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Optimization of the Synthesis of Biolubricant from Palm Kernel Oil (PKO) with Alkali Produced from Oil-Palm Empty Fruit Bunches (OPEFB)

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ABSTRACT

In this study Design-Expert Software Version 11 was used to optimize the synthesis of a biolubricant through the transesterification of palm kernel oil (PKO) methyl ester and propane-1,2-diol, using potassium hydroxide (KOH) produced from Oil-Palm Empty Fruit Bunches (OPEFB). The OPEFBs were first pulverized into small bits, sun-dried, and burned. The resulting fine particles were soaked in distilled water. The concentration of the filtrate was determined by titration as 0.2 mol/dm^3. The KOH produced was odourless, slightly yellow, and hygroscopic. Response surface methodology (RSM) using central composite design (CCD) was employed for the experiment design. The effects of temperature, molar ratio, and reaction time on the yield of biolubricant were evaluated. The predicted yield after process optimization was found to agree with the experimental value. The optimum conditions were obtained at a temperature of 100 °C, a molar ratio of 7:1, and a time of 200 min for a 96% biolubricant yield for PKO. Molar ratio and reaction time were found to be the most significant variables for PKO. The Analysis of Variance (ANOVA) implied that molar ratio and temperature were the most significant factors affecting the yield of biolubricant.

1. Introduction

Transesterification is the frequent approach used to transform triglycerides into biodiesel and Biolubricant. This consists of the reaction between triglycerides and an acyl-acceptor (Helwani, et al., 2009; Burton, 2009). Carboxylic acids, alcohols, or other esters can be used as an acyl-acceptor. Transesterification produces glycerol when an alcohol is used as acyl-acceptor or triacylglycerol when the ester is used. When a catalyst is employed in a transesterification reaction it is called catalytic transesterification, whereas that without a catalyst is called the non-catalytic transesterification (Marchetti et al., 2007). Biodiesel is made by trans esterifying oils using short-chain alcohols or esterifying fatty acids (Vasudevan and Briggs, 2008), whereas biolubricants are prepared using long-chain alcohols/polyols with fatty acids that fulfil the toxicity and biodegradability criteria. For biolubricant production, the fatty acid chain length is usually between C_{12} and C_{24}. The carbon chain length and amount of double bonds in the fatty chain are the two most important elements that influence the

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characteristics of biolubricants. Biolubricants with longer chain lengths have a greater melting point and viscosity, whereas biolubricants with higher double bonds have lower melting points, viscosity, and oxidative stability (Md. Anwar, et al., 2018). Biolubricants are biodegradable, renewable and have higher viscosity and affinity for metal surfaces, allowing them to lubricate surfaces more effectively.

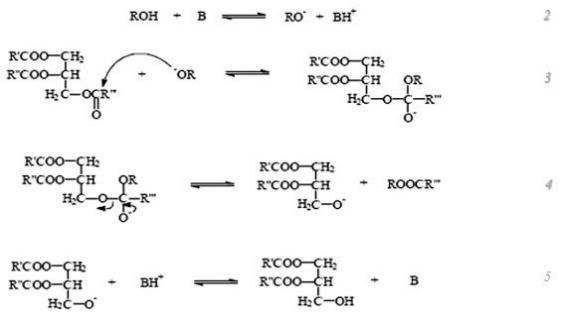
Palm kernel oil is a plant oil made from the kernel seed of palm trees (*Elaeis guineensis*). Palm kernel oil, like any other fat, is made up of fatty acids esterified with glycerol (Adeyemi et al., 2020). Although biolubricants made from vegetable oils are more expensive than mineral lubricants, they are a promising alternative to synthetic and mineral oil-based lubricants due to their unique functional characteristics, such as high viscosity index, good lubricity, superior anticorrosion properties, high flash point, high biodegradability, and low aquatic toxicity (Salimon et al., 2010, 2014). The most crucial first stage in manufacturing biofuel/biolubricant is the transesterification of vegetable oils, which produces fatty acid alkyl esters and glycerol (Fabiano et al., 2012; Musa, 2016). In general, the stoichiometric transesterification reaction requires one mol of triglyceride and three moles of alcohol and can be presented represented as:

$$A + 3B \rightleftharpoons 3R + S \quad (1)$$

where A is the oil; B is the alcohol; R is the biodiesel and S is the glycerol, with a catalyst involved (Deshmane and Adewuyi, 2013; Salaheldeen et al., 2021).

