Characteristics Of Vegetable Oils As Liquid Insulation For Transformer : An Experimental Study

Shazia Feroz*, Mohsin Ali Tunio, Nadeem Ahmed Tunio**, Zubair Ali *****

*(i) Master of Engineering Student, Department of Electrical Power Engineering, Mehran University of Engineering and Technology Shaheed Zulfiqar Ali Bhutto Campus Khairpur Mir's, Sindh, Pakistan.
(ii) Assistant Professor, Benazir Bhutto Shaheed University of Engineering Technology & Skill Development Khairpur Mir's, Sindh, Pakistan.
**Department of Electrical Engineering, Mehran University of Engineering and Technology Shaheed Zulfiqar Ali Bhutto Campus Khairpur Mir's, Sindh, Pakistan.
*** Lecturer, Vocational Training Centre Khairpur, Sukkur IBA University.

Abstract
Utilization of vegetable oil as a liquid insulator in electrical machinery is a best alternative in replacement of petroleum based mineral oil. For power transformers petroleum based mineral oils are widely utilized as fluid protection. The considerable electrical and physical characteristics of insulation oils along with wide accessibility range and been employed in liquid filled electrical devices for different voltage values from the inception of power industry. The main drawback of mineral oil is its low fire and flash point, limited biodegradability and not being a renewable resource. This research describes the study of different insulating fluids, comparative study and experimental measurement of dielectric Breakdown Voltage (BDV) for synthetic Ester, Corn, Olive, Castor and Mineral oil. From experimental investigations carried out in this paper, it can be concluded that vegetable oils analyzed are the better alternative to the mineral oil.

Key words:
Insulation Oil, Breakdown Voltage, Viscosity, Transformer, Natural Esters

1. Introduction

The biodegradable dielectric fluids are produced from seeds or vegetables and are widely been used in transformer compared to the conventional insulating fluids. Since, these oils are more secure and beneficial and have better dielectric properties [1]. In past literature, many researches have been conducted and it was found that the insulation failure is one of the main reasons behind transformer failure. Figure 1 shows the scatter plot referred as FN curve [2].

The conventional oil (Mineral oil), is used in HV transformers due to its reasonable electrical and chemical properties, low dissipation factor and low permittivity [3, 4].

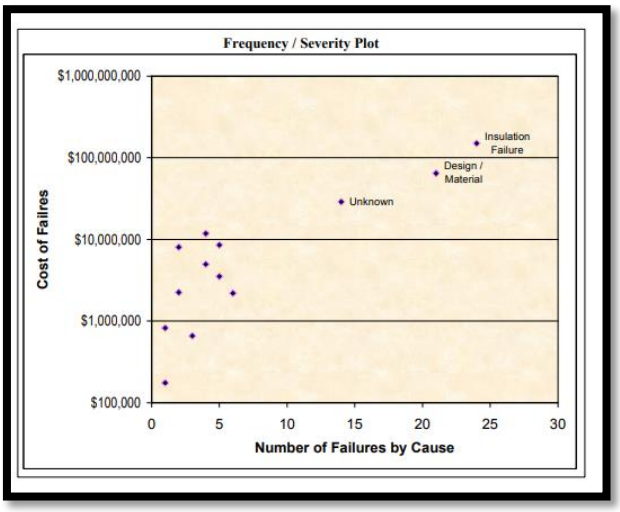

Fig. 1 Frequency-Severity of Transformer Failures [2].

In past silicone oil was also being used as liquid dielectric coolant in distribution transformers under specific conditions. Since both oils are non-compatible and biodegradable and toxic in nature [5-7]. Due to poor degradability of conventional oils, now the vegetable based insulating oils are considered an alternate liquid insulation because of its biocompatibility and higher flash point for power transformers [8].

The first vegetable oil based transformer was installed at Germany by Siemens as shown in Figure 2 [9]. The design parameters of this installed 420kV transformer is summarized in Table 1.

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Fig. 2 Siemens 420 kV vegetable oil based Transformer.

Table 1: Design parameters of 420kV vegetable oil Transformer.

