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Investigation on Electrical characteristics of Mineral oil using nanoparticles

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Abstract: Nanotechnology has the potential to be used in the transformer industry to enhance material properties which may lead to an efficient design of transformers and reduced manufacturing costs. Several types of nanoparticles were selected and added to mineral oil. Breakdown voltage, streamer propagation velocity, oxidation stability, permittivity, electrical resistivity, and dissipation factor were measured and studied. Results show that the dielectric properties of a modified liquid are strongly influenced by the type of nanoparticles added. With the addition of one type of nanoparticles, the breakdown voltage of the liquid is much increased. Transformer oil is refined electrical insulating oil, which is extremely stable at high temperatures and possesses excellent electrical insulating properties. These special types of oils are widely used in high-voltage apparatuses such as power transformers, high-voltage capacitors, and circuit breakers. Traditionally, mineral oils have been most commonly used as a coolant or as an electrical insulation medium. However, the main concern related to mineral oil is overheating, overloading, and short circuits that reduce the shelf life of the transformer unit and restrict its function as a reliable coolant. Moreover, other factors such as high electrical insulation requirements, safety, and economic aspects need to be considered for the development of new insulating liquid material. Nanofluids have become one of the alternatives for the existing products available in the market because of their high thermo-physical and good dielectric properties. This review focuses on the status of nanofluids, the effect of different nanoparticles to enhance the dielectric as well as the heat transfer properties of nanofluids. The thermophysical properties of the newly developed transformer oil-based nanofluids were reported in comparison with different oils. Finally, future directions and challenges need to be addressed. Transformers are considered the heart of the power system, and the majority of the transformers are oil filled in the existing electrical system. In transformers, presently, mineral oil is used as a cooling and insulating medium, which is having good dielectric strength, high flash point & fire point, and high DC resistivity with low loss factor properties. However, it is losing acceptance in the electrical industry due to non-biodegradable petroleum by-products which are causing harm to the environment. Therefore, present studies are concentrated on biodegradable and eco-friendly insulating oil, such as natural ester oil and vegetable oil. It is considered to be the alternative to traditional insulating oil with the investigation of its electrical, thermal, and physical properties. In addition to that, with the recent development of nanotechnology, the above studies are being made with a mixture of nanomaterial and the alternative insulating oil, called nano-fluid. It provides an effective way to enhance the performance characteristics of biodegradable insulating oil. In this paper, critical parameters such as 'Breakdown Voltage (BDV),' 'Flashpoint' and 'DC resistivity' of Rice bran oil-based Titanium Oxide (TiO2) semi-conductive nano-fluids are investigated for probable use as an alternative to traditional mineral oil in the transformer.

IndexTerms : transformer oil; Nano fluids; dielectric strength; heat transfer; coolant

Introduction

During the last 20 years, the search for nanotechnology applications has become one of the busiest in science, engineering, and manufacturing. New nanotechnology-based materials with superior properties have been developed and are already used in many everyday products and processes. Considering that the liquid insulation of transformers acts not only as an electrical insulator but also as a refrigerant, it seems feasible that the application of nanotechnology could lead to liquids with superior properties that increase the reliability of the transformer. With an increase in transformer rating and size, it is necessary to design and develop a compact, cost-effective and reliable insulation system. The cause of transformer failures by the incipient discharge that happens defects present in the insulation system. The growing power demand has been pushed towards the demand for high-performing insulating material, which can make the high voltage (HV) power apparatus compact and reliable in the system. Both the solid and liquid insulation combination is frequently used for the insulation of the transformer. In oil-filled transformers, this combined insulation system provides satisfactory dielectric strength during high voltage stress, suitable cooling pathways for the dissipation of heat, and sufficient winding mechanical strength [1]. However, many transformers fail at half of the expected life due to their insulation failure which is mainly developed due to the failure of transformer oil. Mineral oils are widely used as transformer oil for their excellent thermal and insulation properties. But slowly, mineral oil is trailing its superiority due to its lower bio-degradation property. It also might pollute soil and water quality during leakages; therefore, it is not environment-friendly. Several studies are suggested that natural ester oil is an alternate insulating oil because it is low-cost, recyclable, environment-friendly, and slower aging rate. Present studies have also suggested that the nano-fluid, which is a mixture of fluid such as transformer oil, ester oil, and vegetable oil with nanomaterial, provides a successful path to enhance the critical properties of insulating fluids. It has been reported that the cooling performance of transformers is also improved by nanoparticles along with the enhancement in dielectric properties [4]. This paper focused on the investigation of dielectric and thermal properties of semiconductive TiO2 nano-fluid which is a mixture of eco-friendly rice bran oil as the base insulating oil with different volume fractions of TiO2 nanomaterial.

