Proceedings of 4th International Conference on Energy Engineering
Faculty of Energy Engineering - Aswan University -Aswan - Egypt
December 26-28, 2017

Effect of BT Nanoparticles on Dielectric and Thermal Properties of Transformer Oil

Diaa-Eldin A. Mansour
High Voltage and Superconductivity Laboratory
Department of electrical power and machines engineering
Faculty of engineering–Tanta University
Tanta, Egypt. (mansour@f-eng.tanta.edu.eg)

Essam A. Shaalan
Department of electrical power and machines engineering
Faculty of engineering at Shoubra–Benha University
Cairo, Egypt. (engesam2007@yahoo.com)

Sayed A. Ward
Department of electrical power and machines engineering
Faculty of engineering at Shoubra–Benha University
Cairo, Egypt. (drsayedw@yahoo.com)

Adel Z. El Dein
Department of High Voltage Networks
Faculty of energy engineering–Aswan University
Aswan, Egypt. (azeinm2001@hotmail.com)

Hesham S. Karaman*
Department of electrical power and machines engineering
Faculty of engineering at Shoubra–Benha University
Cairo, Egypt. (Hesham.said@feng.bu.edu.eg)

***Abstract*– In order to preserve the life time of oil transformers and to improve their performance, the transformer oil must play its role as insulating and cooling medium efficiently. Nanotechnology is an effective science used for improving the dielectric and thermal properties of the transformer oil. In this paper, barium titanate (BT) nanoparticles were mixed with the neat insulating oil by 0.01 g/L and 0.02 g/L concentration. Breakdown voltage and heat transfer coefficient were measured to excogitate the transformer oil dielectric and thermal properties, respectively. From the obtained results, for 0.01 g/L sample, it is noticed that BT enhances the thermal properties of the transformer oil by about 28.3% but, the dielectric properties were slightly increase by about 2%. The increasing of the BT nanoparticles concentration to 0.02 g/L achieves unsatisfied results due to the agglomeration and the sedimentation of BT particles into the oil.**

Index Terms — Breakdown strength, dielectric properties, heat transfer coefficient, nanofluids, nanoparticles, thermal properties, transformer oil.

1. INTRODUCTION

The enhancement of power grid equipment performance is one of the most important power quality criteria that grantee the system reliability and continuity. The most common equipment in the electrical power system are the oil transformers. So, the improving of the dielectric and thermal properties of the transformer oil is necessary to achieve an efficient performance of the transformer. Whereas, transformer oil has been used not only as insulating medium but also as cooling medium. Nanotechnology is applied to this field of high voltage engineering.

Regarding dielectric properties of insulating oil, Yuzhen et al. added 0.05 g/L of insulating metal oxide nanoparticles with average size 20 nm to pure transformer oil. The AC breakdown voltage and impulse breakdown voltage were enhanced by about 43% and 7% respectively [1]. Atiya et al. improved the dielectric properties by the dispersion of 0.06 g/L of TiO_2 into the base insulating oil. Due to this dispersion process, the breakdown voltage at 50% probability and at 10% probability were increased by about 28% and 75% respectively [2]. The AC breakdown strength of the transformer oil with Fe_3O_4 nanoparticles showed obvious increase when the concentration is under 100 ppm as was concluded in [3]. Li et al. improved the AC breakdown voltage of transformer oil to about 15% by the insertion of 0.1 wt% of ceria nanoparticles to it [4]. In [5], it is observed from the results that the AC breakdown voltage for nanofluids achieves an increase of 16% in the presence of SiO_2 nanoparticles. The dispersion of Al_2O_3 and TiO_2 nanoparticles with different band gap structure into pure transformer oil increases the breakdown voltage above that of the base oil with increasing the weight percent until a certain point [6].

On the other hand, regarding the thermal properties of the transformer oil, Timofeeva et al. presented 10% thermal conductivity improvement by the insertion of 5% volume fraction of SiO_2 nanoparticles with the synthetic oil. Whereas, the thermal conductivity is increased due to the increasing of volume fraction [7]. In [8], a significant improvement in thermal properties due to the addition of BN nanoparticles into pure insulating oil was presented. Furthermore, due to the increasing of the concentration of BN nanoparticles, the more enhancing of thermal properties becomes evident. Mansour et al. achieved increasing of heat transfer coefficient by 7.5% and 9% due to the dispersion of 0.3 g/L and 0.4 g/L of Al_2O_3 respectively into neat oil with 0.1% weight percent of surfactant [9].

In this work, barium titanate nanoparticles (BT) were dispersed into pure transformer oil with two different weight percents to form nanofluids samples. Breakdown strength and heat transfer coefficient were measured for these samples and compared with that for base oil. The obtained results were analyzed to conclude the effect of BT nanoparticles on the dielectric and thermal properties of the transformer oil.

