Global Scientific JOURNALS

GSJ: Volume 13, Issue 6, June 2025, Online: ISSN 2320-9186

www.globalscientificjournal.com

Soft Computing Optimization of Alkyd Resin Production from Cotton Seed Oil

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Abstract

The application of machine learning techniques in predicting fractional conversion in bioprocessing is enhancing the widespread use of first-generation biomass, particularly vegetable oils, in alkyd resin production. This study concentrated on the soft computing optimization of process parameters for alkyd resin synthesis using Artificial Neural Networks (ANN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS). The procured oil was characterized and used to produce alkyd resin in a triple reaction of alcoholysis, esterification and copolymerization. The process was modeled using ANN and ANFIS and optimized with ANFIS. The produced alkyd resin at optimal conditions were characterized to determine some physio-chemical properties and evaluate drying characteristics and chemical resistance. The findings revealed that ANN outperformed ANFIS, achieving a high coefficient of determination of 0.999 and a low error of 0.051 in prediction accuracy. An optimal fractional conversion of 91.8% was attained under conditions of 90 minutes, 240°C, 0.3, and 0.06 wt%. 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. These results represent a significant advancement toward establishing sustainable and renewable bio-processing methods.

Keywords: Artificial neural networks, adaptive neuro fuzzy inference systems, cotton seed oil, alkyd resin, soft computing.

1. Introduction

The primary binder used in most conventional paints is alkyd resin, which facilitates the formation of a consistent film that adheres to substrate surfaces and bonds other substances together (Ezeagba et al., 2014; Gabriel et al., 2013). Alkyd resin is a polycondensation product derived from a polybasic acid, such as phthalic anhydride, and a polybasic alcohol like glycerol, modified with monobasic fatty acids or triglyceride oils (Kyenge et al., 2012). Essentially, it is a fatty acid polyester polymer obtained commercially by reacting polybasic acids and alcohols with monobasic fatty acids or triglycerides. Over the years, Nigeria's surface coating industry has experienced a significant increase in demand for alkyd resins due to their cost-effectiveness and versatile applications among polymer classes in surface coatings (Aigbodion and Okieimen, 2001; Holmberg, 2005). In fact, alkyd resins account for approximately 70% of binders used in surface coatings (Bajpai, 2000).

Alkyd resins are highly versatile and are extensively employed across various coating sectors, including architectural, industrial, and specialized applications (Onukwuli & Obodo, 2015). Their popularity stems from desirable properties such as film hardness, durability, gloss, gloss retention, abrasion resistance, and the ability to modify these characteristics through alterations in the drying oil component. Despite these benefits, alkyd resins have certain limitations, including susceptibility to alkali hydrolysis, which can break ester linkages, a typical issue with ester-based compounds. Additionally, compared to other synthetic resins, alkyds tend to dry more slowly (Onukwuli & Obodo, 2015). Nonetheless, modifications through physical blending and chemical copolymerization can enhance their performance, allowing alkyd resins to meet a broad spectrum of application requirements. The acceptability of alkyd resins as coating vehicles is mainly due to their film hardness, color stability, durability, gloss retention, abrasion resistance, compatibility with various polymers and resins, and other desirable attributes achieved through modification of the drying oils used during synthesis. Replacing alkyd resins is challenging; however, their properties can be tailored to meet specific needs. A key property of surface coatings, including alkyds, is their ability to dry surface-wise rapidly, which can be improved by modifying the resin with drying oils that impart quick-drying characteristics (Aninwede et al., 2022). The drying capability of alkyd resins largely depends on the drying oils incorporated during manufacture, with oils such as linseed and tall oil serving as benchmarks due to their high drying efficiency (Aninwede et al., 2022).

However, reliance on these drying oils faces challenges such as high import costs, limited natural availability, and the tendency of alkyds made from these oils to develop a yellowish hue caused by their high degree of unsaturation (Uzoh et al., 2015). These issues underscore the importance of exploring locally available vegetable oils as potential substitutes for alkyd production. Cottonseed oil is a promising candidates, considering its desirable attributes as a renewable, cost-effective, and semi-drying oil with a favorable fatty acid composition which made it an attractive and sustainable precursor for the production of alkyd resins, offering a balance of drying properties, film performance, and economic benefits (Omowonuola, et al., 2024), provided they are properly modified to meet specific industrial requirements. The chemical and physical modification of vegetable oils, including processes like alcoholysis or transesterification, can improve their suitability for alkyd resin synthesis by converting triglycerides into fatty acid alkyl esters (Ikhuoria et al., 2004).

Proper control and optimization of reaction conditions such as temperature, reaction time, phthalic anhydride dosage, oil ratios, and catalyst concentration are crucial for producing high-quality alkyd resins from cottonseed oil. These parameters significantly influence the final product's properties and must be carefully managed to meet commercial standards. Typically, this research focuses on reaction time, temperature, and phthalic anhydride dosage due to their critical roles in the synthesis process.

In pursuit of optimal production processes, researchers are employing various modeling and optimization techniques like Response Surface Methodology (RSM), Artificial Neural Networks (ANN), and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) (Ingie et al., 2023; Nwosu-Obieogu et al., 2024). RSM evaluates linear, interaction, and quadratic effects to identify ideal process conditions but has limitations in extrapolating beyond experimental ranges and handling complex variables. Conversely, soft computing approaches such as ANN and ANFIS have demonstrated superior predictive capabilities—ANN for pattern recognition and regression, and ANFIS for combining neural learning with fuzzy logic reasoning, offering greater interpret-ability (Okeleye and Betiku, 2019; Samuel et al., 2020; Ude et al., 2020). Employing both models allows leveraging ANN's data-processing strength alongside ANFIS's interpret-ability, leading to more robust insights into complex processes. Despite the growing interest, limited research exists on applying these advanced modeling techniques to optimize alkyd resin production parameters. This study aims to utilize soft computing methods to model and optimize the production of alkyd resins derived from locally available oils, specifically focusing on cotton seed oil, with a particular emphasis on understanding the effects of reaction time, temperature, and phthalic anhydride dosage.

