Producing Biodiesel and Optimized by Taguchi Design against Palm Oil as Sustainable Alternative Fuels in Bangladesh

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Abstract *– In food and cosmetics industries palm oil is considered as main element though it is treated unhealthy to human body. However, in case of energy industries palm oil has been realized as sustainable alternative feedstock recourses for biodiesel which can balance energy scarcity while conserving essential ecosystems with biodiversity. This present study illustrates formation of small batch (10-25 liters/batch) biodiesel in the laboratory against oil based palm. An orthogonal approach with L9 Taguchi was selected to find out the transesterification optimization parameters involve reaction time, methanol to oil ratio, reaction temperature and Catalyst concentration. The production process of biodiesel was performed by varying different conditions being methanol to palm oil molar ratio (M/O) and the wall warmth. The maximum yield was settled to be 86% by using M/O value 6 and wall warmth 55°C by experimental approach. Properties of biodiesel were tested, namely density, flash point, kinematic viscosity and calorific value. The density was found to be 898 kg/m³, flash point 179.33°C, kinematic viscosity 4.98 mm²/s and the calorific value was found to be 37.06 MJ/kg. These values are very relative to the standard values of biodiesel composed from oil based palm.*

Keywords – *biodiesel production, palm oil biodiesel, POME, sustainability, Taguchi method.*

1. INTRODUCTION

Diesel is used widely in the transportation sector, especially to run trucks, locomotives, aircraft engines, military vehicles and passenger cars. The economy of any country is directly dependent on the availability of diesel. In 2019 Energy and Mineral Resources Division, Ministry of Power, Energy and Mineral Resources, Bangladesh reported that around 6.6 million metric tons of petroleum products and crude oil are generally imported in Bangladesh each year and about 68.9% fossil fuel based energy consumption happens where the share of biomass based energy was only 29.1% in the year 2017-18. It was reported that petroleum based product demand has increased about 2-4% per annum and by 2030 the demand will be around 10 million tons in Bangladesh [1]. Addition to that, drastic rise in transport facilities will take place for the port facility service in Mongla and Chittagong ports. Scarcity of diesel may undermine the growth of a nation by jeopardizing functions of various kinds in different sectors. Diesel is however, a non-renewable resource and its usage should be strictly monitored. With the ever-growing population, the numbers of vehicles on the streets are increasing on a daily basis, producing a massive demand on diesel. This demand cannot be met with the required supply unless the fossil fuel reserves are extinguished. In Bangladesh Diesel is the predominant petroleum based fuel among other fuels, about 70% consumption (Figure 2) in form of diesel has been occurred in year 2017-18 [1]. However, this paper aims to attain three objectives such as (i) prepare biodiesel in the laboratory from palm oil in the presence of methanol and KOH catalyst, (ii) determine the properties of prepared biodiesel in order to compare the results with standard values. (iii) determine and compare the response magnitude of biodiesel for a number of parameters using ANOVA.

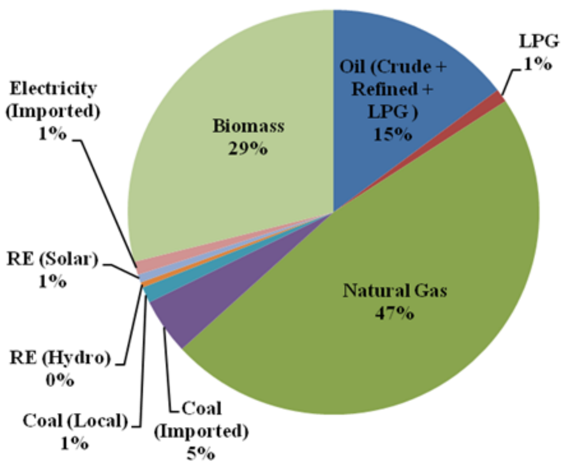

Fig. 1. Various types of energy resources consumed in Bangladesh year 2017-18 [1].

A wealth of literature is available on related issues and learning lessons from the literature may help to develop a board understanding about it. Narayana *et al.*

