International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 9 (2017) pp. 1826-1830

Effect of the Concentration of the Nanoparticles on the Dielectric Behavior of a Transformer Oil

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Abstract

The purpose of this paper is to investigate the changes in the properties of pure transformer oil including dielectric strength, Tan delta, Capacitance etc on adding nanoparticles. Here three different nanoparticles are added in different concentrations to observe the variations in above mentioned properties before and after the addition, into pure transformer oil. Nanoparticles used were Alumina (Al_2O_3), Titanium dioxide or Titania (TiO_2) and Copper oxide or Cupric Oxide (CuO). Dielectric property experiments were performed in accordance with IEC standard. Some gave favorable readings where as some didn't. The performance varied for different concentrations. As the concentration increased some properties increased and some decreased. So a plot also is available based on the so obtained readings showing the variations.

Keywords: Dielectric Strength, Tan Delta, Capacitance, Nanoparticles, Nanotechnology, Electrical Engineering

INTRODUCTION

Transformer oil is being used in transformers not only as an insulator but also as a coolant. For better operation, this must have good breakdown strength, better capacitance and less dissipation factor. The above mentioned properties of the oil can be altered if nanoparticles are added to it in certain concentrations. This can either adversely affect the properties or can enhance them. Either way the variations must be known so that further improvements can be done in this sector. Pure transformer oil is semi-transparent, less viscous in nature. Its breakdown strength in kV/cm, dissipation factor, and capacitance in pF vary with variation in concentration of nanoparticles added. So the variations can be clearly observed as the samples of different concentrations are generated using the nanoparticles and are tested.

Considerable research works were done regarding the breakdown strength variation of transformer oil when added with nanoparticles like Titania, Silica etc. Enhancement in breakdown strength were obtained for different concentration of nanoparticles. For Titania, a weight percentage of 0.007% gave 28% enhancement of breakdown strength [1-5]. For Silica, no improvement was shown in the breakdown strength for low concentrations. Improvements were found in case of 20% weight [6]. This paper analyses the capacitance and dissipation factor values along with the variations in breakdown strength, of transformer oil, when it is filled with different nanoparticles like Alumina, Titania, Copper oxide and to see what concentration suits best for the given transformer oil.

SAMPLE PREPARATION

In total, 9 L of transformer oil was taken. About 550 ml of transformer oil was taken for each sample as the amount of oil required to fill each test cell is that much. Pouring of oil can be done using a funnel to prevent spilling. The process that took for creating each sample was 90 minutes. As there were 3 conical flasks, 3 samples of one concentration was prepared simultaneously using the Professional Ultrasonic Cleaner. This device uses Ultrasonic sound to completely mix the nanoparticles in the transformer oil. The arrangement of conical flasks inside the sonicator is shown in Fig. 1.

Just a small amount of stirring is required accompanied by the sonication process for perfect dispersion. Stirring can be performed using a glass rod available. The ultrasonic cleaner can accommodate 3 conical flasks at a time without any contact between each other. The nanoparticle concentration was measured using a highly accurate weigh balance available. This instrument is used to measure weights in very low range accurately. Intense care must be given while measurement to get accurate values as the instrument is hyper sensitive.

Reset option must be done before putting the nanoparticle on the paper so that we can just eliminate the weight of the paper and get the weight of the nanoparticle alone. Obtained reading is cross-checked for some time to check it is correct and not varying. A total of 4 samples were created for each type of material where the concentration varied as follows :

(1) 0.1 g per L of oil

(2) 0.2 g per L of oil

(3) 0.3 g per L of oil

(4) 0.4 g per L of oil

So for the given 550ml of transformer oil the concentration of nano particle are as follows:

(1) 0.055 g per 550ml of oil

(2) 0.11 g per 550ml of oil

(3) 0.165 g per 550ml of oil

(4) 0.22 g per 550ml of oil

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 9 (2017) pp. 1826-1830

Hence the derived weight percentages are

(1) 1wt% per L of oil

(2) 2wt% per L of oil

(3) 3wt% per L of oil

(4) 4wt% per L of oil

The steps for sample preparation is explained below:

