Optimisation of Babassu (Attalea Speciosa) biodiesel using Taguchi's Technique

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***Abstract* - Current work deals with the optimisation of Babassu oil; a non-renewable source for biodiesel preparation and the parameters that affects the yield. It is pale yellow oil with 70% lipids and 50% of lauric acid. The Taguchi method was applied for estimation of factors that affect the biodiesel production using S/N ratio (signal to noise ratio). Molar proportion of methanol to oil, response time and amount of catalyst was picked keeping mechanical agitation and response temperature steady. In DOE (design of experiments) L9 3X3 symmetrical exhibit was employed. The investigation uncovered that catalyst amount was the prime factor that brought about improvement of biodiesel took after by molar proportion and response time. ANOVA method also calculated the contribution of each parameter. R -sq. value 0.9513 revealed validation of our analysis model up to 95.12%. 6:1 methanol to oil ratio, 0.5g KOH and reaction time being 75 minutes under constant stirring at 60^0 C were finalised as optimised parameters. The yield obtained at optimised conditions was as high as 98.18% and the fuel properties of obtained biodiesel were analysed and complied with ASTM D7652 method. Hence, BOME (Babassu Oil Methyl Ester) proved to be an excellent biodiesel raw material.**

Keywords: Babassu oil; Taguchi method; Babassu Oil Methyl Ester; Transesterification; Design of Experiments

1. INTRODUCTION

With increasing urbanisation and industrialisation there has been a significant boom in energy demands. Fast utilization of non-sustainable wellsprings of vitality prompts consistently expanding GHGs (Green House Gases). In present times where climate change and global warming poses a serious threat to human mankind, there is an immediate need to find alternate sources of ever increasing energy demands. Efforts have been made to minimise the prices by choosing low priced raw material. [1] Biodiesel production is one such method which is an excellent alternative source of energy. The outside epicarp and the wooden endocarp can be utilized as a fuel and the boring mesocarp utilized as feed. [2] It possesses excellent fuel properties that can be employed in CI engines with or without any blends. Another attractive features of biodiesel includes biodegradability, abridged levels of SO_x and CO emissions, to keep in check of CO_2 levels, good lubricity and convenient handling and transportation. Main concern of using edible vegetable oils for biodiesel production is its attractiveness with food crops which might add problems to already occurring food shortages and high price levels. Various sources of biodiesel production are soyabean oil, rapeseed oil, Jatropha, Sesame. The commitment of non-consumable oils, for example, Babassu, a palm oil having a place with Palmae family tends to the issue of palatable oil as a wellspring of biodiesel generation. It is apparent, light yellow coloured oil it constitutes around 66% babassu kernel weight and roughly 83% of grease composition is comprised of saturated oil rendering it a formidable biodiesel production source [3]. The fruit of babassu palm is exploited at its maximum potential and various parts are used for energy source, fodder and food. The kernels are rich in proteins and carbohydrates; containing 90 % to 95% of its total substance. Some of the aspects for biodiesel production via transesterification process are molar ratio, catalyst concentration, reaction time and reaction temperature. Methanol is commonly employed alcohol. Weather the transesterification is to be carried out in single stage or double stage depends upon the FFA (Free Fatty Acid) value [4] Babassu oil has very low FFA value rendering it to single stage alcoholysis process. Alkaline transesterification is preferred to acidic transesterification as reaction carried out in former one is 4000 times faster [5]. Moreover, in acidic transesterification catalyst activity is lower. Owing to excellent annual productivity of babassu nut, overall cost is less thus babassu provides a tremendous source for biodiesel production. The present work deals with optimisation of biodiesel using babassu oil as raw material under various set of parameters using methanolysis.

2. MATERIALS AND METHODS

2.1 Materials

Refined babassu oil was procured from Paras Perfumers, Delhi. Oil has following fatty acid composition (w/v): 1.85% caprylic, 4.02% capric, 46.98% lauric, 15.89% myristic 9.7% palmitic, 3.47% steriac, 14.08% oleic and 3.21% linoleic. Oil has average molecular mass of 709.9g/mol and possess high oxidation stability. [6] Other materials like KOH pallets, distilled water and methanol were obtained from local vendor and they are of analytical grade.

