MODELING AND OPTIMIZATION OF THE THERMOPHYSICAL PROPERTIES OF A NATURAL ESTER BASED NANO FLUID FOR A HIGH VOLTAGE TRANSFORMER

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ABSTRACT

In recent times, due to environmentally friendly issues, sustainable resources, and higher concerns regarding safety, research in the area of alternative liquid insulation in high voltage apparatus has been necessary. To actualize this goal, vegetable oil has been studied extensively and it has the potential to replace mineral oil in power transformers. In addition, the incorporation of nanoparticles has been remarkable in producing improved characteristics of insulating oil. In this study optimization of the Thermophysical properties which include viscosity, and the flash point was done using the Taguchi approach of design of experiment. In the methodology, the concentration of the nanoparticles, mixing, and drying time were varied and an optimal combination of parameters was observed and recorded. The results shows that the optimum parameter combination for flash point is 0.9wt% concentration, 45 minutes mixing time, and 3hrs drying time while Viscosity has its optimum parameter combination at zero concentration of nanoparticles, mixing, and drying time. The optimized values of the thermophysical properties of the nanofluid reveal that the natural ester-based nanofluid is a suitable replacement for mineral oil in transformer cooling and insulation because of its improved properties. A mathematical model for the combination of concentration of nanoparticles, mixing and drying time for viscosity and flash point was developed and statistically validated. Hence can be used to navigate and predict the viscosity and flash point of the nanofluid within and outside the experimental design space.

Keywords: Methyl ester, Viscosity, Flash Point, Optimization

1.0 INTRODUCTION

The insulating fluid finds application in high voltage systems such as power transformers. It serves as a coolant to prevent overheating of the transformer in addition to serving as an insulating material. A good insulating fluid is expected to have a thermophysical property like flash point to be as high as possible especially when the transformer is installed close to buildings and residential areas. Mineral oil has flash point values that are not considered high compared to vegetable oil with flash point values of about 250ºC (Primo et al., 2019; Ranjbarzadeh et al., 2021) and as such tend to combust at temperature values of 140ºC which makes the oil a high-risk fluid in comparison to vegetable oil. Viscosity is another thermophysical property of the transformer oil that deserves attention. A fluid with lower viscosity is best recommended for use in power transformers as this plays a critical role in how the oil takes heat derived away while the transformer is at work (Almeida et al., 2020). The oil takes the heat outside through a convective heat transformer and the viscosity of the fluid is vital for the efficiency of the heat transfer as the oil need to move around in the process. Therefore any research that is done regarding transformer oil must take the thermophysical as well as dielectric properties into consideration (Bhunia et al., 2018). Unmodified vegetable oil possesses viscosity values that are high hence it is necessary the need to modify them to natural esters before use through purification and transesterification process consequently reducing the viscosity of the liquid. Abdelmalik (2014) worked on the modification of palm kernel oil for high voltage usage and reported that the viscosity of natural ester is about 3 to 4 times lower than that of mineral oil which is also in agreement with the results of Raeisian et al. (2019). Raeisian et al. (2019) investigated the possibility of using waste vegetable oil as a suitable replacement to the cooling fluid in high voltage transformer and finds out that both the dielectric and thermophysical properties of waste vegetable ester were better than that of the mineral oil and concluded that the vegetable oil is a better replacement to the commercially available mineral oil. Yuvarajan et al. (2016), produced methyl ester from rice bran oil and observed the effect of adding magnetite nanoparticles. They observed a 2 ^oC increase in flash point with the addition of magnetite.

In this study, the Yellow Oleander seeds oil was used with the addition of aluminium oxide nano particles at varied concentration, mixing and drying time. The extracted oil was purified and transesterified. consequently, reducing significantly the viscosity of the oil (Zareh et al., 2017). The effects of concentration of nanoparticles, mixing and drying time which represent the process parameters were investigated on the flash point and viscosity. The flash point and viscosity were optimized. The optimum parameter settings were observed and consequently, the optimum values were determined.

2. EXPERIMENT
Materials and Methods

2.1 Materials

The materials used include Sodium hydroxide, Whatman no.1 and no. 5, Citric acid, Al_2O_3 nanoparticles, Silica hydrogel, Yellow oleander seeds, Methanol, and Tonsil supreme fuller's earth.

2.2 Processing Yellow Oleander Seeds

Yellow oleander seeds used in this study were gathered locally from the environment in Samaru Zaria, Nigeria. Yellow oleander seed was peeled, de-pulped and the stone (kernel) was dried at 60°C for 14h. The dried kernels were then ground to powder and the extraction was done through mechanical pressing.

2.3 Purification

Acid degumming was the first process in the purification of the oil, where the phospholipids and the gum were removed using citric acid. The oil was heated to 70 ^OC in a round bottom flask then Citric acid measuring up to 200 ml was added to it and was allowed to mix for 20 min duration. The second process is the alkali neutralization where the free fatty acid was reduced using sodium hydroxide. Sodium hydroxide solution was introduced and allowed to stir for 30 min. The mixture of the chemicals and the oil was dried in a vacuum oven for 30 minutes to remove the moisture content. The bleaching of the oil and removal of the oxidation product and colored compound was done using Tonsil supreme. This process was carried out by adding 5 g of the fuller earth to the mixture followed by 45 minutes of stirring. The mixture was then filtered with Whatman No.5 and No.1 inside the oven.

