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Experimental Investigation to Study Impact of Low-Concentration Hybrid ZnO and TiO_2 Nanoparticles on Thermo-Physical Properties of Transformer Oil

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Abstract

Transformer oil (Naphthenic Oil) is vital for the safe and efficient operation of transformer systems. The current experimental investigation mainly concentrates on the impact of low-concentration TiO2 and ZnO hybrid nanoparticles of 0.001 and 0.005 vol. % concentrations on the thermophysical properties of Naphthenic oil (Transformer oil). This investigation separately determines the flash and fire point, viscosity, thermal conductivity, pH, breakdown voltage and strength, and zeta potential analysis for both fresh and used Naphthenic oil and adding hybrid nanoparticles. The addition of hybrid nanoparticles to fresh and used Naphthenic oil increases the flash and fire points, viscosity, thermal conductivity, and pH values but the breakdown strength of the fresh oil decreases and the used oil increases.

Keywords: *Breakdown Voltage, Hybrid Nanoparticles, Thermophysical Properties, Transformer Oil*

1.0 Introduction

The ongoing development of power transformers and associated machinery necessitates advances in lubricating technology to improve efficiency, longevity, and performance. This study delves into the fascinating field of nanotechnology, focusing on how adding nanoparticles to transformer oils could enhance their thermophysical properties[1]. Transformer oil plays a vital part in sustaining the ideal thermophysical properties of transformers, given their varied and rigorous operating circumstances. Research has been started on nanoparticles as an approach to improve oil efficiency. This study aims to extensively explore the effects of nanoparticle additions on transformer oil's thermophysical properties. By utilizing their size-dependent characteristics, nanoparticles can increase transformer oil's heat conductivity[2]. It is essential to improve heat transfer characteristics while maintaining or increasing insulation strength since oil is used by the transformer as both an electrical insulator and a cooling fluid. A slight enhancement in either one or both of the above-described situations leads to increased utilization of a transformer's capacity, an extended lifespan, and significantly reduced construction expenses. Given that transformer oil is used in a cooling cycle, researchers in the transformer sector are considering the idea of using nanoparticles in it. The many disadvantages of using additives in transformer oil, such as oil oxidation, ageing of insulating materials, sedimentation, and sludge development, call for more precise theoretical and practical studies[3].

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2.0 Literature Review

Suhaib Ahmad Khan, *et al.*,[4] investigated that GO-based nanofluids, with up to 3.77% improved thermal conductivity, upgrade natural and synthetic ester oils, outperforming TiO_2 counterparts. Optimal cooling solution: GO nanofluids, chemically inert and resistant to oxidation, offer superior thermal conductivity and viscosity, practical application: recognized as a promising alternative, GO-based nanofluids present a viable solution for transformer cooling, ensuring efficient performance and longevity.

C. Choi, *et al.*,[5] investigated that Al_2O_3 and AlN nanoparticles in transformer oil enhance thermal conductivity, with a 0.5% volume fraction of AlN increasing it by 8% and improving the overall heat transfer coefficient by 20%. Surfactant precision: Controlling surfactant levels is crucial; excess surfactant harms heat transfer and stability, emphasizing the need for precise management in nanoparticle-oil suspensions. Next-gen heat transfer fluids.

Fontes D.H., *et al.*,[6] investigated the study which focuses on the experimental investigation of the thermophysical properties of coconut oil, soybean oil, and palm oil-based hybrid nanofluids suspended with Al_2O_3-TiO_2 nanoparticles at a mass concentration of 0.2, 0.4, and 0.6%. The characterization of the Al_2O_3 and TiO_2 nanoparticles indicated that the sizes of the nanoparticles are within the range specified in the material datasheet provided by Sigma Aldrich.

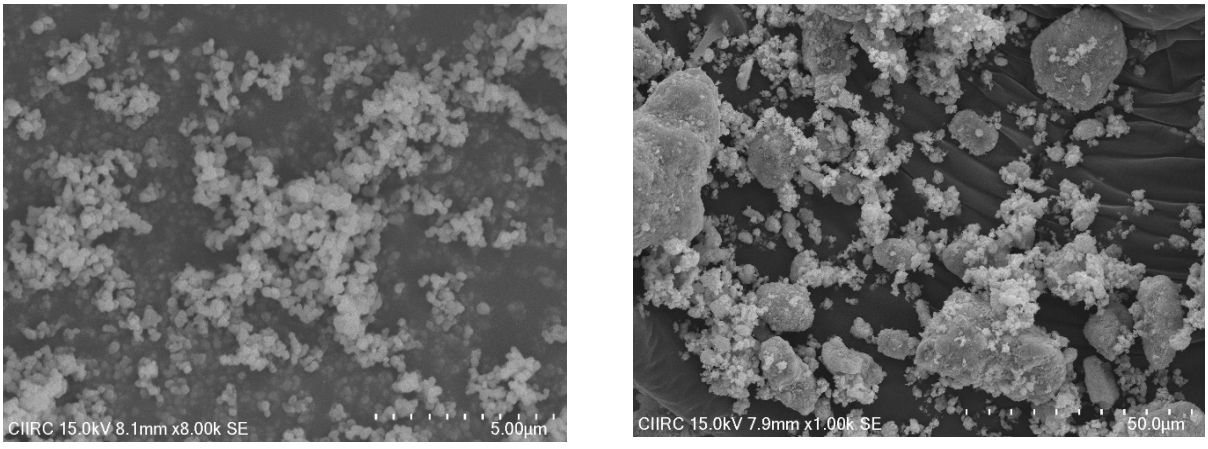
Ghasemi *et al.*,[7] investigated the lightning impulse breakdown voltage of magnetic nanofluids based on transformer mineral oil for use in power systems. These magnetic nanofluids are obtained from the dispersion of magnetic nanoparticles (Fe_3O_4) within transformer oil, serving as the base fluid. The Fe_3O_4 nanoparticles were synthesized using a coprecipitation method, coated with a surfactant, and dispersed within the uninhibited transformer mineral oil NYTRO LIBRA using an ultrasonic processor.

