Optimization and Comparison of Catalysts in Rubber Seed Oil-Based Biodiesel Production

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Abstract. This study investigates the production of biodiesel from rubber seed oil using two different catalysts and compares the resulting fuel properties. Rubber seed oil was selected as the biofuel feedstock, and the process involved acid esterification followed by transesterification. Acid esterification effectively reduced the free fatty acid content of the oil, enabling efficient transesterification that produced biodiesel and glycerol as by-products. The manufacturing process was modelled using DWSIM chemical simulation software, with flow diagrams developed to analyze and compare performance outcomes. Catalysts such as NaOH and KOH were evaluated for their effectiveness in biodiesel production, and their influence on fuel properties was examined. Based on simulation results, the most suitable catalyst for biodiesel manufacturing was identified, highlighting the potential of rubber seed oil as a viable feedstock for sustainable fuel production.

1 Introduction

Global oil reserves are diminishing rapidly due to rising demand, and at current consumption levels, crude oil supplies may last only a few more years [1-3]. India, the second-largest importer of crude oil in Asia, faces significant economic challenges from its reliance on foreign oil. Reducing imports could save substantial resources while mitigating environmental impacts, as petroleum diesel is a major contributor to air pollution in the country [4-6]. These circumstances have driven global efforts to explore alternative fuels, with biofuels emerging as promising substitutes for diesel in automobile engines. Rubber seed oil (RSO) biodiesel offers a viable solution, providing cleaner combustion and lower emissions than petroleum diesel. Studies show that biodiesel significantly lowers carbon monoxide, hydrocarbons, sulphates, and other harmful pollutants, with reductions in disease-causing compounds reaching up to 85% [7]. Blending biodiesel with petroleum diesel further reduces emissions, with the reduction proportional to the biodiesel content. Additionally, biodiesel's lower volatility enhances safety during storage and transport, while its reduced net carbon emissions contribute to climate change mitigation [8-11]. India, ranking fourth globally in rubber production, has abundant potential to utilize rubber seed oil

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as a non-edible feedstock for biodiesel. Unlike edible oils, which are costly and compete with food supply, RSO provides an economical and sustainable alternative. However, raw RSO cannot be directly used due to its high free fatty acid (FFA) content. For efficient biodiesel production, FFA levels must be reduced to below 2%, as transesterification is inhibited when FFA levels exceed 3%. To address this, acid esterification is first employed to reduce FFA levels, followed by transesterification to produce biodiesel and glycerol as by-products. The chemical composition of RSO, containing both saturated and unsaturated fatty acids, confirms its suitability as a biodiesel feedstock. Extraction methods such as pressing and solvent extraction yield a characteristic yellow oil that, after processing, can be converted into a clean, renewable fuel source [12-14]. This work investigates the optimization and comparative performance of catalysts for rubber seed oil-based biodiesel production.

2 Materials and Methods

Rubber seeds (*Hevea brasiliensis*) were collected from the southern region of Tamil Nadu. The shells were manually removed, and the seeds were thoroughly cleaned. Approximately 500 grams of seeds and kernels were then heated in an oven at 110 °C for 5 hours to eliminate moisture content. The dried seeds were subsequently powdered and prepared for further processing.

2.1 Soxhlet Extraction of Rubber Seed Oil

Using the Soxhlet extraction process, the rubber seed oil was extracted as shown in Figure 1. A total of 350 grams of Hevea seed powder was weighed and transferred into a Soxhlet extraction tube. Approximately 400 mL of n-hexane was added to a round-bottomed flask, and the Soxhlet apparatus was assembled with a Liebig condenser. The solvent was then heated using a heating mantle at 70 °C for 48 hours. The extracted rubber seed oil was subsequently recovered through distillation.

Fig. 1. Soxhlet Extraction of Rubber Seed Oil.

