Optimization of Various Natural Ester Oils Impregnated Nomex Paper Performance in Power Transformer Applications under Different Ageing Conditions

S.Senthil Kumar, A. Arul Marcel Moshi, S.R.Sundara Bharathi, K.Karthik Kumar

Abstract*: Vegetable oils are being considered as the potential replacements to mineral oils because of their better natural execution and for their high fire point. In spite of the fact that these fluids have been utilized as a part of appropriation transformers, it is as yet a huge advance to receive vegetable oils in control transformer because of high cost and abnormal state of well being and unwavering quality required in benefit for these units. Vegetable oils such as honge oil (HO), neem oil (NO), mustard oil (MO), punna oil (PO) and castor oil (CO) offer the reasonable option for mineral oil. It is expected that the greater part of the un-matured oil could fulfil the base necessity of dielectric protection fluids in the transformer. This paper concentrated on the impact of maturing on the electrical and physicochemical properties of HO, NO, MO, PO and CO. Fixed maturing tests have been set at 90°C for 30 days, 60 days and 90 days. Prior to the maturing procedure, the examples were dried in a vacuum broiler under the pressure of 0.8kPa at 85°C for 48 hours keeping in mind the end goal to evacuate the dampness content in the oils. At that point, the oils were impregnated with the Nomex paper and keep on ageing for choosing the span time. The electrical properties (relative permittivity, dielectric misfortunes, resistivity and breakdown quality), mechanical properties (thickness and elasticity) and substance properties (dampness and corrosiveness) of the oils were estimated all through the maturing time frames. It can be reasoned that the research center quickened warm maturing test uncovers that every single vegetable oil in this examination are safe towards oxidation in light of the steady thickness and low corrosiveness estimations of vegetable oils all through the maturing term even with the nearness of oxygen. The AC breakdown voltages of vegetable oils can in any case conform to the prescribed furthest reaches of new Vegetable oil set by ASTM 6781 even after subjected to maturing. From the results, it may be concluded that the proposed vegetable oils can be used as the alternatives for mineral oil.

***Keywords:* vegetable oils, ageing, electrical properties, mechanical properties.**

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I. INTRODUCTION

Transformers in administration could be subjected to warm and numerous natural parameters. Because of that, the oil could be subjected to maturing [1]. The compound properties of the oil may change and its execution could be influenced by the nearness of maturing results, for example, dampness and acids [2]. In this way, considering the use of new dielectric protection fluids, for example, HO, NO, MO, PO and CO in transformer, it is essential to first analyze its maturing exhibitions at the research facility level [3].

Electrical properties and mechanical quality are the significant parameters while picking protecting oils for controlling transformers. The chosen oil should have a doubt guarantee with the electrical protection work and also great impregnation of the distinctive protecting segments. The primary oil properties are separated to the mechanical, compound and electrical characteristics. It is important to have information on performance of the oil such as viscosity, breakdown voltage, relative permittivity, resistivity and dielectric losses [4, 5].

Protecting oil serves as electrical protection as well as a cooling medium utilized as a part of transformer. Protecting oil is subjected to the debasement due to the maturing, high temperature and concoction responses of the oxidation [6]. The protecting oil condition should be observed routinely and kept up when fundamental. This procedure is to guarantee the solid activity of oil and to keep away from the sudden disappointment of the transformer. It will be exceptionally attractive if the transformer oil remaining lifetime can be anticipated, every once in a while [7]. Transformer oil (TO) has been utilized as a protecting fluid for a long time. The primary motivation behind why the mineral oil is utilized as a protecting fluid may be, it has a decent protection execution with less expensive in cost and it has a low blaze point [8-10]. Due to the poor biodegradability qualities of TO, there is as yet ecological worry to the utilities in the event of spillages amid task or because of a mischance [11-12].

Numerous analytics have been completed to take a gander at the elective hotspots for protecting oils [13-15]. The vegetable oil based protecting oil is known as the most potential source to supplant the mineral oil as a result of its biodegradability [16-19].

In view of the past research works, electrical execution (breakdown quality trademark) of vegetable oils has a decent execution than that of the TO [20]. Along these investigations, this paper researches the execution of maturing vegetable cooking oils impregnated paper that effectively accessible in the market. In this examination, the TO is kept up as the base protecting oil for correlation purposes. The ultimate aim of the proposed study is to examine how ageing affects the electrical performance, chemical properties and the mechanical properties of vegetable oils with impregnated paper [21-24].

