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Impact of Concentration of Nanoparticles on Characteristics of Transformer Oil

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In this study, we investigate the change of breakdown voltage and energy band gap of transformer oil by adding different concentrations varying from 0.01 wt. % to 0.1 wt. % of cerium oxide nanoparticles. Cerium oxide nanoparticles were prepared by sol-gel method with heat treatment at 200 °C for four hours. Structural and morphological study of cerium oxide was carried out by XRD and SEM. The average crystallite size was 17 nm with well-defined peaks which endorses crystalline structure of the nanoparticle. To confirm purity of cerium oxide EDX test was carried out which revealed 99 % atomic weight percentage of O and Ce and confirmed the formation of CeO_2 compound. The breakdown voltage experiment was performed in transformer oil testing kit. The testing was carried out six times for liquid test sample according to IS 6792, IEC 60156 for different concentration of CeO_2. It was observed a sharp change in breakdown voltage for different concentration and BDV is optimum for 0.05 wt. % of cerium oxide. To investigate the energy band-gap of the prepared nanofluid UV-Vis spectrophotometer was used. The transmittance for pure oil and 0.05 wt. % of cerium oxide is 60 %, whereas for other concentrations transmittance is less. From the spectrometer data, the band gap was calculated and it was observed that band gap changes with concentration of cerium oxide in transformer oil and it has maximum of 5.25 eV for 0.05 wt. % of cerium oxide. From this study, we observe the breakdown voltage and band gap of transformer oil is maximum at 0.05 wt. % of cerium oxide nanoparticles.

Keywords: Cerium oxide, Transformer oil, BDV, XRD.

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1. INTRODUCTION

Transformer oil plays a vital role in electric transformers mainly due to its dual role as insulating medium and cooling material. However, safety and stability of power system is interrupted due to the operation failure of electric transformers in certain case. Therefore, efforts should be focused on improving the property of transformer oil for the stable operation of insulating system. The oil applied in transformers is highly refined mineral oil which performs dual functions of insulating and cooling materials. This oil is customarily a highly refined mineral oil (MO) and employed in transformers as a cool and because of its high stability [1] at elevated temperatures and excellent electrical insulating properties. Insulation is essential as the winding inside has to be separated to prevent voltage from leaking or shorting. As the thermal conductivity of MO is low, it is not uncommon to experience thermally driven failures from instantaneous overload. Therefore, to achieve significant extension in transformer lifetime and increment in load/cooling capacity, it is pertinent to increase the insulation break down strength and thermal conductivity of the transformer oil. Suspensions prepared by dispersing nanometer sized solid particles, rods or tubes in the base fluids are called nanofluids. These are found to possess enhanced physical properties such as thermal conductivity, thermal diffusivity and convective heat transfer coefficients [2] compared to those of base fluids. In many cases, the viscosity of the nanofluids is also considerably reduced. The presence of nanoparticles with large surface cannot only be expected to enhance the heat-transfer, but also to increase the stability of the suspension [3]. Moreover, the size and the weight of the transformer and the current density of the transformer windings depend on the amount of oil and the rate of heat transfer. Thus any work related to transformer oil must take into account both its dielectric and thermal characteristics.

The base concept of dispersing solid particles in fluid to enhance the thermal conductivity is not new. Solid particles are added because they conduct heat much better than liquids [4]. For more than a century scientists and engineers have made great efforts to enhance the inherently poor thermal conductivity of traditional heat transfer liquids, such as water, oil and ethylene glycol [5]. Numerous theoretical and experimental studies of the effective thermal conductivity of suspensions that contain solid particles have been conducted. However, all of the studies have been confined to millimeter- or micrometer-size particles. The major problem with the use of millimeter- or micrometer-size particles is the rapid settling of the particles in fluids. The large size particles and the difficulty in production of small particles are the limiting factors for liquid/solid suspension to be investigated for practical applications.

Some of the investigators suggested to use nanoparticles instead of increasing pump power to increase the convection of heat power [6]. After that, Choi and Eastman have tried to suspend various metal and metal oxides nanoparticles in several different fluids. The results showed that nanoparticles stay suspended longer than larger particles and nanofluids exhibit excellent thermal properties and cooling capacity. Since then numerous research groups have investigated thermal

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conductivity, convective heat transfer and breakdown strength of nanofluids [7]. The nanofluid technology is still in its early phase and scientists are working now to help using nanofluids as a tool to solve technological problems of industry.