2.2 Optimization of Biodiesel Process

The thermodynamic model chosen to study the liquid phase of the two-liquid system is the non-random activity coefficient (NRTL) model. The rubber seed contains the main fatty acids, as linoleic acid (62%) and oleic acid (38%), which are used for biodiesel production. The DWSIM software is the most suitable tool for creating and implementing a comprehensive biodiesel production optimisation process to achieve accurate results. In this study, two homogeneous catalysts, potassium and sodium hydroxide, were used to evaluate biodiesel efficiency. In this study, the catalyst's feed rates, input pressures, and temperatures were calculated and used in the simulation. DWSIM software also provides a final report of the flowsheet analysis and a graph of the respective outcomes. The components needed for biodiesel production plants were determined using the DWSIM analysis. It is very convenient to set the systematic values and yield to achieve the best results. To study the yield of biodiesel produced by different homogeneous and heterogeneous catalysts. Data entities such as pressure, temperature, and stirring rpm are shown in the flow diagram generated in DWSIM software. After entering all values and simulating the flow diagram one by one with different catalysts, the results are displayed, and homogeneous catalysts are finally selected based on the properties obtained from the simulations. The final results are presented by selecting the optimal catalyst based on the yield. The compounds required for the flow diagram in DWSIM software are listed in sequence. The compounds are explained below in the order of the flow process in the simulation diagram. In this design software flowsheet, the process simulation for the production of ethyl ester from rubber seed oil has been demonstrated. Oleic acid, NaOH, and ethanol are the feed components provided along with the mixture. Initially, the catalyst NaOH and the substitute ethanol are added to MIX-000. After the main feed in the process, oleic acid will be added to the stream mixture, where all three components are mixed in MIX-001.

2.2 Catalytic 1 Biodiesel Conversion in a Reactor

In the second stage of the flow diagram, the three feed components undergo reaction within the reactor chamber, as illustrated in Figure 2. A simplified mass and energy balance, incorporating the heat of reaction, was performed based on the changes in the quantities of the base components. Accordingly, an energy stream (E) was added and linked to the reactor at the outlet, with no energy input in kcal/h since the process operates under stable and steady conditions. The reactor functions under adiabatic operation. Outlet 1 serves as a pressure-relief stream (“p”), discharging material at a temperature exceeding 85 °C and a pressure of 1 atm. Outlet 2, designated as reaction product stream M1, contains the remaining components at 87 °C and 1 atm, with a mass flow rate of 305 g/s, and is directed to VALVE-000. The reactor acts as the inlet to this unit, with M1 as the outlet. VALVE-000 operates under an outlet-pressure calculation mode, with a pressure drop of less than 1 atm (outlet pressure: 0.2 atm; Kv(max) according to IEC 60534). A flash calculation using pressure and enthalpy (PH) specifications is applied to determine the stream conditions at an inlet temperature of 65 °C and pressure below 1 atm, involving ethanol, glycerol, and NaOH_BD. The heater is connected to the energy stream E-04 as the primary energy source. Its inlet and outlet streams are M1 and M1**, respectively, with the outlet temperature specified as 44 °C and an assumed efficiency of 100%. The combined heating and cooling duty for the component adjustments is −19,693 kcal/h.

Material stream M1** contains the outlet from the heater. The next process in biodiesel production, i.e., ethanol separation *via* an ethanol distillation column. The M1** inlet connection includes a single feed stage that is connected to the column. The shortcut column is used to calculate the minimum reflux and the product distribution in a distillation column. The column contains a single feed stage, two products (top and bottom), a condenser (partial

or total), and a reboiler. The two product streams are shown in this distillation process. The top product is called a distillate column. The purpose of that is to recycle the ethanol to the material stream, ethanol recycle ** for the next simulation process. The energy stream connects both product streams with 3, 54,883 kcal/h and 4,44,266 kcal/h. The bottom stream is connected to the biodiesel and impurity material stream. The duty of the condenser and reboiler is connected to the ESTR-048 and ESTR-049 energy streams. The calculation parameter is a light key component, and heavy key components are Ethonal_BD and Etp. The reflux ratio is 10, and the total condenser type with the condenser and reboiler pressure is 0.3 atm. Finally, the rectified liquid and vapour flow rates are 8.741 mol/s and 9.615 mol/s, respectively. Next, the output is carried to the final stage for the purification process, with a 264.74 g/s molar flow rate of biodiesel, and impurities were removed.