2.2 Properties of babassu oil

Physicochemical properties of babassu oil and babassu oil methyl ester were figured by ASTM portrayed standard techniques at Mechanical Engineering Research and Development Organization, Ludhiana an ISO 9001 association which is set up under CSIR. The comparison of physico chemical properties of babassu oil from various researchers and properties of oil are tabled below [7]

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S No	Properties	Diesel	Babassu oil
1	Density (at 15^0C) kg/m^3	838-872	925
2	Viscosity (at 40^0C cSt)	3.2	29.5
3	Flash point (^{0}C)	50-98	150
4	Cetane Number	45-55	38
5	Heating value (Mj/kg)	42-45.9	NA
6	Acid value	N A	1.22

Table 1 Properties of babassu oil and comparison with diesel

2.3 General procedure of biodiesel production-Transesterification

Catalyst is prepared by mixing KOH pallets in methanol. Methanol is favoured over ethanol since it is modest and promptly accessible. Single stage alkaline transesterification is employed because of low FFA value of oil and alkaline medium provides activity around 4000 times faster than acidic transesterification. Oil of 100 g samples are taken in a batch of four. The methoxide solution prepared is poured in the oil sample after the sample is subjected to mild heating. It is specifically done to increase the catalyst activity. The samples are then transferred into the water bath shaker whose temperature is maintained at 60^0 C and stirrer speed is kept constant. After the samples left undisturbed for given amount of time, the reaction mixture was then transferred into a separating funnel and after some time phase separation takes place. Glycerol, being heavier, settles at the bottom and the upper layer obtained is methyl ester.

Parameters	Levels		
	Level 1	Level 2	Level 3
Catalyst conc (gm.)	0.5	1	1.5
Reaction time (mins)	60	75	90
Methanol/oil ratio	4:1	6:1	8:1
Reaction temperature (°C)	60	60	60

Table 2 Process parameters and levels

2.4 Design of Experiments using Orthogonal Array

A new method of studying various process parameters was established by Dr, Taguchi. This is the method for optimisation of process parameters that affects the process using orthogonal array. Different combinations are made up to optimise the process. OA is decided depending upon the number of controlling parameters that may affect the process. Number of experiments can be calculated using the formula, N = (L-1) P +1. The primary advantage of using this method is that it significantly cuts down the number of experiments that are to be carried out.

2.5 Signal to Noise Ratio (SNR) and Analysis of Variance (ANOVA)

Using Taguchi method, S/N ratio is obtained that is employed for optimisation of process. SNR are log functions that are obtained from outcomes of the experiments. SNR is used to calculate the extent of deviation of expected outcomes. There are three types of SNR used namely LTB (Larger the Better), STB (Smaller the Better) and NTB (Nominal the Better) to optimise the problem. [8]

$$Nominal\ is\ best = 10\log(\frac{\overline{y}_i^2}{s_i^2}) \quad (1)$$

$$Smaller\ is\ best = -10\log(\sum_{j=1}^{n}\frac{y_j^2}{n}) \quad (2)$$

$$Larger\ is\ best = -10\log\frac{1}{n}(\sum_{j=1}^{n}\frac{1}{y_j^2}) \quad (3)$$

Here i is the experiment number, j is the trial number and n is trial numbers. SNR experimentation is employed for investigation of optimisation of parameters. For maximising the yield of babassu biodiesel, LTB is used and for calculation of viscosity, STB is preferred. After conducting ANOVA, it can be investigated that which parameter has maximum contribution to the outcome of the process.

$$\%\ \text{contribution factor} = \frac{SS_f}{SS_T} \times 100 \quad (4)$$

$$SS_f = \sum_{j=1}^{3} n\,[(SNR_L)_{fj} - SNR_T]^2 \quad (5)$$

$$SS_T = \sum_{i=1}^{9}(SNR_i - SNR_T)^2 \quad (6)$$

Experiment No.	Process Parameters			Biodiesel Yield (%)	S/N ratio
	Catalyst concentration (gms) (A)	Reaction time (mins) (B)	Alcohol /oil ratio (w/w) (C)		
1	0.5	60	4:1	95.37	39.5882
2	0.5	75	6:1	98.18	39.8405
3	0.5	90	8:1	86.25	38.7152
4	1.0	60	6:1	93.52	39.4181
5	1.0	75	8:1	85.63	38.6515
6	1.0	90	4:1	83.12	38.3941
7	1.5	60	8:1	82.6	33.3396
8	1.5	75	4:1	74.33	37.4233
9	1.5	90	6:1	82.28	38.3059