Nanofluids have some potential features which make them special for various engineering applications. A large number of research groups focused on the drastically enhanced thermal properties of nanofluids, especially the thermal conductivity and convective heat transfer [8].

2. SYNTHESIS OF CERIUM OXIDE

Cerium oxide was prepared by sol-gel method. In this process, cerium nitrate is dissolved in glycine and then added to the distilled water. This solution is stirred for 2 h by using a magnetic stirrer. After the process of stirring, the sol is heated up to 200 °C. The heating process is done for about 4 h in Indfurr furnace, which then forms the clusters of ceria. They are then allowed to cool naturally and then the clusters are made into fine powder by using mortar and pestle. After that, the prepared particles are kept under calcination process for 4 h at 200 °C in a vacuum oven.

3. PREPARATION OF NANOFLUID

The cerium oxide thus prepared by above method is mixed with transformer oil percentage wise, and a surfactant is added. After this, the mixture is stirred with a magnetic stirrer at ambient temperature for 1.5 h. Finally, the mixture is put under ultrasonication for 8 h to get a well dispersed nanofluid. The magnetic stirring helps to disperse the nanopowders evenly in the base fluid, but the energy is not enough to break any agglomeration of nanoparticles. So an ultrasonic bath is used to break the agglomerations of nanoparticles.

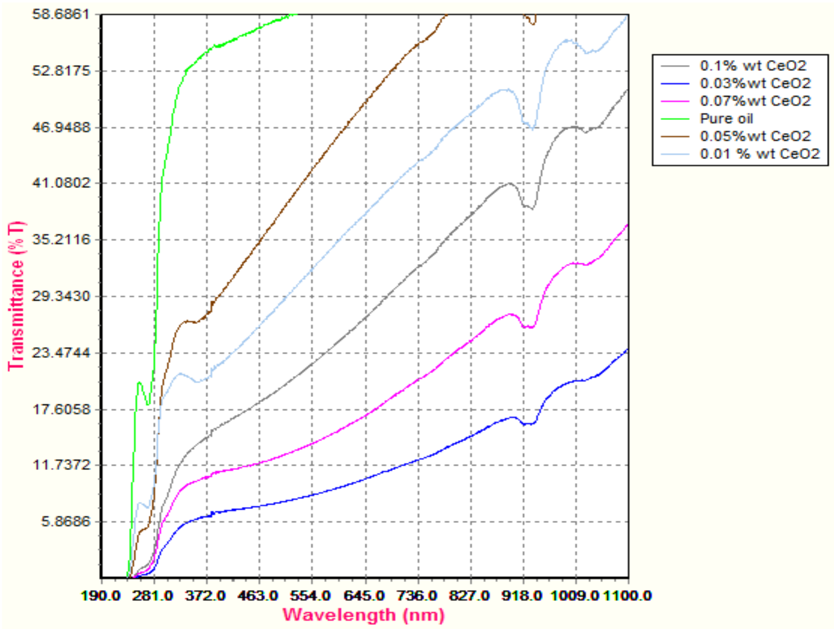

Fig. 1 – Optical transmittance spectra of CeO_2

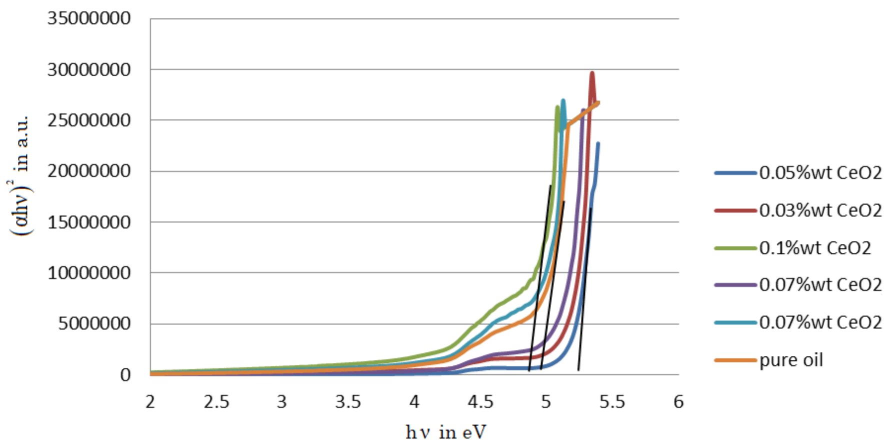

Fig. 2 – Band gap of CeO_2

4. OPTICAL CHARACTERIZATION

Optical properties of nanofluids are characterized by the transmission % vs wavelength graph using the equipment ELICO double beam UV-Vis spectrophotometer (model SL-210) in the range of 190 nm to 1100 nm. From this data, the band gap of a nanofluid is determined [9].

