# Otimization Of Water-Reducible Alkyd Resin Production from Cotton Seed Oil Using Hybridized Response Surface Methodology-Genetic Algorithm (RSM-GA)

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***Abstract-*** ***Growing environmental regulations and a heightened awareness of sustainability have spurred intensive research into the development of eco-friendly coating technologies. Water-reducible alkyd resins have emerged as a promising alternative, offering the advantages of reduced VOC emissions, ease of cleanup with water, and improved safety profiles.This study focused on synthesizing Water-reducible alkyd resin from cotton seed oil utilizing a hybridized response surface methodology-genetic algorithm (RSM-GA). Key parameters influencing fractional conversion namely; reaction time, reaction temperature, acid-to-oil ratio, and catalyst concentration—were identified. The cotton seed oil was characterized and subsequently used in a multi-step process involving alcoholysis, esterification, and copolymerization to produce the alkyd resin. The process was modeled and optimized through both RSM and RSM-GA techniques. The resulting alkyd resin, produced under optimal conditions, was characterized to assess its physicochemical properties, drying behavior, and chemical resistance. Results indicated that the RSM-GA model achieved the highest yield of 92.51% at optimal parameters: 93 minutes reaction time, 243.5°C temperature, 0.332:1 acid-to-oil ratio, and 0.062 wt% catalyst concentration. This demonstrates that GA-based optimization was more effective than traditional RSM. The fractional conversion of the oil under these conditions closely matched the predicted value, and the quality of the produced alkyd resin met standard specifications. Future research is recommended to explore the application of particle swarm optimization (PSO) for further process enhancement.***

***Indexed Terms-*** ***Cotton seed oil, Fractional conversion. Genetic Algorithm, Optimization, Water-reducible Alkyd resin***

## I. INTRODUCTION

Alkyd resin is the most commonly employed binder in traditional paints, facilitating the formation of a uniform film that adheres firmly to substrate surfaces and bonds other materials together (Ezeagba et al., 2014;Egbun and Aninwede,. 2018). It is often modified with monobasic fatty acids or triglyceride oils (Kyenge et al., 2012). Essentially, the synthesis of alkyd resins typically involves the polycondensation of polyols, polybasic acids, and fatty acids or oils as expressed in eqn 1.

$$\boldsymbol{Alcohol}\ (-\boldsymbol{COH}) + \boldsymbol{Acid}\ (-\boldsymbol{COOH}) \rightarrow \boldsymbol{Ester}\ (-\boldsymbol{COOC}-) + \boldsymbol{Water}\ (\boldsymbol{H_2O}) \quad (1)$$

Over recent years, surface coating industry has experienced significant growth in demand for alkyd resins, primarily because of their affordability and wide-ranging applications among polymer-based surface coatings (Aigbodion and Okieimen, 2001; Holmberg, 2005). It is estimated that alkyd resins contribute about 70% to the total binders used in surface coatings (Bajpai, 2000).

Recognized for their versatility, alkyd resins are extensively used across all major coating sectors, including architectural, industrial, and specialized applications (Onukwuli & Obodo, 2015). Their widespread popularity is attributed to properties such as film hardness, durability, gloss, gloss retention, and abrasion resistance, which can be enhanced

through modifications of the drying oils incorporated in their formulation. Despite these advantages, alkyd resins do face certain drawbacks, such as their vulnerability to alkali-induced hydrolysis, which involves the breakdown of ester linkages—a typical ester reaction. Additionally, compared to other synthetic resins, alkyds tend to have slower drying times (Onukwuli & Obodo, 2015). Nevertheless, they can be further improved through physical blending or chemical copolymerization, broadening their range of applications.

The widespread acceptance of alkyd resins in surface coatings is mainly because of their desirable qualities—such as film hardness, color stability, durability, gloss retention, abrasion resistance, and compatibility with various polymers and resins; attributes that can be significantly enhanced by modifying the drying oils used during synthesis. While replacing alkyd resins entirely is challenging, their properties can be tailored to specific needs through modifications. A key feature of effective surface coatings, including alkyd-based ones, is their ability to dry quickly on the surface, a property that can be improved by incorporating drying oils that promote rapid drying (Aninwede et al., 2022). The drying rate of alkyd resins largely depends on the drying characteristics of the oils used, with linseed and tall oils serving as standard benchmarks due to their high drying efficiency (Aninwede et al., 2022).

