Prediction of Optimum Process Parameters for Karanja Biodiesel Production Using Support Vector Machine, Genetic Algorithm and Particle Swarm Optimization

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ABSTRACT: *The growing energy demand and depletion of conventional energy resources presented a need for an alternative reliable source of energy that can readily replace conventional fuels like diesel and petrol. In the current work, biodiesel is synthesized from Karanja oil by using transesterification. The yield is obtained at varying KOH concentrations (1 wt %, 1.5 wt %, 2 wt %), varying molar ratios of methanol: oil (3:1, 4.5:1, 6:1), and varying times (15 min, 30 min, 45 min, 60 min). The optimal conditions from the experiment are obtained as a temperature of 50° C, a reaction time of 45 minutes, a methanol-oil ratio of 4.5:1, and a catalyst concentration of 1.5 %. The viscosity of biodiesel is found to be between 0.036 - 0.038 stokes. The optimum conditions obtained were compared with the statistics available in the literature. The produced biodiesel from Karanja oil conforms to the ASTM D6751 standards. The produced biodiesel is characterized using Fourier Transform Infra Red (FT-IR) Analysis and Gas Chromatography-Mass Spectrometry (GC-MS). Further Artificial Intelligence techniques namely Support Vector Machine, Genetic Algorithm, and Particle Swarm Optimization have been used for predicting the optimum conditions of biodiesel production. The predicted yield with the Support Vector Machine is compared with the yield obtained from experiments. The SVM accurately predicted the experimental results with* $R^2 = 0.999$. *PSO and GA can effectively be used as a tool for predicting the optimum parameters for biodiesel production.*

KEYWORDS: *Biodiesel; Genetic Algorithm; Karanja oil; Particle Swarm Optimization; Support Vector Machine; Transesterification.*

INTRODUCTION

Every sector of our society is directly or indirectly dependent on fuel. The thought that they are going to be exhausted and will be no more is something that is dwelling in the minds of engineers. On the other hand, convectional fuels leave their impressions on the earth releasing toxic exhausts and greenhouse gases that are considered a great threat to the earth. It is high time to act upon and switch ourselves to the most reliable and renewable, eco-friendly fuel which could replace the conventional fuels in engines [1-3].

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Biodiesel can be called an eco-friendly source as the total carbon dioxide released in its combustion is equal to the carbon content in oil seeds [4]. Oils derived from the plant, the origin is known to be used as alternative fuels for the last 100 years. An alternative to fossil fuels is to use tree-borne oils, which can be called biodiesel. This has the advantage of being non-toxic and biodegradable. Apart from this biodiesel also have lower emissions when compared to diesel. Using biodiesel also permits a balance between the environment and agricultural economic development [5-6].

As per the research, the main factors affecting the transesterification reaction are Temperature, Catalyst, Mixing, Alcohol to oil molar ratio, Moisture content, and presence of Free fatty acids. Out of these factors, Catalyst and Alcohol to oil molar ratio play a major role in the transesterification reaction [7-9].

Many researchers worked in the area of Biodiesel production with different methods in the last 25 years using a range of feedstocks, both edible and non-edible. They have studied the mechanism of the transesterification reaction and found that this method can be made commercially with a maximum yield of biodiesel. People have worked with different types of catalysts and found that alkaline catalysts give optimum yield. Many researchers have used conventional reactors for biodiesel production. Some researchers have reported work with sono reactors [10-12].

An optimization study was carried out with ASPEN PLUS 2006, for modeling the process for the optimized route. Further, the optimization studies were performed with "multi-objective genetic algorithm optimization" for finding the best exchange between the minimization of energy necessities in the process and the maximization of the purity of compounds [13-15].

ANN and GA were used for predicting optimal parameters for biodiesel production. Prediction of optimum parameters for successful transesterification was done using an ANN-based program together with GA on the MATLAB platform. ANN was used with a single-hidden layer feed-forward type to predict dynamic trending for 10 reaction components for the input parameter of time. ANN has given a good performance and has the potential for applying real-time process modeling and control in the production of biodiesel [16-18].

Researchers have even applied artificial intelligence techniques like Fuzzy, ANN, and GA to predict the optimum yield of biodiesel. However, still work needs to be done using SVM, as it gives more accuracy than ANN and Fuzzy logic. Similarly, Particle Swarm Optimization (PSO) which is comparable to GA in predicting the optimum values needs to be used as it gives more accuracy than GA [18-20]. The potential of Karanja oil and Jatropha oil has been reported to be very high in India. Considering these salient features, a systematic study of the transesterification was carried out with Karanja oil (as it gives a higher yield than Jatropha oil) to ascertain the optimal reaction conditions for the highest yield using both the conventional batch reactor and the sono reactor. The biodiesel thus produced is tested for the similarity of the properties with the diesel fuel [21-22].

In the current work, a methodical study of the transesterification of Karanja oil has been carried out to ascertain the optimal reaction conditions. At a temperature close to methanol's boiling point, within the first 15 minutes of reaction time, more than 80 % of fatty acids have been transformed into resultant Fatty Acid Methyl Esters (FAME), Biodiesel.

The objective of this paper is to synthesize methyl esters (biodiesel) from Karanja oil using a batch reactor and obtain optimum conditions of methanol-oil ratio, temperature, percentage of catalyst, and time. This paper also discusses the application of the Artificial Intelligence methods like SVM, GA & PSO for predicting the optimum conditions of biodiesel production.

EXPERIMENTAL SECTION

Raw materials

Non-edible oil namely Karanja oil obtained from locally grown Karanja seeds is taken for study in the current work; as in a country like India where many people don't get enough to eat and also edible oil is imported for catering to the requirements, it is dissolute to use edible oil for making biodiesel [26-27]. The density of Karanja oil is 880 kg/m^3 and its viscosity is0.306 stokes. The Fatty acid composition of Karanja oil is given in Table 1 [28].

Methanol from Merck (AR grade) was taken as the alcohol due to its lower boiling point. Potassium Hydroxide, KOH from *Merck(AR grade)*is taken, as there is less soap formation with KOH. The KOH pellets are dissolved in methanol to form a methoxide solution.

Table 1: Fatty acid composition of Karanja oil.

