**Biodiesel Production Optimization from Waste Cooking Oil Using Animal Bone Catalyst**

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**Abstract**

The goal of the current study is to use a heterogeneous catalyst made from biological-waste (animal bone) to optimize the process parameters needed to transform used cooking oil (WCO) into methyl- esters. The methyl esters and synthetic calcium oxide (CaO) from animal dumps were both analyzed. At temperatures between 900 and 950oC, calcined catalyst was obtained. Utilizing central composite architecture, reaction effects from temperature (40–80oC), time for the reaction (30–180min), as well as CL (1–0.15×102 w/w%) were examined in a 3-level, 3-factor array. To identify the most important parameter, ANOVA testing as well as R.S.M optimization are utilized for the studies. The linear terms of CL (p-value of 0.0146), reaction time (p-value 0.0339), as well as temperature of the reaction combination (p-value of 0.0344) had greatest impact on the biodiesel yield. The quadratic terms of CL (p-value = 0.0271) and temperature of the combining reaction (p-value = 0.0508) had the greatest impact on the oil yield. Therefore, it is practical to apply C.C.D design, R.S.M, as well as ANOVA to optimize the generation of biodiesel from used cooking oil.

**Keywords:** R.S.M. Biodiesel. W.C.O. ANOVA. C.C.D. Animal-bone. Optimization

**Nomenclature**

|  |  |
| --- | --- |
| ANOVA | Analysis of Variance |
| ASTM | American Society for Testing and Materials standard |
| CaO | Calcium oxide |
| C.C.D | Central Composite Design |
| CICL | Confidence intervalCatalyst  |
| CO2 | Carbon (IV) oxide |
| C.V | Coefficient of variance |
| A.V | Acid value |
| Df | Total degree of freedom |
| EU | European Union |
| FFA | Free Fatty Acid |
| g wt % | Gram-weight percent |
| H2SO4 | Tetraoxosulphate (VI) acid |
| KOH | Potassium hydroxide |
| NaOH | Sodium hydroxide |
| Ph | potential of Hydrogen |
| R2 | Coefficient of determination |
| R.S.M | Response Surface Methodology |
| SEM | Scanning Electron Microscopy |
| Std  | Standard |
| VIF | Variance inflation factor |
| W.C.O | Waste Cooking Oil |
| H2O | Water |
| W.C | Water content |
| P.V | Peroxide value |
| I.C | Iodine content |
| CL | Catalyst load |
| w/w% | Weight per weight percent |

**1. Introduction**

Since fossil fuels cannot be replenished, there has been a drop in petroleum reserves as a result of an over reliance on them as the primary source of energy (Pramanik *et al.,*2023). Global energy demand is escalating yearly due to the growing population and the use of more energy-intensive machinery and processes. Thus, there is a need for utilizing more of renewable source of power in order growing energy needs and to lessen the harmful effects of fossil fuels, such as environmental damage, increased global warming, and greenhouse gas emissions. Biodiesel is an excellent potential as an alternative to diesel fuel (Holechek *et al.,*2022). It is a renewable and biodegradable fuel which can be manufactured from any oil-bearing seed or animal fat. It has lengthy alkyl-chained-esters as well as it is constituted of chemically combining lipids. As a diesel fuel substitute, biodiesel has great promise (Zailan *et al.,*2021). Any oil-bearing seed or fat from animals can be used to create this sustainable and biodegradable fuel. It is generated by chemically interacting lipids utilizing a catalyzed-alcohol to give methyl ester fatty acids, which are composed of long chain alkyl esters (Athar & Zaidi, 2020).

As a fossil fuel substitute, the manufacturing of biodiesel has received a lot of attention. Never the less, since bio diesel can be obtained from vegetative source for oils, concerns as time continues to move ahead, foods may become scare as its production depends directly or indirectly on feed stocks linked to bio diesel, scaling highly the money of feed stock products. Finding non-edible sources of feedstock that could be utilized as the primary source for synthesis of bio-diesel is hence the recent focus. To give biodiesel an economic advantage over petroleum diesel, it is also crucial to identify the ideal production conditions (such as catalyst quantity, solvent/ molar ratio of oil, measured temperature as well as period). By doing this, one can reduce the money for making bio-diesel while maximizing profits (Ahmad *et al.,*2023).

