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Performance Analysis of Blended Neem and Olive Oil as Alternate Liquid Insulation for Power Transformers

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Abstract-The transformer is a critical part of the power system. The liquid insulation used in transformers should have improved thermal and dielectric properties, widespread availability, longer life, and lower cost. Despite the fact that transformers have long employed petroleum based insulating oils, recent environmental concerns, health and safety issues and many technical factors have boosted the demand for novel alternative and biodegradable liquids. This work focuses on using natural esters to replace traditional mineral oil to operate transformers efficiently. Two natural esters, neem oil and olive oil have been blended in various ratios to examine how well they work as liquid dielectrics with power transformers. With the blended samples, the critical parameters including moisture content and resistivity, capacitance, dielectric constant, dissipation factor, viscosity at various temperatures are measured according to IEC and ASTM standards. The results were statistically analyzed and shown to conform fitted line plot and residual plot analysis. From the investigations, it is found that the blended natural ester samples exhibit characteristics that are closer to those of liquid insulation standards used in power transformers and have the potential to supersede conventional mineral oil as an alternative liquid insulation.

Keywords Power transformer; Liquid insulation; Natural ester; Blended oils; Fitted line plot.

1. Introduction

Power transformers are the most significant component in the power system and hence transformer failure is most crucial failures in generating stations[1], and life of the transformer certainly depends on the viability of the insulation that has been used [2,3]. The liquid dielectrics present in the transformer serve both as insulation and also as a coolant that withstands the transformer operating temperature within permissible limits [4]. Mineral-based oil is the most commonly utilized insulating liquid in oil-immersed transformers. However, mineral oil is non-biodegradable, non-renewable, and non-biocompatible in nature. Also, if there is a spillage, it leads to a serious issue becoming toxic and holds the potential of disturbing the environment [5]. With all the disadvantages, the utilization of renewable sources are expanded widely due to energy crisis[6,7].

In order to cater the need of liquid dielectrics to the power transformers, research had been carried out on natural esters which had proven that they can subjugate the conventional mineral oil by showing higher dielectric, thermal properties, improved biodegradability. The exceptional chemical composition of natural esters is the major reason for their outstanding chemical and electrical stability. Transformer filled with natural esters complies very well with IEC standards, therefore, hold great prospects as mineral oil substitutes in transformer insulation.

Natural esters have high viscosity with limited oxidation stability, and low pour points in their as received condition which led to the formation of hotspots in the transformers which suppresses the ability of heat dissipation[8] and due to various loading condition and external faults also leads to insulation damage [9]. To overcome these limitations, natural esters are blended with mineral oil by adding antioxidants and additives [10, 11]. Due to the miscibility property of oils, blending of these oils together could be one of the methods to improve the dielectric properties [12]. Hence in this paper, two natural esters, neem oil and olive oil has been selected to investigate its suitability to power transformers as liquid insulation.

Neem is an indigenous plant to India and other subtropical regions [13]. Neem oil is extracted from the seed kernels through pressing or crushing either cold pressed method or by incorporating temperature extraction. The dielectric strength, flash and fire point of neem oil is found to be better and are within the acceptable range, but are poor in terms of viscosity, dissipation factor and resistivity [14]. Further, previous studies ensure the use of the neem oil as a potential alternative insulation in power transformers due to its availability, less cost and better thermal and electrical characteristics.

In contrast, olive oil exhibits a high resistance to the flow of electrical charges, making it a very good insulator. They pose less threat to the environment due to low volatility, high flash point, low vapor pressure, less flammable, hygroscopic and high solvency [15]. Also, the significant amount of phenolic compounds found in olive oil has a key part in the oil's resistance to oxidation, whereas the amount of halogenated solvents in the oil influences the presence of moisture content in it [16].

In this paper, investigation has been carried out to examine the suitability of replacing mineral oil with blending neem and olive oil in different proportions. Measurements of moisture content , dissipation factor, capacitance, dielectric constant, electrical resistivity and viscosity at various temperatures has been carried out. Also, fitted line plot and residual plot analysis has been implemented for the measured properties of natural esters.

The principal objective of a fitted line plot is to examine the underlying hypotheses (the errors are independent with a zero mean and constant variance which follow a normal distribution) in a regression study, primarily fitting a straight-line model to experimental data using residual plots. The experiment's response and predictor data are shown on the fitted line plot. The regression line, which is an algebraic representation of the regression equation used to represent the association between the response and the components in the model, is shown in the plot. The linear model's regression equation has the form of Eq. (1).

$$y = b_0 + b_1 x_1 \quad (1)$$

Where$y$is the response variable,b_0 is the constant or intercept,$b_1$is the predicted coefficient for the linear term, and $x_1$is the term's value.

The p-value evaluates the probability of the evidence being in opposition to the null hypothesis. Stronger evidence is presented against the null hypothesis, which does not account for any of the response variance, by lower probability. It is effective to use an alpha threshold of 0.05 for significance. A significance level of 0.05 represents a 5% chance of declaring that the model accounts for response variance when it does not. If the residuals don't exhibit a propensity that tends to refute the assumptions used to do the regression analysis, they should indicate a trend that appears to validate those assumptions. The residual's normal probability plot compares the residuals to what would be predicted with a normal distribution.

