EFFECT OF THERMAL AGEING ON THE OIL-PAPER INSULATION

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ABSTRACT

Insulation system is one of the most important part of electrical devices. This insulation system is usually composed by solid part and liquid part. Oil impregnated insulation paper is used in transformers for many years. There are a lot of factors which have significant influence on the insulation system during the life time of electrical devices. Temperature is one of the factors which has strong influence on condition of oil paper insulation. This paper is focused on measuring of electrophysical properties of oil paper as relative permittivity, AC breakdown voltage and polarization index of insulation before and after thermal ageing. Vegetable oil paper insulation and mineral oil paper insulation were investigated and analyzed.

Keywords: *oil-paper, properties, ageing, breakdown voltage, relative permittivity*

1. INTRODUCTION

In a liquid-filled transformer, the insulating liquid plays an important function by providing both the electrical insulation (in combination with a solid such as cellulose) and the means of transferring the thermal losses to the cooling system. The insulating liquid can also provide important and easily obtainable information for use in diagnosing the health of a transformer [1]. For the reliable operation of high voltage power transformers, it is essential that the cellulose insulation structures used in their construction are completely oil impregnated. The oil impregnation procedure is important to ensure that no cavities are left inside the cellulose insulation and thereby dangerous partial discharges are avoided [2]. The thermal degradation affects electrical, chemical and mechanical properties of insulation paper. Thermal stress is one of key factors which cause the degradation of oil-paper insulation. Accelerate thermal experiments have been performed by many researchers over the last a few decades, and the results of these experiments have been used to make predictions of transformer lifetime [3]. Conventional mineral oil is some possibility of environmental pollution and fire with explosion. But natural ester insulating oils are non-toxic, more biodegradable and less flammable than a mineral oil. Therefore conventional mineral oil is being replaced with natural ester insulating oil [4]. Influences of thermal ageing on the natural ester impregnated paper and mineral oil impregnated paper were researched.

2. EXPERIMENT

Influence of thermal ageing on rapeseed oil impregnated paper and mineral oil (ITO 100) impregnated paper was tested. Measurement of base electrophysical properties, as relative permittivity, breakdown voltage and polarization index were realized. For these purposes was chosen insulation paper with 0.06 mm thickness. Insulation system of transformers is composed with several layers of insulation paper and oil, therefore our experiment is composed of six layers of insulation paper and oil. The thickness of paper insulation was 0.36 mm. The temperature of accelerated ageing was 90°C. We gave a piece of copper into samples of oil paper, for simulating a real insulation system of transformer. This experiment was made at room temperature and atmospheric pressure. The first measurement was realized at 0 hours thermal ageing, and next two different thermal aging intervals have been selected (500 hours and 750 hours).

3. METHODS OF MEASUREMENT

The measurement methods which were used for these experiments are described in following chapters.

3.1. AC breakdown voltage of oil impregnated paper

Electrical breakdown voltage is one of the most important properties of the dielectric material. The AC breakdown voltage was measured using two electrodes which were 25 mm diameter brass hemispherical types. Breakdown voltage of mineral oil paper insulation and rapeseed oil paper insulation were measured with High-Voltage DTS-60D equipment (Fig. 1). For each types oil, five oil impregnated paper samples were tested, and the average value was calculated. The voltage was applied at a rise rate of 2 $kV.s^{-1}$ until breakdown occurs. Paper insulation was changed after the each breakdown. There was a 1 minute break between two measurements.

Fig. 1 High Voltage DTS-60D

3.2. Relative permitivity

Relative permittivity ε_r it can defined as ratio of capacity dielectric between capacitor electrodes and capacity of the same capacitor which is filled by air. It describes how many times force is exerted on charge in dielectric lower than in vacuum. Relative permittivity is used to expresses of skills of material accumulate electric charge. Accumulation of electric charge is consequence of polarization of material [5]. Polarization is moving of a free charges in electric field. It depend of temperature of specimens and frequency of voltage. Relative permittivity is dependent on dipole moments of molecules, and their speed in electrical field [6]. Relative permittivity in depending on voltage were measured with automatic Schering bridge TETTEX AG (Fig. 2). Measurement was realized at temperature 20°C and voltage was increased from 0.2 kV to 2 kV with step 0.2 kV at frequency 50 Hz. The electrode system for measurement of relative permittivity is shown on (Fig. 4). In chapter of results and discussion, the rapeseed oil paper is represented by abbreviation (RO-IP) and mineral oil paper is represented by abbreviation (MI-IP).