Charishma Almeida, *et al.*,[8] examined the impact of increased electricity demand on the development of transmission and distribution systems in electrical networks. They experimentally investigated graphene-transformer oil nanofluid's thermophysical and electrical properties at three weight percentage concentrations (0.01%, 0.03%, and 0.05%). The experiments aimed to determine viscosity, surface tension, density, specific resistance, electrical conductivity, and dielectric dissipation across temperatures ranging from 20°C to 90°C.

From the literature, there is a scope for studying the impact of low-concentration hybrid nanoparticles on the thermophysical properties of transformer (Naphthenic) oil. The current investigation mainly focused on the impact of 0.001 and 0.005 vol.% concentration (TiO_2+ZnO) hybrid nanoparticles on the thermal properties of Naphthenic oil.

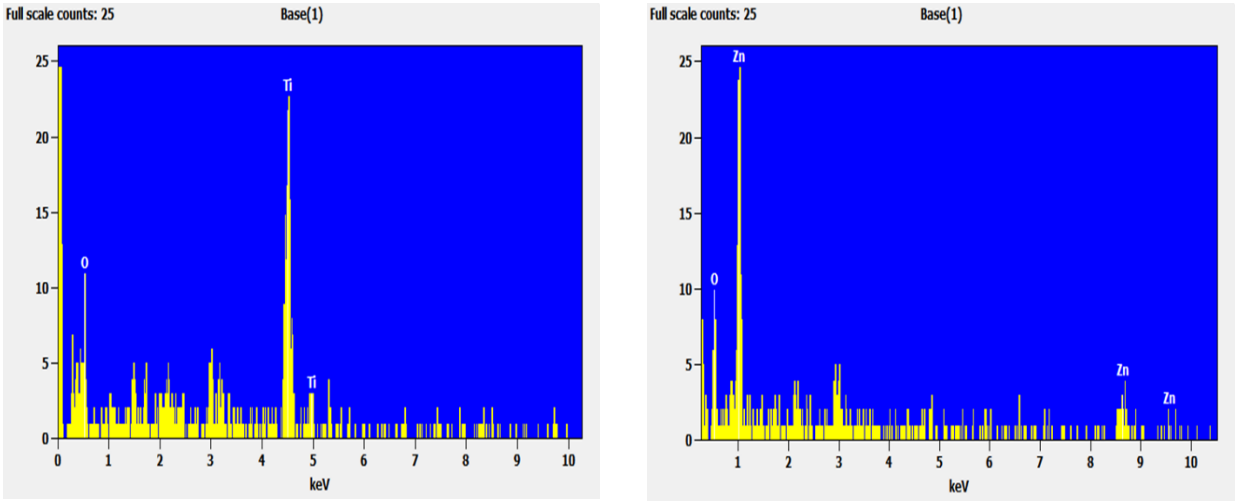
3.0 Nanomaterials Characterization

The Ad Nano technology Shimoga Karnataka India supplies the TiO_2 and ZnO nanoscale materials, which have a size of less than 100 nm and are 99% pure. The



(a) (b)

Figure 1. SEM images of TiO_2 and ZnO nanoparticles.



(a) **(b)**

Figure 2. EDX analysis of **(a)** TiO_2 and **(b)** ZnO nanoparticles.

Table 1. Thermo-Physical properties of TiO_2 and ZnO

Parameter	TiO_2	ZnO
Particle Average size in nm < 100		< 100
Density, ρ in kg/m^3	900	540
Thermal Conductivity, k in W/m-K	11	60
Specific Heat, Cp in J/kg K	700	500
Colour	White	Gray
Morphology	Nearly Spherical	Nearly Cylindrical
Purity	99%	99%

characteristics of the TiO_2 and ZnO nanoparticles used in this experiment are shown in Table 1. To understand and cross-verify the TiO_2 and ZnO morphology and purity conducted Scanning Electronic Microscope (SEM), X-ray Diffraction (XRD), and Energy Dispersive X-ray Spectroscopy Analysis (EDX) using VEGA3 TESCON at Jyothi Institute of Technology (CIIRC) Bengaluru India. Figure 1 (a) and (b) shows the SEM images of TiO_2 and ZnO nanoparticles. From the images, most TiO_2 nanoparticles had a smooth, spherical appearance. It was discovered that the particle size distribution was narrow, and the average size was less than 100 nm. There was very little agglomeration, which suggests that the preparation technique produced good dispersion. The ZnO nanoparticles have rough surfaces and a rod-like shape. The ZnO nanorods had a diameter of less than 100 nm. There was some agglomeration, which indicates that better dispersion methods are required.