2. Materials and Methods

Two natural esters, neem and olive oil have been chosen. 500 ml of each sample is taken for analysis. Further, these oils are blended with each other in different proportions and their thermal and dielectric properties are investigated.

2.1. Sample Preparation

Neem and olive oils are collected from the local commercial market in APMC, Mysuru. 5 litres of each oil are purchased and stored in airtight glass container. With these oils as a primary sample, other samples are prepared by blending them with each other as in Table 1.

Table 1. Samples and their proportions taken for the study

Samples	Natural ester 1 Neem Oil (ml)	Natural ester 2 Olive oil (ml)
NM100	1000	0
OL100	0	1000
NM50+OL50	500	500
NM60+OL40	600	400
NM80+OL20	800	200

As per Table 1 oil samples are blended by using Magnetic stirrer method. Magnetic pellet is dropped into the oil beaker and made to spin at the speed of 1500 rpm for about 10-15 mins.

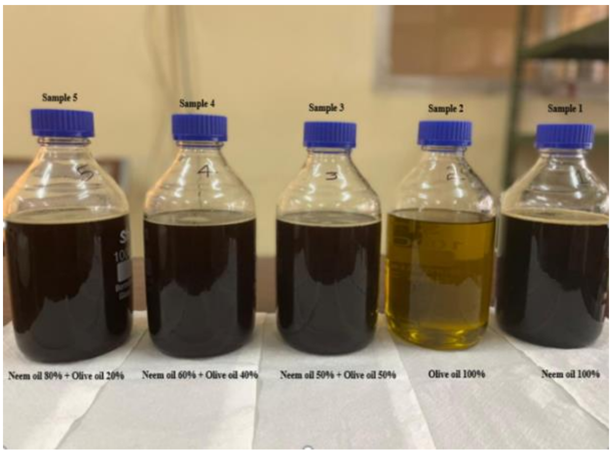


Fig. 1. Prepared samples for investigation.

2.2. Moisture Content measurement

The prepared samples shown in Fig.1 are analyzed for presence of moisture content by using a Volumetric Karl Fischer titrator which is designed to determine a wide range of moisture content from a few ppm to 100% water. The amount of oil required for the test is 10 ml.

2.3. Dielectric Property Measurement

The dielectric properties including capacitance, dielectric constant, Resistivity, and dissipation factor of the oil samples are tested at five different temperatures (40°, 60°, 80°, 90°, 100°C) using Automatic Dielectric Constant Tan Delta & Resistivity Test Set in accordance with the IEC and ASTM type oil cell with a 2 mm spacing, 100-1200 Volts/mm.

2.4. Viscosity Measurement

The viscosity of the oil samples is measured by using a Redwood viscometer for various temperatures (from room temperature to 90°C with 5°C differences) accordance with the ASTM D 445 standards.

The oil viscosity is measured in accordance with ASTM D 2162-06 standards, time taken by 50ml of an oil sample is made to flow through the orifice is recorded and the time it takes for 50cc of oil to flow through the orifice is noted viscosity is calculated. An electric heater is employed for rising the temperature from 40 to 90°C to measure the viscosity at various temperatures.

3. Results and Discussion

Our study examines the feasibility of replacing commercial mineral oil with natural esters in its received form and blended form. The obtained results with respect to its dielectric and thermal properties are analyzed to optimize the suitable proportions of the oil as transformer insulation.

3.1. Moisture Content Analysis

It is widely known that the presence of moisture in the transformer, especially if there is an excessive amount, can seriously impair mechanical and electrical performance. It reduces the dielectric breakdown strength and hastens the aging of insulation paper and hence excessive moisture is not ideal. Further, the presence of moisture shall lead the transformer to acidic, which is a harmful property for a transformer to work with [17].

Presence of the moisture content in the samples are illustrated in Fig.2 and tabulated in the Table 2. NM100 exhibits the highest value of 1530 ppm moisture content, whereas OL100 exhibits the least value of 777.64 ppm. This is due to the presence of more fatty acids in the olive oil than in the neem oil [18].

Hydrolysis process occurs due to the presence of moisture content and enzyme activity. The moisture content of neem oil is higher than that of the olive oil. Higher moisture content in neem oil is most likely due to the presence of water, which causes hydrolysis and fastens the deterioration of the oil life [19]. Where in the case of olive oil, the lower moisture content is due to ligase activity.

Table 2. Propriety values of moisture content present in the samples.

