Optimization and Residence Time Distribution Study of Waste Cooking Oil Transesterification in a Continuous Stirred Tank Reactor

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Abstract

Waste cooking oil (WCO) transesterification using a catalyst of Dodecylbenzenesulfonic acid was investigated using a continuous stirred tank reactor. A techniques of surface response plus the design of centered composite were used for the optimizing the factors effecting on the process. The optimum conditions in this research were concluded as (catalyst amount: 1 wt. %; reaction time: 20 min; methanol/oil flow ratio: 4; reactor temperature: 60°C). The biodiesel obtained at the optimum conditions in the process was obtained at yield of 98.5%. The distribution of residence time was found experimentally and a dead zone of (110 cm³) was estimated in the CSTR using the compartment model. The physic-chemical properties for the biodiesel were found in agreement with the ASTM standard (D-6751-2) and the conventional diesel properties. The specific gravity value of biodiesel (0.87) was greater than that one of the diesel fuel (0.834). The calorific value was slightly lower than that one prescribed in the ASTM D-6751 specifications. The kinematic viscosity proved to be within the accepted limits of the. The flash point was found greater than the value specified in the ASTM and that for mineral diesel, which means safer. Acid value of 0.4 mg KOH/g was found accepted according to the biodiesel standard ASTM D-6751-2. Cetane value was found greater than that for mineral diesel.

Keywords: Response surface methodology, Transesterification, Waste cooking oil, Continuous stirred tank reactor, Dodecylbenzenesulfonic acid.

1 Introduction

Increasing the demand of energy and the accumulation of the waste accompanied the increase of the world population. Huge amount of waste cooking oil are daily produce by the restaurant, need to be recover, and reused [1]. Biodiesel has recently become the subject of many literatures in order to overcome the two concerns of energy demand and waste accumulation [2]. Biodiesel or as called FAME can be produced using the acid and basic catalyzed transesterification reaction proved as a good alternative fuel [3]. Fat and vegetable oils are the key raw materials for the biodiesel production. Animal fats and Edible oil uses in the production of biodiesel create a series problem due to the competition with the food [4]. Therefore, any low quality type of non-edible oil accepted for the production of biodiesel and reduced the cost of the method. The collection of waste cooking oil from the household and restaurants can also effectively resolve the disposal problem [5]. Industrially, the catalyst used in the process usually homogeneous acidic or basic. Many traditional acidic catalysts like HCl, H₂SO₄ and BF₃ are used in the literature for the esterification step only [6-10]. Dodecylbenzenesulphonic acid is an organic material used as a catalyst for both
transesterification and esterification reactions. The presence of linked aromatic ring to the alkyl chain makes the catalyst more amphiphilic in nature and highly soluble in the oil phase [11]. Therefore, transesterification process was accelerated using the organic acid catalyst and it is proved as a promising alternative catalyst.

The commercial biodiesel production depends on the scaling up the bench scale experiments. Most of the researchers concentrated on the investigation the parameter effecting on the biodiesel yield in the batch mode. The scaling up for the batch reactor cannot solve the problems associated with the continuous flow processes that used industrially for the biodiesel production. The continuous process improves the factors effecting on the production of biodiesel due to increase the reaction rate, mass transfer and heat transfer. Moreover, continuous separation of biodiesel can be achieved in the process [12]. In a recent review on biodiesel production in the continuous mode, the researchers showed the advantages and disadvantages of the different types of continuous flow processes [13]. The statistical experimental techniques of surface response had been used in optimizing the process parameters for biodiesel production in batch and continuous processes [14-22]. The parameters (residence time, methanol/oil ratio, and temperature) effecting on the yield of biodiesel were optimized in a tubular packed reactor using the techniques of surface response [23]. The present work, investigate experimentally the possibility of using waste cooking oil (WCO) collected from local restaurants for production of biodiesel using DBSA catalyst in the continuous stirred tank reactor (CSTR). A design of experiment using techniques of surface response plus the design of centered composite was applied for checking the influence of (residence time, catalyst loading, methanol to oil ratio, reaction temperature and mixing rate) on the yield of biodiesel from waste cooking oil raw material using DBSA catalyst. The design of the continuous stirred tank reactor was investigated by estimating the residence time distribution and applying the compartment model. The experimental results obtained in the present work were compared with two compartment models: (1) Perfect mixing model and (2) Mixing with dead time model. 4. The properties of biodiesel was compared to the ASTM standard (D-6751-2) and the conventional diesel properties.

