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Research Article

Modeling Reaction Parameters for Biodiesel Production from Binary Oil Mixtures: A Kinematic Viscosity-based Approach

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Abstract

This study aimed to optimize parameters for biodiesel production from binary oil blends, specifically focusing on kinematic viscosity as an important parameter. It aimed to determine the optimal conditions for the production of biodiesel from mixtures of canola oil and waste frying oils by varying various production parameters, including reaction temperature, methanol concentration, and NaOH catalyst. Using Response Surface Methodology (RSM), this study evaluated the relationship between input parameters and viscosity using ANOVA to identify significant factors. The performance of the model was evaluated using R-squared, RMSE and MAPE, which demonstrated high accuracy in predicting viscosity. The results showed that NaOH and methanol concentrations significantly affected the viscosity. The study underlines the importance of parameter tuning to achieve desired viscosity levels and thus optimize biodiesel production. These findings contribute to improving the efficiency and quality of biodiesel production processes.

Keywords: *Kinematic viscosity, optimize biodizel production, binary oil blends.*

Introduction

The increase in global energy demand and environmental concerns has directed researchers towards sustainable and environmentally friendly energy sources. In this context, biodiesel stands out as a renewable fuel that can be produced from both vegetable and animal oils (Aghbashlo, Hosseinpour, Tabatabaei, & Soufiyan, 2019; Gonçalves, Mares, Zamian, da Rocha Filho, & da Conceição, 2021; Pali, Sharma, Kumar, & Singh, 2021). Compared to fossil fuels, biodiesel has lower greenhouse gas emissions and exerts less harmful effects on the environment due to its biodegradability. However, there are some challenges regarding the efficiency and sustainability of the raw materials used for biodiesel production. Traditionally, vegetable oils have been widely used in biodiesel production; however, concerns exist about their sustainability as increasing agricultural land for large-scale production may lead to environmental impacts and compete with food production (Balasubramanian, Kamaraj, & Krishnamoorthy, 2020). Therefore, exploring and utilizing alternative feedstock sources are crucial for the sustainability of the biodiesel industry.

In this context, the utilization of waste cooking oils (WCO) for biodiesel production has gained increasing interest in recent years. Significant amounts of WCO are generated in both residential and commercial settings such as restaurants, cafeterias, and food processing facilities. However, improper disposal of WCO can lead to environmental and health risks (Ahmed, *et al.*, 2023; Dharmalingam, *et al.*, 2023). The use of WCO for biodiesel production offers potential advantages in waste reduction, efficient utilization of energy

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resources, and reduction of greenhouse gas emissions. However, the quality and composition of WCO can be significant factors in the biodiesel production process. The presence of impurities such as water, free fatty acids, and unsaturated compounds can reduce the efficiency of the transesterification process and lower the quality of the biodiesel product (Aghbashlo, *et al*., 2019; Gonçalves, *et al*., 2021; Weldeslase, Benti, Desta, & Mekonnen, 2023). Therefore, effective utilization of WCO and improvement of biodiesel production processes can offer a more energy-efficient and environmentally friendly approach.

The development of machine learning techniques and statistical modeling approaches plays a significant role in optimizing biodiesel production processes. The use of these techniques provides new opportunities to enhance the efficiency of the raw materials used in biodiesel production and ensure the sustainability of the process (Almohana*, et al*., 2022; Behnam, Shafieian, Zargar, & Khiadani, 2022; Shehadeh, Alshboul, Al Mamlook, & Hamedat, 2021). The study conducted by Xing, Zheng, Sun, and Agha Alikhani, (2021) emphasizes the robustness and reliability of machine learning models in biodiesel production processes, making them suitable for industrial applications. Similarly, the works of S. Wang, Qin, Feng, Javadpour, and Rui, (2021) and Zhang, *et al*. (2020) demonstrate valuable findings obtained in biodiesel production processes through the analysis of experimental data and the use of machine learning models.

However, due to the complexity of the biodiesel production process and the interaction of multiple parameters, the combination of response surface methodology (RSM) and machine learning (ML) techniques is increasingly preferred. For example, the study by Zhang, *et al*. (2020) shows that the use of a unified ML-RSM approach leads to a significant increase in biodiesel yield. This approach optimizes the biodiesel production process using machine learning techniques such as the random forest algorithm. Similarly, the work of Ahmad, Yadav, and Singh, (2023) demonstrates that the combination of RSM and ML algorithms enhances biodiesel efficiency and reduces production costs. These studies indicate that the effective use of machine learning techniques in biodiesel production can improve process efficiency and economic viability.