EDX profiles are shown in Figure 2 (a) and (b) show that no other elements are present in the TiO_2 and ZnO nanoparticles. The two main components of interest for TiO_2 are titanium (Ti) and oxygen (O). We will see peaks related to O (O-Kα at approximately 0.52 keV) and Ti (such as Ti-Kα at approximately 4.51 keV). Similarly, Zn-Lα at around 1.01 keV, Zn-Kα at around 8.64 keV, and O-Kα at around 0.52 keV. The detailed composition of the NPs in terms of elements by weight and atomic percentage is represented in Table 2.

Figure 3 (a) and (b) show the XRD analysis of TiO_2 and ZnO nanoparticles. The XRD pattern suggests that the

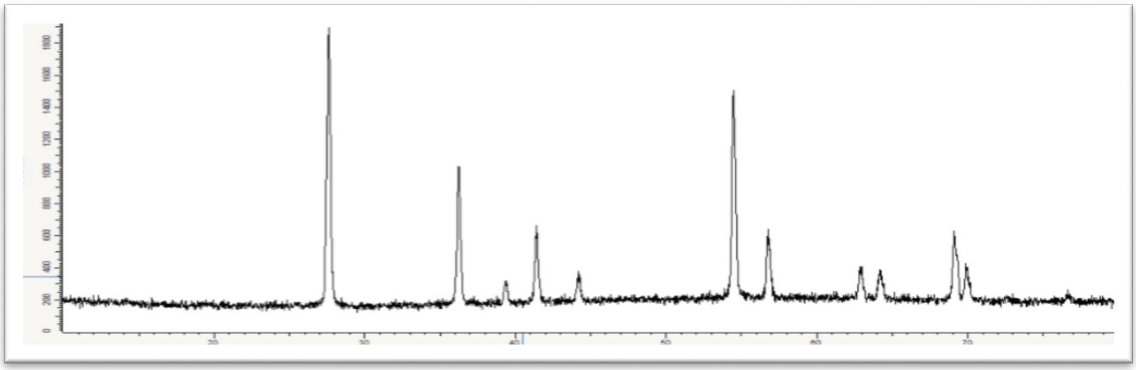
Table 2. EDX analysis report

TiO_2		ZnO	
Ti (K)	**O (K)**	**Zn (K)**	**O (K)**
Elements by weight %			
85.83	14.17	93.70	6.30
Elements by Atomic %			
66.93	33.07	78.45	21.55

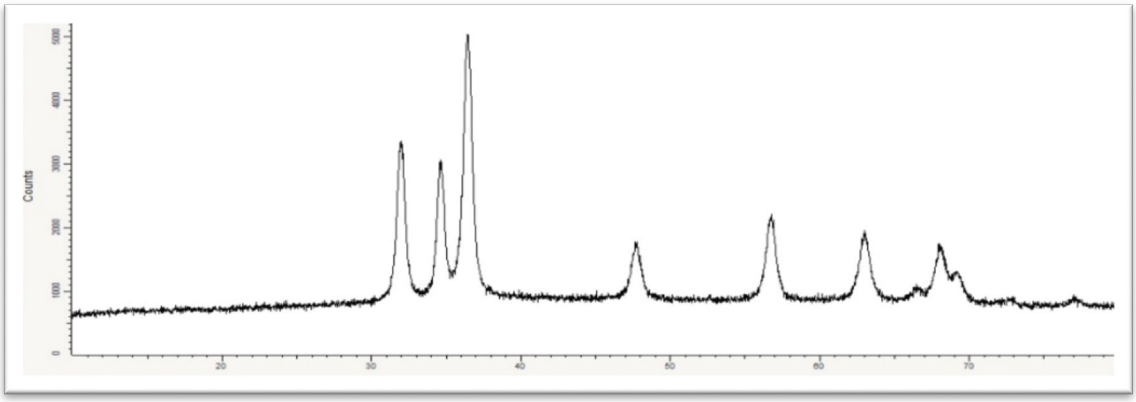
TiO_2 nanoparticles are in the anatase phase and crystal in structure. From the XRD pattern provided, the prominent peaks appear at the following 2θ positions (approximate values): 81.29° and Anatase of TiO_2 (JCPDS No. 21-1272): 70.3° (116). Rutile TiO_2 (JCPDS No. 21-1276): 69.0° (301). Comparing these values with the observed peaks, the positions closely match the anatase phase of TiO_2. The estimated crystallite size is approximately 79.7 nm based on the Scherrer equation (Equation (1)). Similarly, from the XRD pattern provided, the prominent peaks appear at the following 2θ positions 68.0°. ZnO typically crystallizes in the hexagonal wurtzite structure. ZnO (Wurtzite Structure) (JCPDS No. 36-1451): 68.00° (112). The estimated crystallite size is approximately 81.2 nm based on the Scherrer equation[9].

$$D = \frac{K\lambda}{\beta cos\theta} \quad (1)$$

Where:
D is the average crystallite size.
K is the shape factor, typically around 0.9.