The R.S.M is a collection of arithmetic as well as data analyzing applications established to proffer a sequence of tests to make accurate predictions of a response. The process of fitting a proposed (empirical) design to data gathered using the selected design (Breig & Luti, 2021). Identifying the ideal circumstances for the input (control) variables of the model that result in the maximum or least response within a region of interest (Khan *et al.,*2023).

 Given the foregoing, it is necessary to optimize the synthesis of bio sourced diesel from WCO utilizing R.S.M as an optimization tool while using a catalyst made from leftover animal bone as a catalyst.

**2. Utilized Materials and Methodology**

*2.1 Gathering of needed materials as well as preparations*

 For this study, WCO, obtained from a close by eatery in Ugbomro community in Effurun, Delta state, as waste frying oil in a 20-liter can, was employed for the process. The oil was transferred right away to the lab so that particulates and other undesired items could be removed. The refining was achieved via gradually pre-heating up the unrefined oil, thereby reducing its thickness thereby increasing its filterability and the refined oil obtained.

*2.2 Preparation and Characterization of Animal Bone-Derived Catalyst*

 The calcination process was used to prepare the calcium oxide (CaO) that was found in the animal bone. The sample was laid out in the open sun to dry after being cleaned with distilled water. In order to effectively dry the sample, it was oven dried at a temperature 105°C for a period of 3hrs. The obtained sample (dried) then followed by crushing and a furnace was further utilized to heat up the sample at 10°C/min for 6hrs and further calcined at 950°C. To prevent its reactivity with carbon dioxide (CO2) and air humidity before usage, the product was first produced as a white powder and then a desiccator was used to chill the obtained sample before being maintained in a closed vessel. By using strong sulfuric acid, the produced CaO was sulfonated. The sample CaO was immersed in a concentrated H2SO4 for 24 hours. The sample was then thoroughly rinsed with a solution of 2M NaOH before being tested for pH levels. The sample was next dried at 105°C in the oven before being activated for 60mins at roughly 400°C in the furnace. A desiccator was finally utilized to cool the catalyst for usage.

*2.3 Catalyst porosity*

 The porosity of the catalyst was calculated experimentally using the difference between the theoretical volume expected and the actual volume of animal bone after it had been calcined. The calcined animal bone was transferred to a 100cm3 measuring cylinder and vigorously shaken up to the 50cm3 mark. Measured and recorded 50cm3 of distilled water was then added. The experiment was left for an hour to allow the water to percolate and fill the pores between the animal bone.

*2.4 Acid Value and FFA Contents*

 A conical flask was filled with a weighed 1.0g oil sample. The fat was added along with 10ml of benzene and 10ml of ethanol, and the mixture was agitated. The mixture was titrated using phenolphthalein as an indicator against 0.1M KOH until the mixture turned pink. The acid value was obtained using equation 1.

$Acid Value=\frac{S – B\left(56.1\right)N}{M}$ (1)

N is the oil's molarity, [mol/ml], M is the oil's mass, [g], S depicts titre value (sample), [ml], and B represent the recorded titre value (blank sample), [ml]. be used to estimate the Free Fatty Acid (FFA) content:

$FFA=\frac{Acid Value}{2}$ (2)

*2.5 Saponification value (S.V)*

 1.09 grams of measured oil sample were weighed into a flask with a circular bottom. It received 50ml of alcoholic potassium hydroxide, and the mixture was then refluxed for an hour. Then, using phenolphthalein as an indicator, it was titrated against a 0.5M hydrochloric acid until the pink tint vanished. The value of the iteration was noted. By refluxing 50ml of alcoholic potassium hydroxide for an hour and titrating it against a 0.5M hydrochloric acid using phenolphthalein-indicator, the titre value of the blank was ascertained.

$Saponification Value=\frac{S-B\left(56.1\right)n}{m}$ (3)

Where n is Normality of acid, [g/l], m is the oil’s mass, [g], S is the recorded titre value (sample), [ml] and B is the recorded titre value of the blank sample, [ml].

*2.6 Production of Biodiesel*

 Using a trans-esterification reaction, biodiesel was created. The experiment was carried out in a 1000ml round-bottom flask with a thermometer attached on a magnetic stirrer that maintained a constant temperature. The rate of methanol and oil sample mixing was constant. The "Design Expert Software" used - C.C.D in a R.S.M to create the reaction experiment. The CL ranged from 0.5g wt% to 10g wt%, the temperature of the combining reaction ranged from 40oc to 80oc, and the reaction period ranged from 30 to 180mins.