2. EXPERIMENTAL WORK

2.1 Nanofluids Preparation

The nanofluid was prepared by dispersing of BT nanoparticles into the pure transformer oil with a certain weight percent as shown in Figure 1. In this work, two nanofluids samples were prepared. These two samples have concentration of 0.01 g/L and 0.02 g/L (BT/Transformer oil). To prepare these samples, a quantity of pure insulating oil was put in a graduated beaker and the required weight of BT nanoparticles (average size 50 nm) was detected using a sensitive electronic balance. The BT nanoparticles were added into this beaker. This beaker was put on a magnetic stirrer for 15 minutes at 1500 rpm. For well dispersion of BT nanoparticles into base oil, ultrasonic disruptor was used for 60 minutes after stirring with an interval of 5 minutes after each 30 minutes. To remove gas bubbles and moisture content composed during ultrasonic process, the obtained sample was dried by putting it in a vacuum oven at 45°C for 24 hours. Before testing the obtained sample, the sample was cooled down in air for 20 minutes.

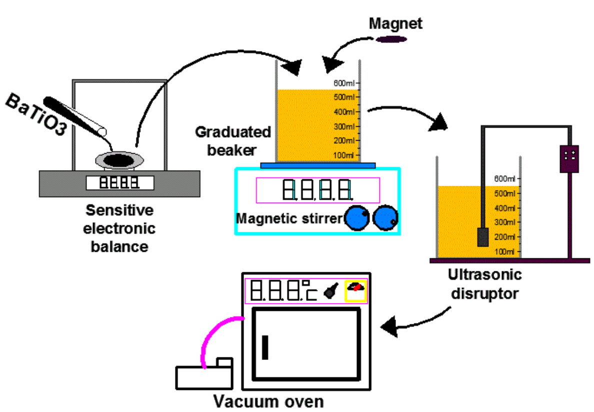

Fig. 1. Nanofluid samples preparation process

2.2 Dielectric Strength of Prepared Samples

The high value of transformer oil dielectric strength means reliable operation of oil transformer. The existing of conducting impurities and moisture content in the insulating oil reduce its breakdown voltage (BDV) and adversely affects the transformer performance. So, the most important property of the transformer oil is its breakdown voltage. At room temperature, an oil breakdown tester is used in this work to measure the AC breakdown voltage of each nanofluid sample. The voltage ramp rate and test electrodes were selected according to IEC-60156 standard. The distance between electrodes was adjusted to 2.5 mm. The voltage ramp rate was set at 2 kV/s. Ten measurements were performed for each sample, and their average is taken as the obtained result for each sample.

To evaluate AC breakdown strength at all probabilities and to provide dielectric failure analysis and failure auspice with small number of tests, Weibull distribution was presented. Assuming that, the breakdown voltage is (v), the scale parameter is (λ) and the shape parameter is (ξ). Weibull distribution function can be given by [2]:

$$F(v) = 1 - e^{-\left(\frac{v}{\lambda}\right)^{\xi}} \quad (1)$$

2.3 Heat Transfer Coefficient of Prepared Samples

Transformer oil is not only insulating medium but also cooling medium for the power oil transformers. Highly heat transferability indicates highly cooling trace of the transformer oil. The following equation is used to calculate the heat transfer coefficient for each prepared sample [9]:

$$H = \frac{Q}{T_i - T_o} \quad (2)$$

Whereas, Q (W/m^2) is the amount of heat transferred, H (W.m^{-2}.K^{-1}) is the heat transfer coefficient and $T_i - T_o$ is the difference in temperature between the solid surface and surrounding fluid area in kelvin.

The experimental setup used for heat transferability test is presented in Figure 2. The heater was connected to a controlled power supply. The inlet temperature (T_i) and the outlet temperature (T_o) were measured at the heater surface and at the opposite side, respectively. Both temperatures were recorded every 5 minutes until thermal steady state condition has been attained. After that, the heat transfer coefficient (H) could be evaluated as the average of the last five values.