STEP 1 : The first step was proper cleansing of the equipments used say beakers, conical flasks etc. Then 550 ml of pure transformer oil was measured using a beaker and was poured into the conical flasks one by one. Now for the first sample the Concentration was 0.1 g per L of oil, thus for 550 ml it will be .055 g of nanoparticle. So the amount of nanoparticle was weighed correctly using the weigh balance and was put in the conical flasks. Each one of the flask were numbered from 1 to 3 to avoid unnecessary confusion of the particles.

STEP 2 : Next step was mixing of these obtained samples. For that we used a sonicator that utilizes ultrasound waves for mixing these particles in the oil. This process must be accompanied by consequent stirring process so as to make the stirring more effective. Timer can be kept in the sonicator such that it stays active for that much time making the sample more and more perfect. The time kept here was 90 minutes. As the time is over the sonicator will stop itself and we can take the samples out. Conical flasks were held using stands available and should not be allowed to touch the bottom mesh and also not with each other. The inside of this instrument is filled with water. The flasks must be made to float without any contact. It can be observed that the temperature of the so filled water in the sonicator gets increased as the process gets over. The front panel of this equipment also shows the temperature of water inside.

The samples produced were of different colour. Copper oxide changed the oil colour to dark brown where as alumina to some sort of glazing translucent colour and that of Titania was a white coloured solution. The next sample was made by adding 0.11 g of nanoparticle in 550 ml of pure transformer oil with the above explained same procedure. Third sample consisted of 0.165 g of nanoparticle in 550 ml of oil and the fourth and last sample was made of 0.22 g of nanoparticle in 550 ml of oil. So over all it took 360 minutes to prepare the samples. The samples created in the conical flasks before pouring into the test cells are shown below in Fig. 2. In Fig. 2, the 1st conical flask consists of sample containing Titania the 2nd one is of Copper Oxide and the 3rd one is of Alumina.

Figure 1: Arrangement of conical flasks inside the sonicator using holder

Figure 2: Samples created and ready for the tests

EXPERIMENTAL SETUP FOR CAPACITANCE AND TAN DELTA MEASUREMENT

Tan Delta and Capacitance of the samples were measured first. Measurements were done in a test voltage of 1kV. The arrangement for measuring Capacitance and Tan Delta is shown in Fig. 3. The test voltage is held constant for all the samples and the quantities were measured using Tan Delta and Capacitance measuring equipment. Tan Delta and Capacitance were measured using a single experimental set up and breakdown test were done with a separate arrangement.

Figure 3: Arrangement to find out the Capacitance and Tan Delta of a sample

EXPERIMENTAL SETUP FOR BREAKDOWN STRENGTH MEASUREMENT

The tests that are performed here are to find out the breakdown strength of the nano filled transformer oil. Initially the samples are subjected to capacitance and tan delta measurements. After this the samples are subjected to breakdown test. This is to ensure that the property of the samples remains unaltered for breakdown measurement. So Tan Delta and Capacitance of the samples were measured first followed by the breakdown voltage. For these tests the samples are poured into test cells.

The breakdown test is conducted by pouring the samples mixed with oil in a test cell in which electrodes are immersed. The test is conducted as per IEC standard in which the test cells are filled fully with oil to measure all the properties. These test cells are having 2 electrodes in which one is fixed and the other one is movable. These electrodes are immersed in oil and the arrangement of these electrodes is horizontal. The gap between electrodes can be arranged using the standard measurement available along with it. For the tests conducted here the electrode separation was 2.5 mm.

