Bio-diesel production parameter analysis for Leptadenia Reticulata Oil

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Abstract: *The world is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Diminishing fossil fuel resources, coupled with the steady increase in energy consumption, has spurred research interest in alternative and renewable energy sources. Biodiesel is well known alternative fuel which is methyl or ethyl ester of fatty acid made from virgin or used vegetable oil by transesterification. Non-edible oil which is available in India, which possess high calorific value and is underutilized namely Leptadenia Reticulata has been selected for biodiesel production. Sodium Methoxide was used as a catalyst to assess its technical feasibility and process conditions for transesterification of the oils. Parameters affecting biodiesel production was analyzed. It was observed that a catalyst amount of 1% (v/v) CH_3Ona with 60°C reaction temperature and 600 rpm reaction speed was the optimum conditions for the transesterification of LR oil. Also the optimum oil to methanol molar ratio for the conversion of LR oil to LR ethyl ester was 1:6 while the optimum reaction periods were 180 minute. The combination of the optimum parameters of catalyst amount, oil: methanol molar ratio, reaction temperature as well as reaction time give a yield of about 76.2%.*

Keywords: **Biodiesel, Leptadenia Reticulata, Production, Parameters**

1. Introduction

The ever increasing demand for petroleum based fuels and the uncertainty in their availability has been a matter of concern world over. Crude oil prices and availability are subject to great volatility depending upon the international situation and relationships between the countries. In India, majority of the engines for heavy transportation, agriculture, as well as industries uses diesel as fuel and hence consumption of diesel is almost six times higher than that of petrol. A nations development is strongly dependent on the availability of fuels for transportation, agriculture and power generation. Thus India like many countries faces the major challenges of meeting the high demand of oil. Thus looking for alternative source of energy that in inexhaustible and renewable such as hydro, biomass, geothermal, hydrogen, nuclear, wind and solar is of vital importance because only by using the renewable sources of fuel with clean combustion, we can reduce emissions and also the dependence on conventional petroleum sources. Biofuels are also a possible substitute product for fossil fuels. They are energy carriers that store the energy derived from biomass, commonly produced from plants, animals, microorganism and organic waste. As an alternative fuel biodiesel can be used in neat form or mixed with diesel. It is biodegradable and non-toxic compared to petroleum based diesel. Biodiesel has more favorable combustion profile, such as low emissions of carbon monoxide, particulate matter and unburned hydrocarbons. Carbon dioxide produced by combustion of biodiesel can be recycled by photosynthesis, thereby minimizing the impact of biodiesel combustion on the greenhouse effect. These merits of biodiesel make it a good alternative to petroleum based fuel and have let to its use in many countries, especially in environmentally sensitive areas. Despite its importance more than 95% of biodiesel is mainly prepared from conventionally grown edible oil such as soybean, sunflower, rapeseed, palm etc. This causes an imbalance between the utilization of energy resources and food consumption. In recent times, environmentalists have begun to debate on the negative impact of biodiesel production from edible oil. They claimed that there may be increase in deforestation in countries due to large scale cultivation of oil crop plants for biodiesel production. The land use for production of edible oil as feedstock for biodiesel production competes with the use of land for food production. Arable land that would otherwise have been used to grow food would instead be used to grow fuel crops. In fact, this trend is already being observed in certain parts of the world. In order to meet the increasing demand of biodiesel in the past few years there has been significant

expansion in the plantation of oil crops. The ending stocks of vegetable oils are continuously decreasing due to increasing production of biodiesel even though there is continuous increase in the production of vegetable oil. Thus the implementation of biodiesel as a substitute fuel for diesel may lead to the reduction of edible oil supply worldwide. One way to overcome this issue is to employ low quality feedstock such as waste or used vegetable oil and non-edible oils, which are cheaply available and can be regarded as attractive feed stocks for biodiesel production.