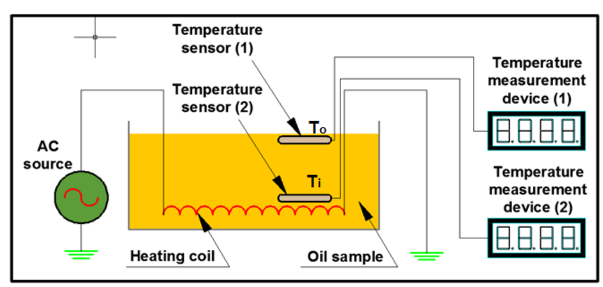

Fig. 2. Experimental setup for heat transferability test

3. RESULTS AND DISCUSSION

3.1 Breakdown Strength

Figure 3 shows the cumulative probability function for 0.01 and 0.02 g/L BT nanofluids samples beside base transformer oil. The average value of the breakdown voltage for each sample is presented in Figure 4. Shape parameter, scale parameter, breakdown voltage at 50% probability, breakdown voltage at 10% probability and average breakdown voltage are presented in Table 1. Due to the dispersion of 0.01 g/L BT nanoparticles into pure transformer oil, the breakdown voltage was slightly increased (65.3 kV) above the breakdown voltage of the base transformer oil (64.1 kV). On the other hand, for 0.02 g/L sample, the breakdown voltage was decreased to 42.6kV. Even though BT has a high dielectric constant, it achieves unsatisfied effects from dielectric properties point of view. The reversely effect of BT on the dielectric properties of transformer oil returns to the agglomeration due to the attraction force that easily attracts the small volume nanoparticles to each other and the sedimentation of BT particles due to its higher density (6.02 g/cm^3) [10].

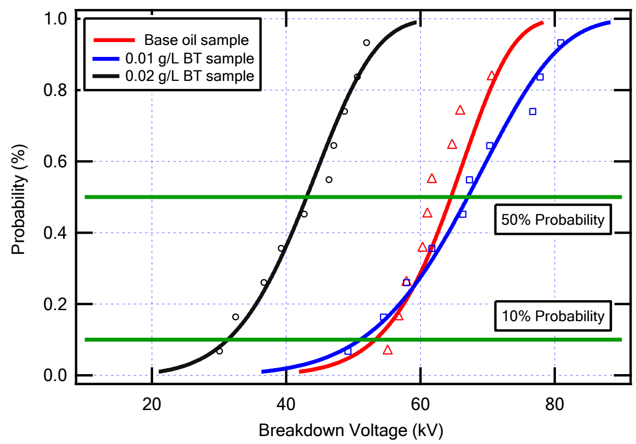

Fig. 3. Cumulative probability versus breakdown voltage for nanofluids samples and for pure transformer oil

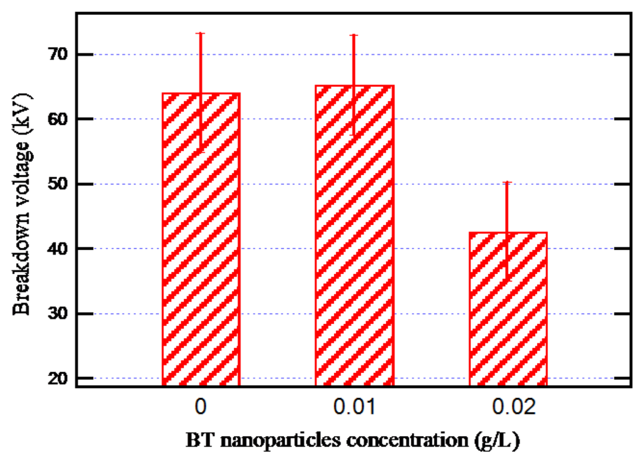

Fig. 4. Breakdown voltage versus BT nanoparticles concentration

Table 4. Weibull distribution analysis results for base oil and nanofluids samples

BT concentration (g/L)	0	0.01	0.02
Shape parameter	9.8	6.9	5.9
Scale parameter (kV)	67	70.7	45.8
v at 50% probability (kV)	64.54	67.04	43.04
v at 10% probability (kV)	53.25	51.02	31.27
$v_{average}$ (kV)	64.1	65.3	42.6

3.2 Heat Transferability

Heat transfer coefficient can be evaluated from equation (2) as mentioned above. The higher heat transfer coefficient the better thermal properties of the insulating oil. The evaluated heat transferability for the base oil is 297 W/m^2.K. After the dispersion of BT nanoparticles, the heat transfer coefficient was increased as shown in Figure 5 and summarized in Table 2. Due to the specific heat capacity of BT nanoparticles (≈ 0.5 J/gK) is lower than that for the base oil (≈ 1.8 J/gK), the dispersion of BT nanoparticles into the base oil provided nanofluid with improved thermal properties compared with the base oil. It was found that, 0.01 wt% and 0.02 wt% enhanced the heat transferability by 28.3% and 24.6% respectively. Due to the agglomeration and the sedimentation of BT, the increasing of nanoparticles weight percent decreases the heat transferability slightly.

