

Process Optimization for Biodiesel Synthesis From *Jatropha Curcas* Oil

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ABSTRACT

Crude *Jatropha Curcas* Oil (CJCO) obtained from the seeds grown in the Western Ghat section of South India was investigated for biodiesel production using one step alkali catalyzed transesterification. The reactions were conducted at 400 rpm agitation rate for 1 hour. Different methanol to oil molar ratios (5.5:1, 6:1, 6.75:1, 7.5:1 and 8:1), catalyst to oil ratios (1.43, 1.68, 1.85, 2.1, 2.35 and 2.52 %w/w of oil) and reaction temperatures (50°C to 70°C) were employed to investigate their effect on biodiesel yield. The maximum yield of 80.5% was obtained at the optimum methanol to oil molar ratio of 7.5:1, catalyst to oil ratio of 2.09%w/w of oil and reaction temperature 60°C. The physiochemical properties of the biodiesel produced meet the ASTM standards. The reason for the low yield was observed as the high free fatty acid content (13.7 mg KOH/g of oil) in the Crude *Jatropha Curcas* oil. A biodiesel fueled four-stroke diesel engine-generator set yielded an overall fuel-to-electricity efficiency of 24.38% at maximum load condition, thus showing the possibility of utilization of CJCO derived fuel in diesel engines.

Key Words: Biodiesel, *Jatropha Curcas* Oil, Transesterification, Engine Performance

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INTRODUCTION

In today's world, petroleum based fuels are the most important energy sources for various applications. But, the increased environmental concern, skyrocketing prices and eventual depletion of these petroleum based fuels have caused the search suitable alternative to the petroleum based fuels. During the last decade, India maintained a very high growth rate which in turn leads to increased energy consumption and demand spending a large amount of valuable foreign exchange. Development of biofuels especially vegetable oil based biofuels as alternative and renewable energy sources, especially to electrify the rural parts of the country and to run the decentralized power units for agricultural purposes, helps the country attain energy self sufficiency. In highly populated countries like India, where the demand for the edible oil is higher, the non-edible oils can be a significant source of biodiesel production. *Jatropha Curcas*, a non-edible plant or shrub, grows practically all over the country (Openshaw, 2000), in most rural areas. Its oil is already a proven fuel for engine applications (Opensha, 2000, Kandpal and Madan, 1995). In India, a national mission to produce biodiesel from *Jatropha Curcas* (13 million tons annually by 2013) has been launched as an initiative to address socio economic and environmental concerns. A pilot project covering 0.4 million hectares has been launched in many states of the country.

Several processes have previously been developed to produce biodiesel from vegetable oils. Transesterification has emerged as the most viable and efficient method to convert the vegetable oils into biodiesel (Hanny and Shizuko, 2008 and Shay, 1993). The primary parameters relevant to transesterification reaction includes the time of the reaction, alcohol quantity used, type of catalyst, quantity of catalyst used, temperature of the reaction (Demirbas, 2003, and Pramanik, 2003) and most importantly the physical and chemical properties of the raw oil especially the free fatty acid content and water content (Emil Akbar et al, 2009, Ma and Hanna, 1999) in the feedstock. The most important fuel component in a vegetable oil is the free fatty acid or FFA. The FFA content of crude *Jatropha curcas* oil (CJCO) will vary and depends on the quality of the feed stock (Hanny and Shizuko, 2008). The physical and chemical properties of *Jatropha Curcas* oil are strongly influenced by processing, season—i.e. climate and geographical influences during the growth of the seed, storage of seed, etc. But India being large

country, the rainfall, soil type, nutrition level of the soil, temperature and other factors vary from region to region and hence the yield and properties of the *Jatropha Curcas* oil produced also vary from region to region

This work mainly discusses the outcome of biodiesel production from CJCO with high FFA content obtained from Western Ghat region of South India using one-step alkali catalyzed transesterification. The various factors influencing the biodiesel yield via catalyst concentration including (a) methanol-to-oil molar ratio and (b) the reaction temperature were investigated for optimum yield.

MATERIALS AND METHODS

Materials

The crude *Jatropha curcas* oil (CJCO) used in this study was supplied by Ms. Renulakshmi agro Industries (India) Limited, Coimbatore, South India. The Chemicals used in this work, such as methanol, Potassium hydroxide (KOH) and Sulphuric acid (H_2SO_4) were of reagent grade. The fatty acid composition of CJCO is given in Table 1. The FFA content of the oil was found to as 13.7 mg of KOH/g of oil. The reactions were carried out in a 1000 ml, specially designed, three-necked, flat-bottom flask equipped with reflux condenser, thermometer and stopper to add the catalyst solution. The reaction mixture was heated and stirred by a hot plate with a magnetic stirrer.