2 Experimental

2.1 Materials and Measuring

Methanol (99.9%), hexane (98.8%), anhydrous MgSO4 (99.8 wt. %), the standards for the analysis of biodiesel yield of analytical grade reagents were procured from Sigma-Aldrich. DBSA (>0.99) was obtained from Shanghai Hanhong Scientific Co. Waste cooking oil was obtained from a local cafeterias in Al Qadisiyah city. First, waste cooking oil was filtered then dried at 105°C in the oven under N2 purge environment for a period of 60 min. GC-FID (Shimadzu 2010, Japan) was used for the yield and free fatty acid analysis. The specification for the GC-FID instrument were (split-splitless injection of a volume=2 μL, temperature of the oven= 483.15 K, injector temperature = 513.15 K, detector temperature = 523.15 K ratio of splitting of 1:50, volumetric flow rate of 1ml/min, dimensions of column (film thickness of 0.25mm, length = of 30 m, inside diameter = 0.25 mm. The WCO analysis for fatty acids in (%) shows that the lipid consists primarily from Linoleic acid (C18:2 =13.72), Linolenic Acid (18:3=0.9), myristic acids (C14:0=1.06), stearic acid (C18:0=5.42), oleic acid (C18:1=53.5), palmitic acid (C16:0=22.4) and others=3. The water content analysis of the waste cooking oil was done using Karl Fischer instrument. The American Oil Chemist Society method (standard titration) was used for calculating the WCO acid value. The experimental tests were done in triplicate and the average values were recorded.
2.2 Direct Transesterification in CSTR

The WCO acid value was found to be 1.4 mg KOH/g. The laboratory configuration comprised primarily of a CSTR scheme with requirements of (inside reservoir diameter: 8 cm, reservoir height: 10 cm) and a thermostat and mixer. Methanol was added to appropriate quantity of DBSA and blended evenly. Methanol combination and waste cooking oil were then heated to an appropriate temperature and fed into the CSTR scheme. A dosing pump was used to introduce methanol and waste cooking oil into the CSTR scheme. In a product vessel, the biodiesel product was obtained. Figure 1 provides the diagram illustrating the schematic of the method.

The variables investigated in the CSTR scheme were: residence time, quantity of catalyst, methanol/oil, and reaction temperature. Biodiesel output was explored under variant factor situations and triplicate tests were conducted (standard deviation for any level was less than 5 percent). The CSTR residence time was calculated on the basis of the following equation [24].

\[
\tau = \frac{V_t}{v_o} = \frac{\pi h d^2}{4 v_o}
\]  

Where \( \tau, V_t, v_o, h, \) and \( d \) are the residence time (min), tank volume (cm³), flow rate (cm³/min), height of the fluid in the reactor (cm), and inner diameter of the reactor (cm), respectively.

![Figure 1](image)

**Figure 1** Representation diagram of the CSTRs system set-up: 1- dosing pump; 2- Rotameter; 3- Tracer syringe; 4- CSTR; 5- check valve; 6- mechanical mixer.

Subsequently, remaining methanol was removed using rotating evaporator then hexane was introduced to purify the biodiesel product. Finally, the blend vacuum filtered and dried the supernatant over anhydrous MgSO₄. To characterize the product collected from the CSTR scheme, GC-FID was used. Triplicate experiments were performed. The yield of waste cooking biodiesel has been calculated:

\[
\text{Biodiesel Yield (wt. %)} = \frac{W_b}{W_t} \times 100 = \frac{CF_s A_b W_s}{CF_b A_b W_b}
\]  

Where \( W_t, W_s, W_b \) are the total sample, internal standard added to the sample, and mass of biodiesel, respectively, \( A_s, A_b \) is the peak area of internal standard, and biodiesel, respectively, \( CF_s, CF_b \) is the correction factor of internal standards, and biodiesel.