Fig. 2 Automatic Schering bridge

3.3. Measurement of resistance

Measurement of resistance belongs between the oldest and the simplest diagnostic method. Measurement of resistance after connection of DC voltage during the certain time interval is the principle of this method. Polarization index is used for assessment of quality of insulation system. It is ratio of resistance in two different time intervals. 1 minute polarization index and 10 minute polarization index are used in diagnostic of insulation system of electrical devices. It is ratio of resistances in 60 and 15 seconds after the connection voltage and resistance in 600 and 60 seconds. In this paper is used only 1 minute polarization index [7]. Unilap ISO 5kV was used for measurement of resistance (Fig.3). There was used the same electrode system, as with the measurement of dissipation factor and relative permittivity. Electrode system with sample is shown on (Fig. 4).

Fig. 3 Unilap ISO 5kV.

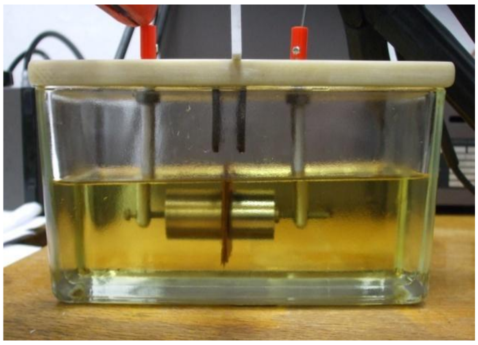

Fig. 4 Specimen of oil-paper insulation

4. RESULTS AND DISCUSION

Influence of thermal ageing on the breakdown voltage of different types of oil paper insulation is shown in Tab. 1 and Tab.2

Table 1 Influence of thermal ageing on breakdown voltage of insulation paper impregnated by rapeseed oil

number of measuremt	RO-IP 0h 0°C	RO-IP 500h 90°C	RO-IP 750h 90°C
	Ub(kV)	Ub(kV)	Ub(kV)
1	17.8	23.3	22.4
2	18	20.7	24.8
3	20.4	19.5	22.8
4	19. 2	20.7	23.4
5	21.1	20.2	23.3
Average	**19.3**	**20.88**	**23.34**

Electrical discharge is statistically random phenomenon, therefore measurement of breakdown voltage was realized five times. Then average value was calculated. Table of breakdown voltage of rapeseed oil paper show that breakdown voltage is higher than breakdown voltage of mineral oil paper. This fact is confirmed also the average values of breakdown voltage. Average value of breakdown voltage before thermal ageing for rapeseed oil paper is 19.3 kV while for mineral oil paper is 18.2kV. For 500 hour thermal degradation at 90°C is this value 20.88 kV for rapeseed oil paper and

20.3kV for mineral oil paper. The biggest difference is at 750 hour thermal ageing at 90°C. Average value for this case is 23.34 kV for rapeseed oil paper and 20.32 kV for mineral oil paper. This fact is caused by evaporation of moisture from the oil and paper after thermal ageing.

Table 2 Influence of thermal ageing on breakdown voltage of insulation paper impregnated by mineral oil

number of measuremet	MI-IP 0h 0°C	MI-IP 500h 90°C	MI-IP 750h 90°C
	Ub(kV)	Ub(kV)	Ub(kV)
1	18	20.7	19.4
2	18	20.3	20.1
3	18.9	19.9	20.4
4	17.9	19.3	20.6
5	18.2	21.3	21.1
Average	**18.2**	**20.3**	**20.32**

Results from measuring of relative permittivity of rapeseed oil paper and mineral oil paper are shown at Fig. 5 and Fig 6. The samples were exposed thermal stress 0 hours, 500 hours at 90°C and 750 hours at 90°C.

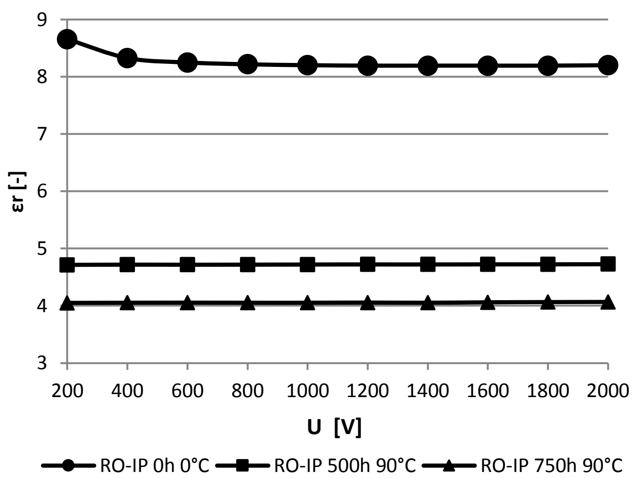

Fig. 5 Influence of thermal ageing on relative permittivity of insulation paper impregnated by rapeseed oil.