Samples	Moisture content (ppm)
NM100	1530.026
OL100	777.646
NM50+OL50	1009.51
NM60+OL40	910.416
NM80+OL20	972.33

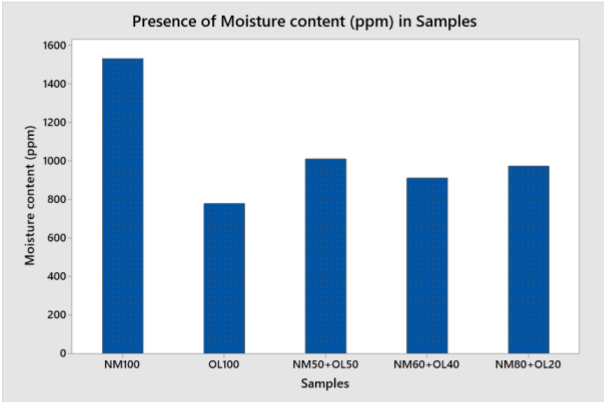


Fig. 2. Presence of moisture content in different insulation liquids

From the experimental results it is evident that NM100 has highest moisture content which breaks down the molecular bonds of the insulating oil and hinders the suitability of insulating liquid due to degradation. However, when blended with the olive oil, the characteristics of olive oil lowered the moisture content of the neem oil and hence the blended samples are more competent as transformer oil.

3.2. Dielectric Property Measurement

At higher load conditions power transformers get heated up, in order to study the behavior of the insulating liquid under various temperatures the samples are examined for its thermal and dielectric properties. According to IEC standards, experiments on thermal and dielectric properties are conducted. Investigation of blended oil's dissipation factor, capacitance, electrical resistivity, and dielectric constant are performed. Table 3 depicts the values of parameters under investigation.

Table 3. Propriety values of parameters under investigation at various temperature.

Samples	NM100					OL100					NM50+OL50					NM60+OL40					NM80+OL20				
Temperature (°C)	40	60	80	90	100	40	60	80	90	100	40	60	80	90	100	40	60	80	90	100	40	60	80	90	100
Capacitance (pF)	196.6	195.7	191.5	189.5	187.6	170.7	167.1	168.2	167.1	164.0	181.1	178.0	174.5	172.2	171.3	189.5	186.4	183.4	189.1	188.3	200.8	194.1	192.8	191.4	196.2
Dielectric Constant (ϵ)	3.364	3.349	3.277	3.245	3.213	2.922	2.859	2.877	2.859	2.806	3.098	3.046	2.985	2.946	2.932	3.243	3.19	3.137	3.295	3.221	3.436	3.222	3.299	3.275	3.356
tanδ (DF)	1.918	3.475	5.368	6.505	7.977	0.1237	0.02321	0.03993	0.0459	0.0719	0.717	1.312	2.045	2.345	2.863	0.968	1.533	2.551	2.97	3.709	1.352	2.418	3.667	4.487	5.338
Resistivity (ρ) GΩ-cm	5.646	3.248	2.169	1.836	1.53	1215	637.3	378.6	301.1	201.1	15.87	8.991	5.891	4.896	4.293	11.5	7.467	4.684	3.901	3.287	7.669	4.521	3.071	2.694	2.107

3.3. Dissipation factor

According to ASTM D924 standards, the dissipation factor of natural esters ranges between 0.08 at 25°C and 0.64 at 90°C [20]. Fig.3 shows that OL100, NM50+OL50, NM60+OL40 samples are lying under the acceptable ranges at 100°C, due to the higher degree of polymerisation leading to lower dissipation factor and the measured values are tabulated in Table 4 [21].

Table 4: Propriety values of dissipation factor of samples for various temperature

Temperature	40°C	60°C	80°C	90°C	100°C
NM100	1.918	3.475	5.368	6.505	7.977
OL100	0.0237	0.02321	0.03993	0.0459	0.0719
NM50+OL50	0.717	1.312	2.045	2.345	2.863
NM60+OL40	0.968	1.533	2.551	2.97	3.709
NM80+OL20	1.352	2.418	3.667	4.487	5.338

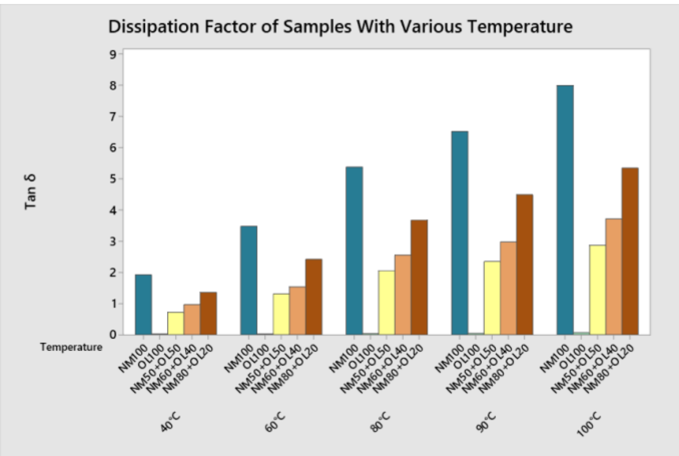
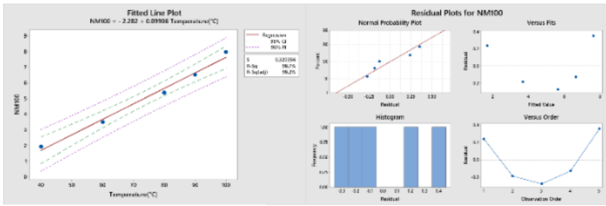


Fig. 3. Variation in dissipation factor of samples with various temperature.