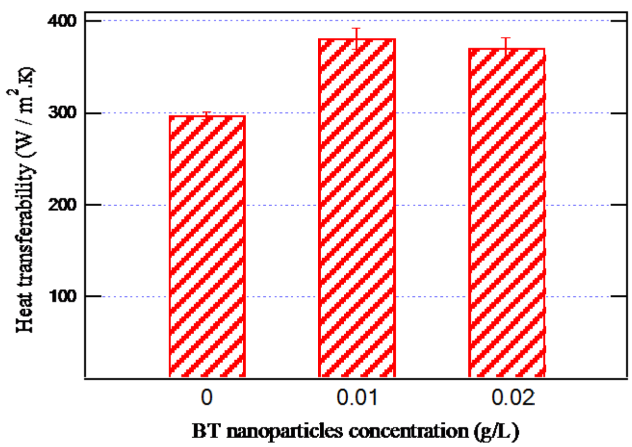

Fig. 5. Heat transfer coefficient versus BT nanoparticles concentration

Table 2. Heat transferability enhancement for nanofluids samples

BT concentration (g/L)	0	0.01	0.02
H $(\mathrm{W}.m^{-2}.K^{-1})$	297	381	370
Enhancement ratio (%)	-	28.3	24.6

4. CONCLUSION

In this paper, the effect of BT nanoparticles insertion into the pure transformer oil was studied. BT nanoparticles were dispersed into the base insulating oil with concentrations equal 0.01 g/L and 0.02 g/L. Because of the dielectric constant of BT nanoparticles is high and its specific heat capacity is low, the breakdown voltage and the heat transferability are improved for 0.01 g/L sample by about 2% and 28.3%, respectively. For the increment of BT nanoparticles concentration to 0.02 g/L, a degradation of breakdown voltage is obvious and the heat transfer coefficient is increased by about 24.6%, which is lower than the increasing ratio for 0.01 g/L sample. It was noted that, the increasing of the BT nanoparticles concentration achieves unsatisfied results regarding dielectric and thermal properties due to the agglomeration and the sedimentation of BT particles into the transformer oil.

REFERENCES

[1] Y. Lv, W. Wang, K. Ma, S. Zhang, Y. Zhou, C. Li and Q. Wang, "Nanoparticle Effect on Dielectric Breakdown Strength of Transformer Oil-Based Nanofluids", IEEE Annu. Repo. Conf. on Electr. Insul. Dielectr. Phenom., pp. 680-682, 2013.

[2] E. G. Atiya, D. A. Mansour, R. M. Khattab and A. M. Azmy, "Dispersion Behavior and Breakdown Strength of Transformer Oil Filled with TiO_2 Nanoparticles", IEEE Trans. Dielectr. Electr. Insul., Vol. 22, No. 5, pp. 2463-2472, 2015.

[3] B. Du, J. Li, B. M. Wang and Z. T. Zhang, "Preparation and Breakdown Strength of Fe_3O_4 Nanofluid Based on Transformer Oil", IEEE Int'l. Conf. High Voltage Eng. Appl. (ICHVE), pp. 311-313, 2012.

[4] S. Li, M. Karlsson, R. Liu, A. Ahniyaz, A. Fornara and E. Johansson, "The Effect of Ceria Nanoparticles on the Breakdown Strength of Transformer Oil", IEEE Int'l1. Conf. Prop. Appl. Dielectr. Mater. (ICPADM), pp. 289-292, 2015.

[5] M. Rafiq, C. Li, Q. Du, Y. Lv and K. Yi, "Effect Of Sio_2 Nanoparticle on Insulating Breakdown Properties of Transforme r Oil", IEEE Int. Conf. High Voltage Eng. Appl. (ICHVE), pp. 1-4, 2016.

[6] D. A. Mansour, A. M. Elsaeed and M. A. Izzularab, "The Role of Interfacial zone in Dielectric properties of Transformer Oil-based Nanofluids", IEEE Trans. Dielectr. Electr. Insul., Vol. 23, No. 6, pp. 3364-3372, 2016.

[7] E. V. Timofeeva, M. R. Moravek and D. Singh, "Improving the Heat Transfer Efficiency of Synthetic Oil with Silica Nanoparticles", J.Colloid Interface Sci., Vol. 364, No. 1, pp. 71-79, 2011.

[8] B. X. Du, X. L. Li, "High Thermal Conductivity Transformer Oil Filled with BN N anoparticles", IEEE Int. Conf. Liquid Dielectr., pp. 1-4, 2014.

[9] D. A. Mansour and A. M. Elsaeed, "Heat Transfer Properties of Transformer Oil-Based Nanofluids Filled with Al_2O_3 Nanoparticles", IEEE Conf. on power and energy (PECON), Egypt, pp. 123-127, 2014.

[10] B. Ertuğ, "The Overview of the Electrical Properties of Barium Titanate", American Journal of Engineering Research (AJER), Vol. 2, No. 8, pp. 1-7, 2013.