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[2] reported an optimal condition for maximum yield of biodiesel for mass production as 6:1 molar ratio of methanol to Pungam oil, 1.92 percentage weight of catalyst at 55℃. Biodiesel is a good example of an alternative fuel. Intrinsic approach describes durability and constancy of environmental, fiscal and social facet of humanity is termed as Sustainability. Reliability of biofuel (vegetable oil) in unmodified diesel engine was tested on the desire of French government for energy independence in its province (Africa) [3]. In 1900 at Paris Exhibition, peanut oil fueled small diesel engine by company Otto and then castor oil powered locomotives were showed prosperity by Rudolph Diesel [3]. In the time of Second World War vegetable oils were treated as crisis fuel, shipping of cottonseed oil had been restricted in Brazil. Since 1930, attempts have been taken to assimilate divergent renewable fuel, which are primarily achieved by research academy, universities and government management [3]. PRO-alcohol was developed in 1975 to establish the production of ethanol for transport sector. It was envisioned blends of 30% vegetable oil in diesel for fully substitute fossil fuel in future. At the same era, a specialized method the transesterification of vegetable oil was recommended. Regrettably the initiative was discarded cause of crude oil price fall in International retail and high production cost for biodiesel [3]. Methyl ester of oil based palm as alternative for diesel had been established since 1988 by Research Institute in Malaysia [4]. Kapilakarn and Peugtong [5] presented an economic design to determine the optimal operating conditions of biodiesel yield. It has been reported that at 6:1 methanol to oil ratio at 70℃ with 20 minutes reaction time provides the optimal condition to reduce the operating cost [5].

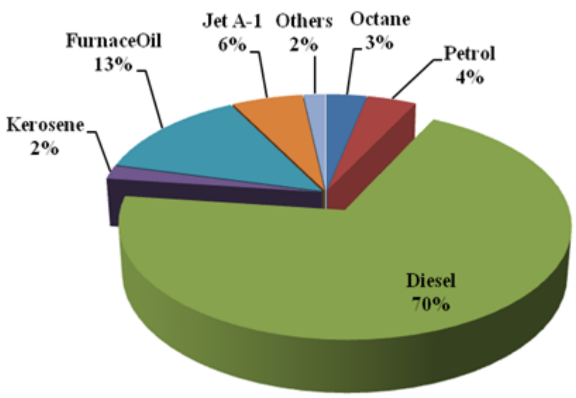

Fig. 2. Percentage of diesel consumption among other petroleum based fuel in Bangladesh year 2017-18 [1].

Oil based palm is gleaned from palm fruit sapling, native Western Guinea. The palm tree was later introduced to different states. In Malaysia palm tree was popularized since 1870 as exquisite plant. In 2014 the universal productions of oil have expanded about 155.8 million tons. Only in Malaysia there was 60% growth of palm agricultural land by 2005 [6]. The fruit of the palm tree is produced two or three years after being planted. Palm tree produce fruit for twenty five years. The amount of oil produced per hectare is more as compared to other oilseed crops. In the year of 2014, the government of Malaysia had mandated the adoption of 5% palm oil methyl ester biodiesel (B5 POME) with petroleum diesel in transport sector entire nationwide [7]. In 2018 researchers have claimed that industrial palm oil can yield sufficient biodiesel (POME) to effectively balance Malaysia's full diesel consumption. Diesel engine manufacturers provide engine warranties on consumption of biodiesel up to B7 in Malaysia and the fact that without any major modification diesel engine can handle biodiesel-diesel blends up to B100 (100% biodiesel) can promise better future environment [8]. Araby *et al.* [9] estimated the important fuel requirements of Palm oil and POME blend with diesel and results indicate that blended fuel values were very adjacent to petroleum diesel till 30% (B30). About 91.07% palm oil biodiesel yield was reported at 70°C with 2 to 3 hours reaction time at a 1:15 molar ratio of palm oil to methanol with catalyst concentration of 3 to 6 wt% KOH along with the support of heterogeneous catalysts, although consumption of potassium based species was observed in both spent catalysts [10].

Enthusiastic researchers from Bangladesh have taken initiatives to develop biofuels [11]. Introduction of 5% bioethanol blend with conventional fuel in transport sector has been planned by Bangladesh Government, [12] though; no such activity has been reported in Bangladesh. Feedstock resources for biodiesel in Bangladesh have been reviewed [13]. Though, the production of bioethanol from renewable feedstock has been overlooked. Among the various feedstock palms retain high relevance. In ancient world palm was used for sugar producing. Addition to that palm can flourish in grim habitats and their sap consists of about 10-20% sugar [14]. The sap can be collected without destroying the palm tree aged about 5-100 years. A male palm tree could produce 140.42 kg sugar based mass with 29.85% sugar concentration per annum; however a female tree can provide 195.56 kg sugar based mass [14]. Nabi *et al.* [15] from Bangladesh reported 96 vol% biodiesel yield at 60°C with 22 vol% methanol and 0.45 wt% catalyst concentration from a vegetable feedstock. Also the reduction in carbon monoxide emission along with engine noise and smoke with all biodiesel blends was reported [15].

