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Study of Accelerated Thermal Aging Effects on Nomex-Mylar-Nomex and Dacron-Mylar-Nomex Insulating Paper

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Abstract— In this paper, accelerated thermal aging of rotating machines insulating papers was done on two different type of insulating papers such as Nomex-Mylar- Nomex (NMN) and Dacron-Mylar-Dacron(DMD). These insulating materials wrapped on copper conductor with single layer and placed in an oven are thermally aged at 90^oC, 130^oC and 170^oC with 300hrs duration of each sample. Then, breakdown voltage test is performed at each temperature for fresh and aged samples to determine their dielectric strength. Further, correlation analysis between breakdown voltage and different applied temperatures is performed for these samples. By using Scanning Electron Microscopy (SEM) how the bonds in fresh and aged sample is seen. Popular Arrhenius plot is drawn by short term test data on breakdown voltage for an extrapolation to long term performance of various types of insulating paper used in rotating machines. From these remaining lifetime of NMN and DMD insulation is predicted.
Index Terms— Accelerated aging, Breakdown Voltage, NMN, DMD, Arrhenius equation, SEM.

I. INTRODUCTION

The electrical insulation system is one of the most significant parts of high voltage rotating machines with respect to the engineering costs as well as to the maintenance and life time aspects [1]. Practically one-third of the forced outages of large motors in industrial plants and generating stations are affected by the failure of the insulation system in the stator winding. The insulation failures in electrical power equipment's are commonly due to gradual deterioration of the insulation due to aging. The aging results from dissimilar stresses such as thermal, mechanical, electrical, thermo-mechanical and environmental during their operation. The insulation system may change its behaviour due to various kinds of overstress or due to normal aging behaviour. The investigation on the behaviour of insulation systems exposed to dissimilar stresses during their process is very significant in electrical power engineering to increase the design and class of the insulation systems, so that they can better withstand such aging stresses. Such studies can be done for different purposes like development of new insulating materials, estimation of new insulation systems, criterion of insulating systems, approval tests after production, or for diagnostic of the state of high voltage machine insulation and its outstanding lifetime estimation [3].

To establish the ability of an insulation system one of the best techniques is to resist aging is to implement accelerated aging tests on an insulation system using a model. In an accelerated aging test, one or more of the aging stresses are applied to the insulation at a significantly higher than normally experienced, or at a rate of variation which is faster than in normal service [4]. The result is that the insulation declines much more quickly, affecting breakdown in hours or days, rather than years. Such accelerated aging tests have been recognized industry practice for decades. In certain, the ability of motor and generator insulation systems to withstand thermal aging has been proven by industry-standard tests at high temperatures [5, 6]. Manufacturers normally apply accelerated aging tests using electrical, thermal and mechanical stresses to aid in the design of new insulation systems [7].

For that reason, accelerated aging study was done on NMN and DMD to know their performance on thermal aging. The results obtained in the present paper are one part of the results of the functional test existing for thermal evaluation of a candidate machine insulation system. The analysis has been carried out through different aging temperatures including 90^0C, 130^0C and 170^0C for 300hrs each.

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Paper is organized as follows. Section II describes accelerated aging of insulation papers. Section III and Section IV describes the experimental tests like breakdown voltage test and SEM. Results of these experimental test is shown and discussed. In these remaining life of the insulating paper are calculated in section V. Lastly, Section VI presents conclusion.

II. ACCELERATED AGING

To study the effect of thermal stress on cellulose insulation systems of rotating machines, insulation is wrapped on copper conductor were placed in borosil glass. These samples are placed in air circulated oven for thermal aging of insulation to study its behaviour with thermal aging. The accelerated ageing experiments were executed at different temperatures viz. 90^0C, 130^0C and 170^0C in oven for 300hrs each. Primarily these samples are placed in oven at 90^0C for 300 hours and after these sample of each type is taken out from oven and place other samples in oven and increase the temperature to 110^0C for 300 hours, after this take that sample out and repeat this for 130^0C and 170^0C accordingly. While studying its behaviour with breakdown voltage and SEM cool the sample to room temperature.