2.3 Process Parameter Optimization (RSM and CCD)

Based on prior research on the biodiesel production from vegetable oil raw materials, the variety of parameters investigated was selected[4-6]. The Central Composite Design (CCD) technique is intended to use a minimal number of studies to evaluate the statistical model for absolute fit lack [25-27]. Techniques of surface response can be described in three phases (1. Gathering of test information and layout of tests that
match a quadratic equation; 2. Variance analysis and analysis of regression; 3. Experimental data in contour and surface models). To enhance the biodiesel output, a two-level, four-parameter CCD optimization method was used. For design of experiments and optimizing the system variables effecting on the yield of biodiesel, techniques of surface response plus the design of centered composite using STATISTICA 12 software were used. The factors investigated as independent variables were residence time (X₁), Catalyst amount (X₂), methanol to oil flow rates (X₃) and process temperature (X₄) plus the dependent function was the biodiesel yield (Yₜ). The factors affected on the yield of biodiesel were chosen according to the previous studies [4-7]. Table 1 present the parameters level for the statistical design in the current research where the center points signed as zeroes and the upper and lower values signed as +1, -1. A 27 test were done experimentally and listed in the Table 2. The quadratic + 2- ways model was found a suitable choice in the software of STATISTICA 12 for solving the statistical model and general model is shown in the equation (3):

\[ Y_b = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_{11} X_1^2 + \alpha_{22} X_2^2 + \alpha_{33} X_3^2 + \alpha_{44} X_4^2 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{34} X_3 X_4 \]  

(3)

Where \( Y_b \) is the biodiesel yield, \( X_{ab} \) are the affecting parameter on the yield of biodiesel, \( \alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4 \) are the intercept and linear coefficients, \( \alpha_{12}, \alpha_{22}, \alpha_{32}, \alpha_{42} \) are the quadratic coefficients, \( \alpha_{12}, \alpha_{13}, \alpha_{14}, \alpha_{23}, \alpha_{24}, \alpha_{34} \) are the interaction coefficients.

Table 1 The level of parameters for the design of experiments.

| Parameter                      | Symbol | Levels |
|--------------------------------|--------|--------|
| Residence time (min)           | X₁     | -1     | 0      | +1     |
| Catalyst loading (wt%)         | X₂     | 0.5    | 1      | 1.5    |
| Methanol/oil flow ratio (M)    | X₃     | 2      | 4      | 6      |
| Reaction temperature (°C)      | X₄     | 55     | 60     | 65     |

Table 2 The experimental and predicted values of response yield with coded and uncoded parameters.

| Run | Coded parameters | Uncoded parameters | Biodiesel yield, \( Y_b \) (%) |
|-----|------------------|--------------------|--------------------------------|
|     | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( X_4 \) | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( X_4 \) | Experiment | Predicted | Deviation (%) |
| 1   | -1    | -1    | -1    | 1    | 10    | 0.5    | 2    | 65    | 68    | 68.78    | -1.14706 |
| 2   | -1    | -1    | 1    | -1   | 10    | 0.5    | 6    | 55    | 80    | 80.28    | -0.35    |
| 3   | -1    | 1    | -1   | -1   | 10    | 1.5    | 2    | 55    | 88    | 89.27    | -1.44318 |
| 4   | -1    | 1    | 1    | 1    | 10    | 1.5    | 6    | 65    | 80    | 80.56    | -0.7     |
| 5   | 1     | -1    | -1   | -1   | 30    | 0.5    | 2    | 55    | 82    | 81.7     | 0.365854 |
| 6   | 1     | -1    | 1    | 1    | 30    | 0.5    | 6    | 65    | 83    | 82.76    | 0.289157 |
| 7   | 1     | 1     | -1   | 1    | 30    | 1.5    | 2    | 65    | 78    | 77.92    | 0.102564 |
| 8   | 1     | 1     | 1    | -1   | 30    | 1.5    | 6    | 55    | 95    | 94.52    | 0.505263 |
| 9   | 0     | 0     | 0    | 0    | 20    | 1      | 4    | 60    | 98    | 98.37    | -0.37755 |
| 10  | -1    | -1    | -1   | 10   | 0.5    | 2    | 55    | 83    | 82.11    | 1.072289 |

"
2.4 Distribution of Time Analysis (RTD)

Distribution of residence time assessment was performed by injecting NaCl (25 gm) as a tracer at the inlet of CSTR and evaluating the outlet stream's electrical conductivity as a result of time. A calibration curve with tracer concentration was prepared to adjust conductivity. Following the following equation, the age equation \(E(t)\) was calculated from the shift in tracer volume with time[28]:

\[
E(t) = \frac{C(t)}{\int_0^\infty C(t)dt}
\]  

(4)

The mean time for the CSTR was calculated by using equation (5):

\[
t_m = \int_0^\infty t. E(t). dt
\]  

(5)

2.5 Analysis of Biodiesel Properties

2.5.1 Specific Gravity

The hydrometer technique was used for the specific gravity calculation according to the requirements (ASTM D 4052). In order to read the specific gravity straight, biodiesel was loaded into the graduated cylinder while the hydrometer continued to trickle in biodiesel.

