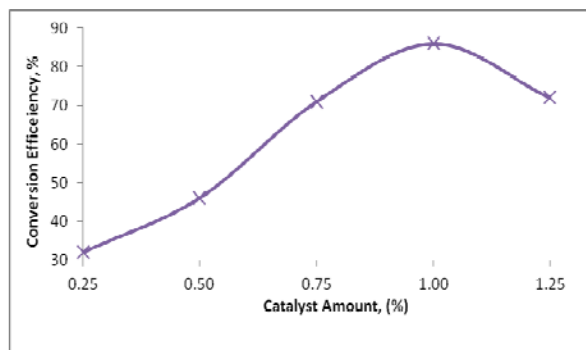
**Figure-9.** Influence of molar ratio on conversion efficiency.

Catalyst amount 1% w/w, reaction temperature 60°C, reaction time 45 min

The variation of the biodiesel conversion efficiency for molar ratio of 3, 6, 9, 12 and 15 was studied. The molar ratio of alcohol to vegetable oil is one of the important factors that affect the biodiesel conversion efficiency as well as biodiesel production cost. Molar ratio is the ratio of number of moles of alcohol to number of moles of glycerides in the oil. Theoretically, transesterification reaction requires three moles of alcohol for each mole of oil. But, in practice, the molar ratio should be higher than that of stoichiometric ratio in order to drive towards a completion reaction. The conversion efficiency of initial step in relation with molar ratio obtained during the present study is shown in Figure-9. The maximum conversion efficiency is achieved very close to the molar ratio of 6:1; further increase in the molar ratio should be avoided because the reduction in acid value was insignificant. In addition, the high molar ratio of alcohol to vegetable oil interferes with the separation of glycerin because there is an increase in solubility. When glycerin remains in the solution, it helps drive the equilibrium back to the left side of equilibrium, resulting in the lower yield of esters [30].

### 5.2. Influence of alkali catalyst on biodiesel conversion efficiency

The amount of alkali catalyst that should be added to the reactor varies from 0.5% to 1% w/w (weight of KOH/ weight of oil) [31, 3]. The conversion efficiency at different catalyst amount used in this experiment was shown in Figure-10. The result shows that the reaction was highly dependent on the catalyst amount. The effect was most evident in relation to the initial reaction rate. The maximum conversion efficiency is achieved at 1.0% of KOH. With further increase in catalyst quantity, there was a decrease in the conversion efficiency. Addition of excess amount of catalyst, gave rise to the formation of soap and glycerol phase. Esterification does not take place effectively for insufficient amount of KOH addition.

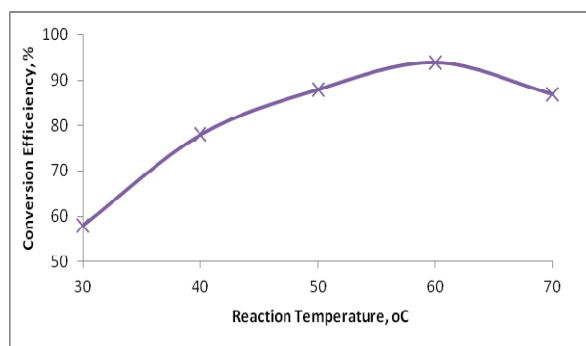


**Figure-10.** Influence of acid catalyst amount on conversion efficiency.

Molar ratio 6:1, reaction temperature 60°C, reaction time 45 min.

### 5.3. Influence of reaction temperature on biodiesel conversion efficiency

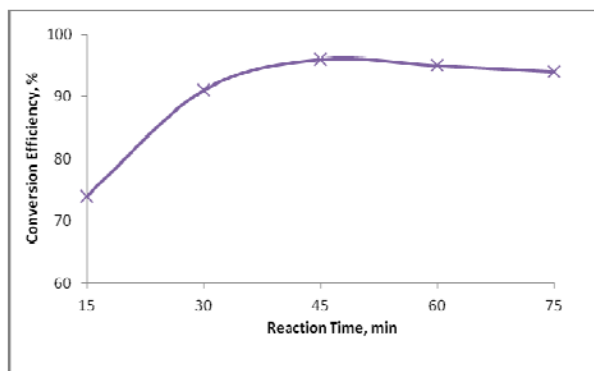
Studies were carried out at different temperature such as 30,40,50,60 and 70°C with 1% KOH as catalyst and molar ratio of 6:1 at a stirring speed of 500-600rpm. The yield of ceiba pentandra oil methyl ester versus time was plotted at different reaction temperature is shown in Figure-11. It was observed that temperature had positive influence on methanolysis of ceiba pentandra oil. The reaction temperature above boiling point of alcohol is avoided since at high temperature it tends to accelerate the saponification of glycerides by the alkaline catalyst before completion of the alcoholysis [32].



