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Investigation of the Dielectric Performance of Mineral Oil –Based Nanofluids

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ABSTRACT

The ongoing demands for the extra high voltage boost the need for looking for improving the conventional insulating materials by various modification techniques. Transformer insulating oil-based nanofluids (NFs) is one of these techniques. The present work aims to investigate the dielectric performance of transformer oil-based nanofluids and their dependence on the type of nanoparticles. To achieve this, three types of nanoparticles namely Zinc Oxide(ZnO) as conductive nanoparticle, Titanium Oxide (TiO2) as semi conductive nanoparticle and Silicon Dioxide (SiO2) as dielectric nanoparticles have been suspended in mineral oil (MO) at various concentration levels and the dielectric performance was tested by performing experiments such as AC breakdown voltage test, relative permittivity and DC conductivity. Experimental findings reveal that the use of nanofluids technique could improve the efficiency of the dielectric performance of mineral oil. The nanoparticle type and concentration have critical effect on the dielectric performance of prepared samples. For breakdown voltage, it is manifested that, samples prepared with ZnO nanoparticles exhibited the highest percentage of improvement. While for relative permittivity, samples prepared with TiO2 nanoparticles at higher concentrations, showed the highest percentage of improvement. On the other hand, all samples showed higher values in conductivity comparing with bare mineral oil sample.

KEYWORDS: *Mineral oil, Breakdown Voltage, DC conductivity, Permittivity, Nanoparticles*

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I. INTRODUCTION

Transformer oil plays a very significant role in transformer operation, since it provides electrical insulation medium between the various energized parts, stop arcing and corona discharge and act as a cooling medium to enhance heat dissipation inside transformers [1]. Transformer oil also impregnates the voids in fibrous cellulosic insulation and fills the gaps between components in the transformer tank to increase the dielectric strength of the insulation system. Moreover, the oil can affect the dielectric property of oil-paper insulation system and thus influence the breakdown strength of the transformers [2]. Nowadays, there are several types of insulating liquids widely used in oil filled transformers. However, mineral oil is still the industry predominant selection among various types of transformer oils. Its popularity is not just because of its optimum insulating and heat dissipation properties, but also because of its better compatibility with cellulose materials, wide availability, low cost and intense resistance to electrical and thermal ageing.

The increase in voltage levels and associated additional electrical stresses on the electrical equipment have resulted in needs for new electrical insulation materials that should have high breakdown strength, low losses and high thermal conductivity [3]. Use of transformer oils-based nanofluids in power transformer application is a promising approach as nanofluids have superior dielectric and thermal properties over conventional insulating oils.

Recent output of many research works confirm that the transformer oils-based nanofluids provides enhanced dielectric and thermal performance when compared with conventional transformer oil. Regarding dielectric performance, the first measurements of the breakdown strength of mineral oil with suspended nanoparticles were reported by Segal et al [4] who are considered one of the pioneers to apply nanofluid concept in power transformers applications. They reported considerably improvement in breakdown strength of mineral oil –based Fe_3O_4 nanofluid (NF) at various particles volume fractions. Afterward, many research studies using Fe_3O_4 nanoparticles have been performed to achieve improved dielectric properties without compromising physic-thermal properties of base insulating liquid [5-7]. N. Yadav et.al [8] investigated the dielectric properties such as breakdown voltage (BDV), resistivity, permittivity and loss tangent at different concentrations of Fe_3O_4 nanoparticles suspended in mineral oil. They found that the optimal concentration in terms of maximum BDV improvement 34 % was at 20 w/v %. Also the resistivity parameter is in accordance with BDV and reported a maximum improvement of 501.44% at same concentration. Permittivity values of various concentrations were less than that of bare oil and the least value was 52.4% for 20 w/v %. concentration. While the dielectric dissipation measurements at various concentrations were more than bare oil.