(a)



(b)

Figure 3. XRD of **(a)** TiO_2 and **(b)** ZnO nanoparticles.

λ is the wavelength of the X-ray source (Cu Kα radiation, λ=1.5418 Å).

β is the Full Width at Half Maximum (FWHM) of the peak in radians.

θ is the Bragg angle.

4.0 Preparation of Hybrid Nanofluid

The first important stage in experimental research is the preparation of nanofluid. In this work, a two-step approach is used to create a TiO_2+ZnO+Napthenic oil-based nanofluid. Special mixing and stabilization techniques of the nanoparticles are necessary to create the nanofluid by distributing them in a base fluid. In this study, the solution was stabilized using three efficient approaches to prevent the sedimentation of nanoparticles. These techniques include the use of mechanical stirring, ultrasonic processors, and the inclusion of surface activators or surfactants. Making use of nanofluids is a crucial initial phase in experimental research. This work prepares a TiO_2+ZnO+Naphthenic oil-based nanofluid in two steps. Praveenkumara B M *et al.*,[10] claims that the two-step process is more feasible and cost-effective than the one-step method for creating a stable nanofluid. In this investigation, the target volume concentrations were 0.001 and 0.005 vol. %. Figure 4 represents the schematic way of preparation of TiO_2+ZnO+Napthenic

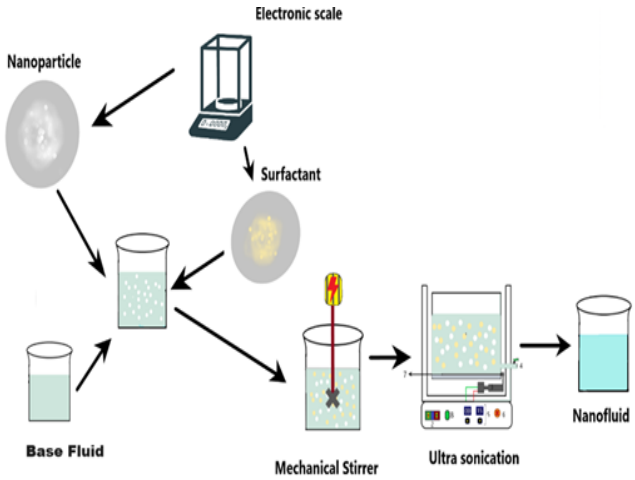


Figure 4. Two-step method for nanofluid preparation.

