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Nanofluids for Transformer Insulation

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Abstract: The nanofluids are considered as next generation insulating fluids for the transformer application. In this work, synthetic ester, MIDEL 7131 based nanofluids were prepared under ultrasonication by employing nanoceramics such as Ba0.85Ca0.15Zr0.1Ti0.9O3 (BCZT), Calcium Ferrite (CaFeO3) and eggshell nanomaterials. These nanofluids were evaluated for parameters such as AC breakdown voltage, loss tangent and resistivity, and also for viscosity and total acidity. There is an improvement in A C breakdown voltage for all the nanofluids under the study. There is no variation in the viscosity and total acidity for the nanofluids upto 0.005 wt percent of nanoceramic in a base oil. These nanofluids exhibited improved critical parameters.

Keywords: *Synthetic ester, nanofluids, mineral oil, nanomaterials, electric strength.*

1.0 INTRODUCTION

Mineral oil (transformer oil), a petroleum based by product has been used as an insulating oil for power transformers till date [1-3]. Research work is concentrated to find an alternative to mineral oil with better insulating properties at the same time bio-degradable in nature. The vegetable based ester oil of natural and synthetic types will be the future sources to achieve better insulating properties than mineral oil [4-7]. The development of nanotechnology provides an effective way to achieve improvement in the performance of insulating fluids. The field of nanodielectrics is the future for the development of insulating oils with improved critical parameters that can change the design aspects of high voltage power apparatus. It has been reported that new insulating nanofluids were developed by mixing nanopowder with insulating oils [8-18]. Recently a dielectric nanoceramic, CaCu3Ti4O12 (CCTO) has been used for the development of nanofluids and improvements in the critical parameters were observed [19]. Enhanced AC breakdown characteristics were also observed for the synthetic ester based eggshell nanofluids [20]. In order to improve the critical parameters of the insulating liquids, various nanofluids were developed and studied. This has motivated us to develop nanofluids by employing nanoceramics

with the aim of improving the critical parameters. In this work, nanoceramics such as Ba0.85Ca0.15Zr0.1Ti0.9O3 (BCZT), Calcium Ferrite (CaFeO3) and eggshell were employed for the preparation of synthetic ester based nanofluids. The critical parameters such as AC breakdown voltage, loss tangent and resistivity and also for viscosity and total acidity were evaluated and the results are discussed in this paper.

2.0. PREPARATION OF NANOFLUIDS

The synthetic ester oil (MIDEL 7131) received from M/s M&I Materials India Pvt Ltd, has been used in this study. The nanoceramics such as BCZT

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and CaFeO3 were prepared in-house by chemical synthesis as per the reported literature [21], and eggshell nanopowders were prepared as per the reported literature [22]. Series of nanofluids were prepared by mixing nanopowders (BCZT, CaFeO3 and eggshell) in different weight percents of 0, 0.001, 0.0025, and 0.005 in synthetic ester. These samples are subjected to ultrasonication (Make: Sonics, Sonics Materials, Vibracell-750W) for 20 minutes for obtaining homogeneous samples and to reduce the agglomeration of nanoparticles.

3.0 EXPERIMENTAL INVESTIGATIONS

The electric strength was measured using a 100 kV automatic breakdown voltage tester as per IEC 60156 standard [23]. The standard spherical electrode with the gap spacing of 2.5 mm was used. The average of five values were taken and computed as breakdown voltage. The tan delta, resistivity and dielectric constant has been measured using an automated ELTEL Bridge at 50 Hz as per ASTM D 924 [24] & ASTM D 1169 [25] respectively. The applied voltage is set as 500 V/mm (rms) in the three-electrode test cell. The testing has been carried out at 27°C and 90°C. The Viscosity of the samples were measured using a U-tube calibrated glass capillary viscometer at various temperatures like 27, 45 and 70°C as per ASTM D 445 standard [26].

4.0. RESULTS AND DISCUSSION

AC Breakdown Strength

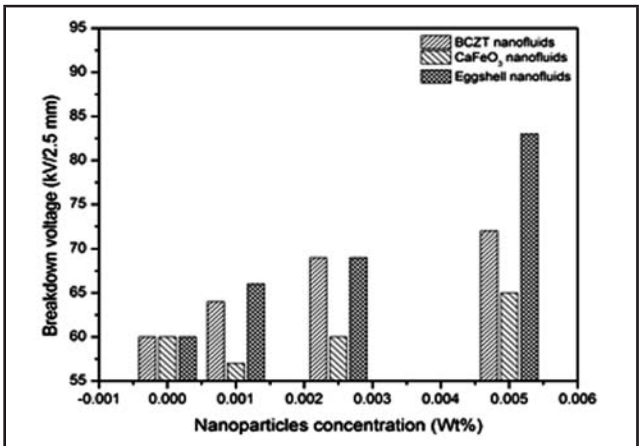

FIG 1. BDV AS A FUNCTION OF BCZT, CAFEO3 AND EGGSHELL NANOPARTICLES CONCENTRATION.