I. EXPERIMENTAL SETUP

A. Breakdown voltage Test

For measuring the BDV of transformer oil, a portable BDV measuring kit is generally available on-site. In this kit, oil is filled in a test cell in which one pair of electrodes are fixed with a gap of 2.5mm or 4.5 mm between them. The voltage between two electrodes is increased at a rate of rise of 2kV/sec and observed the voltage at which sparking/breakdown starts between the electrodes. The observed voltage is recorded as the Dielectric Strength or BDV of transformer oil, which should be within the specified limit for the safe operation of the transformer. The test set up with a photograph of the BDV test set with test cell . BDV test is one of the most common tests done on all insulating fluids, and it is a test of primary choice because it takes very less time to an overall assessment of the condition of the insulating liquid, before carrying out extensive series of other tests such as humidity, moisture, flash point & fire point, DC resistivity test, etc. [10]

B. Flash Point test:

The minimum temperature at which the insulating oil generates sufficient vapor so that it can create a flash during the contact of fire is considered as the flash point. After that, when the insulating oil catches fire and it continues for at least five seconds considered a fire point. The Flash Point test for nano-fluids has been carried out on the lines of ASTM D93 standard using Pen-sky Martens closed cup flash point tester[11].

C. Loss Tangent:

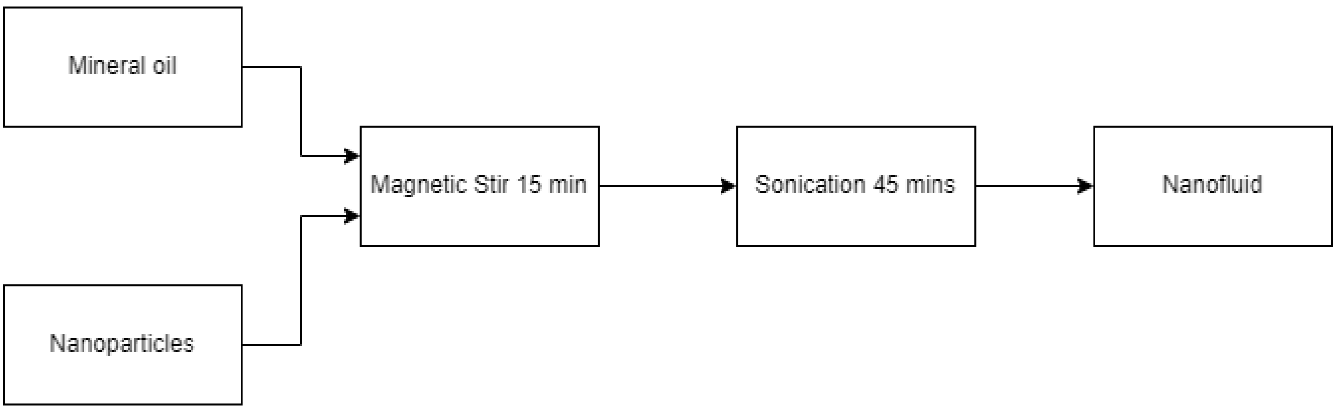
The leakage current through oil is measured in terms of loss tangent. The presence of contaminations like resins, varnish, or other impurities in insulating oil is also reflected in the loss angle. The loss tangent test of nano-fluid has been carried out on the lines of the ASTM D924 standard using a digital loss tangent measurement setup[12].

D. DC Resistivity:

The ratio of the DC potential gradient in volts per centimeter paralleling the current flow within the specimen, to the current density in amperes per square centimeter at a given instant of time is known as resistivity in ohm-centimeters of a liquid. It is equal to the resistance between opposite faces of a cubic centimeter of a liquid filled in a test cell having its specific dimension [13]. The DC resistivity test of nano-fluids has been carried out on the lines of the ASTM D1169 standard using the DC resistivity oil test setup [13]. The set voltage of 500V/mm is applied to the three-electrode cell filled with samples at 27_oC and 90_oC.