Fatty Acid	Percentage
Palmitic acid	30.6 %
Stearic acid	10.5 %
Oleic acid	53.6 %
Linoleic acid	1.5 %
Eicosanoic acid	2.2 %
Docosanoic acid	1.6 %

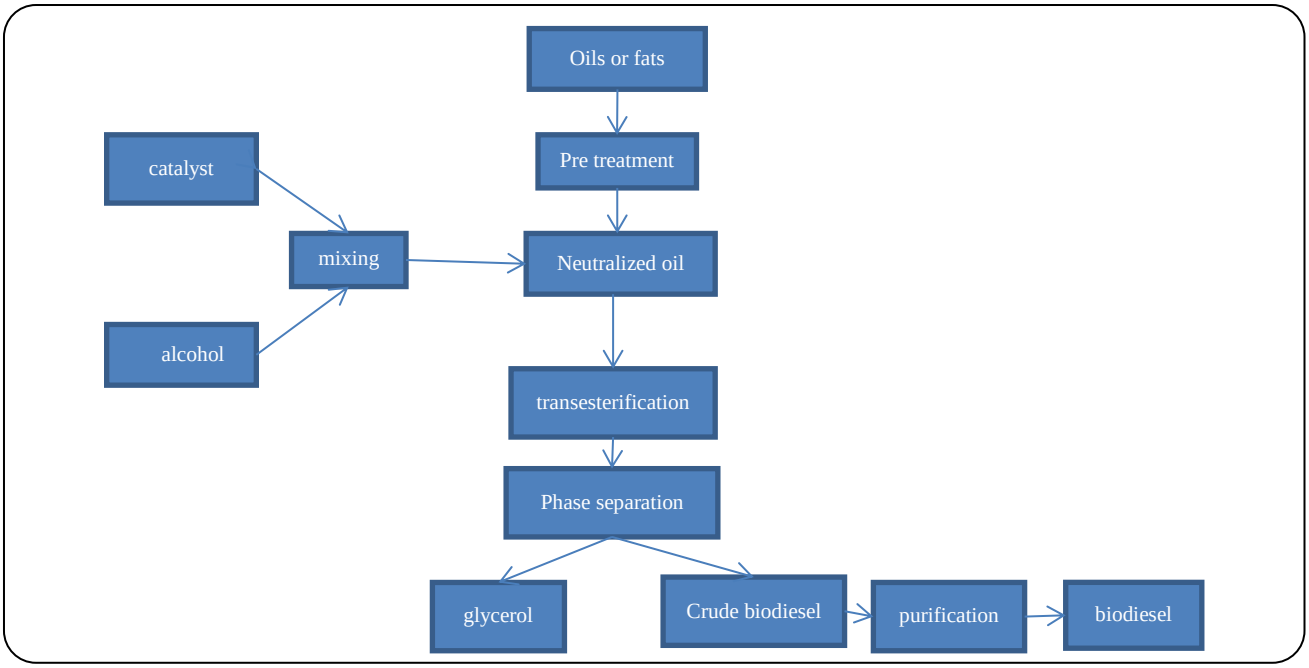

Fig. 1: Flow sheet for the production of Biodiesel.

Process Description

The overall process flow sheet for the production of biodiesel is given in Fig. 1.

Experiments were performed by varying the following parameters [27, 28]:

1. Methanol - oil ratio: (3:1, 4.5:1, 6:1)
2. Concentration of catalyst: (1%, 1.5%, 2%)
3. Time of Reaction: (30 min, 45 min, 60 min)
4. Temperature: (40 °C, 50 °C, 60 °C)

Batch transesterification

Transesterification Reaction

The reaction taking place during the transesterification is given in Fig. 2.

Experimental set-up

The experimental setup consists of a batch reactor set-up (with 3-neck 500 ml, round bottom flask), Stirrer with 180 rpm (fixed), Thermometer, and Reflux Condenser (Figs. 3 and 4).

Experimental procedure

100 gm of Karanja oil sample is taken for each analysis. A fixed amount of catalyst is dissolved in a specific amount of methanol. The oil sample is preheated in a round bottom flask for about 15-20 min. The solution of alcohol and catalyst is added to the pre-heated oil in the batch reactor and the reaction is allowed at a stirring of 180 rpm and a temperature of about 50^0 C for different time periods (15 min - 60 min)[23-25]. The sample is poured into the separating funnel and it is allowed to stay for about 30 min

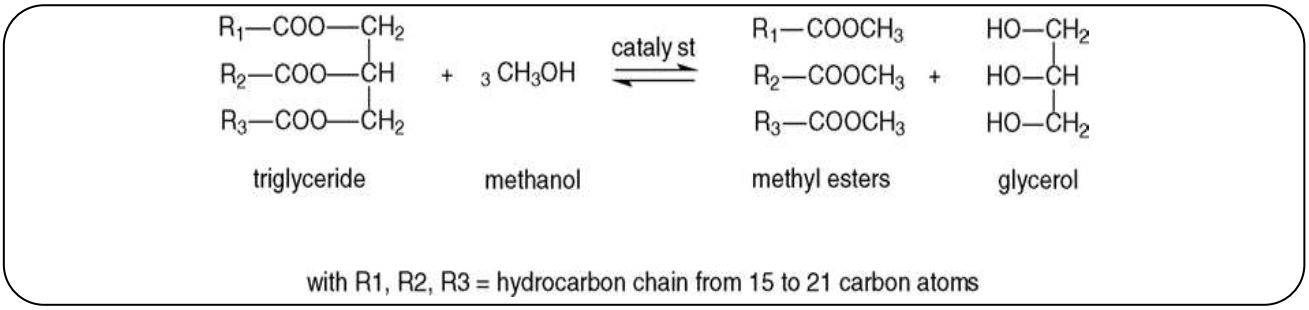

Fig. 2: Transesterification Reaction.