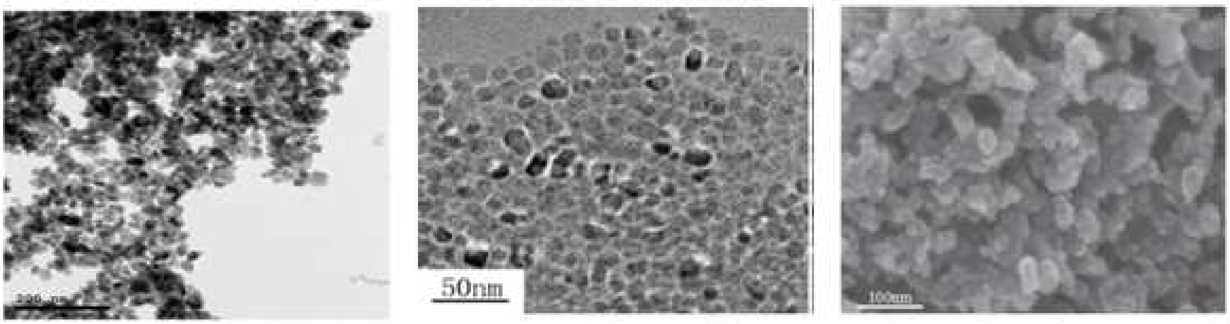
Researchers have also investigated semiconducting and insulating nanoparticles to offer more range of possible alternatives. Du et.al, [9] presented a study of the effect of adding semiconducting Titanium Oxide (TiO_2) nanoparticles. They measured the AC Breakdown Voltage of nanofluids with different concentration ranging from 0.003 g/L to 0.05 g/L. The result indicated that the AC breakdown strength is improved with the increase of concentration until a certain concentration (0.006 g/L). When the concentration of nanoparticles is further increased, the AC breakdown voltage starts to decline and even reached a value lower than that of bare oil. The authors reported that this tendency of decline is due to agglomeration of nanoparticles which result in reduction of breakdown voltage of nanofluid. Yu Wang, et.al [10] investigated the AC breakdown voltage mineral oil-based Al_2O_3 NF at different concentrations and relative humidity. The results indicated that different concentrations and relative humidity affect significantly the breakdown voltage of oil. The breakdown voltage of the NF greatly improved compared with that of bare oil with the introduction of Al_2O_3 NPs at varying relative humidity.

The present work, as a first attempt in this way, intends to investigate and compare the dielectric performance of three different nanofluids containing; conductive (Zinc Oxide), semi conductive (Titanium Oxide) and dielectric (Silicon Dioxide) nanoparticles added in different concentrations in mineral transformer oil. The AC breakdown voltage is measured for the different nanofluid samples. Weibull distribution is used to estimate and compare the breakdown probability among the different samples. Also, the relative permittivity and DC conductivity is measured and compared to investigate the influence of nanoparticle type into mineral oil.

II. Experimental Procedure

A. Samples Preparation

The base liquid used in this present work, was naphthenic mineral oil, NYTRO LIBRA, uninhibited type, which is good as insulation and coolant. The specification of this insulation oil as provided by the manufacturer is shown in [11]. The nanofluid samples are prepared by adding various nanoparticles, namely Zinc Oxide, Titanium Dioxide and Silica Oxide at different concentrations. The TEM images of utilized nanoparticles are shown in fig. 1. The concentrations of nanoparticles in the base mineral oil were in the range of 0.01% to 0.1% weight concentration (wt.). All utilized nanoparticles were of size < 30 nm. The dispersion of nanoparticles is done with the help of "two step method". Firstly, the solid nanoparticles quantities have been weighted by using sensitive digital analytical balance and specific amount were added to the base mineral oil to achieve desirable concentrations. Then, magnetic stirrer processes is applied for about 45 minutes, so that the samples homogeneity can be achieved. At the last step, ultra-sonication process is involved for a period of two hour. After preparation, the samples were dried in an air oven for 2 hours at 45 °C in order to remove all the small bubbles created during ultra-sonication process. The work flow of preparing stable nanofluids by using two-step method is shown in Fig 2. All the prepared samples are preserved in same conditions until the beginning of the dielectric tests.