2. Materials and Methods

2.1 Materials

The commercial refined, edible grade cottonseed oil was purchased from Shoprite Enugu. Research grade of Maleic anhydride ($C_4H_2O_3$) with minimum assay >97%, Trimellitic anhydride

($C_9H_4O_5$) with assay 98%, glycerol ($C_3H_8O_3$) with assay >99%, sodium bisulphate (Na_2CO_3) 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 (2021). 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.

2.3.1 Alcoholysis

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 230-240^{o}C. 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 140^{o}C.

2.3.2 Esterification

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 – 260^{o}C. 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.

$$Acid\ value\ (AV) = \frac{M*V*40}{W} \quad (1)$$

$$Y = 1 - \frac{AV_j}{AV_o} = 1 - \frac{V_j}{V_o} \quad (2)$$

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

2.3.3 Copolymerization

Polyethylene glycol was heated up to 230^{o}C and introduced into the reaction mixture and maintained at 230-240^{o}C 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 Soft Computing of Alkyd Resin Production

The alkyd resin production from cotton seed oil was modelled with artificial neural network (ANN) 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 (^{o}C), methanol/oil molar ratio and catalyst concentration with a total of 30 experimental runs (Table 1).

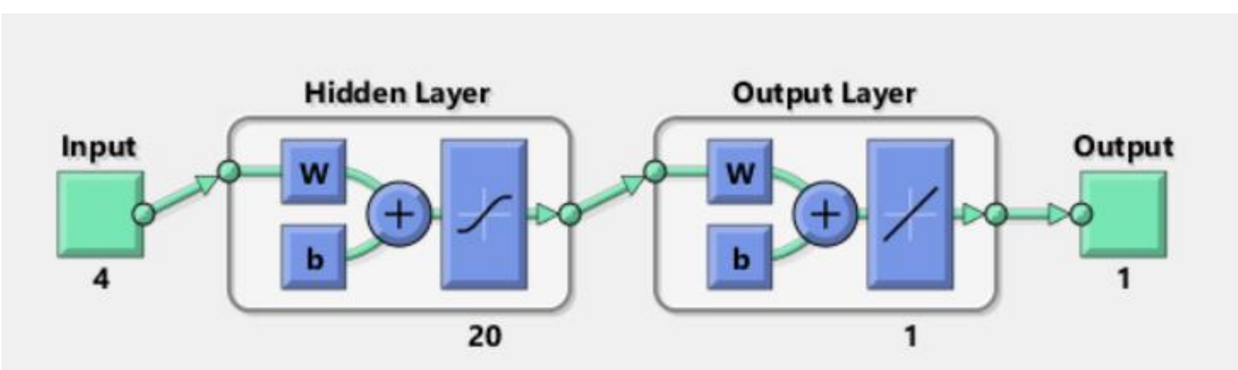
Table1: Responses of Experimental Design Matrix

Std	A:Time	B:Temperature	C:Acid/oil molar ratio	D:Catalyst concentration	Fractional Conversion, X	ANN Predicted X	ANFIS Predicted X
	Minutes	Deg. Cel.		wt%	%	%	%
1	60	220	0.2	0.04	51	50.999	50.999
2	120	220	0.2	0.04	60	59.999	60.000
3	60	260	0.2	0.04	64	63.999	63.997
4	120	260	0.2	0.04	71	70.999	71.002
5	60	220	0.4	0.04	67.7	67.699	67.699
6	120	220	0.4	0.04	70	69.999	70.002
7	60	260	0.4	0.04	71.8	71.799	71.805
8	120	260	0.4	0.04	77	76.999	76.999
9	60	220	0.2	0.08	73	72.999	72.999
10	120	220	0.2	0.08	77.4	77.400	77.396

11	60	260	0.2	0.08	73.9	73.899	73.896
12	120	260	0.2	0.08	81	81.000	81.001
13	60	220	0.4	0.08	76.8	76.799	76.795
14	120	220	0.4	0.08	77.8	77.800	77.801
15	60	260	0.4	0.08	69.8	70.275	69.800
16	120	260	0.4	0.08	73.9	73.900	73.899
17	30	240	0.3	0.06	63.3	63.299	63.302
18	150	240	0.3	0.06	72.9	72.900	72.900
19	90	200	0.3	0.06	68.8	68.799	68.803
20	90	280	0.3	0.06	76.4	76.399	76.399
21	90	240	0.1	0.06	63.4	63.399	63.403
22	90	240	0.5	0.06	72.8	72.799	72.800
23	90	240	0.3	0.02	65.3	65.299	65.294
24	90	240	0.3	0.1	83.9	83.900	83.903
25	90	240	0.3	0.06	91.4	91.856	91.849
26	90	240	0.3	0.06	92.4	91.856	91.849
27	90	240	0.3	0.06	91.8	91.856	91.849
28	90	240	0.3	0.06	91.5	91.856	91.849
29	90	240	0.3	0.06	92.1	91.856	91.849
30	90	240	0.3	0.06	91.9	91.856	91.849

2.4.1 Artificial Neural Network (ANN) Modelling

The multi-variable-single output (MISO) neural architecture (Figure 1) 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 was duplicated, and the number of neurons was adjusted to prevent overtraining and overfitting. Consequently, sixty (60) sets of data were utilized for training, and the data was analyzed using the logsig nonlinear transfer function in the hidden layer, along with the purelin function in the output layer. As noted by Ude et al. (2025), the network was trained with seventy percent of the data, representing 42 samples, while fifteen percent each was allocated for both testing and validation, with each comprising 9 samples. The model's performances were assessed with mean square errors (MSE) and the coefficients of determination.