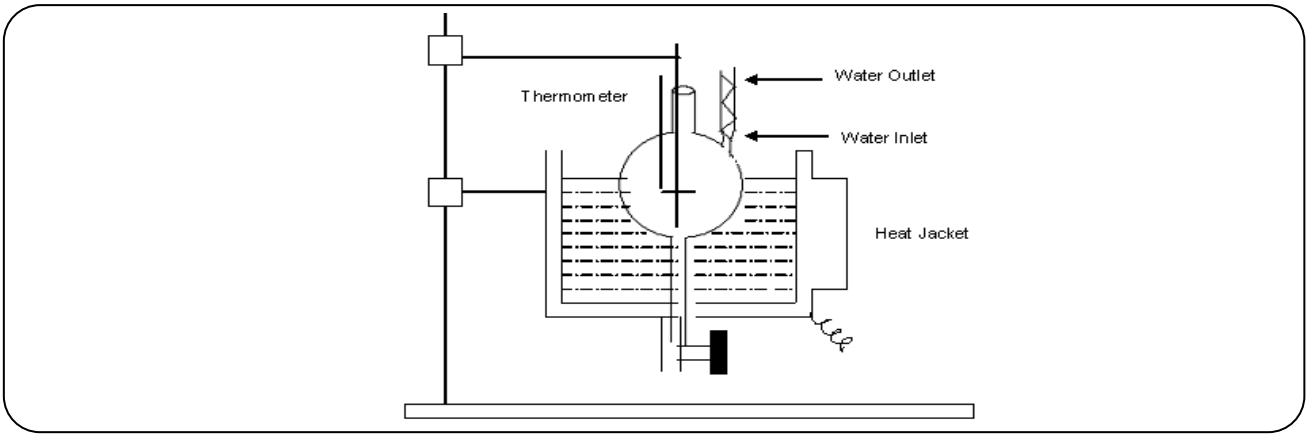

Fig. 3: Schematic batch reactor setup.

Fig. 4: Experimental batch reactor setup.

Fig. 5: Biodiesel separation from glycerol.

until a clear separation of the two layers is observed [25]. The obtained product is a uniform mixture of biodiesel along with glycerol. The mixture is then separated and the glycerol is removed. The separation takes place based on the density differences. The top layer is biodiesel and the bottom layer is glycerol (Fig.5).

The yield for the biodiesel is then calculated. This method is continued for the various catalyst percentages, alcohol-oil ratios, and reaction times.

* Yield of Biodiesel = Weight of biodiesel formed after the reaction / Weight of oil used for the reaction.

Washing of biodiesel

The biodiesel thus obtained is thoroughly washed by adding water to the biodiesel. The mixture is shaken vigorously for about 10 min and then allowed to settle in a separating funnel. The separation into two layers takes place based on the density differences and as the water is

Fig. 6: Purifying biodiesel with water wash.

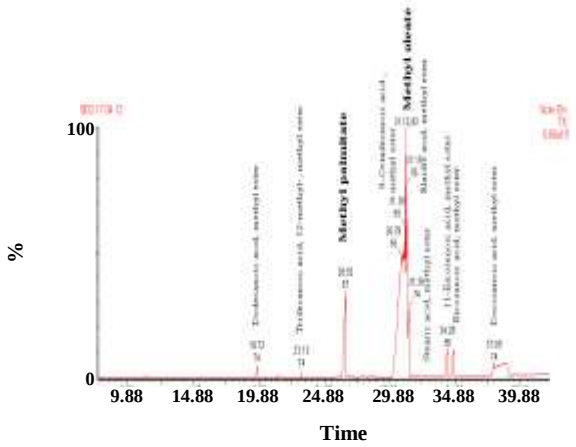

Fig. 7: GC-MS chromatogram of Karanja biodiesel.

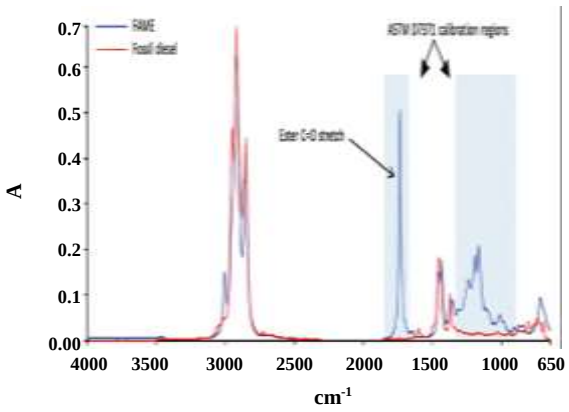

Fig. 8: FT-IR Spectra of fossil diesel and FAME (ASTM D7371 calibration regions are shaded).

denser than biodiesel it settles down (Fig. 6). The water is removed and the process of water washing is repeated until a clear layer of the water is observed.

RESULTS AND DISCUSSIONS

Characterization of biodiesel

GC-MS analysis of Karanja biodiesel

The Biodiesel samples were analyzed by Gas Chromatography Mass Spectrometry (*Thermo Scientific, USA*). This is a quantitative method to find the completion of the reaction. The characteristic peaks in the GC Chromatogram (Fig. 7) show the abundance of fatty acid methyl esters, methyl oleate, and methyl palmitate at 31.12 minutes and 26.52 minutes respectively. This confirms the nearly complete transesterification of oil into biodiesel. Thus, the reproducibility of results in Fig. 7 for different biodiesels is ensured because the GC Chromatogram has validated the correctness of the reaction conditions.

FT-IR (ASTM D7371) analysis of Karanja biodiesel

The Biodiesel samples were analyzed by FT-IR Spectrometer (*Perkin Elmer, UK*). This is a quantitative method to find the completion of the reaction. Biodiesel has a high infrared absorption at about 1745 cm-1 (because of the ester-carbonyl bond). The characteristic peak the FT-IR Spectra (Fig. 8) confirm the nearly complete transesterification of oil into biodiesel. Thus, the reproducibility of results in Fig. 8 for different biodiesels is ensured because the FT-IR Spectra have validated the correctness of the reaction conditions.

Experimental results

Plots between yield % versus time at 1%, 1.5%, and 2% KOH

The yield increases from 15 minutes to 45 minutes and then decreases at 60 minutes. This is because after a certain time when equilibrium has been reached, the reaction shifts to the left. Based on this it is concluded that the yield obtained is highest at the time of 45 minutes. The yield is also the highest for the methanol - oil ratio of 4.5:1 and it reaches about 75 % in the first 15 minutes of the reaction (Figs. 9, 10, 11).

