Improvement on Characteristics of Transformer Oil Using Nanofluids

S. Sumathi, R.Rajesh

Abstract: Transformers plays an important role in the transmission and distribution systems. Even to this day, 75% of high voltage transformer failures are the outcome of improper dielectric insulation. The reliable operation and aging characteristics of the transformers mainly depend on the insulation material. Mineral oil has been used as insulation and coolant for almost a century in power transformers. Due to the development of extra high voltage in the recent scenario and to cope up with the increasing demand in the voltage level a nanofluids based transformer oil is proposed. In this work, nanoparticles such as Aluminium Oxide (Al_2O_3), Molybdenum disulfide (MoS_2) and Titanium Dioxide (TiO_2) are proposed with transformer oil to investigate the various critical characteristics like dielectric strength, acidity, interfacial tension, viscosity, flash point and fire point of the power transformer. The observed results show that the proposed nanofluids based transformer oil produces better performance than the normal transformer oil.

Keywords: Transformer oil, Nano Fluids, Dielectric strength, Acidity, Interfacial Tension, Flash Point, Fire Point, Viscosity.

I. INTRODUCTION

Transformer is the most important and critical component in the transmission and distribution networks which requires a high level of condition monitoring to sustain uninterrupted power supply [1-4]. Many of the transformers in action nowadays are near to or beyond their designed life. Therefore, major attention has been given to the working reliability of these existing units. The existing transformer failure statistics reveals the typical service lifespan of transformers, which failed because of insulation difficulties in 17-18 years, which is nearly half of the predictable lifetime of 35 to 40 years [5], and 75% of transformers failure due to dielectric insulation failure [6].

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The operational consistency and life of transformers mainly depend on the performance of the insulation material. Mineral oil which was used over the century but could not be used for extra high voltage power transformer due to lower breakdown voltage [7-8]. Also, it is not having biodegradability and its availability is diminishing day by day [9].

Solid dielectrics are frequently used as insulation for electrical instruments, as these solid dielectric elements have the property to resist the high electric field. The thermal and electric field withstanding properties of solids dielectric elements are further improved by adding nanoparticles and hybrid nanoparticles [10-11].

Nanodielectrics fluid is expected to meet the good dielectric property, thermal management, and to improve lifespan, after notable advancement in nanotechnology right from its inception in the 1990s. A nanofluid is a well-known term currently in dielectric culture. In fact, Choi at Argonne National Laboratory of USA first presented the word nanofluid in 1995 [12]. Nanofluid or Nanoliquid can be defined as a fluid with nanosized particles homogeneously suspended at very few weight percentages. In high voltage liquid electrical insulation research, the word or term nanofluids and nanoliquids are used equally to mention to any combination of insulation with nanomaterial.

Initially nanomaterial is used in the insulation of solid polymers to increase the life span. The similar method was also applied to dielectric liquid insulation to improve its dielectric and thermal characteristics [13-14]. Initially micron sized particles were used in these liquids for thermal conductivity improvement. The main disadvantage involved with the fluids holding micron-sized particles was the succeeding decrease in the dielectric strength because their density is higher than the density of the continuous phase for which they were added [15-17].

In the recent years, nanofluids have attracted more attention due to their wide range of applications, particularly, in electrical appliances. In this article, nanoparticles such as Aluminium Oxide (Al_2O_3), Molybdenum disulfide (MoS_2) and Titanium Dioxide (TiO_2) are proposed with transformer oil to investigate the various critical characteristics like dielectric strength, acidity, interfacial tension, viscosity, flash point and fire point of the power transformer.

II. SYNTHESIS OF NANOMATERIALS

The commercially available TiO_2, Al_2O_3 and MoS_2 of average grain size of 50-70µm with 97.6-98.7% level of purity were preferred for the experiment. Each particles were separately grinded using ball mill of 100mm diameter and balls of different diameters are employed to achieve maximum collision energy. Steel balls with varying diameter 10mm to 25mm are used and the speed of the drum is maintained about 350 rpm to reduce the grain size of the particles between 60 to 70 nm. The mode of operation is through a variable frequency drive whose frequency is 50 Hz. A shaft with arms, which are rotating at high speed, then agitates the material. The samples of TiO_2, Al_2O_3, and MoS_2 brought with 0.025% weight concentrations are taken in this work and each sample was kept for five hours in a magnetic stirrer.