2. Literature Review

The use of vegetable oil for diesel fuel production was first expressed by Rudolph Diesel, the inventor of the diesel engine. The problems encountered the use of vegetable oil in CI engine were high viscosity, poor cold flow properties and low volatility, injector tips chocking, carbon deposition in combustion chamber, piston ring sticking, polymerization, and oxidations. One solution to the poor fuel properties of vegetable oil was to convert it into mono alkyl esters of fatty acids by the process of transesterification and esterification. Sharma and Singh [1] produced biodiesel from karanja and mahuva oils as well as the mixture of the two non-edible oils in the same ratio on volume basis. The higher fatty acid content of the above said two straight vegetable oils forced them to use two step reactions. The first one was acid esterification for lowering fatty acid content to a desired limit. The second step was alkaline transesterification for the conversion of the already treated oil to fatty acid methyl ester or biodiesel. Saka and Kusdiana [2] employed a method to produce biodiesel through transesterification reaction of rapeseed oil without using a catalyst. The above said method was termed as a supercritical methanol biomass conversion method. The pressure and temperature in this process were quite elevated compared to the normal pressure and temperature of transesterification reaction. Venkanna and Reddy [3] produced biodiesel from hone oil through a three stage transesterification process with methanol which comprised of acid esterification, alkali transesterification and post treatment. Sulphuric acid was used as catalyst in acid esterification and potassium hydroxide was used in alkali transesterification. The post treatment method consisted of gentle water wash thrice using distilled water. Srivastava and Verma [4] did not employ any pretreatment of raw karanja oil, but they used some after treatment of the biodiesel produced by the transesterification process. The after treatment method employed was bubble wash method with the aid of 10% phosphoric acid solution in warm water. For getting the final quality biodiesel, it was purified by passing air through aquarium stone for at least 24 hours. The whole process was repeated three times to get the final product in the form of karanja biodiesel. They have tested both karanja oil and its biodiesel and the yield was found to be 84%. Ghadge and Raheman [5] produced biodiesel from mahuva oil having high free fatty acid in it. Firstly, the fatty acid content was determined by a standard titrimetry method and after that a pretreatment method was involved for lowering the higher acid value. Finally, the transesterification reaction was carried out with methanol using potassium hydroxide as an alkaline catalyst. Biodiesel from different straight vegetable oils having high phosphorous content and having either low or high acid values were studied by Mendow et al [6]. Due to low acidity of soybean oil, direct transesterification with methanol as an alcohol was used to obtain biodiesel using sodium hydroxide as a catalyst. Due to higher acid value of crude coconut oil, they used a two stage method of transesterification with methanol. It was consisted of alkali esterification using sulphuric acid as a catalyst followed by transesterification using sodium hydroxide as a catalyst to obtain biodiesel. Ilkilic et al [7] produced biodiesel from sunflower oil by transesterification process using sodium hydroxide as a catalyst. After separation of glycerol from product sulphuric acid was added as a depolarizer and the biodiesel was then washed adding equal amount of water to separate catalyst and the remaining portion of alcohol. Production of biodiesel from rubber seed oil through a two stage method of transesterification with methanol, which followed an alkali esterification using sulphuric acid as a catalyst and transesterification with methanol using potassium hydroxide as a

catalyst was studied by Ramadhas et al [8]. Sharon et al [9] produced biodiesel from used palm oil by transesterification process in laboratory scale set up with the addition of methanol in a proportion of 6:1 molar ratio, using potassium hydroxide as a catalyst. After completion of the reaction process glycerol was separated using separating funnel. Patil and Deng [10] prepared biodiesel from raw jathropha and karanja oils in two step namely, acid esterification and alkali transesterification. But in case of corn and canola oils only the alkali transesterification step was needed as the fatty acid content of them were lower than that of jatropha and karanja. Soyabean oil was used to produce biodiesel by Lin and Lin [11] through transesterification process using methanol using potassium hydroxide as a catalyst accompanied by peroxidation to improve the fuel properties of the biodiesel. Water wash and distillation process were used to remove unreacted methanol, water and other impurities.