Many states have taken already initiatives for carbon dioxide emission mitigation. With regard the universal carbon cycle; biodiesel is mediated to be carbon dioxide inactive. More special conveniences cover very less sulphur fuel which is crucial in next generation catalytic converter and diesel particulate filter, along with less emission, steep cetane number, and biodegradation in marine environment [16]. Manufacturing of biodiesel or fatty acid methyl ester requires vegetable oil and can be identified into heterogeneous, homogenous with catalytic or non-

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catalytic approach based on catalyst concentration. Normally homogenous approach is followed in economic manufacturing [17]. Biodiesel conversion from vegetable oil occurs chemically by transesterification of large, branched triglycerides with alcohol. As compared, biodiesel is also very user-friendly since it can be mixed with any proportional of diesel and can be suited to diesel engine without prior adjustment [18]. Mahanta *et al.* [19] reported at laboratory level transesterification maximum conversion to biodiesel was about 72% at 600C operating temperature with 20 wt% of methanol for Pongamia pinnata as feedstock and about 82% conversion to biodiesel with 25 wt% of methanol for Jatropha curcus as feedstock. Also, it was observed that both biodiesel meet the ASTM specifications [19]. The scarcity of fossil fuels is posing a serious threat in all sectors. The evolving states are in relentless monetary discrepancy cause of importing fuel price [20]. Agarwal and Dhar [21] have conducted experiments with 20% biodiesel blend in a generator engine. It was reported marginal increment in brake specific fuel consumption but noticeable improvement in thermal efficiency for biodiesel blend compared to diesel [21]. Alternate fuels are of utmost importance presently. Biodiesel is one such alternative fuel which can run in traditional diesel engines. The biodiesel manufactured from palm oil shows characteristic compatible to diesel and suitable without modifying the engine. In the present work, manufacturing and examination of palm biodiesel as a fuel had been done established on literature available.

2. PRODUCTION OF POME, MATERIALS AND METHODOLOGY

2.1 Materials

Commercial grade palm oil was acquired from regional market, Kolkata, West Bengal as the unprocessed ingredient for biodiesel production. The fatty acid (FFA) content was less than 0.6%. The oil was then filtered and dried for 2 hours at temperature 90-100°C in oven to extract contamination and moisture. Other analytical grade reagents methanol (assay 99%, Merck and Co.) and alkaline catalysts KOH (assay 97%, Merck and Co.) were acquired from venders for this experimental study.

2.2 Design of Experiments (DOE) using L9 Taguchi

OVAT or one variable at a time is not practical for organized optimization process as the other variables are also important for maximum yield of biodiesel. Accordingly, software governed approximation are preferred which cover RSM (response surface methodology) consisting of CCD (Central Composite Design), or one factor approaches consisting of Taguchi Orthogonal Arrays (OA). To develop the optimum parametric circumstance for a process an enormous quantity of experiments are usually required [26]. The Taguchi method emerged by Dr. Genichi Taguchi has the very distinctive specialty of not explore every workable parameters combination, basically shrinking the bulky optimization method to a few run. Taguchi OA applies orthogonal arrays to resolve the least of notable runs within associated variables at different levels of each variable that are acceptable in anticipating the optimum response within a remarkably reduced number of experimental runs. This results in a least number of required runs which are recommended for a proper prediction of the response [24]. The runs were systematically randomized to reduce analytical errors. Traditional optimization methods for any experimental investigation are complicated and difficult to practice. Manual optimization is a hard task because the increase in process parameters and levels the number of experiments increases largely. Taguchi method utilizes to sort out this problem with lesser number of experiments [22, 23]. Taguchi method applied on the mean and variance of performance parameters to analyze the influence of various restriction of a process that resolves the convenient operations. It is a convenient method for optimization of various parameters affects the operations and the extent to which they can be varied. This method is not specifically investigated all the possible parameters combinations but only few pairs of combinations [24]. The required number of experiments and their parameters can be finalized from the Orthogonal Arrays (OA).

In the midst of different parametric criterion regulating the yield of biodiesel such as Methanol to oil ratio, Catalyst concentration, Reaction time, Reaction temperature, alcohol type and quantity, catalyst type, stirring speed or agitation, moisture quantity in reactant and quality of the oil, only four largest affecting parameters with three levels (L = 3, P = 4) have been treated in this paper (Table 1). The effects of selected parameters at three various levels have been observed by attending only nine experiments as per L9 OA. To reduce the errors all experiment has been repeated three times. The minimum feasible total of experiments 'N' is determined against the total of levels 'L' and total no of design and selected control parameters 'P' adopting the correlation $N = (L-1)P+1$. [25].

Table 1. Parameters chosen at three levels for L9 design.