GSJ: Volume 13, Issue 6, June 2025
ISSN 2320-9186

Figure 1: ANN-MISO neural architecture.

2.4.2 ANFIS modelling

The ANFIS network designs employed five distinct layers, including the fuzzy process, output, rule, defuzzy process, and total addition layers (Ude et al., 2025). For this study, the first-order Sugeno model was applied, using an input variable for fractional conversion (Figure 2a & 2b). The fuzzy rules implemented were based on the IF-THEN rules developed by Takagi and Sugeno, as referenced by Betiku et al. (2018) and Ude et al. (2022). The modeling was conducted using the fuzzy logic toolbox in MATLAB R2013a.

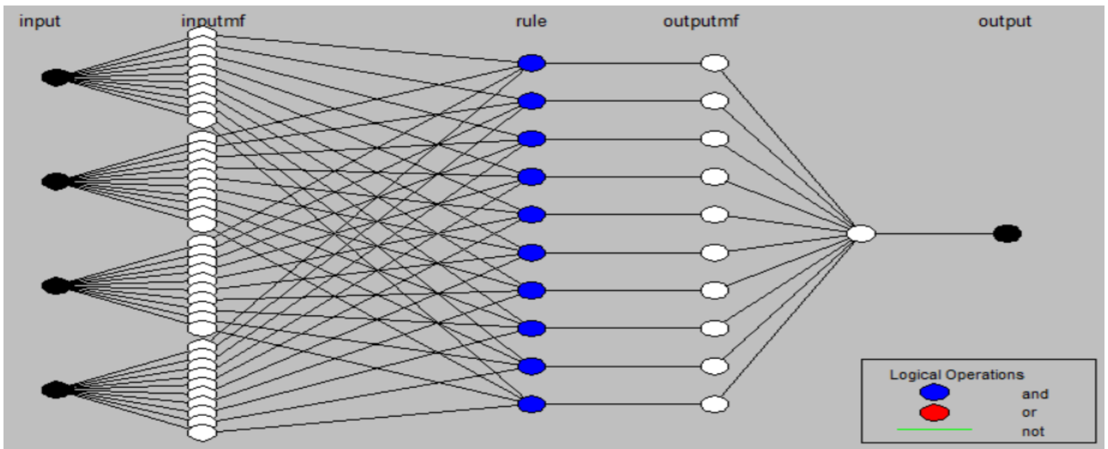


Figure 2a: ANFIS Architecture.

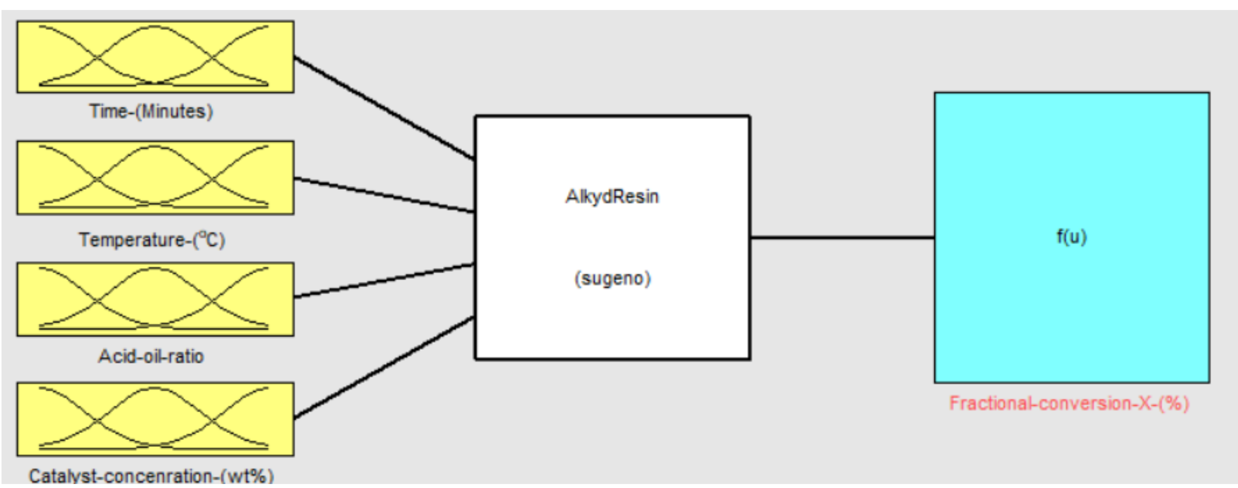


Figure 2b: ANFIS Properties.

2.4.3 Statistical Evaluation of the models

The performance of each model was validated by assessing statistical metrics including root-mean-square error (RMSE), coefficients of determination (R^2), and coefficients of regression (R). The statistical indicators were evaluated using Eqs. (3) – (5), as outlined by Ude et al. (2025).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(w_{a.i} - w_{p,i})^2} \quad (3)$$

$$R = \frac{\sum_{i=1}^{n}(w_{p,i} - w_{p,ave}).(w_{a,i} - w_{a,ave})}{\sqrt{[\sum_{i=1}^{n}(w_{p,i} - w_{p,ave})^2][\sum_{i=1}^{n}(w_{a,i} - w_{a,ave})^2}} \quad (4)$$

$$R^2 = \frac{\sum_{i=1}^{n}(w_{p,i} - w_{a,i})^2}{\sqrt{\sum_{i=1}^{n}(w_{a,ave} - w_{p,ave})^2}} \quad (5)$$

2.5 Characterization and Performance of the Alkyd Resin

The produced 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).