II. EXPERIMENTAL ANALYSIS

The entire experimentation includes the preparation of the oil samples and measuring their parameters like breakdown voltage, viscosity, dissipation factor, acidity, resistivity, dielectric dissipation factor, tensile strength of the oil impregnated paper and moisture content present in the oils[25-27].

A. Preparation of oil samples

Six types of oil impregnated papers of TO, HO, NO, MO, PO and CO were prepared initially for the investigation. TO used in this study was obtained from a local manufacturing sector (commercial TO). The sizes of Nomex Paper T410 Class C are 0.08mm x 20mm (thickness x width) and the papers were cut accordingly in order to meet the predetermined weight of the oil and nomex paper. The TO, HO, NO, MO, PO and CO samples were obtained from readily available food preparation oils in the market [28-30].

All the oil samples were filtered independently for 3 cycles through a membrane filter with pore size of 0.4μm [31]. It was found that the oils were clean enough and oil contaminations could not be decreased further even with more filter cycles. The samples were put into heat-resistant and preserved glass bottles. Sample of oils were dried with the aid of vacuum oven for 48 hours at 90°C and were left for another 24 hours at ambient temperature condition (24-27°C)[32].

While the oils were exposed to the ambient atmospheric condition, the impregnated papers were put inside the oils. In this study, samples were aged in oil impregnated papers at constant temperature of 90°C for 30 days, 60 days and 90 days.

B. AC Breakdown Voltage Test

Breakdown voltage is a vital property of oil insulation which determines the ability of oil to be used in an insulation medium. The breakdown voltage was measured according to the IEC standard 60156. An oil test cup with spherical electrodes separated by 2.5 mm was used and the supply voltage was varied at the rate of 2 kV/s[33].

The breakdown voltage was measured five times with sufficient interval between each measurement. The average of the five readings was taken as the breakdown voltage for the consideration. Figure I represent the Breakdown Voltage Kit used in this analysis.

Fig. I. Breakdown voltage kit

C. Viscosity Measurement

Viscosity is a measure of the oil's resistance to flow. This is an indirect measure of the cooling ability of the oil. Viscosity was measured by means of Redwood viscometer as shown in the figure II according to the ASTM standards D445 and D3828. The viscosity was measured at room temperature (RT) under 40, 50, 60, 70, 80, and 90◦ C for determining the viscosity profile of the oil samples [33-35].

Fig. II. Redwood Viscometer setup

D. Acidity Measurement

Acidity is used to analyze the considered oil whether it has the nature of free organic acid or inorganic acid. Corrosion and deformation increase with the increase in the acid content of oil. The British Standard (BS) BS2000 (Part-1) was used for the titration method, was followed for measuring the acidity level. In this method, the required amount of potassium hydroxide needed to neutralize the free acids in the oil was measured.

E. Resistivity Measurement

Resistivity is a measure of the DC resistance between the opposite sides of an oil cube (1cm × 1cm × 1cm). A small percentage of free ions and ion-forming particles lead to higher resistivity. This property is very much dependent on the existence of oil soluble impurities and ageing products. The measurement was conducted according to the ASTM standard D1169.

F. Determination of Dielectric Dissipation Factor

Dielectric dissipation factor also indicates the quality of oil. This property is measured according to the standard ASTM D924.

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The resistivity and dielectric dissipation factor were measured by a TO dielectric dissipation/loss tangent tester (OTS2K1 model).

G. Prediction of the tensile strength of the paper

Tensile strength was measured using Universal Testing Machine (UTM) according to the IEC 60554 standards. A paper strip was clamped at each end between two jaws, and an increasing load was applied causing the clamps to move apart until the strip breaks at a certain loading condition [36].

H. Measurement of moisture content present in the oils

The moisture in oils affects adversely the dielectric properties of oil and also affects the paper insulation of the core and winding transformer. In this research, the moisture content present in the oils was measured by Karl Fischer Titrator (Coulometer) instrument. The volume of oil needed in test requirement is 500 ml.

I. Relative permittivity measurement

The relative permittivity values of the samples were measured according to IEC60247 standards by using ADTR-2K PLUS oil tester. The temperature was set to 90°C. The volume of the oil in the test container is around 45 ml and the frequency was set to 60 Hz .