In this context, the main objective of this study is to model the reaction parameters for biodiesel production from binary oil mixtures at different ratios based on kinematic viscosity. By altering some parameters used in production, aiming to determine the optimum conditions for producing biodiesel from oils obtained by mixing canola oil and waste cooking oils at different ratios. The parameters altered include the reaction temperature, methanol as alcohol, and NaOH as a catalyst. In the transesterification method, the oil was maintained at different temperatures during the reaction process.

Materials and Methods

The primary objective of the study is to model the reaction parameters for the production of biodiesel from binary oil mixtures with different ratios based on kinematic viscosity. Canola oil and waste cooking oils were mixed in different proportions to prepare the oils for biodiesel production, with the aim of determining the optimal conditions by altering some production parameters. These altered parameters included reaction temperature, methanol as the alcohol, and NaOH as the catalyst. During the transesterification process, the oil was maintained at different temperatures.

Canola oil used in the research was obtained from the market, while household cooking oil was utilized as waste oil. The oils were mixed in different ratios and prepared for the transesterification process. The mixed oils were heated to the desired temperature. Sodium methoxide solution was prepared using the desired molar ratios of alcohol and catalyst amounts. The obtained methoxide was added to the preheated mixed oils. The transesterification reaction was conducted by stirring for 1 hour at different temperatures After the reaction, it was left to rest for 8 hours and the glycerol forming the precipitate was separated from the methyl ester. The temperature of the methyl esters was raised to 70°C, and the remaining methyl alcohol in the crude methyl ester was removed. Then, during the washing stage, the methyl ester and distilled water were heated to 50°C, and the washing process was carried out. After the washing process, the water was allowed to settle for 12 hours, and the separated wastewater was removed. The raw biodiesel, from which the wastewater was removed, was subjected to a drying process at 100°C for 120 minutes in a probe heater magnetic stirrer to remove any remaining water. Biodiesel production was completed for all trial fuels.

In the study, the kinematic viscosity of all fuels and blends was determined using the fuel analysis laboratory and measurement devices established as part of the DPT 2004/7 project within the Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Selçuk University (Öğüt, Akınerdem, Pehlivan, Aydın, & Oğuz, 2004). The kinematic viscosity device used was the Koehler K23377 model, operating with a measurement accuracy of ±0.01 and according to the EN ISO 3104 standard.

In recent years, Response Surface Methodology (RSM), which has gained significant prominence in the field of engineering, is widely employed as a computer-based application for modeling and optimization (Uslu & Celik, 2020). The fundamental objective of this method is to determine the effects of various input factors on response parameters and optimize them. In this context, RSM evaluates the relationship between input and output parameters to optimize responses based on input factors. Particularly, RSM utilizing the method of least squares evaluates effective factors for achieving desired outcomes and optimizes the communication among variables (Inayat, Sulaiman, & Kurnia, 2019; Kumar & Dinesha, 2018). This method optimizes responses based on input factors by establishing a relationship between input and output parameters, employing the method of least squares.

The primary aim of this study is to model the binary different mixture ratios of canola and waste cooking oil biodiesels and different biodiesel production stages (temperature, NaOH, and methanol) using the RSM method. The initial step in RSM is to establish an appropriate relationship between output and input parameters. For this correlation, a second-degree equation model, as shown below, is applied (Uslu & Celik, 2020):

Findings and Discussion

$$y = \beta_0 \sum_{i=1}^{k} \beta_1 x_1 + \sum_{i=1}^{k} \sum_{j\geq 1}^{k} \beta_{ij} x_i x_{j+} \sum_{i=1}^{k} \beta_{ii} x_i^2 + \varepsilon$$

Table 1 illustrates the design table containing experimental data. While waste cooking oil biodiesel and canola biodiesel ratio, temperature, NaOH, and methanol are selected as input parameters for the embedded RSM model, viscosity is chosen as the output parameter.