Plot between yield % versus time at 3:1 methanol - oil ratio

The yield increases from 15 minutes to 45 minutes and then decreases at 60 minutes. This is because after a certain time when equilibrium has been reached, the reaction shifts to the left. Based on this it is concluded that the highest yield is obtained at 45 minutes. The yield is highest for the methanol-oil ratio of 4.5:1 and it reaches about 54 % in the first 15 min of reaction (Fig. 12). The highest yield obtained is 71 % at 1.5 wt % KOH. The decrease in the yield is due to

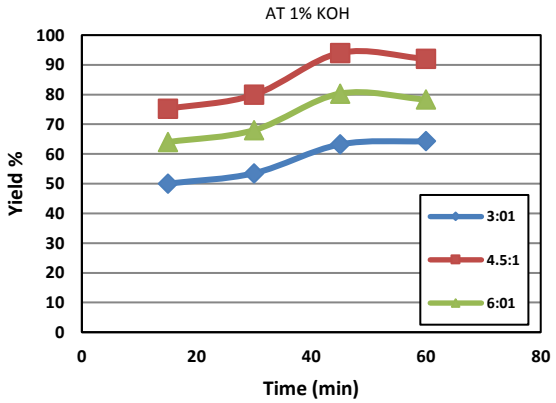

Fig. 9: Graph representing yield at various MeOH - oil ratios at 1 % KOH.

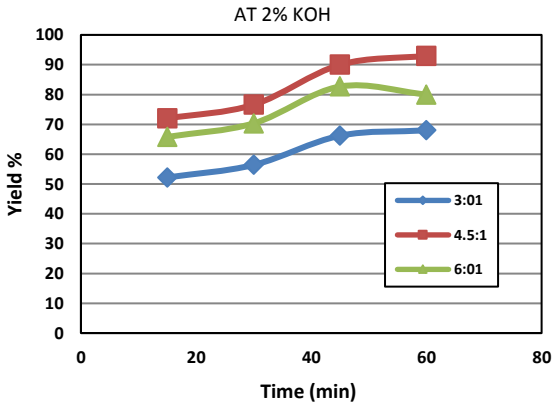

Fig. 11: Graph representing yield at various MeOH - oil ratios at 2 % KOH.

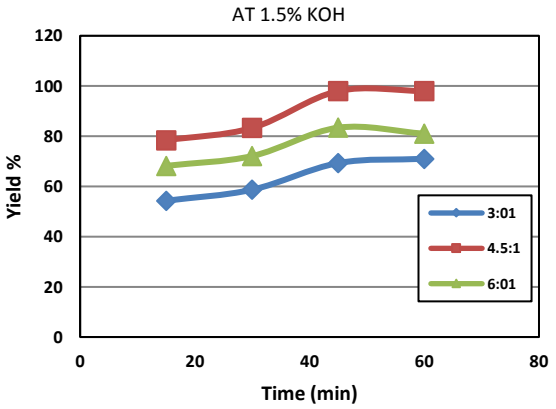

Fig. 10: Graph representing yield at various MeOH - oil ratios at 1.5 % KOH.

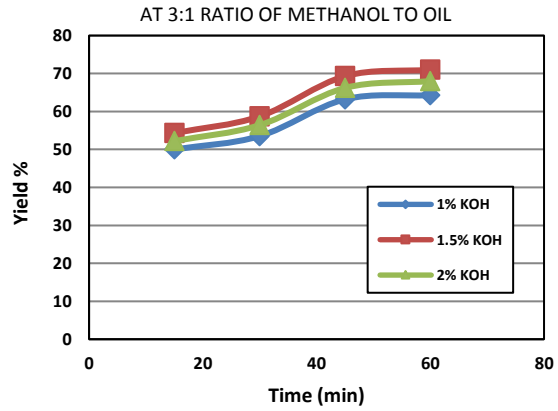

Fig. 12: Graph representing yield at various KOH % at 3:1 MeOH - oil ratio.

the exact stoichiometric amount of methanol – oil ratio of 3:1 was used. Thus, the reaction gets limited by the amount of methanol.

Plot between yield % versus time at 4.5:1 methanol - oil ratio

The yield increases from 15 minutes to 45 minutes and then decreases at 60 minutes. This is because after a certain time when equilibrium has been reached, the reaction shifts to the left. Based on this it is concluded that the highest yield obtained is at 45 minutes. The yield is highest for the methanol - oil ratio of 4.5:1 and it reaches about 78 % in the first 15 minutes of the reaction. The yield is constant between 45 minutes and 60 minutes (Fig. 13).

Plot between yield % versus time at 6:1 methanol - oil ratio

The yield increases from 15 minutes to 45 minutes and then decreases at 60 minutes. This is because after a certain time when equilibrium has been reached, the reaction shifts to the left. Based on this it is concluded that the highest yield obtained is at 45 minutes. The yield is highest for methanol - oil ratio of 4.5:1 and it reaches about 68 % in the first 15 minutes of the reaction (Fig. 14). The decrease in yield is due to the increased dilution of oil in methanol beyond 4.5:1 methanol - oil ratio.

Plot between yield % versus time at 4.5:1 methanol-oil ratio, 1.5 KOH catalyst at different temperatures

It is observed that the yield increases from 15 minutes to 45 minutes and then becomes constant between 45 minutes and 60 minutes. The yield obtained shows a similar trend for the temperatures of 50°C and 60°C. Whereas the yield is lower at a temperature of 40°C (Fig. 15). Thus the optimal temperature for the transesterification is suggested as 50°C.

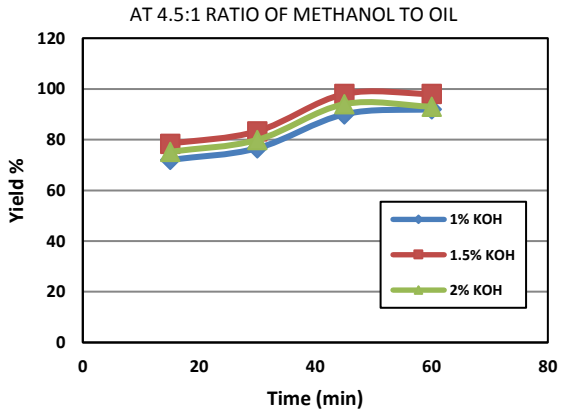

Fig. 13:Graph representing yield at various KOH % at 4.5:1 MeOH - oil ratio.