*2.7 Density and Specific Gravity Measurement*

 A 50ml capacity density measurement bottle was utilized to calculate the density of produced bio-diesel. A weighing balance was used to calculate the density bottle's mass. A temperature of 40 °C was reached for the biodiesel. The heated biodiesel was poured into the density bottle, which was then weighed. The mass of the density bottle was subtracted from the obtained mass to get the mass of the biodiesel.

Mb = MDb – MEb (4)

Where Mb is $Mass of biodiesel as measured$, [kg], MDb is the $mass of filled density bottle$, [kg], and MEb is the $mass of empty density bottle$, [kg].

The density of the biodiesel was determined by finding the ratio of the mass of the biodiesel to its volume.

$ρ=\frac{m}{v}$ (5)

The specific gravity was determined using the expression given below:

$SG=\frac{ρ\_{biodiesel}}{ρ\_{water}}$ (6)

Where $ρ\_{biodiesel} is the density of biodiesel at 40°C$ and $ρ\_{water} is density of water at 40°C$

*2.8 Viscosity Measurement*

 Ostwald viscometer was utilized to measure the viscosity of the biodiesel. The Oswald viscometer, also known as a capillary or U-tube viscometer, is a device for figuring out the thickness of a liquid whose density is known. The viscosity can be determined by timed how long it takes for a known amount of liquid to pass navigate via the narrow capillary while being affected by gravity (Han *et al.,* 2019).
 At a temperature of 40°C, water was added to the viscometer, and the time it took for the water to flow was noted. For the biodiesel sample, the steps were repeated, and the time of flow was also noted. The following expression was used to calculate the viscosity of the biodiesel:

$$Ƞ=\frac{Ƞ\_{°}ρt}{ρ\_{°}t\_{°}} (7)$$

Noted that Ƞ is biodiesel’s thickness, [ kg/ms], $Ƞ\_{°}$ represent the thickness of H2O [kg/ms] and $ρ$ is the biodiesel’s mass per volume, [kg/m3], $t$ is flow time, [s], $ρ\_{°}$ is H2O density, [kg/m3], $t\_{°}$ is time of flow of H2O, [s].

*2.9 Flash Point Measurement*

 A Pensky-Martens covered flash temperature recorder, that is made of a covered cup of copper, a coiled-up heater, as well as a source of continuous flame radiator, was utilized to measure the flash heated point of the bio-diesel. The test cup was sealed with a lid that allows an ignition source to be supplied and filled to the mark with the biodiesel sample. When a flash is seen, the temperature is recorded as the flash point temperature. The biodiesel sample was heated and the vapor that had gathered inside the cup was periodically brought into contact with flames of fire.

**3. Results and Discussion**

*3.1 WCO Testing*

 Obtained studies on the used vegetable oil is presented in Table 1. The oil contained 12% FFA, according to Table 1. Since excessive FFA lowers catalyst efficiency and lowers production output, studies have indicated that the optimal level of FFA in WCO should not exceed 2wt%. In contrast, it was claimed that heterogeneous catalysts could, without any pre-treatment, accelerate oil with a high FFA level of between 6 and 15%. The high basic strength of CaO can be used to explain the findings in the current investigation. WCO had a moisture level of 0.2wt%, which was less than the 0.5wt% suggested by the literature to have a negative impact on bio-diesel output. A higher value of iodine (108.4 I2g/100g) was brought by FFA (12.0%), which brought about noticeable change in the value of the iodine.

Table 1: Physical and Chemical Features of WCO

|  |  |
| --- | --- |
| **Properties (Unit)** | **Recorded value** |
| A.V (mgKOH/g) | 24 |
| S.V (mgKOH/g) | 208 |
| FFA (%) | 12% |
| H2O amount (wt %) | 0.21 |
| I.V amount (I2g/100g) | 108.4 |
| P.V (Meq/kg) | 9.4 |
| I.C (I2g/100g) | 108.4 |

*3.2 Properties of WCO Biodiesel using ASTM Standard*

 Some attributes of biodiesel were assessed using the ASTM to assess its purity following distilled water purification. Refine bio-diesel (B100) correlate certain requirements for it to be utilized as fuel as well as diesel fuel, according to ASTM. All of the measured values must be within ASTM test limit's range, according to the results' summaries (Table 2).