The technical basics to select concentration at 0.025% level to prepare nanofluid is to achieve better stability, homogenized particles by avoiding higher concentration, and avoiding uneven particle sizes. The low concentration values has been taken based on literature [18-20]. Different low concentration values were also tested but 0.025% concentration produced optimum result compared to other concentration value.

III. MEASUREMENT ON CHARACTERISTICS OF NANOFLUIDS BASED TRANSFORMER OIL

In this section to determine, the characteristics of the transformer oil and nanofluids based transformer oil are measured. Each measurement was carried out five times and mean value is presented to maintain the accuracy of measurement.

III.a Measurement of Dielectric Strength

The breakdown voltage is the most significant factor in defining the oil performance as insulation in transformer. The dielectric strength of the insulating oil is a measure of the oil's ability to withstand electrical stress without failure, pressure, temperature, humidity and electrode configuration. The dielectric strength of the transformer oil should always be high [21-27].Presence of moisture, solid particles, presence of bubbles, and acidity are the important factors which affect the dielectric strength of the oil.

The test method of IEC 156 [28] involves applying an AC voltage at a controlled rate to two electrodes immersed in the insulating fluid. The gap is a specified distance (2 mm). When the current arcs across this gap the voltage recorded at that instant is the dielectric breakdown strength of the insulating liquid. Contaminants such as water, conducting particles and sediment decrease the dielectric strength of the insulating oil.

Figure 1, and Figure 2, shows the schematic diagram of dielectric strength measuring equipment and circuit arrangement of dielectric strength measurement is shown in Figure 3.

The voltage slowly raised and it is kept at 30kV for one minute and it was checked whether oil sample withstand the specified voltage. If it fails at a voltage lesser than 30kV that voltage is reordered as breakdown voltage. Then the voltage raised once again until such time that there is a breakdown, and that particular voltage is recorded. If breakdown strength is less than 30 kV, the oil should be send for reconditioning [29]. Now a day's transformer oil breakdown strength more than 65 kV are available [30 -33]. The experimental results are tabulated in Table 1 which shows TiO_2 based transformer oil has higher breakdown strength compared to Al_2O_3 and MoS_2 based transformer oil. The graphical bar chart comparison of the results is also shown in Figure 4.

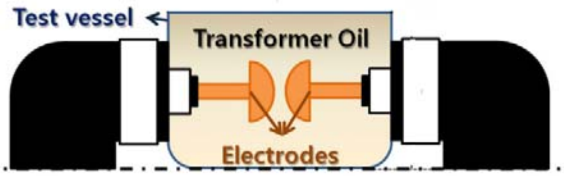

Figure 1. Schematic diagram of front view of dielectric strength measuring equipment.

Figure 2. Schematic diagram of dielectric strength measuring equipment.

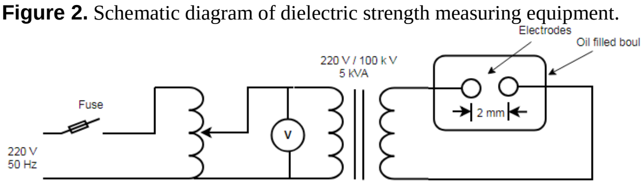

Figure 3. Circuit diagram of dielectric strength test

Table 1. Dielectric strength measurement of transformer oil and nanofluids based transformer oil (in kV).

Transformer oil	TiO_2 with Transformer oil	Al_2O_3 with Transformer oil	MoS_2 with Transformer oil
52.5	72.6	66.2	59.2

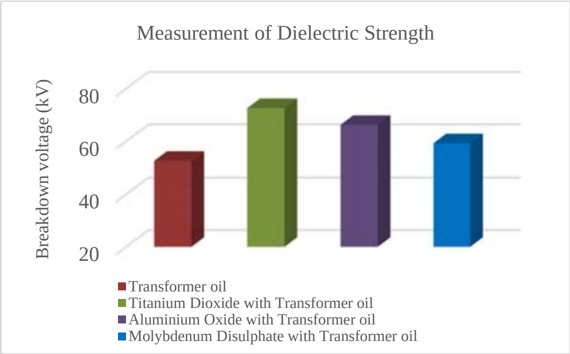

Figure 4. Graphical comparison of dielectric strength between the transformer oil and nanofluids based transformer oil (in kV).