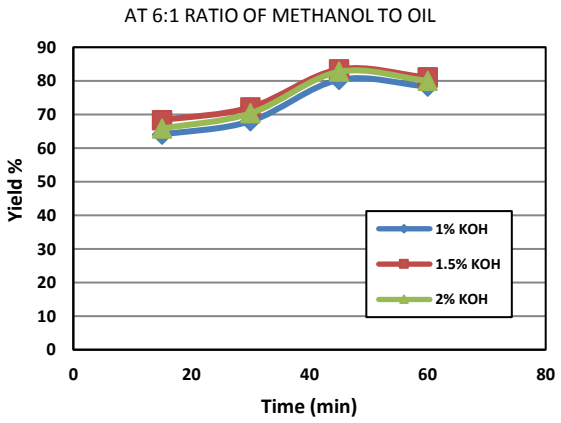

Fig. 14: Graph representing yield at various KOH % at 6:1 MeOH - oil ratio.

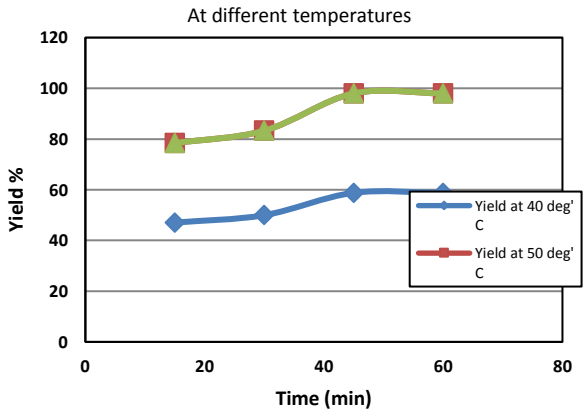

Fig. 15: Graph representing yield at 4.5:1 MeOH - Oil, 1.5 KOH catalyst %.

On overall comparison, the data suggest the following optimum parameters for obtaining the highest yield:

- Optimum methanol–oil ratio is 4.5:1,
- Optimum concentration of the catalyst is 1.5%,
- Optimum time of reaction is 45 minutes.
- Optimum temperature is 50°C.

The produced biodiesel has the following properties: Density -830 kg/m^3, Viscosity -0.038 stokes, Flash Point -140 ^{o}C, Fire Point -148 ^{o}C, Cetane Number -49, and Heating Value - 39.5MJ/kg. This also meets the ASTM D6751 standards.

Application of Artificial Intelligence (AI) techniques

Optimization is using of explicit methods for establishing the efficient and cost-effective elucidation or design of any process. The main purpose of modeling is to predict the optimum yield using experimental values. In this process of transesterification, the parameters involved are Catalyst concentration (%), Ratio (MeOH: Oil), Time (h), and finally Yield. The optimum values obtained through various models are compared against experimental values [11,12].

The models used are:

- Support Vector Machine
- Genetic Algorithm
- Particle Swarm Optimization

Support Vector Machine (SVM)

SVM is a model that identifies patterns and examines data, used for regression and classification studies [14,15].

Algorithm

- Start
- Input and output values are to be given in the command window
- Those input values should be saved in the workspace
- All the files pertaining to the main SVM program are to be kept in one folder
- A set of input values should be given in the program
- The main SVM program is executed
- Result is obtained corresponding to the input values given
- The result is checked for multiple values of input
- Stop

Training of the model

The SVM is trained with the following 35 experimental data sets. The resulting error is also shown in Table 2.

Table 2: Comparison of Experimental and SVM results.

S No.	InputParameters[C:R:T]	Experimental yield (at optimal temperature of 50 ºC)	SVM result	Error %
1	[1:6:15]	65.9	65.9	0
2	[1:4.5:15]	76	75.7	0.395
3	[1:3:15]	52.88	52.77	0.208
4	[1.5:6:15]	68.63	68.97	0.495
5	[1.5:4.5:15]	78.94	79.33	0.494
6	[1.5:3:15]	57.28	57.39	0.192
7	[2:6:15]	67.8	67.52	0.413
8	[2:4.5:15]	77.7	77.39	0.399
9	[2:3:15]	55.57	55.44	0.234
10	[1:6:30]	70.01	69.72	0.414
11	[1:4.5:30]	80.75	80.42	0.409
12	[1:3:30]	56.18	56.12	0.107
13	[1.5:6:30]	72.9	73.26	0.494
14	[1.5:4.5:30]	83.87	84.32	0.537
15	[1.5:3:30]	60.87	61.88	1.659
16	[2:6:30]	72.05	71.75	0.416
17	[2:4.5:30]	82.56	82.22	0.412
18	[2:3:30]	59.04	58.95	0.152
19	[1:6:45]	82.37	82.03	0.413
20	[1:4.5:45]	95	94.62	0.4
21	[1:3:45]	66.1	65.96	0.212
22	[1.5:6:45]	85.79	86.21	0.489
23	[1.5:4.5:45]	98.67	99.16	0.497
24	[1.5:3:45]	71.61	71.75	0.196
25	[2:6:45]	84.76	84.4	0.425
26	[2:4.5:45]	97.13	96.75	0.391
27	[2:3:45]	69.46	69.29	0.245
28	[1:6:60]	80.4	80.08	0.398
29	[1:4.5:60]	95	94.64	0.379
30	[1:3:60]	67.3	67.1	0.297
31	[1.5:6:60]	83.5	83.88	0.455
32	[1.5:4.5:60]	98.66	99.11	0.456
33	[1.5:3:60]	72	72.23	0.319
34	[2:6:60]	81.7	81.37	0.404
35	[2:4.5:60]	96.8	96.44	0.372

Average error = 0.39 %; R^2 = 0.999
Where, C = Catalyst concentration (wt %)
R = MeOH:Oil ratio
T = Time (min)

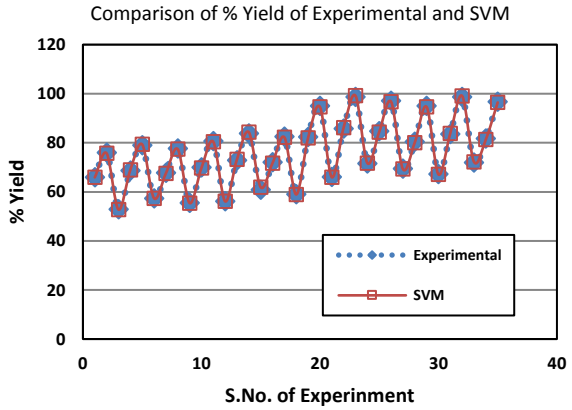

Fig. 16: Comparison of the biodiesel yield obtained for the Experiment and SVM.