Table 2: Physicochemical Properties of WCO Biodiesel

|  |  |  |
| --- | --- | --- |
| **Features obtained** | **Values Obtained** | **Standard ASTM Values** |
| Density @ 40oC (g/ml) | 0.87 | 0.88 |
| Kinematic viscosity @ 40oc (mm2/s) | 4.97 | 1.9 – 6.0 |
| Free Fatty Acid (%) | 0.17 | NA |
| Flash Point (oC) | 133 | 100 – 170 |
| Pour Point | -2.5 | NA |
| Cloud Point | 1.6 | NA |
| Calorific Value (MJ/kg) | 40.41 | 35> |
| Oxidative Stability | 2hrs 47mins | 3hrs |

Note: NA = Not Available.

 Utilizing processed WCO with an A.V and W.C of 0.02mg of KOH/g and 0.02% accordingly, the trans-esterification reaction was carried out. Pretreatment of the melon oil was required to lower its FFA and W.C. The presence of FFA and water during the trans-esterification of fats obtained from animals and conventional vegetable oils for the generation of bio-diesel results in making of soaps, usage of catalyst, and reduce catalyst activeness, which all together points to a minimal reaction conversion. Before utilizing alkaline catalysis, researchers recommended that the FFA content of a feedstock be lowered to less than 1%.

*3.3 Catalyst Characterization*

 Table1 provides a summary of the physical characteristics of the waste animal bone catalyst. It was found that the reactions had a strong activity as a result of the features. The catalyst SEM photos provide evidence in favor of this hypothesis. Table 3 lists the characteristics of the biodiesel made with animal bone catalyst under normal experimented circumstances considering the variables.

 Table 3: Properties of the waste animal bone catalyst

|  |  |
| --- | --- |
| **Calcined animal bone**  | **Value** |
| Surface Area  | 86.10 m2/g |
| Pore Volume  | 0.12cm3/g |
| Particle Size  | < 200μm |
| Porosity | 48%  |

 The produced catalyst has big pores (0.12 cm3/g) and a large surface area (86.10 m2/g), which enable reactants to diffuse into the catalyst's core with ease (Table 2). It is also suggested that a high pore diameter is preferable for improved reactant and product molecule diffusion. The observation is consistent with that of a CaO catalyst with a slightly greater pore volume.

**Table 4: Central composite optimization results**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Std** | **Run** | **Factor 1****A: Temperature****(oc)** | **Factor 2:****CL****(w/w%)** | **Factor 3:****Reaction Time****(Minutes)** | **Response 1****Biodiesel Yield****(wt%)** |
| 20 | 1 | 60 | 8 | 105 | 61.24 |
| 5 | 2 | 48.1079 | 3.83778 | 149.595 | 50.74 |
| 8 | 3 | 71.8921 | 12.1622 | 149.595 | 62.11 |
| 2 | 4 | 71.8921 | 3.83778 | 60.4047 | 52.22 |
| 17 | 5 | 60 | 8 | 105 | 89.08 |
| 14 | 6 | 60 | 8 | 180 | 92.5 |
| 13 | 7 | 60 | 8 | 30 | 44.42 |
| 3 | 8 | 48.1079 | 12.1622 | 60.4047 | 56.32 |
| 9 | 9 | 40 | 8 | 105 | 41.42 |
| 6 | 10 | 71.8921 | 3.83778 | 149.595 | 69.24 |
| 18 | 11 | 60 | 8 | 105 | 90.26 |
| 11 | 12 | 60 | 1 | 105 | 38.8 |
| 1 | 13 | 48.1079 | 3.83778 | 60.4047 | 38.01 |
| 19 | 14 | 60 | 8 | 105 | 90.5 |
| 7 | 15 | 48.1079 | 12.1622 | 149.595 | 78.84 |
| 16 | 16 | 60 | 8 | 105 | 90.52 |
| 12 | 17 | 60 | 15 | 105 | 85.94 |
| 4 | 18 | 71.8921 | 12.1622 | 60.4047 | 76.28 |
| 15 | 19 | 60 | 8 | 105 | 90.06 |
| 10 | 20 | 80 | 8 | 105 | 90.52 |

*3.4 Model fitting and statistical analysis*

ANOVA method was utilized in determining the imperativeness of the affecting conditions on the response as linear, quadratic, or interaction coefficients. As can be seen in Table 4, the linear progression of CL (p-value of 0.0146), reaction time (p-value of 0.0339), and temperature of the combining reaction (p-value 0.0344) had the greatest impact on the biodiesel yield. The quadratic terms of CL (p-value = 0.0271) and temperature of the combining reaction (p-value = 0.0508) had most significance on the impact of oil yield.