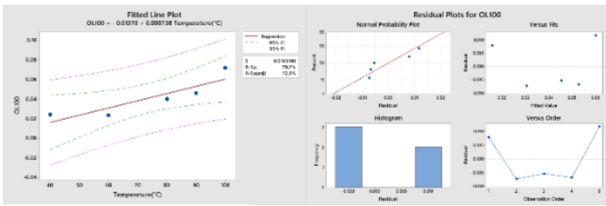
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	22.7676	22.7676	221.85	0.001
Error	3	0.3079	0.1026		
Total	4	23.0755			



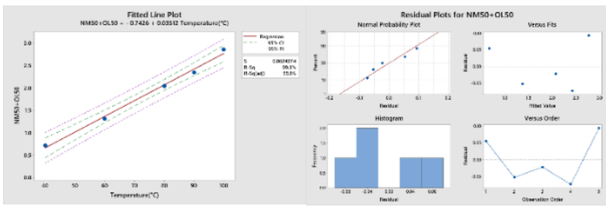
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.0012643	0.0012643	11.44	0.043
Error	3	0.0003314	0.0001105		
Total	4	0.0015957			



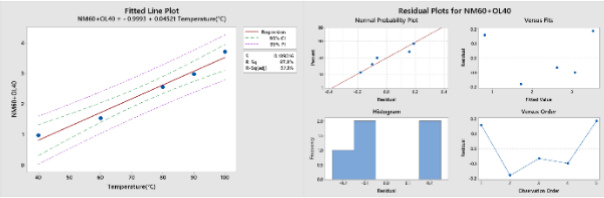
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2.86177	2.86177	421.41	0.000
Error	3	0.02037	0.00679		
Total	4	2.88215			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4.74184	4.74184	132.72	0.001
Error	3	0.10718	0.03573		
Total	4	4.84902			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	10.0587	10.0587	318.04	0.000
Error	3	0.0949	0.0316		
Total	4	10.1536			

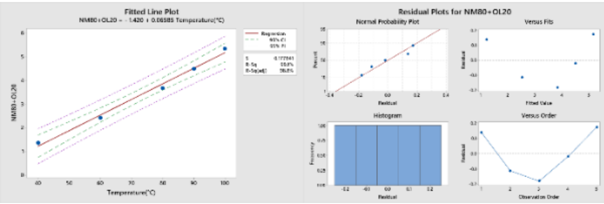


Fig. 4. Fitted line plots and residual plots for the variation of dissipation factor of investigated samples with temperature.

Figure 4 shows the fitted line plots for the prepared samples to observe the variation of dissipation factor with regard to rise in temperature. R-sq is the percentage of variation in the dissipation factor that is explained by the model which is always between 0% and 100%. The higher the R-sq value, the better the model fits. It is noted that the R-sq value of NM50+OL50 has 99.3% and hence the model fits better. In the regression equation, coefficients of temperature are positive which depicts that as the temperature increases, the mean value of the dissipation factor increases. Also, it is evident that the significance value (P) for all the samples is less than 0.05 which indicates that there is a statistically significant association between the dissipation factor and the temperature.

3.4. Capacitance

Figure 5 illustrates that the capacitance values of all the samples are decreasing with increasing temperature and its value should be more for highly insulating liquid.

Table 5. Propriety values of capacitance of investigated samples at various temperature.

Temperature	40°C	60°C	80°C	90°C	100°C
NM100	196.6	195.7	191.5	189.5	187.6
OL100	170.7	167.1	168.2	167.1	164
NM50+OL50	181.1	178	174.5	172.2	171.3
NM60+OL40	189.5	186.4	183.4	189.1	188.3
NM80+OL20	200.8	194.1	192.8	191.4	196.2

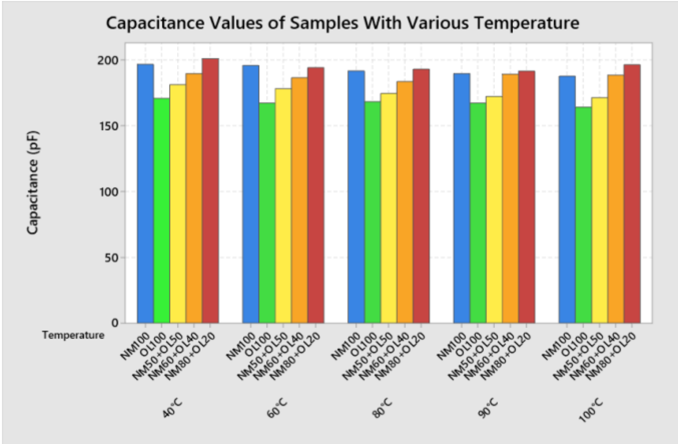
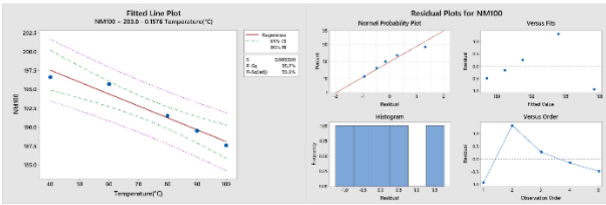


Fig. 5. Variation in capacitance values of samples with various temperatures.