2.4 Transesterification

This first process is the heating up of 200 ml of purified yellow oleander seed oil to 60 ^OC in a conical flask followed by the addition of Sodium methoxide to the preheated oil and heating at a constant temperature (60 ^OC) for 1hr. Later on, about 2.7 g of anhydrous sodium hydroxide was dissolved in methanol to develop a methoxide solution. The solution was poured into a separating funnel after an hour for effective separation of ester and glycerol. The ester gotten was then washed with warm water to remove excess sodium hydroxide. Finally is the drying of the sample to remove water molecules and methanol in a vacuum oven at 60 ^{O}C.

2.5 Nanofluid development

The process employed to develop the transformer natural ester-based nanofluids with desirable features was as follows:

i. The nanoparticles (Al_2O_3), after surface modification, were added into the produced oil to the proposed concentrations (0, 0.3, 0.6, 0.9wt.%).

ii. The developed nanofluids was placed in an oven to vacuum drying for some specific time to exclude the influence of moisture and gas bubbles generated while forming nanofluid. (See Table 3.1 for details)

2.6 Experimental Design

The Taguchi approach was used in this study to optimize the process parameters for the development of Natural Ester Nano Fluid for single performance characteristics

Taguchi Approach

The effects of varying the process parameters which include concentration, mixing, and drying time were observed using Taguchi Design of Experiments. From Table 1, the three process parameters and the four levels are shown. Four levels are the number of levels that will give the least number of experiments in regards to the number of factors on the orthogonal array.

Table 1. Experimental outlay and variable parameters

Code	Parameters	Levels			
		1	2	3	4
A	Concentration (wt. %)	0	0.3	0.6	0.9
B	Mixing Time (mins)	0	15	30	45
C	Vacuum Drying Time (hrs.)	0	1	2	3

The formula to get the minimum number of experiments to be carried out is given by:

$$N_{Taguchi} = 1 + N(L - 1) \tag{3.1}$$

Shahri et al., (2018)

Where $N_{Taguchi}$ is the minimum number of experiments to be carried out.
L is the number of levels while N is the number of parameters, and from Table 3.2 above, N = 3, L = 4. Therefore $N_{Taguchi}$ = 10. Being that the optimization procedure can be carried out with at least 10 runs. But Minitab software used, only has 16 runs as a minimum of the number of runs for this number of factors and levels. Therefore $N_{Taguchi}$ = 16.

Table 2. The Result of Orthogonal Test L16

Runs	Concentration (A)	Mixing Time (B)	Drying Time (C)
1	0.0	0	0
2	0.0	15	1

3	0.0	30	2
4	0.0	45	3
5	0.3	0	1
6	0.3	15	0
7	0.3	30	3
8	0.3	45	2
9	0.6	0	2
10	0.6	15	3
11	0.6	30	0
12	0.6	45	1
13	0.9	0	3
14	0.9	15	2
15	0.9	30	1
16	0.9	45	0

The diversity of factors is shown in Table 2 with a total of 16 runs as minimum number of experiments.

The predicted optimum value of means or S/N ratio (T_{opt}) of the response is determined by the expression;

$$T_{opt} = T_{iA} + T_{iB} + T_{iC} - 2T_m \tag{3.2}$$

Where: T_m is the overall mean or S/N ratio while T_{iA}, T_{iB} and T_{iC} stands for the highest or lowest value of mean from the response table under concentration, mixing, and drying time respectively depending on whether it is the higher the better or lower the better category.

The predicted value was confirmed by a confirmation experiment. In this study, a sample was prepared with the optimal parameters as revealed and the optimized property tested for. The result of the test was compared within the range of a confidence interval and a percentage error was drawn from the difference between the experimental and predicted value.

Confidence Interval

$$C.I = \sqrt{F_\alpha(1, F_e)V_e\left[\frac{1}{\eta_{eff}} + \frac{1}{\eta_{ver}}\right]} \tag{3.3}$$

Where; C. I = Confidence interval;
$F_\alpha(1, F_e) =$ F ratio required for α;

$\alpha =$ Risk;
$F_e =$ Error DOF;
$V_e =$ Error Variance (obtained from the Anova Table) ;
$\eta_{ver} =$ number of trials to run confirmation test i.e.
same as the number of replication for each run; $\eta_{eff} =$ Effective number of replications

$$\eta_{eff} = \frac{N}{1+[Total\ DOF\ of\ controlled\ factors]}$$

The percentage error is calculated using equation 3.27

$$Error = \frac{Experimental\ value - Predictive\ Value}{Experimental\ Value}$$

SN ratio

The SN ratio was used to reduce the noise from the experimental result. It was calculated using equations 3.4 and 3.5 for the Higher the better and Smaller the Better category.

$$\left(\frac{S}{N}\right)_{HTB} = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (3.4)$$

$$\left(\frac{S}{N}\right)_{STB} = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right) \quad (3.5)$$

Where n is the number of experiments $\bar{y}^2$ is the mean, S^2 stands for the variance and y_i stands for the response value of the i^{th} the experiment in the orthogonal array.