Transesterification Process

The transesterification process is the reaction of a tri-glyceride with an alcohol to form esters and glycerol. The alcohol reacts with

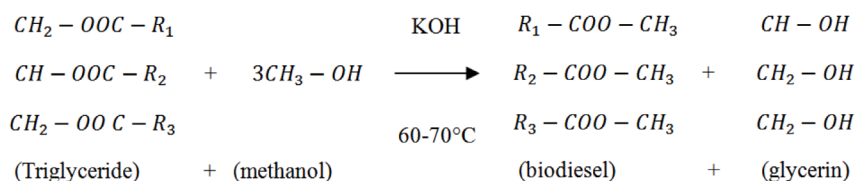
Table 1. Fatty acid composition of crude *Jatropha curcas* oil ^a

Fatty acid	Formula	Systemic name	Structure ^b	Wt%
Palmitic	C ₁₆ H ₃₂ O ₂	Hexadecanoic	16:00	11.3
Stearic	C ₁₈ H ₃₆ O ₂	Octadecanoic	18:00	17.0
Arachidic	C ₂₀ H ₄₀ O ₂	Eicosanoic	20:00	4.7
Oleic	C ₁₈ H ₃₄ O ₂	Cis-9-octadecenoic	18:01	12.8
Linoleic	C ₁₈ H ₃₂ O ₂	Cis-9, cis-12-octadecenoic	18:02	47.3

^aAdopted from Tiwari et al., 2007

^bxx: y indicates xx carbon in the fatty acid chain with y double bonds

the fatty acids to form the mono-alkyl esters or biodiesel and crude glycerol. Since methanol was used in this process it is called *methanolysis*. Base catalyzed Transesterification process was selected as it is a simple process and requires low temperature potassium hydroxide (KOH) was used as base catalyst. The process reactions are shown as follows.



Process Parameters

The factors that affect the conversion of vegetable oil into biodiesel are time and temperature of reaction, type and, quantity of catalyst and temperature of reaction, and alcohol quantity used (Demirbas, 2003, Pramanik, 2003). Normally, the reaction is conducted at a temperature closer to the boiling point of methanol (60°C to 70°C) and at atmospheric pressure. Further increase in temperature was reported to have a negative effect on the conversion (Srivastava and Prasad, 2000). The amount of catalyst required is based on the amount of free fatty acid present in the oil. (Hanny and Shizuko, 2008). Most of the researchers used 0.4 to 1.5% KOH/NaOH by weight of oil for biodiesel production (Purnanand et al., 2009). The stoichiometry of transesterification reaction requires three mol of alcohol per mol of triglyceride to yield three mols of fatty ester and one mol of glycerol. Lower molar ratios of alcohol to oil require higher reaction time (Kalbande et al., 2008). With higher molar ratios, the conversion increased but the recovery decreased due to poor separation of glycerol (Srivastava and Prasad, 2000). However an excess amount of alcohol is always required to shift the reaction in to forward side. Most researchers used molar ratio of 6:1 (alcohol: oil). Based on the above discussion the reaction parameters were selected as agitation rate 400 rpm and reaction time 90 minutes. The experiments were planned and conducted using different catalyst to oil ratios (1.43%, 1.65%, 1.87%, 2.1%, 2.53% w/w), methanol to oil molar ratios (5.5:1, 6:1, 6.75:1, 7.5:1 and 8:1) and reaction temperatures (50°C to 70°C) to investigate the influence of catalyst quantity and alcohol to oil ratio and reaction temperature on the methyl ester yield of CJCO.

Experimental Procedure

All the reactions were carried out in the three-necked flat bottom flask. The CJCO was first heated to 110°C for removal of moisture. Then the oil was cooled down to 60°C and taken in the reaction flask. The catalyst methanol mixture was than mixed with the oil and stirred continuously by magnetic stirrer. After the reaction was over the product mixture of the reaction was transferred into a separating funnel and allowed to settle overnight and then the glycerol layer at the bottom and the biodiesel including the methyl ester fraction at the top layer were separated in bottles. Purification stage after separation was omitted as small samples were used for each experiment.