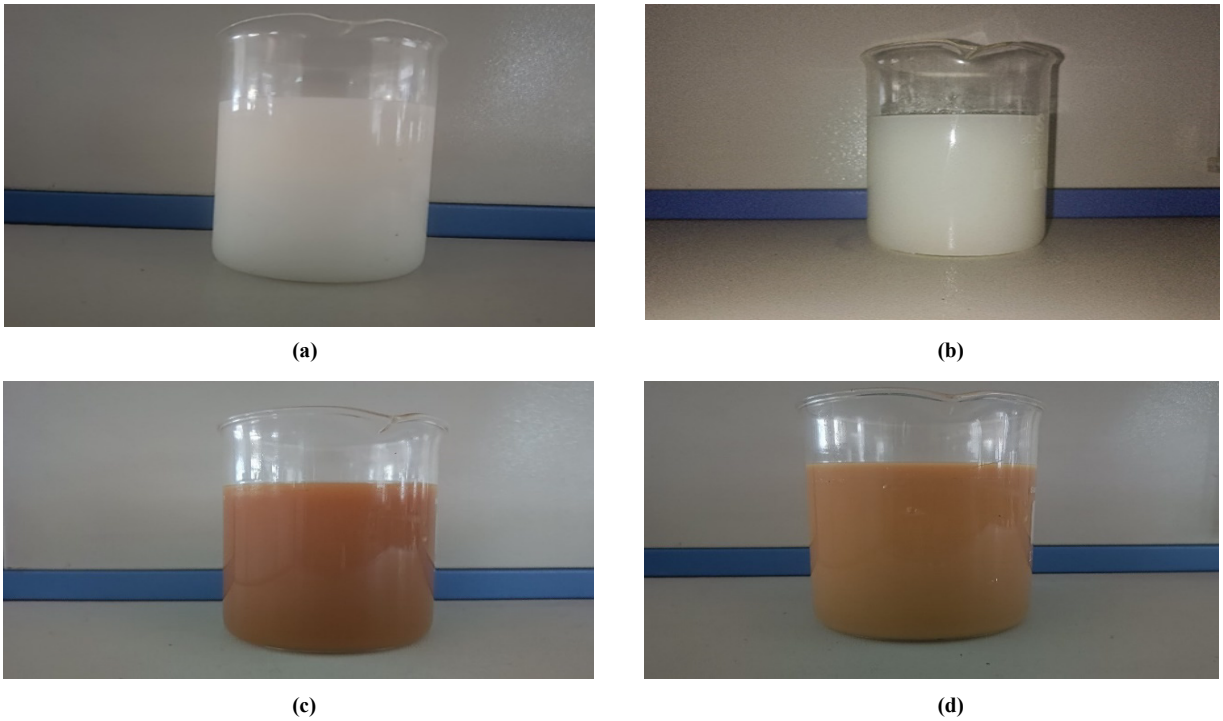


Figure 5. **(a)** Fresh Naphthenic oil with 0.001 vol.% of (TiO_2+ZnO) nanoparticles. **(b)** Fresh Naphthenic oil with 0.005 vol.% of (TiO_2+ZnO) nanoparticles. **(c)** Used Naphthenic oil with 0.001 vol.% of (TiO_2+ZnO) nanoparticles. **(d)** Used Naphthenic oil with 0.005 vol.% of (TiO_2+ZnO)

oil-based nanofluid using a two-step method of various concentrations. In this two-step technique, nanoparticles were weighed with the electronic scale (least count 0.01 mg) based on the volume per cent and directly dispersed in base fluid (naphthenic oil) of 1 litre. To stabilize the nanofluid by adding 0.025% weight of Sodium Dodecyl Sulphate (SDS) to the base fluid. A mechanical stirrer was used for three hours to disperse homogeneously the particles in the base fluid. After completion of the mechanical stirring fluid is shifted to an Ultrasonic bath-type sonicator (capacity = 45-liter, Power = 480 W, Frequency = 37 kHz, Input supply AC =230V and 50Hz) for homogenizing the mixture. The fluid is sonicated for about 3 hours to get better stability. Figure 5 shows the oil samples with hybrid nanoparticles.

Volume Concentration of nanofluid[10]:

$$\phi = \left[\frac{W_{np}/\rho_{np}}{\frac{W_{np}}{\rho_{np}}+\frac{W_{bf}}{\rho_{bf}}}\right] \Diamond 100 \qquad (2)$$

5.0 Test Carried Out

5.1 Flash and Fire Point Temperature Test

To determine the flash and fire point temperatures of transformer oil used open-cup Abel-Pensky flash point apparatus used. Before the test, meticulous cleaning and drying of all parts of the cup are carried out. The oil sample is carefully filled into the cup until the desired level is reached. An initial oil temperature is determined using a thermometer inserted into the lid. The equipment is set up with the appropriate electrical connections.



Figure 6. Able Pensky flash and fire point apparatus.

A burning stick is introduced into the oil for every 5°C temperature increase to monitor any signs of ignition. The oil is gradually heated, and temperature readings are recorded upon reaching the flash and fire point. The experiment is done for the pure Naphthenic oil, Used Naphthenic oil, and Fresh and used naphthenic oil with 0.001 and 0.005 vol.% of TiO_2+ZnO hybrid nanoparticles. Figure 6 shows the Able Pensky Flash and Fire point apparatus.

5.2 Viscosity Test

The Redwood viscometer is used to determine the viscosity of the oil. The procedure involves filling the viscometer cylinder with the oil up to the designated level, sealing the orifice with a ball valve, and recording the oil temperature. The initial weight of the empty flask is recorded. Subsequently, the oil flask is positioned below the orifice, and upon opening, the flow of oil is allowed, while the time taken for 50 cc of oil to descend is noted and the weight of the flask containing the oil is measured. This process is carried out at room temperature and up to 100°C to investigate variations in viscosity. The same experiment is done for all oil samples. The pictorial view of the Redwood viscometer is shown in Figure 7.



Figure 7. Redwood viscometer apparatus.

5.3 Thermal Conductivity Test

The procedure begins with the setup of essential electrical and water connections for the instrumentation. This entails activating the control panel by switching on the



Figure 8. Redwood viscometer apparatus.



Figure 9. pH value determination setup.

MCB and console, followed by adjusting the voltage within the specified range of 70–80 volts. The initiation of the cooling water supply through the water jacket ensues, while temperatures are meticulously recorded at different points until reaching a steady state. This process is repeated for varying heater inputs. Upon completion, the voltage is gradually reduced to the minimum, and both the heater and main switches are turned off. Finally, the water flow through the jacket can continue for a designated period before being halted. The same experiment is repeated to test the thermal conductivity of all oil samples. Figure 8 shows the thermal conductivity apparatus setup.

5.4 pH Determination

Figure 9 shows the experimental apparatus used to determine the pH level of transformer oil samples for varying temperature ranges from 30 to 100 °C. The procedure begins by preparing the necessary equipment and solutions for pH measurement. This involves setting up the pH meter and ensuring it is calibrated correctly according to the manufacturer's instructions. Next, an oil sample is taken and placed in a clean container. The container is then subjected to varying temperatures using a controlled heating system, with measurements taken at room temperature and incrementally up to 100°C. The pH electrode is carefully immersed into the sample at each temperature, ensuring it is fully submerged and there are no air bubbles trapped around the electrode. The pH reading is then recorded once the meter stabilizes at each temperature interval. This process is repeated for each sample, ensuring accuracy and consistency in measurements across the temperature range. Transformer oil's acidity is determined by the pH test, which also shows the degree of contamination and oil degradation. To shield transformer components from corrosive damage, it is imperative to maintain the proper pH. Frequent pH testing ensures the protective qualities of the oil, extending the life and dependability of transformers.

