Investigation of Electrical Characteristics of Mixed Insulating Liquids for their use in Electrical Power Equipments

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Abstract— It has been seen that, mineral oil is the most widely used insulting liquid in the world today because of the wide availability and low cost. However, poor biodegradability and limited reserves of mineral oil has promoted the development of environment friendly insulating liquids. Natural and synthetic esters are considered as potential candidates to replace mineral oil in electrical equipments. Both natural and synthetic esters are fully biodegradable, less toxic and less flammable. But their high cost and availability has limited their use in special applications today. The aim of this paper is to investigate typical electrical characteristics of mixture of mineral oil with biodegradable synthetic oil. This new mixed insulating liquid will be proposed as alternative to mineral oil with lower environmental risk and comparatively lower cost of insulating liquids that has higher biodegradability.

Key words: Mineral Oil, Biodegradability, Synthetic Oil, Mixed Insulating Liquid

I. Introduction

Electrical insulation plays an important role in proper operation of electrical equipments like Transformers, Reactors, Instrument transformers & Capacitors. Electrical insulating materials are broadly classified in to dry and wet type. Dry type insulation system consist of solid insulating materials like PVC, glass, asbestos, rigid laminate, varnish, resin, paper, Teflon and rubber are used as a protective coating on electrical wire and cables. And gaseous insulation such as compressed air and SF6 has limited applications in power system equipments such as circuit breakers and Gas Insulation Substations (GIS) to disconnect very high voltages safely. Wet type insulation system consists of insulating oils like Mineral Oil, Synthetic Oil, Synthetic Esters and Natural Esters used as an electrical insulator and thermal conductor in transformers, reactors, cables, bushings, circuit breakers & power capacitors.

Petroleum based mineral oil has been used as main insulating liquid in power equipments because of its good aging behavior, low viscosity, ready availability, and low cost. Polychlorinated biphenyl (PCB) based insulating liquids were introduced in the early 1930s due to requirement of high fire security standards. Later PCB liquids had been banned in 1970s in view of their toxicity and low biodegradability. Later no other insulating liquid replaced the mineral oil in power equipment. But the desire for the higher fire point and environmental acceptance of insulating liquids, researchers has investigated multiple alternatives to mineral oil which includes synthetic hydrocarbon fluids, synthetic esters, natural esters and mixed insulating liquids [1], [2], [6], [9]. However, mineral oil is the most widely used insulting liquid in the world today because of its wide availability and low cost.

In this work, conventional non-biodegradable mineral oil and biodegradable synthetic oil is mixed in various proportions and typical electrical characteristics like breakdown voltage, dielectric constant and permittivity are investigated.

II. Experimental Setup

A. Breakdown Voltage

Breakdown voltage is one of the important property of insulating material. It defines the maximum voltage difference that can be applied across the material before the insulator collapses and conducts. Following breakdown of an insulation material a disruptive electrical discharge causes mechanical, thermal and chemical processes that change dielectric characteristics. These changes are so significant, that dielectric is not able to restore to its initial state it had before breakdown [7], [8], [9].

Electric breakdown strength of an insulating liquid is the breakdown voltage measured across two electrodes immersed in the insulating liquid separated by a specific gap. IEC 60156 specifies the use of mushroom shaped electrodes separated by a 2.5mm gap. Care must be taken when filling the test cell with liquid under test to avoid trapped air bubbles [2]. This can lead to misleading and lower breakdown voltages. BDV of insulating liquid can be influenced by contamination like conducting and non-conducting particles, moisture and gases [4]. BDV is measured with megger BDV tester shown in Fig. 1 & 2.