However, the feasibility of using these drying oils for modifying alkyd resins is limited by factors such as their high costs, scarcity in natural sources, and the tendency of alkyds derived from these oils to develop a yellowish hue, owing to their high degree of unsaturation (Uzoh et al., 2015). These challenges motivate the exploration of other available vegetable oils that could serve as substitutes in alkyd resin production. Cotton seed oils is among the locally accessible options that, when properly modified, could fulfill specific industrial requirements. The ease with which vegetable oils can be chemically or physically modified—along with their fatty acid compositions—determines their industrial value (Ikhuoria et al., 2004). Technologies such as alcoholysis or transesterification, which convert vegetable oils into fatty acid alkyl esters through controlled chemical reactions, are used to enhance their chemical properties (Ikhuoria et al., 2004). For example, in response to the growing environmental regulations and a heightened awareness of sustainability, water-reducible alkyd resins have emerged as a promising alternative, offering the advantages of reduced VOC emissions, ease of cleanup with water, and improved safety profiles (Ezidinma,et al. 2015) Stable emulsion with micro and nano scale particles of polymer in water medium was also reportedly achieved by incorporating some water soluble monomers into an alkyd resin structure via copolymerization (Yousefi, 1991). Mini-emulsion polymerization was used in preparation of stable water-based alkyd-acrylic hybrid resins. The resulting hybrid resins not only have many advantages of both alkyd and acrylic resins but also are water-based resins (Yousefi, 2011). Hybrid resin consisting of two different oils and water soluble polymers and dispersible in water medium was achieved from copolymerization of alkyd with stable acrylic emulsion (Pishvaei, 2008). Mini-emulsion technique was used to copolymerize alkyd resin with methyl -methacrylate and butyl-acrylate to obtain a stable emulsion possessing satisfactory binder properties (Asua,2002, Chern, 2006, Ouzineb, et al ,2006, Guyot, et al, 2007, and Landfester, 2009). A water- reducible alkyd-acrylic resin resulted from a copolymer of 15 to 40% n-butyl-acrylate and maleic anhydride polymer-grafted on modified palm kernel oil (Saravari, et al,2005). Thus many researches have been successfully conducted on synthesis of water-soluble alkyd resin.

To produce high-quality water- reducible alkyd resins from cotton seed oil, it is essential to optimize reaction conditions such as temperature, reaction time, phthalic anhydride dosage, oil ratios, and catalyst concentration. These parameters must be carefully controlled and optimized to meet commercial standards and achieve the desired product properties.

Optimization, as defined by Data (2011), involves selecting the best operational conditions to achieve the most favorable outcome for a given process or system. It involves balancing an objective function—representing the goal or problem—and various influencing variables and constraints. In this context, the effects of independent variables are typically

studied using Design of Experiments (DOE) and Analysis of Variance (ANOVA). Response Surface Methodology (RSM), especially the full factorial central composite rotatable design (CCRD), is commonly employed for such optimization because of its accuracy and efficiency, as it provides reliable results without requiring multiple three-level factorial experiments ( Aninwede et al., 2022).

RSM aims to model how response variables are affected by process factors, enabling the development of a statistical model based on experimental data (Asadu et al., 2019; Okpe et al., 2018). It is preferred over other optimization techniques because of its ability to handle multiple factors simultaneously and to provide insights into individual and interaction effects while reducing the number of experiments needed (Aninwede et al., 2022). Although, RSM has limitations, such as difficulties in extrapolating beyond the tested experimental ranges and challenges in modeling highly complex systems. To overcome these limitations, it is integrated with soft computing algorithm such as genetic algorithm (GA) (Ude et al., 2023). While RSM has been applied to optimize alkyd resin production from seed oils, there is limited research utilizing a hybridized RSM-GA for this purpose. Therefore, this study aims to optimize the alkyd resin production parameters using a hybridized RSM-GA.

## II. MATERIALS

The commercial refined, edible grade cottonseed oil was purchased from Shoprite Enugu. Research grade of Maleic anhydride (C4H2O3) with minimum assay >97%, Trimellitic anhydride (C9H4O5) with assay 98%, glycerol (C3H8O3) with assay >99%, sodium bisulphate (Na2CO3) with assay 97.5%, Polyethylene glycol (PEG 4000) with assay 97%, and Lithium hydroxide (LiOH) with assay >96.8% were purchased from Gerald Chemical Services Ltd, Ogbete Main Market. Xylene, white spirit, naphtha solvent and distilled water were obtained from Conraws Science Equipment and Chemicals Ltd Enugu.