Many research investigations on the synthesis of biodiesel/biolubricant follow a three-step transesterification process, where initially the triglycerides are transesterified to a diacylglycerol or fatty acid methyl esters (FAEE) and then the diacylglycerol is then converted to monoacylglycerol giving an additional fatty acid ester and then transesterified again with the respective alcohols to produce desirable Biolubricant components (long-chain esters) or glycerol (Taher et al., 2011;Van Gerpen et al., 2010). Transesterification is an equilibrium reaction in which a large excess of alcohol must drive the reaction in the right direction. The triglyceride interferes with the separation of glycerol because there is an increase in solubility. The separation is difficult and the apparent yield of esters decreases because part of the glycerol remains in the methyl ester phase. When glycerol remains in the solution, it drives the equilibrium back to the left, thereby lowering the yield of esters.

The alkaline catalyst mostly used is the potassium hydroxide (KOH) since it decreases the tendency for soap formation compared to sodium hydroxide (NaOH). It also reduces the number of methyl esters dissolved in the glycerol phase after the reaction and thus reduces ester losses (Anusi, et al., 2018).



Since cost is the main concern in biodiesel production and trading, successful studies on the feasibility of low-cost precursors (either the oil, alcohol or catalyst) to reduce the overall cost of production would revolutionize investment in the sector. This study investigates the production of

biolubricant from Palm Kernel oil (PKO) and propane-1,2-diol using potassium hydroxide catalyst prepared from OPEFB. The objectives of the study are the preparation of potassium hydroxide (KOH) from pretreated OPEFB, the design of the experiment using Design-Expert software (for the optimization of production yield), and characterization of the biolubricant produced.

2. Materials and Methods

PKO was used for the transesterification and was obtained from the neighbourhood of Enerhen Junction, in Effurun, Delta State, Nigeria. The OPEFBs were obtained from a local market at a very low cost (a tip). Ethanol was employed as the alcohol to react with PKO. KOH (prepared from OPEFBs) was used as the catalyst. PET bottles were used for the reaction. Other equipment and apparatus that were used include viscometer, weigh balance, heater, thermometer, glass spatula, funnel, Bunsen burner, Whatman filter paper, retort stand, separator funnel, Erlenmeyer flask, measuring cylinder, beaker, masking tape, and PET bottle for storage

2.1 Methods

2.1.1 Preparation of ash from Oil Palm Empty Fruit Bunches

The OPEFB precursors were chopped into small pieces and dried for 6 to 10 days in the sun. The sun-dried OPEFBs were charred using an open-air fire. After that, the ash samples were pulverized into fine powder. The samples were then placed in a crucible and heated for at least 80 minutes using a Bunsen burner to obtain finer particle size, which was then dissolved in distilled water in a beaker and agitated with a glass spatula. To obtain a potassium hydroxide solution, the resultant solution was filtered with Whatman filter paper. The solution was then titrated against a known concentration of a standard acid to ascertain its concentration.