2.5.2 Kinematic Viscosity

According to the ASTM D445, biodiesel kinematic viscosity was tested using a Redwood viscometer. First, a 50 ml of biodiesel loaded into the viscometer cup and a valve shut the orifice. The viscosity was evaluated with a water bath and thermometer at a set temperature of 40°C. The time it takes to collect the 50 ml biodiesel sample from the Redwood viscometer is called the Redwood time.
2.5.3 Calorific Value

According to ASTM D2015, the calorific value of biodiesel was measured using the bomb calorimeter. The calorimeter's crucible was filled with a one gram of sample while the water bath of the instrument was filled with 1750 ml of purified water. The oxygen was provided to the device for the ignition of the sample at a pressure of 25 psig and the temperature variation was measured over time at equal intervals.

2.5.4 Cloud and Pour Points

The D 2500 requirement calculated the cloud and pour point. A bottle was loaded to the height of 2.25-inch biodiesel sample and a thermometer attached. The container was placed at a temperature spectrum from -1 to 2°C in the ice bath. The cloud point has been measured as the temperature where the sample begins to crystallize. While, the temperature at which the biodiesel sample can still be poured from the jar was recorded as the pour point.

2.5.5 Flash Point

The biodiesel flash temperature was evaluated in accordance with ASTM requirements no. D 93. In accordance with the D 93 specification, Pensky-Martens (closed cup) instrument was used to heat the biodiesel sample and the source of ignition was directed to it at the same time intervals. The temperature of the flash point is the smallest temperature that gives enough flammable vapor that is heated.

2.5.6 Acid Value

Biodiesel acid value was calculated in accordance with the ASTM D664 requirement. The experiment can be performed by incorporating an appropriate quantity of KOH in a titration technique to neutralize the acids in the biodiesel sample. The acid value is the mg of KOH needed for one gram of biodiesel sample to be neutralized.

2.5.7 Cetane Number

The Cetane Number is described as a percentage of the quantity of Cetane in a blend of Methyl Naphthalene and Cetane that, under standard conditions, has similar ignition period as that of normal sample petrol. The large volume of Cetane in the fuel shows a reduced ignition period and works well in the motor.

3 Results and Discussion

3.1 Variance Analysis

Variance assessment was performed for the experiential formula acquired using the techniques of surface response plus the design of centered composite with a confidence level of more than 95% for the dependent variable (biodiesel output). The next equation demonstrates the current study's empirical model:

\[
Y_b = 98.37 + 4X_1 + 6.67X_2 + 2.83X_3 - 6.67X_4 - 4.68X_1^2 - 6.43X_2^2 - 5.93X_3^2 - 14.43X_4^2 + 3.5X_1X_4
\]

Figure 2 displays the relation between the expected results and the results. The R² rating in the chart gave a significance of 0.959, indicating that the model has been validated and can be used effectively to predict biodiesel output. In addition, the empirical equation was evaluated using the
null assumption and the empirical regression coefficients were evaluated using a test called F-test to evaluate the statistical model's significance. Compared with the tabulated F-values, the calculated F-values were noticed to be higher than it, indicating the model's significance, and the null hypothesis can be denied. The rotability and orthogonal value for the empirical model has been calculated by the Alpha (α) value of 2, where the Alpha variable is the distance from the center point and can be evaluated by the formulation \((2n/4)\) subject to the number of parameters \(n\) [27].

The current research model acquired a nice prediction based on the calculated and tabulated F-values scores \((F_c=2.7, F_t=2.3)\). The model demonstrates a reasonable fit with \(<0.05\) p-value, which is important at a confidence level of 95 percent. The fit lack of the model was small as the valuation of p was equivalent to \((0.203)\) suggesting an adequate relationship between independent and dependent parameters is provided by the model.