III. RESULTS AND DISCUSSION

The results obtained for all the considered samples at different ageing conditions out of the experimental analysis are discussed in this chapter.

A. Electrical Properties of Oil Impregnated Paper with Different Time Ageing

i) Effect on AC Breakdown voltage

The Breakdown voltage varies from 25kV to 90kV. The Mustard oil has the highest Breakdown voltage value when compared with the other oil samples. The Neem oil and Punna oil have Breakdown voltage values next to the mustard oil. Ageing with 90 hours gave the better values of AC Breakdown voltage when compared with other ageing conditions. Table I presents the breakdown voltage values for the chosen oil samples at different ageing conditions, and the figure III represents the analogy of the breakdown voltage for different samples.

Table- I: AC Breakdown voltage values for all the samples

Samples	Breakdown Voltage (kV)		
	Ageing 30 days (720 hours)	Ageing 60 days (1440 hours)	Ageing 90 days (2160 hours)
Transformer oil (TO)	25	24	23
Honge oil(HO)	50	70	75
Neem oil(NO)	52	72	80
Mustard oil(MO)	55	80	90
Punna oil(PO)	49	60	70
Castor oil(CO)	40	55	60

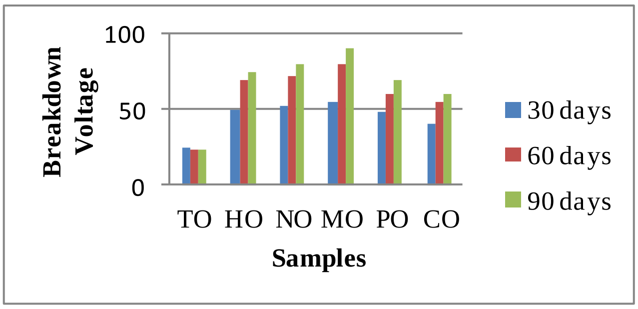

Fig. III. Analogy of Breakdown voltage values for all the oil samples

ii) Effect on relative permittivity

The relative permittivity values vary from 1.356 to 2.123. The mustard oil has the higher relative permittivity value when compared with the other oil samples. The neem oil and punna oil have higher relative permittivity values next to the mustard oil. Ageing with 90 hours yielded the better values of relative permittivity when compared with the other ageing conditions. The relative permittivity values for the chosen oils at different ageing conditions are presented in table II. Figure IV represents the analogy of the relative permittivity values for different samples.

Table- II: Relative permittivity values for all the samples

Samples	Relative Permittivity		
	Ageing 30 days (720 hours)	Ageing 60 days (1440 hours)	Ageing 90 days (2160 hours)
Transformer oil (TO)	1.356	1.401	1.456
Honge oil(HO)	1.823	1.856	1.882
Neem oil(NO)	1.834	1.875	1.900
Mustard oil(MO)	1.912	1.987	2.123
Punna oil(PO)	1.702	1.735	1.856
Castor oil(CO)	1.812	1.801	1.823

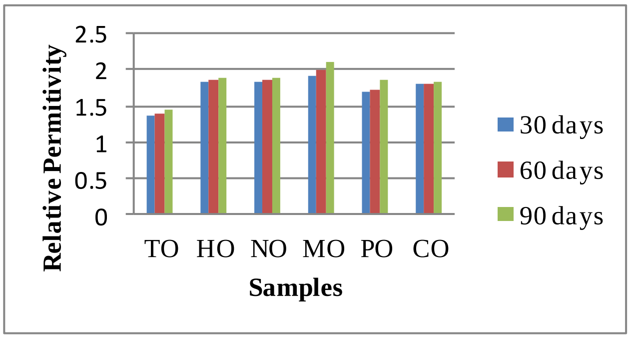

Fig. IV. Analogy of Relative Permittivity Values For All Samples

iii) Effect on resistivity

The resistivity values of the oils vary from 320 Ω-cm to 520 Ω-cm. The Punna oil has the highest resistivity value among the considered oil samples. The neem oil and Mustard oil has the 2nd and 3rd highest resistivity values next to the punna oil. Ageing with 30 hours offers the better values for all the samples in comparison with other conditions. Table III details the relative resistivity values for different oil samples and the figure V represents the analogy of the resistivity for different samples.