Parameters	Variables	Levels 1	Levels 2	Levels 3
Methanol to oil ratio	A	5:1	6:1	6.5:1
Catalyst concentration (%)	B	0.5	1	1.5
Reaction time (hour)	C	2	2.5	3
Reaction temperature (°C)	D	50	55	60

Transesterification hinges on specific essential variables such as reaction temperature, extent of excess alcohol, and catalyst concentration, reaction time and RPM of stirrer. RPM are kept constant for present experiments RPM=1500. Parameter level was set as:

Methanol to oil molar ratio: 5:1, 6:1, 6.5:1
Amount of KOH (wt% of oil): 0.5, 1, and 1.5
Reaction temperature (°C): 50, 55, 60
Reaction time (hour): 2, 2.5, 3

Four parameters, 3-levels experiments are considered by Taguchi method in the form of L9 OA to optimize the different parameters influencing the process. From the OA, the required number of experiments and their conditions can be confirmed. . Based on the information from L9 orthogonal there are a total nine (9) experiments (see Table 1) that have to be conducted and each experiment has to be conducted 3 times, to assure repeatability.

2.3 Signal to Noise Ratio (SNR)

Taguchi method evaluates SNR based on test data. The important factor SNR of Taguchi design differentiates it from conventional design methods which specify the attributes of the experimental responses. This ratio expresses a test level which furnishes the optimum performance in the test factors. There are distinct SNR like 'larger the better' (LTB), 'smaller the better' (STB) and 'Nominal the better' (NTB). STB for minimization problem, LTB for maximization problems and NTB for normalization problems can be selected. In this research 'larger is better' for biodiesel yield percentage is suitable as the objective is to define maximum biodiesel yield optimum conditions for different parameters. To determine the discrepancy amid the experimental and aim amount of performance parameters, use of loss function (LF) was suggested by Taguchi. The LF amount has moreover been reformed in a signal to noise ratio (SNR). SNR based empirical information assessment has been executed for the recognition of optimal parameter combinations. Considering the equitable is to obtain max yield of biodiesel, out of the possible distinct SNR quality characteristics, depended on the nature of variables, Larger-the-Better (LTB) has been embraced. Respectively, design criterion will be the level with the highest SNR. By using SNR reasoning, it is feasible to access optimum level of each parameter and optimum set of parameters producing the maximum biodiesel yield [24]. The distinct SNR like 'larger the better', 'smaller the better' and 'Nominal the better' can be obtained by the following equations. Where 'Y_i' is the result of each experiment measured from experiments, 'n' is the number of trials and 'j' is the number of design parameters.

Larger the better-

$$SNRi = -10\log\frac{1}{n}\left(\sum_{j=1}^{n}\frac{1}{y_j^2}\right) \tag{1}$$

Smaller the better-

$$SNRi = -10\log\left(\sum_{j=1}^{n}\frac{y_j^2}{n}\right) \tag{2}$$

Nominal the better-

$$SNRi = 10\log\left(\sum_{j=1}^{n}\frac{y_j^2}{s_j^2}\right) \tag{3}$$

Where,

$$y_i = \frac{1}{n}\left(\sum_{j=1}^{n} y_{ij}\right) \text{ (Response mean)}$$

$$s_i^2 = \frac{1}{n-1}\left(\sum_{j=1}^{n} y_{ij} - \overline{y_i}\right) \text{ (Variance)}$$

i = experiment number, and n = number of trials.

To identify the factor with large scattering, ANOVA analytical method can be applied [27]. In this paper, the results from experiments can be inspected by performing analysis of variance based on the orthogonal arrays to exhibit the degree of influence of each factor that remarkably influenced the response variables. The comparable mathematical relations entrenched with ANOVA are given in Equations (4), (5), (6) and (7) [27]. Equation (4) provides the mean value of SNR, where number of the trials is given by k. Variations of the overall mean (SS) sum of squares is expressed by (5). The influencing factors mean (SS_i) is calculated as (6). The individual factors contribution percentage of the selected response variables will be treated to conclude the optimized combination and calculated through Equation (7) as follows:

$$\overline{SNR} = \frac{1}{9}\sum_{k=1}^{9}(SNR)_k \tag{4}$$

$$SS = \sum_{i=1}^{9}(SNR_{ij} - \overline{SNR})^2 \tag{5}$$

$$SS_i = \sum_{j=1}^{3}(SNR_{ij} - \overline{SNR})^2 \tag{6}$$

$$Contribution\% = \frac{SS_i}{SS}\times 100\% \tag{7}$$

The SNR were inspected for all biodiesel yield percentage. In conferment with the output, the best sequences were decided, and ANOVA was practiced to draft the scale of individual contribution. ANOVA estimates the effect of one or more aspects by correlating the response variable means at the different aspect levels.