Characteristics	Value
Rated Voltage	420 kV
Rated Power	300 MVA
Performance	180/300/400 MVA
Ratio	405 + 11%/115/22 kV
Cooling	KNAN/KDAF1/KDAF 2
Liquid	Soy-Based Natural Ester
AC insulation Level	630 kV
Lightning Impulse Insulation Level	1425 kV
Switching Impulse Insulation Level	1050 kV
Operating Weight	400 ton
Liquid Capacity	97 ton

2. Insulation Fluids

2.1 Mineral Oil

Mineral oil comprises of mixture of various organic compounds having different structures of carbon and hydrogen molecules. Mineral oil obtained through refining crude petroleum products by collecting hydrocarbons during the distillation process [10]. The chemical structure of mineral oil is shown in Figure 3 [11].

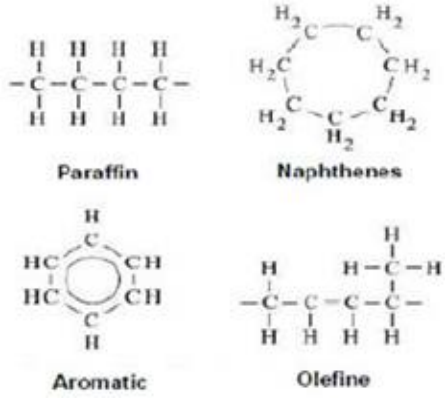

Fig. 3 Chemical Structure of Mineral Oils [11].

2.2 Natural Ester/ Vegetable Oil

Vegetable oils are biodegradable and sustainable oils comprise of triglycerides. These oils are environmental friendly, economical and vastly available and can be considered substitute insulating and cooling mediums for transformers. The chemical structure of natural ester is shown in Figure 4. Referring to Figure 4, R,R' and R'' indicate the fatty acid chains present in natural ester oil [12].

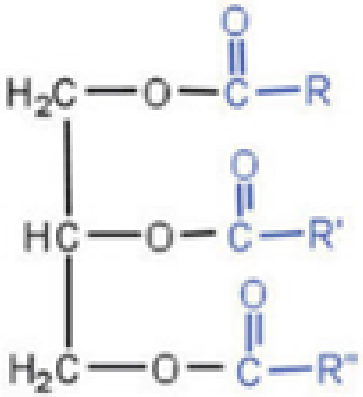

Fig. 4 Triglyceride Structure for Natural Ester oil [12].

In this research work, breakdown voltage and viscosity test was conducted on various insulating oils. The characteristics of vegetable oils (selected test samples) were investigated experimentally and comparison has been made on the basis of main properties required for insulating fluids. The main aim of this work was to analyze selected oil test samples to check the suitability of vegetable oils as liquid insulation. Through this work, understanding on vegetable oil characteristics as liquid insulation may be enhanced.

3. Experiments

3.1 Breakdown Voltage Test

The breakdown voltage of selected oil samples (olive, castor, corn, synthetic ester and mineral oil) was measured. The measurement was done according to IEC 60156 standards by using BDV tester (Megger OTS A100 AF) as shown in Figure 5. The experimental results for different insulating oils are presented in this section.
Figure 6 shows the measured results for selected oil samples. This experimental investigation showed that the natural ester oils have a significantly higher breakdown voltage than mineral oil. Referring to Figure 6, the natural ester oils, especially corn oil, have highest average BDV, among all natural esters as well as compare to the Synthetic ester and mineral oil. Thus vegetable oils can be used as satisfactory alternative to mineral oil insulants.

Fig. 5 BDV Tester.

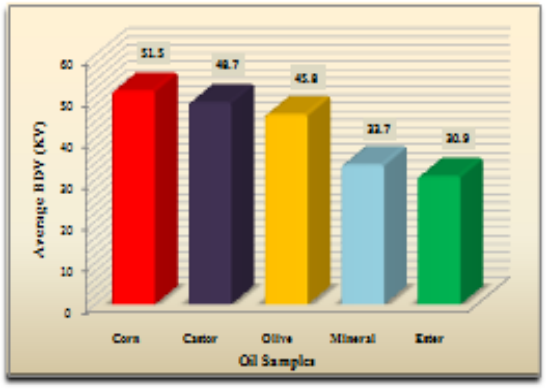

Fig. 6 BDV measurement of various insulating oils.