Table- III: Resistivity values for all the samples

Samples	Resistivity(G-Ωcm)		
	Ageing 30 days (720 hours)	**Ageing 60 days (1440 hours)**	**Ageing 90 days (2160 hours)**
Transformer oil (TO)	320.18	300.12	280.56
Honge oil(HO)	520.23	502.58	490.45
Neem oil(NO)	519.41	501.23	491.87
Mustard oil(MO)	517.32	497.15	487.23
Punna oil(PO)	520.26	503.26	492.85
Castor oil(CO)	390.56	370.87	360.21

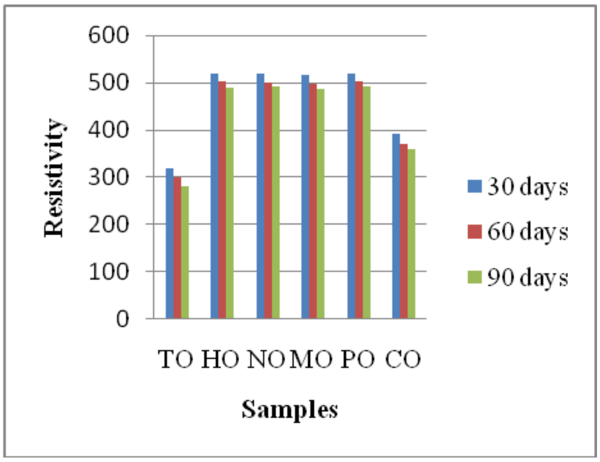

Fig. V. Analogy of resistivity values for all the samples

iv) Effect on Dielectric Loss

The Dielectric loss values for the oils at the different proposed ageing conditions were measured which varies from 0.12 to 0.23. The much amount of dielectric loss was experienced with mustard oil. Neem oil and punna oil have dielectric loss value next to the mustard oil. Ageing with 90 hours give the better value when compared with other time conditions. The below table IV describes the dielectric loss values for the different samples and the figure VI represents the analogy of the dielectric loss for different samples.

Table- IV: Dielectric loss values for the tested samples

Samples	Dielectric Losses		
	Ageing 30 days (720 hours)	**Ageing 60 days (1440 hours)**	**Ageing 90 days (2160 hours)**
Transformer oil (TO)	0.15	0.16	0.16
Honge oil(HO)	0.12	0.15	0.21
Neem oil(NO)	0.17	0.19	0.22
Mustard oil(MO)	0.19	0.21	0.23
Punna oil(PO)	0.15	0.18	0.21
Castor oil(CO)	0.14	0.17	0.18

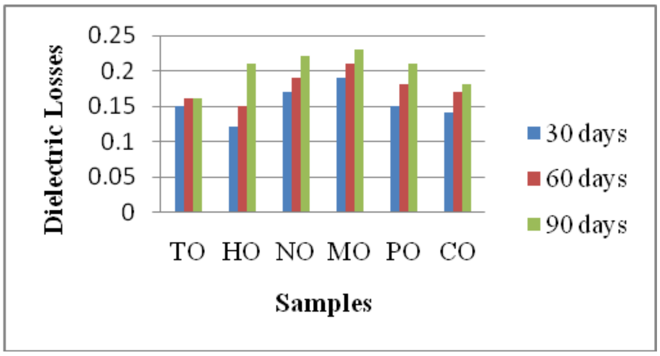

Fig. VI. Analogy of Dielectric Loss Values For All Samples

B. Physical Properties of Oil Impregnated Paper with Different Time Ageing

i) Effect on viscosity

The measured viscosity values ranges between 45 to 155 cSt. The castor oil has the higher viscosity value when compared with the others. The mustard oil and punna oil have higher viscosity values next to the castor oil. Ageing with 30 hours offered the better viscosity values when compared with other ageing conditions. Usually lower the viscosity value gives the better result. Table V describes the viscosity values for different samples and the figure VII represents the analogy of the dielectric loss for different samples.