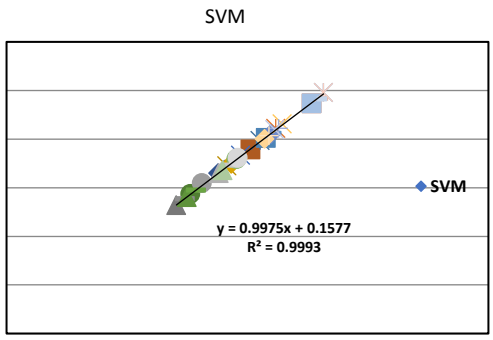

Fig. 17: Error of SVM predicted yield w.r.t. to Experiment.

Validation of the trained model

The trained SVM model is validated with input data set [C, R, T] as [2, 3, 60] and output dataset as [70.8]. The SVM model gave output as [70.78]. The dataset for the validation has been purposely selected to be outside the experimental array for training, such that it can hold datasets for various arrays of experimentation.

The yield predicted by SVM is compared with the yield obtained by experiments and the corresponding error is stated (R^2 = 0.999) (Fig. 16 & Fig. 17). Thus SVM can be used as an effective tool to predict the yield.

** The MATLAB programs for SVM are given in Annexure 1.*

Genetic algorithm (GA)

In a genetic algorithm, a population of solutions is evolved towards improved solutions for an optimization problem. The set of properties for each solution can be changed and mutated. Conventionally, solutions correspond to strings of 0s and 1s [16,17].

G.A consists of 4 major steps:

* Encoding

* Reproduction

* Crossover

* Mutation

Algorithm*(Fig. 18)*

•Start the program

•Initialize the parameters and population size in the command window

•Conduct cross-over and mutation using a tool

•Evaluate and find the best offspring

•If it is the best solution update it or else create enough generations

•Go to step 2

•Return the best solution.

Approach

The experimental data is taken as input for estimating the objective function between each of the 3 variables i.e., concentration, ratio, time of reaction, independently (i.e. keeping other two as constant).

Then these functions are used as 'fitness function' to apply GA and predict the optimal value w.r.t all the 3 inputs.

After creating fitness functions then we need to perform the program and it is as follows:

The command for running Genetic Algorithm:

[x,fval]=ga(@function name, number of variables,[],[],[])

Function name can be written in the MATLAB by creating a new M-file.andthe number of variables depends on the function.

Execution

STEP 1

Individually 3 objective functions have been formulated according to their variation patterns with respect to yield, using CFTOOL of MATLAB.

The objective functions were thus obtained as follows:

(i) For concentration vs yield data:

$f(x) = p1 * x^2 + p2 * x + p3$

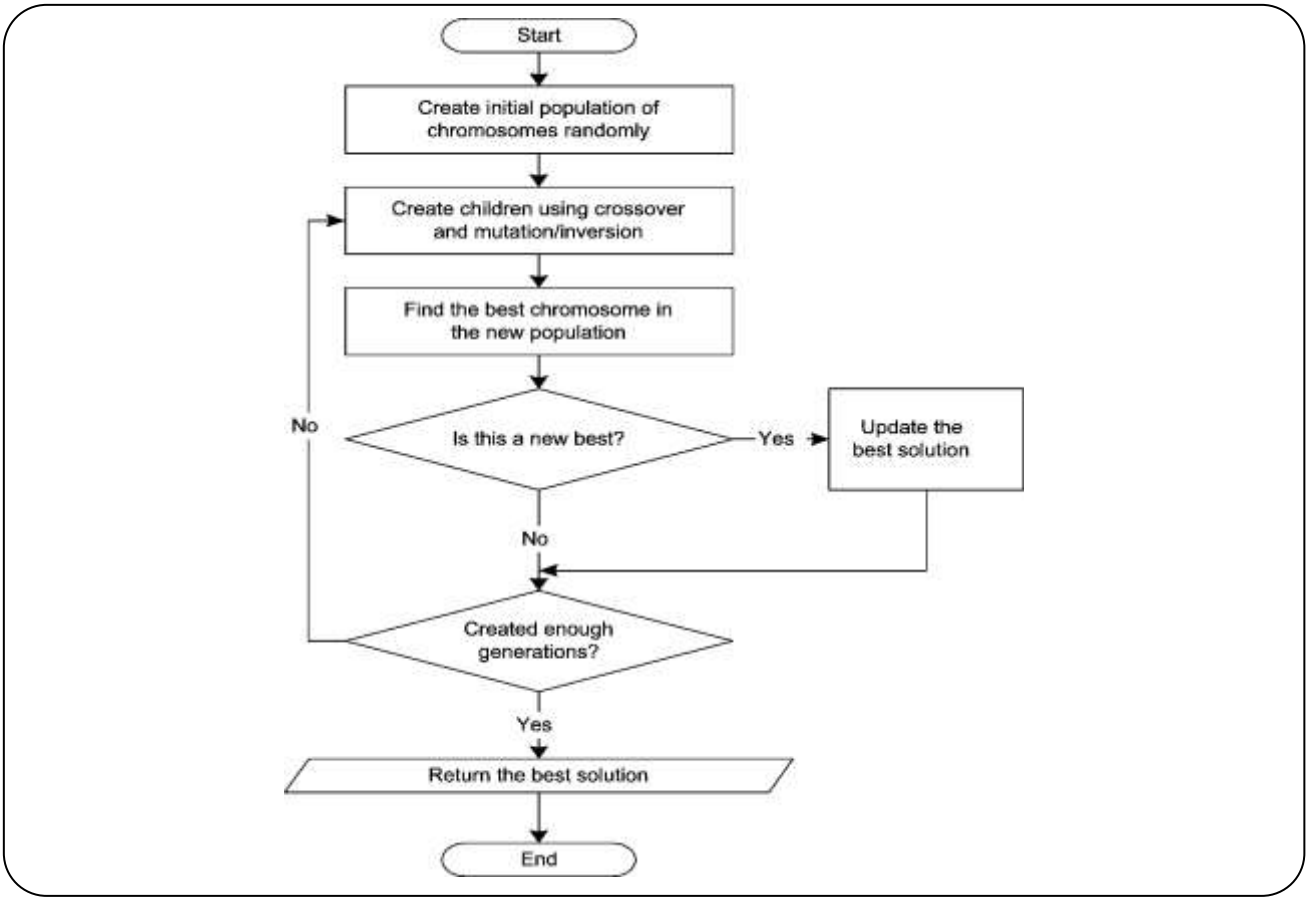

Fig. 18: Algorithm for GA.