3.2 Comparative Analysis of Degraded Oil

In this section, the comparative analysis of three insulating oils samples was investigated. For this analysis, BDV of fresh mineral oil was measured and compared with two degraded oil (Cat-1: 3 years and Cat-2 years aged) samples as shown in Figure 7. Figure 8 shows the measured data. Referring to experimental results, the BDV of fresh mineral oil is found higher compared to other aged oil. These obtained results showed that BDV decreases with time due to thermal degradation.

Fig. 7 Mineral oil (Fresh, Cat: 1& Cat: 2).

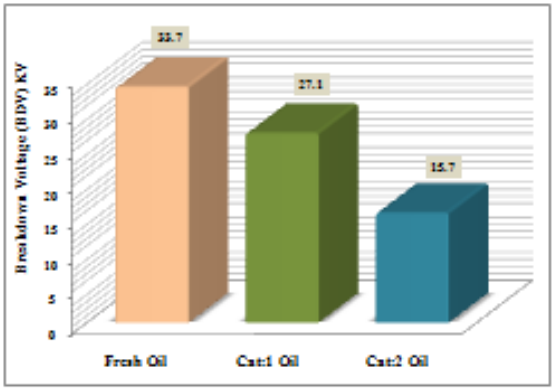

Fig. 8 Comparison of Mineral Oil (Fresh & Degraded).

3.3 Kinematic Viscosity

Viscosity is one of the main parameter of insulating oil. This section presents measurement results done on viscosity test. This test was conducted on various oils samples i.e. corn, olive, castor, ester and mineral oil in the laboratory. The viscosity tester is shown in Figure 9. Figure 10 presents the measurement results according to ASTM D1665 standard. Referring to Figure 10, it has been found that ester oil is less viscous compared to mineral oil. Nevertheless, the value of viscosity for corn oil is found lower than mineral oil. Moreover, all tested oils shows the reasonable results compared to mineral. Therefore, these tested oils can be considered as insulating fluids for transformer.

Fig. 9 Viscosity Tester (Bath Engler DP-103).

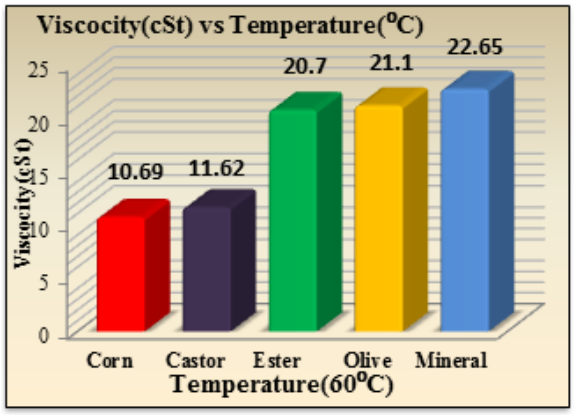

Fig. 10 Viscosity results for selected Oil Samples.

4. Conclusion

In this experimental work, five different oil samples were selected and those were analyzed systematically. Petroleum based mineral oil, synthetic ester and vegetable or seed oils (Corn, Olive and Castor) were examined. The Breakdown Voltage (BDV) was measured at room temperature and it was found that, the natural esters have higher BDV value among all selected insulation oils; however, corn oil depicts highest BDV strength compared to all other fluids, while the lowest BDV value was determined for the synthetic ester oil. From the results determined for viscosity point of view, it is concluded that, vegetable oils have lower viscosity as contrast to the petroleum product mineral oil; again, corn oil has lowest viscosity value whereas viscosity of mineral oil is quite high. Moreover degraded oils were also examined to check their BDV, and it was found that with the passage of time, thermal degradation occurs and it affects the BDV strength of the oil. Overall it was concluded that vegetable or seed oils may be the best alternative insulation oils for power industry.

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