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OPTIMIZING CHARACTERISTICS IN MINERAL INSULATING OIL USED IN HIGH POWER TRANSFORMERS

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Abstract
The most commonly used insulating liquid in transformers is mineral oil. Special synthetic applications such as silicone, ester, perchloroethene, etc. are used today in special applications, with different characteristics, very low or nonexistent toxicity to mineral oils used in transformers.
On the other hand, they have a much better biodegradability than mineral oils in both aerobic and anaerobic conditions. But they cannot directly replace the mineral oil in operation or in repaired units.
They have dielectric properties and good heat transfer but have limited their use to special transformers due to the relatively high cost and availability.

Keywords*:* *biodegradability, characteristics, mineral oil, liquid ester, investigations*

Introduction

The purpose of this paper is to compare the results of the mineral oil, liquid ester investigations and, for this, the characteristics of the mixed insulating liquids with those of pure insulation liquids under extreme aging conditions.
Mixtures are a combination of mineral oil and a specific amount of a liquid ester that has similar electrical properties and presents a lower risk of pollution but with high hygroscopicity. The water saturation limit is more than 40 times higher than that of mineral oils.
Pure liquids have also been investigated to provide basic data for comparison. In addition to pure mineral oil and liquid ester, short- and long-term behaviours of insulating fluids were determined.
Generally, if the transformer is routinely operating at very low temperatures, the application of mineral and ester blends offers increased insulation reliability. Furthermore, adding the ester to mineral oil helps to reduce the gas trend under stress (Beyer et al. 1986).

Experimental

The mineral oil and an amount of ester liquid were poured into a vessel and mixed slowly with the aid of a stirrer. To assess the degree of miscibility, the dissipation factor and the relative permeability were determined for three types of mixtures.
The results presented in Figure1 demonstrate that there is no significant difference, regardless of the amount of added ester. To see the temperature effect on the liquid mix, they were heated to 90°C and after a few days, no visible separation was found. We can say that the two liquids are miscible with up to 50% of the ester liquid.

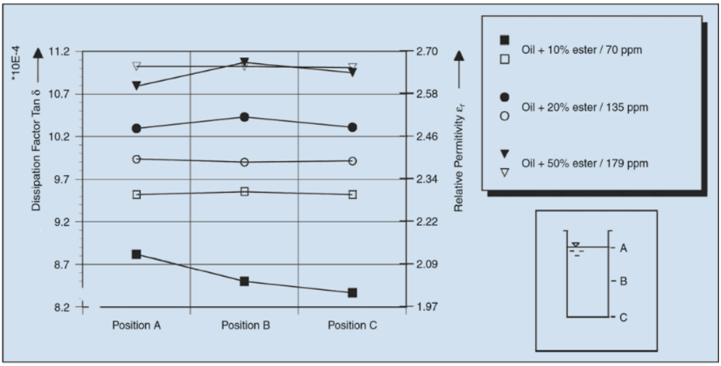

Figure 1. The relative permittivity and dissipation factor of three mixtures

When preparing the insulating liquids for a transformer, it must be kept in mind that gases can be found dissolved in the insulating oil. The electrical resistance of an insulating liquid is reduced by the presence of dissolved or dispersed gases, which are the main degradation products of low energy discharges that may occur in oil-filled transformers.

Dissolved gases such as hydrogen, oxygen, methane, carbon dioxide, etc. are present in crude oils as residues due to improper handling prior to use or manufacturing process. Hydrogen has low solubility in transformation oils so that gas bubbles can easily form.

Bubbles can intensify the partial discharge activity and/or trigger the breakdown in the affected regions.

Before it is inserted into a transformer, it is advisable to dry and filter the insulating fluids (Borsi 1991). For this experiment, the liquid samples were dried and degassed using two-step drying (Borsi 1991). The mixture obtained has a percentage of less than 0.5% gas and very low water content.

Dielectric characteristics of mixed liquids

The dissipation factor (tan δ) and relative permittivity (εr) are important dielectric properties of insulating oil.

D*etermination of relative permittivity of mixed liquids*

A previously proposed concept by Aguet et al it is assumed (Aguet & Ianoz 1987): a liquid mixture can be considered as two different dielectric layers where indices 1 and 2 are the mineral oil and ester, the thickness d1 and d 2 of each depends on the percentage of each liquid. Relative Permittivity (εr) Figure 2 varies with temperature for samples of crude mineral oils, aged and uncoated liquid mixtures.