5.5 Breakdown Voltage

The transformer oil's dielectric strength is determined by the breakdown test, which makes sure the oil can efficiently cool and insulate the transformer. This test looks for impurities and moisture that could harm a transformer's functionality and security. The operating life of the transformer is extended by routine testing, which helps to prevent electrical breakdowns. The apparatus had to be precisely assembled for the experiment, with a constant 2.5 mm space between the electrodes submerged in dielectric oil. Once the power supply was verified to be connected correctly, a stabilization period was permitted. The voltage between the electrodes was then progressively raised while being closely observed for any sparking activity. The failure began at the voltage at which the first spark appeared, as was appropriately reported. Every experiment was carried out in the same way to guarantee accuracy and repeatability. Lastly, the average breakdown voltage was determined using the gathered data to improve reliability. The same experiment is repeated to



Figure 10. Breakdown voltage test.

determine the breakdown voltage of all fluid samples. Figure 10 shows the pictorial view of the breakdown voltage test setup.

5.6 Zeta Potential Test for Stability

As it significantly affects the thermal properties, the stability of the nanosuspension contents in the base medium needs to be closely checked. Aggregation of nanoparticles may result in precipitation and obstruction, which lowers the thermophysical properties of the nanofluid. The amount of electrostatic repulsion potential between the charged nanoparticles and the base fluid is known as the zeta potential. A zeta potential test was carried out for the oil samples using a Zetatrac analyser and was determined using the dynamic light scattering method at Vijnana Bhavan Mysuru University. The detailed Zeta potential report is represented in Table 3.

6.0 Results and Discussions

Different tests were carried out for transformer (naphthenic oil) oil to verify the thermophysical properties. The detailed results are discussed in detail.

6.1 Flash and Fire Point Temperature

Figure 11 shows the variation of flash and fire point temperature of fresh and used naphthenic oil (transformer oil) with and without TiO_2+ZnO hybrid nanoparticles of 0.001 and 0.005 vol.% concentrations. From the graph, it is understood that adding a nanoparticle into the base fluid improves the flash and fire point temperature. The flash and fire point temperatures of used transformer oil are very low compared to fresh oil, because of contamination and deterioration, used naphthenic oil has lower flash and fire point temperatures than fresh oil. The oil's volatility is increased by accumulated contaminants and breakdown products, which reduces the oil's resistance to ignite. For fresh oil, the flash and fire point temperatures are 152 and 162 °C. By adding hybrid NPs of concentration 0.001 vol.% to base fluid the flash and fire points increased to 173 and 180 °C respectively. Similarly, for 0.005 vol.% concentration, the temperatures are further increased to 178 and 183 °C respectively. Similarly, used oil inherently exhibited lower flash and fire points of 135 and 145 °C. Adding TiO_2+ZnO hybrid NPs of 0.001 vol. % concentration, the flash point increased to 140°C, and the fire point improved to 155°C. Similarly for 0.005 vol. % concentration flash point temperature is 144°C and the fire point temperature is 160°C respectively.

By increasing thermal stability and lowering volatility, adding TiO_2 and ZnO hybrid nanoparticles to naphthenic oil raises its flash and fire point temperatures.

Table 3. Zeta potential analysis of nanofluids with 0.001 and 0.005 vol.%

Sl. No	Nanofluid	Concentration in vol. %	Zeta Potential Value in mV	Stability Remarks
	Fresh Naphthenic Oil	0.001	-49.2	Good
		0.005	-47.3	Good
	Used Naphthenic Oil	0.001	+21.6	Moderate
		0.005	+23.1	Moderate

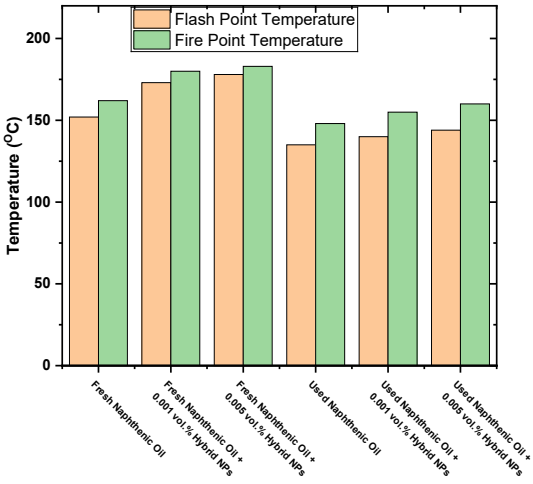


Figure 11. Flash and fire point for naphthenic oil.

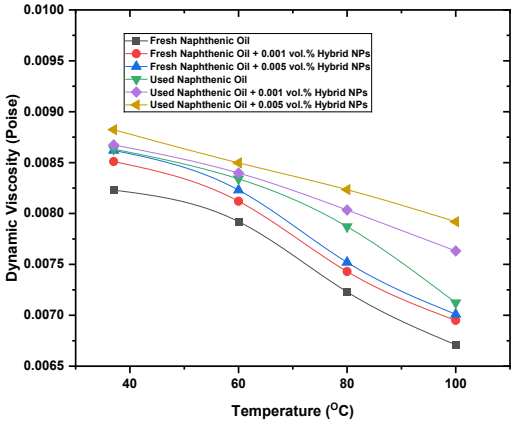


Figure 12. Kinematic viscosity naphthenic oil.