3. CHARACTERIZATIONS

3.1 Viscosity

The dynamic viscosity of the natural ester-based nanofluids was measured using RVDV-1 digital viscometer by ASTM D445 standard at a temperature of 60^{o}C for all the samples

3.2 Flash Point

The flash point of the oil was determined according to the American Society for Testing and Materials (ASTM) D93 standard (Sani et al., 2018)

4. RESULTS AND DISCUSSION

4.1 Optimization of Flash point values for Natural Ester Based Nanofluid

Table 3. Mean and SN ratio of Flash Point (^{O}C) for Natural Ester Based Nanofluid

RUNS	Mean Flash Point (^{O}C)	SN ratio (dB)
1	153.67	43.73
2	153.33	43.71
3	151.00	43.58
4	150.67	43.56
5	152.33	43.66
6	153.33	43.71
7	155.00	43.81
8	156.00	43.86
9	155.00	43.81
10	156.00	43.86
11	157.00	43.92
12	156.00	43.86
13	155.00	43.81
14	156.00	43.86
15	157.33	43.94

16	158.00	43.97
Mean	154.73	43.79

Table 3 shows the mean and sn ratio of flash points for the natural ester based nanofluid. The experiment was carried out three times for each run and an average value and sn ratio was generated from the design of experiment software.

Table 4: Flash Point Response Table of Means (^{O}C) and SN ratio (dB)

Level	Conc. A		Mixing time B		Drying time C	
	Means (^{O}C)	**SN ratio (dB)**	**Means (^{O}C)**	**SN ratio (dB)**	**Means (^{O}C)**	**SN ratio (dB)**
1	152.2	43.65	154.0	43.75	155.5	43.83
2	154.2	43.76	154.7	43.79	154.8	43.79
3	156.0	43.86	155.1	43.81	154.5	43.78
4	156.6	43.89	155.2	43.81	154.2	43.76
Delta	4.4	0.25	1.2	0.06	1.3	0.07
Rank	1	1	3	3	2	2

Also, Table 4 shows the response Table of means and SN ratios of flash point. It also shows the general mean of all the experimental runs carried out and the mean of the SN ratios of the experimental runs. The SN ratio for the flash point was calculated using the Higher the Better category for the performance characteristics obtained from equation 3.2

4.2 Effect of Concentration on the Flash Point of the nanofluid

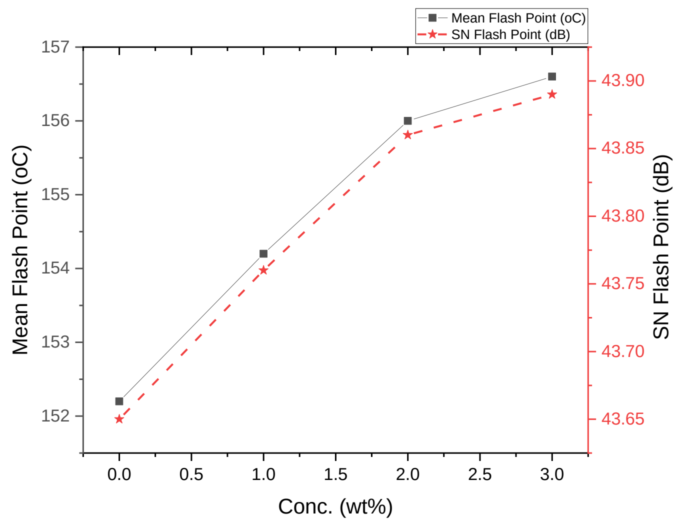

Fig. 1. Variation of Flash Point with Concentration of AL_2O_3 Nanoparticles

Figure 1 shows the effect of the concentration of aluminium oxide nanoparticles on the flash point. It can be observed from figure 1 that as the concentration of the nanoparticles increases, there is a corresponding increase in the flash point of the nanofluid which is in agreement with the results of Ma et al. (2020), Mousavi et al. (2020), and Pourpasha et al. (2020). They reported an increase in flash point with the addition of nanoparticles. The flash point increases slightly by 3.2% with concentration having a percentage contribution of 67%. The peak value of the flash point of the natural ester nanofluid obtained was 158ºC which is higher than that of the mineral oil of 140ºC (Dombek et al., 2018; Rathna et al., 2021). The flash point may have enhanced as a result of the attachment of the nanoparticle to the triglycerides of the base fluids and restricting its dissociation. (Musa et al., 2018). When the flash point of the fluid is higher, it becomes more thermally stable at a high temperature. A fluid with a high flash point is more advantageous. This affirmed the potential of nanofluids as an excellent replacement for mineral oil in liquid-filled transformers for indoor and adjacent to building installations.