3. Results and Discussions

3.1 Characterization of the oil

The property evaluation results for the refined cottonseed oil and the subsequently treated (neutralized and dehydrated) oil are summarized in Table 1. No significant change was observed in the oil's color after neutralization and dehydration; the golden yellow hue remained consistent. However, the viscosity decreased from 63 cP to 42.81 cP, aligning with reductions in acid value, moisture content, and free fatty acid levels. These changes notably influenced the specific gravity, which increased from 0.91 to 0.98, and the iodine value, which markedly improved from 22.10 gI_2/100 g oil to 98.20 gI_2/100 g oil. Additionally, the saponification value showed a substantial rise from 63.19 to 194. These alterations are attributed to the molecular condensation of triglycerides during dehydration—resulting from water loss—and the removal of free fatty acids during neutralization, which are converted into soap. Overall, the neutralization and dehydration processes significantly impacted the iodine and saponification values, properties known to influence the drying characteristics and molecular weight of alkyd resins that can be synthesized from the oil.

Table 1: 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 Alkyd Resin Production

3.2.1 ANN Modelling

An artificial neural network (ANN) was employed to predict the parameters involved in alkyd resin production, using a supervised learning methodology. The training process achieved optimal performance with 20 neurons. As shown in Figure 3a, the network's training performance demonstrated a mean square error of 0.05082 at a maximum of 5 epochs, indicating a high level of accuracy with minimal prediction errors. Figure 3b depicts the error distribution via a histogram, revealing that errors were evenly spread across both negative and positive values. The errors across training, validation, and testing datasets were all confined within 0.008969, underscoring the reliability of the fractional conversion predictions. Furthermore, Figure 4 displays the correlation plot between predicted and actual fractional conversion values, illustrating a strong relationship with a correlation coefficient exceeding 0.99. This confirms that the ANN model effectively and accurately predicted the fractional conversion.

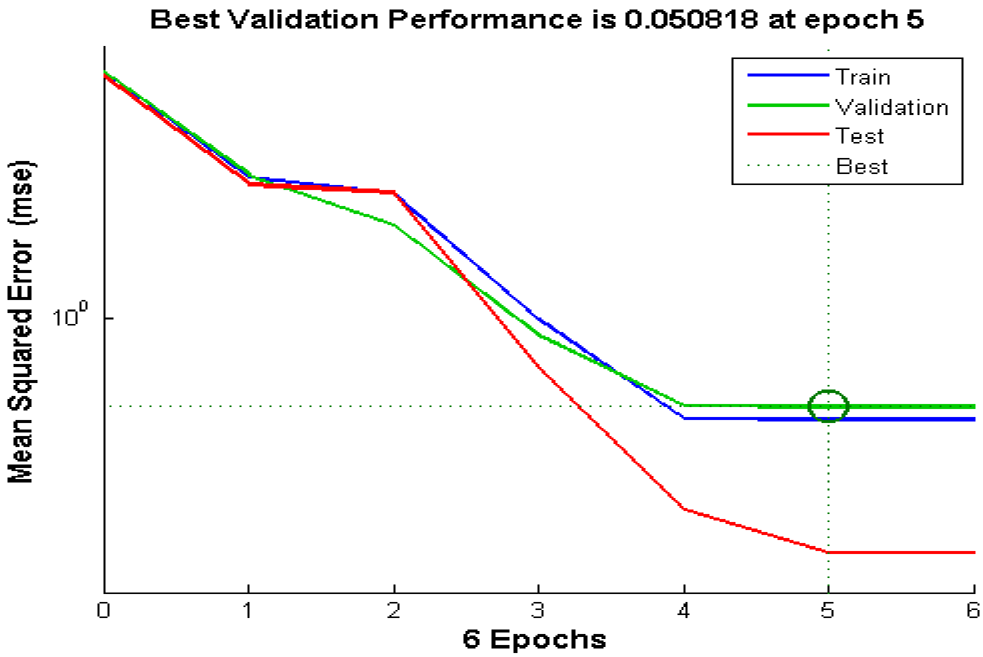


Figure 3a: MISO Performance MSE.