By acting as catalysts, these nanoparticles encourage the development of a barrier that prevents oxidation and degradation. As a result, this improvement promotes safer operation and a longer oil life in conditions with high temperatures.

6.2 Viscosity

Figure 12 depicts the variation of the kinematic viscosity of the naphthenic oil concerning temperature and nanoparticle concentrations. The viscosity of the naphthenic oil decreases with increasing temperature and increases with increasing the nanoparticle concentrations. Compared to fresh naphthenic oil, the used naphthenic oil exhibits a higher viscosity range across all temperatures. Fresh naphthenic oil exhibits the lowest dynamic viscosity ranging from 0.00823 to 0.00671 poise. By adding TiO_2+ZnO hybrid nanoparticles of 0.001 and 0.005 vol.% concentration the viscosity increases from 0.00851 to 0.00695 poise and 0.00862 to 0.00701 poise respectively. Similarly, the used naphthenic oil exhibits viscosity ranging from 0.00863 to 0.00712 poise. The addition of hybrid nanoparticles of 0.001 and 0.005 vol.% concentrations increases the viscosity of the oil from 0.00867 to 0.00763 poise and 0.00882 to 0.00792 poise respectively.

The quantity of solid-liquid interfaces in the oil is increased by the inclusion of nanoparticles. These contacts impede flow and cause friction. Because of the increased surface area interactions, evenly dispersed nanoparticles can increase viscosity. But when nanoparticles begin to group, larger clusters may form, which will further obstruct flow and raise viscosity. Moreover, the solid nanoparticles in the oil matrix function as physical barriers. These blockages become more noticeable as the concentration of nanoparticles rises, which raises the viscosity and total flow resistance.

6.3 Thermal Conductivity (k)

The influence of TiO_2 and ZnO hybrid nanoparticles on the thermal conductivity of naphthenic oil samples was investigated, yielding significant enhancements as illustrated in Figure 14. The fresh Naphthenic oil is 0.1322 W/m K, when added 0.001 and 0.005 vol.% of hybrid nanoparticles in it the thermal conductivity enhanced up to 0.1782 and 0.1953 W/m K nearly 34.12% enhancement respectively. Similarly, for used naphthenic oil, which inherently exhibited a lower thermal conductivity of 0.1234 W/m K. naphthenic oil experiences oxidative and thermal stress during operation, which causes oxidation products including acids, varnish, and sludge to form. Furthermore, impurities like water, dirt, and metal particles can build up in the oil, which makes it even less effective at transferring heat. The addition of nanofluid additives demonstrated significant improvements in the thermal conductivity, with 0.001 and 0.005 vol. % nanoparticle concentrations exhibiting improvement in the thermal conductivity of 0.1702 (27.49%) and 0.1888 W/m K (52.99%) respectively.

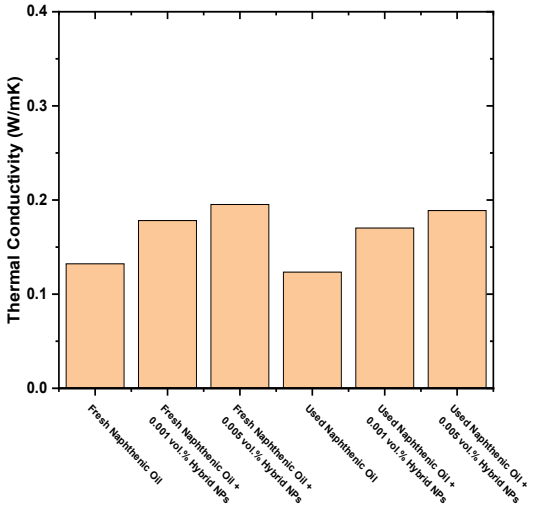


Figure 13. Thermal conductivity of naphthenic oil.

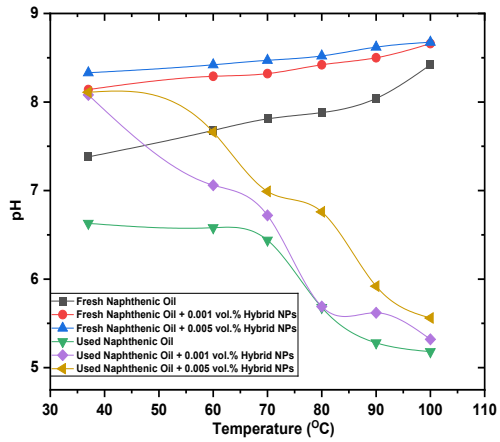


Figure 14. pH variation of naphthenic oil.

The nanoparticles dispersed within the oil matrix act as conductive pathways, facilitating the transfer of thermal energy more effectively. Additionally, the high surface area-to-volume ratio of nanoparticles enhances their interaction with heat, leading to increased thermal conductivity of the fluid.

