Parametric Optimization and Biodiesel Production from Coconut Fatty Acid Distillate

Rajesh K.*+; Devan P.K.

Department of Mechanical Engineering, RMK College of Engineering and Technology, Puduvoyal, Tamil Nadu, INDIA

Bharath Sai Kumar G.K.

HCL Technologies Limited, Pune 411057, Maharashtra, INDIA

ABSTRACT: *In this study, a low-cost feedstock was chosen for biodiesel production. Coconut fatty acid Distillate (CD) is the by-product collected from coconut oil refineries which contain lauric fatty acid as a major saturated fatty acid. The standard titration procedure was adopted to find Free Fatty Acid (FFA) content. The FFA was found to be 24.5% which requires esterification and transesterification processes to produce biodiesel. In the first stage, FFA was reduced to 1.8% by acid (H_2SO_4) esterification followed by transesterification to produce biodiesel. The CD BioDiesel (CDBD) production was optimized involving four parameters and three levels of L9 orthogonal array. The optimized parameters were reaction time (40 min), reaction temperature (50 °C), catalyst concentration (0.5%), and methanol to oil ratio (8:1). The order of significance of parameters was determined using ANOVA. The results showed that reaction time had more influence on the biodiesel production whereas methanol to oil ratio had the least influence. A linear regression model was developed to predict the yield and was compared with the experimental values. R^2 value for the model was 95%, and the error value is less than 15% indicating a good fit of the model. A maximum yield of 92.9% was obtained utilizing the optimized, which was very close to the prediction. Thus, a low-cost feedstock, which is otherwise marketed as a low-value product, could be utilized in making biodiesel adding sustainability.*

KEYWORDS: *Coconut fatty acid distillate; Biodiesel; Esterification; Optimization; ANOVA; Fatty acid composition,*

INTRODUCTION

The usage of automobiles increases day by day due to the growing population and transportation requirements. This has created a demand for naturally occurring petroleum-based fossil fuels and lead to an increase in cost [1]. Some of the catastrophic environmental consequences of continuous combustion of fossil fuels, in catering automobile and energy demands are global warming, acid rain, ozone layer depletion, and harm to human health [2,3]. To eradicate such trouble, an imminent need for alternate energy sources is apparent. One of the most promising sources of alternate fuel

* *To whom correspondence should be addressed.*
\+ *E-mail*: *rajeshmechh@gmail.com*
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is biodiesel since it can be directly used in I.C engines without making much modification to its construction [4,5]. The primary advantage of using biodiesel is renewability, less polluting, rich oxygen content, sulfur-free, and biodegradability [6-8]. Biodiesel extracted from various vegetable oils and animal fats serve as a better alternative for conventional fuel [9,10]. Biodiesel production from edible oils, which are first-generation feedstock leaves behind a trail of deforestation, exploitation of soil fertility, disturbance in the food chain etc. The cost of raw material alone comes around 75% of the cost involved in overall biodiesel production and they eventually prove to be 1.5 to 2.0 times costlier to produce in comparison with diesel [11,12]. However, second-generation feedstocks which are cheaper and non-edible can be used for biodiesel production, sparing conventional feedstocks adding to the economy and sustainability of the process [13,14]. Soapstocks, fatty acid distillates, and acid oils are the by-products of edible oil refining which could be used as significant feedstocks for biodiesel production at a cheaper cost [15,16]. These by-products have a high percentage of FFA and require two-stage processing for biodiesel production. Many works have been presented to extract biodiesel from high FFA feedstocks. High FFA oils require acid catalyst (e.g., HCl, H_2SO_4, Potassium bisulfate, p-toluenesulfonic acid, etc.,) esterification to produce esters and base or alkaline catalyst (e.g., NaOH, CaO, NaOMe, CH_3ONa, KOH, $KOCH_3$, etc.,) transesterification to produce Methyl Esters [5,10,17-20]. Very few works were reported so far on fatty acid distillates as a potential source of biodiesel production.

