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Preventive Measurement and Online Insulation Evaluation of Power Transformer

[1]T.Saranya.,[2]R.Dheivanai,.
[1]PG Scholar, Department of Electrical and Electronics Engineering, Vivekanandha institute of Engineering and technology for Women, Tiruchengode, Namakkal District-637205.
Email id:saranyaeee.47 @gmail.com
[2]Assistant Professor, Department of Electrical and Electronics Engineering, Vivekanandha institute of Engineering and technology for Women, Tiruchengode, Namakkal District-637205.
Email id:rkdeivanai@yahoo.com

ABSTRACT

Cellulose based non conducting materials and mineral oils have widely been used in liquid filled transformers. Environmental and fire-safety concerns have accelerated the use of Natural Esters (NE) as a sustainable alternative to mineral oil. To ensure a safe and long-term operation of the vegetable oil filled transformers, it is need to clarify the knowledge gaps with respect to the ageing of vegetable oil impregnated cellulose and insulation diagnostic methods. The condition monitoring of mineral oil filled transformers has been well characterised, due to the numerous laboratory and field studies conducted during the past several decades. The application of these available condition monitoring techniques for NE filled transformers is yet to be validated as the use of NE for power transformers is in the tested stage. In this paper the performance of NE as insulation in transformers by evaluating the ageing of NE impregnated cellulose pressboard is presented. For this purpose, an accelerated ageing experiment has been carried out in sealed tubes at 120 ^{0}C. The ageing of oil impregnated pressboard has been characterised by decrease in the degree of polymerisation (DP) of pressboard, and the formation of both 2-furfuraldehyde and dissolved carbon dioxide (CO_2) in the oil. The structural changes of cellulose have been supported by fuzzy logic algorithm. Moreover, the results have been compared with cellulose insulation samples aged under similar conditions in conventional mineral oil.

Index Terms — Cellulose, degree of polymerisation (DP), Breakdown voltage, fuzzy logic algorithm, 2-furfuraldehyde, natural ester (NE).

1.INTRODUCTION

Natural esters (vegetable oils) formulated as dielectric fluids have environmental and fire safety advantages over conventional transformer mineral oil. In thermal evaluation comparisons of transformer insulation systems, production distribution transformers filled with natural ester dielectric fluid exhibited less deterioration than did the corresponding transformers using mineral oil [6].The environmental properties of natural esters are such that in Germany they are classified as “non-hazardous to waters” [5].

Aquatic biodegradation tests [4] of the natural ester dielectric fluid used in this experiment found >99% metabolized conversion to CO_2, equivalent to compounds defined as “ultimately biodegradable”. In acute trout toxicity tests [8]**,** the same fluid had no observable effect on fish at 1000 mg/l, the highest concentration tested. Transformers using natural ester fluids deliver very important improvements in fire safety compared to those using mineral oil. Natural ester dielectric fluids have fire points in the range of 350-360°C; conventional mineral oil has a fire point of about 155°C. Two natural ester dielectric fluids are accepted as “less-flammable” per Section 450.23 of the US. National Electrical Code” [7].Accelerated aging tests of distribution transformers gave early indications that the rate of paper aging is fluid-dependent [7]**.**An earlier study quantified this dependence for thermally upgraded

Kraft insulation paper [3]. This work examines the aging rate dependence on fluid type for plain (not thermally upgraded) Kraft insulation paper.

2.Water

Water content of natural ester fluid can be considerably different from mineral oil. Fig.1 shows water saturation versus temperature for mineral and vegetable oils.

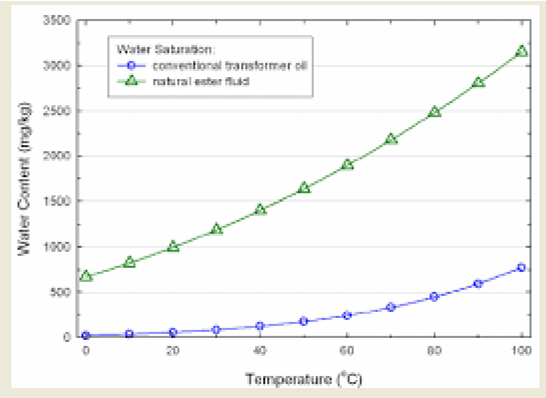

Fig.1.Water saturation versus temperature for natural ester fluid and conventional transformer oil.

At room temperature, the water saturation of mineral oil is about 60 mg/kg. Natural esters have room temperature saturations of approximately 1000 mg/kg. The dielectric strength of an insulating fluid starts to reduced when the relative saturation increases to 40-50%.Using percent saturation instead of absolute water content allows direct comparisons between natural ester fluids and mineral oil to be made.