Table 1: Table of design related to the experimental results

Std Order	**Run Order**	**Pt Type**	**Blocks**	**Canola biodiesel rate (%)**	**Waste cooking biodiesel rate (%)**	**Temperature (°C)**	**NaOH (gr/lt)**	**Methanol (%)**	**Viscosity (mm^2 s^{-1})**
10	1	1	1	50	50	55	5.25	22.5	4.84
30	2	0	1	25	75	45	3.5	30	4.96
21	3	-1	1	25	75	65	7	30	4.44
19	4	-1	1	75	25	65	3.5	15	5.94
15	5	1	1	25	75	65	7	15	5.56
14	6	1	1	50	50	55	5.25	7.5	13.84
22	7	-1	1	50	50	45	5.25	22.5	5.12
12	8	1	1	25	75	65	3.5	15	6.72
7	9	1	1	25	75	45	3.5	15	6.28
27	10	0	1	75	25	65	3.5	30	4.78
2	11	1	1	25	75	45	5.25	30	4.70
23	12	-1	1	75	25	65	7	30	4.42
18	13	-1	1	50	50	55	5.25	15	6.41
16	14	1	1	75	25	55	3.5	15	7.32
6	15	1	1	75	25	45	7	15	5.15
28	16	0	1	25	75	45	7	15	4.85
26	17	0	1	25	75	65	5.25	30	4.40
24	18	-1	1	0	100	55	5.25	22.5	4.40
3	19	1	1	25	75	45	7	30	4.25
20	20	-1	1	75	25	45	3.5	30	4.63
9	21	1	1	75	25	65	5.25	30	4.49
4	22	1	1	100	0	55	5.25	22.5	4.47
1	23	1	1	50	50	55	5.25	30	4.54
31	24	0	1	75	25	45	5.25	30	4.93
13	25	1	1	75	25	45	7	30	4.55
8	26	1	1	50	50	65	5.25	22.5	4.53
11	27	1	1	25	75	65	5.25	15	5.49
25	28	0	1	50	50	45	5.25	30	4.59
5	29	1	1	75	25	65	7	15	4.86
17	30	-1	1	75	25	45	3.5	15	6.14
29	31	0	1	25	75	65	3.5	30	5.10

Variance analysis (ANOVA) was employed to indicate significant values between input factors and responses. A higher F-value and a smaller P-value indicate the greater significance of the respective term in the proposed correlation for the response, hence the P-value is accepted as significant at 0.05 (Dana, Sobati, Shahhosseini, & Ansari, 2020).

In Table 2, concerning linear coefficients, the p-value for the NaOH and Methanol variables is less than 0.05. The linear coefficients of these two input factors have a significant impact on viscosity. The effect of binary biodiesel mixture ratio and temperature on viscosity appears to be insignificant. However, in terms of second-degree coefficients, the p-value for the binary biodiesel ratio, temperature, and NaOH is greater than 0.05, and the p-value for methanol ratio is again less than 0.05. This implies that the methanol ratio has a greater impact on viscosity.

Table 2: Variance analysis of viscosity values

Source	DF	Adj SS	F-Value	P-Value
Model	14	855.286	14.86	0
Linear	4	603.418	36.69	0
CBR	1	0.0088	0.02	0.885
Temperature	1	0.0249	0.06	0.809
NaOH	1	36.062	8.77	0.009
Methanol	1	568.310	138.22	0
Square	4	439.647	26.73	0
CBR*CBR	1	0.1324	0.32	0.578
Temperature*Temperature	1	18.202	4.43	0.052
NaOH*NaOH	1	0.5319	1.29	0.272
Methanol*Methanol	1	337.162	82	0
2-Way Interaction	6	0.7885	0.32	0.917
CBR*Temperature	1	0.0921	0.22	0.642
CBR *NaOH	1	0.1009	0.25	0.627
CBR *Methanol	1	0.0068	0.02	0.899
Temperature*NaOH	1	0.0002	0	0.985
Temperature*Methanol	1	0.0015	0	0.952
NaOH*Methanol	1	0.6055	1.47	0.243
Error	16	65.784		
Total	30	921.070		

CBR: Canola biodiesel rate (%)

The quadratic equation generated by RSM to estimate the output parameters based on the input parameters is shown in Equation (1).

Viscosity = -0.3 + 0.0157 CBR + 0.830 T + 0.046 NaOH – 1.581 M – 0.00013CBR*CBR – 0.00747 T*T – 0.1053 NaOH*NaOH + 0.03113 M*M – 0.000267 CBR*T + 0.00178 CBR*NaOH + 0.000096 CBR*M – 0.00018 T*NaOH + 0.00012 T*M + 0.0145 NaOH*M (1)

The model was evaluated using the Model R-squared (R^2), root mean square error (RMSE), and mean absolute percentage error (MAPE). The R^2 value was utilized to measure the model's performance because it indicates the percentage of variation in the response variable that can be explained by the independent variables (Shahhosseini, Martinez-Feria, Hu, & Archontoulis, 2019). A higher R^2 value signifies a stronger predictive relationship. Conversely, RMSE and MAPE are used as error metrics, and lower values indicate better model performance (Gültepe, 2019; W. Wang & Xu, 2004). The R^2 value of the viscosity model was calculated to be 0.928, indicating a very high value. The RMSE and MAPE error metrics for this model were calculated as 0.46 $mm^2\ s^{-1}$ and 6.74%, respectively (Table 3).