Chongkhong et al. investigated biodiesel production from palm fatty acid distillate (PFAD) and reported that FFA reduced from 93 wt% to 2 wt% by esterification using methanol to oil ratio of 0.4:1 to 12:1 and H_2SO_4 catalyst up to 5.502% followed by transesterification [21]. *Akinfalabi et al.* discussed esterification of PFAD using sulfonated soaked palm seed cake derived catalyst (2.5 wt %) with a reaction time of 2 hours to achieve 98.2% FFA conversion and FAME yield of 97.8% [22]. Cho et al. studied the greenhouse gas emissions and net energy ratio associated with the PFAD biodiesel production. It is found that greenhouse gas emission during PFAD methyl ester production is 86.5% less compared to diesel fuel. The energy yield is 3.23 times greater than the input of fossil fuel energy in the production [23]. *Yin et al.* produced biodiesel from soybean oil deodorizer distillate (SODD) using calcined duck eggshell catalyst. The SODD was esterified in the first stage using an acid catalyst (H_2SO_4) followed by transesterification with a catalyst concentration of 10 wt %, molar ratio of 10:1, temperature 60 °C, and reaction time 80 min and obtained a yield of 94.6% [24]. Yin et al. studied the effect of a Static Probe Ultrasonic Enhanced (SPUE) and Counter-Current Probe Ultrasonic Enhanced (CCPUE) transesterification on the biodiesel production of soybean oil deodorizer distillate. CCPUE was found to be better and achieved a yield of 96.1 % under optimal conditions of molar ratio 10:1, catalyst 1.8%, initial temperature 25 °C, ultrasound working on-time of 4s, off-time 2s, and a total process time of 50min [25]. *Liu et al.* studied the effect of biodiesel synthesis from rapeseed oil deodorizer distillate (RODD) in a column reactor packed with cation exchange resins (D002, 002CR, and 732). D002 cation exchange resin was efficient under optimal conditions and achieved a yield of 96%. It is concluded that biodiesel production through a packed column reactor is more significant compared to the sulphuric acid catalyst process [26].

Although few studies are made on fatty acid distillates, parametric optimization of biodiesel production is very limited. In a large-scale biodiesel production process, optimization is important in order to improve biodiesel yield and reduce production costs. Many researchers have used optimization to increase the biodiesel yield by selecting suitable parameters and levels. Lokman et al. investigated the effect of a Sulfonated-Glucose Acid Catalyst (SGAC) to produce PFAD biodiesel through esterification. Optimization was done by Response Surface Methodology (RSM) and results the result predicted by RSM were molar ratio 12.2:1, catalyst concentration 2.9%, and reaction time of 134 min. The reaction under optimum conditions resulted in a yield of 92.4% PFAD methyl ester [27]. Karmakar et al. reported a yield of 90.83 % from castor oil using L16 Taguchi orthogonal approach with methanol to oil ratio 20:1, reaction time 60 min, reaction temperature 50° C, catalyst concentration of 1% w/w, and agitation speed of 700 rpm as optimizing parameters [28]. *Onukwuli et al.* achieved a max biodiesel yield of 96 % from refined cottonseed oil using response surface methodology at optimum parameter values of reaction time 60 min, temperature 55° C, the molar ratio of 6:1 and catalyst loading of 0.6 wt % [29]. *Kumar et al.* base-catalyzed transesterification reaction on Manilkara zapota (L.) seed oil considering the parameters such as 50° C reaction temperature, 90 min reaction time, 6:1 methanol to oil ratio and 1 wt% catalyst concentration for optimization

and attained a biodiesel yield of 94.83 % [30]. *Dhawane et al.* used Taguchi method for optimization of Hevea brasiliensis oil biodiesel production. They attained a yield of 89.81% at catalyst loading of 3.5%, reaction temperature 55 °C, methanol to oil ratio of 15:1, and reaction time 60 min [31]. *Wu et al.* attained product and FAME yield of 95.8 and 98.4 % from camelina oil using an orthogonal experiment optimization technique. Optimum parameters considered are molar ratio 8:1, the reaction time of 70 min, reaction temperature of 50 °C, and catalyst concentration 1 %. From the study, it is clear that only minimal investigation was done on the usage of fatty acid distillates derived from oil refining. Few fatty acid distillates like palm, rapeseed, soybean oil were studied as feedstock under different conditions. Very/limited literatures are available for coconut fatty acid distillate (CD) oil biodiesel production. CD oil is a by-product obtained from refining of coconut oil. It is used as raw material for soap and animal feed. The cost of edible grade coconut oil is 5-6 times higher compared to CD oil. There is immense difference between edible grade coconut oil and CD oil cost and hence CD oil is considered as low cost feedstock. The present work is aimed at producing biodiesel from low cost CD as feedstock by standard esterification and transesterification process. Parameters influencing the biodiesel production are optimized by using Taguchi method.

EXPERIMENTAL SECTION

Materials

The raw material for CD biodiesel was obtained from an oil dealer Rassi Foods Ltd, Tamil Nadu, India. The oil used in this work has a high acid value which is a second-generation feedstock. High-grade methanol of 99.9% pure, potassium hydroxide (KOH), and sulphuric acid were purchased from Sriram Chemicals, Tamil Nadu, India. Ethanol and phenolphthalein used for titration were purchased from Lab Chemicals, Tamil Nadu, India.