(a) (b) (c)

Fig.1 TEM images of (a) ZnO (b) TiO2 (c) SiO2 nanoparticles

Fig. 2 Nanofluids preparation work flow

B. AC Breakdown Voltage

The AC breakdown voltage was conducted according to the IEC60156 standard by using insulating oil tester set, model (T&R Portatest 90s) with maximum applied voltage of 90 kV for 50 Hz. The electrode configuration consisted of two spherical brass electrodes with 13 mm diameter. The distance between the electrodes was kept constant at 2.5± 0.05 mm for all the experiments. For the BDV experiments, only 300 ml of both transformer mineral oil and nanofluids was used which was enough to immerse the electrodes completely in the transformer oil. The voltage was applied manually without interruption from zero until the occurrence of breakdown with an increasing rate of approximately 2kV/s. Each sample was tested for twelve BDV times and an average breakdown voltage and standard deviation were calculated based on three independent tests (fresh samples were used for each test) for each type of samples. Related with the BDV tests, moisture content measurements were also performed by using Karl-Fischer method (IEC 296), to ensure that all experiments carried out at the same conditions and to enable the comprehension of BDV results. The moisture content of all samples is being controlled at 20 – 25 ppm.

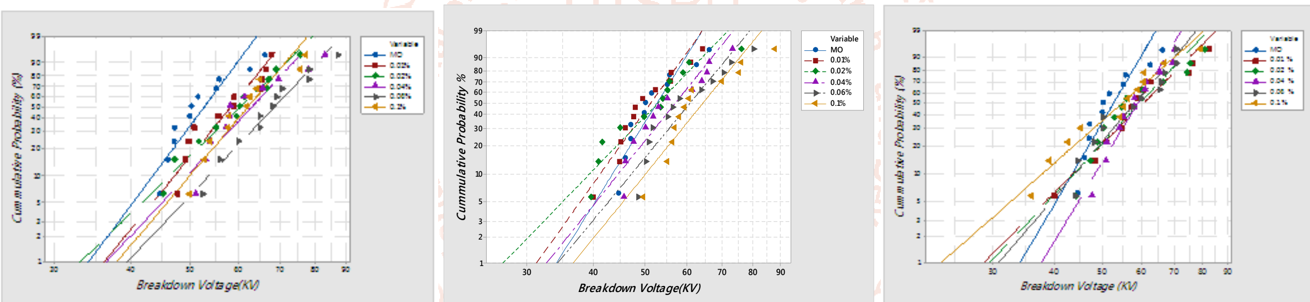
C. Relative Permittivity and DC Conductivity

Tests for relative permittivity and DC conductivity were measured based on standard test methods IEC 60247 using the Automatic Dissipation Factor and Resistivity Test Equipment Dieltest DTL system (Baur), which uses the Schering Bridge concept. The relative permittivity was measured using an AC electrical stress of 1kV/mm at standard frequency (i.e., 50 Hz) while the conductivity was measured by applying a DC electrical stress of 250 V/mm for electrification time of about 1 minute. The experiments are conducted at several temperature ranges between 30 and 90 °C to study the relation between thermal influence and dielectric parameters.

III. Results and Discussion

A. AC Breakdown Voltage

Fig. 3 shows the two-parameter Weibull analysis of the AC BDV of three types of tested nanofluids at different weight percentages in comparison to bare mineral oil. The breakdown voltage at 50% cumulative probability is considered as the estimated breakdown voltages for mineral oil and nanofluids. It can be seen that 50% BDV of all tested nanofluids are higher than that of bare mineral oil whatever the type of nanoparticles. However, the optimal concentration to obtain the maximum BDV is different for the three tested nanofluids. The maximum breakdown voltage is obtained with conductive ZnO nanoparticles at a weight percentage concentration 0.06%; the 50% BDV is increased by 30 % with respect to bare mineral oil. While with semi-conductive TiO_2 NPs, maximum BDV is increased by around 22.26 % for a concentration of 0.1 %.in the case of SiO_2NPs, the improvement with BDV is only of 14.8 for 0.01 % concentrations. The parameters of the Weibull plots are summarized in table.1.