Fig. 1 indicates the variation of transmittance with wavelength for transformer oil with different wt. % of CeO_2. Fig. 1 shows that the transmittance of 0.05 wt. % cerium oxide is about 60 %, and for other concentrations it is less and for 0.03 wt.% it is minimum.

Fig. 2 indicates the band gap energy of CeO_2 nanofluid and pure transformer oil. Band gap was calculated from the graph $(\alpha h\nu)^2$ vs. $(h\nu)$. When the linear portion of the graph is extended back, it intersects eV axis and this intercept is the energy band which varies from 4.7 to 5.25. For 0.01 wt. % and 0.07 wt. %, the band is less than that of pure transformer oil, whereas for 0.05 wt. % the band gap is more.

5. STRUCTURAL ANALYSIS

Structural analysis of CeO_2 is carried out by XRD using copper having the wavelength range $\lambda = 1.540$ Å radiation with a diffraction angle 5° to 80°. XRD spectra were analyzed with Gaussian function where FWHM was determined by using Debye-Scherrer formula [10]

$$D = \frac{0.94\lambda}{\beta\cos\theta},$$

where D is the mean grain size, β = FWHM (full width at half maximum) of the observed peak (radians), λ is the wavelength of X-ray used for diffraction, θ is the angle of diffraction.

The different sharp peaks (111), (200), (220), (311) and (331) are obtained for 2θ value of 28.65°, 33.18°, 47.60°, 56.45°, and 76.82°, respectively. The well-defined peaks indicate the crystalline structure of the particles. From XRD analysis, mean grain size D was calculated as 17.00 nm.

Morphological analysis was carried out using SEM. Fig. 3 shows the crystalline structure of cerium oxide.

Fig. 4 shows EDX image of cerium oxide. Energy dispersive X-ray spectroscopy analysis was carried out for CeO_2 nanoparticles. The atomic percentage of O was found to be 78.22 % and that of Ce was found to be 21.78 %. The near 99 % atomic weight percentage of O and Ce confirmed the formation of CeO_2 compound.

6. BDV TEST

The breakdown voltage is measured by observing at what voltage, sparking strands between two electrodes immersed in the oil, separated by a specific gap. Low value of BDV indicates the presence of moisture content and conducting substances in the oil. To study BDV test transformer oil testing kit was employed. In this kit, oil is kept in a pot in which one pair of electrodes are fixed with a gap of 2.5 mm between them. Now slowly rising voltage is applied between the electrodes. Rate of rise of voltage is generally controlled at 2 kV/s and observe the voltage at which sparking starts between the electrodes. That means at which voltage dielectric strength of transformer oil between the electrodes has been broken down. The testing was carried out 6 times for each liquid test sample according to IS 6792, IEC 60156. For different concentration of CeO_2, i.e. 0.01 wt. %, 0.03 wt. %, 0.05 wt. %, 0.07 wt. % and 0.1 wt. %.

Fig. 5 shows the dependence of BDV on wt. % of cerium oxide added in transformer oil. It was observed that BDV changes with addition of cerium oxide and the