Physicochemical properties of CD Oil

The raw oil was filtered to remove any impurities and heated between 100 & 120°C to remove any moisture present in it [28,32]. The properties of the CD oil were determined before starting the esterification reaction. The evaluation of physicochemical properties is essential to check the suitability of oil to be used as biodiesel feedstock. The fatty acid composition is the foremost important property of vegetable oil. Gas Chromatography (GC) analysis of raw

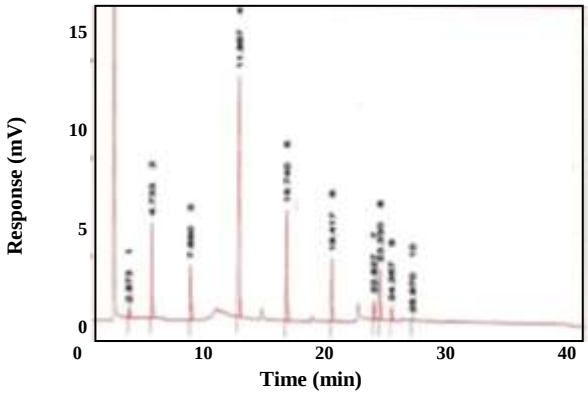

Fig. 1: Gas Chromatogram for CD oil sample.

CD oil was carried out before the esterification process to determine the fatty acid composition. The oil consists various type of saturated and unsaturated fatty acids which have a greater influence on cetane number of biodiesel [33] and has notable effect on combustion and emission characteristics [34]. The result of GC test is given in Fig. 1 which shows a high area percentage of lauric acid and myristic acid. Fatty acid composition of CD oil is given in Table 1 which signifies a large percentage of saturated fatty acids. Oleic, linoleic, and linolenic were the only unsaturated fatty acids contributing 8.47% and the rest 91.53% were saturated fatty acids.

The FFA was determined by titration of oil sample dissolved in an equal volume of ethanol and diethyl ether in a 0.1 N KOH solution with 2-3 drops of phenolphthalein indicator. The titration continued till a permanent pink color appeared on the mixture [29]. FFA value in terms of lauric acid was calculated using the relationship given below

$$\%FFA = \frac{V \times 0.02003}{W} \times 100 \quad (1)$$

Where, V = volume of KOH solution consumed (mL), 0.02003 = Constant (1 mg of KOH required to neutralize the weight of lauric acid), and W = mass of the oil sample (g) taken. The *FFA* calculated was 24.5 % which signifies the usage of heterogeneous catalysis for biodiesel production [21]. The properties of CD oil are given below in Table 2.

Experimental Setup

A half-liter beaker was used as a container for adding the mixture of oil and methoxide (Methanol + KOH) solution. Hot plate was used to maintain the temperature and a speed-

Table 1: Fatty acid composition and Structure of CD oil.

Peak No.	Fatty Acids	Structure	Molecular Weight (g/mol)	Area (%)
1	Caproic	C6:0	116.1	0.724
2	Caprylic	C8:0	144.2	10.206
3	Capric	C10:0	172.3	6.749
4	Lauric	C12:0	200.3	45.533
5	Myristic	C14:0	228.4	16.922
6	Palmitic	C16:0	256.4	8.841
7	Stearic	C18:0	284.4	2.551
8	Oleic	C18:1	282.47	6.776
9	Linoleic	C18:2	280.44	1.634
10	Linolenic	C18:3	278.43	0.064

Table 2: Physicochemical properties of neat CD oil.

Properties	CD oil	Testing Procedure
Kinematic Viscosity (cSt@40°C)	10.34	ASTM D445
Density (kg/m^3 @ 15°C)	892	ASTM D1298
Saponification value (mg KOH/g)	249.54	ASTM D5558-95
Iodine Value (g Iodine/100g)	8.66	ASTM D5768-14
Acid Value (mg KOH/g)	49	ASTM D974
Free fatty acid (% as Lauric)	24.5	-
Colour	Dark brown	-

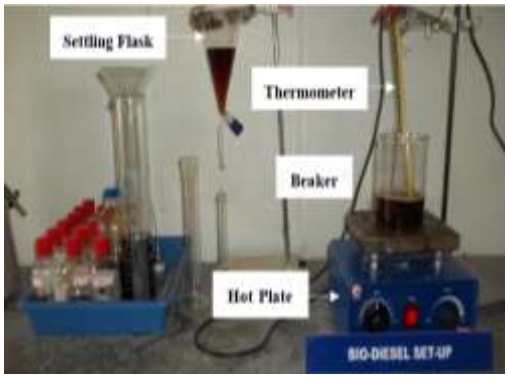

Fig. 2: Experimental setup for biodiesel extraction.

controlled stirrer for proper mixing. The thermometer was used to monitor the proper temperature during the reaction process. Fig. 2 shows the experimental setup used for CD biodiesel extraction. A half-liter separating funnel is used for phase separation of methyl esters and glycerine.