Table 3 Result of experiments and SNR values

3. RESULTS AND DISCUSSIONS

3.1 Static design analysis of signal to noise ratio (SNR)

Different process parameters influencing the yield of biodiesel generation. Out of the considerable number of parameters, three factors namely alcohol/oil ratio, amount of catalyst, and time of activity were examined. The experimental outcomes suggested that experiment no 2 has the highest value of biodiesel production yield of 98.18% and experiment no 8 has lowest yield. For calculating the biodiesel yield, LTB was applied. SNRs value were obtained statistically using Minitab software. It was envisaged that the most contributing parameter that brought about advancement of biodiesel creation was catalyst amount followed by molar proportion and response time. Using Minitab software optimum condition was predicted as 6:1 alcohol/oil ratio, 0.5g catalyst concentration and 75 minutes reaction time. Yield was observed as 96.17% which was well within predicted model equation.

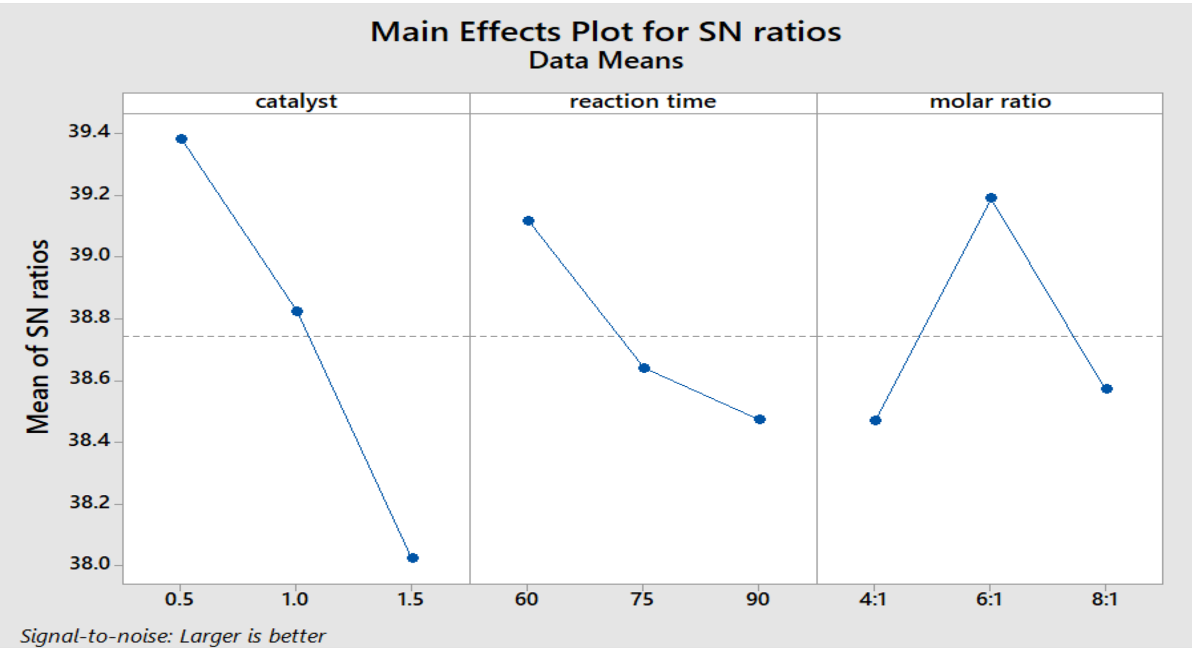

Figure 1 Effect of process control parameters on average SNR for biodiesel yield

3.2 Catalyst concentration

Data revealed that out of all the controlling parameters that were studied individually, catalyst amount had huge impact on methyl esters change took after by response time and methanol to oil proportion. The conversion rate was higher for 6:1 methanol to oil ratio.