This design is significant by the model F-value of 3.9300. The noise tendency result is the F-value which is approximately 2.2%. The design model is correlated to the P-value is below 0.0500. A, B, C, and B2 represent imperative design parameters considering this system. Model terms becomes not viable with the value < 0.1000. The arithmetic modellings could add additional value to the model system if a lot of unwanted terms are involved (prior to exceptional cases where higher level is considerable). The F-value of 1.470 which is not the best match with the model system, shows that the absence of correlation is not significantly important in comparison to pure-error. A bigger lack of fitted F-value with a 34.11% possibility of being instigated by noise.

**Table 5: Quadratic-model ANOVA**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Source** | **Sum of Squares** | **Df** | **Mean Square** | **F-value** | **p-value** |
| Model | 6.07618×103 | 9.0 | 0.67513×103 | 3.9300 | 0.02190 |
| A-Temp. | 1.02850×103 | 1.0 | 1.02850×103 | 5.990 | 0.03440 |
| B-CL | 1.48939×103 | 1.0 | 1.48939×103 | 8.680 | 0.01460 |
| C-Time | 1.03623×103 | 1.0 | 1.03623×103 | 6.040 | 0.03390 |
| AB | 0.10863×103 | 1.0 | 0.10863×103 | 0.63280 | 0.44480 |
| AC | 0.13122×103 | 1.0 | 0.13122×103 | 0.76440 | 0.40250 |
| BC | 0.05725×103 | 1.0 | 0.05725×103 | 0.33340 | 0.57640 |
| A² | 0.84484×103 | 1.0 | 0.84484×103 | 4.920 | 0.05080 |
| B² | 1.14907×103 | 1.0 | 1.14907×103 | 6.690 | 0.02710 |
| C² | 0.66173×103 | 1.0 | 0.66173×103 | 3.850 | 0.07800 |
| Residual | 1.71675×103 | 10 | 0.17168×103 |  |  |
| Lack of Fit | 1.02204×103 | 5.0 | 0.20441×103 | 1.470 | 0.34110 |
| Pure Error | 0.69472×103 | 5.0 | 0.13894×103 |  |  |
| Cor Total | 7.79294×103 | 19 |  |  |  |

\*P- value represents the probability, while the F-value represent the statistic’s test

The trans-esterification process was optimized utilizing the RSM, as well as experimental outcomes are shown in Table 5. Regression-modeling was done using analysis of experimental yields. Utilizing a regression model, the projected bio-diesel yield values were determined and contrasted with the experimental values. Table 5 provides the regression model's estimated coefficients. The model accurately describes the outcomes of the experiment, as shown by the coefficient of multiple determination (R2 = 0.7797).

**Table 6: Fit statistics**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Std. Dev.** | **13.10** |  | **R²** |  **0.7797** |
| Mean | 69.45 |  | Adjusted R² |  0.5814 |
| C.V. % | 18.87 |  | Predicted R² |  -0.1666 |
|  |  |  | Adequate Precision |  6.6492 |

The overall averaged-mean could be a more fitting prediction for the process, with respect to the R2 obtained. In other experiments, a higher order-model could be potentially more viable. Output disturbance signal ratio is measured by adequate accuracy. Preferably a ratio of four and above is more accurate. The signal notice is well acceptable based on the ratio of 6.649. To navigate the defined area of the model space, this model is needed to be utilized.

**Table 7: Coefficients in terms of coded factors**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Factor** | **Coefficient Estimate** | **df** | **Std Error** | **95% CI Low** | **95% CI High** | **VIF** |
| Intercept | 85.40 | 1 | 5.34 | 73.50 | 97.31 |  |
| A-Temperature | 8.68 | 1 | 3.55 | 0.7783 | 16.58 | 1.0000 |
| B-CL | 10.44 | 1 | 3.55 | 2.54 | 18.34 | 1.0000 |
| C-Time | 8.71 | 1 | 3.55 | 0.8108 | 16.61 | 1.0000 |
| AB | -3.69 | 1 | 4.63 | -14.01 | 6.64 | 1.0000 |
| AC | -4.05 | 1 | 4.63 | -14.37 | 6.27 | 1.0000 |
| BC | -2.68 | 1 | 4.63 | -13.00 | 7.65 | 1.0000 |
| A² | -7.66 | 1 | 3.45 | -15.35 | 0.0337 | 1.02 |
| B² | -8.93 | 1 | 3.45 | -16.62 | -1.24 | 1.02 |
| C² | -6.78 | 1 | 3.45 | -14.47 | 0.9141 | 1.02 |

On keeping every other determining condition constant, the relating attached design coefficient estimate represents the effective changes in the production rate. The mean output as described by the orthogonal modelling which is the intercept of the runs. Depending on the adjustment of the production conditions, the averages around the conditions is adjusted based on the coefficients of the production parameters. VIFs = 1 for orthogonal factors of the design model. With model-factors which are multi-collinear, the VIFs.> 1. The greater the VIF, the higher the extreme level of the correlation-factors. VIFs < 10 are generally regarded to be within tolerable limits.