Table- V: Viscosity values for all the samples

Samples	Viscosity(cSt)		
	Aging (720 hours) (RT)	**Aging (1440 hours) (RT)**	**Aging (2160 hours) (RT)**
Transformer oil (TO)	45	43	40
Honge oil(HO)	120	110	101
Neem oil(NO)	119	109	101
Mustard oil(MO)	121	115	109
Punna oil(PO)	126	116	105
Castor oil(CO)	45	43	40

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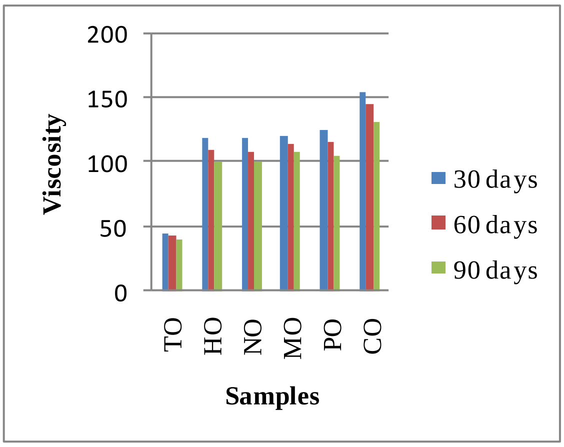

Fig. VII. Analogy of viscosity values for all the samples

C. Mechanical Properties of Oil Impregnated Paper with Different Time Ageing

i) Effect on Tensile Strength

The tensile strength values obtained varied from 62 MPa to 72 MPa. The mustard oil has the highest tensile strength value than others. The neem oil and punna oil has higher values of tensile strength values followed by the mustard oil. Ageing with 90 days provides the better values of tensile strength when compared with the other two ageing conditions. The below table VI details the tensile strength values for the oil samples and the analogy of the tensile strength for different samples under different ageing conditions are presented in figure VIII.

Table- VI: Tensile strength values for all samples

Samples	Tensile Strength (MPa)		
	Ageing (720 hours) (RT)	Ageing (1440 hours) (RT)	Ageing (2160 hours) (RT)
Transformer oil (TO)	62	61	48
Honge oil(HO)	65	58	45
Neem oil(NO)	70	65	51
Mustard oil(MO)	72	66	51
Punna oil(PO)	70	65	49
Castor oil(CO)	68	61	48

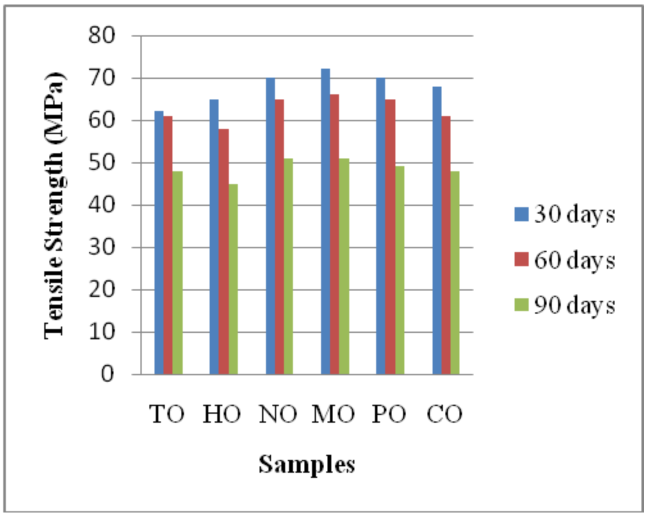

Fig.VIII.Analogy of Tensile Strength Values For All sample

ii) Effect on Total Acid Number

The acidity value of the tested oil samples got varied from 0.0281 mg KOH/g to 12.214 mg KOH/g. The mustard oil has the highest acidity value among all. The neem oil and punna oil have higher values of acidity next to the mustard oil. Ageing with 90 hours yielded better value of acidity in comparison with other considered conditions. Usually lower the acidity value shows the better sample. The details presented in the table VII describe the acidity values for all the samples and figure IX represents the analogy of the acidity values for different samples.

Table- VII: Acidity values for all Samples

Samples	Acidity(mg KOH/g)		
	Ageing (720hours) (RT)	Ageing (720hours) (RT)	Ageing (720hours) (RT)
Transformer oil (TO)	0.0281	0.0356	0.0386
Honge oil(HO)	0.0254	10.123	12.451
Neem oil(NO)	0.0255	8.258	10.236
Mustard oil(MO)	0.0265	11.369	12.214
Punna oil(PO)	0.0245	7.357	9.256
Castor oil(CO)	0.0235	9.591	11.236

D. Chemical properties of the oil impregnated papers with different ageing time conditions

i) Effect on moisture content present in the oil

The moisture content measured in the oil samples varied from 150 ppm to 350 ppm. Among the six oil samples, castor oil contained maximum moisture content. The mustard oil and punna oil have higher moisture content values next to the castor oil. Ageing with 30 hours gave most desirable values of moisture content. Table VIII provides the moisture content data for the tested oils and figure X presents the analogy of the moisture content present in the oil samples.