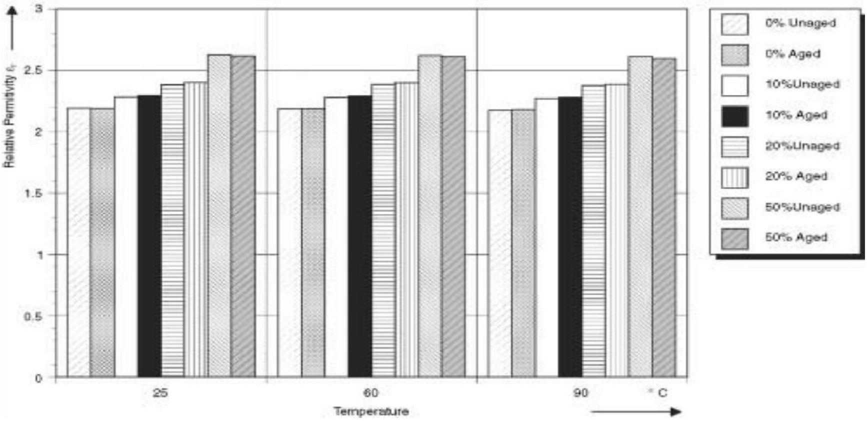

Figure 2. Values of the relative permittivity of mineral oil and mixed liquids

The (εr) values at each temperature are the average of the results for all the water content. The following conclusions can be drawn:
increasing the proportion of the liquid ester in a liquid mineral / liquid ester mixture. This can be seen in Table 1.

Table 1. Values of the Relative Permittivity (εr) and Dissipation Factor (tan δ) for Various Mixtures of Mineral Oil and Ester Liquid.

Ester liquid amount (%)	0	10	20	50	100
εr	2.1±0.1	2.274±0.1	2.354±0.1	2.63±0.1	3.2±0.1
tan δ (10^{-4})	5.4±4.5	12.2±10.7	19.6±17.3	42.2±40.7	103.2±93.5

There is a correlation between experimental and theoretical results for all liquid mixtures studied.
With a relatively high value (εr> 2.6), the 50% ester liquid mixture could improve the electrical resistance of liquid / solid composite insulation when used in transformers, and these are similar to silicone fluids (Borsi 1991).
Values εr were higher for mixed elderly samples of and sometimes lower than non-target specimens, but the variation was less than 5% of the absolute value Figure 2. The mixture of fluids is only slightly influenced by the aging process.

The dissipation factor (tan δ)
The temperature dependence of the dissipation factor of the aged and new aged mineral and aged liquid samples is shown in Figure 3a, where in the tan δ values are the average for all water content at a certain temperature.

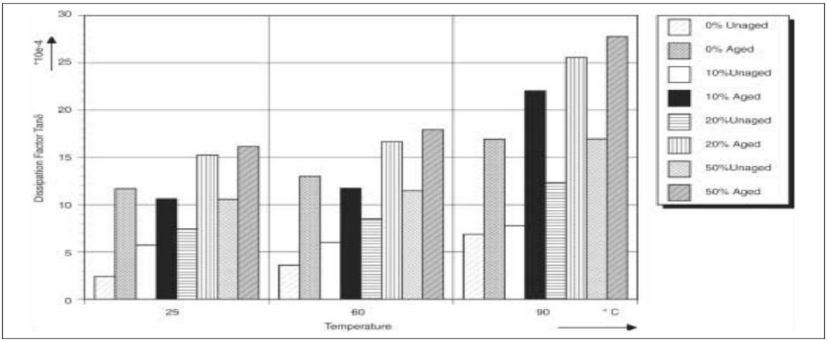

Figure 3a. Values of the dissipation factor of mineral oil and mineral oil/ester liquid mixtures.

For all oils and oil mixtures, the higher the temperature, the mixtures of mineral oil and liquid ester do not behave differently (Borsi 1991).
However, the values for all mixtures for unmasked and elderly specimens are within the 0.005 required by the IEC and VDE (IEC 60296) for the new oil.
The presence of water in mixtures has only a slight influence on their dielectric behavior due to the saturation limit, which is higher than that of mineral oils.
From Figure 3b it can be seen that the higher the ratio of the ester liquid to the aging rate.

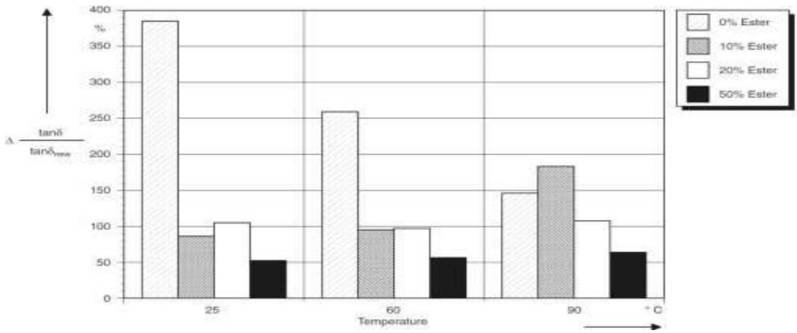

Figure 3b. Aging effect on the dissipation factor tan of the mineral oil and the mineral oil mixed with different amounts of ester liquid

The higher the amount of liquid mixed with mineral oil, the more it will have a beneficial effect on the aging of the insulating oil. The air that normally enters the transformer passes through a dehydrated apparatus filled with silica gel.
A malfunction of this appliance may cause the insulating fluid to come in contact with atmospheric humidity. It is necessary to monitor the moisture absorption of mixed insulating liquids under such conditions. Thus, the dry samples of each insulating liquid were exposed to the same atmospheric conditions in which the water content was well controlled.