*3.5 Response Surface Analysis*

The increase in the performance of the processes involved in biodiesel production from fat as well as oil feedstocks, such as used cooking oil, has been accomplished by using response surfaces. By showing the output as a determining factor with modelling function of dual conditional effective factor thus, holding the other part fixed, R.S.M can be shown in three dimensions. Figures 1 to 3 display the biodiesel yield in respect to the interactions between temperature, time, and catalyst concentration. The surface tracing yield with respect to the reaction (transesterification) against CL and temperature is depicted in Figure 1.



**Figure 1: Interaction of CL and temperature on biodiesel yield**

The yield of methyl ester is directly influenced by temperature and CL, as shown in Figure 1, but the yield of biodiesel starts to decrease as temperature and CL increase until methanol is close to boiling at 65°C and at the optimal molar ratio of 6:1.

Temperature plays a big role in influencing the reaction fastness as well increased the ester's change to methyl ester of fatty acid. The output of biodiesel grew swiftly to close to the boiling point of methanol with an increase in the temperature of the combining reaction. The diffusion of methanol molecules caused a poor conversion to fatty acid methyl ester to be obtained at low temperatures of about 30 to 40oc. The yield decreases because methanol evaporates at temperatures above its boiling point and is therefore unavailable for the process.

As illustrated in Figure 1, the yield of biodiesel decreased as catalyst concentration climbed beyond 7.9 wt% because a smaller amount of biodiesel could separate from glycerol as soap formation grew exponentially with catalyst concentration. In addition to decreasing ester conversion, the resultant soaps further exacerbate other phase separation issues. Figure 2's interaction impact of reaction time and temperature showed that this was the case. The value of the interaction coefficient (p>0.05) and the effect of temperature on the time on the yield are evidence of this.



**Figure 2: Interaction of reaction time and temperature on biodiesel yield**

One of the crucial variables in the reaction (transesterification), which is performed utilizing a glass converter using calcined animal bone as the catalyst, is reaction time (Etim *et al.,*2022). The yield increased during the course of the experiment, from 30 to 180 minutes, as did the temperature (Figure 2) and CL (Figure 3). At around 105 minutes, the maximum yields of 87.42% were attained. The generation of biodiesel increased quickly during the initial phases of the transesterification reaction before slowing down and reaching a stable state at reaction times of 120 minutes and above. As the contact period lengthens, the uptake value rises. After 100 minutes, approximately 88.15% of the maximum dialogue was seen.



**Figure 3: Interaction of CL and reaction time on biodiesel yield**

According to Figure 3, as more catalytic sites were occupied by reactants, rates rose until saturation was reached. Higher CL increased the impact of mass transfer limitation, which restricted reactants' accessibility to active sites. The yield is directly impacted by the transesterification reaction's significant dependence on the CL. The number of the catalyst's active sites increases with an acceptable rise in catalyst concentration, which raises the yield of methyl ester. Excessive CL produces unsatisfactory reaction mixtures due to high slurry viscosity.

**4. Conclusion**

 The optimization of transesterification of methanol with fatty acids from used cooking oil using response surface methods with effectiveness. The second-order polynomial's high regression coefficients demonstrated how well the model fit the experimental data. The ANOVA suggested that catalyst concentration, temperature of the combining reaction, and reaction time all have a significant impact on the biodiesel yield. Temperature, reaction time, and catalyst concentration all exhibit negative quadratic behavior in the generation of biodiesel. Within the experimental range, it was projected that the ideal reaction conditions would be a reaction time of 180 minutes, amount of utilized catalyst of 8wt% and heat level of 60°C. When everything is perfect, we can produce a yield of more than 92%. The fatty acid methyl ester which was produced at the best operating conditions has properties which are much acceptable as compared petro-diesel. Therefore, conclusively, the obtained biodiesel is a fit to petro-diesel with varying changes to suit any machine/engine.

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