II. PREPARATION OF NANOFLUIDS

For the preparation of the required NF, an amount of 0.01wt.% of TiO_2 NPs is considered to disperse in the base fluid. Firstly, the MO is taken as a base fluid, and 0.01 wt.% NPS are taken and dispersed in the MO. For proper mixing, ultrasonication is carried out for 2-3 hours, whereby the particles are uniformly distributed in the base fluid. After the process of ultrasonication, the prepared NF is kept in a vacuum oven to dry out an appreciable amount of moisture. The process of NF preparation is shown in fig. 2. The MO and MO-NF samples prepared are shown in fig. 2. It should be noted that the exact amount of nanoparticles must be added for proper measurement and the base fluid should be free from moisture as much as possible. To understand the heat transfer behavior of the prepared NF, thermal conductivity and viscosity studies are carried out and the results are compared with the base fluid.



III. RESULTS AND DISCUSSIONS

A. BDV test: The numbers were obtained from the automated BDV test set running at standard pressure and temperature. Test of the BDV on nanofluid

Table II & Table III displays some sample outcomes. According to the BDV results and its increased percentage, the volume fraction of nanoparticles increases linearly with the dielectric strength of fluid. Among them, NF3 outperformed the base fluid in terms of dielectric strength.

TABLE II. BDV RESULTS OF PURE & AGED TRANSFORMER OIL

SAMPLES	BREAKDOWN VOLTAGE(KV)
SAMPLE 1	60.2
SAMPLE 2	56.2
SAMPLE 3	50.3
SAMPLE 4	49.2
SAMPLE B	36.5
SAMPLE C	34.5

TABLE III. ENHANCED RESULTS USING NANOPOWDER

SAMPLES	BDV(KV)	% ENHANCED
Base oil	40.08	-
NF1	45.20	47.30
NF2	54.30	77.80
NF3	67.40	120.30

B. Flash Point test:
Table IV displays the samples flash points and boosted percentages. Although the lower volume fraction sample NF1 has a lower flash point than the base fluid, the other samples all have flash points that are greater than the base fluid, ensuring that even at higher temperatures; the insulating fluids can function without flash or fire.

TABLE IV. FLASH POINT TEST RESULTS

SAMPLES	FLASH POINT (Degree Celcius)	% Enhanced
Base oil	260	-
NF1	263	-0.341
NF2	269	1.592
NF3	274	3.059

C. Loss Tangent:
Table V lists the loss tangent measured in 90oC as of the standards. The characteristics of tan degradation. Less dielectric loss in transformers may be caused by the increased volume fraction of the sample.

TABLE V. LOSS TANGENT TEST RESULTS

Samples	Tan Delta	% Decreased
Base oil	1.7 E-3	-
NF1	1.42 E-3	29.92
NF2	1.2 E-3	37.82
NF3	1.1 E-3	43.21

D. DC Resistivity:

Table VI displays the samples DC volume resistivity at room temperature and 90oC.The resistivity was improved by the nanoparticles in both the top load and lower operating temperature conditions of the transformer.

TABLE VI. DC Resistivity Test Results

Samples	Resistivity(ohm-cm)		% Enhanced	
	@RTP	@90 Degree C	@RTP	@90Degree C
Base oil	6.20 E12	0.49 E12	-	-
NF1	6.71 E12	0.62 E12	5	9.42
NF2	9.23 E12	0.79 E12	44	28.79
NF3	13.03 E12	1.18 E12	93	97.73

IV. CONCLUSION

Although research on the thermophysical, dielectric, and stability improvements of transformer oil has been done, it is still difficult and presents new research prospects using nanoparticles has shown intriguing characteristics to improve these properties of transformer oil, ranging from totally conductive to insulating nanoparticles. The invention of transformer oil might enhance the performance of the transformer itself and perhaps result in a smaller or more compact unit overall.

Even though this research has been presented and examined, there are still other problems that need to be resolved.

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