2.1.2 Production of biolubricant

PKO was filtered and heated to remove water and other impurities that could affect the result. Then, potassium ethoxide was prepared from potassium hydroxide and ethanol in a PET bottle. The PKO was poured into another PET bottle, the potassium ethoxide was poured into the PKO, and then the bottle lid was tightened. The mixture in the PET bottle was stirred and heated to a temperature of not more than 78°C, which is the boiling point for ethanol, for at least 30 minutes. The mixture was poured into a separating funnel, suspended by a retort stand, and allowed to settle. This showed a phase separation after about 10 minutes. The reaction mixture was then separated into the upper amber-coloured ethyl ester layer (biodiesel) and the lower impure glycerol layer. The ethyl ester produced was heated in a water bath at 70°C and 0.9 g/mole of potassium hydroxide (base-catalyst) solution was added. After 10 minutes, 20 g/mole of propane-1,2 diol was added to the reaction vessel and the reaction was allowed to proceed for 2 hours at 80°C. Thereafter, the reaction mixture was allowed to settle at room temperature. The mixture was then transferred into a separating funnel and the propane-1,2-diol triester (biolubricant) was collected at the bottom as a viscous layer. All the aforementioned steps were repeated at varied input parameters (temperature, mola, ratio, and time) for PKO using the Design layout of the Design-Expert software for an array 20 experimental runs to investigate the impact of process variables on response, as well as the interaction of the process variables. The

percentage yields of KOH, ethyl ester, and biolubricant are calculated using Equations 2, 3 and 4, respectively (Alang, et al., 2010) % yield of KOH = $\frac{\text{Mass of KOH obtained}}{\text{Mass of ash taken}}$ * 100 (2)

Yield of ethyl ester = $\frac{Vp}{Vs}$ * 100 (3)

where V_P is the volume of product and V_S the volume of sample oil used for the synthesis

% yield of biolubricant = $\frac{Vp}{Vs}$ * 100 (4)

where V_P is the volume of product and V_P the volume of sample taken.

2.2 Design of experiment

Central composite design (CCD) was used to study the effect of transesterification reaction variables and subsequent process optimization. This method is suitable for fitting quadric surfaces, which help optimize the effective parameters with the least number of experiments and analysing the interaction between the parameters. To describe the effects of temperature, time, and molar ratio on the yield of biolubricant, batch experiments was conducted based on the Central Composite Design. Equation 5 is used to determine the coded values of the process parameters.

$x_i = (X_i - X_0)/\Delta X$ (5)

where x_i is the coded value of the ith variable, X_i is the uncoded value of the ith test variable and X_0 is the uncoded value of the ith test variable at the centre point. A second-order polynomial equation (6) is used to express the biolubricant yield (Y) as a function of the independent variables:

$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ij} X_i^2 + \sum_{j=1}^{k} b_i X_i X_j + e$ (6)

where Y is the response factor (% yield), i and j denote linear and quadratic coefficients, respectively; b_0 is the intercept, b_i is the first-order model coefficient, k is the number of factors and e is a random number.

3.0 Results and Discussion

3.1 Analysis of transesterification product

The factors levels of the independent variables for PKO are presented in **Table 1**. Regression analysis was performed to estimate the response function as a second-order polynomial. A statistical software package, Design Expert 11, was used for regression analysis of the data obtained and to estimate the coefficient of the regression equation. An analysis of variance (ANOVA) was further carried out to determine the adequacy of the model. Response surfaces were generated to determine the individual and interactive effects of the test variable on the yield of Biolubricant. The high (+) and low (-) values for ester synthesis variables were temperature (80°C and 100°C), time (120 and 200 minutes), and molar ratio (3 and 5). **Table 2** shows the complete design matrix of the experiment carried out, with the results obtained

Table 1: Factors levels of independent variables

Factor	Name	Units	Level	Low Level	High Level	- alpha	+ alpha

A	Temperature	°C	95.98	80	100	52.7283	187.272
B	Molar Ratio		6.30934	3	7	1.63641	8.36359
C	Time	Minute	141.447	120	200	92.7283	227.272

3.2 Model fitting and Analysis of Variance (ANOVA)

The optimization process of the transesterification reaction was performed using the Central Composite Design (CCD). Three important factors: temperature, time and molar ratio were the independent variables. Their combined effects were examined while the percentage yield of the Biolubricant was the response (dependent) variable useful for the development of the empirical model. This was carried out to determine the best conditions for the optimum yield of biolubricants. Central Composite Design usually consists of six centre runs, 2(n) axial runs, where n is the number of factors. It was used to analyze the correlation between Biolubricant preparation variables and the percentage yield. In this work, a set of 20 experiments for PKO was performed which includes 6 central points each. The experiments were performed at random to avoid a systematic error. **Table 2** shows the combined effects of temperature (A), the molar ratio (B), and time (C). The highest percentage yield of Biolubricant for PKO of 96% was obtained at 100°C, 120min, and a molar ratio of 3:1.