Biodiesel production process

The FFA percentage of vegetable oil plays a vital role in biodiesel production. If the vegetable oil has FFA less than 2.5%, the biodiesel is produced through alkaline transesterification else the oil must be esterified using acid catalyst followed by base-catalyzed transesterification [30]. Direct transesterification of high FFA oil will produce certain undesirable consequences such as increased reaction time, soap formation, yield reduction, and phase separation difficulty [12]. In the current work, oil extraction is done by acid esterification followed by transesterification, owing to the high FFA content. A schematic of the extraction procedure is shown below in Fig. 3.

Esterification using acid catalyst

Since the oil had a FFA content of 24.5% with esterification process was carried out with methanol to oil ratio of 10:1 (v/v of oil) and 2.5% (v/v of oil) of sulphuric acid. The oil was preheated to 60°C initially and stirred

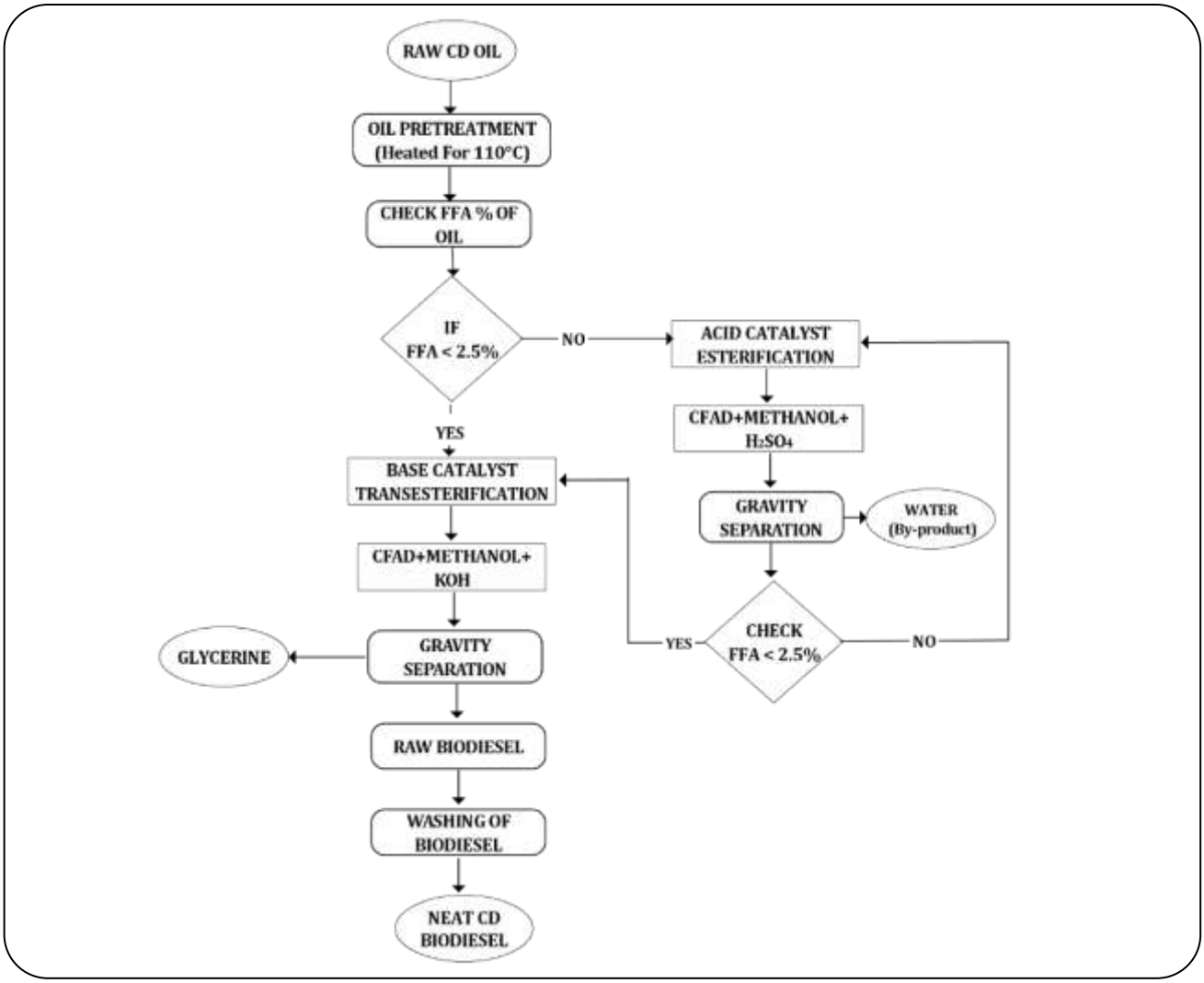

Fig. 3: Process flow of CD Biodiesel Production.