### 2.2. Characterization of Cottonseed Oil

The physical and chemical properties of the refined cottonseed oil and that of neutralized/ dehydrated oil were determined following the method described by AOAC, (2004).

### 2.3 Synthesis of Water- Reducible Alkyd Resin

In the synthesis of the alkyd resin, three stages were involved as described by Aninwede et al. (2022) and Ezidinma (2015). The stages were alcoholysis, esterification and copolymerization. The basic reagents utilized for the coupled operations include neutralized and dehydrated cottonseed oil, glycerol, Maleic anhydride (MA), Trimellitic anhydride (TA), Polyethylene glycol (PEG) and Lithium hydroxide (LiOH) as catalyst.

The monoglyceride was first synthesized by reacting neutralized and dehydrated cottonseed oil with glycerol. The oil was heated maintaining agitation speed of 600 rpm. Glycerol and selected catalyst (0.1wt% LiOH) were added and alcoholysis reaction was allowed to progress at 230-240oC. The reaction was continued for 120 minutes at the end of which, sample of the reaction mixture became soluble in 3 volume of anhydrous methanol. After alcoholysis was completed, the reaction mixture was cooled to 140oC.

Then maleic anhydride (MA) and Trimellitic anhydride (TA) at 8:1 ratio was added to the monoglyceride mixture and followed by introduction of calculated quantity of xylene. The temperature of the mixture was maintained at the range of 220 – 260oC. Progress of the reaction was monitored by intermittent measurement of the acid value (AV) and viscosity (V). These parameters were measured off-line for all reaction durations after a uniform delay period of 30minutes. The conversion to alkyd resin (Y) calculated analytically in terms of measured reduction in AV equation (1), for a given reaction phase using equation (2), relying on data obtained from normal titration while the viscosity was measured instrumentally for cold sample using viscometer.

$$Acid\ value\ (AV) = \frac{M*V*40}{W} \quad (2)$$

$$Y = 1 - \frac{AV_j}{AV_o} = 1 - \frac{V_j}{V_o} \quad (3)$$

Where M is molarity of NaOH, V is volume of NaOH, W is weight of cotton seed oil, and are the acid values of the mixture determined at the initial time (t=0) and later time t=j respectively while and are the corresponding volumes of NaOH(aq) used in the titration.

Finally, polyethylene glycol was heated up to 230oC and introduced into the reaction mixture and maintained at 230-240oC while at constant agitation speed of 600rpm. Progress of the reaction was monitored again by checking the acid value at 20mins interval until and acid value of 13mgKOH/g was attained.

2.4 Modelling of Water-Reducible Alkyd Resin Production

The alkyd resin production from cotton seed oil was modelled with response surface methodology (RSM) and adaptive neuro-fuzzy inference systems (ANFIS) using design matrix generated by Design Expert version 13. The dependent variable is fractional conversion, Y (%) while the independent variables are time (minutes), temperature (oC), methanol/oil molar ratio and catalyst concentration with a total of 30 experimental runs (Table 1).

