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Effect of new and aged mineral oil based TiO_2 nanofluid for power transformer application

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Transformer is one of the cost effective and critical component in high voltage (HV) electrical system network. The quality of mineral oil is the key parameter to determine the health of the transformer. Globally, electrical and physical parameters of mineral oil are considered as the most primitive critical parameters for monitoring the transformer throughout the year. In this paper, electrical parameters like AC breakdown voltage (BDV), volume resistivity and physical parameters like flash point and fire point of new and aged mineral oil are analyzed by dispersing TiO_2 nanoparticles in mineral oil under different vol.% concentration. It is found that, new mineral oil with TiO_2 nanoparticles shows enhanced BDV compared with base mineral oil. In addition to this, volume resistivity, flash point and fire point also shows improved results with TiO_2 nanoparticles.

Keywords: *Mineral oil, Electrical parameters, Physical parameters, TiO_2 nanoparticles, Nanofluids.*

1.0 INTRODUCTION

Transformer plays a vital role in electrical system for power flow and its failure causes an unwanted power interruption. In transformer, mainly two types of insulation are used namely solid insulation (Kraft paper & pressboard) and liquid insulation (Mineral oil) [1]. Mineral oil, a composition of paraffin, naphthene, aromatic and olefin is mainly used as liquid insulation as well as cooling medium of transformer. Mineral oil degraded with time due toelectrical, thermal, chemical and mechanical stress [2]. The presence of water & other contaminants/impurities depends on the rate of oxidation, temperature, moisture content due to the ageing and discharges in the transformer [3]. For a review of breakdown phenomena in any insulating oil, it is observed that it depends on the streamer propagation velocity of discharges where propagation velocity reached nearly 15- 100 km/sec in mineral oil [4]. The breakdown voltage (BDV), flash point and fire point of mineral oil depends on the thermal properties of the material. [5]. The concept of adding the nanoparticles in mineral oil was introduced by the American physicists Richard Feynman in his famous lecture of "There is plenty of room at the bottom" in 1959 [6]. The first nanofluids are prepared by Choi et al in 1995 at Argonne National Laboratory where nanofluids were prepared by dispersing the nanoparticles in the base fluid as mineral oil. It is observed that with the application of electric field the nanoparticles tend to polarization by creating a dipole which captures the free electrons on the positive side and it reduces the streamer propagation velocity [7, 8]. In this paper, critical properties like breakdown voltage, volume resistivity, flash point and fire point of new and aged mineral oil have been analyzed with and without doped TiO_2 nanoparticles. It is

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observed that new mineral oil based nanofluids shows improved BDV, volumeresistivity, flash point and fire point compare to the new mineral oil (base oil).

2.0 EXPERIMENTAL DETAILS

2.1 Preparation Method of Nanofluids

The Semi conductive type TiO_2 nanoparticles (50 nm) purchased from Sigma-Aldrich India. It is mixed with 500 ml of mineral oil in a beaker to prepare the nanofluids with different particle volume fractions (P.V.F) of 0.01%, 0.02%, 0.03% and 0.04% respectively.

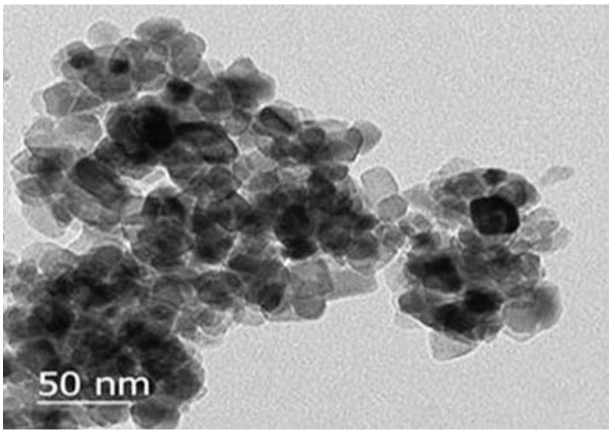

FIG. 1 TEM IMAGE OF TIO_2 NANOPOWDER (50NM)