Table 2: Design matrix of experiments and experimental yields using CCD

Run	Factor 1 Temp.	Factor 2 Molar ratio	Factor 3 Time	Response	Run	Factor 1 Temp.	Factor 2 Molar ratio	Factor 3 Time	Response
1	80	3	200	80	11	100	7	200	96

2	90	8.3635	160	25	12	106.8179	5	160	93
3	100	7	120	40	13	90	5	160	87
4	80	7	200	87	14	73.1820	5	160	83
5	90	5	160	82	15	90	1.6364	160	93
6	90	5	160	85	16	90	5	92.7282	67
7	100	3	200	78	17	80	7	120	65
8	90	5	227.2717	89	18	90	5	160	82
9	90	5	160	80	19	90	5	160	83
10	80	3	120	77	20	100	3	120	88

The summary of p-value statistics is shown in **Table 3**, while the model summary test and lack of a fit test for the synthesis of Biolubricant are presented in **Tables 4 and 5**, respectively.

Table 3: Summary of P-values for Biolubricant synthesis

Source	Sequential P-value	Lack of Fit P-value	Adjusted R^2	Predicted R^2	Remark
Linear	0.02010164	0.000253021	0.3462528	0.0077331	Suggested
2FI	0.179939875	0.000312932	0.4403959	-0.3726229	
Quadratic	0.101725727	0.000521453	0.5984077	-0.63835	Suggested
cubic	8.04939E-05	0.518303847	0.9816681	0.8801303	Aliased

Table 4: Summary of model statistics for Biolubricant synthesis

Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	**Remark**
Linear	14.17537	0.449476	0.3462528	0.0077331	5794.839	Suggested
2FI	13.11505	0.617113	0.4403959	-0.3726229	8016.118	
Quadratic	11.11021	0.788636	0.5984077	-0.63835	9567.964	Suggested

Cubic	2.373738	0.994211	0.9816681	0.8801303	700.0393	Aliased

Table 5: Lack of fit test for Biolubricant synthesis

Source	Sum of squares	Df	Mean square	F-Value	P-value	Remark
Linear	3184.226719	11	289.475156	46.941917	0.000253	Suggested
2FI	2205.226719	8	275.65334	44.700542	0.000313	
Quadratic	1203.534514	5	240.706903	39.033552	0.000521	Suggested
Cubic	2.974461375	1	2.97446137	0.4823451	0.518304	Aliased
Pure Error	30.83333333	5	6.166666667			

The ANOVA results for Biolubricant from PKO are presented in **Table 6** and the model variables from the table show that B, C, BC, and B^2 were significant while the regression F-value of 4.15 implies that the model was significant, which was validated by the P-values of less than 0.05 (Yuan et al., 2008). There is only a 1.84% chance that an F-value this large could occur due to noise.

Table 6: ANOVA for Biolubricant synthesis

Source	Sum of Squares	df	Mean square	F Value	P-value
Model	1961.299462	9	217.922162	3.50561	0.03178
A-Temperature	8.426405188	1	8.42640519	0.13555	0.72042
B-Molar ratio	1371.570305	1	1371.57031	22.0638	0.00085
C-Time	8.06E-01	1	0.8060896	0.01297	0.91159
AB	69.03125	1	69.03125	1.11047	0.31677
AC	63.28125	1	63.28125	1.01798	0.33679

BC	19.53125	1	19.53125	0.31419	0.58746
AA^2	6.336630063	1	6.33663006	0.10193	0.75609
BA^2	425.8658014	1	425.865801	6.8507	0.02571
CA^2	0.254032538	1	0.25403254	0.00409	0.95029
Residual	621.6380376	10	62.1638038		
Lack of Fit	600.3047043	5	120.060941	28.1393	0.00114
Pure Error	21.33333333	5	4.26666667		
Cor Total	2582.9375	19			