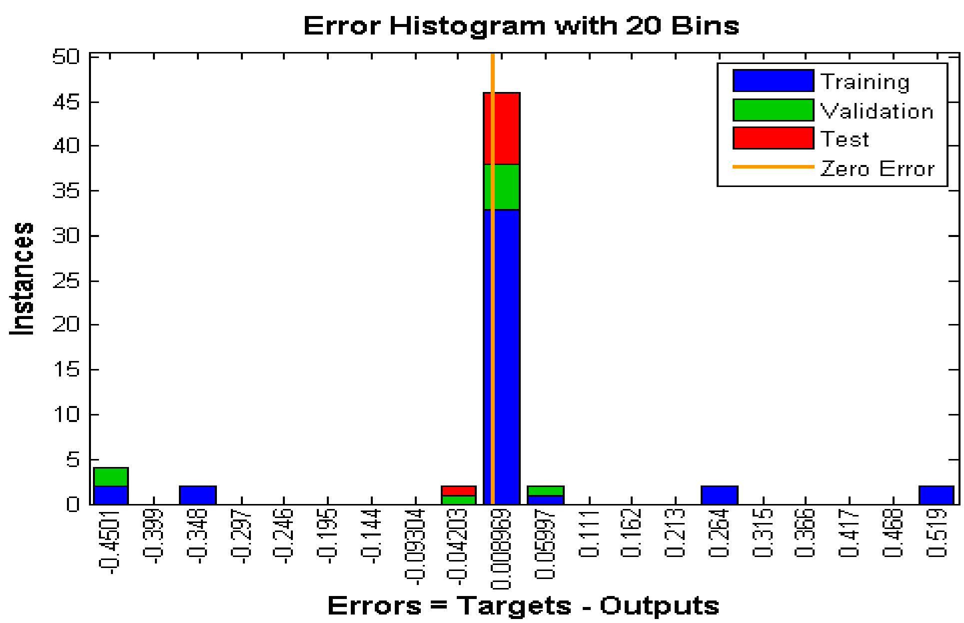


Figure 3b: MISO Error distribution

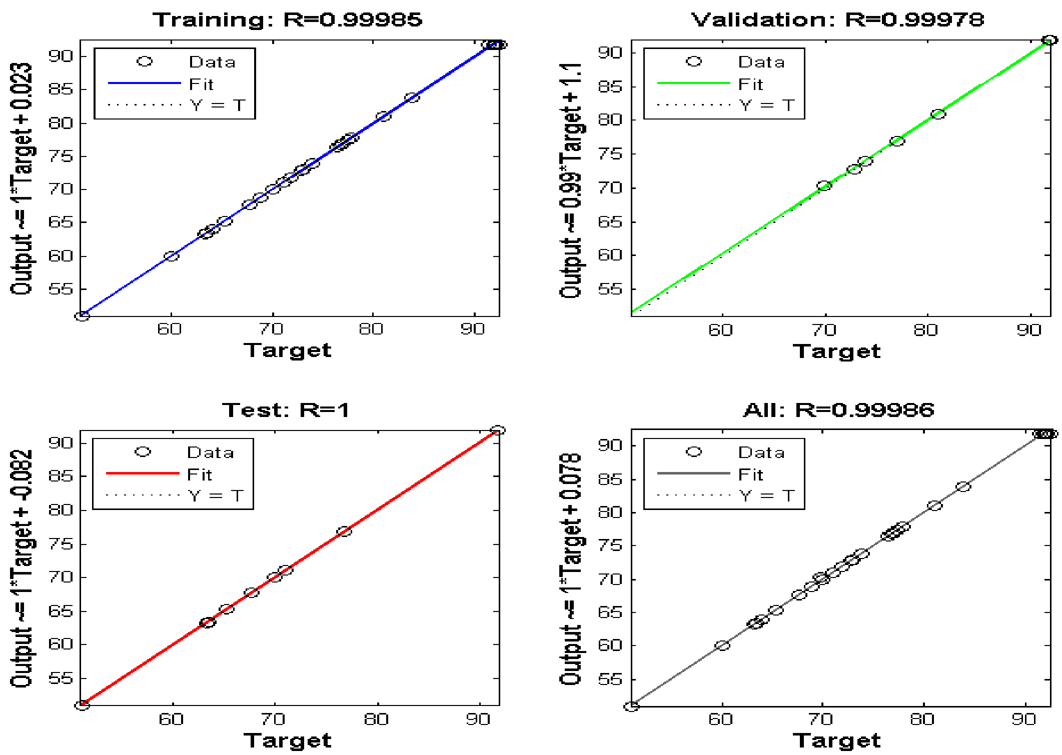


Figure 4: MISO Regression Analysis.

3.2.2 ANFIS Modelling

The responses from the experimental design matrix for extracting oil from gmelina seeds were modeled using the ANFIS approach, as shown in Table 1. Figure 5 illustrates the correlation between the actual and generated yields for the ANFIS oil extraction model. The model achieved a R^2 of 0.9899, with an error of 0.15223, as demonstrated in Figure 5. The high R^2 value and the low average testing error indicate a strong correlation between the actual and generated results, with the model accounting for 98.99% of the variability observed.

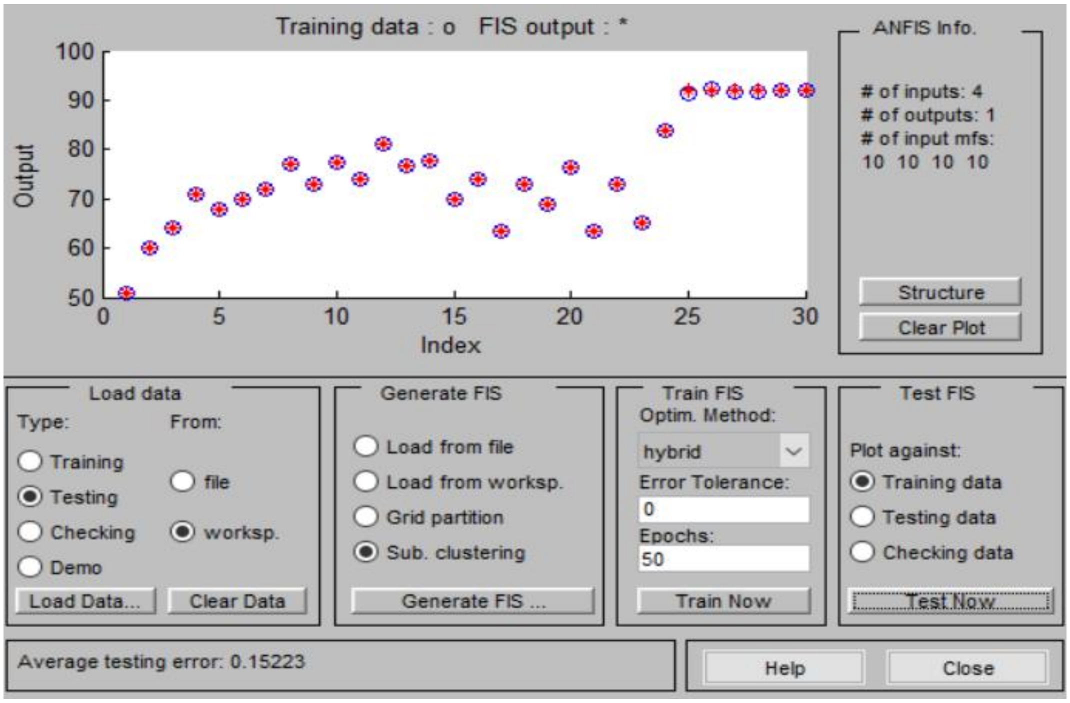


Figure 5: Actual and Predicted Fractional Yield.