The electric strength of an insulating material is a measure of its ability to withstand electrical stress. The electric strength values obtained for the BCZT synthetic ester nanofluids are shown in the figure.1. Improved AC breakdown voltage characteristics were observed. The electric strength of base oil is 60 kV, which has increased to 72 kV when the nanoparticles concentration is increased to 0.005 wt%.

The electric strength values obtained for the CaFeO3 nanofluids are also shown in the figure 1. The nanofluids showed improvement in the AC breakdown voltage characteristics. When the CaFeO3 concentration increased to 0.005 wt%, the AC breakdown voltage had increased to 65kV.

In the case of eggshell nanofluids, tremendous improvements in the AC breakdown voltage characteristics were observed when the eggshell concentration increased to 0.005 wt%. The electric strength of base oil is 60 kV, which has increased to 83 kV when the eggshell nanoparticles concentration is increased to 0.005 wt % (figure 1). It is noted that even at high moisture content, these synthetic esters are able to withstand high voltages. These observations revealed that the synthetic esters have superior moisture tolerance. Similar results were obtained and are reported in the literature [8,11,15,17].

Ten delta & Resistivity

The Dissipation factor was measured at 90°C as per ASTM D924 and the tan delta values obtained were shown in the figure 2.

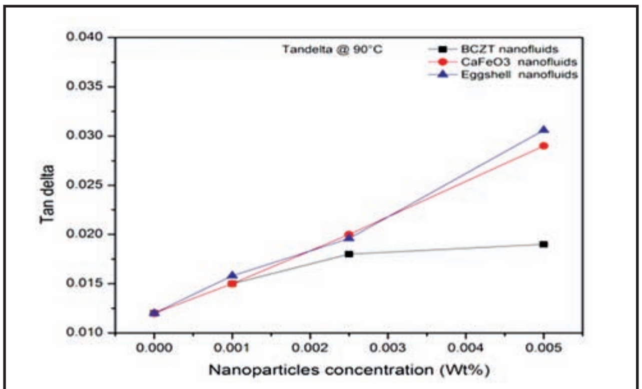

FIG 2. TAN DELTA MEASURED FOR THE NANOFLUIDS

The tandelta value obtained for the base oil at 90°C is 0.012. It has been observed that all the nanofluids had exhibited increase in the tandelta values. The eggshell nanofluids has shown higher tandelta value as compared to that of other nanofluids. The dielectric constant (not shown here) doesnot show any variation in the values for all the nanofluids under this study.

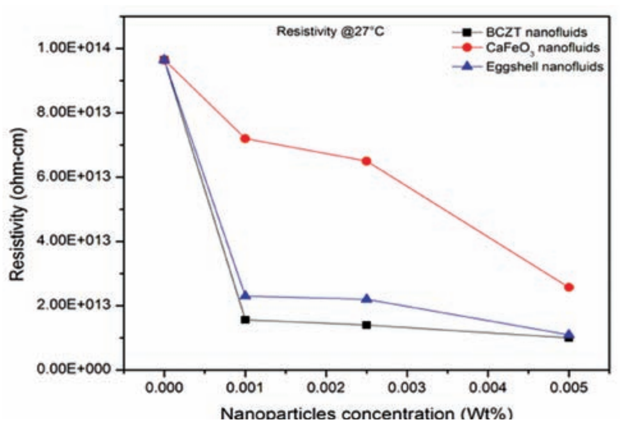

FIG 3. RESISTIVITY MEASURED FOR THE NANOFLUIDS AT 27°C.

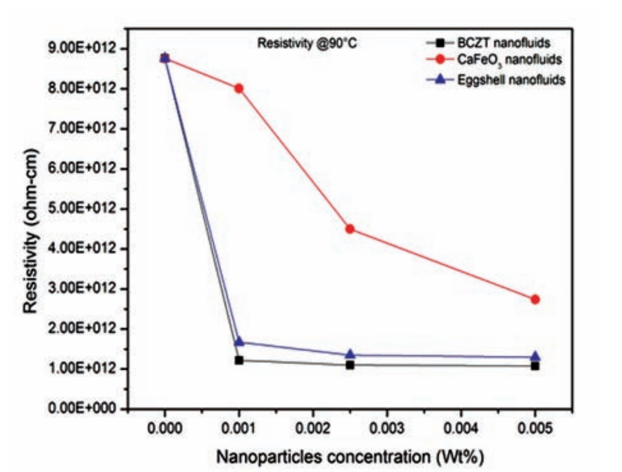

FIG 4. RESISTIVITY MEASURED FOR THE NANOFLUIDS AT 90°C.