2.4 Experimental Setup and Production of POME

Vegetable oil obtained from various sources are very useful to prepare biodiesel cause it has almost similar fuel properties and compatible to diesel and suitable without modifying the engine. The primary solvent relevant for transesterification of triglycerides is methanol. Methanol is preferred for it is easily available in the market along with cheap price and advantages of chemical and physical properties also it can quickly react in transesterification process. Catalyst improves reaction by dropping its activation energy, potassium hydroxide (KOH) is used as catalyst.

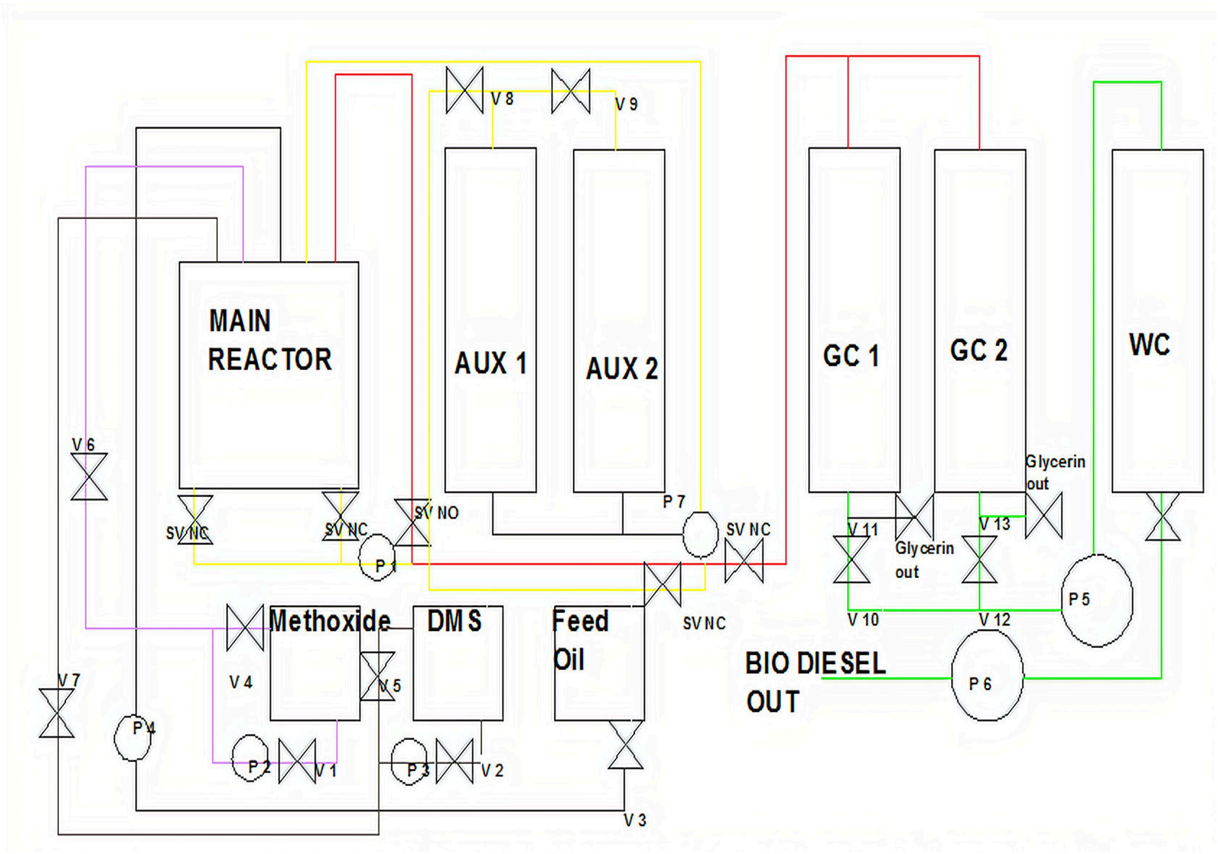

Fig. 3. Biodiesel production experimental set-up for small batch (10-25 liters/batch).

The experiment set up consists of nine cylinders. Out of them, five are useful for the preparation of palm oil biodiesel. In the schematic diagram as shown in Figure 3, in the lower part, out of three chambers the first chamber from the left is for catalyst, second one is for alcohol like methanol, ethanol and last one is for mixing. These chambers are connected by pump which helps in pumping alcohol and catalyst to the main reactor cylinder. Also three valves are there which controls the rate of flow. For the acceleration of rate of chemical reaction, in the main reactor chamber fan is there that helps in proper mixing of reactant. Temperature sensors and controllers maintain required temperature inside the cylinder. Temperature control is essential for higher yielding and of minimum time requirement. Main reactor chamber is linked by pump, valve to WC chamber, here mixture remains for some time and due to different molecular weight, upper portion is filled with diesel and lower part with glycerol. At the bottom most part of the WC chamber, a valve is there that opens and glycerol comes out. The remaining portion of the product that is biodiesel is taken later. Biodiesel at that time is not pure. Further purification is necessary. For that washing should be done repeatedly with water until pH value of water comes to 7.