4.3 Effect of Mixing Time on the Flash Point of the nanofluid

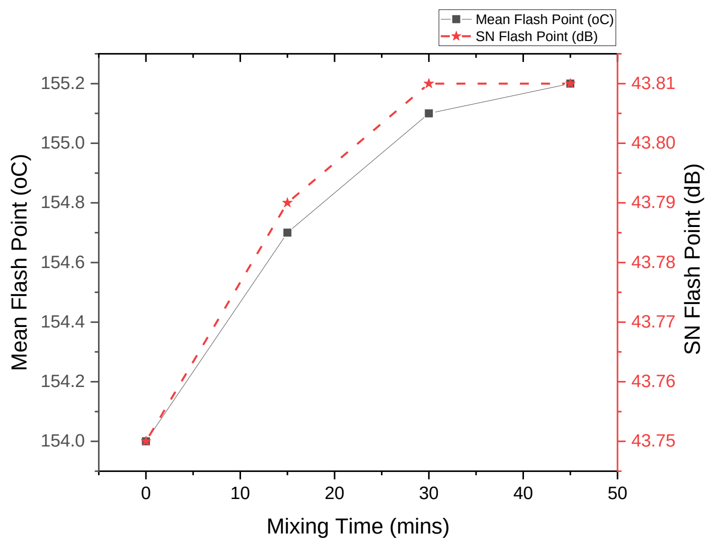

Fig. 2. Variation of Flash Point with Mixing Time

The effect of mixing time on the flash point of the nanofluid can be observed from figure 2. As the mixing time increases the flash point tends to increase due to a possible achievement of a better distribution of the nanoparticles in the fluid which results in the restriction of the triglycerides of the base fluids from dissociation through the attachment of nanoparticles (Oparanti et al., 2020; Musa et al., 2018).

4.4 Effect of Drying time on the Flash Point of the nanofluid

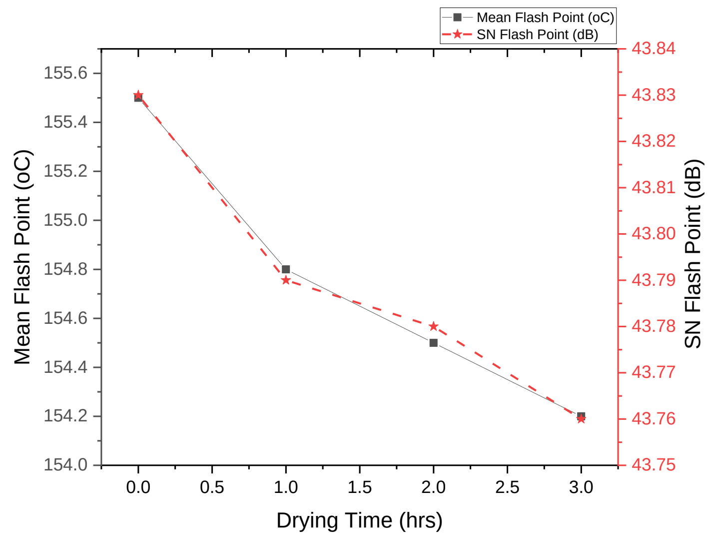

Fig. 3. Variation of Flash Point with Drying Time

As drying time increases, we can see a decrease in the Flash Point of the nanofluid as can be seen in figure 3. This can be as a result of the presence of little water molecules in the fluid which increases the Flash Point and as such, when drying occurs, Flash Point was reduces. This result is in agreement with Othman et al. (2017), Udoh et al. (2017), and Madavan et al. (2017) all of which observed the effects of moisture on flash point and observed an increment in flash point as a result of the presence of moisture

4.5 Analysis of Variance for Flash Point

Table 5. Analysis of Variance of Means for Flash Point of nanofluid

Source	DF	Seq SS		Adj MS		P		Perc. Cont. (%)	
		Means	**SN ratio**	**Means**	**SN ratio**	**Means**	**SN ratio**	**Means**	**SN ratio**
Conc.(wt.%)	3	47.743	0.15133	47.743	0.050443	0.029	0.030	67.72	67.68
Mixing time (mins)	3	3.410	0.01043	3.410	0.003476	0.733	0.745	4.83	4.67
Drying time (hrs)	3	3.854	0.01217	3.854	0.004056	0.697	0.702	5.46	5.44
Residual Error	6	15.486	0.04965	15.486	0.008275				
Total	15	70.493	0.22357						

Where DF=Degree of Freedom, SS=Sum of square, MS=Mean Square Conf. level=95%

Table 5 shows the analysis of variance of means and SN Ratio of flash point. From the analysis of variance of means, concentration has a P value of 0.029 which implies it is significant. Mixing time is seen to have a P value of 0.733 with a percentage contribution of 4.83 while Drying time has a P value of 0.697 with a percentage contribution of 5.46, which implies both mixing and drying time are insignificant.

4.6 Optimal Flash Point for the Natural Ester Based Nanofluid

The optimal flash point by means and sn ratio observed at A4B4C4 was calculated to be 157.84 and 43.89 using equation 3.2

4.7 Confirmation Test for the Flash Point for the Natural Ester Based Nanofluid at Optimal Combination

To confirm the predicted optimum flash point, a confirmatory test was carried out with the optimum set of parameters A4B4C4. The confidence interval calculated from equation 3.11 showed that the interval lies within ±7.09 of the predicted flash point. The Flash point test was replicated 3 times. The SN ratio of the confirmatory result was obtained using equation 3.4. The result of the confirmatory test is presented in table 4.6.

Table 6. Observation of confirmation test (Flash Point)

SN	**Trial Number**			Flash Point	**SN Ratio (dB)**
	1	2	3		
1	158	159	158	158.3333	43.89

The average (Mean) of the confirmatory test was 5.63 which was within the confidence interval. Such that 150.75 < 158.33 < 164.93.

Table 7. Confirmatory test result for the Optimal Flash Point of Natural Ester Based Nanofluid

	Optimal Process Parameter Settings	**Predictive Values**	**Experimental Values**	**% Difference**
SN Ratio (dB)	A4B4C4	43.89	43.99	0.2
Mean Flash Point	A4B4C4	157.84	158.33	0.34

The experimental and predictive value for the flash point of means and sn ratio was found to be 158.33 and 157.84 with a percentage difference of 0.34 for means then 43.99 and 43.89 with a percentage difference of 0.34 for SN ratio which is a very good prediction.