III.b Measurement of Acidity

It is a measure of organic and inorganic acid present in the oil and is expressed in terms of milligrams of KOH required to neutralize the total free acids in 1 gm of oil. The acidity level of transformer oil is measured using standard ASTM D974 [34].

The total acidity of the oil is expressed as neutralization number which is defined as the number of milligrams of potassium hydroxide required to neutralizing completely the acids present in one gram of oil. Acids in the oil originate from oil decomposition/oxidation products. Acids can also come from external sources such as atmospheric contamination. These organic acids damage the insulation system and can produce corrosion inside the transformer when water is present. The new transformer oil contains practically no acids if properly refined. In pure transformer oil, there should be no presence of acid content. However, in most of the cases, there will be some acid content. The result expresses the number of mg of KOH required to neutralize the acidity of 1 gm of sample. It is calculated as follows:

$$\text{Total acidity} = (A \times N \times 56.1)/W \text{ mg of KOH/gm of oil} \quad (1)$$

Where,

A - Quantity of KOH solution in ml used in titration

N - Normality of the KOH solution used for titration

W - Weight of the sample

Table 2 shows the acidity comparison between transformer oil and nanofluids based transformer oil. The result shows that the nanofluid based transformer oil has low acid content compared to normal transformer oil. So there will be no chance of corrosion occurring in transformers. The graphical bar chart comparison of the results is shown in Figure 5.

Table 2. Acidity measurement of transformer oil and nanofluids based transformer oil (in mgKOH/gm).

Transformer oil	TiO_2 with Transformer oil	Al_2O_3 with Transformer oil	MoS_2 with Transformer oil
0.25	0.12	0.21	0.18

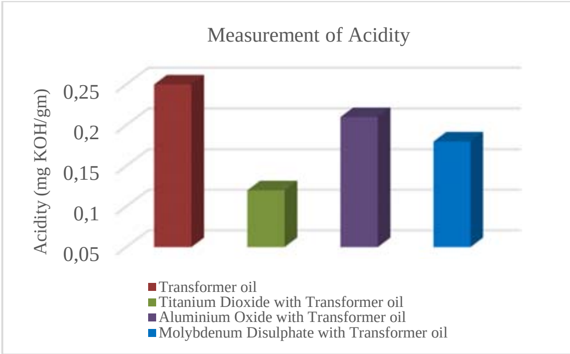

Figure 5. Graphical comparison of acidity between the transformer oil and nanofluids based transformer oil (in mgKOH/gm).

III.c Measurement of Interfacial Tension

Interfacial tension is the measure of molecular attractive force between the oil and water molecules at their interfacial level. By interfacial tension test is possible to determine the soluble polar contaminants present in the oil, which reduces the molecular attraction force between the oil and water. The pure transformer oil should have minimum 18 dynes/cm and maximum 40 dynes/cm. The interfacial tension of transformer oil is measured using ASTM D971 [35] standard. Tensiometer is used to determine the interfacial tension of the transformer oil, which is working based on the Du Nuoy principle.

Table 3 shows the experimental results of the interfacial tension of transformer oil and nanofluids based transformer oil. The results showed that nanofluids based TiO_2 and Al_2O_3 have higher interfacial tension. MoS_2 based transformer oil has low interfacial tension when compared to transformer oil. The graphical bar chart comparison of the results is given in Figure 6.

Table 3. Interfacial tension measurement of transformer oil and nanofluids based transformer oil (in Dynes/cm).

Transformer oil	TiO_2 with Transformer oil	Al_2O_3 with Transformer oil	MoS_2 with Transformer oil
25	40	30	20

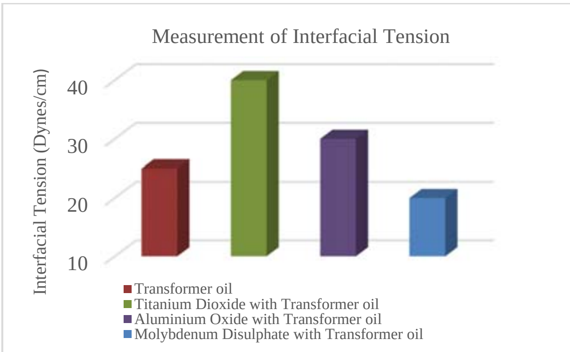

Figure 6. Graphical comparison of interfacial tension between the transformer oil and nanofluids based transformer oil (in Dynes/cm).