Std. Dev. = 11.11; Mean = 78.00; C. V. = 14.24%; PRESS = 9567.96.
R^2 = 0.7886; Adjusted R^2 = 0.5984; Predicted R^2 = -0.6383; Adequate precision = 6.4377

The test for accuracy of the regression models, significance of individual model coefficients and the lack of fit test was carried out using the same statistical package. The P-values were used as a tool to check the significance of each of the coefficients, which was necessary to understand the pattern of the mutual interactions between the test variables (Kumar et al., 2003). According to Shrivastsvs et al., (2008) the higher the F-test value and the smaller the P-values, the higher the significance of the corresponding coefficient

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable (Yunardi et al., 2011). The ratio of 6.438 indicates an adequate signal for PKO (Russell, 2009). This model can be used to navigate the design space. The coefficient of regression R^2 was used to validate the fitness of the model equation. For Biolubricant produced from PKO, the R^2 has a pretty high value of 0.7886, showing that 78.86% of the variability in the response can be explained by the model. This implies that the prediction of experimental data was quite satisfactory. The obtained quadratic model equation after eliminating non-significant terms for the transesterification from PKO is given by Equation 7:

$$Yield\ (\%) \equiv +83.14 - 11.53B + 7.69C - 10.25BC\ 7.81B^2 \quad (7)$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. In a regression equation, when an independent variable has a positive sign, it means that an increase in the variable would cause an increase in the response while a negative sign would result in a decrease in the response (Minodora et al., 2010). Hence, an increase in temperature, time and molar ratio would cause an increase in the percentage yield. Time and temperature will have a more significant effect on the increment of the response since their coefficients were higher. Normal plots of residuals for PKO production (Figure 2) and

the predicted vs actual plots for PKO production (Figure 3) were used to check the distribution of residuals. The close distributions of the points along the straight lines indicate a good relationship between the experimental values and the predicted values of the response. These plots also confirm that the chosen model was adequate for the prediction of the response variables in the experimental values.

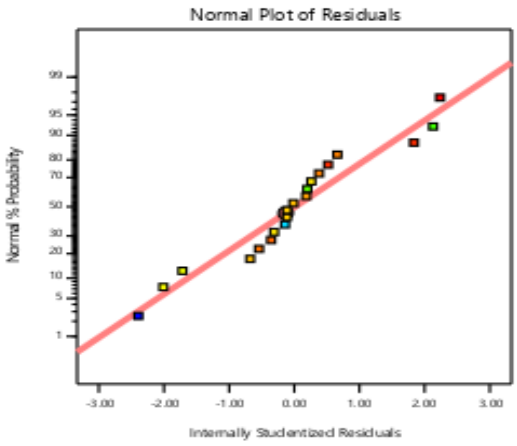


Fig. 1: Normal plot of residuals for Biolubricant synthesis

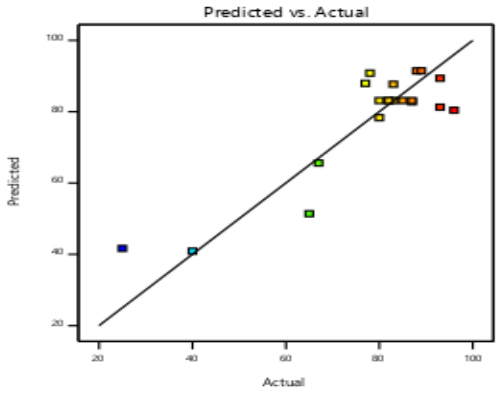


Fig. 2: Predicted vs Actual plot for Biolubricant synthesis

3.3 Effect of process parameter on transesterification reaction

The two factors' interactions response surface plots were drawn for the three reaction parameters of temperature, time, and molar ratio. The yield was found to vary between 25% to 96% for PKO.

3.3.1 Effect of molar ratio and temperature on transesterification reaction

Figure 4 shows the plots of the effect of temperature and molar ratio on Biolubricant at a fixed time of 2 hours 40minutes for PKO.