The volume resistivity was measured both at 27°C and 90°C, as per ASTM D 1169 and the values obtained were shown in figure 3&4. The volume resistivity of the base oil at 27oC is 9.65X1013 Ohm-cm, which has decreased to 8.76X1012 Ohm-cm at 90oC. Similar trend has been observed even for the nanofluids at all concentrations. In the case of BCZT nanofluids, the room temperature resistivity has decreased to 1.0X1013 when the nanoceramic concentration has increased to 0.005 wt%. The value obtained for CaFeO3 nanofluids is 2.57X1013 and for the eggshell nanofluids it is 1.09X1013. The resistivity measured at 90oC also showed the similar trend for all the nanofluids.

Total Acidity

The total acidity has been measured for all the nanofluids under this study. The base oil as well as the nanofluids were measured for the total acidity content and found that the total acid content is negligible in both base oil as well as in nanofluids. Since the synthetic esters are formed between the acid and an alcohol, they are neutral in characteristics and free from polar compounds, suspended particles and all the acidic components such as ketones, aldehydes and peroxides. The acidic components such as ketones, aldehydes and peroxides are the products of oxidation generated during the ageing process. Though the addition of nano powder in ester does not show any variation in the total acidity, the stability of these nanofluids can be assessed only after subjecting to the accelerated ageing studies.

Kinematic Viscosity

TABLE 1.
VISCOSITY (C-ST)

Nan oparticles concentration (Wt%)	Temp (^oC)	BCZT nanofluids	$CaFeO_3$ nanofluids	Eggshell nanofluids
0.00	27	49.5	49.5	49.5
	45	27.7	27.7	27.7
	70	10.3	10.3	10.3
0.001	27	49.05	49.6	49.7
	45	22.04	24.5	23.5
	70	10.41	10.5	10.5
0.0025	27	50.34	49.7	49.7
	45	23.92	24.6	23.5
	70	10.75	10.5	10.5
0.005	27	51.51	49.7	49.7
	45	23.9	26.8	23.5
	70	11.23	10.5	10.5

Kinematic viscosity as a function of temperature has been measured for all the nanofluids as per ASTM D 445 and the results are given in the table.1. As expected, the kinematic viscosity has decreased as the temperature of the measurement is increased. The base oil having the viscosity of 49.5 c-St @ 27oC, had decreased to 10.3c-St @ 70oC. However, increasing concentration of nanomaterials up to 0.005 wt % in synthetic ester, no variation in the viscosity has been observed, indicating that the nanomaterials may not hinder the heat transfer characteristics of the nanofluids.

5.0 CONCLUSIONS

The synthetic ester based nanofluids were successfully prepared by employing the nanoparticles under ultra sonication. The electric strength values increased as the weight percent of the nanoparticles increased in the synthetic esters. There is no variation in the viscosity and acidity of the nanofluids, however change in the viscosity with increase in temperature has been observed. Further studies on paper-oil ageing and thermal conductivity on these nanofluids would give rise to other intresting results. The stability of these nanofluids is another area wherein research on thses lines needs to be addressed by employing suitable surfactants/dispersants.

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REFERENCES

[1] M Xose, López-Fernández, H Bülent Ertan and Janusz Turowski Transformers: Analysis, Design, and Measurement, ISBN 9781466508248, June 2012.

[2] Vishal Saurabh, Vikas and Prashant, "Transformers History and its Insulating Oil", 5th National Conf. on INDIA Com, Computing for Nation Development, 2011.

[3] Emmanuel O Aluyor and Mudiakeoghene Ori-jesu, "Biodegradation of mineral oils – A review", African Journal of Biotechnology Vol. 8, No.6, pp. 915-920, 2009.

[4] M&I Materials Ltd, "Product Overview Midel 7131", Technical Datasheet No 2, 01.2007.

[5] G J Pukel, R Schwarz and F Schatzl, "Environmental friendly insulating liquids -a challenge for power transformers" 6th Southern Africa Regional Conference, Cigré 2009.

[6] H Borsi and E Gockenbach, "Properties of Ester Liquid MIDEL 7131 as an Alternative Liquid to Mineral Oil for Transformers", Division of High Voltage Engineering Hannover, Germany, 2005.