Table1: Responses of Experimental Design Matrix

| Std | A: Time | B: Temperature | C: Acid/oil molar ratio | D: Catalyst concentration | Fractional Conversion, X | RSM Predicted X |
|---|---|---|---|---|---|---|
| | Minutes | Deg. Cel. | | wt% | % | % |
| 1 | 60 | 220 | 0.2 | 0.04 | 51 | 51.69 |
| 2 | 120 | 220 | 0.2 | 0.04 | 60 | 58.52 |
| 3 | 60 | 260 | 0.2 | 0.04 | 64 | 63.23 |
| 4 | 120 | 260 | 0.2 | 0.04 | 71 | 71.74 |
| 5 | 60 | 220 | 0.4 | 0.04 | 67.7 | 67.38 |
| 6 | 120 | 220 | 0.4 | 0.04 | 70 | 70.49 |
| 7 | 60 | 260 | 0.4 | 0.04 | 71.8 | 71.85 |
| 8 | 120 | 260 | 0.4 | 0.04 | 77 | 76.63 |
| 9 | 60 | 220 | 0.2 | 0.08 | 73 | 72.7 |
| 10 | 120 | 220 | 0.2 | 0.08 | 77.4 | 77.8 |
| 11 | 60 | 260 | 0.2 | 0.08 | 73.9 | 73.87 |
| 12 | 120 | 260 | 0.2 | 0.08 | 81 | 80.65 |
| 13 | 60 | 220 | 0.4 | 0.08 | 76.8 | 76.52 |
| 14 | 120 | 220 | 0.4 | 0.08 | 77.8 | 77.9 |
| 15 | 60 | 260 | 0.4 | 0.08 | 69.8 | 70.62 |
| 16 | 120 | 260 | 0.4 | 0.08 | 73.9 | 73.67 |
| 17 | 30 | 240 | 0.3 | 0.06 | 63.3 | 63.26 |
| 18 | 150 | 240 | 0.3 | 0.06 | 72.9 | 73.15 |
| 19 | 90 | 200 | 0.3 | 0.06 | 68.8 | 69.05 |
| 20 | 90 | 280 | 0.3 | 0.06 | 76.4 | 76.36 |
| 21 | 90 | 240 | 0.1 | 0.06 | 63.4 | 63.85 |
| 22 | 90 | 240 | 0.5 | 0.06 | 72.8 | 72.56 |
| 23 | 90 | 240 | 0.3 | 0.02 | 65.3 | 65.68 |
| 24 | 90 | 240 | 0.3 | 0.1 | 83.9 | 83.73 |
| 25 | 90 | 240 | 0.3 | 0.06 | 91.4 | 91.85 |
| 26 | 90 | 240 | 0.3 | 0.06 | 92.4 | 91.85 |
| 27 | 90 | 240 | 0.3 | 0.06 | 91.8 | 91.85 |
| 28 | 90 | 240 | 0.3 | 0.06 | 91.5 | 91.85 |
| 29 | 90 | 240 | 0.3 | 0.06 | 92.1 | 91.85 |
| 30 | 90 | 240 | 0.3 | 0.06 | 91.9 | 91.85 |

2.4.1 RSM Modelling

The central composite design (CCD) was implemented to model the alkyd resin production process. The independent variables are listed in Table 1, while the single output represents the fractional conversion. The dataset in Table 1 were used to formulate a model equation in the form of equation 3.

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{4} \beta_{ii} X^2_i + \sum_{i=1}^{4} \sum_{j=i+1}^{4} \beta_{ij} X_i X_j \quad (4)$$

The model's performances were assessed with mean square errors (MSE) and the coefficients of determination.

2.4.2 Optimization by RSM-GA

The ideal combination of the four process variables looked at was found using RSM-GA optimization technique in order to optimize the fractional conversion. The RSM model discussed above were used as fitness functions after being separately coupled with the GA method (Ude et al., 2023). The GA was utilized to look for the best values that produced the highest yield. Table 2 lists the primary characteristics of the GA that was employed. By conducting trials in duplicate, the optimum values calculated by each approach were verified, and the average values achieved were compared to the estimated values. GA optimization was carried out using the MATLAB R2013a (Mathworks Inc., Natick, MA, USA) GA tool kit.

Table 2. GA optimization parameters

| Genetic algorithm | Property | ANFIS | RSM |
|---|---|---|---|
| | Population | 10 | 20 |
| | Crossover | 1/constraint dependent | 1/intermediate |
| | Mutation rate | 0.01/constraint dependent | 0.01/uniform |
| | Generation | 50 | 50 |
| | Selection | Stochastic uniform | Stochastic uniform |
| | Creation function | Constraint dependent | Uniform |

2.5 Characterization and Performance of Water-Reducible Alkyd Resin

The produced water-reducible alkyd resin at optimal conditions were characterized to determine some significant properties such as color, specific gravity, acid value, saponification value and iodine value using the method employed by Ezidinma et al. (2015).

Performance evaluation tests were also carried out on the synthesized resin by formulating the resin into paint and evaluating the drying characteristics and chemical resistance, Film hardness and abrasion resistance tests by adopting the methods of Exidinma et al. (2015). These properties were compared with that of paint prepared with conventional soyabean oil medium alkyd obtained from Intecil Resin plant Emene Enugu using a recipe for the production of standard alkyd gloss paint as in Ezidinma et al. (2015).

## III. RESULTS AND DISCUSSIONS

3.1 Characterization of the oil

The results of the property evaluation of the refined cottonseed oil and that of the further treated (neutralized and dehydrated) one is tabulated in Table 3. There was no remarkable change in color as a result of the neutralization and dehydration. The golden yellow color of the oil remained stable. The viscosity dropped from 63cP to 42.81cP. This is in trend with the drop-in acid value, moisture content and free fatty acid content. These drastically affected the specific gravity which appreciated from 0.91 to 0.98, the iodine value which improved from 22.10gI2/100g oil to 98.20gI2/100g oil and also the saponification value that showed remarkable increase from 63.19 to 194. These are attributable to the molecular condensation of the triglycerides following the loss of water molecules during dehydration and also loss of the free fatty acid converted to soap during neutralization. Obviously, the neutralization and dehydration processes imparted immensely on the iodine and saponification values of the oil. These properties were known to impart remarkably on the drying properties and molecular weight of alkyd that may be synthesized from the oil.