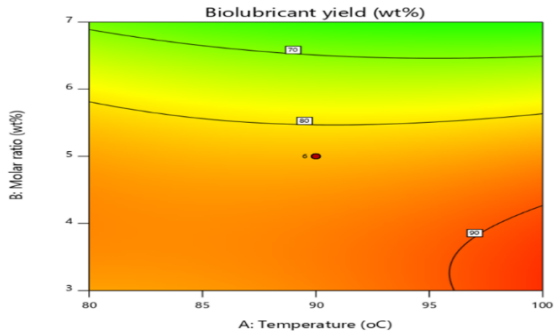


Fig. 3: 2D surface plot for the effect of temperature and molar ratio on Biolubricant yield

3.3.2 Effect of time and temperature on transesterification reaction

Figure 5 shows the plots of the effect of temperature and time at a fixed molar ratio of 5:1 for PKO.

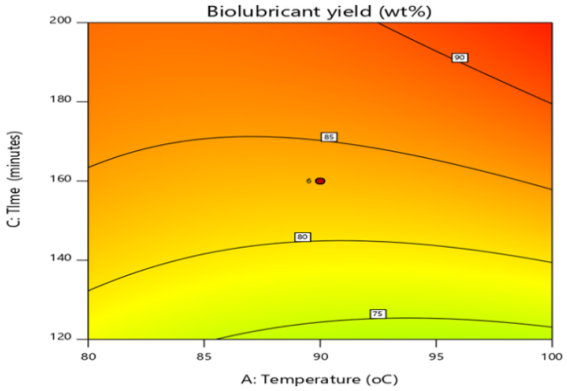


Fig. 4: 2D surface plot for the effect of temperature and time on Biolubricant yield

3.3.3 Effect of time and molar ratio on transesterification reaction

Figure 6 shows the plots of the effect of molar ratio and time at a fixed temperature of 90°C for PKO.

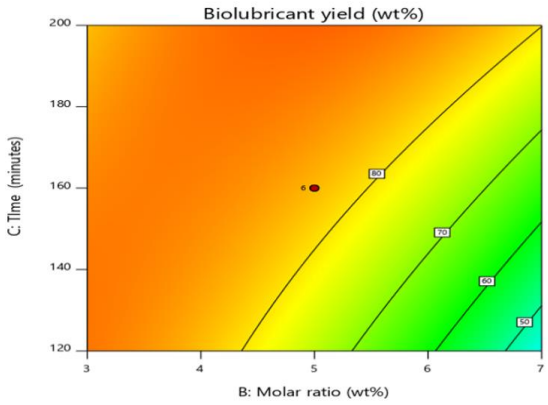


Fig.5: 2D surface plot for the effect of molar ratio and time on Biolubricant yield

The response surface contours which are graphical results of interactive effects are shown in Figure 7, 8, and 9. The optimum value of 96%, which was higher than the highest value amongst the calculated values based on experimental design. The surface plot of conversion of Biolubricant as a function of molar ratio and temperature demonstrated maximum conversion of 96% as obtained from the contour plot at the maximum value of molar ratio and temperature.

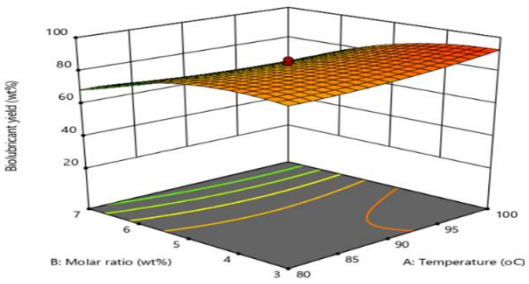


Fig. 6: Surface and contour plot between molar ratio and temperature against Biolubricant yield

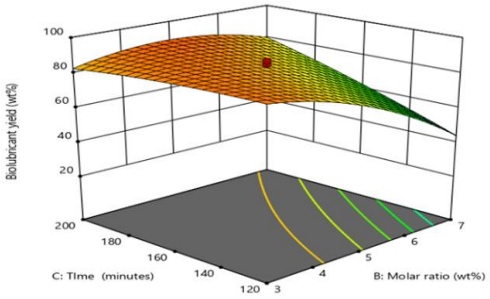


Fig.7: Surface and contour plot between molar ratio and time against Biolubricant yield