continuously at a speed of 600 rpm. H_2SO_4 catalyst was added to the mixture and consequently a rise in temperature of the mixture was detected. Fig. 4 (a) shows the raw CD oil and CD oil during the esterification reaction is given in Fig. 4 (b). The mixture was then heated at 60°C for 90 minutes with a stirring speed of 600rpm. The reactant mixture was then transferred to a phase separating funnel to remove excess methanol, water, and other impurities. The reactant mixture was allowed to settle for 24 hours and the formation of two distinct layers was observed. The bottom layer consisted of an aqueous phase (water) while the ester of CD moved to the top layer due to density. This setup is shown in Fig.4 (c). The ester collected was washed with cold water to remove any traces of H_2SO_4 and checked for FFA Percentage. The process was repeated till the FFA become lower than 2.5%. A schematic of the same is shown in Fig. 3. Before proceeding to the transesterification, it is ensured that all the water present in the ester has been removed by heating. The presence of water may result in soap formation and difficulty in the separation of methyl esters.

Transesterification using alkali catalyst

200 mL of the product of esterification was taken in a 1litre beaker and preheated for 30 minutes for attaining a stable and desirable reaction temperature. Methoxide solution that was prepared separately with methanol and KOH catalyst, was added to the oil at the reaction temperature. Stirring was carried on throughout the reaction time at 600 rpm. The start of the reaction was considered after the addition

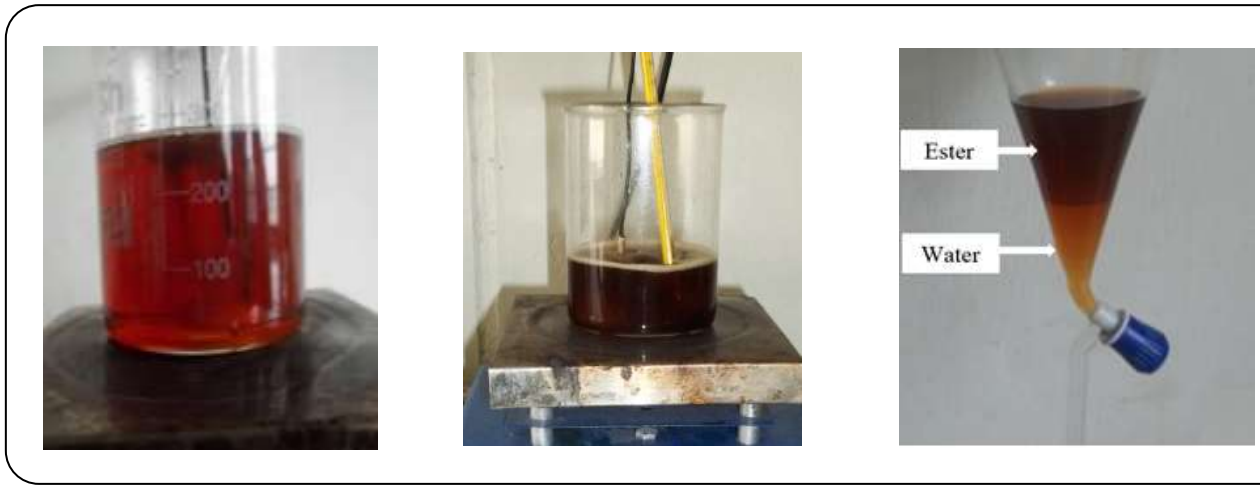

Fig. 4: (a) CD oil, (b) CD oil during esterification, (c) Phase separation after esterification.

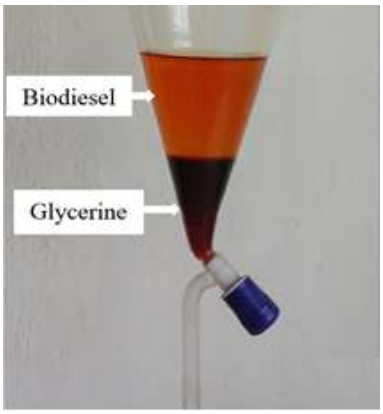

Fig. 5: Phase separation after Base transesterification.

of the methoxide solution to the preheated CD esters and was allowed to continue up to the predefined time. The mixture was poured into a 1litre separating funnel and was allowed to settle for 24hours. The biodiesel forms at the top and glycerine settle at the bottom of the settling flask as given in Fig. 5. The crude biodiesel collected was washed with distilled water at room temperature to remove salts, water, unused alcohol, and excess catalyst [35]. The washing is repeated six times to eliminate all the impurities. The biodiesel is then heated for 110°C to remove residual water retained during the washing process [14]. The properties of CD biodiesel along with other biodiesel and those of petrodiesel were compared and are given
in Table 3. The yield of biodiesel produced is calculated using the formula (2). The production of biodiesel from CD under optimum conditions and the effects of various influencing parameters were discussed in this investigation.

$$\%\,\text{Biodiesel yield} = \frac{\text{Weight of methyl esters produced}}{\text{Weight of raw oil used}} \times 100 \quad (2)$$