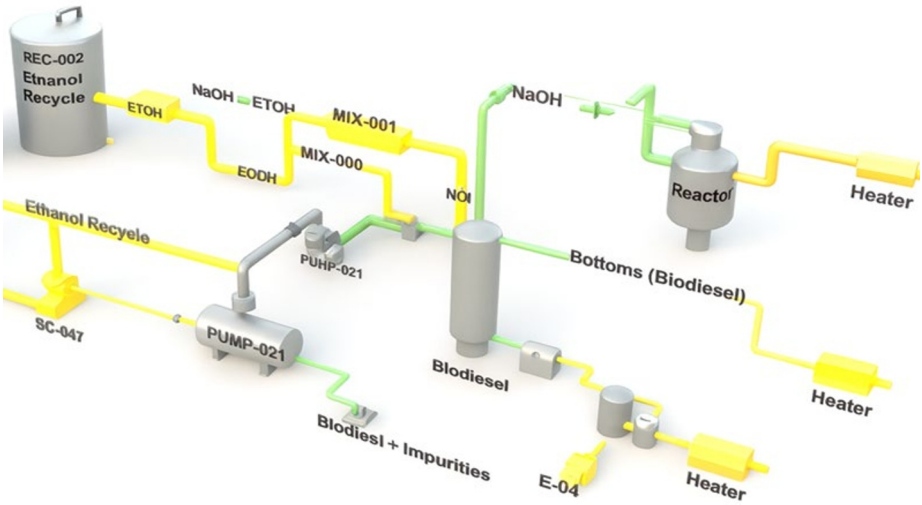

Fig. 2. Flow diagram for NaOH catalyst in the biodiesel process optimization.

2.4 Purification of Biodiesel in a Reactor

The material stream is an inlet to the pump. The pump provides energy to a liquid stream in the form of pressure. The outlet stream is M4, with a pressure-increasing type, and the pressure is increased to 0.70 atm with 100% efficiency. The outlet temperature from the pump is 235.9°C, and the temperature change is 32.1°C. The power required for the system pump process is 26.169 kcal/h, and this is then transferred to the material stream M4, with a molar flow of 264.74 g/s, to the absorption column. The extraction column is a unit operation that functions as a fractionating tower, separating components in a mixture at various equilibrium stages. The absorber is a liquid-liquid extractor with 12 stages. Convergence tolerance is 1E-05, with a maximum of 100 iterations. The top-stage stream is used to extract water and impurities from the biodiesel column. The material stream has a 0.9 water-to-other-impurities ratio at 100 °C and 1 atm, with a molar flow rate of 302.5 g/s. The bottom stream contains the biodiesel, the pressure, the enthalpy flash Spec, and the temperature is 60.4 °C; the volumetric flow in the compound is 272.68 cm^3/s. VALVE-001 inlet stream is bottom (biodiesel), and the outlet stream is M3. Material stream 3 is connected to a separator vessel inlet, and the vapour stream is M4, and the liquid stream inlet is M6. The material stream 6 inlet pump is a pressure-increase type pump, with an efficiency of 75% and an output temperature of 60 °C. The pump outlet stream is connected to M6*. Finally, the cooler inlet

from M6* and the outlet are biodiesel products; the energy stream added to the cooler is used for heating and cooling. Outlet temperature is 25 °C, and the heating and cooling energy stream efficiency is 100%, with a value of 8,868 kcal/h. The energy stream of the end process obtained the product at a molar rate of 226.47 g/s, and the product's density is 0.856 g/cm^3. The pure biodiesel obtained from the initial feed component, oleic acid from rubber seed oil, is converted into oleic acid ethyl ester using a homogeneous catalyst, NaOH. This process is continuously operated by the ethanol recycle stream, and it will again simulate a thought process by adding feed components. This catalyst process is more suitable and efficient for biodiesel efficiency.

2.5 Catalytic 2 Biodiesel Conversion in a Reactor

The production of ethyl ester from rubber seed oil containing oleic acid as the main fatty acid profile using KOH as a catalyst has been demonstrated, as shown in Figure 3. The flac spec is temperature and pressure, and the input is 6 g/s molar flow feed. Because the catalyst KOH feed rate needs to be more than that of NaOH. Next steps are mostly similar to the catalyst one in the flow diagram for simulation. Consequently, Oleic acid, KOH, and ethanol are the feedstocks used in the mixture. Initially, the catalyst KOH and the substitute ethanol are added to MIX-000. After the main feed, oleic acid was added to the stream mixture in MIX-001, where all three components are mixed, then introduced into the reactor via the material stream, and the relief is extracted. Reaction products enter into the heater to achieve a suitable pressure drop and temperature increase, similar to the catalyst 1 (NaOH), and the flow simulation is adjusted accordingly. Ethanol distillation occurs in the shortcut column using the ESTER method. Ethanol recycling is linked to the KOH feed to prepare for the subsequent simulation. The bottom stream carries the biodiesel and the impurity material stream to pump and M4. For the absorption chamber, the purification of the catalyst KOH is similar to the previous flow process. Temperature and pressure were varied with different feed rates, while the mode functions remained the same. In biodiesel purification using the separator, we obtained the by-products and pure biodiesel as the final material stream, with a mass flow rate of 225.8 g/s. Density is 0.8 g/cm^3 at 25 °C. Feed of the KOH is more than NaOH to achieve the suitable ratio for the ethyl ester.