Coefficients (with 95% confidence bounds):

p1 = -10.36 (-48.44, 27.71)

p2 = 33.38 (-81.37, 148.1)

p3 = 50.97 (-30.17, 132.1)

(ii) For ratio vs yield data:

$f(x) = p1 * x^2 + p2 * x + p3$

Coefficients (with 95% confidence bounds):

p1 = -8.283 (-10.81, -5.755)

p2 = 78.9 (56.05, 101.7)

p3 = -98.89 (-147.4, -50.42)

(iii) For time vs yield data:

$f(x) = p1*x^2 + p2*x + p3$

Coefficients (with 95% confidence bounds):

p1 = -0.005217 (-0.0221, 0.01166)

p2 = 0.798 (-0.4881, 2.084)

p3 = 54.88 (33.73, 76.02)

STEP 2

The objective functions were now used to calculate optimal yield using the Genetic Algorithm optimization technique. The population is chosen to be 60. The Roulette wheel selection method is used.

Validation of the Model

The corresponding optimal values of the input parameters have been obtained as:

The optimal values are found to be:

Yield: 98.335 %;

Conc: 1.487 %;

Ratio: 4.48;

Time: 45 min.

Thus, the optimal results attained by the Genetic Algorithm are well in concurrence with the experimental values. Hence Genetic Algorithm can be effectively used as a tool for predicting the optimum parameters for biodiesel production.

* MATLAB programs for Genetic algorithms are given in Annexures 2 & 3.

Particle Swarm Optimization (PSO)

PSO is easier to apply than GA with only a few parameters to adjust. PSO also gets good results in a quicker way in comparison to other methods.

Algorithm

- Start
- A program named ***tracklsq*** with an overall objective function is written
- Another program on ***PSO*** is to be written taking into consideration all the values necessary for the program
- The PSO program is executed
- The best result is obtained after performing a valid no: of iterations
- Stop

Approach

The experimental data are taken as input for estimating the objective function between each of the 3 variables, concentration, ratio, and time of reaction, independently (i.e. keeping the other 2 constants).

Then these functions can be used as 'fitness functions' to apply PSO and predict the optimal value w.r.t all the 3 inputs.

Command for PSO

[x,fval]=pso (@function name, number of variables,[],[],[])

The function name can be written in MATLAB by creating a new M-file and the number of variables depends on the function.

Execution

STEP 1

Individually we have formulated 3 objective functions according to their variation patterns with respect to yield, using CFTOOL of MATLAB.

The objective functions were thus obtained as follows:

For concentration vs yield data:

$f(x) = p1 * x^2 + p2 * x + p3$

Coefficients (with 95% confidence bounds):

p1 = -10.36 (-48.44, 27.71)

p2 = 33.38 (-81.37, 148.1)

p3 = 50.97 (-30.17, 132.1)

For ratio vs yield data:

$f(x) = p1 * x^2 + p2 * x + p3$

Coefficients (with 95% confidence bounds):

p1 = -8.283 (-10.81, -5.755)

p2 = 78.9 (56.05, 101.7)

p3 = -98.89 (-147.4, -50.42)

For time vs yield data :

$f(x) = p1 * x^2 + p2 * x + p3$

Coefficients (with 95% confidence bounds):

p1 = -0.005217 (-0.0221, 0.01166)

p2 = 0.798 (-0.4881, 2.084)

p3 = 54.88 (33.73, 76.02)

STEP 2

The objective functions were now used to calculate optimal yield using Particle swarm

Optimization technique. A generic particle swarm optimizer called

Pso_Trelea_vectorized has been used in MATLAB environment.

The population is chosen to be 35.

Validation of the Model

After executing the complete function we obtain the result as follows.

The corresponding optimal values of the input parameters have been calculated as:

The optimal values are found to be:

Yield: 98.496 %;

Conc: 1.5 %;

Ratio: 4.49;

Time: 45 mins.

Thus the experimental values and the values generated by Particle Swarm Optimization are almost similar. Hence Particle Swarm Optimization can be effectively used as a tool for predicting the optimum parameters for biodiesel production.

** MATLAB programs for PSO are given in Annexures 2 and 3.*

From Table 3, it is observed that PSO gives more accurate results in comparison to GA, as the values are nearer to the experimental values.

CONCLUSIONS

The produced biodiesel from the Karanja oil conforms to the ASTM D6751 standards. The optimal conditions from the experiment are obtained at a temperature of 50° C, a reaction time of 45 minutes, a methanol-oil ratio of 4.5:1

Table 3: Comparison of the conditions predicted by GA and PSO.

S. No	Parameters	Experiment	GA	PSO
1	Yield	98.67 %	98.335 %	98.496 %
2	Catalyst Concentration	1.5 %	1.487 %	1.5 %
3	Alcohol to Oil Ratio	4.5	4.48	4.49
4	Time	45 mins	45 mins	45 mins

and catalyst concentration of 1.5 %. Among all the operational variables studied, methanol-oil ratio and catalyst %illustrated larger credence on biodiesel formation. The SVM accurately predicted the experimental results with $R^2 = 0.999$. PSO and GA can be effectively used as a tool for predicting the optimum parameters for biodiesel production with PSO giving more accurate results in comparison to GA.

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REFERENCES

[1] Mohammad Shirazi A., Akram A., Rafiee Sh., Bagheri Kalhor E., Energy and Cost Analyses of Biodiesel Production from Waste Cooking Oil, *Renewable and Sustainable Energy Reviews*, **33:** 44-49 (2014).

[2] Alenezi R., Santos R.C.D., Raymahasay S., Leeke G.A., Improved Biodiesel Manufacture at Low Temperature and Short Reaction Time, *Renewable Energy*,**53:** 242-48 (2013).

[3] Talebian Kiakalaieh A., Amin N.A.S., Zarei A.R., Noshadi I., Transesterification of Waste Cooking Oil by Heteropoly Acid (HPA) Catalyst: Optimization and Kinetic Model, *Applied Energy*,**102**: 283-92 (2013).

[4] TalebianKiakalaieh A., Amin N.A.S., Mazaheri H., A Review on Novel Processes of Biodiesel Production from Waste Cooking Oil, *Applied Energy*,**104:** 683–710 (2013).