Engine Performance Test

The biodiesel produced was used as a fuel to run a four stroke diesel engine coupled with an electric generator (schematic diagram is given in Figure 1). The performance test was conducted at different load conditions using neat biodiesel as fuel and also with the petrodiesel and raw *Jatropha Curcas* oil as fuel.

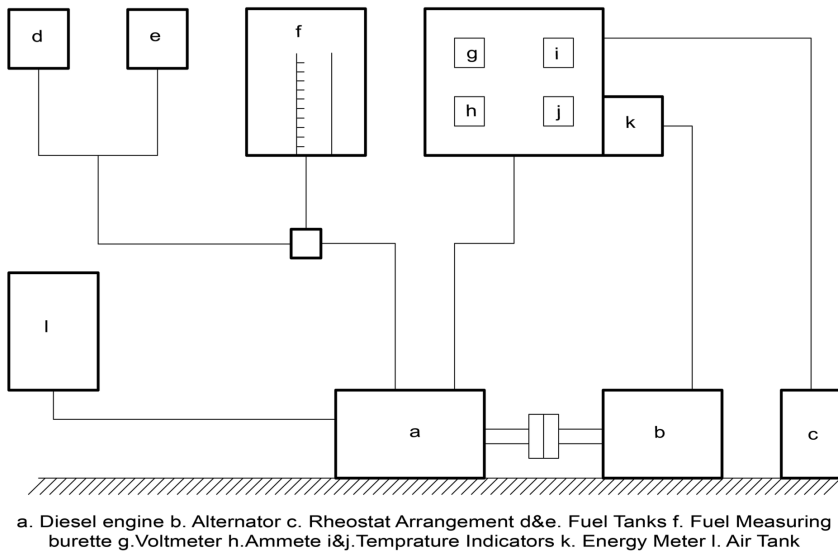


Figure 1. Layout of the engine test rig

RESULTS AND DISCUSSIONS

Effect of Catalyst to Oil Ratio on Biodiesel Yield

Alkali catalyzed transesterification results of CJCO was investigated by changing catalyst KOH to oil ratios (%w/w) using methanol-to-oil molar ratio of 6:1 and a 60°C reaction temperature. The results are shown in Figure 2. The results show that the catalyst concentration had a significant effect on the process yield. It was found that reaction scarcely occurred with the catalyst concentration 1.43%w/w of oil. At catalyst concentration 2.09%w/w of oil, the maximum biodiesel yield was achieved. Further increase in catalyst resulted in reduced biodiesel yield because of incomplete reaction due to soap formation at higher catalyst concentrations. High FFA content was considered the reason for low yield and the higher consumption of the catalyst in the transesterification process of CJCO. High FFA in the oil deactivates the catalyst and the addition of excess catalyst as compensation gave rise to the formation of emulsion (Ma and Hanna, 1999) which increased the viscosity, leading to the formation of gels and problem associated with glycerol separation and loss in ester yield.

Effect of Methanol to Oil Molar Ratio on Biodiesel Yield

The reactions were carried out with different methanol to oil molar ratios (5.5:1, 6:1, 6.75:1, 7.5:1 and 8:1) to investigate their influence

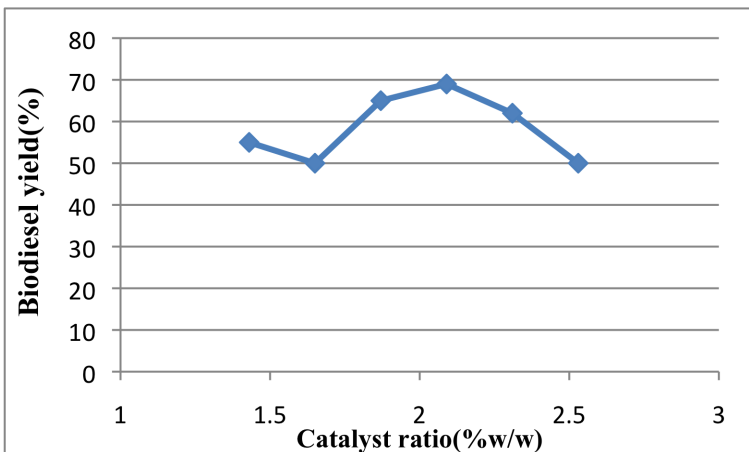


Figure 2. Effect of catalyst concentration on biodiesel yield at temperature 60°C and methanol to oil molar ratio 6:1

on the biodiesel yield at 60°C reaction temperature with the optimum catalyst to oil ratio (2.09%w/w). The results are given in the Figure 3. It was observed that biodiesel yield was increased as the methanol to oil molar ratio was increased. Maximum biodiesel yield of 80.5% was achieved at the methanol to oil molar ratio of 7.5:1 and reaction temperature of 60°C. Further increase in methanol to oil ratio resulted in small reduction of biodiesel yield. At higher methanol to oil ratios the conversion increased but the recovery decreased due to poor separation of glycerol (Srivastava and Prasad, 2000) and this might be the reason for decrease in biodiesel yield beyond 7.5: 1 methanol to oil molar ratios (Figure 3).