Design of Experiments (DOE) for optimization

Minitab software (version 18.1) was used to optimize parameters using Taguchi method. The use of the Taguchi method provides few pairs of parameter combinations to be tested instead of all the possible combinations without any adverse effect on the process conditions. Another advantage of this process is the identification of the most influencing parameter in the process. Taguchi analysis saves time, raw materials, and other costs involved in carrying out an experiment. The number of experiments to be conducted can be found using an orthogonal array. The number of experiments was determined based on the number of parameters and their levels. The minimum number of experiments was found using Eq. (4).

$$N = (L-1)P + 1 = \left[(3-1)4\right] + 1 = 9 \quad (4)$$

where
N- Number of Experiments
L- Number of Levels
P- Number of Parameters

Different parameters such as reaction temperature, reactants, time, catalyst, agitation speed, type of alcohol, reactant quality, alcohol to oil ratio, moisture content in oil, etc., influence the transesterification process [39,40].

Table 3: Comparison of fuel Properties of CD Biodiesel, Coconut oil Biodiesel, PFAD Biodiesel and Petrodiesel.

Properties	CD biodiesel	Coconut oil bioidesel [36]	PFAD Biodiesel [37]	Jatropha Biodiesel [38]	Petrodiesel	Testing Procedure
Kinematic Viscosity @40°C (cSt)	4.30	2.80	3.96	4.8	2.3	ASTM D445
Density @30°C (kg/m^3)	879	872.1	879	880	810	ASTM D1298
Flash Point (°C)	90	118	120	135	55	ASTM D93
Calorific Value (J/kg)	36,069	37785	38600	39230	42500	ASTM D240
Pour point (°C)	-3	-9	-	2	-12	ASTM D97
Acid value (mg KOH/g)	0.8	0.49	0.8	0.4	0.36	ASTM D974

Table 4: Optimization Parameters and selected levels.

Parameters	Levels		
	1	2	3
Methanol to oil ratio (molar ratio)	6:1	8:1	10:1
Catalyst concentration (wt %)	0.5	1	1.5
Reaction time (min)	40	60	90
Reaction temperature (°C)	50	55	60

Methanol to oil ratio, catalyst concentration, reaction time, and reaction temperature are the four parameters selected for study which have a significant effect on the transesterification process [28-32,35]. Therefore it is essential to select a suitable range of parameters to achieve maximum yield. The range of parameters selected are methanol to oil ratio 6:1 to 10:1, catalyst concentration 0.5 to 1.5 wt %, reaction time 40 to 90 min and reaction temperature 50 to 60°C [30,41,42]. Selected four Parameters (P) and their levels (L) are shown in Table 4. From the orthogonal array relation, the number of experiments to be conducted was found to be nine. The variation in the process parameters and level for the L9 orthogonal array is mentioned in Table 5.

Signal to Noise Ratio (S/N)

Taguchi suggests that response variation of expected value can be determined using S/N ratio and the relative parameters influencing the biodiesel yield. The signal to noise ratio can be used to analyze experimental values and the combination of optimum parameters. The S/N ratio has three categories and the appropriate S/N ratio is selected based on the objective. Since the objective of the work is to achieve the maximum yield of biodiesel, S/N ratio of Larger the Better (LTB) is selected [30].

Analysis of Variance (ANOVA)

S/N ratio is used to analyze the combination of optimum parameters for the maximum biodiesel yield. The identification of parameters that influence the most and percentage contribution of parameters on the biodiesel yield is not possible by S/N ratio. The stricture in S/N ratio can be achieved using ANOVA. The importance of the model and its parameters are determined using the Fischer test (F-value) and probability (p-value). The F-value increases with the decrease in the p-value. A confidence level 95% for all intervals of ANOVA analysis is selected. The significance of a parameter increases if the p-value is <0.05% and its involvement in the process has a notable effect [31].

Regression Analysis

It is a type of prediction modeling method which explores the connection between dependent and independent variables. If the study involves response and one parameter, the relation between them is given by a simple linear regression model and for more than one parameter multiple linear regression is used. In this study, the response (yield) depends on the independent variables like methanol to oil ratio, catalyst concentration, reaction time, reaction temperature. The relationship between

Table 5: Process Parameters with different levels using L9 orthogonal array.

Sl. No	Methanol to oil ratio	Catalyst concentration (wt %)	Reaction time (min)	Reaction temperature (°C)
1	6:1	0.5	40	50
2	6:1	1	60	55
3	6:1	1.5	90	60
4	8:1	0.5	60	60
5	8:1	1	90	50
6	8:1	1.5	40	55
7	10:1	0.5	90	55
8	10:1	1	40	60
9	10:1	1.5	60	50

the response and parameters is represented by multiple linear regression model by the following equation (5)

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots \beta_k X_k + e \quad (5)$$

Where

β_j = Regression coefficients (j =0,1,2,3,....k)

X_1, X_2, X_3, X_4,… X_k = Parameters selected

e = Random error

RESULTS AND DISCUSSION

Analysis of optimum Parameters for experimental conditions

Based on the orthogonal array of four parameters and three levels, the number of experiments identified was 9. The oil was first esterified till the FFA% was reduced to less than 2.5%. Transesterification was carried out based on the parameters obtained from the orthogonal array. The experiments were repeated thrice to minimize the error and the mean value is considered for getting optimized parameters.