4.8 Regression Analysis

A mathematical model for the combination of concentration of nanofluid, mixing, and drying time was derived from the regression analysis carried out using the Minitab® 19 statistical software used for the prediction of flash point of the Natural Ester Based Nanofluid. The regression analysis model is presented in Table 7

Table 8. Regression Analysis model for Flash Point

Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**
Constant	153.24	1.06	145.02	0.000
A	0.02	3.48	0.00	0.996

B	0.0120	0.0695	0.17	0.868
C	-0.15	1.04	-0.14	0.892
A*B	0.104	0.112	0.93	0.380
A*C	0.88	1.68	0.52	0.615
B*C	-0.0182	0.0336	-0.54	0.603
A*B*C	0.0389	0.0486	0.80	0.447

Regression Equation

Flash Point =153.24 + 0.02 A + 0.0120 B - 0.15 C + 0.104 A*B + 0.88 A*C - 0.0182 B*C + 0.0389 A*B*C
From the regression analysis, R^2 is 85.32% which is good

Table 9. Results at optimal level Flash Point

	Optimal Process Parameter Settings	Predictive Values	Experimental Values	% Difference
Flash Point	A4B4C4	160.1195	158.3	1.136

The predicted results with the regression equation and the experimental results have a percentage difference of 1.136 which confirms a high-reliability value.

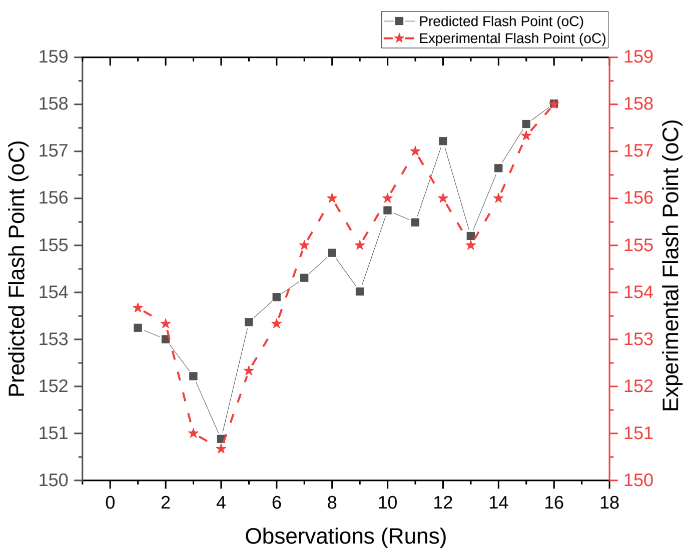

Fig. 4. Comparison of Predicted and Experimental Flash Point

Figure 4 shows the variation of the predicted flash point from regression analysis with the experimental flash point. No significant deviation was observed which implies the equation has high reliability.

4.9 Optimization of Viscosity values for Natural Ester Based Nanofluid

Table 10. Mean and SN ratio of Viscosity values for Natural Ester Based Nanofluid

Runs	**Mean Viscosity**(m**Pa**.s)	**SN Ratio (dB)**
1	3.9333	-11.8958
2	3.9667	-11.9691
3	4.0833	-12.2204
4	4.1633	-12.3889
5	4.1467	-12.3540
6	4.1733	-12.4097
7	4.1833	-12.4305
8	4.1600	-12.3819
9	4.1400	-12.3400
10	4.2000	-12.4650
11	4.2600	-12.5882
12	4.2700	-12.6086
13	4.3800	-12.8295
14	4.3400	-12.7498
15	4.3000	-12.6694
16	4.2467	-12.5610
Mean	4.1842	-12.4289

Also, Table 11 shows the response table of means and sn ratio of viscosity. It also shows the general mean of all the experimental runs carried out and the mean of the SN ratios of the experimental runs. The SN ratio for the viscosity was calculated using the Lower the Better category for the performance characteristics obtained from equation 3.2

Table 11. Viscosity Response Table for Means and SN ratio

Level	Conc. A		Mixing time B		Drying time C	
	Means (mPa.s)	**SN ratio (dB)**	**Means (mPa.s)**	**SN ratio (dB)**	**Means (mPa.s)**	**SN ratio (dB)**
1	4.037	-12.12	4.150	-12.35	4.153	-12.36
2	4.166	-12.39	4.170	-12.40	4.171	-12.40
3	4.217	-12.50	4.207	-12.48	4.181	-12.42
4	4.317	-12.70	4.210	-12.49	4.232	-12.53
Delta	0.280	0.58	0.060	0.13	0.078	0.16
Rank	1	1	3	3	2	2