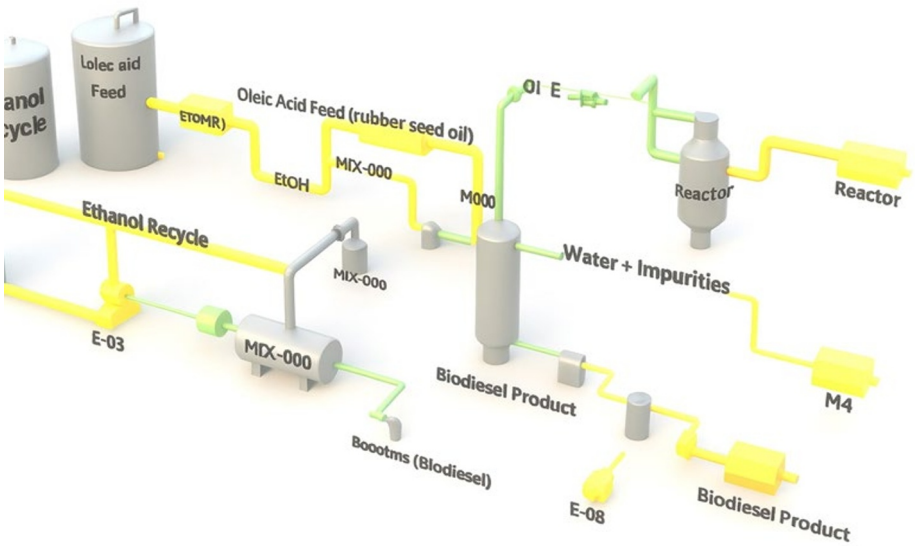

Fig. 3. Flow diagram for KOH catalyst in the biodiesel process optimization.

3 Results and Discussions

The simulation results for both the KOH- and NaOH-catalyzed processes were analyzed to obtain the final outcomes of the biodiesel production model. The key differences in the catalytic properties are compared and summarized in Table 1.

Table 1. Properties of Sodium Hydroxide–Ethanol Mixture

NaOH + EtOH		
Object	NaOH + EtOH	
Temperature	36.925741	°C
Pressure	1	atm
Mass Flow	79.030072	g/s
Molar Flow	1.722756	mol/s
Mass Fraction (Mixture) / Ethanol_BD	0.971569	
Mass Fraction (Mixture) / EtP	0.000031	
Mass Fraction (Mixture) / PPP	0	
Mass Fraction (Mixture) / NaOH_BD	0.028369	
Mass Fraction (Mixture) / Glycerol_BD	0.000031	

From stage 1 of the process flowchart, the input feed NaOH and EtOH mixture obtain an outcome composition of 36.9°C temperature and 1 atm pressure, with a mass flow of 79.03 g/s and a molar flow of 1.72 mol/s was occurred, and the mass fraction mixture of ethanol_BD is 97% was generated in the NaOH and EtOH mixture process as shown in Table 1. After the mix of all three input feed components, the NaOH, EtOH, and oil result in the output temperature of 68.11°C and pressure of 1 atm. The mass flow of this mixture is 303.28 g/s, and the molar flow of the mix is 2 mol/s. In this process, the mass fraction mixture of Ethanol_BD is 25 % as shown in Table 2. Those three mixture components, after entering the reactor and valve, form the M1 stream, which has a temperature of 89.35°C and a pressure of 1 atm. The stream has a mass flow rate of 303.28 g/s and a molar flow rate of 2 mol/s, and its generated mass fraction mixture of ethanol_BD is 13 % as shown in Table 3.