![Figure 2 Predicted versus experimental values.](image)

### 3.2 Surface Analysis and Variable Interaction

The interacted influence on the biodiesel output variables has been explored and shown in figures 3-8. The research procedure was performed by keeping as constants two variables and altering the other two variables. The graphs that result are a 3D graph called graphs of the response surface. Values of \((P < 0.05)\) show the conditions of the model are significant. In this situation, \(X_1X_4\) is the only significant interacted parameter. Values of \(P >0.05\) as in other contexts show that the conditions of the model are not significant. In the current model, all linear and quadratic conditions are significant. Figure 3 displays the interacted influence of time \((X_1)\) and catalyst loading \((X_2)\) factors on the biodiesel yield \((Y_b)\) at constant methanol/oil flow ratio \((X_3)\) and reaction temperature \((X_4)\) of 4:1 and 60°C, respectively. The 3D graph demonstrates the rise in biodiesel output with higher residence time and catalyst loading up to the optimum level of 98.37%. Then, a reduction in biodiesel output was noted owing to the inverse transesterification reaction impact on the biodiesel output to further increase the residence time and catalyst utilization. The same scenario was examined by Mohamad et al., 2017[29]. Figure 4 displays the interactive effect of residence time \((X_1)\) and methanol to oil flow ratio \((X_3)\) factors on the biodiesel yield at constant catalyst loading \((X_2)\) and reaction temperature \((X_4)\) of 1 wt% and 60°C, respectively. Increasing the excess amount of the methanol / oil flow proportion beyond the theoretical significance of 3 would boost the biodiesel output owing to the forward reaction stimuli. Figure 5 shows that the interaction between the residence time \((X_1)\) and reaction temperature \((X_4)\) factors was clear and can be explained as follows at a constant catalyst load of 1 wt percent and a methanol / oil flow ratio of 4:1. The forward transesterification reaction rate increases towards biodiesel production until the optimum temperature of 60°C is reached at the reduced residence time. As the residence time decreased, the output of biodiesel improved by raising the temperature and residence time to the optimum levels of 20 min and 60°C. Miladinovi et. al. recorded the same outcomes [ 23]. Figure 6 shows the interaction between the catalyst amount \((X_2)\) and the methanol to oil flow ratio \((X_3)\) at a constant 60°C temperature and 20 min residence time. The joint increase in catalyst amount and the ratio of methanol to oil
flow would intensify the yield of biodiesel to the optimum 1 wt value. Catalyst amount percentage and methanol to oil flow proportion of 4. Any further rise in the methanol to oil flow proportion can dilute the quantity of the catalyst and decrease the output of biodiesel as shown in the 3D graph. The same finding and conclusion was recorded by Ullah et al.[30]. Figure 7 shows the interacted impact of methanol / oil flow proportion (X₃) and reaction heat (X₄) variables at 1 wt percent loading catalyst and 20 min residence time. Figure 7 indicates a rise in biodiesel output to optimum levels owing to the rise in methanol to oil flow proportion and temperature. A reduction in the biodiesel output is then noted as the methanol level in the reaction blend is lost and decreased at a greater temperature than 60°C. In the 3D figure 8, the combined influence of catalyst loading (X₂) and reaction temperature (X₄) factors is shown at 4 methanol / oil flow ratio and 20 min residence time. The same result can be seen here with the mixed methanol / oil proportion and temperature effect.

3.3 Parameters Optimization

The resulting optimized parameters were: residence time (20 min), catalyst load (1 wt. percent), methanol / oil flow proportion (4:1) and reaction temperature (60°C) using the STATISTICA 12 software. Compared to the experimental value of 98.5 percent, the expected biodiesel output was 98.37 percent with a percentage error of less than 0.5 percent as per the validation using STATISTICA 12 software.
Figure 4  Effect of methanol to oil flow ratio and residence time on biodiesel yield: temperature 60°C; catalyst amount 1 wt. %.