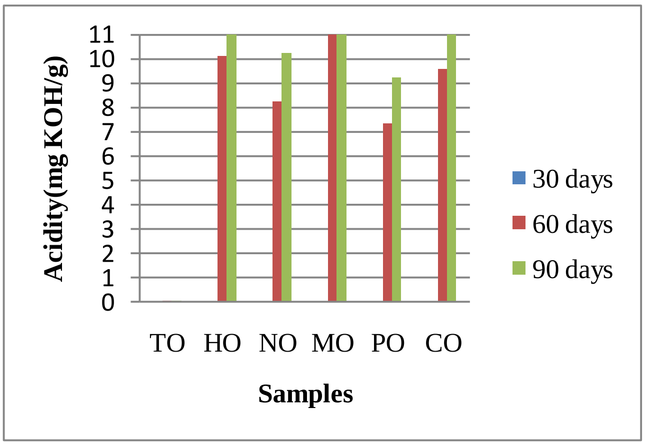

Fig. IX. Analogy of acidity values for all samples

Table- VIII: Moisture content present in different oil samples

Samples	Moisture data (ppm)		
	Ageing (720 hours)	Ageing (1440 hours)	Ageing (2160 hours)
Transformer oil (TO)	150	125	110
Honge oil(HO)	1400	1100	650
Neem oil(NO)	1200	1009	750
Mustard oil(MO)	1300	1050	850
Punna oil(PO)	1250	1080	900
Castor oil(CO)	1350	1110	750

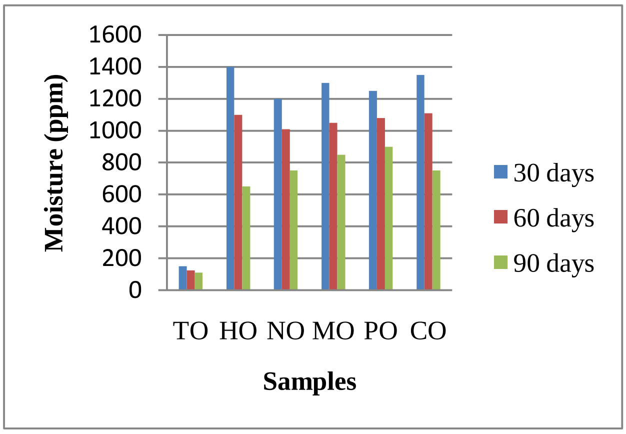

Fig. X. Analogy of moisture content present in different oil samples

IV. CONCLUSION

Dielectric properties, mechanical properties and chemical properties of vegetable oils and mineral oil with impregnated nomex paper have been investigated and compared. The results are summarized as follows:

- The vegetable oils have better breakdown voltages than mineral oil throughout the ageing duration, where NO has the highest breakdown voltage at 90 days of ageing duration.
- From the dielectric losses viewpoint, mineral oil has the lowest dielectric loss from all the samples. The dielectric loss of NO remains the highest throughout the ageing duration followed by MO, HO and CO. The NO is still a good choice in term of dielectric loss because the value of dielectric loss close to zero is the best for the transformer application.
- For the same temperature level, vegetable oils possess higher relative permittivity than the mineral oil. This gives an advantage to the vegetable oils where the vegetable oils would be experiencing lower electric field stress than mineral oil.
- The resistivity of TO is less than vegetable oil due to less presence of moisture in MO than vegetable oils.
- Viscosity of mineral oil lowest compared to the vegetable oils. Good insulating oils should have low viscosity so that it offers less resistance to flows the oil.
- Paper insulation impregnated in CO has the lowest lost part of its tensile strength than other vegetable oils and mineral oil.
- The effect of moisture in oil impregnated Nomex paper shows that significant reduction for all vegetable oils. This shows that vegetable oils can hold more moisture than mineral oil, which is good for transformer application.
- Vegetable oils produce higher acidity than mineral oil throughout the ageing duration. The acidity in mineral oil remains almost constant throughout the ageing duration.

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