Table 2. Properties of Sodium Hydroxide–Ethanol Mixture and Oil

NaOH + EtOH + Oil		
Object	NaOH + EtOH + Oil	
Temperature	68.11091	°C
Pressure	1	atm
Mass Flow	303.289072	g/s
Molar Flow	2.000534	mol/s
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.253168	
Mass Fraction (Mixture) / EtP	0.000008	
Mass Fraction (Mixture) / PPP	0.739423	
Mass Fraction (Mixture) / NaOH_BD	0.007392	

Mass Fraction (Mixture) / Glycerol_BD	0.000008	

Table 3. Characteristics of M1 Stream

Reaction Products		
Object	Reaction Products (M1)	
Temperature	89.353081	°C
Pressure	1	atm
Mass Flow	303.289072	g/s
Molar Flow	2.000539	mol/s
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.132914	
Mass Fraction (Mixture) / EtP	0.742583	
Mass Fraction (Mixture) / PPP	0.036971	
Mass Fraction (Mixture) / NaOH_BD	0.007392	
Mass Fraction (Mixture) / Glycerol_BD	0.080139	

The M1 stream, after entering the heating process and experiencing a pressure drop at the heater exit, is designated M1** and enters the Ethanol distillation column, where the component properties are 44.67°C and 0.29 atm. The mass flow rate in the distillation column is 303.28 g/s, corresponding to a molar flow rate of 2 mol/s.The mass fraction mixture of Ethanol_BD generated is 13 % as shown in Table 4. The M1** stream, after entering the ethanol distillation chamber, where ethanol and biodiesel with impurities are separated. The M2 stream then enters the biodiesel purification chamber and exits with two products: bottoms (biodiesel) and water and impurities. The bottoms (biodiesel) product gives properties such as a temperature of 60.45°C with a pressure of 1 atm, and it provides a mass flow rate of 226.47 g/s and a molar flow rate of 0.78 mol/sec, as shown in Table 5. The bottoms (biodiesel) then enter the separator, where the two phases are separated; the biodiesel product is then separated from the by-products and cooled to reduce the temperature. The final biodiesel product has properties such as a temperature of 25°C with a pressure of 1 atm. Mass flow rate in the biodiesel is found to be 226.47 g/s, and the molar flow rate produced is 0.78 mol/s. The result gives a density mixture of 0.856375 g/cm^3, and the value is closer to the petroleum diesel density, as shown in Table 6.

Table 4. Characteristics of M1** stream

M1**		
Object	M1**	
Temperature	44.67	°C
Pressure	0.296077	atm
Mass Flow	303.289072	g/s
Molar Flow	2.000539	mol/s
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.132914	
Mass Fraction (Mixture) / EtP	0.742583	
Mass Fraction (Mixture) / PPP	0.036971	
Mass Fraction (Mixture) / NaOH_BD	0.007392	
Mass Fraction (Mixture) / Glycerol_BD	0.080139	

Table 5. Properties of the output components after liquid-liquid extraction

Liquid-Liquid Extraction			
Object	Bottoms (Biodiesel)	Water + Impurities	
Temperature	60.455534	100.610148	°C
Pressure	1	1	atm
Mass Flow	226.472356	302.584363	g/s
Molar Flow	0.78513	15.110749	mol/s
Mass Fraction (Mixture) / Ethanol_BD	0.000059	0.000127	
Mass Fraction (Mixture) / Water_BD	0	0.879341	
Mass Fraction (Mixture) / Glycerol_BD	0	0.08025	
Mass Fraction (Mixture) / EtP	0.978211	0.012079	
Mass Fraction (Mixture) / NaOH_BD	0	0.00741	
Mass Fraction (Mixture) / PPP	0.02173	0.020793	

Table 6. Properties of the final biodiesel product using NaOH catalyst

Biodiesel Product		
Object	Biodiesel Product	
Temperature	25	°C
Pressure	1	atm
Mass Flow	226.472356	g/s
Molar Flow	0.78513	mol/s
Density (Mixture)	0.856375	g/cm^3
Mass Fraction (Mixture) / Ethanol_BD	0.000059	
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Glycerol_BD	0	
Mass Fraction (Mixture) / EtP	0.978211	
Mass Fraction (Mixture) / NaOH_BD	0	
Mass Fraction (Mixture) / PPP	0.02173	