4.10 Effect of Concentration on the Viscosity of the nanofluid

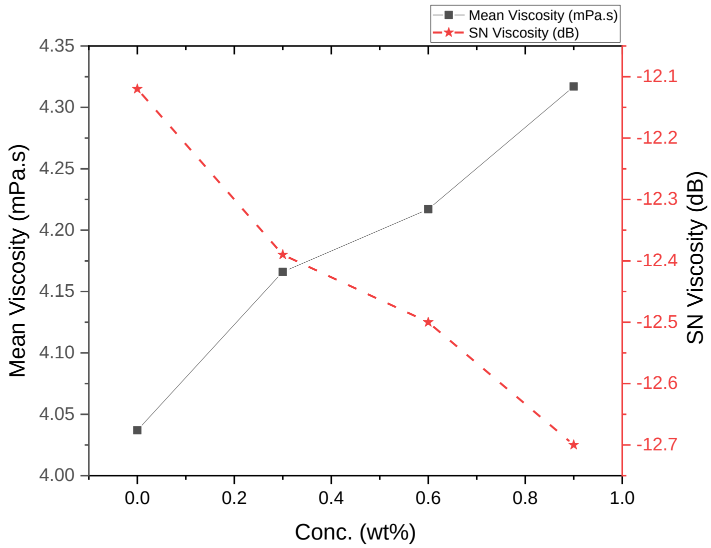

Fig. 5. Variation of Viscosity with Concentration of AL_2O_3 Nanoparticles

The viscosity of the pure ester was determined to be 3.95mPa.s. From figure 5, as the concentration of nanoparticles was increased an increase in viscosity was observed of about 7%. This might be a result of flow resistance which increases with the increase in nanoparticles concentration. Flow resistance occurs because the nanoparticles collide more with each other when moving randomly, giving rise to increased viscosity. This is in agreement with the result of Du et al. (2015), Mousavi et al. (2021), and Khodadadi et al. (2019). They reported an increase in viscosity as a result of the addition of nanoparticles. In as much as there is a slight increase in viscosity due to the addition of nanoparticles, the viscosity of the natural ester nanofluid is still better than that of the mineral oil which is in use today. The low viscosity of natural ester makes it a better replacement as an insulating fluid in power transformers (A. A Abdulmalik, 2014)

4.11 Effect of Mixing Time on the Viscosity of the nanofluid

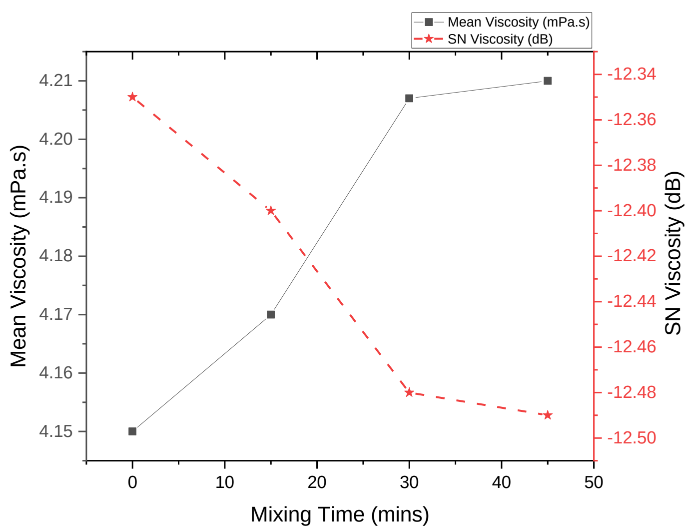

Fig. 6. Variation of Viscosity with Mixing Time

Figure 6 shows the variation of viscosity with mixing time. It was observed from the graph that mixing time affects the viscosity of the nanofluid. The viscosity increases with an increase in mixing time. This can be a result of the uniform distribution of the nanoparticles in the fluid attained after mixing which increases the flow resistance of the overall fluid thereby increasing viscosity (Du et al., 2015; Ranjbarzadeh et al., 2021).

4.12 Effect of Drying time on the Viscosity of the nanofluid

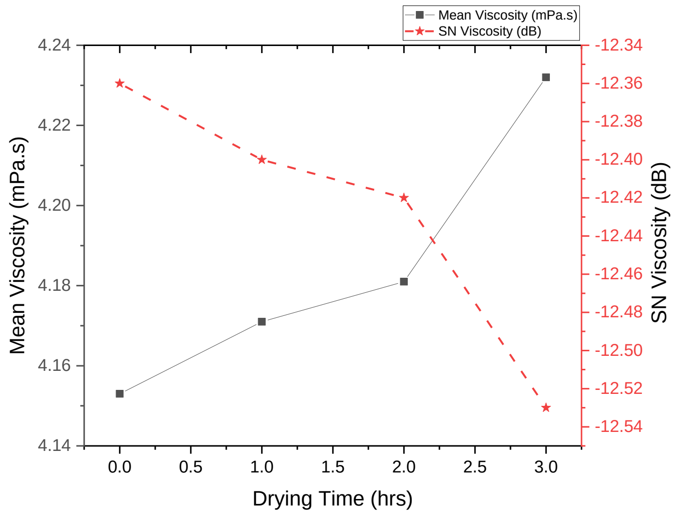

Fig. 7. Variation of Viscosity Drying Time

Figure 7 shows the variation of Drying time with viscosity. An increase in drying time increases the viscosity of the nanofluid slightly which implies that moisture reduces viscosity. This is in agreement with the results of Wang et al. (2018), Jiaqiang et al. (2018), and Radhakrishnan et al. (2019) who observed the effects of water molecules on viscosity and reported a decrease in viscosity due to moisture. This can be as a result of little water molecules in the nanofluid which reduces as a result of drying thereby increasing viscosity.