3. Methodology for Biodiesel Production

The cost of biodiesel is largely dependent on the cost of feedstock. The cost of feedstock accounts for about 88% of the total production costs.

3.1 Vegetable Oil

Traditional oilseed feed stocks for biodiesel production predominantly include soybean, rapeseed, palm, corn, sunflower, cottonseed, peanut, and coconut oil. Current agronomic efforts are focused on increasing feedstock supply by increasing yields. Moreover, alternative feedstock such as non-edible jatropha oil has recently attracted considerable interest as a feedstock for biodiesel production in India and other climatically similar regions of the world. Another non-edible feedstock of Indian origin is karanja, which is medium sized deciduous tree that grows fast in humid and subtropical environments and matures after 4 to 7 year to provide fruit that contains one to two kidney shaped kernels. The oil content of karanja ranges between 30 and 40 wt %. Madhuca indica commonly known as mahua is a tropical tree found largely in the central and northern plains. Non-edible fruit is obtained from the tree in 4 to 7 years and contains one to two kidney shaped kernels. The oil content of dried mahuva seeds is around 50 wt%. Simmondsia chinensis commonly known as jojoba. It is unique in that the lipid content of the seeds which is between 45 and 55 wt % is in the form of long chain esters of fatty acids and alcohols as opposed to triglyecerol. Waste oil may include a variety of low value materials such as used cooking or frying oils, vegetable oil and other waste materials. Waste oil are normally characterized by relatively high FFA and water contents and potentially the presence of various solid materials that must be removed by filtration prior to conversion to biodiesel. Used or waste frying or cooking oil is primarily obtained from the restaurant industry and may cost anywhere from free to 60% less expensive than commodity vegetable oils depending on the source and availability.

3.2 Animal Fats

Animal fat may include materials from a variety of domesticated animals such as cows, chickens, pigs and other animals such as fish and insects. Animal fats are normally characterized by a greater percentage of saturated fatty acids in comparison to oils obtained from the plant kingdom. Animal fats are generally considered as waste products, so they are normally less expensive than commodity vegetable oil, which make them attractive feedstock. Animal fat such as beef tallow and chicken fat are by products of the food processing industry and represent low value feedstock for biodiesel production. The primary fatty acids found in beef tallow include oleic, palmtic, and linoleic acids. As a result of the very low poly unsaturated fatty acid content of beef tallow, the corresponding methyl esters display excellent oxidative stability while due to high poly unsaturated fatty acid content of chicken fat, the corresponding methyl esters display poor oxidative stability.

3.3 Leptadenia Reticulatta Oil

The Leptadenia Reticulata (LR) oil is a member of Apocynaceae plant family. Its taxonomic position is (a) Kingdom – Viridiplantae (b) Phylum – Streptophyta (c) Class – Magnoliopsida (d) Order – Gentianales (f) Family – Apocynaceae (g) Sub-family – Asclepiadoideae (h) Genus – Leptadenia (i) Species – Leptadenia reticulate. In India it is mainly found in Rajasthan, Gujarat, Punjab, the Himalaya ranges, Khasi hills, Sikkim, Deccan plateau, Konkan ranges, Karnataka and Kerela up to an altitude of 2000 m. LR is an evergreen xerophyte grows in warm tropical and subtropical regions with moderate rainfall. The plant can survive wide range of climatic conditions. LR seeds is 10-15 mm long as shown in Figure 1. The seed of this plant contain 40-43% oil. The seed oil can also be used as feed stock for biodiesel production as combustion energy of oil is comparable to that of diesel.