Figure 4 shows the simulation-calculated iteration range plotted against the SP/CV molar flow (mixtures)/ethanol_BD (mol/s) and the MV molar flow (g/s) values. The adjusted value is 1.6666. In the steady-state controller, the convergence method is secant, and the tolerance is 0.0001. The blue colour point indicates the set point variable (mol/s), the green point indicates the controlled variable (mol/s), and the orange point shown in the graph is the manipulated variable (g/s). The X-axis represents the number of iterations as a function of Y. In the ADJ control panel, the values and the flowsheet are calculated successfully and end at iteration 3 out of 10 in the simulation software, indicating that a perfect working flow diagram is provided. Moreover, the graph shows that the iteration with the NaOH catalyst yields the most accurate results. Each iteration indicates that the coordinate points of the ethonal_BD and the molar flow of the process slow the calculated values based on the component inputs given in the flow diagram.

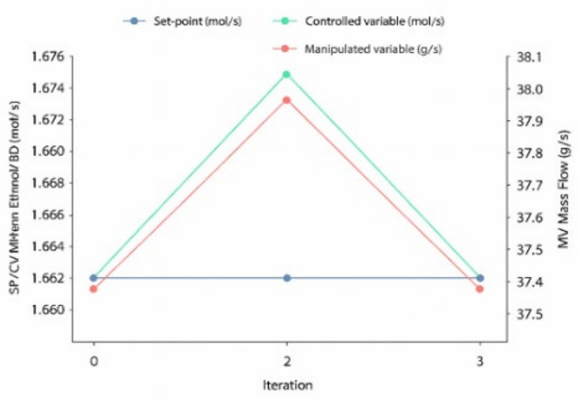

Fig. 4. Iteration plot for the NaOH Catalyst

From the first stage of the process flowchart, the input feed KOH and EtOH mixture (Table 7) shows an outcome composition of 34.02°C temperature and 1 atm pressure, with a mass flow of 82.78 g/s and a molar flow of 1.81 mol/s, and the mass fraction mixture of ethanol_BD is 92 % was generated in the NaOH and EtOH mixture process. From the first stage of the process flowchart, the input feed KOH and EtOH mixture (Table 7) shows an outcome composition of 34.02°C temperature and 1 atm pressure, with a mass flow of 82.78 g/s and a molar flow of 1.81 mol/s, and the mass fraction mixture of ethanol_BD is 92 % was generated in the NaOH and EtOH mixture process. After the mixture of all three input feed components, the KOH, EtOH, and oil will give the output temperature of 25°C and a pressure of one atm. The mass flow of this mixture is 225.80 g/s, and the molar flow of the mixture is 0.78mol/s. In this process, the mass fraction mixture of Ethanol_BD is 0.0061 percent (Table 8). Those three mixture components, after entering the reactor and valve, form the M1 stream, which has a temperature of 84.90°C and a pressure of 1 atm. The stream has a mass flow rate of 307.04 g/s and a molar flow rate of 2.09 mol/s. Moreover, its generated mass fraction mixture of ethanol_BD is 13 % (Table 9).

Table 7. Properties of KOH–Ethanol Mixture

KOH + EtOH		
Object	KOH + EtOH	
Temperature	34.021938	°C
Pressure	1	atm
Mass Flow	82.788072	g/s
Molar Flow	1.816713	mol/s
Density (Mixture)	0.77665	g/cm^3
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.927467	
Mass Fraction (Mixture) / EtP	0.000029	
Mass Fraction (Mixture) / PPP	0	
Mass Fraction (Mixture) / Glycerol_BD	0.00003	

Table 8. Properties of KOH–Ethanol Mixture and Oil

KOH + EtOH + Oil		
Object	Biodiesel Product	
Temperature	25	°C
Pressure	1	atm
Mass Flow	225.800674	g/s
Molar Flow	0.783095	mol/s
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.000061	
Mass Fraction (Mixture) / EtP	0.97876	
Mass Fraction (Mixture) / PPP	0.021178	
Mass Fraction (Mixture) / Glycerol_BD	0	

Table 9. Properties of M1 stream using KOH catalyst

Reaction Products		
Object	Reaction Products (M1)	
Temperature	84.902588	°C
Pressure	1	atm
Mass Flow	307.047072	g/s
Molar Flow	2.094496	mol/s
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.131287	
Mass Fraction (Mixture) / EtP	0.733495	
Mass Fraction (Mixture) / PPP	0.036519	
Mass Fraction (Mixture) / Glycerol_BD	0.079159	