Fig. 1: Breakdown voltage measurement test set up

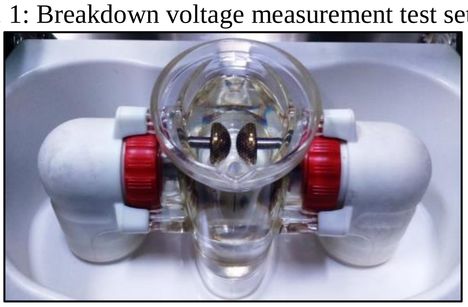

Fig. 2: Mushroom electrodes separated by 2.5mm gap

B. Permittivity

Permittivity or absolute permittivity is the measure of resistance that is encountered when forming an electric field in a particular medium. The linear permittivity of a homogeneous material is usually given relative to that of free space, as a relative permittivity [9], [11]. Relative permittivity is also commonly known as dielectric constant. Permittivity is measured with the help of Eltel model ADTR–2K Plus fully automatic test set shown in Fig. 3 & 4.

Electric stress distribution in mixed dielectrics mainly depends on the permittivity ratio. Materials with less permittivity receive more electric stress compared to higher ones [2].

C. Dissipation Factor (tanδ)

Dissipation factor expresses degree of dielectric loss in an electrical insulating liquid in alternating electric field and of the energy is dissipated in the form of heat. Dissipation factor is strongly depending on frequency of applied voltage, the temperature of specimen [7], [9]. It is defined as ratio of real part and capacitive part of the current. In case of measuring of the dissipation factor, the insulation must be connected as dielectric of capacitor. Dissipation factor (tanδ), of individual base liquid and mixed insulating oil is measured with the help of Eltel model ADTR–2K Plus fully automatic test set shown in Fig. 3 & 4.

Fig. 3: Permittivity and tanδ measurement test set up

Fig. 4: Three terminal oil test cell for permittivity and tanδ measurement

III. SAMPLE PREPARATION

In order to obtain a relatively stable insulating liquid with suitable properties, basic properties of base dielectric fluid intended to be used in mixture are compared. Comparative characteristics of Mineral oil and Synthetic Oil based on manufacturer's datasheet are given in Table 1.

When characteristics of mineral oil compared with synthetic oil and esters, it has been observed that, mineral oil and synthetic oil have comparative characteristics like flash point, Moisture content, Permittivity, Dissipation factor and Breakdown voltage. As far as our aim is concern, synthetic oil is biodegradable and has relatively low cost compared to other biodegradable liquids. Hence, we selected mineral oil and synthetic oil for mixture preparation and evaluation.

Samples were prepared with synthetic oil as base oil and different proportion of mineral oil were mixed with the base oil to investigate its typical electrical characteristics. Proportion ratios of mineral oil with synthetic oil are shown in Table 2.

Characteristics	Unit of Measure	Mineral Oil	Synthetic Oil
Physical properties			
Specific gravity at 20°C	g/cm^3	0.88	0.98
Kinematic Viscosity at 20°C	g/cm^3	27 at 27°C	5
Pour Point	°C	-6	-46
Chemical Properties			
Acid number	mg KOH/g	0.03	0.005
Water content	µg/g	50	35
Thermal Properties			
Flash Point	°C	>144	144
Electrical Properties			
Permittivity		2.02	2.52
Dissipation factor at 90°C		0.002	0.0005
Breakdown voltage	kV/2.5mm	60	72
Environmental			
Biodegradability		No	Yes
Economical			
Price	Rs./Litre	55	170

Table 1: Comparative Characteristics of Mineral and Synthetic Oil

Sample No.	Ratio of base fluids
Sample 1	Synthetic oil 90% + Mineral oil 10%
Sample 2	Synthetic oil 80% + Mineral oil 20%
Sample 3	Synthetic oil 70% + Mineral oil 30%
Sample 4	Synthetic oil 60% + Mineral oil 40%

Table 2: Sample Proportion Ratios

IV. RESULT AND DISCUSSION

A. Miscibility

As a first step, the miscibility of both the liquid was investigated [5]. The tendency of some liquids to form homogeneous mixtures is referred to as their miscibility. Two liquids are miscible if they are each soluble in the other, regardless of the relative proportions used [12]. Miscibility test performed on mixture of Mineral oil and Synthetic oil with different proportion and found miscible.