The reaction of vegetable oil with alcohol is called transesterification or alcoholysis to form esters and glycerol. The reaction is shown in the following equation.

CH_2-OOC-R_1			Catalyst (KOH)	R_1-COO-R’		CH_2-OH
|						|
CH-OOC-R_2	+	3R’OH	↔	R_2-COO-R’	+	CH-OH
|						|
CH_2-OOC-R_3		Alcohol methanol		R_3-COO-R’		CH_2-OH
Glyceride				Esters		Glycerol

Transesterification is very rapid with alkali-catalyst compared to acid catalyst. Potassium hydroxide is used as catalyst to boost the reaction rate and biodiesel yield. Surplus methanol is applied to shift the reversible reaction to the product side.

After separation of phases purification of biodiesel is necessary and attends by washing to nullify the catalyst in biodiesel. This process should be continued until pH value of water comes to 7. Free fatty acids can be recovered from the ester phase by distillation at 30-50°C. Finally wash biodiesel should be kept at 50°C for eight hours in a heater oven and then biodiesel is ready for use. The biodiesel procured was measured based on literature [24] and used to evaluate the biodiesel yield using the following equation.

$$Yield(\%) = \frac{weight - of - Biodiesel}{weight - of - oil} \times 100 \quad (8)$$

The relevant fuel properties for produced POME were examined with standard methods and validated with literature (Table 2). Using the fuel volume and mass, density has been determined. A viscometer (Brookfield Model: DV-II) was used to resolve the kinematic viscosity. Flash point was resolved by a flash point tester (Silver Pensky-Martens, Model: VT4643) and heating value was measured by bomb calorimeter (Parr Instrument, Model: 6100).

Table 2. Measured value and standard value comparison of POME.

Properties	Method	POME	POME [9]	ASTM 6751	EN 14214
Density (kg/ m³)	-	898	877	870-900	860-900
Kinematic Viscosity (mm²/ s at 40°C)	ASTM D2983	4.98	4.56	1.9-6.0	3.5-5.0
Flash Point (°C)	ASTM D93	179.33	196	>130°C	>120°C
Calorific Value (MJ/ kg)	ASTM D4809	37.06	41.3	-	-

Table 3. Fuel properties of produced POME compared to petroleum diesel.

Properties	Method	POME	Diesel
Density (kg/ m³)	-	898	832.6
Kinematic Viscosity (mm²/ s at 40°C)	ASTM D2983	4.98	2.96
Flash Point (°C)	ASTM D93	179.33	68
Calorific Value (MJ/ kg)	ASTM D4809	37.06	45.9

Table 4. Uncertainty of the measured quantities and measurement accuracy.

Properties	Units	Uncertainty (%)	Measurement accuracy
Density	(kg/ m³)	± 0.01	± 0.1
Kinematic Viscosity (at 40°C)	mm²/ s	± 0.11	± 0.01
Flash Point	°C	± 2.42	± 0.1
Calorific Value	MJ/ kg	± 0.13	± 0.001

2.5 Uncertainty Analysis

The uncertainty while collecting data from experimental instruments had been caused by various operational and physical limitations. An uncertainty analysis was made to ensure accuracy in respect with preciseness and repeatability of the experiment results. The uncertainties of collected data along with the measuring equipment accuracy are very important to substantiate the correctness of the experimental data. Using root mean square method the analysis was organized, when the total uncertainty U of a quantity Q had been predicted, relying on independent variables X1, X2,.,Xn (Q as a function of X1, X2,.,Xn) carrying particular errors ΔX1, ΔX2,..,ΔXnas given by following equation [28].

$$\Delta U = \sqrt{\left(\frac{\partial U}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial U}{\partial X_2}\Delta X_2\right)^2 + \ldots + \left(\frac{\partial U}{\partial X_n}\Delta X_n\right)^2} \quad (9)$$

In Table 4 percentages of uncertainty and measurement accuracy of the measured experimental values.