Table 3: Physiochemical properties of the oil

| Properties | Commercially Refined Oil | Neutralized/ Dehydrated Oil |
|---|---|---|
| Color | Golden Yellow | Goilden Yellow |
| Specific gravity | 0.912 | 0.98 |
| Viscosity (cp) | 63.90 | 42.80 |
| Acid Value (mgKOH/g) | 0.29 | 0.20 |
| Idine Value ($gI_2$/100goil) | 22.10 | 98.20 |
| Saponification Value | 63.19 | 194 |
| Free fatty acid | 0.15 | - |
| Moiture content (%) | 0.16 | - |

3.2 Modelling of Water-Reducible Alkyd Resin Production

3.2.1 RSM Modelling

The responses of the experimental design matrix for fractional conversion of cotton seed oil to alkyd resin are presented in Table 1. The data were fitted to the central composite design second-order model. The model that relates the fractional conversion to the process variables in terms of coded form is described in Eq. (4).

$$Y_{CSO} = 91.85 + 2.47A + 1.83B + 2.18C + 4.51D + 0.42AB - 0.93AC - 0.43AD - 1.77BC - 2.59BD - 2.97CD - 5.91A^2 - 4.79B^2 - 5.91C^2 - 4.29D^2 \quad (5)$$

Where,

$Y_{CSO}$ is the fractional conversion of cotton seed oil and A = reaction time, B = temperature, C = acid to oil ratio, and D = catalyst concentration.

The mathematical regression model's statistical significance was assessed through analysis of variance (ANOVA), which was presented in Table 4. The results demonstrated a significant model at a 95% confidence level, with a respective p-value and F-value of <0.0001 and 528.18. Furthermore, ANOVA was utilized to ascertain the importance of each parameter, and the findings confirmed that all linear terms, together with all interaction terms, and all quadratic terms, were notable at the 95% confidence level. Therefore, the model remained unchanged.

Statistical indicators were used to assess the effectiveness of the mathematical model, and the following findings were obtained: R2 = 0.9980, adjusted R2 = 0.9961, and anticipated R2 = 0.9892. The modified and projected R2 had a respectable degree of agreement. These showed both good model fit and a good correlation between experimental and predicted values. According to Ude et al. (2023), a decent model should have an R2 of at least 0.8. The signal-to-noise ratio, which is a measure of adequate precision, was 84.9167. The model can be used to explore the design space because a ratio greater than 4 is necessary. The model's coefficient of variance (CV) was 0.89 percent. The residuals in relation to the projected value are smaller, the lower the CV. The low CV found suggested a sound model.

Table 4: ANOVA of Fractional Conversion of CSO to Alkyd Resin

| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| Model | 3308.22 | 14 | 236.30 | 528.18 | < 0.0001 | significant |
| A-Time | 146.52 | 1 | 146.52 | 327.50 | < 0.0001 | |
| B-Temperature | 80.30 | 1 | 80.30 | 179.49 | < 0.0001 | |
| C-Acid/oil molar ratio | 113.97 | 1 | 113.97 | 254.75 | < 0.0001 | |
| D-Catalyst concentration | 488.70 | 1 | 488.70 | 1092.35 | < 0.0001 | |
| AB | 2.81 | 1 | 2.81 | 6.27 | 0.0243 | |
| AC | 13.88 | 1 | 13.88 | 31.01 | < 0.0001 | |
| AD | 2.98 | 1 | 2.98 | 6.65 | 0.0210 | |
| BC | 50.06 | 1 | 50.06 | 111.88 | < 0.0001 | |
| BD | 107.64 | 1 | 107.64 | 240.60 | < 0.0001 | |
| CD | 141.02 | 1 | 141.02 | 315.20 | < 0.0001 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| $A^2$ | 958.50 | 1 | 958.50 | 2142.43 | < 0.0001 | |
| $B^2$ | 628.39 | 1 | 628.39 | 1404.58 | < 0.0001 | |
| $C^2$ | 958.50 | 1 | 958.50 | 2142.43 | < 0.0001 | |
| $D^2$ | 503.97 | 1 | 503.97 | 1126.46 | < 0.0001 | |
| Residual | 6.71 | 15 | 0.4474 | | | |
| Lack of Fit | 6.02 | 10 | 0.6016 | 4.33 | 0.0598 | not significant |
| Pure Error | 0.6950 | 5 | 0.1390 | | | |
| Cor Total | 3314.93 | 29 | | | | |

Figure 1 depicts the actual and predicted graphs. The picture showed that all of the catalysts utilized had data points on the plot that were linearly distributed, showing a good link between the experimental and projected values of the response and demonstrating that the underlying assumptions of the previous study were accurate. The outcome also implies that the quadratic models chosen were appropriate and sufficient for predicting the response variables for the experimental data.