In this experiment, first the electrodes are subjected to a variable voltage for a given gap spacing. Then the voltage is increased steadily and for each voltage it is checked whether the breakdown is present or not. If not, the voltage is again increased till the sample breaks down the corresponding voltage is measured. The input voltage is taken from a high voltage cascaded transformer connected to the input side of the test cell. The experiment is conducted in the High voltage lab with proper standard atmospheric conditions maintained.

RESULTS AND DISCUSSIONS

The tests are conducted such that initially the samples are subjected to capacitance - tan delta measurement by adding the required concentration of the nanoparticles into the transformer oil. After collecting the reading, the samples are poured into the test cell immersed with electrodes of given spacing. The voltage is then steadily increased and the flash over voltage for a given sample of Alumina is taken. The experiment is repeated to get different breakdown voltages for the same sample. Finally from the set of readings obtained, the actual flash over voltage of the sample is assessed. This experiment is then repeated by varying the concentration of the Alumina sample. Thus for all 4 concentrations of Alumina including 0.055g, 0.111g, 0.165g and 0.22g the experiment is repeated. Then the sample is replaced with a new samples having a Copper Oxide and Titania and the same process is repeated for the same concentration of samples. For all nanoparticles, the concentration is maintained to be the same so as to compare the results. The obtained values were tabulated in tables 1, 2 and 3 and the plots are shown in Fig. 4, 5 and 6.

From table 1, which is for Alumina sample, it can be seen that the dissipation factor is highest for the sample of 0.111g and next comes 0.22g and then 0.165g and least for 0.055g. In case of Alumina the dissipation factor value reaches top at 0.02% concentration and is less than that for 0.01% and 0.03% concentration. Whereas the capacitance is at the peak for sample 3 and least for sample 1. Also breakdown voltage is maximum for sample 4. Table 2 shows the observed results for Copper oxide samples which gave a highest Tan Delta for sample 4 and least for sample 3. Capacitance is maximum for sample 3 and minimum for sample 2. In case of Alumina the Capacitance gets increased up to 0.03% concentration and then gets decreased for the final sample. Breakdown voltage is maximum for sample 3 and least for sample 2. From table 3, it is seen that the variation of Tan Delta is more or less uniform with peak value for sample 4 and least for sample 3. Similarly, the capacitance is peak for sample 1 and least for sample 3. Also, the breakdown voltage is at the peak for sample 1 and least for sample 4.

Copper Oxide samples have the dissipation factor getting decreased up to 0.03% concentration and increases thereafter. Capacitance decreses upto 0.02% and then increases upto 0.03% and then decreases for all the other concentrations.

The variation of Capacitance with respect to percentage concentration Titania shows an initial increase and steep decrease of breakdown voltage as the concentration is increase from 0.01% to 0.04%. The minimum capacitance value is observed in case of Titania for 0.04% concentration of nanoparticles and the maximum capacitance at 0.01%. Titania shows a linear decrease in tan delta as the concentration is increase from 0.01% to 0.03% and gets increased for the last sample of 0.04% concentration.

For the variation of breakdown voltage with respect to % concentration Titania shows an initial increase and steep decrease of breakdown voltage as the concentration is increase from 0.01% to 0.04%. In case of Alumina the breakdown strength gets an initial decrease and then is increased as the concentration is increased from 0.01% to 0.04%. And for Copper Oxide breakdown strength gets top at 0.03% and is lesser than that for all the other concentrations. Well the least breakdown value is observed in case of Titania for 0.04% concentration of nanoparticles and the top breakdown value is observed in case of Alumina for 0.04% concentration.

Each of the nano particle behaves differently for the different properties of transformer oil. Alumina shows a steady capacitance but Tan Delta is fluctuating a lot between samples. Titania shows almost steady Tan Delta and copper oxide shows a rise in breakdown voltage from sample 1 to sample 4, except for sample 2. Generally, Sample 2 is a least choice when compared with sample 3 or sample 4.