3.Degree of Polymerization

Another measure of cellulose degradation is degree of polymerization (DP). The change in DP over time is shown in Fig.2**,** and is similar to the change seen in TS**.** A rapid DP reduced in the first 500 hours of aging was observed. Retained degree of polymerization (DP) versus time for Kraft paper aged in natural ester and mineral oil. New paper DP is 1175 +_50**.** Horizontal error bars represent time-at-temperature uncertainty. Original DP at 500 hours, in line with other published results [10,11]. The retained DP of paper aged in natural ester fluid remained above 20% after 4000 hours of aging.

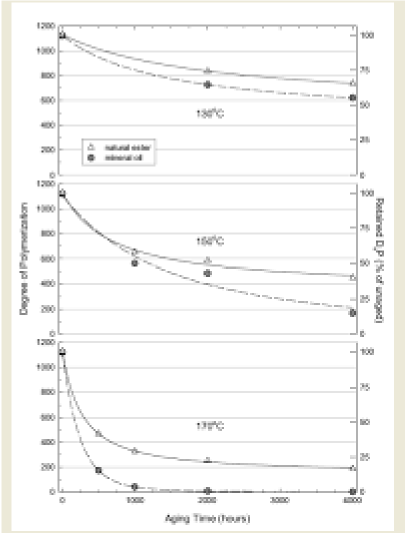

Fig.2. Degree of polymerization versus aging time for natural ester fluid and conventional transformer oil.

3.DISSIPATION FACTOR AND VISCOSITY

Fig.3a compares the dissipation factor (tanδ) measured at 55 °C of mineral and NE oil samples. At higher temperatures, current for a given voltage is higher than that at room temperature. Therefore the accurate measurement is high at high temperature. On the other hand, the influence from impurities comes from outside (oil handling) could be significant at high temperature. Thus, in this study a moderate temperature (55 °C) to measure the dissipation factor has been selected. Measurement was performed using an IDA 200 insulation analyser under an applied voltage of 50 V across 2 mm oil gap in a three electrode test cell. As shown in Figure3 in all cases the dissipation factor has changed significantly between un-aged and 1280 h of ageing followed by a relatively low variation of it. The initial rise of dissipation factor may be due to the formation of acids and other polar substances due to ageing of oil and pressboard. In this study headspace of the test tube was vacuumed only up to 10-20 KPA before sealed with dry nitrogen. Moreover, the oil used in test tubes was exposed to air during the sampling period (about 5 minutes). Thus, one can expect that a considerable amount of oxygen could have dissolved in oil and it may contribute to the initial oxidation of oil. This may be one reason for increasing dissipation factor during the first 384 h of ageing. Moreover, the overall moisture content in oil has also been increased

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during first 840 h of ageing (particularly oil aged standalone).This may also cause the initial rise of dissipation factor. The increase of the dissipation factor of oil sample aged with pressboard is less than that of oil samples aged stand alone in first 384 h. The ageing of pressboard may also consume dissolved oxygen in oil and retard the oxidation reaction in the oil. This may be a reason for observed different trends of dissipation factor between oil aged standalone and with pressboard during the initial stage of ageing. Oxidation of oil produces radicals, which can combine with ionic particles in the oil. This phenomenon causes to increase the physical size of ions; that consequently decreases ionic mobility. When this effect is dominant, dissipation factor starts to decrease. This could be a reason for decreasing the dissipation factor of oil samples aged standalone after the first 384 h of ageing. When pressboards exist in the oil, radicals and ionic particles are adsorbed by pressboard surfaces. As a result there is no big change in dissipation factor due to above mention phenomenon in both MIN_P and NE_P. On the other hand, since there is no continuous oxygen supply, it can expect only limited oxidation in the oil until dissolved oxygen is consumed.

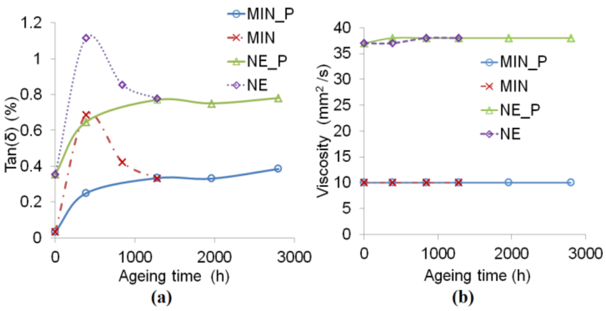

Fig.3. Change of dissipation factor and viscosity of oil over ageing.

