Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10607

Changing of the Insulating Characteristics of Mixtures (Mineral Oil and Synthetic Ester) During Prolonged Exposure of Elevated Temperature

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Motivation

- The ever-growing demand for electricity requires an increase in capacity from generation, transmission and distribution networks. Consequently, the thermal load on the insulation system increases, thus leads to an increase in the aging rate of the insulation and a reduction in its service life. Therefore, there is a need to enhance the properties of insulating materials in the first place. The most optimal option **for improving the properties of mineral oil (MO) is mixing it with biodegradable synthetic esters (SE)**.
- **The purpose of this study** is to assess the change in the electrical insulating properties of mixtures of aromatic oil with different ester content under conditions of prolonged thermal aging.

Method/Approach

- Dielectric liquids (MO, SE, and their mixtures) were divided into two batches: **Series I** - throughout the aging period, the bottles remained open for free air access (**with air access**); **Series II** - after pouring degassed liquids into glass bottles they were closed with airtight stoppers (**without air access**).
- The aging of two batches took place at a temperature of 110 °C for 3000 hours.
- During the ageing process, the **physicochemical and dielectric parameters** of insulation liquids were measured:

  - Breakdown voltage (*BDV*);
  - Water content (*WC*);
  - Dielectric dissipation factor at 90 °C (*DDF*);
  - Acidity (*ACI*);
  - Interfacial tension (*IFT*);
  - Corrosive sulfur (*SUL*);
  - Optical turbidity (*OTUR*);
  - Ester value (*EV*);
  - Peroxide value (*POV*).

Objects of investigation

- The objects of research are **aromatic mineral oil (MO)** which was taken from operating equipment and unused **synthetic ester** Midel 7131 **(SE)**, as well as their mixtures (the proportion of MO and SE in the mixture by volume (%): 100/0, 90/10, 80/20, 70/30, 50/50 and 0/100).

Test results & discussion

- **The appearance of liquids after aging.** In the case of thermal oxidative degradation of liquids after 3000 hours of exposure to high temperature is formed a fine-crystalline sediment: 1) with air access - in the MO and a mixture of oil with a 10 % SE; 2) without air access - in the MO and a mixture of oil with a 10 % and 20 % SE.

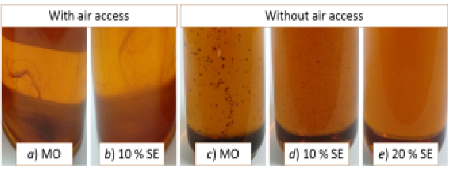

Figure 1. Appearance of mixtures of MO and SE after aging

- **Optical turbidity (OTUR).** The value of the turbidity of aromatic oil, and mixtures based on this oil and synthetic ester, aged without air access (Figure 2) is several times higher than during thermal-oxidative aging. The turbidity value after 3000 h of thermal oxidation in different conditions decreases in the following sequence: MO > MO(90):SE(10) > MO(80):SE(20) > MO(70):SE(30) > MO(50):SE(50) > SE. In other words, mixing the synthetic ester with aromatic oil of 20 % and higher (with air access) or 30 % and higher (without air access) by volume prevents the formation of sediment.

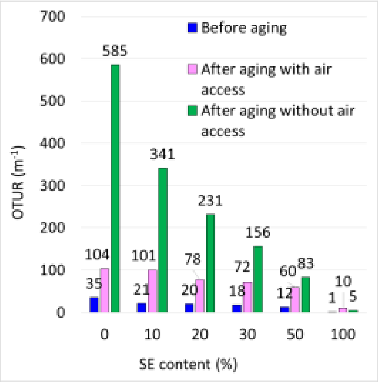

Figure 2. Change in OTUR of dielectric liquids after aging at 110 °C for 3000 h

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- **Water content (WC).** Figure 3 shows the trends in water content change during the aging of liquids with access and without air access.

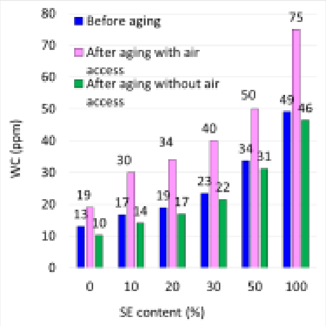

Figure 3. Change in WC of dielectric liquids after aging at 110 °C for 3000 h

- **Breakdown voltage (BDV).** The most significant drop in breakdown voltage (BDV) occurs in samples of aromatic mineral oil and a mixture of oil with an ester content of 10 %, aged at high temperatures with air access.