Temperature is one of the important factors influencing relative permittivity of insulating materials. The value of relative permittivity is decreasing after each thermal stresses. Natural esters absorbed three times more moisture as mineral oils. Decreasing of relative permittivity is caused by evaporation of moisture from oil paper. Relative permittivity of rapeseed oil paper before thermal ageing is 8.2 and after thermal ageing is 4.7 and 4.1 respectively.

Mineral oil paper insulation has lower value of relative permittivity as natural oil paper, generally. There are several differences against the natural oil paper insulation. First difference is that relative permittivity of mineral oil paper is increasing if voltage is increased in each of cases. The second difference is that, after first thermal ageing the value of relative permittivity is higher than before thermal ageing. The value of relative permittivity of mineral oil paper before thermal stresses was from 3.17 to 3.24 and after 750 hour thermal stresses was approximately 3.

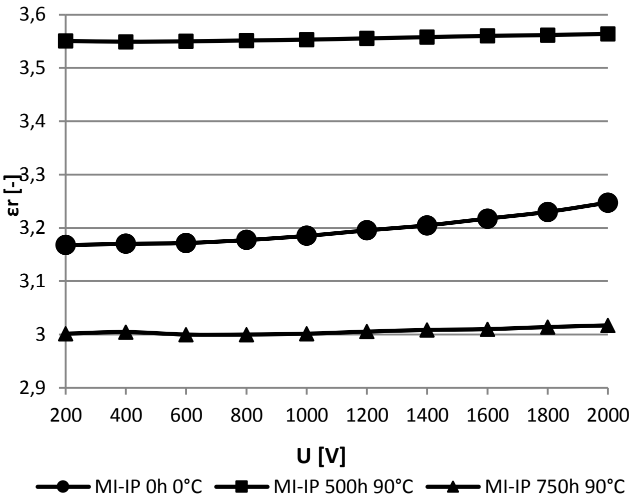

Fig. 6 Influence of thermal ageing on relative permittivity of insulation paper impregnated by mineral oil.

Results from measurement of resistance are in Tab. 3 and Tab.4. The resistance of mineral oil paper insulation is higher than resistance of rapeseed oil paper insulation. Thermal stress has a strong influence on the resistance and polarization index of oil paper insulation. The values of polarization index are increased after each thermal stress for both insulation systems. This fact has connection with moisture which is evaporated after thermal stress. That means the current which flowing through of insulation after connection DC voltage is lower.

Table 3 Polarization index of rapeseed oil paper insulation

RO-IP 0h 0°C		**RO-IP 500h 90°C**		**RO-IP 750h 90°C**	
R_{15}	R_{60}	R_{15}	R_{60}	R_{15}	R_{60}
1.021 GΩ	1.026 GΩ	72 GΩ	90 GΩ	320 GΩ	440 GΩ
p_{i1}=1.005		p_{i1}=1.25		p_{i1}=1.37	

Table 4 Polarization index of mineral oil paper insulation

MI-IP 0h 0°C		**MI-IP 500h 90°C**		**MI-IP 750h 90°C**	
R_{15}	R_{60}	R_{15}	R_{60}	R_{15}	R_{60}
44 GΩ	45 GΩ	96 GΩ	1.16 TΩ	1.47 TΩ	1.93 TΩ
p_{i1}=1.02		p_{i1} = 1.21		p_{i1}=1.31	

5. CONCLUSIONS

This paper provides view on the influence of thermal stress on the oil paper insulation. Mineral oil paper insulation and natural oil paper insulation were measured and analyzed. Breakdown voltage, relative permittivity and polarization index were measured. Measurement of dissipation factor wasn't the aim of this paper. There were used two different samples of oil paper insulation and two different thermal aging intervals. From the results we can make following conclusions.

* Tables of breakdown voltage show that breakdown voltage of rapeseed oil paper is higher than breakdown voltage of mineral oil paper.

* The value of relative permittivity is decreasing after each thermal stresses. Decreasing of relative permittivity is caused by evaporation of moisture from oil paper. Relative permittivity of mineral oil paper is increasing if voltage is increased in each of cases.

* The resistance of mineral oil paper insulation is higher than resistance of rapeseed oil paper insulation. Thermal stress has a strong influence on the resistance and polarization index of oil paper insulation.

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