Figure 1. Seeds from which oil is extracted

Table 1. Free Fatty Acid Profile of LR Oil

	14:0	16:0	18:0	18:1	18:2	20:0	22:0
LR Oil	0.3	17.6	19.7	45.5	13.3	3.3	0.6

Table 2. LR oil properties

Property	Unit	Value
Acidic Value	-	34.8
Calorific Value	kCal	6500
Density	gm/cm^3	0.89
Flash point	°C	245
Free Fatty Acid contain	%	17.5
Pour point	°C	5
Viscosity	cps	39.9
Water Contain	%	0.22

Raw LR oil contain nearly 16-18 % of free fatty acid. Its free fatty acid profile is shown in Table 1. The primary fatty acid found in LR oil is oleic acid. Other property such as Acid value, water content, flash point, pour point, viscosity, density, water contain, and calorific value of the oil were determined according to IS 15607 and these values are

shown in Table 2. Transesterification is a reaction where one ester is transformed into another ester by the interchange of the alkoxy moiety. The process is also known as alcoholysis, since the alcohol from the ester is replaced by another alcohol. The process is similar to that of hydrolysis, except the fact that an alcohol is used instead of water. When trigycerides are subjected to transesterification the reaction yields fatty acid esters along with glyecerol as the by product. The reaction proceeds in three steps, with diglycerides and monoglycerides forming in subsequent steps and finally the ester along with glyecerol in the last step. When alcohol is used as the lower alcohol to replace the glycerol of the triglyceride the process is called transesterification and ester is formed. The excess of the alcohol is used to increase the yields of the alkyl ester according to Le Chateliers's principle and to allow its phase separation from the glycerol is formed. The reaction is shown in figure 2.

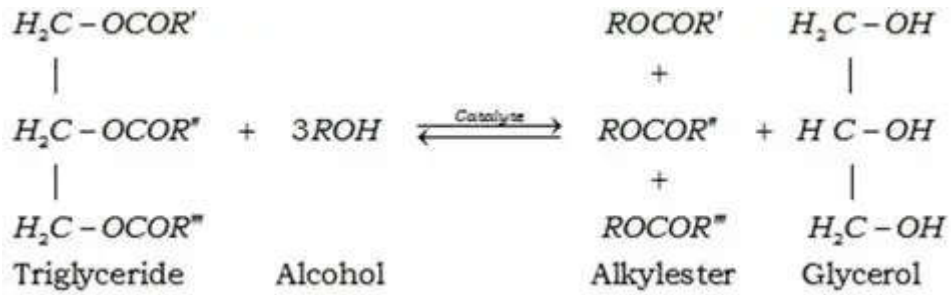

Figure 2. Transesterification reaction using alcohol

The yield of biodiesel in the process of transesterification is affected by several process parameters. The most important variables are (a) Reaction temperature (b) Molar ratio of alcohol and oil (c) Catalyst concentration (d) Reaction time (e) Free fatty acid and water contents.

3.4 Biodiesel Production

An experimental set up consist of round bottom flask, separating funnel, heating plate, temperature, stirrer speed controller and reflux condenser as shown in figure 3. The entire production of biodiesel is divided in three steps (a) oil extraction and filtration process (b) esterification process and (c) transesterification process. The oil extraction was carried out using oil pressing machine a mechanical method for extracting oil from seeds. For extracting oil 2 kg of LR seeds were collected and washed with water afterwards drying in sunlight for entire day. In oil expeller seeds are inserted at one end and waste come out at other end with oil dropped in between so that can be collected in vessel. The extracted oil was weighed and the percentage of oil content was calculated. After extraction of about 500 ml LR oil was heated strongly at 130°C for 30 minutes to remove moisture content. Then it was filtered by using grade 4 filter paper to remove suspended solid matter from the oil. The esterification was carried out to reduce FFA content from LR oil. For small scale production 100 ml LR oil with 30 ml methanol and 1% v/v sulphuric acid were taken in round bottle flask with water cooled condenser and magnetic stirrer. The whole reaction mixture was vigorously stirred at 600 rpm for 2 hours under reflux condition at 55°C temperature. After the reaction the reaction mixture was poured into a separation funnel and was allowed to settle for 8 hours. After the separation process, two layers was seen upper layer was esterified oil while the bottom layer known as residues which contain excess methanol with water. The upper layer was collected and washed with brine solution 2-3 times. In transesterification process the acidic esterified LR oil was used for production of LRME. 100 ml of esterified LR oil was poured into the reaction flask and heated to 55°C temperature. Then 25 ml methanol and 1.5% v/v sodium methoxide were mixed separately and then added to the preheated oil. The whole reaction mixture was