**Figure-11.** Influence of reaction temperature on biodiesel conversion efficiency.

Molar ratio 6:1, Catalyst amount 1% w/w, reaction time 45 min.

### 5.4. Influence of reaction time on biodiesel conversion efficiency



**Figure-12.** Influence of reaction time on biodiesel conversion efficiency.  
Molar ratio 6:1, catalyst amount 1% w/w, reaction temperature 60°C,

In order to optimize the reaction time, the different reaction duration selected for this study was 15, 30, 45, 60 and 75 min. To achieve a perfect contact between the reagents and the oil during transesterification, they must be stirred well at constant rate. Figure-12 shows the influence of reaction time on biodiesel conversion. The results clearly signify that the biodiesel yield increased with reaction time. The biodiesel yield was found to be more or less same at 45-75 min of reaction time. Results

obtained from the present experiments reveal that, about 45 min of reaction is sufficient for the completion of the esterification.

## 6. PROPERTIES OF METHYL ESTERS OF CEIBA PENTANDRA SEED OIL

The fuel properties of ceiba pentandra oil methyl ester in comparison with that of diesel is shown in Table-3. The comparison of these properties with diesel shows that the methyl ester has a relatively closer fuel property values to that of diesel [33]. The viscosity value of vegetable oil decreases sharply after two step transesterification. The viscosity of biodiesel is closer to that of diesel. Hence, in the existing engine no hardware modifications are required for handling biodiesel. The calorific values of methyl ester are lower than that of diesel because of their oxygen content. The oxygen presence in the biodiesel helps for complete combustion of fuel. The flash point of ceiba pentandra seed oil is lowered by transesterification but it is still higher than that of diesel. A small percentage addition of biodiesel with diesel increases the flash point of diesel. Hence, it is safer to store biodiesel - diesel blends as compared to diesel alone. The properties of biodiesel are compared with ASTM biodiesel standards.

**Table-3.** Fuel properties of ceiba pentandra oil, ceiba pentandra oil methyl ester and diesel.

Properties	Crude ceiba pentandra oil	Ceiba pentandra methyl ester	Diesel	Biodiesel standards ASTM D 6751-02
Density (kg/m <sup>3</sup> )	916	885.2	854	880
Kinematic viscosity at 40°C (mm <sup>2</sup> /s)	30.42	4.36	2.60	1.9-6.0
Flash point (°C)	297	158	52	>130°C
Fire point(°C)	315	169	64	-
Cetane index	49	49	52	41 min
Gross calorific value (MJ/Kg)	41.62	41.79	44.72	-

## 7. CONCLUSIONS

The biodiesel production from low-cost, high FFA ceiba pentandra feed stock has been investigated in the present study. It is found that the feedstock with high FFAs could not be transesterified with the commercial alkaline catalyst transesterification process due to the formation of soap that prevents the separation of glycerin and ester. A two stage transesterification process was selected to convert the high FFA oil to its methyl ester. The first stage was acid pretreatment process. The high FFA (14.71%) crude ceiba pentandra oil can be reduced to less than 1% in acid esterification, using acid catalyst (1% v/v H<sub>2</sub>SO<sub>4</sub>) reacting with methanol oil ratio of 9:1 at 60°C and 45min reaction time. Excess addition of sulphuric acid darkens the product. The first stage product having acid value less than 2mg KOH/g is used for the second stage

alkali catalyzed (1% w/w KOH) transesterification reaction, molar ratio of 6:1 favors the completion of alkaline catalyzed esterification process in 45min. The maximum ester conversion is achieved at the reaction temperature of 60°C. The process gives a yield of 92.35% ceiba pentandra biodiesel, which has comparable fuel properties with that of diesel. The viscosity of biodiesel is nearer to that diesel. The flash point of biodiesel is greater than that of diesel and the calorific value is slightly lower than that of diesel. The present experimental study reveals that biodiesel from ceiba pentandra seed oil is quite suitable as an alternative to conventional diesel fuel.





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