S/N Ratio

The yield percentage was calculated for all the experiments with different parameters and levels. Experiment number 1 has a maximum yield of 91.74% and experiment 3 has the least value of 73.66%. The yield values obtained from experiments and the S/N ratio obtained by Taguchi analysis are listed in Table 6. Fig. 6 shows the S/N ratio graph of parameters at different levels selected for the study. The optimum parameters selected are based on the higher value of S/N ratio from the graph. The parameters determined for maximum yield are methanol to oil ratio (8:1), catalyst concentration (0.5%), reaction time (40min), and reaction temperature (50°C).

ANOVA and Regression

ANOVA is used to analyze the biodiesel yield of CD statistically. The most influencing parameter is determined by the F-value. ANOVA of the regression model and process parameter is given in Table 7. Table 7 shows that the reaction time has high F-value of 32.89 and methanol to oil ratio has the lowest value of 3.85. From the ANOVA analysis, it is inferred that reaction time has the greatest influence in biodiesel conversion and methanol to oil ratio has very minimal effect i.e conversion rate does not have a considerable variation concerning molar ratio. Linear regression analysis was carried out on the experimental data of CD yield. In this study, four parameters are predictors and the yield of biodiesel is the response. A regression equation is formed to describe the correlation between the response and predicting parameters. The ANOVA of the regression model shows that the p-value for three parameters are significant and values are less than 0.05. The parameter methanol to oil ratio has a p-value of 0.12 indicating insignificance in the process [31].

R^2 and adj R^2 value obtained from the regression analysis are 0.95 and 0.90 signifying the high value of the coefficient of determination **[14].** Thus the model signifies 95% of the total variation and implies a good fit of the model since 5% of the total variations are not explained. Equation (6) can be used to predict the yield of CD oil for different levels of parameters.

Table 6: CD methyl ester yield values and S/N ratio for L9 orthogonal array.

Sl.No	Methanol to oil ratio	Catalyst concentration (wt %)	Reaction time (min)	Reaction temperature (°C)	Yield (%)			Mean Yield (%)	S/N Ratio
					Trial 1	Trial 2	Trial 3		
1	6:1	0.5	40	50	91.5	91	92.7	91.74	39.25
2	6:1	1	60	55	85.6	87.4	86.1	86.4	38.73
3	6:1	1.5	90	60	74.2	70.3	76.5	73.66	37.34
4	8:1	0.5	60	60	83	88.5	84.2	85.2	38.61
5	8:1	1	90	50	79.5	85.1	83.9	82.85	38.37
6	8:1	1.5	40	55	85.4	82.8	83.1	83.76	38.46
7	10:1	0.5	90	55	78.8	80	83.9	80.86	38.15
8	10:1	1	40	60	83.1	81.2	83.2	82.5	38.33
9	10:1	1.5	60	50	82.4	79.1	82.1	81.2	38.19

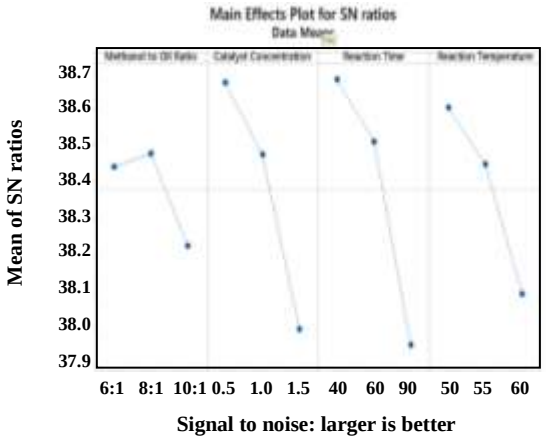

Fig. 6: S/N ratio graph of parameters at different levels.

$$CD\ Yield = 129.69 - 0.603A - 6.39B - 0.1402C - 0.481D \quad (6)$$

The experimental yield value is compared with the predicted value and is given in Fig. 7 (a). The predicted value is in close range with the experimental value proving the close accuracy of the regression model. Fig. 7 (b) shows that the residuals are normally distributed and random indicating a good fit of the model.