Since the capacitance is indirectly proportional to the dielectric constant of the insulating medium. It is observed from Table 5, increase in temperature decreases the capacitance value and hence the dissipation factor is increasing. Experimental results justify the relation between capacitance and dissipation factor.

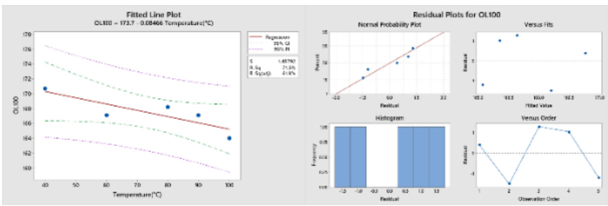
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	57.6135	57.6135	58.90	0.005
Error	3	2.9345	0.9782		
Total	4	60.5480			



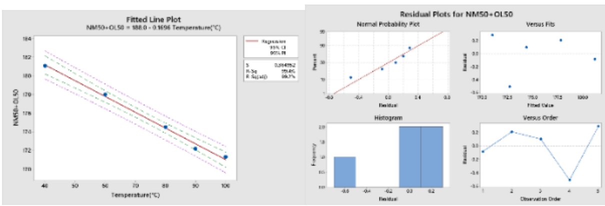
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	16.6263	16.6263	7.51	0.071
Error	3	6.6417	2.2139		
Total	4	23.2680			



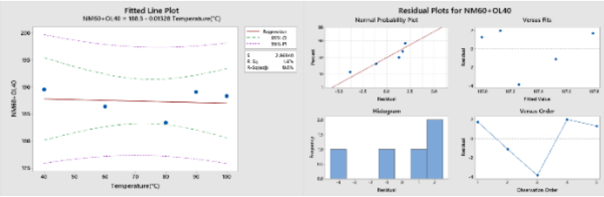
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	66.7084	66.7084	500.85	0.000
Error	3	0.3996	0.1332		
Total	4	67.1080			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.4089	0.40890	0.05	0.838
Error	3	24.6831	8.22770		
Total	4	25.0920			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	21.6662	21.6662	2.03	0.249
Error	3	32.0058	10.6686		
Total	4	53.6720			

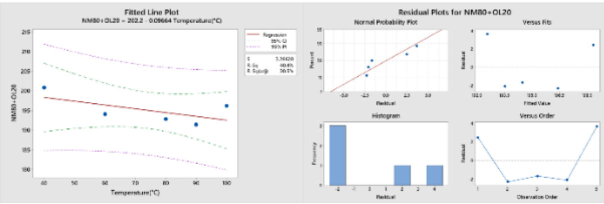


Fig. 6. Fitted line plots and residual plots for the variation of capacitance of investigated samples with temperature.

Figure 6 shows the fitted line plots for the prepared samples to observe the variation of capacitance with regard to rise in temperature. It is noted that the R-sq value of NM50+OL50 has 99.4% and hence the model fits better. In the regression equation, coefficients of temperature are negative which depicts that as the temperature increases, the mean value of the capacitance decreases. Also, it is evident that the significance value (P) for NM100 and NM50+OL50 is less than 0.05 which indicates that there is a statistically significant association between the capacitance and the temperature.

3.5. Dielectric Constant

Table 6 illustrates the values of dielectric constants of all samples decreasing, as a function of temperature increasing. It is evident from the experimental results as shown in Fig.7, that OL100, NM50+OL50 at 100°C is lying under the acceptable range, 2.8@90°C [20]. By increasing the kinetic energy of the moving segments and decreasing the dipole orientation, an increase in temperature, lowers the dielectric constant by increasing the randomness of motion [22].

Table6. Propriety values of dielectric constants of investigated samples at various temperature.

