CHAPTER 9

ANALYSIS OF BREAKDOWN STRENGTH AND VOLUME RESISTIVITY OF NANO-MINERAL OILS

9.1 INTRODUCTION

In this chapter, breakdown strength and volume resistivity of nano mineral oils are evaluated. Weibull distribution analysis of breakdown strength of nano mineral oils is also performed.

9.2 CONCEPT OF DIELECTRIC BREAKDOWN STRENGTH CHARACTERISTICS

It is generally expected from a dielectric material that it should not conduct electricity, however due to several factors such as operating temperature, applied voltage, polarity of the waveform, geometrical shape of the electrodes, presence of moisture, presence of metal particles, etc. the real situation is different. Many insulating materials fail due to applied voltage stress. When the voltage increases beyond a threshold limit, then it leads to entire breakdown of the medium. Hence understanding the breakdown voltage, which is the measure of ability of the insulating medium to withstand the maximum voltage level, is very important. In the case of liquid insulating medium, the breakdown voltage raises with increase in temperature from 30°C to 110°C due to the reduction in moisture content of the oil.
Breakdown strength of liquid insulating medium can be expressed as minimum electrical stress that will result in breakdown of the material under some condition and it is commonly reduced by ageing, high temperature and moisture. BDV is given as:

\[ \text{Dielectric strength or Breakdown voltage} = \frac{V}{t} \text{ in kV/mm or in V/mm} \]

\( V \rightarrow \text{Breakdown Potential. } t \rightarrow \text{Thickness of the dielectric material.} \)

### 9.3 RESULTS OF BREAKDOWN STRENGTH OF NANOSiO\(_2\)MINERAL OIL

It is always essential to know the correlation between the dispersion of breakdown voltages between the conventional mineral oil and nano modified mineral oils in order to estimate the safety margin while designing the electric power apparatus insulation system.

![Figure 9.1](image)

**Figure 9.1** BDV values of Nano-Modified Mineral oil at different electrode gap distance and at different %wt concentration of nanofiller materials
Figure 9.1 shows the BDV values of sample Nano Modified Mineral oil at at different electrode gap distance and at different %wt concentration of nanofiller materials. In general, it is perceived that the BDV value of all the samples increases with respect to increase in gap distance between the electrodes. Also at each gap distance, BDV of sample D is slightly higher when compared with other tested samples. In particular, BDV of nano-modified mineral oil significantly improves when compared with sample A.

9.3.1 Weibull Distribution Analysis of Breakdown Voltage

Figure 9.2 shows the Weibull distribution results of BDV characteristics of sample nano mineral oil at different electrode gap distances. In this plot, solid line represents the fit to the BDV data and statistical distribution of each data is shown in different markers. In general, it is observed that more fit to the curve is obtained in the case of nano mineral oils, when compared with type A specimen. In addition, distribution is narrow in the case of nano mineral oils, whereas in the case of type A specimen a wider distribution is noticed at all gap distances.

In this work, important parameters of Weibull distribution analysis such as scale parameter and shape parameter are also evaluated. Tables 9.1 and 9.2 shows the variations in scale parameter ($\alpha$) and shape parameter ($\beta$) at different gap distances of nano mineral oils.

In general, electrical breakdown strength is related with scale parameter $\alpha$ (kV) of Weibull distribution and the dispersion of breakdown data is related with shape parameter $\beta$ of Weibull distribution. From the results, it is noticed that scale parameter value of nano mineral oils are
significantly higher when compared with pure mineral oil. This displays increase in breakdown strength of mineral oils added with nano filler materials.

Figure 9.2 (Continued)
Figure 9.2 Weibull distribution of breakdown voltage of nano mineral oils at different electrode gap distance (a) 1 mm (b) 2.5 mm (c) 4 mm (d) 5 mm
Table 9.1 Variations in scale parameter of nano mineral oils at different electrode gap distances

<table>
<thead>
<tr>
<th>Scale parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>12.5177</td>
<td>33.0309</td>
<td>45.5393</td>
<td>56.1414</td>
</tr>
<tr>
<td>2.5 mm</td>
<td>18.4799</td>
<td>35.1822</td>
<td>55.2455</td>
<td>63.7800</td>
</tr>
<tr>
<td>4 mm</td>
<td>26.6504</td>
<td>45.6301</td>
<td>65.1551</td>
<td>77.5912</td>
</tr>
<tr>
<td>5 mm</td>
<td>32.1443</td>
<td>51.3848</td>
<td>72.0084</td>
<td>91.5243</td>
</tr>
</tbody>
</table>

Table 9.2 Variations in shape parameter of nano mineral oils at different electrode gap distances

<table>
<thead>
<tr>
<th>Shape parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>6.6358</td>
<td>27.0320</td>
<td>15.4727</td>
<td>19.2319</td>
</tr>
<tr>
<td>2.5 mm</td>
<td>12.9986</td>
<td>19.2373</td>
<td>24.9764</td>
<td>20.1996</td>
</tr>
<tr>
<td>4 mm</td>
<td>12.0883</td>
<td>19.4016</td>
<td>19.4829</td>
<td>19.8335</td>
</tr>
<tr>
<td>5 mm</td>
<td>8.7273</td>
<td>22.4440</td>
<td>22.4247</td>
<td>30.2307</td>
</tr>
</tbody>
</table>

Pure mineral oil Shape parameter value lies below 13, whereas nano modified mineral oils show higher shape parameter value above 19, which implies that nano mineral oils have smaller dispersion of breakdown voltages.