III. BREAKDOWN VOLTAGE TEST

Breakdown voltage test of solid insulation has been done according to ASTM D 3755-97, IEC 243-2 standards [14]. The experimental setup of BDV is shown in Fig. 2. In this setup two identical electrodes have been used which are vertically associated. The lower electrode which is above the ground plane is grounded and the top electrode is coupled with HV connector. The electrode has a diameter of 25 cm and made of Aluminum material with nickel coating. With the application of the high voltage between the sphere electrodes, a non-uniform electric field is generated as the surfaces of the electrodes are not even. The HV electrode is energized from the 50 Hz transformer with a power rating of 15 kVA with a transformation ratio of 230 V/100kV. The sample is positioned between the electrodes and electrical stress is applied continuously increasing up to breakdown occurs.

Fig-1: Solid insulation BDV experimental laboratory set-up.

IV. SCANNING ELECTRON MICROSCOPY (SEM)

Scanning electron microscopy, SEM, is used for investigating the surfaces of samples at very high magnifications. The SEM uses a beam of electrons to scan the topography of a specimen to build a three dimensional image of the specimen. An electron gun generates, accelerates (100-30,000 electron volts) and focuses the electron beam on the target material. SEM uses an intensive beam of high-energy electrons to generate a variety of signals at the surface of solid samples. The signals that arise from electron-sample contacts disclose information about the sample including external morphology, chemical configuration, and crystalline arrangement and alignment of materials making up the sample. In most applications, data is collected over a certain area of the surface of the sample, and a 2-dimensional image is created that displays spatial variations in these properties.

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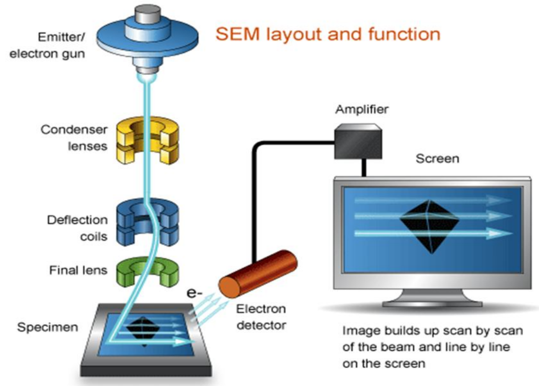


Fig-2: Working of SEM

V. RESULTS AND DISCUSSION

After completing ageing for 300hrs at each temperature at 90,130, 170^{o}C then these aged insulating paper samples were collected form temperature oven at every cycle and checked their BDV using BDV set-up. The change in the BDV values with respect thermal aging is shown in below figure.

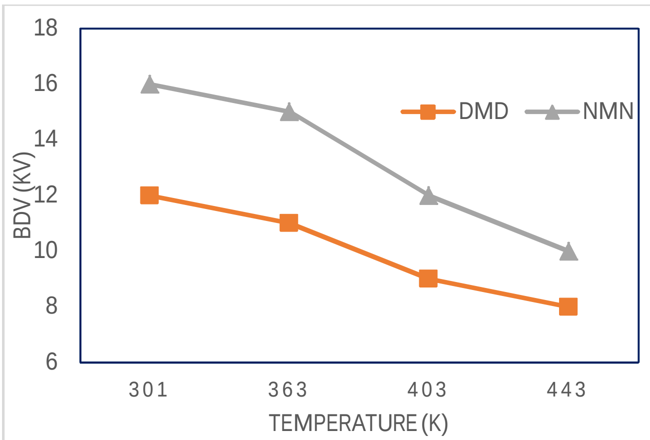
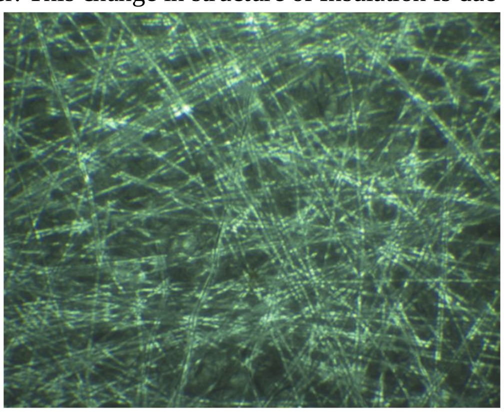