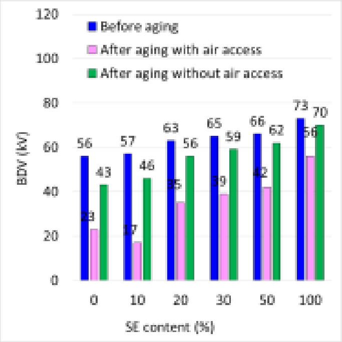

Figure 4. Change in BDV of dielectric liquids after aging at 110 °C for 3000 h

- **Dielectric dissipation factor at 90 °C (DDF).** The value of the dielectric losses of mixtures MO(90):SE(10) and MO(80):SE(20), the aging of which was carried out without air access is higher than in sealed conditions. This fact testifies in favor of the formation of colloidal compounds associated with other polar impurities, including water molecules.

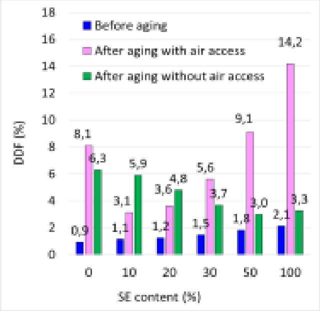

Figure 5. Change in DDF of dielectric liquids after aging at 110 °C for 3000 h

- **Peroxide value (POV), Ester value (EV) and Acidity (ACI).** The trend in the values of POV, EV, and ACI indicates slow degradation of the ester under the influence of prolonged heating in conditions of hermetically sealed container.

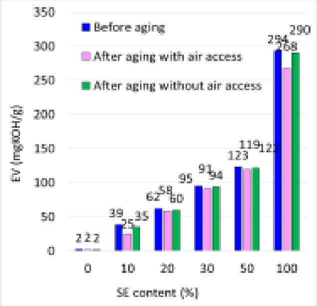

Figure 6. Change in EV of dielectric liquids after aging at 110 °C for 3000 h

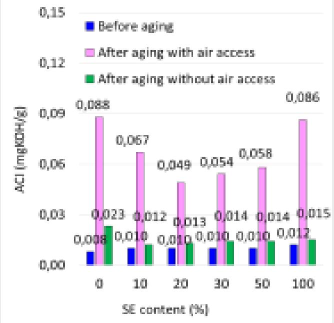

Figure 7. Change in ACI of dielectric liquids after aging at 110 °C for 3000 h

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- **Interfacial tension (IFT).** This indicator is an integral value and, first of all, depends on the presence of polar impurities. The increase in the content of peroxide compounds and acidic substances, undoubtedly, impacts the trend of interfacial tension.

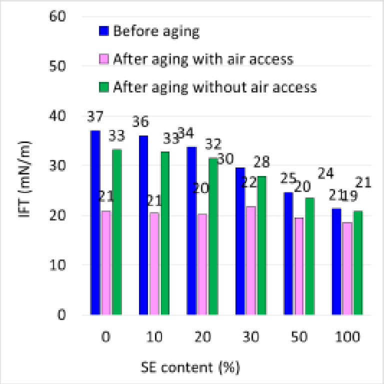

Figure 8. Change IFT of dielectric liquids after aging at 110 °C for 3000 h

- **Corrosive sulfur (SUL).** Having carefully studied the illustrations, it can be noticed that the more ester is in the mixture, the less the silver plate is colored. The plate in oil with an ester content of 10 % - 50 % has a faint golden yellow color. All this indicates that the components of the synthetic ester block the aggressive action of organosulfur compounds on metal structures.

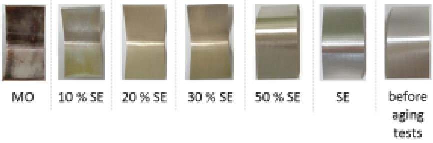

Figure 9. Corrosive sulfur analysis results

Conclusion

- Oxygen-containing compounds are predominantly formed during the aging of mineral oil with a high content of aromatic hydrocarbons with air access.
- High-temperature prolonged heating of mineral oil without air access leads to the formation of compaction products and other colloidal compounds.
- The synthetic ester liquid demonstrates high chemical stability in case of prolonged aging with free air access.
- Test results in this study indicate that mixing the synthetic ester with aromatic oil of 20 % and higher (SE, by volume) leads to the stabilization or slowdown of chemical reactions occurring as a result of thermo-oxidative effects (with air access).
- Under thermal exposure (without air access), the addition of synthetic ester to aromatic oil in a volume of 30 % and higher also makes it possible to reverse the situation with the formation of a sediment due to the degradation of aromatic mineral oil.
- Analysis of corrosive sulfur shows that mixing a synthetic ester (more than 10 % by volume) with aromatic oil, which has a high content of organosulfur compounds, significantly reduces the aggressive effect of sulfur on metal structures.