Table 3: Metric performance of the RSM prediction result

Canola biodiesel rate (%)	**Waste cooking biodiesel rate (%)**	**Temperature (°C)**	**NaOH (gr lt^{-1})**	**Methanol (%)**	**Viscosities ($mm^2\ s^{-1}$)**		
					Exp.	**Pred.**	**Error (%)**
50	50	55	5.25	22.5	4.84	4.56	5.72
25	75	45	3.5	30	4.96	4.73	4.74
25	75	65	7	30	4.44	4.19	5.53
75	25	65	3.5	15	5.94	6.26	5.32
25	75	65	7	15	5.56	5.22	6.09
50	50	55	5.25	7.5	13.84	12.96	6.38
50	50	45	5.25	22.5	5.12	3.85	24.82
25	75	65	3.5	15	6.72	6.61	1.71
25	75	45	3.5	15	6.28	6.55	4.29
75	25	65	3.5	30	4.78	4.54	5.03
25	75	45	5.25	30	4.70	4.74	0.91
75	25	65	7	30	4.42	4.23	4.33
50	50	55	5.25	15	6.41	7.01	9.35
75	25	55	3.5	15	7.32	7.11	2.89
75	25	45	7	15	5.15	5.41	4.99
25	75	45	7	15	4.85	5.18	6.76
25	75	65	5.25	30	4.40	4.83	9.73
0	100	55	5.25	22.5	4.40	4.26	3.13
25	75	45	7	30	4.25	4.12	3.17
75	25	45	3.5	30	4.63	4.71	1.83
75	25	65	5.25	30	4.49	4.71	4.83
100	0	55	5.25	22.5	4.47	4.21	5.72
50	50	55	5.25	30	4.54	5.62	23.78
75	25	45	5.25	30	4.93	4.89	0.85
75	25	45	7	30	4.55	4.42	2.93
50	50	65	5.25	22.5	4.53	3.78	16.48
25	75	65	5.25	15	5.49	6.24	13.58
50	50	45	5.25	30	4.59	4.90	6.68
75	25	65	7	15	4.86	5.18	6.66
75	25	45	3.5	15	6.14	6.47	5.32
25	75	65	3.5	30	5.10	4.82	5.55
R^2						**0.928**	
RMSE						**0.460**	
MAPE						**6.740**	