3. RESULTS AND DISCUSSIONS

3.1 Determination of Optimal Condition of the Experiment by Taguchi Method

Yielding of biodiesel is biodiesel obtained from the amount of oil invested. The yield of biodiesel is dependent on many factors. The variable factors are applied at 3 levels to design the experiment at MINITAB 17. Here in the experiment 0.5%, 1% and 1.5% of the total reactant are used as catalyst. The effect of different M/O ratio was established along with time taken for transformation in biodiesel from oil based palm. As the methanol to palm oil ratio was increased, yield first increased and then decreased, it was found that the yielding reached a maximum at 6 M/O. When the time taken to reach equilibrium was highest, the yield was also highest at 86.2%. In Table 5 effect of reaction temperature was established along with time taken. The yield was found 86.2% and time was taken 3.167 hours. It was found that yielding reached a maximum at 55°C. When the time taken to reach equilibrium was highest, the yield was also highest at 86.2%. It has been obtained from these experiments that the optimum conditions for production of biodiesel are: catalyst should be 1% of the total volume, methanol to palm oil ratio should be 6, and wall temperature should be 55°C. The empirical outcomes (Table 5) indicate that the Experiment No 5 has the max value of SNRA and experiment No 4 has the lowest value of SNRA. In this present study, the escalation of POME yield is the objective, which is why LTB SNR model was applied.

The effect of process control parameters on average SNR for biodiesel yield are the key to find out optimum condition for this experiment. Thus, Figure 4 shows a plot of b/w process control parameter Vs average SNR. From this Figure 4, it is concluded that optimum condition of various parameters are methanol: palm oil = 6.5: 1, KOH = 1wt% of oil and reaction temperature = 55°C Reaction time = 3 hour. It means that experiments number 5 has the maximum yield and highest value of SNRA; this would be the optimum stabilized set of parameter. Where other parameters are RPM = 1500 is kept constant.

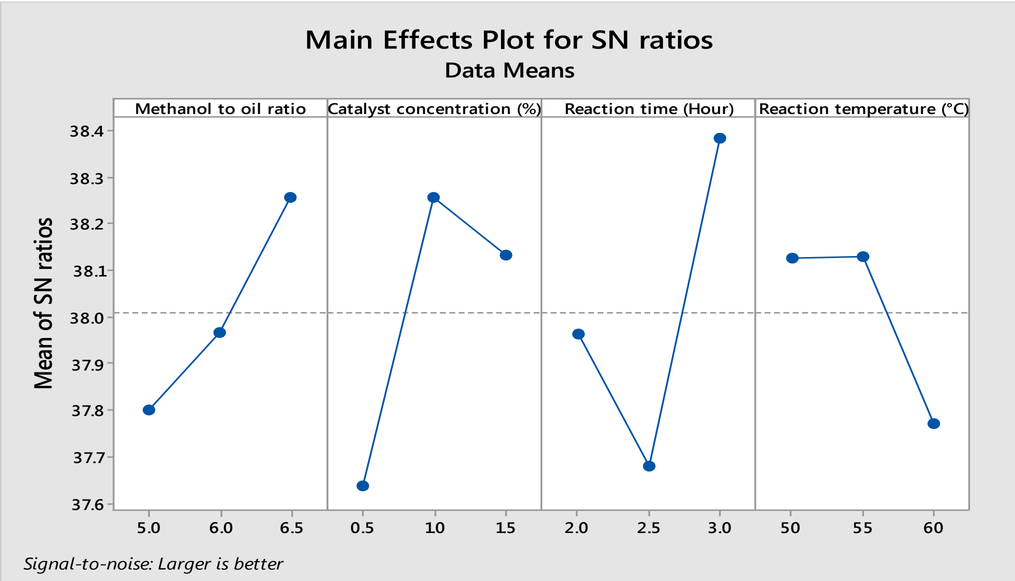

Fig. 4. SNR of each parameter at different level.

Table 5. Percentage of yield and SNR for 9 experiments.

Exp. No.	M/O	Cat cons (%)	Time (hour)	Temp (°C)	Mean Yield (%)	SNRA1
1	5:1	0.5	2	50	75	37.5012
2	5:1	1	2.5	55	78	37.8419
3	5:1	1.5	3	60	80	38.0618
4	6:1	0.5	2.5	60	71	37.0252
5	6:1	1	3	55	86.2	38.7101
6	6:1	1.5	2	50	81	38.1697
7	6.5:1	0.5	3	55	83	38.3816
8	6.5:1	1	2	60	81.5	38.2232
9	6.5:1	1.5	2.5	50	81	38.1697

Table 6. Response table for signal to noise ratios larger is better.