Temperature	40°C	60°C	80°C	90°C	100°C
NM100	3.364	3.349	3.277	3.245	3.213
OL100	2.922	2.859	2.877	2.859	2.806
NM50+OL50	3.098	3.046	2.985	2.946	2.932
NM60+OL40	3.243	3.19	3.137	3.295	3.221
NM80+OL20	3.436	3.222	3.299	3.275	3.356

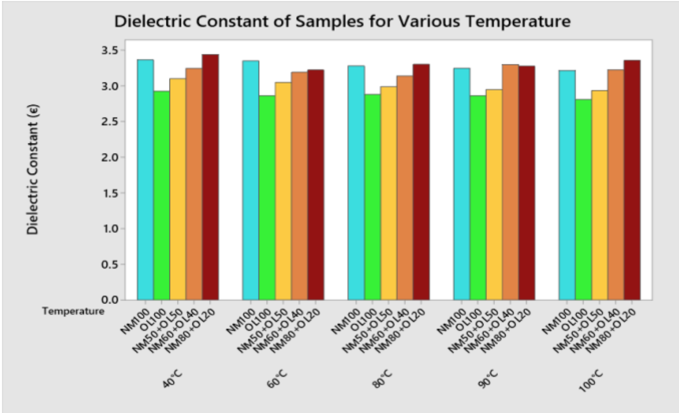


Fig. 7. Variation of dielectric constant values of NM, OL and blended NM-OL mixture for different temperatures.

3.6. Electrical Resistivity

Oil serves as both a cooling medium and insulation in transformers. High oil resistance values are necessary for effective insulation. An insulating liquid's resistivity is measured in order to understand how well it can resist the electric current. Table 7 illustrates the propriety values of electrical resistivity (GΩ-cm) of investigated samples at various temperature.

Table 7. Propriety values of electrical resistivity (GΩ-cm) of investigated samples at various temperature.

Temperature	40°C	60°C	80°C	90°C	100°C
NM100	5.646	3.248	2.169	1.836	1.533
OL100	1215	637.3	378.6	301.1	201.1
NM50+OL50	15.87	8.991	5.891	4.896	4.293
NM60+OL40	11.5	7.467	4.684	3.901	3.287
NM80+OL20	7.6619	4.521	3.071	2.694	2.107

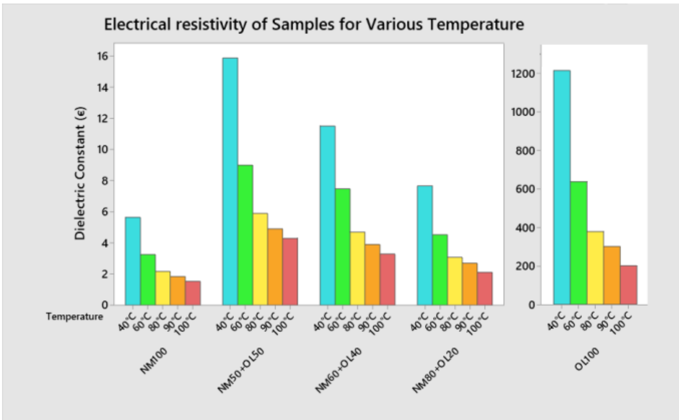


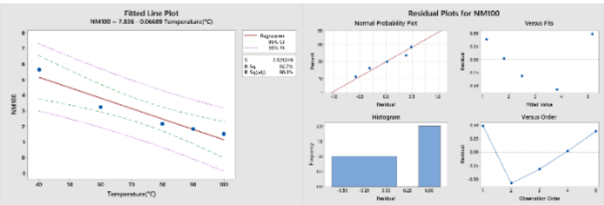
Fig. 8. Electrical resistivity values of NM, OL and the blended NM-OL mixture against temperature.

The temperature has a significant impact on the insulating oil's resistance. The data shown in Fig.8 demonstrate that the resistivity of the various tested liquid types noticeably decreases as temperature rises. According to ASTM D1169 standard, the resistivity value of the natural ester is about 1013 to 1014 GΩ-cm. The values obtained in this study are found to be within the range, demonstrating that the values adhere to the standards [20].

In accordance with Fig.6, olive oil has the best resistivity, followed by blended combinations. When compared to the other insulating liquids, the two natural esters neem oil exhibit the lowest resistivity values. For a good insulating material, the resistivity must be high at room temperature and also at higher temperatures. The decreasing pattern of the resistivity is due to the presence of free ions and ion-forming particles present in the sample. Typically, it denotes a high level of conductive pollutants. As a result, resistivity is a crucial factor in assuring the quality of transformer oil and elevating the effectiveness of transformer operation.

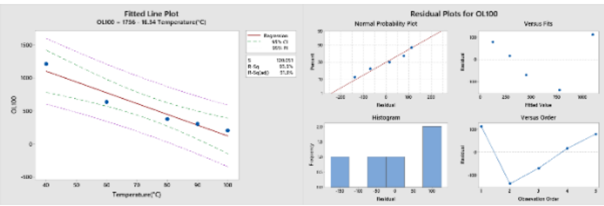
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	10.3807	10.3807	38.21	0.009
Error	3	0.8151	0.2717		
Total	4	11.1958			



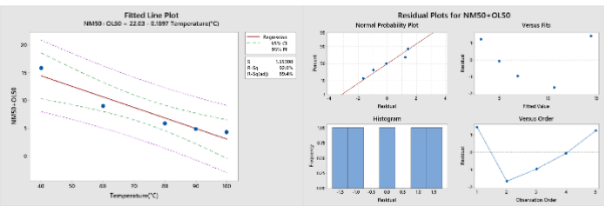
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	619613	619613	42.99	0.007
Error	3	43237	14412		
Total	4	662850			