Thus, one can expect fairly constant dissipation factor after initial increment as observed in both MIN_P and NE_P. In fact, results of viscosity measurements agree with this hypothesis, because the viscosity has not changed during the whole ageing period. It confirms that no severe oil oxidation has occurred during ageing. Figure 3b represents the viscosity of the same oil samples determined at 40 ^{0}C. Moreover, dissipation factor of tested NE oil is greater than that of mineral oil under similar ageing conditions. This is due to a higher dielectric constant associated with NE. There is an inverse relationship between dielectric constant of continuum separating ions and Coulomb force attraction between oppositely charged ions. Therefore, larger dielectric constant of NE enhances the dissociation of ionic impurities leading to a higher dissipation factor.

4. THE AC BREAKDOWN STRENGTH OF OIL IMPREGNATED PRESSBOARDS UNDER DIFFERENT TEMPERATURE

Fig.4 shows the ac breakdown voltage of oil impregnated pressboard dependence on temperature. The natural ester impregnated pressboard also shows higher ac breakdown strength value than mineral oil impregnated pressboard at temperatures of 40, 50, 60 and 70^{0}C.That the relative permittivity of natural ester and mineral oil decreases slightly with temperature. On the other hand, the relative permittivity of natural ester impregnated pressboard and the relative permittivity ratio of natural ester impregnated pressboard to natural ester increases with temperature. There is the same trend in mineral oil impregnated pressboard from 20 to 70^{0}C. However, both the relative permittivity of mineral oil impregnated pressboard and the relative permittivity ratio of mineral oil impregnated pressboard to mineral oil have a slight decline from 70 to 90^{0}C. As described above, the lower permittivity ratio of oil impregnated pressboard to oil is beneficial in oil/pressboard system.

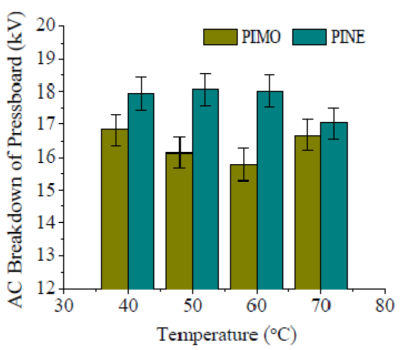

Fig. **4.** ac breakdown strength of pressboard (0.3mm thickness) immersed in natural ester and mineral oil under different temperatures.

That the lower permittivity ratio of natural ester impregnated pressboard to natural ester is good for improving the ac breakdown strength of natural ester/pressboard insulation system

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5.EXPERIMENTAL

The thermal aging procedure and sample preparation methods are identical to those previously described [8]. Sealed steel aging tubes contained 28.4g of Kraft insulation paper dried to a water content of 0.76wt%, 350ml of dielectric fluid, and typical transformer proportions of copper and aluminium.

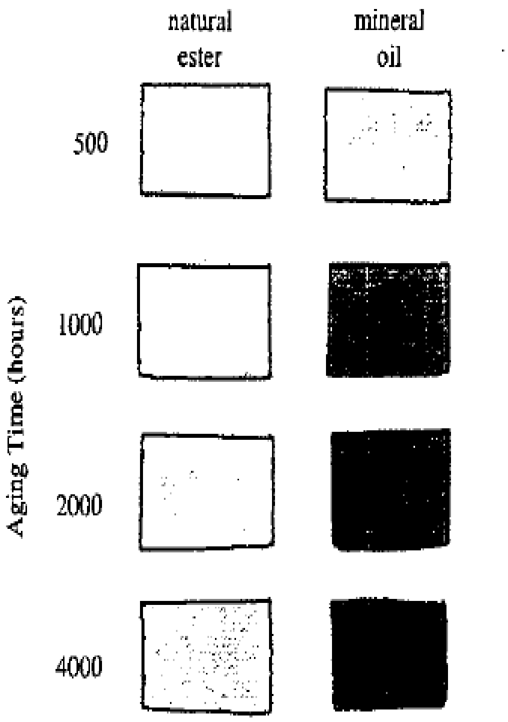

Fig. 5.Kraft paper insulation after 150°C sealed tube aging in natural ester and mineral oil.

The tubes were aged at 150T and evaluated after 500, 1000, 2000 and 4000 hours. The extent of paper aging was determined using changes in the tensile strength (TS) and the degree of polymerization (DP).The total concentrations of four predominant furanic products of paper degradation were measured in the aged fluids. The water also determined contents of both the also determined papers and fluids were also determined.

6.CONCLUSION

This study confirmed that the ageing rate of cellulose material in NE is relatively higher than that in mineral oil up to 1280 h. On the other hand, during 1280 h to 2800 h, the average ageing rate of pressboard in mineral oil is three times greater than that of pressboard in NE. Based on this one could expect that after 2800 h the time to acquire end of life DP for the pressboard in NE will be higher than that in mineral oil.

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