Fig-4: Breakdown Voltage Variation Temperature

In order to monitor the state of the unaged and aged insulation paper, the samples of the solid insulating materials were observed under SEM. In order to be observed with a SEM the samples were first made conductive for current by coating them with an extremely thin layer (1.5–3.0 nm) of gold. The SEM images for fresh and aged insulation paper of NMN are shown in Figure 5. The SEM images of thermally aged and fresh samples insulation paper of DMD are shown in Figure 6. The SEM images indicate a significant change in the structure of the material at elevated doses and this structural damage has resulted in reduction in thermal and mechanical properties in insulation paper. This change in structure of Insulation is due to degradation with thermal aging.



(a)

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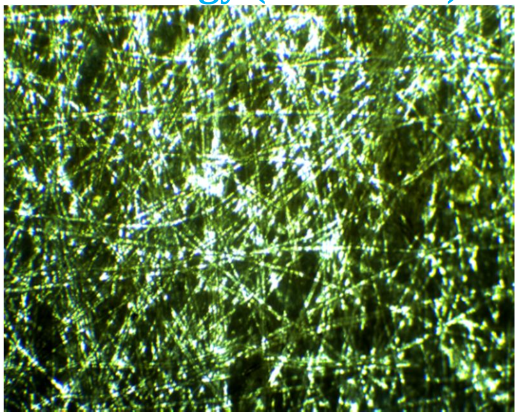
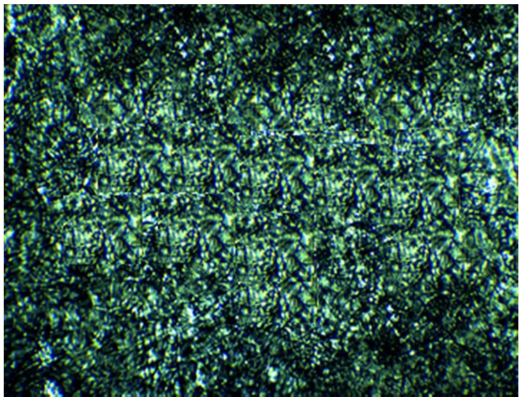
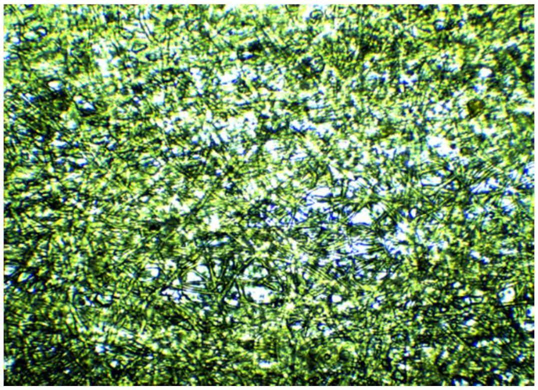


(b)

Fig--5: SEM of NMN (a) Fresh sample image (b) Aged sample at 170°C for 300 hrs



(a)



(b)

Fig-6 SEM of DMD (a) Fresh sample image (b) Aged sample at 170°C for 300 hrs

An exponential law which is dependent on the temperature effect on chemical reaction rates is Arrhenius law. In 1889, Svante Arrhenius revealed that the relationship between temperature and the rate constant for a reaction observed the equation.

$$K = Ae^{\frac{-Ea}{RT}} \qquad (1)$$

Now, assume that the life of the product is proportional to the inverse of rate of reaction, the Arrhenius life relation is given by

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$$t = Be^{\frac{Ea}{RT}} \quad (2)$$

$$\ln(t) = \frac{Ea}{R}(1/T) + \ln(B) \quad (3)$$

In above equations E_a T and R are activation energy, temperature (K) and gas constant respectively, whereas A and B are constant factors. The variation of the logarithm of a lifetime with the reciprocal temperature (K^{-1}) is shown in below figures.