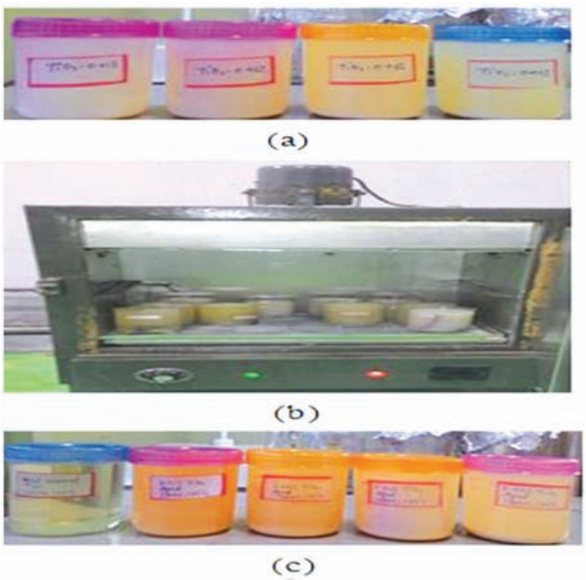

FIG. 2 (A) PREPARED SAMPLES OF NEW MINERAL OIL BASED TIO_2 NANOFLUIDS; (B) ACCELERATED AGEING SAMPLES IN AGEING OVEN; (C) AGED SAMPLES OF TIO_2 NANOFLUIDS

The samples were subjected to ultrasonication for 90 minutes to achieve the stable condition. The fresh samples are described as NT-0, NT-1, NT-2, NT-3 and NT-4, and aged oil samples of AT-0, AT-1, AT-2, AT-3 and AT-4 signifies 0%, 0.01%, 0.02%, 0.03% and 0.04% of nanoparticles respectively. The process for preparation of aged oil samples are carried as on the lines of ASTM D1934 standard [9]. The Figure 1 represents the TEM image of TiO_2 nanopowder and Figure 2 prepared samples before and after ageing for testing.

2.2. AC Breakdown Voltage (BDV)

In determining insulation performance of oil present in the transformer, the BDV plays a vital role. It depends on various factors such as moisture content, acidity, and suspension of solid or ionic particles. Based on the standard IEC 60156, the BDV samples are measured at RTP by using automated AC BDV kit [10]. The spherical electrodes are maintained at 2.5mm gap spacing. The input voltage is varied automatically at the rate of 2 kV/s. The tester generated a mean value of 15 individual tests along with standard deviation from the whole test. The mean value will be the BDV value.

2.3. Volume Resistivity

Volume resistivity of liquid insulating material is one of the critical parameter to determine the conducting particles in the insulating oil and higher volume resistivity implies the less number of free conducting particles in samples. It is a ratio of dc potential gradient (V/cm) to current density (A/cm^2) at a given instant of time. It is analogous to the dc resistance between opposite side of one-centimeter cubic block of oil. The above testing is carried as according to standard ASTM D257 [11].

2.4. Flash Point and Fire Point

Flash point and fire point measurement is used to check the flammability of the insulating oil. Flash point is known as the minimum temperature of mineral oil at which the oil vaporizes due to the heating in a test cell and it catches fire momentarily on the application of pilot ignition known as fire point. In flash point, the fire stays for a very short time, whereas in fire point, the fire stays for a longer duration of time. Flash point & fire point test is carried out at laboratory by Pensky-Martens closed cup apparatus method as per standard ASTM D93 [12].

3.0 RESULTS AND DISCUSSION

3.1. AC Breakdown Voltage

AC breakdown voltage (BDV) tests are carried at RTP. The value of breakdown voltage for new and aged mineral oil in different volume concentrations are tabulated in table 1. In this, the BDV values of new mineral oil based nanofluid are increasing with increase in vol. fractions. Similarly, aged mineral oil also shows linear rise in BDV values in increasing volume fractions. The detailed distribution plot of BDV for different vol. fractions are shown in Figure 3.

TABLE 1
BREAKDOWN VOLTAGE OF NEW AND AGED MINERAL OIL BASED NANOFLUIDS

S. No	Samples		P.V.F (Vol.%)	AC Breakdown voltage (kV/2.5mm)	
	New	Aged		New	Aged
1	NT-0	AT-0	0	30.7	24.7
2	NT-1	AT-1	0.01	35.1	30.7
3	NT-2	AT-2	0.02	39.0	35.2
4	NT-3	AT-3	0.03	42.6	39.2
5	NT-4	AT-4	0.04	45.1	42.8

It is observed that, linear raise in BDV value in both new and aged mineral oil based nanofluids is due to more number of nanoparticles polarized with more concentration of nanoparticles and starts fast capturing of free electron, present in the sample. Decrement in BDV value is due to the ageing of mineral oil that produces the organic compound such as ketone, aldehyde, carboxylic acid along with water which creates a non-uniform electric field and causes a large decrement of BDV in AT-0.But, AT-1 to AT-4, the BDV reduces with increasing concentration of TiO_2 nanoparticles because multimolecular water molecule breaks into single molecule which reduces the non-uniformity of the created electric field [2, 13, 14] and also BDV is increased with increasing concentration of TiO_2 nanoparticles.