III.d Measurement of Flash Point

The flash point of a chemical or any volatile materials in the lowest temperature at which it can evaporate to form an ignitable mixture or combustible concentration in the air. A minimum flash point is specified in order to prevent the risk of fire that might be the result of accidental ignition. For a good transformer oil, the flash point should be higher than 140°C. Flash point of various nanomaterials based transformer oil is measured by cleaveland open cup flash point tester using ASTM D93 [36] Standard as shown in Figure 7.

Table 4 shows the test results of flash point of transformer oil and nanofluids based transformer oil. The results show that all nanofluids based transformer oil has higher flash point when compared to transformer oil. The graphical bar chart comparison of the results is shown in Figure 8.

Figure 7. Schematic diagram of cleaveland open cup flash point tester.

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Table 4. Flash point measurement of transformer oil and nanofluids based transformer oil (in ºC).

Transformer oil	TiO_2 with Transformer oil	Al_2O_3 with Transformer oil	MoS_2 with Transformer oil
142	157	152	148

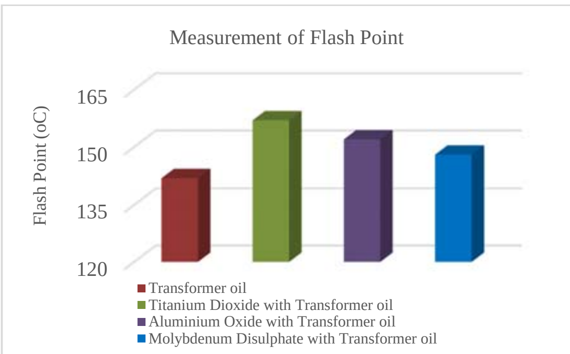

Figure 8. Graphical comparison of flash point between the transformer oil and nanofluids based transformer oil (in ºC).

III.e Measurement of Fire Point

Fire point is the lowest temperature at which the vapour of the oil burns continuously for at least five seconds, when a tiny flame is brought near it.

For a good transformer oil, the fire point should be higher than 150°C. Cleaveland open cup fire point tester measures fire point of various nanomaterials based transformer oil. The test result in Table 5 shows that all nanofluids based transformer oil has higher fire point when compared to transformer oil. Figure 9 shows the blue flame of transformer oil during fire point tests. The graphical bar chart comparison results are shown in Figure 10.

Figure 9. Blue flame produced in transformer oil.

Table 5. Fire point measurement of transformer oil and nanofluids based transformer oil (in ºC).

Transformer oil	TiO_2 with Transformer oil	Al_2O_3 with Transformer oil	MoS_2 with Transformer oil
150	164	155	152

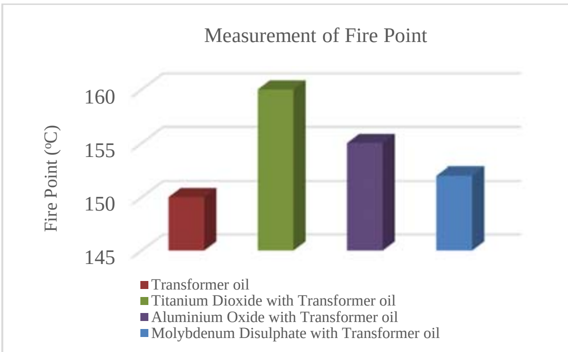

Figure 10. Graphical comparison of fire point between the transformer oil and nanofluids based transformer oil (in ºC).

III.f Measurement of Viscosity

Viscosity is the property of a fluid that determines its resistance to flow. It is an indicator of flow ability of a lubricating oil and the lowest viscosity has greater the flow ability. It is mainly due to the forces of cohesion between the molecules of lubricating oil [37]. Viscosity is measured using IS 1448(P-25):1976 [38] standard.

For a good transformer oil, the viscosity should be low. Viscosity is measured using Red Wood Viscometer as shown in Figure 11.

The experimental results of transformer oil and nanofluid based transformer oil are shown in Table 6. The graphical comparison of viscosity at different temperatures is represented in Figure 12, Figure 13, Figure 14, and Figure 15 respectively. The result shows that Al_2O_3 based transformer oil has high viscosity and TiO_2 based transformer oil has low viscosity compared to the transformer oil.

Figure 11. Schematic diagram of red wood viscometer.

Table 6. Viscosity measurement of transformer oil and nanofluids based transformer oil.