vigorously stirred at 600 rpm for 3 hours under reflux condition. After completion of reaction the whole reaction mixture was transferred into separating funnel to allow clear separation of the biodiesel from glycerol for 12 hours. Two layers was separated out with upper layer which contain LRME while the lower layer was aqueous containing glycerol. The organic phase was separated from the aqueous phase and washed by distilled water 2-3 times to remove residual catalyst or soap thus clear bio diesel was obtained. The above procedure was repeated to determine an optimum catalyst amount for transesterification of LR oil. Once the optimum catalyst amount resulting in a higher yield was obtained, the second part of the experiment followed by maintaining the catalyst at the optimum amount at 55°C reaction temperature for 3 hours whilst the oil to methanol molar ratios was varied during experimentation. These were 1:4, 1:5, 1:6, 1:7 and 1:8 oil to methanol molar ratios. After getting optimized catalyst amount and oil to methanol molar ratio four reactions were carried for different period of time namely 140 minutes, 160 minutes, 180 minutes and 200 minutes to determine an optimum FAME yield. In next step the optimized catalyst amount, oil to methanol molar ratio and reaction time were maintained while the reaction temperature was varied as 50°C, 55°C, 60°C and 65°C to obtain the best yield. It was ensured that all the reaction contents were preheated to the desired temperature.

4. Results and Discussion

The biodiesel yield depends not only on the type of feed stocks used, but also depend on molar ratio of alcohol to oil, the catalyst concentration and reaction conditions such as temperature, duration and stirrer speed. The following results shows the effect of methanol molar ratio, catalyst concentration, reaction temperature and reaction time required for transesterification of LR oil.

4.1 Effect of oil to methanol molar ratio

The stoichiometric ratio for transesterification reaction requires three mole of alcohol and one mole of triglyceride to yield three moles of fatty acid ester and one mole of glycerol. With the increase of oil to methanol molar ratio, conversion of triglyceride into FAEM correspondingly increases. Hence to optimize the amount of methanol required for the reaction, experiments were conducted with 1:4, 1:5, 1:6, 1:7 and 1:8. The concentration of CH_3 NaO, reaction temperature and reaction time were kept constant at 1.5% v/v, 55°C and 180 minutes respectively.

Table 3. Effect of alcohol to oil molar ratio

Molar ratio	Oil (ml)	Methanol (ml)	Catalyst concentration (v/v)	Yield (%)
1:4	100	17.70	1.5	69.4
1:5	100	20.88	1.5	71.3
1:6	100	25	1.5	74.6
1:7	100	29.23	1.5	73.4
1:8	100	33.40	1.5	72.6

The results are enumerated in Table 3 which clearly indicate that the molar ratio of oil to methanol required for effective transesterification of LR oil was 1:6. Moreover it was found that when the concentration of methanol was increased above or decreased below the optimum there is no significant increase in the biodiesel production. The excess or shortfall in concentration of methanol only contributed to the increased formation of glycerol and emulsion. The maximum ester yield of 74.6% was obtained using 1:6 molar ratios.