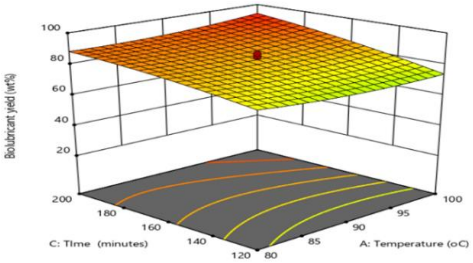


Fig. 8: Surface and contour plot between time and temperature against Biolubricant yield

The response surface of the extent of conversion showed (Figures 7 - 9) a clear peak, suggesting that the optimum condition for maximum yield was well inside the design boundary. It could be observed from the 3D that the conversion increased when the temperature and molar ratio increased. It

was observed that for temperature, yield increased with increasing molar ratio before ceasing; whereas for lower values of temperature, the pattern followed a parabolic path. At a fixed value of the molar ratio, the increased temperature increased the value of the yield until a point where there was no significant increase in yield.

Figure 7 shows the response for the interaction of temperature and molar ratio, Figure 8 shows the response for the interaction of molar ratio and time. The 3D response indicates that the Biolubricant synthesis increased when FAEE concentration increases. Therefore, the maximum Biolubricant conversion was obtained for a high molar ratio. This was due to the stoichiometry of transesterification, which requires a 3:1 ratio for FAEE and Propane-1,2-diol since the reaction involves the conversion of one ester and alcohol towards another ester and another alcohol. Therefore, an excess FAEE could be used to drive the reaction near completion. Consequently, the FAEE concentration results in a greater Biolubricant conversion within a shorter time as indicated in Figure 7.

A higher yield of Biolubricant is strongly favoured when a high molar ratio is employed for a certain time of reaction (C) and temperature (A). The molar ratio is a fundamental variable in the transesterification process for Biolubricant synthesis. 3D response surfaces revealed that increment of reaction temperature leads to increase in Biolubricant yield with reduced time. On the contrary, an increase in the reaction time does not improve the catalytic activity at a low-temperature level. Meanwhile, high temperature improved the dispersion of catalyst particles in liquid medium with better mass transfer between the reactants. The contour plot shows that high Biolubricant yield was favoured by a higher level of reaction temperature with a low or intermediate level of reaction time.

Furthermore, the 3D response surface revealed that an increase in reaction temperature leads to an increase in Biolubricant yield with reduced reaction time. On the other hand, an increase in reaction time does not have a significant effect on the yield after about 3 hours of reaction. Also, high temperature improved dispersion of catalyst particles in liquid medium with better mass transfer between reactants. Also, contour plots show high Biolubricant yield at a high level of temperature with a low intermediate reaction time.

3.4 Process variable optimization and validation

Table 7: Optimization/Validation results for Biolubricant synthesis

Parameter	Optimum operating conditions
Temperature (°C)	100
Time (min)	200
Molar ratio	7:01
Yield (optimum) wt%	96
Yield (validated) wt%	53.6715

Table 7 shows the optimization and validation results for Biolubricant synthesis. Predicted responses were generated using a point prediction node (under the optimization node in the CCD module). Temperature, the molar ratio of reactants and time were all fixed in the range of 80°C - 100°C, 4 – 6 and 2hours – 3hours 20minutes, respectively.

Biolubricant yield from PKO was maximum within the experimental range of 25 – 96 wt%. Using these criteria, the software suggested the following optimum conditions from PKO production: the temperature of 100°C, a molar ratio of 7, time of 200 minutes and yield of 96 wt% at a desirability value of 1.00. Figure 8 shows surface and contour plots for desirability, in which desirability is plotted against temperature and molar ratio respectively at a fixed time of 140.433 min for PKO. Figure 9 shows a 3D contour plot for desirability against temperature and molar ratio for Biolubricant synthesis.