Temperature (°C)	Transformer oil	TiO_2 with Transformer oil	Al_2O_3 with Transformer oil	MoS_2 with Transformer oil
50	73.26	79.61	118.29	98.21
60	65.80	58.58	106.29	87.62
70	51.25	53.04	96.95	79.47
80	44.22	47.35	89.58	73.92

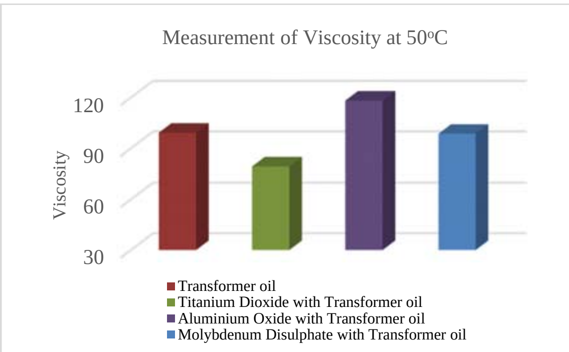

Figure 12. Graphical comparison of dynamic viscosity between the transformer oil and nanofluids based transformer oil at 50°C.

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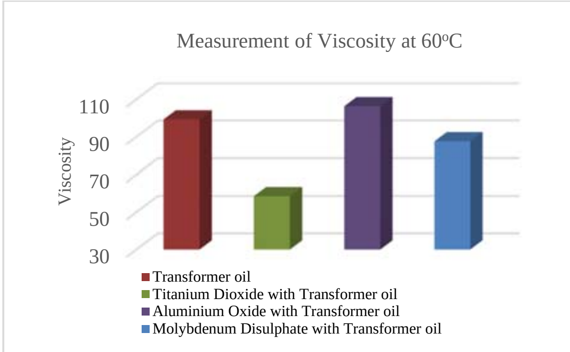

Figure 13. Graphical comparison of dynamic viscosity between the transformer oil and nanofluids based transformer oil at 60°C.

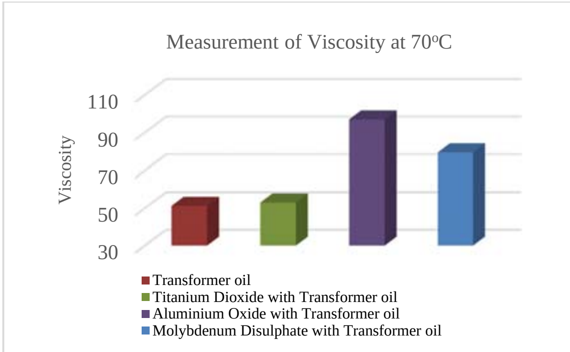

Figure 14. Graphical comparison of dynamic viscosity between the transformer oil and nanofluids based transformer oil at 70°C.

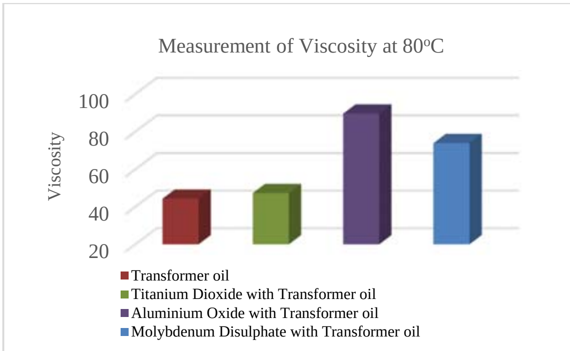

Figure 15. Graphical comparison of dynamic viscosity between the transformer oil and nanofluids based transformer oil at 80°C.

IV CONCLUSION

In order to enhance the properties of transformer oil nanofluids based transformer oil was prepared using semiconductor materials like TiO_2, MoS_2 and insulator like Al_2O_3. Nanomaterials were synthesized in the transformer oil with 0.025% of concentrations using magnetic stirrer. Measurements of Breakdown voltage (IEC 156), Acidity (ASTM D974), Interfacial tension (ASTM D971), Flash point (ASTM D93 - 12), Fire point (ASTM D93 - 12), and Viscosity (IS 1448(P-25):1976) tests were performed according to the standards. TiO_2 based transformer oil has given better properties than MoS_2 and Al_2O_3 based transformer oil, since TiO_2 is stable against higher strength of the electric field, and relatively high dielectric strength.

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Conflict of Interest:

The authors declare that they have no conflict of interest.

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