4.13 Analysis of Variance for Viscosity

Table 12. Analysis of Variance of Means and sn ratio for Viscosity of nanofluid

Source	DF	Seq SS		Adj MS		P		Perc. Cont. (%)	
		Means	SN ratio	Means	SN ratio	Means	SN ratio	Means	SN ratio
Conc.(wt.%)	3	0.16304	0.70981	0.054346	0.23660	0.009	0.009	74.72	74.37
Mixing time (mins)	3	0.01017	0.04758	0.003389	0.01586	0.613	0.588	4.67	4.99
Drying time (hrs)	3	0.01358	0.06008	0.004528	0.02003	0.509	0.503	6.22	6.3
Residual Error	6	0.03142	0.13692	0.005237	0.02282				
Total	15	0.21821	0.95439						

Where DF=Degree of Freedom, SS=Sum of square, MS=Mean Square Conf. level. = 95

Table 12 shows the analysis of variance of means and SN Ratio for Viscosity. From the analysis of variance of means, concentration has a P value of 0.009 which is significant with a percentage contribution of 74.72. Mixing time is seen to have a P value of 0.613 with a percentage contribution of 4.67 which is not significant while Drying time has a P value of 0.509 which is not significant with a percentage contribution of 6.22.

4.14 Optimal Viscosity for the Natural Ester Based Nanofluid

The optimal by means and sn ratio observed at A1B1C1 was calculated to be 3.97 and 11.9722 using equation 3.1

4.15 Confirmation Test for the Viscosity for the Natural Ester Based Nanofluid at Optimal Combination

Table 13. Observation of confirmation test (Viscosity)

SN	**Trial Number**			Viscosity Point	**SN Ratio (dB)**
	1	2	3		
1	3.9	4.0	3.9	3.93	14.1205

Table 14. Confirmatory test result for the Optimal Viscosity of Natural Ester Based Nanofluid

	Optimal Process Parameter Settings	**Predictive Values**	**Experimental Values**	**% Difference**
SN Ratio (dB)	A1B1C1	11.9945	11.9722	0.19
Mean Viscosity	A1B1C1	3.97	3.93	1.0

The experimental and predictive value for the Viscosity of means and sn ratio was found to be 3.93 and 3.97 with a percentage difference of 1.0 then 11.9722 and 11.9945 with a percentage difference of 0.19 which is a very good prediction.

4.16 Regression Analysis

A mathematical model for the combination of concentration of nanofluid, mixing, and drying time was derived from the regression analysis carried out using the Minitab® 19 statistical software used for the prediction of viscosity of the Natural Ester Based Nanofluid. The regression analysis model is presented in Table 14

Table 15. Regression Analysis model for Viscosity

Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**
Constant	3.9515	0.0449	88.08	0.000
A	0.555	0.148	3.76	0.006
B	0.00508	0.00295	1.72	0.124
C	-0.0357	0.0443	-0.81	0.443

A*B	-0.01044	0.00476	-2.19	0.060
A*C	0.0027	0.0714	0.04	0.971
B*C	0.00068	0.00143	0.48	0.645
A*B*C	0.00033	0.00206	0.16	0.877

Regression Equation

Viscosity=3.9515 + 0.555 A + 0.00508 B - 0.0357 C - 0.01044 A*B + 0.0027 A*C + 0.00068 B*C+ 0.00033 A*B*C

From the regression analysis, we have an R^2 value of 91.45% which makes the equation reliable

Table 16. Results at optimal level Viscosity

	Optimal Process Parameter Settings	Predictive Values	Experimental Values	% Difference
Viscosity (mPa.s)	A1B1C1	4.28	3.93	8.17

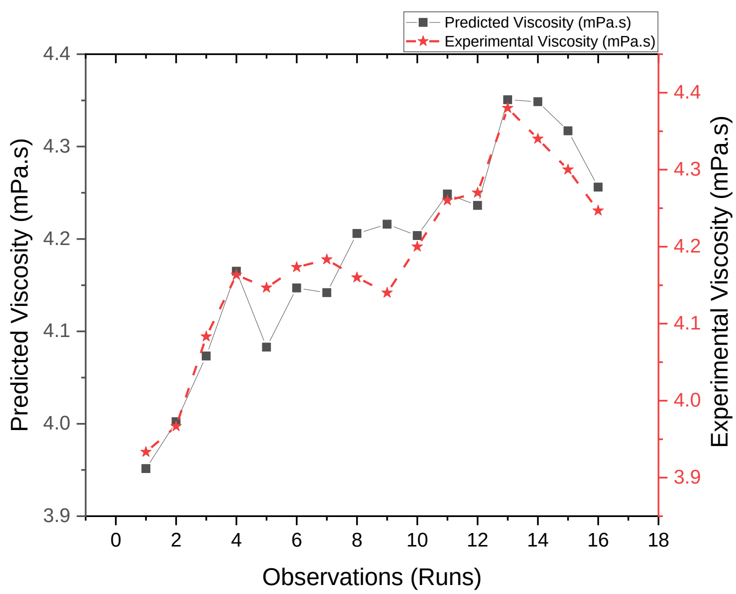

Fig. 8. Comparison of Predicted and Experimental Viscosity

Figure 8 shows the variation of predicted experimental viscosity and the experimental viscosity. It can be observed that there is no significant deviation which implies a high level of reliability.