Level	Methanol to oil ratio	Catalyst concentration (%)	Reaction time (Hour)	Reaction temperature (°C)
1	37.80	37.64	37.96	38.13
2	37.97	38.26	37.68	38.13
3	38.26	38.13	38.38	37.77
Delta	0.46	0.62	0.71	0.36
Rank	3	2	1	4

3.2 *Analysis of Variance*

ANOVA is applied to gauge the response magnitude (in percentage) for each given parameter in the L9 orthogonal array. In this experimental study, ANOVA computes the relation with each parameter of biodiesel production. The utmost important parameter is determined and its contribution also identified by using ANOVA. Reaction time and percentage of catalyst concentration are the utmost important parameters and its contribution is 38.67% and 31.85% for POME production. Contribution percentage of biodiesel production for other two parameters like, M/O ratio and reaction temperature are 16.69%, and 12.79%, respectively shown in Table 7.

Table 7. Data obtained from ANOVA (Analysis of Variance).

Source	DF	Contribution	Adj SS	Adj MS
Methanol to oil ratio	2	16.69%	27.12	13.56
Catalyst concentration (%)	2	31.85%	51.73	25.86
Reaction time (hour)	2	38.67%	62.82	31.41
Reaction temperature (°C)	2	12.79%	20.77	10.39

3.3 *Fuel Properties of POME*

Testing of biodiesel POME is an important task prior to use in engine applications. Different properties like density, lower calorific value, viscosity, flash point is tested in different laboratory and it has been checked whether properties are compatible for engine application or not. Density of biodiesel is measured by measuring the volume of the biodiesel and mass. Mass is measured by an electronic device and volume by a measuring cylinder. Table 2 indicates that the properties of produced biodiesel (POME) are comparable with the biodiesel American standards ASTM D 6751 and European standards EN 14214.

Biodiesel should be advised clear and relieved of contamination. It is elementary but crucial test which is executed in a test tube indicates quality of biodiesel. The biodiesel viscosity is almost two times greater than petrol and diesel and viscosity has tremendous effect on temperature, in cold countries there is problem during the starting condition, at low temperature viscous is high so fuel is not better atomized. The kinematic viscosity or subjective defiance is an essential criterion for fuel injection and fuel injection pump. European standards EN 14214 serves an adequate scope from 3.5 to 5.0 mm^2/s but American standards ASTM D 6751 provides an extensive scope 1.9 to 6.0 mm^2/s. Flash point is crucial for handling of fuel, storage and transport. Flash point determination depends on instrument, and may be open or close accordingly to the apparatus used. Closed flash point of any oil is always lower than open because the enclosed vapour space facilitates the accumulation of vapour in sufficient quantity to ignite at a lower temperature than in the open apparatus. The Pensky-Martens closed tester apparatus is used to measure the flash point of the biodiesel sample. This apparatus is used for all liquid fuels having flash point above 120°F. Calorific value is an important parameter of a fuel, which is defined as the energy per unit mass of the substance at standard temperature and pressure. The higher the calorific value of the fuel the greater the energy content. The calorific value of biodiesel is generally higher than all other liquid fuel and coal but little lower than the diesel fuel and petrol. The bomb calorimeter consist of a water bath, a stirrer mounted on a disconnected bearing and driven by motor, calorimetric jacket, a thermometer, and a switch box leading the current into the motor and igniting the fuel in the bomb. It has been observed from Table 2, the density of POME, flash point and kinematic viscosity are obtained to be marginally fluctuated compared to literature.

4. CONCLUSIONS

Biodiesel was prepared in the laboratory from palm oil in presence of methanol and KOH catalyst. After changing the parameters, the yielding was calculated and the optimum conditions were found. The properties of the biodiesel sample, such as viscosity, calorific value, density and flash point were tested. The results obtained were very close to the standard values. The maximum POME yield obtained was 86.2% and conditions were M/O ratio 6:1, KOH 1.0wt% of oil, reaction temperature 55 °C and reaction time 3 hour. ANOVA computes Reaction time and percentage of Catalyst concentration are the utmost important parameters and its contribution is 38.67% and 31.85% for POME production. Contribution percentages of biodiesel production for M/O ratio and reaction temperature are 16.69%, and 12.79% respectively. By varying the M/O ratio and the wall temperature various yields and reaction completion times were obtained. The optimum conditions were methanol to palm oil ratio as 6 and the wall temperature as 55°C. The density, kinematic viscosity, flash point and calorific value of the biodiesel were found to be 898 kg/m^3, 4.98 mm^2/s, 179.33°C and 37.06 MJ/kg respectively. Ultimately, based on the empirical findings and literature reviewed, it was envisioned that palm has immense effectiveness for biodiesel and bioethanol generation without causing food deficit in Bangladesh. Agricultural production of palm would produce plenty of employment for the growing community, and would not cause the dilemma food versus fuel.

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