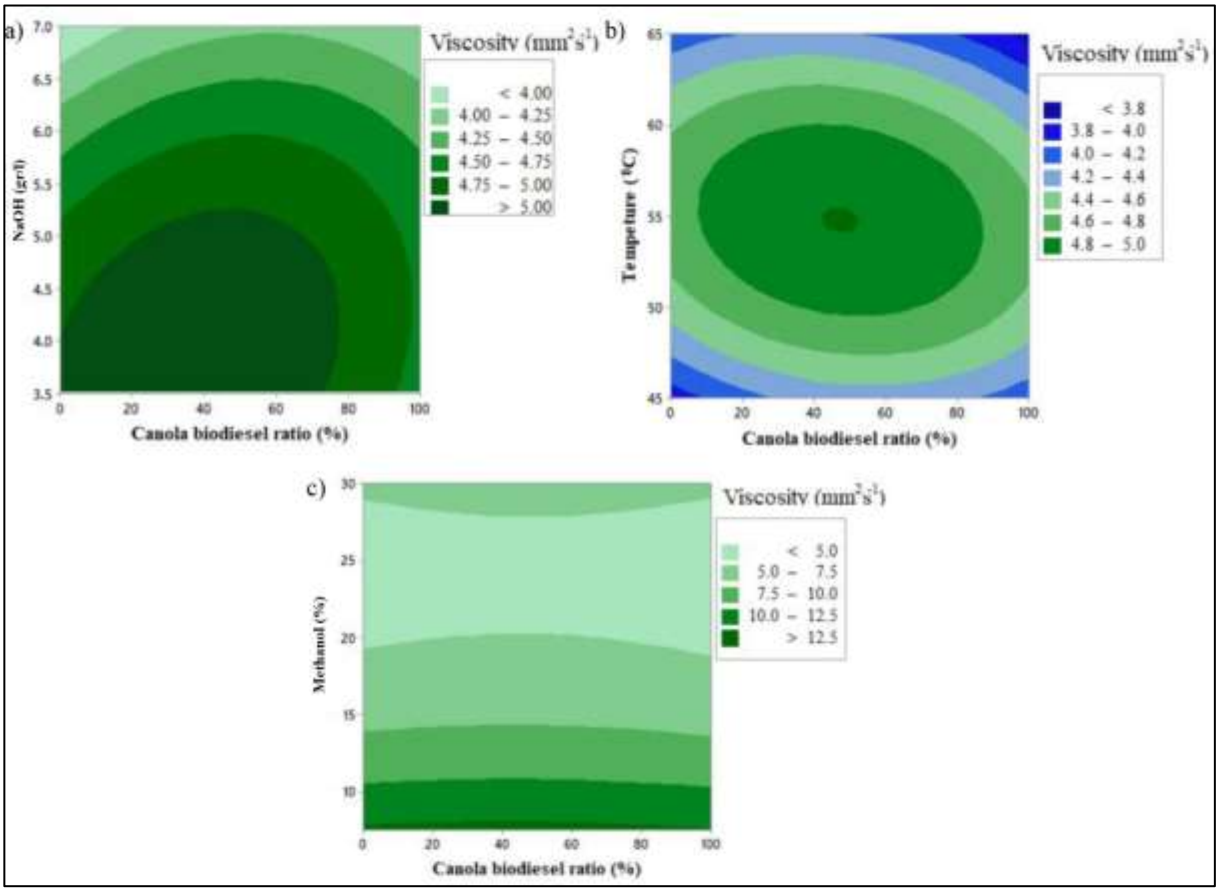

Figure 1: Effect of canola biodiesel ratio, NaOH, temperature and methanol variables on viscosity

The variation in viscosity with the ratio of canola biodiesel to NaOH and temperature at 55°C with 20 % methanol is illustrated in Figure 1a. As the NaOH ratio increases, the viscosity value decreases. Due to insufficient catalyst present in the reaction medium for low catalyst concentrations (e.g., 3.5 gr lt^{-1} sodium hydroxide), most of the triglycerides in the oil cannot be adequately converted to methyl esters throughout the reaction time. This condition increases the kinematic viscosity of the produced biodiesel. When a higher catalyst concentration is used (7 gr lt^{-1}), the efficiency of the transesterification reaction increases, consequently decreasing the viscosity of the produced biodiesel. However, excessive catalyst concentration leads to a decrease in the efficiency of the transesterification reaction, resulting in an increase in the viscosity of the produced biodiesel due to the formation of fatty acid salts (soap) (Bilgin, Gülüm, Koyuncuoglu, Nac, & Cakmak, 2015; Encinar, Gonzalez, Rodriguez, & Tejedor, 2002; Uzun, Kılıç, Özbay, Pütün, & Pütün, 2012). The variation in viscosity with the ratio of canola biodiesel to NaOH and temperature at 5.25 gr lt^{-1} NaOH with 20 % methanol is presented in Figure 1b. The viscosity value decreases with increasing temperature. At constant NaOH value, the kinematic viscosity value decreases as the waste cooking rate decreases.

The change of viscosity with canola biodiesel ratio and methanol at 55 ^{o}C temperature and 5 g l^{-1} NaOH ratio is given in Figure 1c. As the methanol ratio increases, the viscosity value decreases. However, after a certain methanol ratio, viscosity starts to increase. With the use of higher alcohol ratios, the efficiency of the transesterification reaction increases, leading to an increase in the viscosity of the biodiesel as the reaction shifts towards the products (El Sabagh, Keera, & Taman, 2011). Similar results have been reported by Bilgin, *et al.*, (2015).

Results and Recommendations

This study examined the optimization of parameters in the production of canola and waste cooking oil biodiesels using the RSM method. The findings indicate significant factors affecting viscosity and whether these effects are linear or quadratic. Specifically, it was observed that NaOH and methanol concentrations have notable effects on viscosity. One of the factors with the greatest impact on viscosity is the concentrations of NaOH and methanol. Careful adjustment of these concentrations is necessary to achieve optimum viscosity values.

The effect of methanol ratio on viscosity was found to be complex. Determining the optimum methanol ratio and ensuring that this ratio is not exceeded is important to prevent undesirable viscosity changes in biodiesel production. These recommendations should be considered to optimize viscosity during biodiesel production and obtain high-quality products. Future studies should further investigate the effects of other factors (such as reaction time, blend ratios) on viscosity to enhance knowledge in this area.

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