Effect of Catalyst to Oil Ratio on Biodiesel Yield

To know the effect of temperature on biodiesel yield, reactions were conducted at different reaction temperatures (50°C to 60°C) using the optimum ethanol to oil molar ratio (7.5:1) and catalyst concentration (2.09%w/w). Such results are depicted in Figure 4. It was observed that increase in temperature influences the biodiesel yield positively up to 60°C after that it decreases. This reduction in yield of biodiesel was due to the saponification of the glycerides by alkaline catalyst at elevated temperatures.(Tiwari et al.,2007) of the maximum biodiesel yield was achieved at the optimum temperature of 60°C.

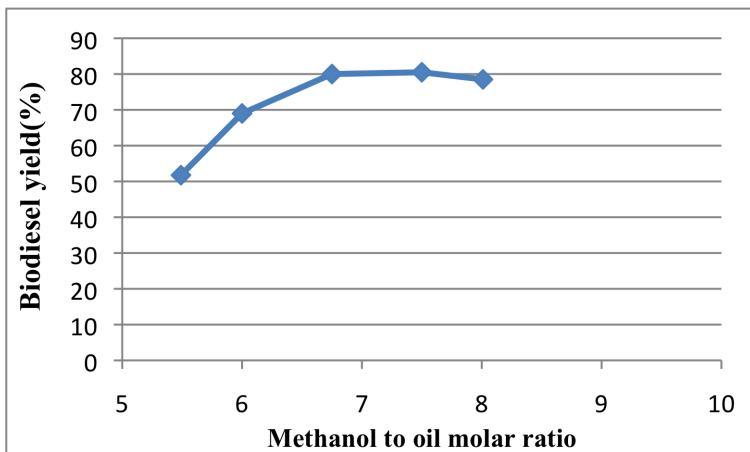


Figure 3. Effect of and methanol to oil molar ratio on biodiesel yield at 2.09%w/w catalyst concentration and temperature 60°C

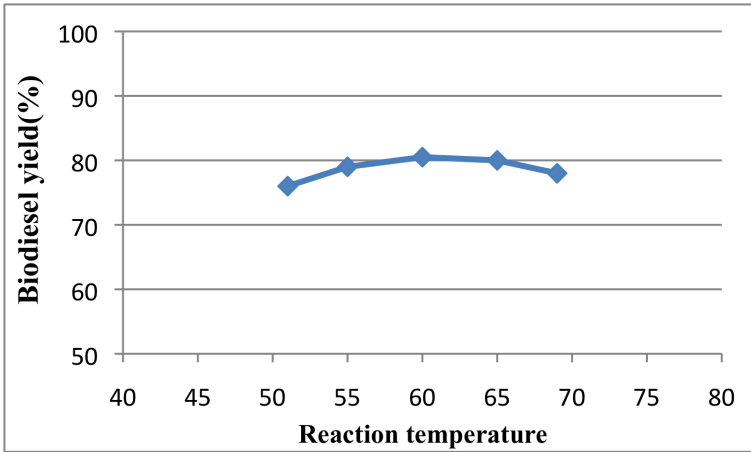


Figure 4. Effect of reaction temperature on biodiesel yield at 2.09%w/w catalyst concentration and 7.5:1 methanol to oil molar ratio