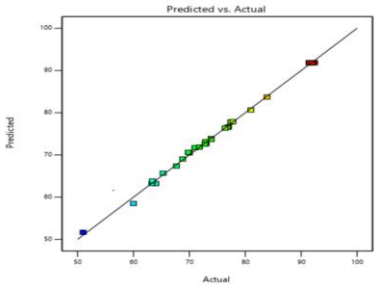


Figure 1. Predicted vs actual values for fractional conversion of cotton seed oil (CSO).

Figure 2 shows the distribution of residuals against experimental runs. It could be observed that the residuals were homogenously disseminated. Since there were few outliers and the skewness were reduced, the model was appropriate and statistically fit the data.

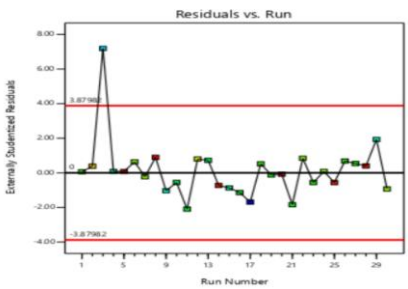


Figure 2. Residual vs run for fractional conversion of CSO

Additionally, surface plots were created to assess the impact of various combinations of alkyd resin production factors on fractional conversion, and these are presented in Figure 3 (a-f). Specifically, Figure 3a illustrates the interactive influence of the temperature and time on the fractional conversion. Temperature and time strongly affect the conversion of cotton seed oil acid value in alkyd resin production. It was observed that higher temperatures speed up the esterification reaction between the oil, polybasic acid, and polyol, but excessive heat and prolonged exposure can cause degradation and lower overall conversion efficiency. This exothermic reaction needs careful temperature control to optimize yield and product quality. Figure 3b illustrates how time and acid to oil ratio interact to influence the fractional conversion of cotton seed oil. The rate and extent of reaction between a vegetable oil and polybasic acid (likely in alkyd resin production) depend on both the acid-to-oil ratio and reaction time in an interactive way. The figure indicates that a higher acid-to-oil ratio initially speed up conversion, but excess acid led to inefficient or unwanted side reactions. Longer reaction times generally improve conversion, but the effectiveness of this increase is dependent on the acid-to-oil ratio.

In Figure 3c, the combination between time and catalyst concentration on fractional conversion is depicted. It is evident from the plot that increasing catalyst concentration initially boosts reaction rate and fractional conversion, as more active sites lead to faster conversion per unit time. However, this effect eventually declined, with further increases in catalyst concentration having diminishing returns on the reaction rate and final fractional conversion. This is because other factors, like reactant availability or diffusion limitations, might become rate-limiting. Figure 3d illustrates the interaction of temperature

and acid to oil ratio on fractional conversion. The figure reveals that as both the temperature and acid to oil ratio rises, so does the fractional conversion, due to increase in kinetic energy that led to more frequent and energetic collision and increase in active sites for the reaction to occur. However, both factors led to diminishing returns and negative effects on fractional conversion at extreme values beyond temperature of 240oC and acid to oil ratio of 0.3. This reduction in fractional conversion may be due to unwanted side reactions, and deactivation of the catalyst. The interaction of temperature and catalyst concentration on fractional conversion is shown in Figure 3e. It can be seen that higher temperature and higher catalyst concentration can lead to a greater fractional conversion. This is because increased catalyst concentration provides more active sites for the reaction, and higher temperature can increase the rate of reaction. The fractional conversion remained constant when temperature and catalyst concentration went beyond 240oC and 0.08wt%.

In Figure 3f, the interaction of acid to oil ratio and catalyst concentration on fractional conversion is presented. The figure shows that as catalyst concentration and acid to oil ratio increase, fractional conversion improves, likely due to more active sizes. The fractional conversion declined beyond 0.3 acid to oil ratio and 0.08wt% catalyst concentration due to mass transfer limitations and side reactions.