Figure 4 shows the variation in moisture absorption of pure and mixed liquids.

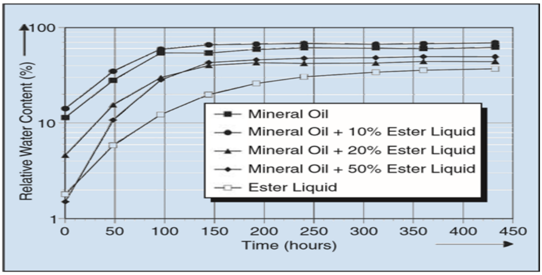

Figure 4. Variation of relative moisture absorption of different insulating liquids versus time.

Viscosity

The viscosity of an insulating liquid is important for the process of dissipation and impregnation of heat.

When the viscosity decreases with temperature, the viscosity of the ester fluid at the working temperature is relatively close to that of the mineral oil. Generally, the viscosity of a mixture increases with increasing molecular size and molecular weight of the constituent compounds (Rouse 1998). The viscosity of the mineral oil is very low compared to that of the liquid ester. By mixing the two liquids, an increase in viscosity due to the proportion of ester fluid is observed. Figure 5 shows the viscosity of the mixtures as well as pure liquids at different temperatures.

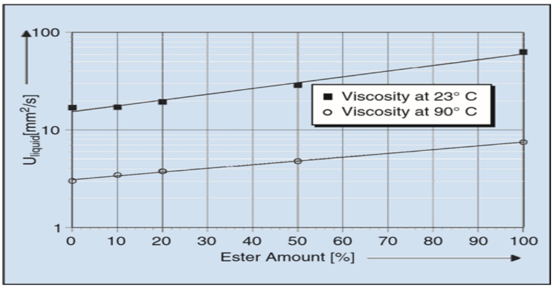

Figure 5. Cinematic viscosity of liquid mixtures versus the ester proportion.

Dissolved Gas Analysis (DGA)

The behavior of gas insulating liquids in thermal insulation stress during operation is usually accompanied by gas generation, which can cause DP. The gas can either be dissolved in liquid or bubble. Dissolved gases are detected by Dissolved Gas Analysis (DGA) methods (Dumke 1998). Gas bubbles, which are generally caused by large defects in a short time or small defects after a long time in which the gas saturates the liquid, find their way to the Buchholz relay (Borsi 2000).

At temperatures between 250 and 300°C, the first gas bubbles in mineral oil appeared, while the temperature of the ester liquid was 350 to 400°C. The higher the gas content, the greater the risk of failure in the insulating liquid. By adding the esteric liquid to the mineral oil it was found that the gas tendency was reduced to the local thermal stresses.

Results and Discussion

Their determinations were made at different temperatures of 25, 60 and 90°C and at different water contents.

Relative Permissibility (εr) increases in proportion to the amount of liquid ester added in a liquid mineral/liquid ester mixture. The (εr) values for mixed age samples were sometimes higher and sometimes lower than the target specimens, but the variation was less than 5% of the absolute value. Mixed samples are only slightly influenced by aging.

The higher the ester ratio, the higher the dissipation factor (tan δ). The tangent of the mixtures with the 50% ester is about twice as high as the mineral oil; however, the values for all mixtures for unmasked and elderly specimens are within the 0.005 range required by the IEC for new oils.

The presence of water in mixtures has only a slight influence on the dielectric characteristics, the saturation limit being greater. A large amount of liquid ester mixed with mineral oil appears to have a beneficial effect on the aging of the mineral oil mixture.

The damping of mixed liquid absorption relative to relative humidity is less than that of mineral oil. The mixture of 10% of the liquid ester has the same characteristics as mineral oil, while 20% and 50% mixture has the characteristics of pure mineral oil or ester oil. It is important to monitor the absorption of mixed moisture in the insulating liquid under such conditions.

To do this, the samples of the dried samples of each insulating liquid were exposed to the same atmospheric conditions in which the water content was well controlled.

High viscosity values, such as those of ester fluids, have the advantage of rapidly achieving the expected service temperature compared to mineral oils during the cold start of the transformer. If the viscosity decreases with temperature, the viscosity of the ester fluid at the working temperature is relatively close to that of the mineral oil.

The first large bubbles of gas occurred at a temperature of 250 to 300°C for the mineral oil, while for the liquid ester a temperature of 350 to 400°C was required.

Conclusions

The electrical and physical characteristics of the mixed liquids investigated are not inferior to those of typical transformation oils, especially for mixtures with an ester content of less than 20%.

50% of the ester mixture liquid density and kinematic viscosity of the obtained values of the standards proposed limit.

In conclusion, thermal insulation and insulation properties are very low, which makes a much better choice of the insulating fluid mix compared to mineral oil.

Acknowledgments

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