Figure 5  Effect of residence time and temperature on yield of biodiesel: methanol to oil flow ratio 4; catalyst amount 1 wt. %.
Figure 6  Effect of methanol to oil flow ratio and catalyst loading on yield of biodiesel: residence time 20 min; reaction temperature 60°C.
3.4 Residence Time Distribution Models

Two comparison models were compared to the laboratory outcomes acquired in the current work: (1) perfect mixing model [28] and (2) mixing with dead time model [31]. The age feature was calculated according to formula (7) for the model of perfect mixing [28]:

$$E_M(t) = \frac{1}{\tau_M} \exp\left(-\frac{t}{\tau_M}\right)$$  \hspace{1cm} (7)

And for the mixing with dead time model was obtained from equation (8) [31]:

$$E_{M+D}(t) = \frac{1}{\tau_M} \exp\left(-\frac{(t-\tau_D)}{\tau_M}\right)$$  \hspace{1cm} (8)

Where $\tau_M$, $\tau_D$ are the space time for mixed and dead zones, respectively. Figure 9 shows the findings for the laboratory results, perfect mixed model and mixed with the dead-time model. A lack of fit for the perfect mixed model has been noted. While the perfect coupled with dead time model indicates a great consensus with matched information ($R^2_{\text{adjusted}} = 0.95$). A perfect mixed region (390 cm$^3$) of the complete CSTR quantity and the other quantity (110 cm$^3$) noted is a dead zone volume without mixing.
3.5 Biodiesel Properties

The biodiesel characteristics generated from waste cooking oil were matched with the standard biodiesel characteristics in accordance with the ASTM D 6751 requirements and displayed approved characteristics in accordance with the requirements. In Table 3, together with the diesel and standard biodiesel properties, the resulting biodiesel properties were listed. Biodiesel specific gravity (0.87) was reported to be greater than diesel fuel value (0.834). The viscosity is the greatest significant asset for the output of biodiesel as the excuse to convert the WCO into biodiesel to decrease viscosity. The viscosity of biodiesel was measured to be 3.45 mm²/s and is within the ASTM D 6751 (1.9-6 cSt) suggested interval. Biodiesel calorific value (37.97 MJ / kg) was noticed to be lower than the diesel value, but in the ASTM D 6751 permitted value. Owing to the rise in oxygen content while the carbon content decreased, the calorific value of biodiesel is decreased. Increasing oxygen material would promote complete combustion and decrease particulate and black matter output. Biodiesel cloud and pour point characteristics are particularly essential in cold locations. Biodiesel cloud point was observed to be equivalent to 4 and the level of pouring was reported to be -2. The flash point is a significant security characteristic. The biodiesel flash point was reported to be greater than the petroleum diesel and standard biodiesel. The acid value of 0.45 mg KOH / g for biodiesel was observed within the agreed value recommended in the standard biodiesel specification. After transesterification, the cetane number for biodiesel increased compared to the waste cooking oil due to reduced viscosity and, as listed in Table 3, the Cetane number value for biodiesel from waste cooking oil increased more than the petroleum diesel value, which implies the engine has a smoother ignition.
### Table 3 The experimental physicochemical WCO biodiesel's properties.

| Properties                | Biodiesel | standard ASTM D 6751-02 | diesel | Test method |
|---------------------------|-----------|-------------------------|--------|-------------|
| Specific gravity          | 0.87      | 0.86–0.90               | 0.834  | ASTM D4052  |
| Viscosity at 40 °C (mm²/s)| 3.45      | 1.9–6.0                 | 1.9-4.1| ASTM D445   |
| Cetane number             | 48.12     | 47 min                  | >46    | ASTM D613   |
| Calorific value (MJ/kg)   | 37.97     | –                       | 45     | ASTM D2015  |
| Pour point (°C)           | -2        | -15 to 5                | -35 to -15 | ASTM D97  |
| Cloud point (°C)          | 4         | -3 to 12                | -15 to 5 | ASTM D2500 |
| Flash point (°C)          | 154       | 130 °C                  | 52     | ASTM D93    |

### 4 Conclusion

The transformation of WCO in the CSTR unit was studied using DBSA as a catalyst, resulting in a large yield rate of 98.5%. Using techniques of surface response plus the design of centered composite, the variables influencing the biodiesel output were optimized and the model displayed a great match with the test results ($R^2=0.959$). The optimum process conditions were concluded (residence time: 20 min; 1 wt. percent catalyst load; 4:1 methanol / oil flow rate; 60°C reaction temperature). DBSA has been concluded to be an effective catalyst for both the transesterification and esterification reactions in the CSTR regime based on the process conditions. RTD's test information gave a very good match with the perfect compartment model combined with a $R^2$ adjusted value$=0.95$. A dead region (110 cm$^3$) for the compartment model identified in the CSTR. The biodiesel product's physicochemical characteristics were consistent with the biodiesel ASTM D 6751 specification.

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