[7] T V Oommen, "Vegetable Oils for Liquid-filled Transformers", IEEE Electrical Insulation Magazine, Vol.1, No.18,pp. 7-11, 2002.

[8] Yuzhen lv, You Zhou, Chengrong Li and B Qi, "Recent Progress in Nanofluids Based on Transformer Oil: Preparation and Electrical Insulation Properties", IEEE Electrical Insulation Magazine Vol. 30, No.5, pp. 23-32, August 2014.

[9] V Sridhara, B S Gowrishankar, Snehalatha and L.N.Satapathy, " Nanofluis- A New Promising Fluid for Cooling" Trans.Ind. Ceram.Soc.Vol.68, No.1, pp 1-17, 2009.

[10] Michael P Beck, Yanhui Yuan, Pramod Warrier and Amyn S Teja, "The effect of particle size on the thermal conductivity of alumina nanofluids", Journal of Nanoparticle Research, , Volume 11, No. 5, pp. 1129–1136, July 2009.

[11] Y Zhong, Y Lv, C Li et al., "Insulating properties and charge characteristics of natural ester fluid modified by TiO2 semiconductive nanoparticles", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 20, No. 1, pp. 135–140, 2013.

[12] K Raj, B Moskowitz and S Tsuda, "New commercial trends of nanostructured ferrofluids", Indian J. Eng. Mater Sci., 11, 241, 2004.

[13] R Karthik, T S R Raja and R Madavan, “Enhancement of Critical Characteristics of Transformer Oil Using Nanomaterials”, Arab J. Sci. Engg, Vol. 38, pp. 2725-2733, 2013.

[14] Mohamoud Jama, Ayman Samara, Tejvir Singh, Rima J. Isaifan, Seifelislam Mahmoud Gamaleldin, and Muataz A. Atieh “Review Article Critical Review on Nanofluids: Preparation,Characterization, and Applications”, Journal of Nanomaterials, Vol. 2016, Accepted 7 August 2016.

[15] Navadeep Ranjan, R T Arun Ram Prasath and Nirmal Kumar Roy, “Ageing Performance on Mineral Oil Using ZnO Nanofluids”, International Journal of Innovations in Engineering and Technology (IJIET), Vol. 6, No. 3 February 2016.

[16] J A Mergos, M D Athanassopoulou, T G Argyropoulos, and C T Dervos, “Dielectric properties of nanopowder dispersions in paraffin oil”, IEEE Trans. Dielectr. Electr. Insul., Vol. 19, No. 5, pp. 1502–1507, 2012.

[17] D E A Mansour, E G Atiya, R M Khattab and A M Azmy, “Effect of Titania nanoparticles on the dielectric properties of transformer oil based nano fluids”, IEEE Conf. Electr. Insu. Dielectr. Phenomena, pp.1-4, 2010.

[18] P Kopcansky, J Cernak, P Macko, D Spisak and K Marton, “Dielectric behavior of mineral-oil-based magnetic fluids-the cluster model”, Journal of Physics D Applied Physics 22(9):1410-1412,September 1989.

[19] R T Arun Ram Prasath, P Thomas, Nirmal Kumar Roy and Sankar Narayan Mahato, “Mineral Oil Based High Permittivity CCTO Nanofluids for Power Transformer Applications”, IEEE Transactions on Dielectric and Electrical Insulation, Vol. 24, No. 4, pp. 2344-2353, 2017.

[20] P Thomas and Nandini E Hudedmani, “A C breakdown voltage characteristics of synthetic ester based eggshell nanofluids”, International Conference on Condition Assessment Techniques in Electrical Systems (CATCON 2017), November 2017.

[21] P Bharathi, P Thomas and K B R Varma, “Piezoelectric properties of individual nanocrystallites of Ba0.85Ca0.15Zr0.1Ti0.9O3 obtained by oxalate precursor route”, J. Mater. Chem. C, Vol. 3, pp.4762-4770, 2015.

[22] D Siva Rama Krishna, A Siddharthan, S K Seshadri and T S Sampath Kumar, “A novel route for synthesis of nanocrystalline hydroxyapatite from eggshell waste”, Journal of Materials Science: Materials in Medicine, Vol 18, No. 9, pp. 1735–1743, September 2007.

[23] IEC 60156 Third Edition, “Insulating Liquids- Determination of Breakdown voltage at Power Frequency- Test method, 2003-11.

[24] ASTM D 924, “Standard Method of Test for Power Factor and Dielectric Constant of Electrical Insulating Liquids”, 2008.

[25] ASTM D 1169, “Standard Method of Test for Specific Resistance (resistivity) of electrical Insulating Liquids”, 2011.

[26] ASTM D 445, “Standard Test Method for Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities), 2011.