3.3 Effect of catalyst amount

In most of the industrial processes that are carried out, the catalyst turns out to be costlier than reagent and its removal from product poses addition problem of energy consumption and alleviated costs. From the Fig 2 it is found that as the catalyst amount increased the yield of methyl esters decreased. This is due to unreacted catalyst that would result in reverse reaction resulting in soap formation.

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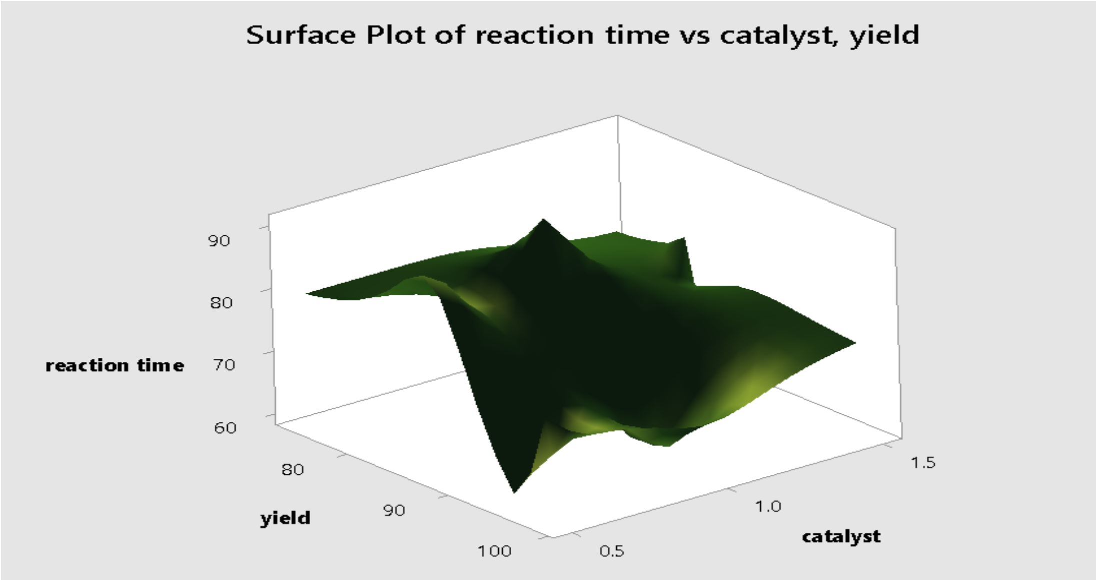

Figure 2 Effect of catalyst and reaction time on yield of BOME yield

3.4 Effect of reaction time

Reaction time was studied as independent controlling factor and it was elucidated that as time increases, yield goes on decreasing. This is attributed by the consumption of catalyst when the reactions are carried out for longer time resulting into decrease in the yields of methyl esters. Maximum yield was obtained at catalyst concentration of 0.5g and for 75 minutes. The yield was observed to be 98.18% which after purification procedure remained at 96.42%.

3.5 Effect of molar ratio

It has been investigated that yield of babassu methyl esters first increases when molar ratio was changed from 4:1 to 6:1 but it decreases when the molar ratio was changed to 8:1 (Fig 3). This is because at higher ratios of methanol to oil ratio, polar nature of methanol comes into play which results in aggravated side reactions leading to formation of more soap and results in decrease of babassu methyl esters. [9]