The main reason for the changes in properties which are being seen is due to the interfaces introduced by the nanomaterials. As the particle size is reduced below 100 nm the specific surface area becomes very large. As the oil gets filled with these fillers the internal interfaces becomes dominant. As a consequence, material properties which rely on mechanisms taking place at the interfaces also become altered. The interfaces are assumed as an interaction zone having a radial dimension of 10 nm. Since the properties of this interaction zone can differ substantially from those of both the base polymer and the nanoparticle material, then, as the particle size is reduced, the material is dominated by the interaction zone. This is very important indeed since it means, in effect, that a truly new material is being created which differs from its constituents. Thus the variations in the properties are observed as the fillers comes into action. When particles are added the relaxation time changes as shown in equation (1).

$$\tau = (2\varepsilon_1+\varepsilon_2)/(2\sigma_1+\sigma_2) \quad (1)$$

Where, ε1 is the permittivity of the transformer oil, σ1 is the conductivity of the transformer oil, ε2 is the permittivity of the spherical nanoparticles, σ2 is the conductivity of the spherical nanoparticles. If the relaxation time of oil/nanoparticles is shorter than microsecond timescales involved in streamer propagation, the nanoparticles could capture the fast electrons and convert them into low mobility negatively charged nanoparticles. This process increases the potential drop along the streamer channel in the nanofluid and leads the improvement of insulating properties. Hence nano particles can act as electron traps thereby causing avalanches to built up slowly and hence improve the breakdown strength of the oil-nanoparticle mixture.

TABLE 1: Capacitance, Tan Delta and Breakdown voltage for different concentration of Alumina Samples

Alumina	Tan Delta	Capacitance (pF)	Breakdown Voltage (kV)
Sample 1 (0.055 g)	0.12	1805	31.3
Sample 2 (0.11 g)	0.39	1840	41.73
Sample 3 (0.165 g)	0.17	1858	44.78
Sample 4 (0.22 g)	0.29	1850	46.95

With titania the breakdown voltage decreases with concentration because at higher concentrations of titania, agglomeration takes place. This leads to less electrons from getting trapped due to opposition from internally generated dipole moments due to polarization fields. Copper oxide and Alumina are more resistant to these agglomerations and hence a steady rise in voltage is experienced.

TABLE 2: Capacitance, Tan Delta and Breakdown voltage for different concentration of Copper Oxide Samples

Copper Oxide	Tan Delta	Capacitance (pF)	Breakdown Voltage(kV)
Sample 1 (0.055 g)	0.22	1778	33.04
Sample 2 (0.11 g)	0.19	1767	29.56
Sample 3 (0.165 g)	0.17	1859	45.6
Sample 4 (0.22 g)	0.44	1813	43.47

TABLE 3 : Capacitance, Tan Delta and Breakdown voltage for different concentration of Titania Samples

Titania	Tan Delta	Capacitance (pF)	Breakdown Voltage (kV)
Sample 1 (0.055 g)	0.27	1850	43.47
Sample 2 (0.11 g)	0.24	1835	38.26
Sample 3 (0.165 g)	0.22	1781	30.12
Sample 4 (0.22 g)	0.28	1760	28.3