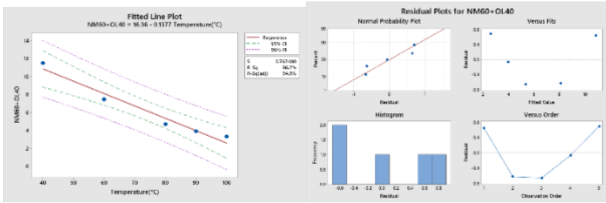
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	83.5067	83.5067	34.62	0.010
Error	3	7.2361	2.4120		
Total	4	90.7428			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	44.0155	44.0155	75.72	0.003
Error	3	1.7438	0.5813		
Total	4	45.7593			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	18.5563	18.5563	43.62	0.007
Error	3	1.2761	0.4254		
Total	4	19.8325			

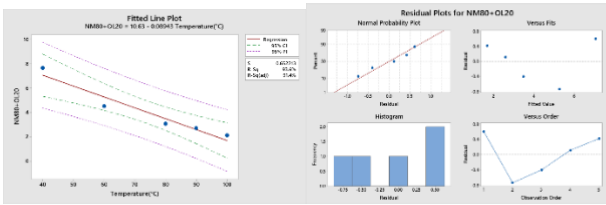


Fig. 9. Fitted line plots and residual plots for the variation of electrical resistivity of investigated samples with temperature.

Figure 9 shows the fitted line plots for the prepared samples to observe the variation of electrical resistivity with regard to rise in temperature. It is noted that the R-sq value of NM60+OL40 has 96.2% and hence the model fits better. In the regression equation, coefficients of temperature are negative which depicts that as the temperature increases, the mean value of the electrical resistivity decreases. Also, it is evident that the significance value (P) for all samples is less than 0.05 which indicates that there is a statistically significant association between the capacitance and the temperature.

3.7. Viscosity as a function of temperature

The viscosities of different samples are measured as a function of temperature and the results are depicted in Fig.10. The drop in viscosity values caused by temperature rise can be attributed to an increase in rate of flow of oil, which augments molecule mobility and intermolecular forces [23].

As per ASTM D445 standard, the viscosity value of the natural ester ranges between 16 to 50, from the Fig.10, it can clearly be observed that the values of the samples taken for this study falls within the range as 41.43 cSt for neem oil, 31.48 cSt for olive oil and 32.97, 35.221 and 38.105 cSt for blended oils @40°C. This confirms that the values are in accordance with the [20].

The deviation in viscosity could be associated with differences in mono and polysaturated fatty acid concentration among the samples. It has also been revealed that when the temperature of the oil rises, the intermolecular interactions in the acylglycerids improves, leading to a decline of viscosity. Lower viscosity in blended oil samples led to lower activation energies [24].

Table 8. Propriety values of viscosity (cSt) of investigated samples at various temperature.

Temperature	NM100	OL100	NM50+OL50	NM60+OL40	NM80+OL20
RTP	50.1129	41.189	42.92	42.4304	43.3468
40	41.437	31.48	32.97	35.221	38.105
45	33.476	28.477	26.217	28.978	33.446
50	28.226	23.95	21.925	22.17907	28.003
55	24.202	19.63	18.611	21.4177	24.665
60	20.4	17.067	16.55	18.611	20.112
65	17.84	15.2511	14.466	16.291	18.012
70	14.99	13.67	12.88	14.203	16.668
75	13.412	12.08	11.271	12.881	14.988
80	12.348	10.727	9.9029	11.542	13.818
85	10.727	9.9029	9.0663	10.453	11.756
90	8.784	8.215	7.6374	8.5	9.978

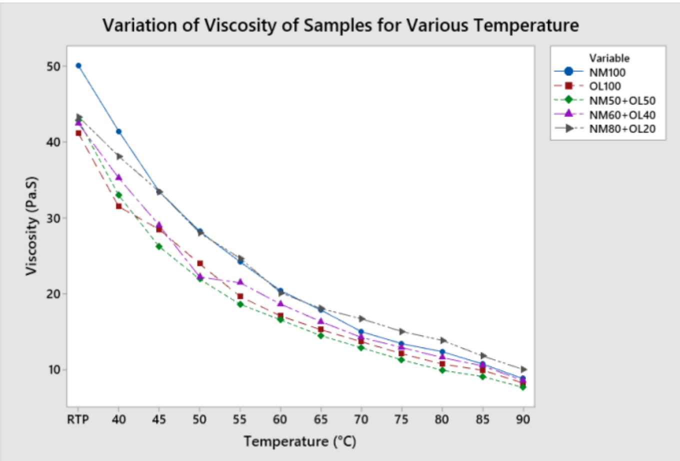
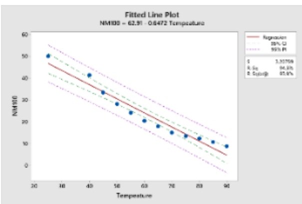


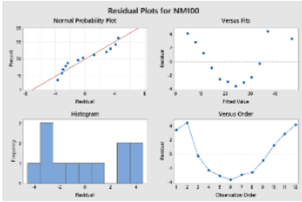
Fig. 10. Viscosity of NM, OL and NM-OL blended oils as a function of temperature.