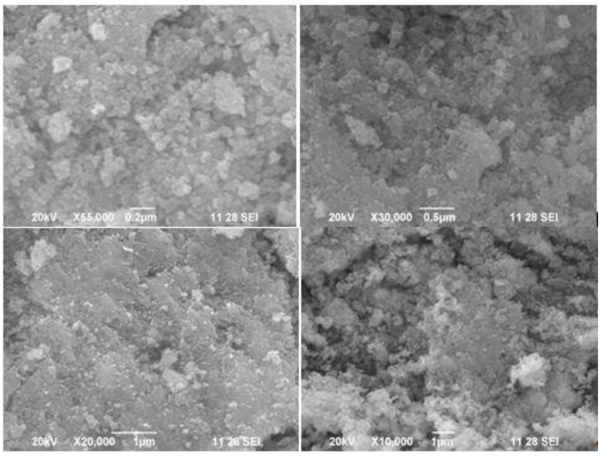

Fig. 3 – SEM images of ceria nonmaterial

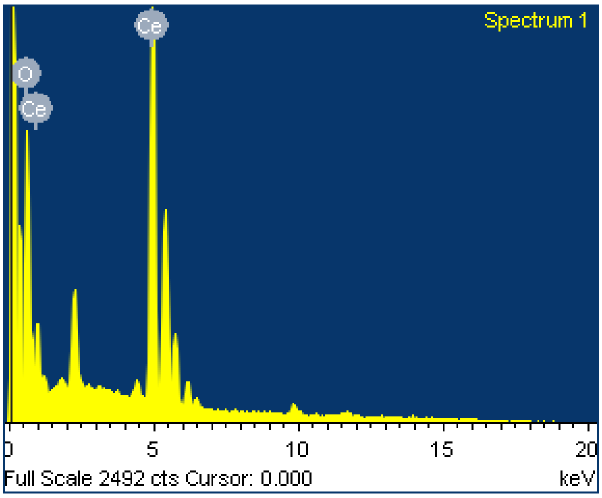

Fig. 4 – EDX of CeO_2

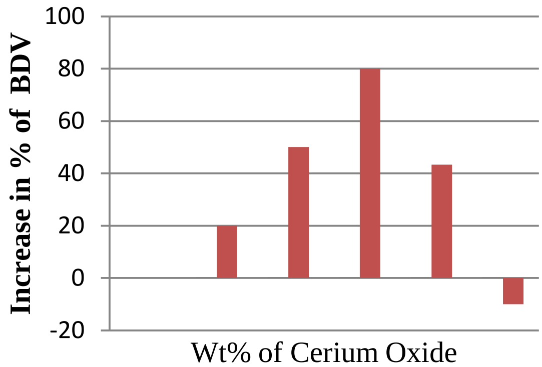

Fig. 5 – Dependence of BDV

maximum was observed for 0.05 wt. %. This may be due to an increase in the energy band gap and, consequently, an increase in the dielectric property of transformer oil.

The effect of concentration of cerium oxide on band gap of transformer oil is similar to the properties of the breakdown voltage. This indicates that the breakdown voltage of oil depends on the particle size and permittivity of the nanoparticle.

7. CONCLUSIONS

Cerium oxide nanopowder was synthesized by sol-gel process. Structural and morphological studies revealed that the average grain size of the particle is 17 nm and also has a highly crystalline structure. Cerium oxide was added in transformer oil with different wt. % and nanofluid was prepared. From optical measurements, the band gap was measured and it was found that the band gap is greater for 0.05 wt. % cerium oxide. The nanofluid was tested for BVD, and it was also observed that BVD is more for 0.05 wt. % of cerium oxide. BDV more at 0.05 wt. % of cerium oxide may be attributed to high dielectric property due to cessation of motion of the electrons. The enhancement of BVD necessarily helps to increase the life of the transformer as well as drastically decrease the maintenance cost of the power transformers.

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Вплив концентрації наночастинок на характеристики трансформаторної олії

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У роботі ми досліджуємо зміну напруги пробою та енергії забороненої зони трансформаторної олії, додаючи різні концентрації наночастинок оксиду церію, що змінюються від 0,01 мас. % до 0,1 мас. %. Наночастинки оксиду церію готували методом золь-гелю з термічною обробкою при 200 °C протягом чотирьох годин. Структурно-морфологічне дослідження оксиду церію було проведено за допомогою XRD та SEM. Середній розмір кристалітів становив 17 нм з чітко визначеними піками, що підтверджує кристалічну структуру наночастинок. Для підтвердження чистоти оксиду церію проводили тест EDX, який виявив 99 мас. % O і Ce та підтвердив утворення сполуки CeO_2. Експеримент з напругою пробою проводився разом з випробуванням трансформаторної олії. Випробування проводили шість разів для рідкого досліджуваного зразка згідно IS 6792, IEC 60156 для різної концентрації CeO_2. Спостерігалася різка зміна напруги пробою для різних концентрацій, а BDV є оптимальним для 0,05 мас. % оксиду церію. Для дослідження енергії забороненої зони підготовленої нанорідини використовувався спектрофотометр з випромінюванням в ультрафіолетовому та видимому діапазонах. Пропускання для чистої олії і 0,05 мас. % оксиду церію становить 60 %, тоді як для інших концентрацій пропускна здатність менша. За даними спектрометрії розраховували ширину забороненої зони, і було помічено, що вона змінюється з концентрацією оксиду церію в трансформаторній олії і має максимум 5,25 еВ для 0,05 мас. % оксиду церію. З дослідження видно, що напруга пробою і ширина забороненої зони трансформаторної олії максимальні при 0,05 мас. % наночастинок оксиду церію.

Ключові слова: Оксид церію, Трансформаторна олія, BDV, XRD.