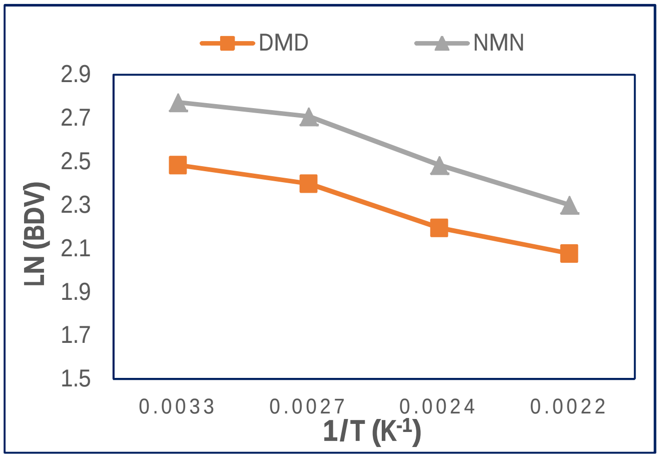

Fig-7 Ln(BDV) with respect to 1/T

In this paper insulation lifetime is forecast for different insulation paper by using equation (3) at any temperature. The results of this work supported the relationship between Log BDV and 1/T in presence of various insulation papers. The estimated lifetime in this work allows a linear relationship with respect to and is almost similar to one as reported based on the studies shown by Roger Wicks from Dupont and Thomas A. Prevost from Weidmann company [7.8]. From the above figures, here NMN and DMD insulation paper is taken in to interpretation for life prediction. By calculating the slope and intercept of above plot for both insulation papers. The remaining lifetime of insulation relation is given below

For NMN $\quad t = 1.49\, e^{\frac{820.6}{T}}$

For DMD $\quad t = 1.52\, e^{\frac{780}{T}}$

From this we can obtain the remaining life time of the NMN and DMD insulation at 80°C equal to 42989 hours which is 5 years and 26074 hours which is 3 years. From these NMN has more remianing lifetime than DMD and also thermal degradation is also more in DMD. Lifetime of NMN and DMD insulation paper with respect to different temperature is shown in figure 8.

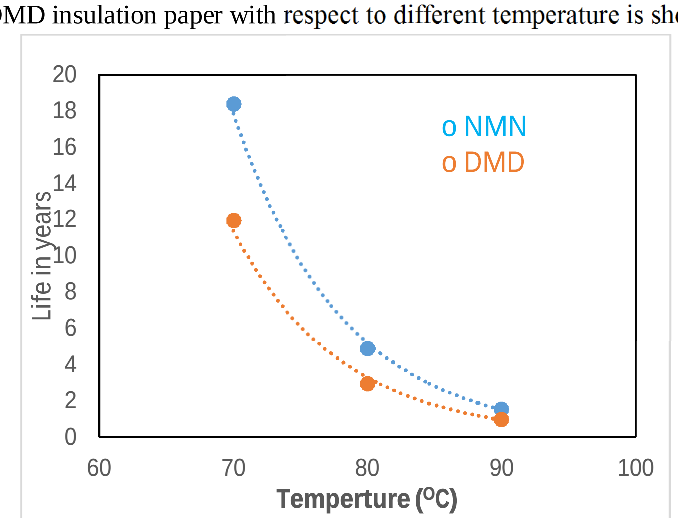

Fig- 8: Life of insulation with respect to temperature

VI. CONCLUSION

In this paper have been measured breakdown voltage of NMN and DMD insulating papers of rotating machines under accelerated thermal stress. SEM was done for fresh and aged sample by that degradation of insulation was shown. For these fresh and aged samples remaining lifetime is predicted by using Arrhenius equation. From these study we concluded that remaining lifetime of NMN is more compared to DMD insulating paper. Lifetime of insulating papers with different temperature is also shown.

VII. ACKNOWLEDGMENT

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