Prediction and Validation of Optimum Yield

The optimum parameter determined based on S/N ratio are methanol to oil ratio (8:1), catalyst concentration (0.5%), reaction time (40min), and reaction temperature (50°C). The theoretical optimum yield predicted using regression equation under optimum conditions is 93.6%. The predicted yield was validated by conducting experiments. The yield values obtained under optimum conditions are 92.8, 94.4, and 91.5%. The mean value of three experiments was taken and the mean yield obtained was 92.9 % which is closer to the predicted value. A small variation in predicted value could be due to independent external variables. The result shows that optimum parameters and model generated have adequate accuracy for achieving maximum yield from CD oil.

CONCLUSIONS

Optimization of parameters for maximum yield of biodiesel from Coconut fatty acid distillate was carried out. Statistical analysis was done to find the most and least significant variables and their effect on the outcome of the process. The following are the conclusions arrived based on the investigation.

- The FFA content was determined through the standard titration procedure to be 24.5% indicating the requirement of acid esterification.
- The FFA was reduced from 24.5% to 1.8% by esterification under the process conditions of methanol to oil ratio (10:1), catalyst concentration (H_2SO_4) 2.5%, reaction time (90min), reaction temperature (60°C) and agitation speed 600 rpm.
- Optimum parameters for CD transesterification were found to be methanol to oil ratio (8:1), catalyst concentration (0.5%), reaction time (40min) and reaction temperature (50° C), and agitating speed (600 rpm).
- The maximum yield achieved under this condition was 92.9% which is comparable with the predicted value of 93.6%.

Table 7: Analysis of Variance of regression model and process parameters.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	
Regression	4	179.457	44.864	19.75	0.007	Significant
Methanol to oil ratio	1	8.736	8.736	3.85	0.121	Insignificant
Catalyst concentration (wt %)	1	61.312	61.312	27.00	0.007	Significant
Reaction time (min)	1	74.704	74.704	32.89	0.005	Significant
Reaction temperature (°C)	1	34.704	34.704	15.28	0.017	Significant
Error	4	9.084	2.271			
Total	8	188.541				

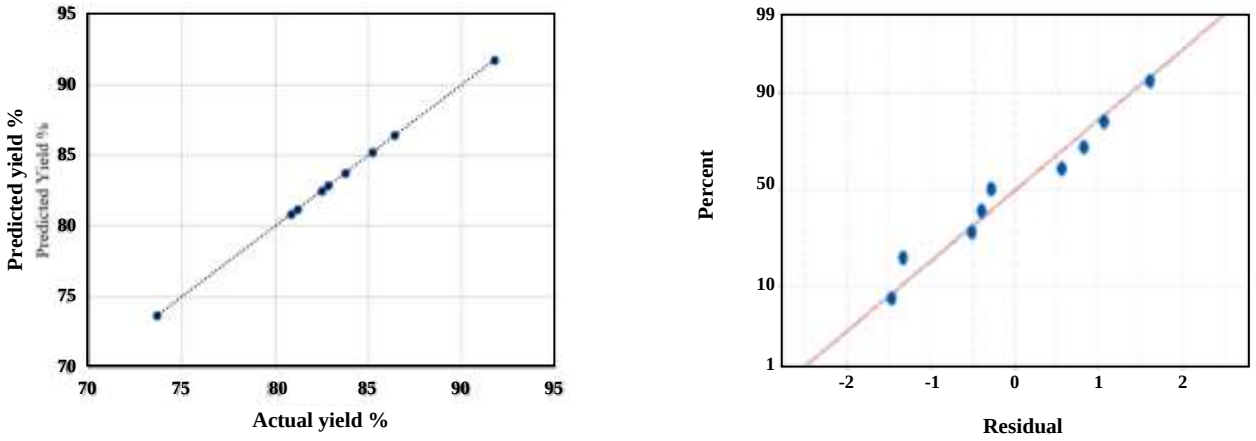

Fig. 7: (a) Predicted vs Experimental yield. (b) Normal probability plot of residual.

● ANOVA results indicate that reaction time has a high influence on the product yield and methanol to oil ratio has the least effect compared to other parameters.

● The regression model generated had a good fit (R^2 = 95% and adj R^2 = 90%) and was found reliable to predict the yield of biodiesel for different parametric conditions.

Thus it is clear that the CD oil is a potential feedstock for biodiesel production at low cost and can be used as a substitute for petrodiesel.

Nomenclature

CD	Coconut fatty acid distillate
FAME	Fatty acid methyl ester
FFA	Free fatty acid
CDBD	Coconut fatty acid distillate biodiesel
ANOVA	Analysis of variance
I.C. Engines	Internal combustion engines
PFAD	Palm fatty acid distillate
SODD	Soybean oil deodorizer distillate
DOE	Design of experiments
SPUE	Static probe ultrasonic enhanced
CCPUE	Counter-current probe ultrasonic enhanced
RODD	Rapeseed oil deodorizer distillate
SGAC	Sulfonated-glucose acid catalyst
sRSM	Response surface methodology
GC	Gas chromatography

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