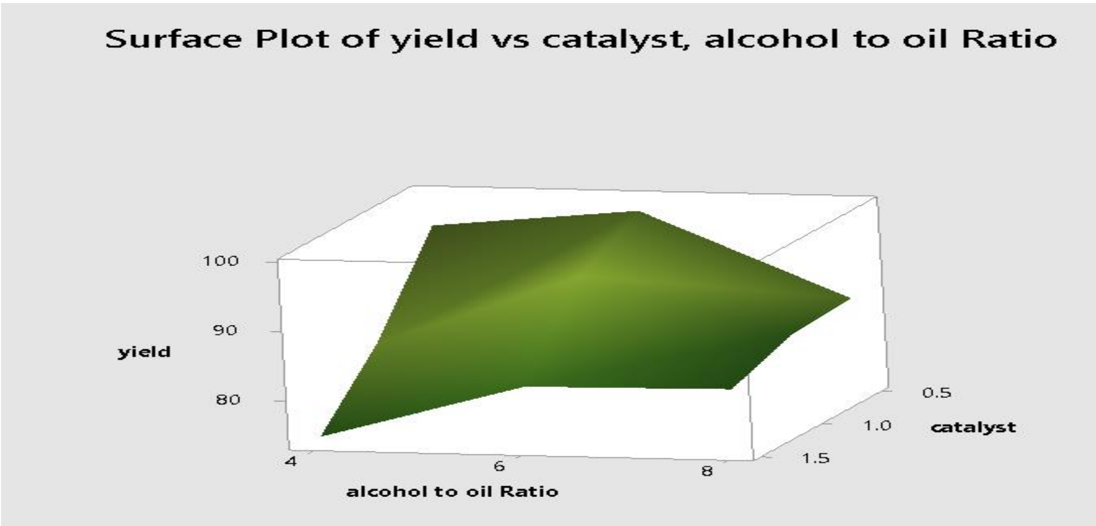

Figure 3 Effect of alcohol to oil ratio and catalyst on yield of BOME yield

3.6 Properties of BOME

Properties of BOME are tabulated below:

Fuel Property	Diesel	BOME	ASTM D6751	EN14214
Density (g/cm^3)	820-835	874	-	860-900
Kinematic viscosity 40^{0}C (cSt)	3.7	1.93	1.9-6	3.5-5
Flash Point(^{0}C)	60	122	>130	>101
Fire point (^{0}C)	65	128	-	Min 120
Cloud point (^{0}C)	-12	5.5	10	-1
Pour Point (^{0}C)	-16	0.5	-15	-
Cetane No	47.48	61	48-67	Min 51
Calorific Value (MJ/kg)	43	36.29	36-41	-
Acid value (mg KOH/g)	0.2	0.18	0.5 max	0.5 max

Table 4 Properties of BOME and diesel

3.7 Analysis of variance (ANOVA)

ANOVA is employed for evaluating magnitude for each given trial in the L9 orthogonal array. ANOVA computes the relation with each parameter of biodiesel production as given in the Eq. Parameter which has the most significant response is find out through ANOVA. Catalyst concentration is the most significant parameter.

$$Y_{YIELD} = 94.85 + 2.150A - 0.4578B - 0.2900C - 0.06111A^2 - 0.01556B^2 - 0.6144C^2 + 0.1200AB + 0.7956AC \quad (7)$$

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Catalyst (A)	2	276.29	276.29	138.15	13.76	0.068
Reaction time (B)	2	68.22	68.22	34.11	3.40	0.227
Molar ratio (C)	2	92.31	92.31	46.15	4.60	0.179
Residual Error	2	20.08	20.08	10.04		
Total	8	456.89				

Table 5 ANOVA for means

4. RESULTS AND DISCUSSIONS

From the statistical analysis, it has been observed that as the temperature of the reaction and mechanical agitation is kept constant, the most persuasive factor that influences the biodiesel yield is catalyst amount. After molar ratio is increased beyond 6:1, decreasing trend in the yield of methyl esters was observed due to side reactions and formation of soap. Catalyst amount was key contributing variable in biodiesel streamlining took after by molar proportion and response time. Also, the observed fuel properties of BOME by optimised process were within the ASTM standards.

5. CONCLUSIONS

The babassu oil exhibits excellent properties as a raw material. It was envisaged that correct tuning of operating parameters would mushroom the yield of methyl esters as high as 98%. The catalyst amount was found to have the most significant factor in the experimentation followed by reaction time and molar ratio. The best conversion rates of methyl ester were obtained using KOH instead of NaOH and the obtained biodiesel possesses excellent fuel properties in comparison to diesel fuel and can be a best alternative in the upcoming times.

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