The M1 stream, after entering the heating process and experiencing a pressure drop at the heater exit, is designated M1** and enters the Ethanol distillation Field, where the component properties are 44.67°C and 0.29 atm. The mass flow produced in the distillation column is 307.04 g/s, and the molar flow rate is 2.09 mol/s. The mass fraction mixture of Ethanol_BD generated is 13 % as shown in Table 10. The M1** stream, after entering the ethanol distillation chamber, where ethanol and biodiesel with impurities are separated. The M2 stream then enters the biodiesel purification chamber and exits with two products: bottoms (biodiesel) and water and impurities. The bottoms (biodiesel) product has a temperature of 60.44°C at 1 atm, a mass flow rate of 225.80 g/s, and a molar flow rate of 0.78 mol/s (Table 11). The bottoms (biodiesel) then enter the separator, which separates two phases; the biodiesel product is separated from the by-products, and the mixture is then cooled to reduce the temperature. The final biodiesel product has properties such as a temperature of 25°C at 1 atm. The mass flow rate of biodiesel is 225.80 g/s, and the molar flow rate produced is

0.783 mol/s. The result yields a density of 0.856365 g/cm^3, which is closer to the petroleum diesel density (Table 12).

Table 10. Properties of M1** stream using KOH catalyst

M1**		
Object	M1**	
Temperature	44.67	℃
Pressure	0.296077	atm
Mass Flow	307.047072	g/s
Molar Flow	2.094496	mol/s
Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Ethanol_BD	0.131287	
Mass Fraction (Mixture) / EtP	0.733495	
Mass Fraction (Mixture) / PPP	0.036519	
Mass Fraction (Mixture) / Glycerol_BD	0.079159	

Table 11. Properties of the output components after liquid-liquid extraction of the KOH catalyst

Liquid-Liquid Extraction			
Object	Bottoms (Biodiesel)	Water + Impurities	
Temperature	60.446864	100.787755	℃
Pressure	1	1	atm
Mass Flow	225.800674	307.020942	g/s
Molar Flow	0.783095	15.206851	mol/s
Mass Fraction (Mixture) / Ethanol_BD	0.000061	0.000138	
Mass Fraction (Mixture) / Water_BD	0	0.866634	
Mass Fraction (Mixture) / Glycerol_BD	0	0.079097	
Mass Fraction (Mixture) / EtP	0.97876	0.013641	
Mass Fraction (Mixture) / PPP	0.021178	0.020947	

Table 12 Properties of the final biodiesel using KOH catalyst

Biodiesel Product		
Object	Biodiesel Product	
Temperature	25	℃
Pressure	1	atm
Mass Flow	225.800674	g/s
Molar Flow	0.783095	mol/s
Density (Mixture)	0.856365	g/cm3
Mass Fraction (Mixture) / Ethanol_BD	0.000061	

Mass Fraction (Mixture) / Water_BD	0	
Mass Fraction (Mixture) / Glycerol_BD	0	
Mass Fraction (Mixture) / EtP	0.97876	
Mass Fraction (Mixture) / PPP	0.021178	

Figure 5 shows the simulation-calculated iteration range plotted against the SP/CV molar flow (mixtures)/ethanol_BD (mol/s), with the MV molar flow (g/s) values. The adjusted value is 1.6666. In the steady-state controller, the convergence method is secant, and the tolerance is 0.0001. The blue color point indicates the set point variable (mol/s), the green point indicates the controlled variable (mol/s), and the orange point shown in the graph is the manipulated variable (g/s). The X-axis represents the number of iterations, and the Y-axis indicates the corresponding values. In the ADJ control panel, the values are adjusted, and the flowsheet is successfully calculated, ending at iteration 3 out of 10 in the simulation software, indicating a perfect working flow diagram. According to the graph, the iteration using the KOH catalyst yields the most accurate results. Each iteration shows that the coordinate points of the ethonal_BD and the molar flow of the process slow the calculated values based on the component inputs given in the flow diagram. Those iterations are shown below for an easily understood purpose, and the picture conveys the understandable results of the flow process of making biodiesel using the KOH catalyst.