4.17 XRD Analysis

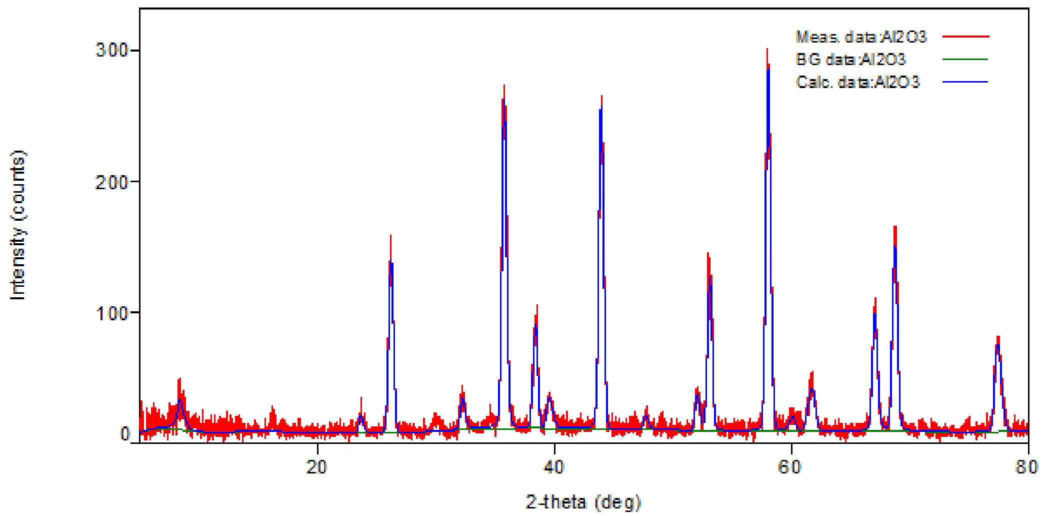

Fig. 9. XRD spectrum of AL2O3 Nanoparticles

Figure 9 shows the pattern of the XRD spectrum of AL2O3 with the value of 2θ at 35º, 38º 53º, and 62º which corresponds to alumina (ICSD 025778) (Matori et al., 2015). The mean crystallite size of the nanoparticle was determined by the manufacturer. The average particle size of AL2O3 is 18nm.

4.18 FTIR Analysis

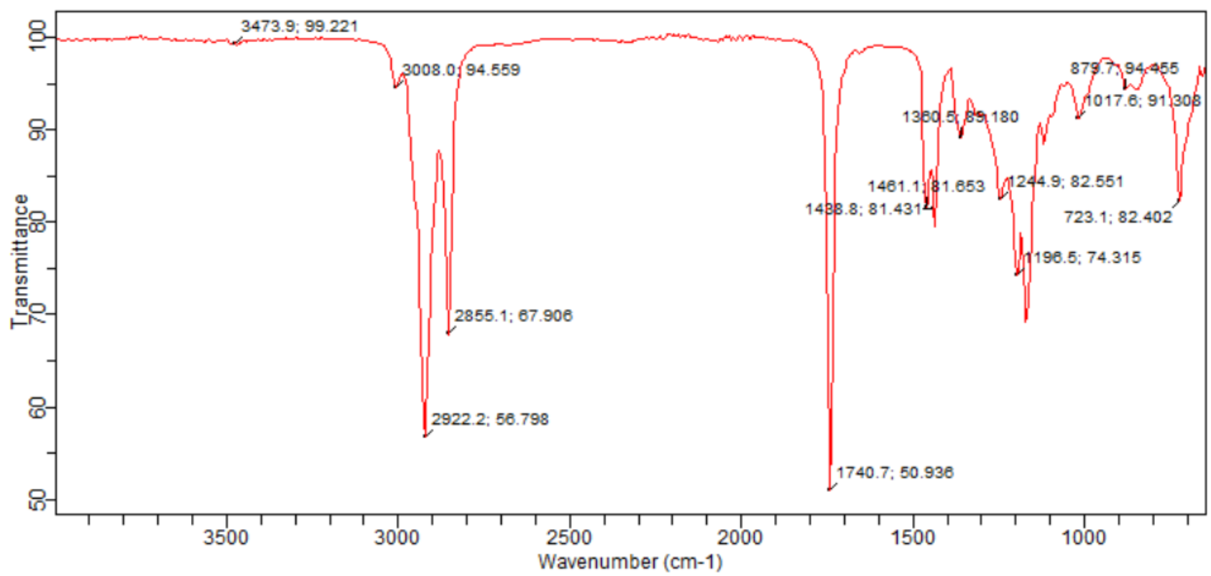

Fig. 10. FTIR of Natural Ester

Figure 10 shows the FTIR spectra of the developed natural ester. The characteristic medium peaks around 1196 cm-1 and 1244 cm-1, and a strong peak around 1166 cm-1, are fingerprints of the methyl ester of long-chain fatty acid (Silverstein et al., 1962).

5. CONCLUSION

At the end of the study the following conclusions were made:

i. A natural ester based nanofluid was developed and the optimal flash point for the nanofluid was found to be 158.3 ^{O}C. This value is greater than that of the conventional mineral oil which is about 140 ^{O}C. The optimal parameter setting for the flash point was at 0.9wt % concentration, 45 minutes mixing time and 3 hrs drying time.
ii. The results also shows that the optimal viscosity for the natural ester based nanofluid is 3.93mPa.s which is 3 times lower than that of the conventional mineral oil.
iii. A mathematical model was developed for the prediction of flash point and viscosity values.

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