4.2 Effect of Catalyst

The amount of catalyst also plays a role on the conversion of the esterification reaction. The varying amount of catalysts from 0.5 to 2 % (v/v of oil) was studied in this work at the following reaction condition. Ratio of oil to methanol 1:6 at constant temperature 55°C and reaction time for 180 minute. The result is shown in table 4 clearly indicate that the optimum concentration of CH_3 NaO required for effective transesterification was 1.0% (v/v of oil). The optimum yield of FAME under the above stated reaction condition was 75.9%. The 0.5% (v/v of oil) catalyst gave a lower yield because the reaction intermediates were unstable. This indicates that 0.5% (v/v of oil) was not sufficient to catalyse the transesterification reaction. An increase in the conversion of oil feed stock to FAME occurred with a corresponding increase in catalyst amount to 1% (v/v of oil). The conversion reduced when the weight of catalyst was increased from 1 to 2% (v/v of oil).

Table 4. Effect of Catalyst

Oil (ml)	Methanol (ml)	Catalyst concentration (v/v)	Yield (%)
100	25	0.5	62.59
100	25	1.0	75.90
100	25	1.5	74.60
100	25	2.0	71.40

4.3 Effect of Reaction Temperature

For the determined optimum catalyst amount and oil to methanol molar ratio and reaction time of 180 minute, the temperature effects on the transesterification reaction were studied at 50°C, 55°C, 60°C and 65°C is separate experimental runs. The maximum temperature level was limited to 65°C as temperatures higher than that might cause the methanol to evaporate excessively. Even though the methanol could be condensed back into the reactor, the extent of evaporation would affect the kinetics of the reaction and that could result in lower yield and affect the purity of the FAME produced. The results are presented in table 5. It is observed that the optimum reaction temperature is 60°C with corresponding FAME yield of 76%. The yield at 55°C were slightly lower with relatively higher standard deviations as compared to the yields at 60°C. Transesterification above 60°C reaction temperature causes excessive methanol loss due to evaporation and significantly reduce the yield of biodiesel.

Table 5. Effect of Reaction temperature

Oil (ml)	Methanol (ml)	Reaction Temperature (°C)	Yield (%)
100	25	50	69.9
100	25	55	73.7
100	25	60	76.2
100	25	65	72.4

Table 6. Effect of Reaction Time

Oil (ml)	Methanol (ml)	Reaction Time (min)	Yield (%)
100	25	140	65.4
100	25	160	69.2
100	25	180	76.2
100	25	200	72.1

4.4 Effect of Reaction Time

Using the optimum catalyst amount, oil to methanol molar ratio and reaction temperature separate experiments were conducted at different reaction times of 140, 160, 180 and 200 minutes to the study the effect on reaction. The results were presented in table 6. The optimum reaction time for the transesterification processes was 180 minutes and corresponding yield was 76.2%. Below the 180 minutes of reaction time, the reaction was incomplete so the concentration of FAME was low. After 180 minutes of reaction time there could also be possible conversion of methyl ester into soap which reduce the yield of biodiesel.

The optimum reaction parameters for the said feed stock obtained during the experimentation are (a) oil – 100 ml (b) methanol – 25 ml (c) catalyst % (v/v) – 1 (d) reaction time – 180 minutes (e) reaction temperature - 60°C and (f) yield – 76.2 %. The comparison are made for fuel properties between diesel and LRME as shown in table 7. The comparisons are also done with the Indian standard. Various properties are found namely density, viscosity, calorific value, water content, flash point, pour point, ash content, carbon residue, cetane number and acid value. Cetane number is a little higher than the diesel which is favourble for the combustion process.

Table 7. Properties of diesel and LRME

Properties	Diesel	LRME	IS Standard
Colour	Light brown	Yellow	-
Density at 40°C (kg/m^3)	814	861	860-900
Viscosity at 40°C (cSt)	2.89	4.86	3.5-5.0
Calorific Value (kJ/kg)	44296	38513	-
Water Content (%)	0.025	0.05	<0.1
Flash point (°C)	68	112	>101
Pour point (°C)	-5	10.2	-
Ash content (%)	0.01	0.012	-
Carbon residue (%)	0.17	0.02	<0.05
Cetane number	53	51	>51
Acid value	-	0.48	<0.5