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 6 (a-f). Specifically, Figure 6a 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 6b 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 6c, 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 6d 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 240^{o}C 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 6e. 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 240^{o}C and 0.08wt%.

In Figure 6f, 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.

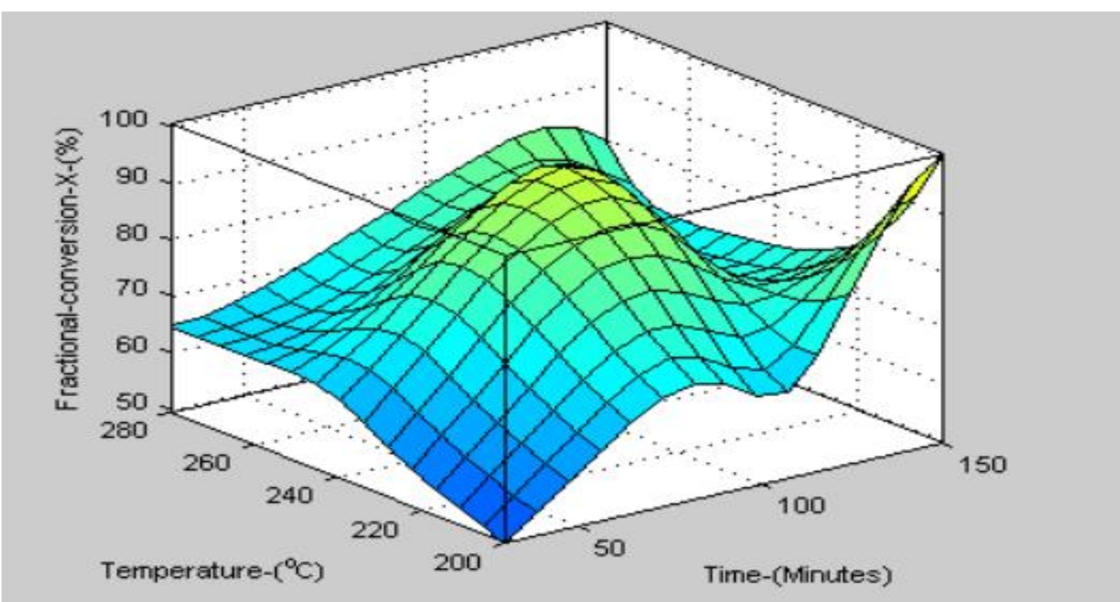


Figure 6a: Interaction of temperature and time on fractional yield

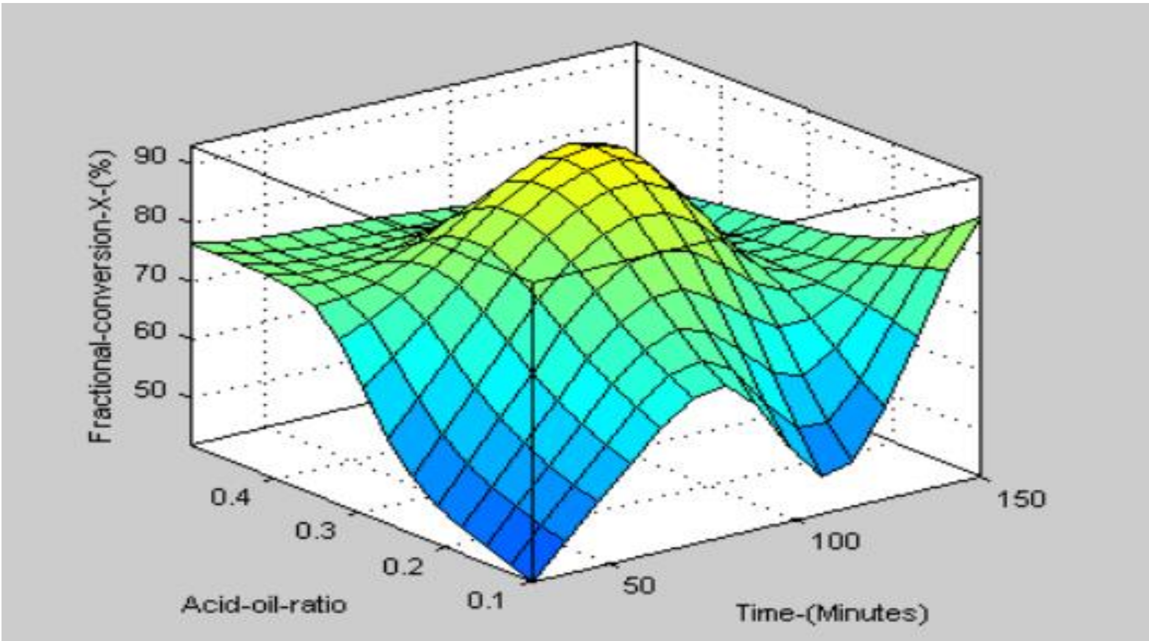


Figure 6b: Interaction of acid to oil ratio and time on fractional conversion

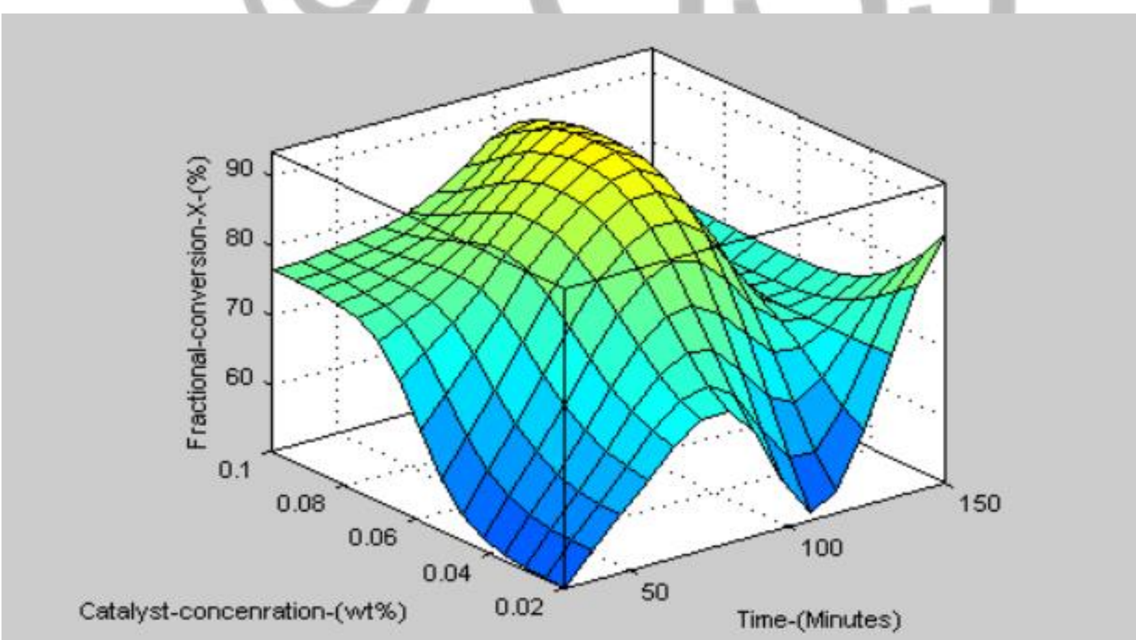


Figure 6c: Interaction of time and catalyst concentration on fractional conversion

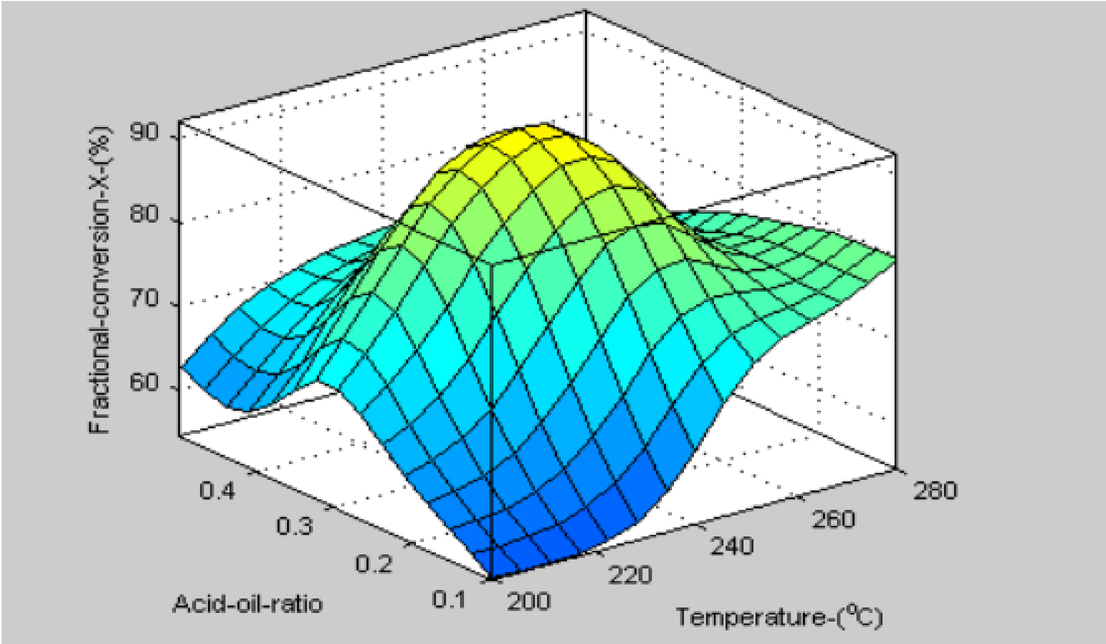


Figure 6d: Interaction of temperature and acid to oil ratio on fractional conversion