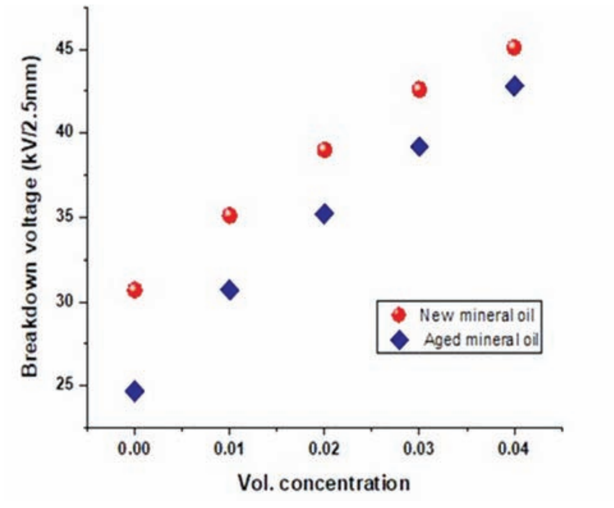

FIG. 3 BREAKDOWN VOLTAGE OF OIL SAMPLES

3.2. Volume Resistivity

Volume resistivity of new and aged mineral oil with and without TiO_2 nanoparticles is measured at 90°C and the values are tabulated in Table 2. Both new (NT-1 to NT-4) as well as aged (AT-1 to AT-4) samples shows linear rise with the increase in concentration of nanoparticles dispersed in the medium compared to base oil samples. Commonly it is observed that, the volume resistivity increases with increasing concentration of TiO_2 nanoparticles for both the new and aged mineral oil.It is due to lower polar contaminants and conducting particles which are attached on the surface of the nanoparticles [14, 15].

TABLE 2
RESISTIVITY OF OIL SAMPLES

S. No	Samples		P.V.F (Vol.%)	Resistivity at 90 °C (ohm-cm)	
	New	Aged		New	Aged
1	NT-0	AT-0	0	1.34 E12	0.05 E12
2	NT-1	AT-1	0.01	5.96 E12	0.55 E12
3	NT-2	AT-2	0.02	9.44 E12	0.77 E12
4	NT-3	AT-3	0.03	19.4E12	6.63 E12
5	NT-4	AT-4	0.04	37.1E12	10.26 E12

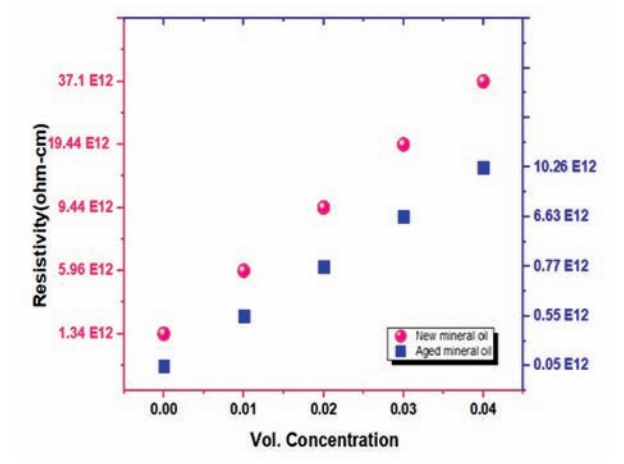

FIG. 4 RESISTIVITY OF OIL SAMPLES WITH VARIOUS CONCENTRATIONS

The comparison of the volume resistivity of the new and aged mineral oil with & without TiO_2 nanoparticles are shown in Figure 4.

3.3. Flash Point and Fire Point

The flash point and fire point values of new & aged mineral oil based TiO_2 nanoparticles are tabulated in Table 3 and 4. The thermal stability properties of the prepared nanofluid samples are studied. The flash point and fire point nature of base mineral oil samples result higher in new mineral oil sample compared to aged one. Flash point and fire point of oil samples are mentioned in Figure 5 and 6.