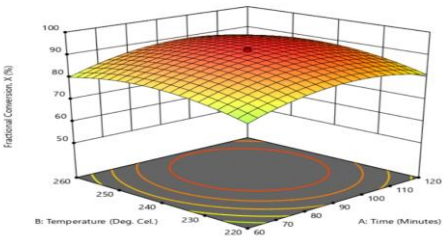


Figure 3a: Interaction of temperature and time on fractional yield

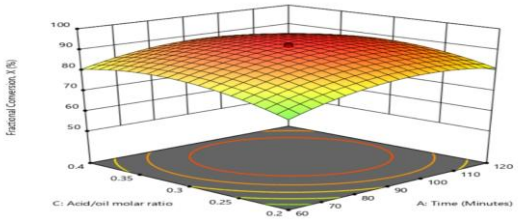


Figure 3b: Interaction of acid to oil ratio and time on fractional conversion

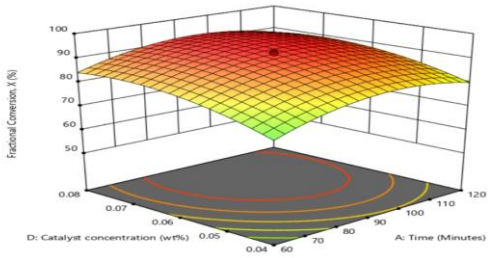


Figure 3c: Interaction of time and catalyst concentration on fractional conversion

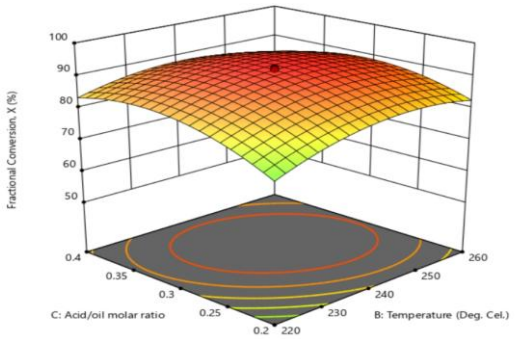


Figure 3d: Interaction of temperature and acid to oil ratio on fractional conversion

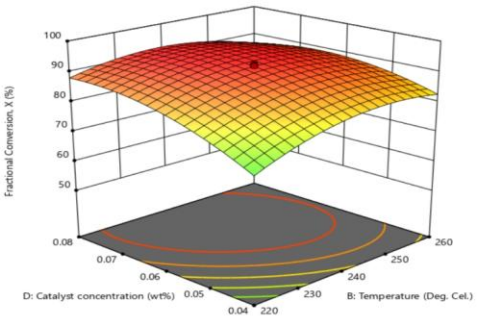


Figure 3e: Interaction of temperature and catalyst concentration on fractional conversion

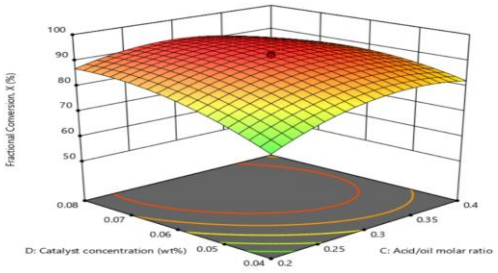


Figure 3f: Interaction of acid to oil ratio and catalyst concentration on fractional conversion

3.2.2 Optimization of the process variables for alkyd resin production

This study optimized important process parameters to achieve the highest fractional conversion of cotton seed oil by using hybridized RSM genetic algorithms (RSM-GA). The genetic algorithm (GA) was incorporated into the developed RSM model, and the model was used as fitness functions. The predicted optimal variables for RSM-GA technique is presented in Table 5. The fitness values decreased from generation to generation for the RSM-GA (Figure 4), which then remained unchanged until the 50th generation. These signify that mutations or crossovers did not occur within the genes (variables) that could alter the conversion (Ude et al. 2023). The predicted optimal variables for the technique are presented in Table 5. The conditions were used to produce alkyd resin from cotton seed oil to validate the predicted fractional conversion. The result indicated the optimization performance order as RSM-GA and RSM (Table 5). The RSM-GA predicted a fractional conversion (92.51%) higher than ( 91.42%) predicted by RSM at optimal conditions of time 93 minutes, reaction temperature 243.5 oC, acid to oil ratio 0.332:1 and catalyst dosage 0.062 wt%. The percentage errors of less than 1% for RSM-GA indicate that the model predicted the fractional conversion accurately.