5. Conclusions

In a world where every action must be weighed against its demerits, where everything should be balanced between power and the environment. In a world like today, where problem reserves are becoming limited and will eventually run out and the critical issue of oil peak and the environmental concerns all have prompted deeper research into the area of alternative to fossil fuels such as biodiesel. Biodiesel is the best candidate for diesel fuel and it burns like petroleum diesel as it involves regulated pollutants. In comparison to petroleum diesel, biodiesel beats its competitors in all categories of toxic substance emissions and poses close to no threat to the environment. Moreover, biodiesel reduce the level of carbon dioxide in the atmosphere which makes it a valuable tool in preventing global warming. Biodiesel produced from non-edible oil namely LR oil was selected. These oils are available all over the year in India. Based on the results from the study it is concluded that (a) the optimized values of process parameters for the transesterification of FFA present in LR oil is methanol to oil ratio 6:1, catalyst amount 1.5% (v/v), reaction time 180 minute and reaction temperature 60°C. (b) The FAME yield that resulted from the optimum reaction was 76.2%. (c) Transesterification reduced the viscosity acid value and water content of the FAME produced thereby improving the quality of biodiesel and enhancing energy efficiency of the engine running on such fuel. (d) Based on the physical properties of chemical composition the results are very mush appreciable as compared to

diesel fuel. This LRME helps in improving the performances, combustion and emissions of the diesel engines.

REFERENCES

[1] *Sharma Y C and Singh B, "A hybrid feedstock for a very efficient preparation of biodiesel", Fuel processing technology, vol. 91, no. 10,* ***(2010),*** *pp. 1267-1273.*

[2] *Saka S and Kusdiana D, "Biodiesel fuel from rapeseed oil as prepared in supercritical methanol", Fuel, vol. 80, no. 2,* ***(2001),*** *pp. 225-231.*

[3] *Venkanna B K and Venkataramana Reddy C, "Biodiesel production and optimization from Calophyllum inophyllum linn oil (hone oil) – a three stage method", Bioresourse Technology, vol. 100,* ***(2009),*** *5122-5125.*

[4] *Srivastava P K and Verma M, "Methyl ester of karanja oil as an alternative renewable source energy", Fuel, vol. 87,* ***(2008),*** *pp. 1673-1677.*

[5] *Ghadge S V and Raheman H, "Process optimization for biodiesel production from mahuva (madhuca indica) oil using response surface methodology", Bioresource Technology, vol. 97,* ***(2006),*** *pp. 379-384.*

[6] *Mendow G, Monella F C, Pisarello M L, and Querini C A, "Biodiesel production from non-degummed vegetable oils phosphorous balance throughout the process", Fuel Process Technology, vol. 92,* ***(2011),*** *pp. 864-870.*

[7] *Ilkili C, Aydin S, Bechet R and Aydin H, "Biodiesel from sunflower oil and its application in diesel engine", Fuel Process Technology, vol. 92,* ***(2011),*** *pp. 356-362.*

[8] *Ramadhas A S, Jayaraj S and Muraleedharan C, "Biodiesel production from high FFA rubber seed oil", Fuel, vol. 84,* ***(2005),*** *pp. 335-340.*

[9] *Sharon H, Karupaasamy K, Kumar D R and Sundaresan A, "A test on DI diesel engine fueled with methyl esters of used palm oil", Renewable Energy, vol. 47,* ***(2012),*** *pp. 160-166.*

[10] *Patil P D and Deng S, "Optimization of biodiesel production from edible and non-edible vegetable oils", Fuel, vol. 88,* ***(2009),*** *pp. 1302-1306.*

[11] *Lu H, Liu Y, Zhou H, Yang Y, Chen M and Liang B, "Production of biodiesel from Jatropha curcas L oil", Computational Chemical Engineering, vol. 33,* ***(2009),*** *1091-1096.*