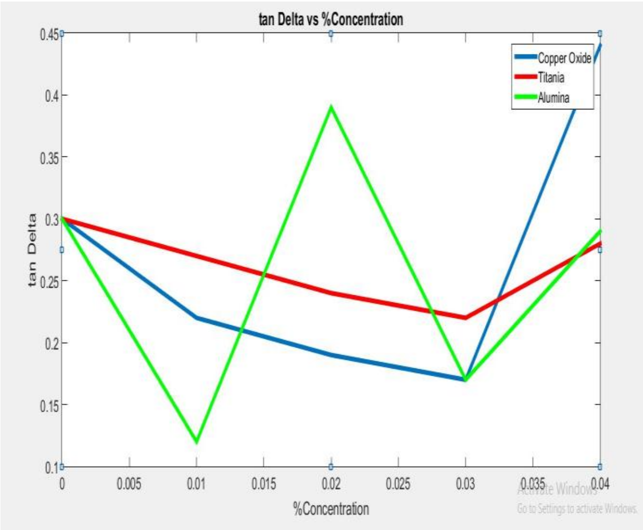

Figure 4: Tan Delta vs % Concentration

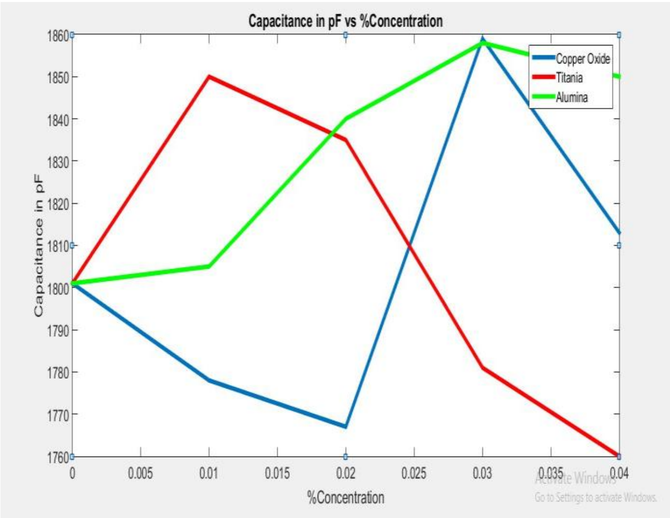

Figure 5: Capacitance vs % Concentration

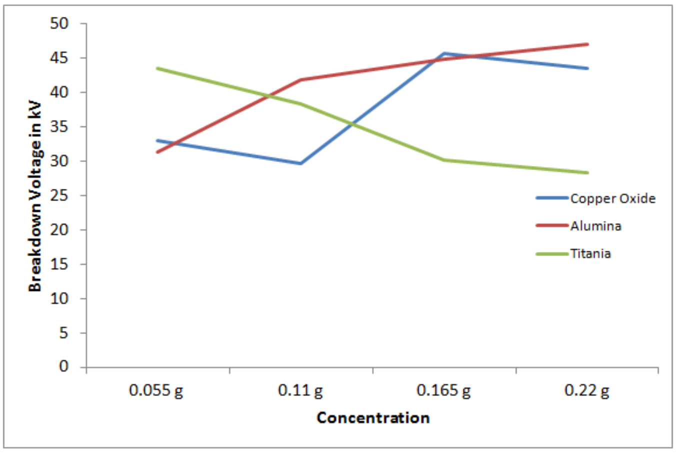

Figure 6: Breakdown Voltage vs Concentration

CONCLUSION

Variations were observed in case of addition of nanoparticles with the transformer oil for all the properties considered. While analyzing the plots we gets the following conclusions,

1. For samples of Alumina,

Breakdown Voltage is increased with the amount of nanoparticles added for the four samples. Tan delta value varies randomly with respect to varying concentration of the nanoparticles added. Capacitance value first increases for the 3 samples and then gets decreased.

2. For samples of Copper Oxide,

Breakdown Voltage varies randomly with the amount of nanoparticles added for the four samples.Tan delta value first decreases and is increased for the last sample concentration. Capacitance value varies randomly with the amount of nanoparticles added for the four samples.

3.For samples of Titania

Breakdown Voltage decreased with the amount of nanoparticles added. Tan delta value first decreases and is increased for the last sample concentration. Capacitance value decreased with the amount of Nanoparticles added.

Several mechanisms have been proposed as how Nanoparticles can affect the breakdown mechanism in transformer oil. M Zahn et al, based on the experimental results of Segal, developed electrons capture model to explain the enhancement of dielectric properties. The Nanoparticles act as electron scavengers, can convert fast electrons into slow negatively charged Nanoparticles. these negatively charged Nanoparticles give high resistance to flow of streamer channel, this will cause increase in breakdown voltage in some Nanoparticles.

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