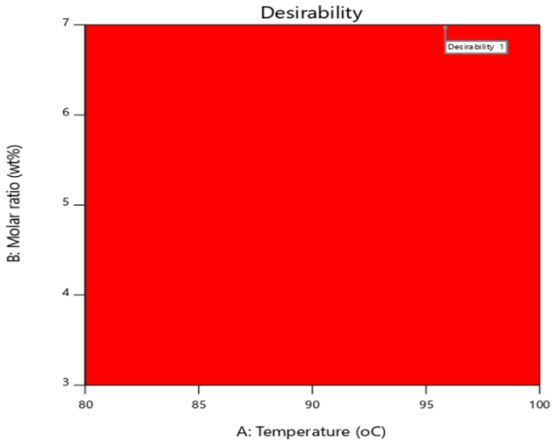


Fig. 9: 2D surface plot for desirability against temperature and molar ratio for Biolubricant

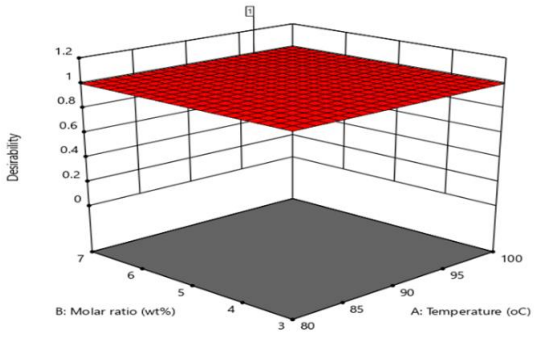


Fig. 10: 3D contour plot for desirability against temperature and molar ratio for Biolubricant synthesis

3.5 Lubricating properties of Biolubricant

A lubricant's viscosity is generally considered one of its most important properties. This is because if the viscosity of a lubricant is even modestly different from what is needed for a particular component and application, the lubricant will not be able to lubricate the component effectively. Thus, this may lead to significant damage and possible equipment failure. In particular, kinematic viscosity was determined at 40°C, and the results for the 20 runs are presented in **Table 8** below

Table 8: Kinematic viscosity of Biolubricant from PKO

Experimental Runs	Viscosity	Experimental Runs	Viscosity
1	24.5	11	29.5
2	15.5	12	24.2
3	19.5	13	21.3
4	20.2	14	25.4
5	21.3	15	24.1
6	20.5	16	24.3
7	19.9	17	17.8
8	20.1	18	18.9
9	22.4	19	19.1
10	23.1	20	10.3

Various kinematic viscosities have been reported for different bio-based lubricants at 40°C. Such reports include 39.7cSt and 54.1cSt for TMP esters of Palm kernel oil and Palm oil (Yunus et al., 2003) and 43.9cSt for TMP esters of Jatropha curcas oil (Ghazi et al., 2009). Furthermore, when compared with ISO VG 32 standard specification for light gear lubricant, the properties of the optimum biolubricants met the stipulated specification. For a lubricant to perform in extremely cold environments, low-temperature fluidity is a highly essential property. The pour point is important in appraising flow properties at low temperatures. As such, it can become the determining factor in selecting one lubricant from a group with otherwise identical properties. The obtained pour point for the optimized PKO is 13°C and the cloud point for the optimized PKO is 3°C. The flash-point and density of the optimized PKO is 190°C, and 0.865kg/cm³ respectively. The specific gravity of the optimized PKO is 0.87.

Conclusion

Response Surface Method (RSM) based CCD was successfully applied for optimizing the reaction parameters for the synthesis of PKO and propane-1,2-diol-based PKO-biolubricant. The effects of reaction temperature, molar ratio and reaction time on the transesterification reaction yield were also studied and optimized. A polynomial quadratic model was used to predict maximum yield and the optimization of reaction parameters. The model predicted the optimal conditions for the selected transesterification variables as reaction temperature of 100°C, a molar ratio of 7:1 and reaction time of 200 min with an actual PKO Biolubricant yield of 96wt%. The ANOVA implied that molar ratio and temperature were the most significant factors affecting the yield of Biolubricant.

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