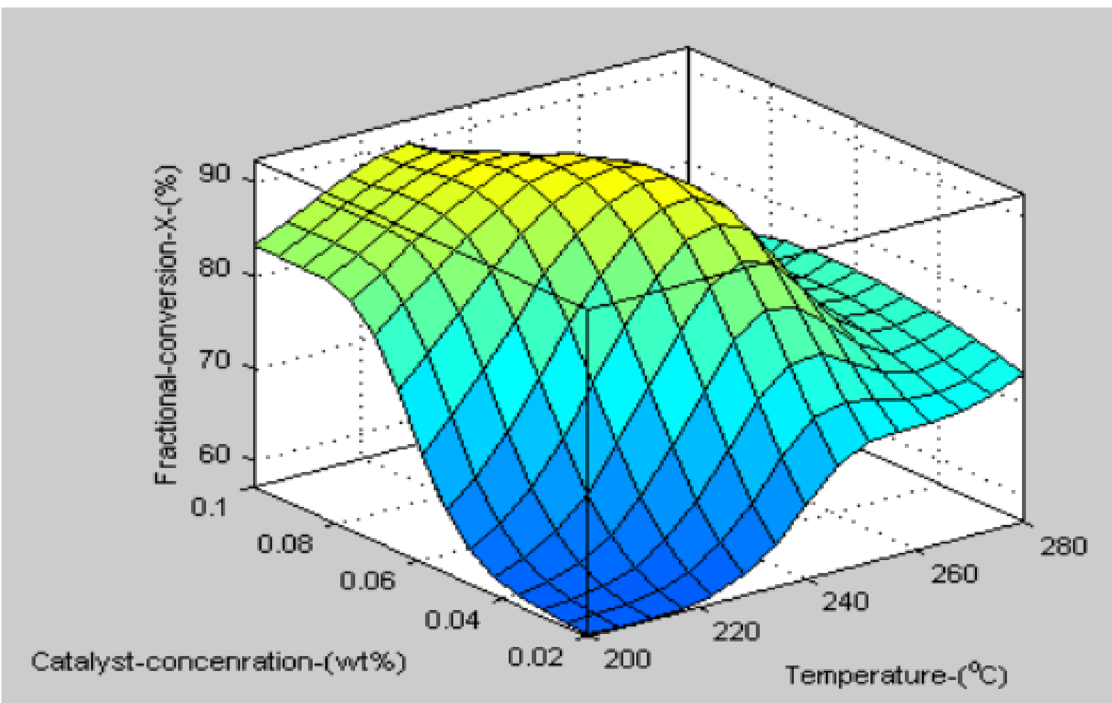


Figure 6e: Interaction of temperature and catalyst concentration on fractional conversion

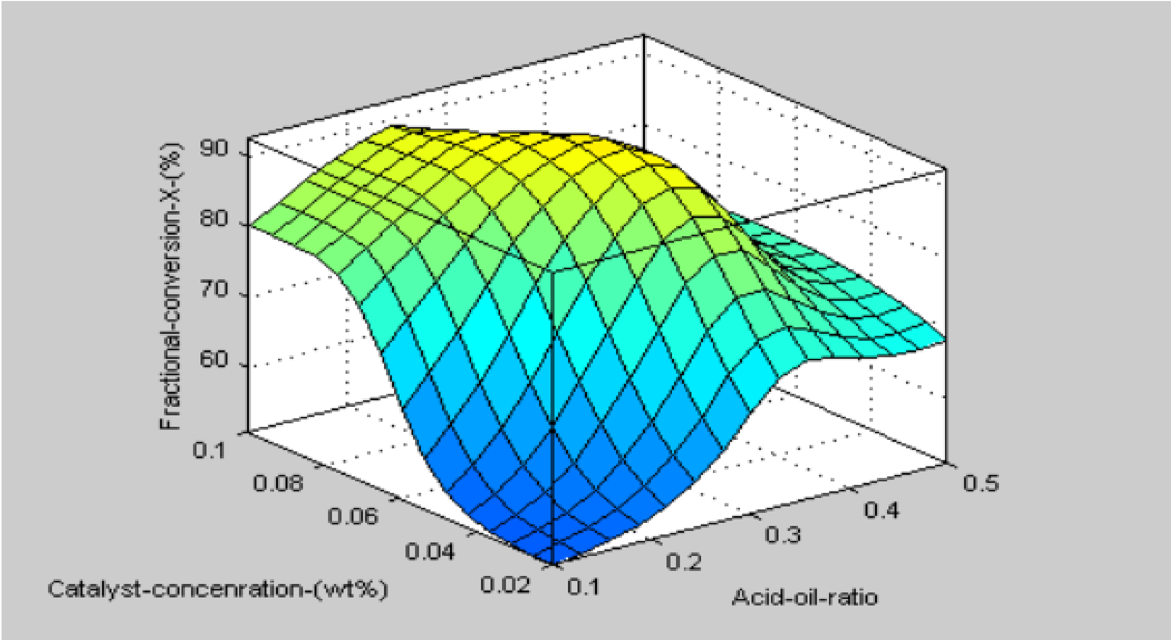


Figure 6f: Interaction of acid to oil ratio and catalyst concentration on fractional conversion

The optimization of fractional conversion cotton seed oil to alkyd resin was conducted through ANFIS rules, focusing on the ideal time, temperature, acid to oil ratio, catalyst concentration. The findings indicated that a fractional conversion of 91.8% was achieved when these parameters were set to 90 minutes, 240°C, 0.3, and 0.06wt%. Furthermore, the validation of the optimal extraction results showed a percentage error of less than 1%. The model demonstrated a strong capability to accurately predict outcomes, confirming its effectiveness in achieving optimal results.

3.3 Performance evaluation of the developed models

Statistical metrics were employed to assess the performance of the ANN and ANFIS models developed for predicting fractional conversion, with the results presented in Table 2. The R^2 and R values for the ANN model were slightly higher than those of the ANFIS model. Moreover, the ANN exhibited lower error rates compared to the ANFIS model, and both models displayed low calculated mean squared errors (MSEs). This suggests that while the ANN is more effective in predicting fractional conversion of cotton seed oil to alkyd resin than the ANFIS model, both models are viable options for estimating fractional conversion.

Table 2: Statistical Indices of the Model

Index	ANN	ANFIS

R^2	0.999	0.987
R	0.999	0.993
MSE	0.051	0.152

3.4 Physicochemical Properties of the Alkyd Resin

Despite achieving a high 91.8% acid conversion, the 13mgKOH/g acid value is still very high (Table 3a). 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. The high iodine value (43.866gI_2/100g oil) indicates a high degree of unsaturation in the ester molecules, likely due to conjugated bonding.

Table 3b 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 3c, 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 3a: 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 3b: Drying characteristics

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

Table 3c: 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

4. Conclusion

This study aimed to optimize the fractional conversion of cotton seed oil into alkyd resin by employing soft computing techniques, specifically Artificial Neural Networks (ANN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS). The results revealed that ANN provided superior predictive performance compared to ANFIS, evidenced by higher coefficients of determination and lower error rates. An optimal fractional conversion of 91.8% was achieved under conditions of 90 minutes, 240°C, 0.3, and 0.06 wt%. The developed predictive model for fractional conversion is anticipated to facilitate the increased utilization of vegetable oils in alkyd resin manufacturing. Overall, this research marks a significant step toward advancing sustainable and renewable bioproducts.

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