(a) (b) (c)

Fig.3 Weibull probability plot for the AC breakdown voltages of nanofluids, (a) ZnO, (b) TiO2 and (c) SiO2 NFs

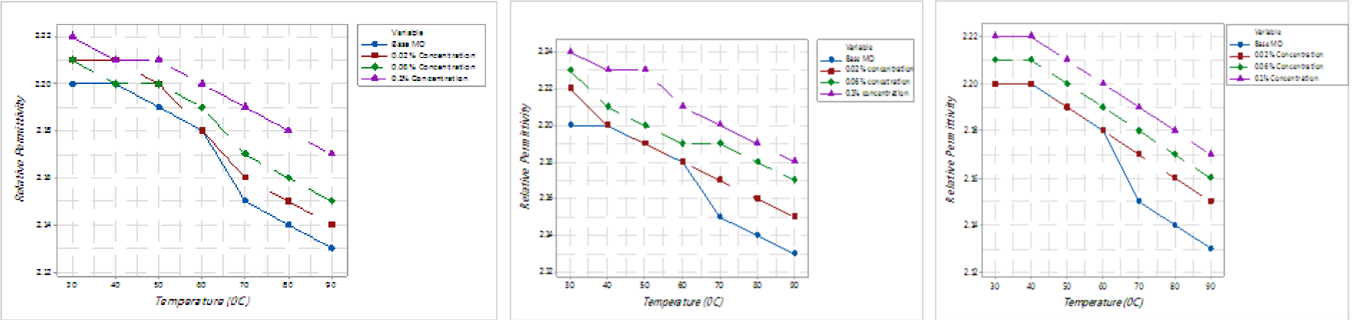
Table.1WEIBULL PARAMETERS FOR TESTED NANOFLUID SAMPLES

	ZnO NFs					TiO2					SiO2				
(%wt.)	0.01	0.02	0.04	0.06	0.1	0.01	0.02	0.04	0.06	0.1	0.01	0.02	0.04	0.06	0.1
Scale parameter (kV)	60.7	63.69	66.16	72.14	64.73	53.5	56.1	59.9	59.9	67.57	64.69	63.37	61.38	61.60	59.12
Shape parameter	8.8	6.9	7.5	8.5	8.4	8.5	6.2	7.5	7.3	7.4	5.9	6.0	7.2	6.6	4.9
BD at 50% probability (kV)	58.2	60.44	63.08	68.74	61.99	51.29	52.96	57.06	60.83	64.34	44.56	43.66	48.29	43.91	37.69

B. Relative Permittivity

The relative permittivity of the samples as a function of the temperature and nanoparticles concentration is shown in Fig.4. From the measurements' graphs, it can be seen that the relative permittivity values of all prepared NFs are higher than that of the bare oil at the same experimental temperatures. The relative permittivity of all tested nanofluids showed a linear increase with nanoparticle weight percentage concentration. For the same temperature level and NPs weight concentration, the TiO_2 NF possesses the highest relative permittivity between all prepared samples. The relative permittivity of TiO_2 NF reached 2.24 at 0.1 wt. % concentration and temperature of 30^{o}C, which is higher than bare oil by 1.2 times. The Sio_2 –NF obtains the lowest value in relative permittivity enhancement. Regarding the effect of temperature on the relative permittivity results of prepared samples, the permittivity measurements of bare oil and nanofluids show a descending trend with the increasing in the temperature.