B. Typical characteristics of individual and mixed liquids

The tests were carried out on individual samples and mixed oil samples. The test results for BDV, Permittivity and tanδ are mentioned in Table 3.

Sample	BDV (2.5mm)	tanδ	ε
Synthetic oil (SO)	98.7	0.0014	2.49
Mineral oil (MO)	62.3	0.0014	2.03
SO 90% + MO 10%	97.7	0.0017	2.44
SO 80% + MO 20%	94.6	0.0023	2.36

SO 70% + MO 30%	88.0	0.0026	2.34
SO 60% + MO 40%	87.3	0.0027	2.28

Table 3: Test Results

C. Breakdown Voltage

Primarily Breakdown Voltage test was carried out on individual base liquids and oil mixtures. The BDV of oil sample is the mean value of six breakdown voltages which were obtained by the conducting six consecutive measurements with same oil sample. The test was conducted at ambient temperature of 28°C. It is known that temperature affects the conduction and breakdown properties of insulating liquids. However, a change in temperature of 20°C to 80°C only resulted in approximately 7% decrease in the AC breakdown voltage of the mineral oil [3], [10]. From the Table 2, BDV of mineral oil is 63% of synthetic oil. It has been observed that, as we increase the percentage of mineral oil in mixture, BDV of mixed oil goes on decreasing. The breakdown voltage variations are shown in Fig. 5.

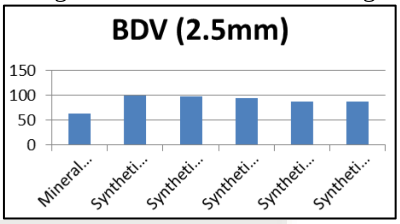

Fig. 5: BDV of base liquids and mixture with different proportion of mineral oil

D. Permittivity

Permittivity of individual base liquids and oil mixtures is measured at 90°C. It has been observed that, as we increase the percentage of mineral oil in mixture, permittivity of mixed oil goes on decreasing. The permittivity variations are shown in Fig. 6.

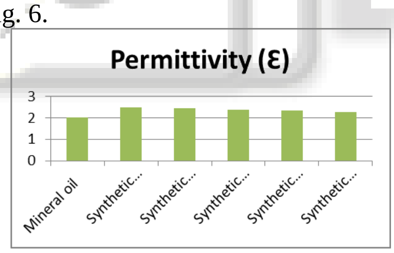

Fig. 6: Permittivity of base liquids and mixture with different proportion of mineral oil

In theoretical determination of the relative permittivity of the mixed liquid, a liquid mixture can be considered as two different dielectric layers. The thickness of each dielectric layer is depends on percentage of each liquid [5].

E. Dissipation Factor (tanδ)

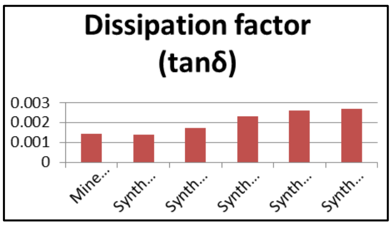

Fig. 7: tanδ of base liquids and mixture with different proportion of mineral oil

Dissipation Factor (tanδ) of individual base liquids and oil mixtures is measured at 90°C. It has been observed that, as we increase the percentage of mineral oil in mixture, tanδ of mixed oil goes on increasing. The tanδ variations are shown in Fig. 7.

V. CONCLUSION

From the observed parameters, it can be stated that as we increase the percentage of mineral oil in mixture has synthetic oil as s base fluid. It's BDV and permittivity decreases with increase in percentage of mineral oil. However, Dissipation factor is increased with increase in percentage of mineral oil.

When studying electrical characteristics of oil mixture composed of Mineral oil and Synthetic Oil. It has been observed that, this mixture has better electric properties than pure mineral oil along with improved biodegradability. BDV, Permittivity and tanδ here shows suitable values to use mixed insulating oil for use in electrical equipment. However the behaviour of mixed insulating liquid should be investigated carefully for physical, chemical and thermal properties before its use in expensive and long term investment of electrical equipments.

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