[5] Aransiola E.F., Ojumu T.V., Oyekola O.O., Madzimbamuto T.F., Ikhu-Omoregbe D.I.O, A Review of Current Technology for Biodiesel Production: State of the Art, *Biomass and Bioenergy*, **61**: 276-297 (2014).

[6] Bharathiraja B., Chakravarthy M., Ranjith Kumar R., Yuvaraj D., Jayamuthunagai J., Praveen Kumar R., Palani S., Biodiesel Production Using Chemical and Biological Methods-A Review of Process, Catalyst, Acyl Acceptor, Source and Process Variables, *Renewable and Sustainable Energy Reviews*, **38**: 368-382 (2014).

[7] Likozar B., Levec J., Transesterification of Canola, Palm, Peanut, Soybean and Sunflower Oil with Methanol, Ethanol, Isopropanol, Butanol and Tert-Butanol to Biodiesel: Modeling of Chemical Equilibrium, Reaction Kinetics and Mass Transfer Based on Fatty Acid Composition, *Applied Energy*,**123**: 108–120 (2014).

[8] Costa A.O., Oliveira L.B., Lins M.P.E., Silva A.C.M., Araujo M.S.M., Pereira Jr.A.O., Rosa L.P., Sustainability Analysis of Biodiesel Production: A Review on Different Resources in Brazil, *Renewable and Sustainable Energy Reviews*, **27**: 407-412 (2013).

[9] Ferella F., Mazziotti Di Celso G., De Michelis I., Stanisci V., Vegli F, Optimization of the Transesterification Reaction in Biodiesel Production, *Fuel*,**89**: 36-42 (2010).

[10] Jain, M., Chandrakant, U., Orsat, V., Raghavan, V, A Review on Assessment of Biodiesel Production Methodologies from Calophyllum Inophyllum Seed Oil, *Ind. Crops Prod.*,**114**: 28–44 (2018).

[11] Gupta A.K., Sastry S.V.A.R, Developing the Rate–Equation for Biodiesel Production Reaction, Advances in Energy Research, Macmillan, ISBN 0230630065, 127-133 (2006).

[12] Kiakalaieha A.T., Amin S., Zarei N.A., Noshadi A.I., Transesterification of Waste Cooking Oil by Heteropoly Acid (HPA) Catalyst: Optimization and Kinetic Model, *Applied Energy*, **102**: 283-92 (2013).

[13] Lakhya Jyoti Konwar, Jutika Boro, Dhanapati Deka, Review on Latest Developments inBiodiesel Production Using Carbon-Based Catalysts, *Renewable and Sustainable Energy Reviews*,**29**: 546-564 (2014).

[14] Liew Weng Hui, ZahiraYaakob, SitiRozaimah, Sheikh Abdullah, Artificial Neural Network Modeling and Performance Optimization on Biodiesel Production Process, *Journal of Applied Sciences Research*, **8**: 4854-64 (2012).

[15] Luis-Fernando Morales Mendoza, Marianne Boix, Catherine Azzaro-Pantel, LudovicMontastruc, Serge Domenech, Biodiesel Production from Waste Vegetable Oils: Combining Process Modeling, Multi-Objective Optimization and Life Cycle Assessment (LCA), *Computer Aided Chemical Engineering*,**33**: 235-240 (2014).

[16] Yin X., Maa H., You Q., Wang Zh., Chang J., Comparison of Four Different Enhancing Methods for Preparing Biodiesel through Transesterification of Sunflower Oil, *Applied Energy*,**91**:320–325 (2012).

[17] Novák V, Perfilieva I, Močkoř J, "Mathematical Principles of Fuzzy Logic", Dordrecht: Kluwer Academic, ISBN 0-7923-8595-0 (1999).

[18] Ramachandran K., Suganya T., Nagendra Gandhi N., Renganathan S, Recent Developments forBiodieselProduction by Ultrasonic Assist Transesterification Using Different Heterogeneous Catalyst: A Review, *Renewable and Sustainable Energy Reviews*, **22**: 410-418 (2013).

[19] Sastry S.V.A.R., Vishnupriya I, Sahoo Abanti, Acid Catalysis of Waste Cooking Oils for Biodiesel Production, *Iranian (Iranica) Journal of Energy & Environment*,**10(2)**: 91-95 (2019).

[20] Sastry S.V.A.R., Sarva Rao B., Ravi Kishor G, Optimization of Biodiesel Transesterification using ANN and Fuzzy Logic, *International Journal of Engineering and Advanced Technology*, **9(2)**: 718-723 (2019).

[21] Sastry S.V.A.R., Rao K.V, Characterizing the conversion of Transesterification reaction by modeling of Glycerol-rich phase, *International Journal of Environment and Waste Management*,**26(3)**: 309-323 (2020).

[22] Sastry S.V.A.R., Ramachandra Murthy Ch.V., Sustainable Energy for Eco-Friendly Development, *i-manager's Journal on Future Engineering and Technology*, **8**: 1-8 (2013).

[23] Sastry S.V.A.R., Murthy Ch.V.R., Prospects of Biodiesel for Future Energy Security, *Elixir, Chemical Engg*., **53:** 12029-12034 (2012).

[24] Sastry S.V.A.R., Ramachandra Murthy Ch.V., Synthesis of Biodiesel by Insitu Transesterification of Karanja Oil, *Bangladesh Journal of Scientific and Industrial Research*,**49**: 211-218 (2014).

[25] Sastry S.V.A.R., "Biodiesel Production: Lab Studies to Pilot Plant Studies", M. Tech Thesis, Department of Chemical Engineering, Indian Institute of Technology, Delhi (2005).

[26] Sharma Y.C, Singh B, Development of Biodiesel from Karanja, a Tree Found in Rural India, *Fuel*,**87**: 1740-42 (2008).

[27] Talebian Kiakalaieh A, Amin NAS, Mazaheri H, A Review on Novel Processes of Biodiesel Production from Waste Cooking Oil, *Applied Energy*, **104:** 683–710 (2013).

[28] Thiruvengadaravi K.V., Nandagopal J., Baskaralingam P., Sathya Selva Bala V., Sivanesan S,Acid - Catalyzed Esterification of Karanja (PongamiaPinnata) Oil with High Free Fatty Acids for Biodiesel Production, *Fuel*, **98**: 1-4 (2012).