TABLE 3

FLASH POINT OF OIL SAMPLES

Sl. No.	Samples		P.V.F (Vol.%)	Flash point (°C)	
	New	Aged		New	Aged
1	NT-0	AT-0	0	160	157
2	NT-1	AT-1	0.01	175	174
3	NT-2	AT-2	0.02	181	179
4	NT-3	AT-3	0.03	185	183
5	NT-4	AT-4	0.04	189	187

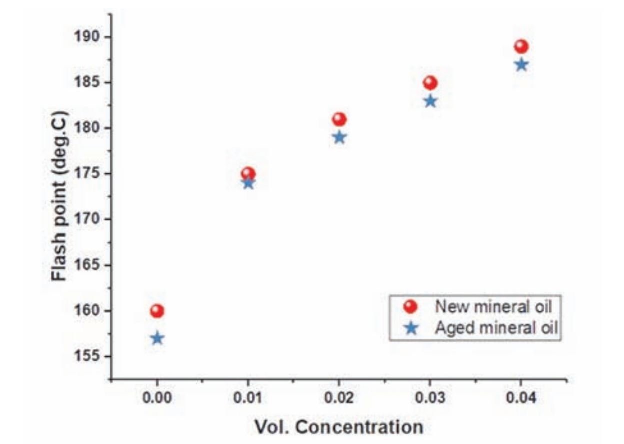

FIG. 5 FLASH POINT OF OIL SAMPLES WITH VARIOUS CONCENTRATIONS

It is observed that flash point and fire point increase linearly with the concentration of nanoparticles in both new and aged mineral oil based nanofluids. Nano particles have the ability to transfer more heat compare to the base liquid.

TABLE 4

FIRE POINT OF OIL SAMPLES

Sl. No.	Samples		P.V.F (Vol.%)	Fire point (°C)	
	New	Aged		New	Aged
1	NT-0	AT-0	0	170	168
2	NT-1	AT-1	0.01	183	182
3	NT-2	AT-2	0.02	190	188
4	NT-3	AT-3	0.03	197	195
5	NT-4	AT-4	0.04	200	198

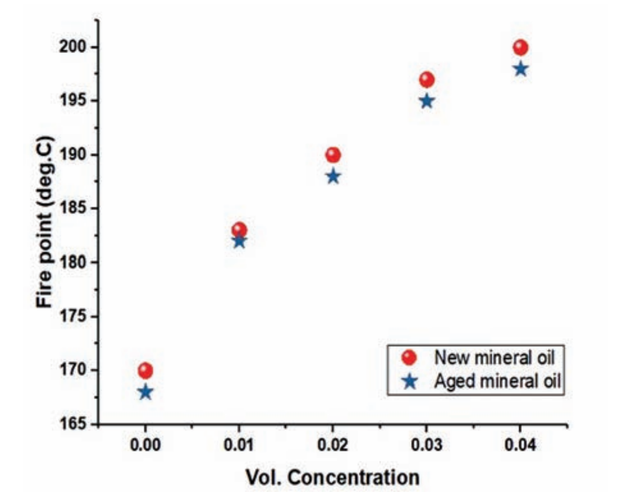

FIG. 6 FIRE POINT OF OIL SAMPLES WITH VARIOUS CONCENTRATIONS

Improved flash point and fire point indicates that thermal stability of mineral oil increases with increasing concentration of TiO_2 nanoparticles compared to base oil samples.

4.0 CONCLUSION

The following conclusions are:

- BDV of new and aged mineral oil with TiO_2 nanoparticles increasing concentration of TiO_2 nanoparticles. It proves that, TiO_2 nanopowder acts as an insulting barrier which hinders the fast moving electron by slower the process of breakdown mechanism.

- Volume resistivity of new and aged mineral oil with TiO_2 nanoparticles increases when it compared with new and aged mineral oil without the presence of TiO_2 nanoparticles.
- Flash point and fire point of new and aged mineral oil with TiO_2 nanoparticles increases when it compared with new and aged mineral oil without the presence of TiO_2 nanoparticles. It proves the TiO_2 nanopowder can increase the thermal stability of the insulating oil.

Based on overall observation, it is concluded that increase in concentration of TiO_2 nanoparticles in new and aged mineral oil, overall critical properties like BDV, Volume resistivity, flash and fire point are enhanced.

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