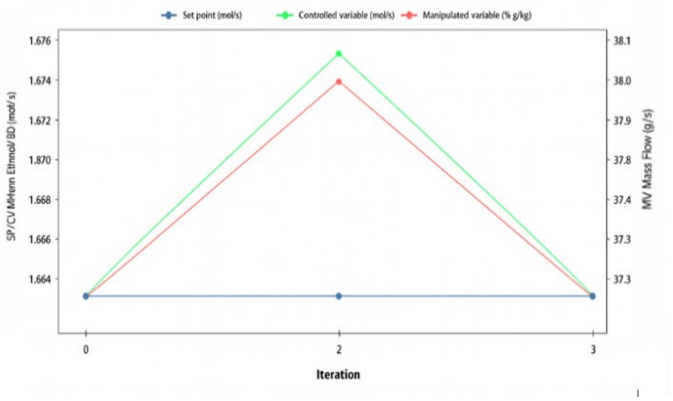

Fig. 5. Iteration plot for the KOH catalyst

The production cost and the amount of raw materials used in the process are the primary factors to consider. For that, the catalyst amounts in the process used as a feed for production vary between the two. To manufacture biodiesel, more KOH (in grams per batch) is required than NaOH. Processes are long chemical explanations as necessary: densities, molar ratios, and the kind of composition. To manufacture a given quantity of biodiesel, more KOH is required than NaOH in the simulation process. The NaOH molar flow feed rate is required to be 2.242 g/s for a perfect batch simulation of biodiesel production. In the KOH catalyst, the molar flow rate is 6 g/s. Based on the availability of raw materials, the percentage of products produced, and the quality standards, they vary. The important thing is to make the right decision to verify the available raw materials. The process time, based on the product manufacturer's needs, will be determined and finalized. The catalyst process yield is the yield of the major product used to make biodiesel. It achieved making a successful product, which yields a percentage. The rate of both catalyst yields in the distillation column phase. The recycled ethanol recovery was successful at 98.7%, and the composition of the final biodiesel was approximately 98.20% ethyl ester, 0.05% ethanol, and 1.74% by-products. And the mass

flow of the biodiesel using the catalyst. For KOH, the mass flow is 225.80126 g/s, and the molar flow is 0.78 mol/s with a density of 0.85636 g/cm^3. For NaOH, the mass flow rate in the biodiesel is 226.47 g/s, and the molar flow rate is 0.78 mol/s. The result gives a density mixture of 0.856375 g/cm^3. Sodium hydroxide (NaOH) and potassium hydroxide (KOH) are both effective catalysts for biodiesel production, though they exhibit notable differences. While both react with oil through similar transesterification processes, NaOH is generally available in a purer form and provides stronger reaction flow at operating temperatures of 80–90 °C. When equipment struggles with methanol boiling, NaOH may be preferred. KOH, however, dissolves more rapidly in methanol, making it advantageous at lower temperatures and enabling faster initiation of biodiesel batches. Additionally, glycerin obtained from KOH-catalyzed reactions can be utilized for liquid soap production, offering manufacturers a potential secondary income stream. NaOH is often preferred when minimizing production costs is the priority, whereas KOH is preferred when by-product utilization is desired. Overall, KOH enables faster processing and additional product opportunities, while NaOH remains cost-effective and efficient at higher temperatures. KOH is also considered less toxic in glycerin applications and more suitable for biodiesel production in colder environments.

4 Conclusion

This study focused on the optimization and comparison of NaOH and KOH catalysts in the production of biodiesel from rubber seed oil. Using the transesterification process and simulating the reaction in DWSIM software, biodiesel yields of up to 98.4% were achieved, along with valuable by-products such as glycerol. The simulation provided accurate insights into process composition and manufacturing pathways, confirming the effectiveness of rubber seed oil as a non-edible feedstock. While previous research has explored biodiesel production with various catalysts, this work uniquely compared the fuel properties obtained with NaOH and KOH, highlighting differences in efficiency, cost, and environmental performance. The results demonstrate that biodiesel produced with these catalysts is smooth-running, cost-effective, and eco-friendly, with lower consumption rates than conventional fuels. The findings establish a clear framework for catalyst selection in biodiesel manufacturing, offering practical guidance for future studies and industrial applications. By elaborating on both energy efficiency and sustainability, this project contributes significantly to the advancement of renewable fuel technologies and provides a foundation for future generations of manufacturers to optimize catalyst choice in biodiesel production.

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