As the temperature increase, the molecules of insulating oil gain more thermal energy, so that the random movements increase and dipoles reorientation process of oil samples decreases. This reduces the polarization process caused by orientation of dipoles and consequently makes decreasing in the relative permittivity value [12, 13]. The higher relative permittivity of nanofluids is caused by the polar nature of the adding nanoparticles. Thereby, the higher relative permittivity of the additional TiO_2 nanoparticles compared with other additional NPs, the TiO_2 NFs show the maximum improvement in the relative permittivity.



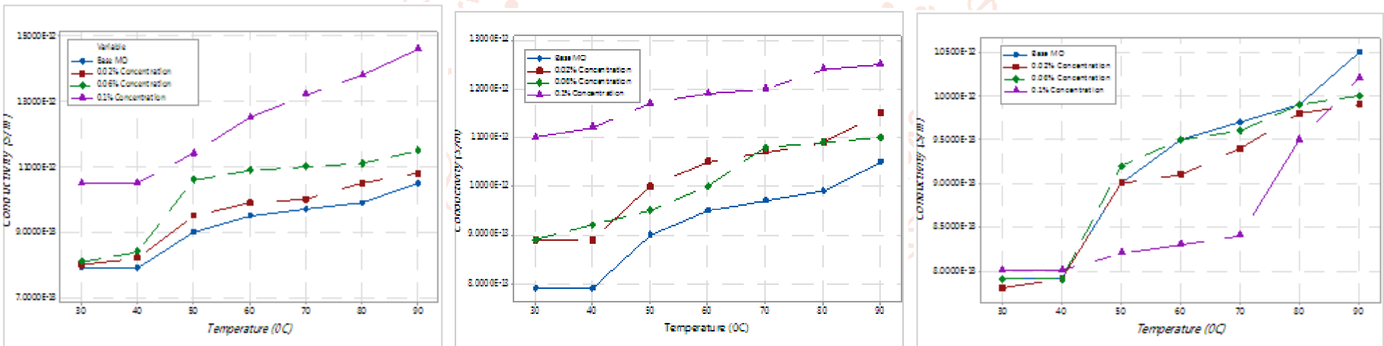
(a) (b) (c)

Fig.4 Relative permittivity of nanofluids VS temperature at different concentrations (a) ZnO NF (b) TiO_2 NF(c) SiO_2 NF

C. DC Conductivity

Fig.5 represents the variation results of conductivity with temperature for pure mineral oil and tested nanofluids at different nanoparticles concentrations. The experimental results reveal that the electrical conductivity increases with the increasing nanoparticles concentrations in a like manner as permittivity. The Electric conductivity of TiO_2 NF at 90^0C reached 1.25pS/m at 0.1% concentrations which is1.1 times larger than that of the bare mineral oil at the same condition.

The electrical conductivity also found to increase with increasing temperature in all prepared samples. Changing temperature alters the conductivity of insulating liquid by changing the activity of atoms within the material. The increment in electrical conductivity of ZnO NF was 39% at 90^0C for 0.1% concentration. Seeing that with increasing the temperature, more free electrons are released either by the dissociation of oil molecules itself or by the electrolytic impurities, resulting in the increase of electrical conductivity []. Furthermore, since a rise in temperature is accompanied by a decrease in the viscosity, the mobility of the free charges increases resulting in a higher conductivity [].



(a) (b) (c)

Fig.5 Electrical Conductivity of nanofluids VS temperature at different concentrations (a) ZnO NF (b) TiO_2 NF(c) SiO_2 NF

IV. Conclusion

This work discusses the effect of ZnO, TiO2 and SiO2 nanoparticles on dielectric characteristics of the mineral transformer oil. As highlighted from the experimental results, the dielectric characteristics change with the addition of nanoparticles' type and concentrations. Results have shown positive effect under the point of view of some dielectric characteristics. Varying improvement percentages in breakdown voltage and relative permittivity have been achieved for the three tested nanofluids at the different concentrations. On the contrary, presence of any types of utilized nanoparticles causes increasing in DC conductivity.

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