From Table 8 it is evident that NM100 possesses the highest viscosity whereas the NM50+OL50 has the least value of 7.63 at 90°C. Since the low viscosity oil is preferred for a better efficiency of the cooling system, blended sample NM50+OL50 is more suitable as an alternative to mineral oil [25].

Analysis of Variance

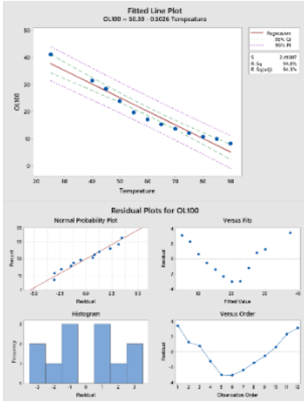
Source	DF	SS	MS	F	P
Regression	1	1766.31	1766.31	171.68	0.000
Error	10	102.89	10.29		
Total	11	1869.20			





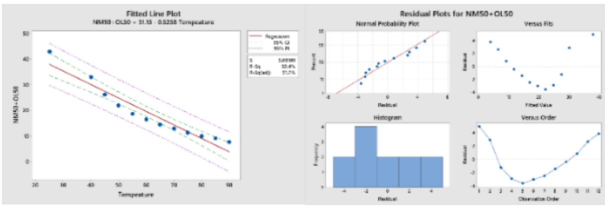
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1065.23	1065.23	183.39	0.000
Error	10	58.08	5.81		
Total	11	1123.31			



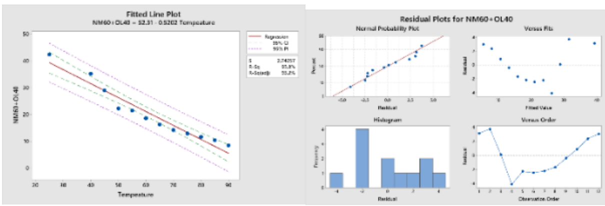
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1165.80	1165.80	122.01	0.000
Error	10	95.55	9.55		
Total	11	1261.35			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1141.24	1141.24	151.73	0.000
Error	10	75.22	7.52		
Total	11	1216.46			



Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1241.44	1241.44	227.16	0.000
Error	10	54.65	5.47		
Total	11	1296.09			

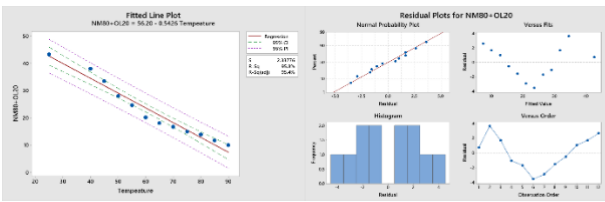


Fig. 11. Fitted line plots and residual plots for the variation of viscosity of investigated samples with temperature.

Figure 11 shows the fitted line plots for the prepared samples to observe the variation of viscosity with regard to rise in temperature. It is noted that the R-sq value of NM80+OL20 has 95.8% and hence the model fits better. In the regression equation, coefficients of temperature are negative which depicts that as the temperature increases, the mean value of the viscosity decreases. Also, it is evident that the significance value (P) for all the samples is less than 0.05 which indicates that there is a statistically significant association between the viscosity and the temperature.

4. Conclusions

The blended samples of neem and olive oil were prepared in this study. The physical and electrical properties of these samples are investigated at varied temperatures and hence the following conclusion can be derived.

The prepared samples (NM100, OL100, NM50+OL50, NM60+OL40, NM80+OL20) were subjected to various test such as moisture content analysis and dissipation factor, capacitance, dielectric constant, electrical resistivity and viscosity test at various temperature according to IEC and ASTM standards.

The dielectric constant of NM50+OL50 has 3.098 @40°C and 2.946 @90°C with dissipation factor of 0.717 @40°C and 2.345 @ 90 °C, also its viscosity is 32.97 cSt @40°C and 7.6374 cSt @90°C which are in acceptable limits of IEC and ASTM standards for liquid dielectrics. And hence, among the prepared samples, NM50+OL50 has been selected as the optimum blending with improved physical and dielectric properties for transformer insulation liquid.

Statistical analysis of experimental data has been conducted using fitted line plot analysis. An appropriate number of trails were found to exist over the whole range of all the predictor values, indicating that the experimental data show a statistically significant correlation between the various parameters and temperature. In order to study the plot and the goodness-of-fit statistics, the model is appropriately fitted to a linear model. The assumption that the residuals are randomly distributed and have a constant variance was confirmed by the residuals versus fits plot. The residuals are independent and normally distributed which exhibits no trends or patterns when shown in time order. Hence the investigated blended sample has the potential to be an alternative to the conventional mineral oil.

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