In general, based on the breakdown strength test results it is understood that nano mineral oils have ability to retain the BDV values at each electrode gap distance when compared with conventionally used mineral oil.
9.4 EVALUATION OF LOSS FACTOR AND VOLUME RESISTIVITY OF NANOSiO$_2$ MINERAL OIL

Figure 9.3 shows the loss factor value of Nano SiO$_2$ Modified Mineral oil at different %wt concentration of nanofiller and at different temperature. In general, increase in loss factor indirectly shows reduction in dielectric strength of the insulating medium. From the results it is noticed that when compared with sample A, all other nano-modified mineral oil samples show low tan delta value. Significant reduction in tan delta value of nanoSiO$_2$ added mineral oils is noticed. However, it is also observed that 0.1% wt concentration of SiO$_2$ sample has higher tan delta value when compared with samples B and C. Hence addition of more %wt concentration of SiO$_2$ above 0.1% has less effect on the reduction in tan delta value.

![Figure 9.3 Factor value of Nano SiO2 Modified Mineral oil at different %wt concentration of nanofiller and at different temperature](image-url)
9.5 EVALUATION OF VOLUME RESISTIVITY OF NANO MODIFIED MINERAL OILS

Variations in volume resistivity with respect to increase in temperature are shown in Figure 9.4 for all the tested oil samples. From the bar chart, it can be observed that the height of the bar corresponding to pure mineral oil is not even visible when compared with other nano oil samples. This clearly shows the amount of improvement in volume resistivity values obtained with addition of nano filler materials in the base oil. At high values of operating temperatures in the range of 70-110°C, it is clearly seen that the 0.05% SiO₂ sample shows tremendous improvement in volume resistivity than other nanofluid samples. Since the top oil temperature of the distribution temperature lies in the range of 100°C, it is confirmed that 0.05% SiO₂ specimen can able to maintain the volume resistivity value even at high operating temperature. However, it is also noticed that 0.1% SiO₂ specimen has less impact on the enhancement of volume resistivity in the mineral oil when compared with 0.01% and 0.05% specimens.

Figure 9.4 Volume resistivity of Nano Modified Mineral oil at different temperature and at different %wt concentration of nanofillers
9.6 EVALUATION OF RELATIVE PERMITIVITY OF NANO MODIFIED MINERAL OILS

Figure 9.5 shows the dielectric constant value of Nano-Modified Mineral oil at different temperature and at different %wt concentration of nanofiller. It is observed that nano modified mineral oil shows major improvement in dielectric constant values when compared with pure mineral oil. Performance of 0.05%wt and 0.1%wt concentration sample is better at all operating temperatures from 50°C to 100°C, when compared with other specimens. Addition of nano filler materials in the pure mineral oil considerably improved the dielectric constant of the liquid insulating medium. However addition of 0.01% wt nano-filler in the mineral oil has less influence on the dielectric constant when compared with 0.1% and 0.05% wt concentrations. In general, with respect to increase in temperature, there is no significant variation in dielectric constant value of oil samples is noticed irrespective of the type of specimen.

Figure 9.5  Dielectric constant of Nano Modified Mineral oil at different temperature and at different %wt concentration of nanofillers
9.7 EVALUATION OF CAPACITANCE OF NANO MODIFIED MINERAL OILS

Figure 9.6 shows the capacitance value of Nano-Modified Mineral oil at different temperature and at different %wt concentration of nanofiller. At room temperature significant improvement in dielectric constant values of nano modified mineral oil when compared with pure mineral oil was noticed. However, with respect to increase in temperature, there is no significant variation in capacitance values of nano modified mineral oil samples when compared with pure oil. This shows that addition of nano fillers has less influence on the capacitance value of the mineral oil. In general, with respect to increase in temperature, the capacitance value of all oil samples shows slight reduction in value.

Figure 9.6 Capacitance of Nano Modified Mineral oil at different temperature and at different %wt concentration of nanofillers
9.8 EVALUATION OF VISCOSITY OF NANO SiO\textsubscript{2} MINERAL OIL

Figure 9.7 shows the kinetic viscosity value of Nano SiO\textsubscript{2} Modified Mineral oil at different %wt concentration of nanofiller and at different temperature. In general, it is observed that the viscosity of nano-modified mineral oil reduces with increase in temperature. When compared with samples B,C and D, it is noticed that the viscosity value of pure mineral oil is slightly lower. Sample C shows higher viscosity value when compared with other samples. However, since there is no big difference in viscosity values of all oil samples at each temperature range, it can be concluded that the addition of nano SiO\textsubscript{2}-filler materials in the mineral oil has less impact on the viscosity values.

![Figure 9.7 Kinetic Viscosity value of Nano SiO\textsubscript{2} Modified Mineral oil at different %wt concentration of nanofiller and at different temperature](image)

Figure 9.7 Kinetic Viscosity value of Nano SiO\textsubscript{2} Modified Mineral oil at different %wt concentration of nanofiller and at different temperature
9.9 EVALUATION OF FLASH POINT AND FIRE POINT OF NANO SiO$_2$ MINERAL OIL

In this section, the basic thermal properties such as flash point and fire point results of nano-modified mineral oil will be discussed.

Figure 9.8 Flash point value of Nano SiO$_2$ Modified Mineral oil at different %wt concentration

Figures 9.8 and 9.9 shows the flash point and fire point values of Nano SiO$_2$ Modified Mineral oil at different %wt concentration respectively. It is noticed that pure mineral oil sample A has slightly higher flash point and fire point when compared with nano-modified mineral oil. However, since the % reduction in flash point and fire point value of nano-modified value is very less, it can be decided that the addition of nano-fillers in the mineral has less impact on the values of fire point and flash point.
Figure 9.9  Fire point value of Nano SiO$_2$ Modified Mineral oil at different % wt concentration

9.10  CONCLUSION

In this chapter, breakdown strength, loss factor, capacitance, volume resistivity, dielectric constant, flash point and fire point of nano modified mineral oils are analyzed in detail.