Properties of Jatropha Biodiesel

The quality of the biodiesel is very important for the performance and emission characteristics of a diesel engine. Thus the *Jatropha curcas* biodiesel produced at optimum condition was tested to determine its physicochemical properties. The measured CJCO properties are given in Table 2. The table indicate that the alkali catalyzed transesterification reduced the kinematic viscosity of the biodiesel ($4.2 \text{ mm}^2/\text{sec}$) to approximately one-tenth of its initial value of as raw oil ($40.82 \text{ mm}^2/\text{sec}$). The biodiesel viscosity at 40°C ($4.2 \text{ mm}^2/\text{sec}$) was slightly higher than that of the petro-diesel ($3.068 \text{ mm}^2/\text{sec}$) but well within the limits of ASTM standards. The decrease in kinematic viscosity is an important fuel property of transesterified *Jatropha* oil. This indicates that the flow capability of raw *Jatropha Curcas* oil was increased to a significant extent by transesterification. The Cetane Number—the ability of a diesel fuel to burn smoothly without detonation—of the biodiesel was considerably increased and well within the ASTM specified limit which indicates the better combustion quality of the fuel. The flash point of the biodiesel is 105°C and it is lower than the ASTM specification and indicates that it is safer to handle and store. This increase in fuel's ability to flow would increase combustion property of the fuel without any ignition delay. The specific gravity of the biodiesel was 0.887 and it was also reduced to a significant extent when compared to the specific gravity of the raw *Jatropha Curcas* oil which was 0.9107.

Table 2. Properties of raw Jatropha Curcas oil and Jatropha biodiesel

Property	Jatropha Curcas oil	Jatropha Biodiesel	ASTM Standards
Specific gravity	0.9107	0.887	-
Calorific Value	9002 kcal/kg	9486 kcal/kg	-
Acid number	13.7 mg KOH/g oil	0.14	0.50 maximum
Kinematic Viscosity	40.28 mm ² /sec	4.2 mm ² /sec	1.9 - 6.0 mm ² /sec
Flash Point	2200C	105 ⁰ C	130 ⁰ C min
Cetane No	51	52.3	47 min
Iodine value	110.5	109	-
Saponification value	192	186	-
Moisture content	0.06%w/w	0.03%w/w	0.05% v/v max
Peroxide value	1.93	1.72	-
Sulphur content	0.02%w/w	NIL	15ppm max
Refractive Index	1.46	1.43	-

Determination of Engine Performance

The biodiesel produced by biodiesel processor using transesterification process was used to run a four stroke diesel engine coupled to an electric generator. The engine was also run using petrodiesel and raw *Jatropha Curcas* oil as fuel and comparisons were made with the performance of the biodiesel produced. The overall efficiency of the engine-generator set at different load conditions were measured and are presented in Figure 5. It is evident that the overall efficiency of the engine when running on biodiesel was better than the overall efficiency of the engine running on petrodiesel and raw *Jatropha Curcas* oil as fuels at all load conditions. This is because of the oxygen content available in the biodiesel which improves the combustion process.

CONCLUSIONS

Crude *Jatropha Curcas* oil (CJCO) was selected as feed stock for biodiesel production as it is non edible and locally available. Biodiesel was produced from *Jatropha Curcas* oil by alkali catalyst based transesterification. The effect of Catalyst concentration, methanol to oil molar ratio and reaction temperatures on biodiesel yield were investigated. A maximum of 80.5% of biodiesel yield was achieved under

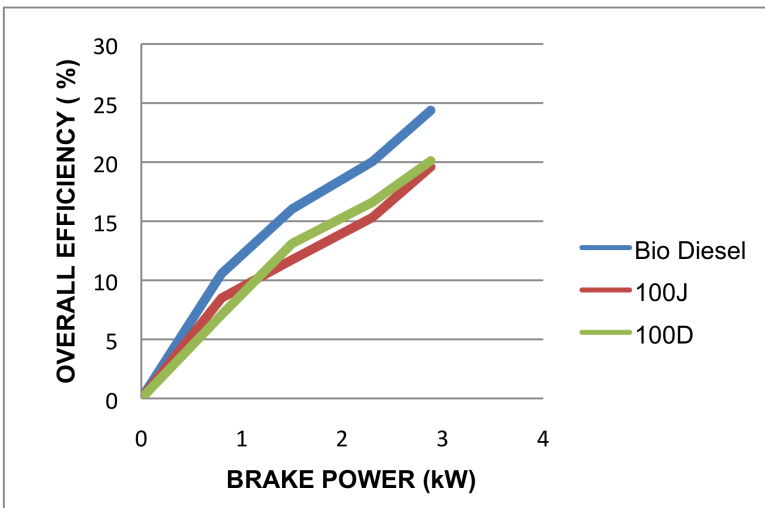


Figure 5. Overall efficiency of the test system for three fuels

optimum conditions. The reason for the lower yield was found due to the presence of high free fatty acid content in the raw *Jatropha Curcas* oil. The physical and chemical properties of biodiesel produced meet the ASTM specifications. Notably, the kinematic viscosity and acid value were reduced to a significant extent and the cetane number was increased as compared to raw *Jatropha Curcas* oil.

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