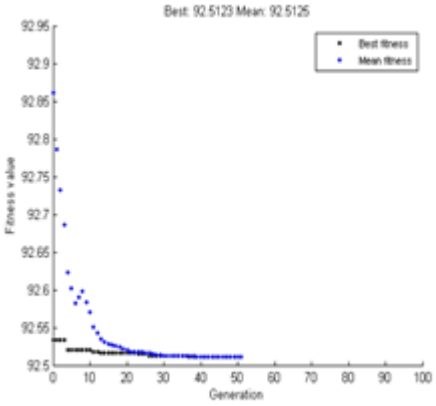


Figure 4: Fitness value against generation using RSM-GA for fractional conversion

Table 5: Optimal conditions and validation

| Process parameters/Tool | Time (mins) | Temp. (°C) | Acid to oil ratio | Catalyst conc. (%wt) | Predicted Y (%) | Actual Y(%) | % Error |
|---|---|---|---|---|---|---|---|
| RSM-GA | 93 | 243.5 | 0.332 | 0.062 | 92.51 | 92.15 | 0.39 |
| RSM | 95 | 237 | 0.30 | 0.079 | 91.42 | 91.20 | 1.10 |

3.3 Physiochemical Properties of the Alkyd Resin

Despite achieving a high 92.15% acid conversion, the 13mgKOH/g acid value is still very high. Further processing was deemed undesirable due to the already high viscosity (8896cp) to prevent gel formation. This high acid value stems from the very high acid values (1142mgKOH/g and 865mgKOH/g) of the polybasic acids (maleic anhydride and trimellitic anhydride) used in the synthesis (Table 6a). The high iodine value (43.866g$I_2$/100g oil) indicates a high degree of unsaturation in the ester molecules, likely due to conjugated bonding.

Table 6b shows the dust-free, set-to-touch, and hard dry times for the paint samples. The water-reducible resin-based paint had a longer drying time, even with a high iodine value. This extended drying time may be due to the low volatility of the water used as a

solvent. Despite this, the paint exhibited excellent adhesion, as expected. The resin's polar groups (–COOH from the polybasic acids and –OH from the PEG grafting) likely contribute to this strong adhesion.

The resistance of the alkyd film to various media (water, 2% $Na_2CO_3$, and 2% $H_2SO_4$) was tested. The results, shown in Table 6c, indicate that the alkyd film exhibited excellent resistance to water, moderate resistance to acid ($H_2SO_4$), and poor resistance to alkali ($Na_2CO_3$). After 8 hours in 2% $Na_2CO_3$, the film whitened; after 16 hours, it blistered; and after 24 hours, it was removed. The poor alkali resistance is likely due to the resin's composition, specifically its susceptibility to degradation by the strong alkaline environment.

Table 6a: Physiochemical properties of the alkyd resin

| Properties | Value |
|---|---|
| Color | Dark Brown |
| Specific gravity | 1.05 |
| Acid Value (mgKOH/g) | 13 |
| Iodine Value ($gI_2$/100g oil) | 43.86 |
| Saponification Value | 372 |
| Viscosity (cP) | 8896 |

Table 6b: Drying characteristics

| Drying Stage | Standard | Specimen |
|---|---|---|
| Dust free | 6hrs | 8hrs |
| Set-to-touch | 18hrs | 20hrs |
| Hard dry | 24hrs | 38hrs |

Table 6c: Chemical Resistance Test

| Chemical | Observation Period (hrs) | Effect on Standard | Effect on Specimen |
|---|---|---|---|
| 2%$Na_2CO_3$ | 24 | Film removal | Film removal |
| 2%$H_2SO_4$ | 24 | Color change | Color change |
| Distilled water | 48 | No effect | No effect |

## CONCLUSION

In this study, the production of alkyd resin from cotton seed oil was optimized through hybridized response surface methodology-genetic algorithm (RSM-GA). The significant parameters that affect the fractional conversion included the reaction time, reaction temperature, acid to oil ratio and catalyst concentration. The results showed that the RSM-GA model gave the highest yield (92.15%) under optimized conditions of 93 minutes reaction time, 243.5 oC reaction temperature, 0.332 acid to oil ratio and 0.062 w%t catalyst concentration. This implies that GA incorporated optimization tools were more effective than the optimization tools of RSM. The fractional conversion of the oil achieved under optimal conditions validated the predicted fractional conversion, and the quality of the alkyd resin was within acceptable standard limits. In future studies, it is suggested to explore the use of utilizing the particle swarm optimization (PSO) tool.

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