6.4 pH Variation

Figure 14 indicates the variation of the pH value concerning temperature and the addition of TiO_2 + ZnO hybrid nanoparticles of 0.001 and 0.005 vol.%. The pH values for fresh naphthenic oil increase with increasing temperature and increasing concentrations of hybrid nanoparticles. From the results, fresh naphthenic oil shows a pH value ranging from 7.38 to 8.42. To fresh oil adding a 0.001 and 0.005 vol.% concentration enhances the pH values by 8.14 to 8.66 and 8.33 to 8.68 respectively. Fresh naphthenic oil's pH rises with temperature because, at higher temperatures, weakly acidic components dissolve more easily and are more soluble. The pH value for used Naphthenic oil is reduced and ranges from 6.63 to 5.18. by addition of hybrid nanoparticles improves the pH values to 8.08 to 5.32 and 8.11 to 5.56 respectively for 0.001 and 0.005 vol.%. But in the case of used oil pH value is decreasing with increasing of temperature. Because of the rapid generation of acidic oxidation products and the enhanced solubility of acidic impurities, the pH value of used naphthenic oil declines with increasing temperature.

6.5 Breakdown Voltage and Strength

Figures 15 and 16 indicate the breakdown voltage and strength of the naphthenic oil. From the results, it is understood that fresh oil shows the highest breakdown voltage, peak breakdown voltage, and breakdown strength of 56.72 kV, 80.21 kV, and 32.084 kV/mm respectively compared to all other oil samples. For fresh naphthenic oil addition of TiO_2+ZnO hybrid nanoparticles of 0.001 and 0.005 vol. % concentration reduces the breakdown voltage to 42.06 and 46.63 kV, peek breakdown voltage to 59.49 and 66.07 kV, breakdown strength to 23. 79 and 26.42 kV/mm respectively. Due to the addition of nanoparticles into oil may agglomerate, forming larger clusters that create weak points, it leads to increased electrical conductivity, and nanoparticles might introduce impurities or residual solvents, which can degrade the oil's insulating properties that lead to the reduction of dielectric properties of the oil. The used naphthenic oil exhibits very low breakdown voltage, peek breakdown voltage, and breakdown strength of 22.47 kV, 31.77 kV, and 12.71 kV/mm respectively. The addition of hybrid nanoparticles into the used naphthenic oil improves the breakdown voltage to 26.62 and 28.72 kV, the breakdown voltage to 37.66 and 40.78 kV, and the breakdown strength to 15.06 and 16.28 kV/mm respectively for 0.001 and 0.005 vol.% concentrations. By ensnaring and neutralizing free electrons and ions, TiO_2 and ZnO nanoparticles can function as charge traps, stopping the start and spread of electrical discharges. By enhancing the oil's thermal stability, the nanoparticles can

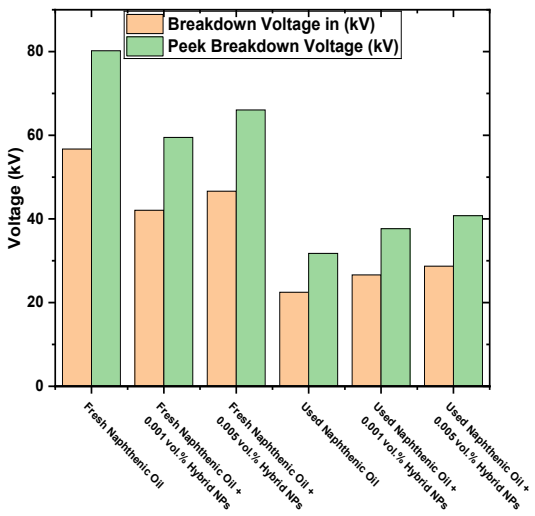


Figure 15. Breakdown voltage and peak breakdown voltage of naphthenic oil.

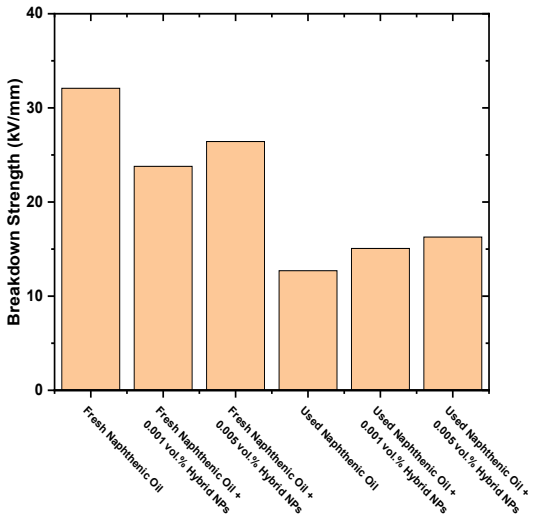


Figure 16. Breakdown strength of naphthenic oil.

lessen the likelihood of additional degradation products forming, which could erode the dielectric qualities. By creating a physical barrier that prevents charged particles from moving freely within the oil, the nanoparticles can improve the oil's insulating qualities and strength of breakdown.

7.0 Conclusion

The addition of the TiO_2+ZnO hybrid nanoparticles of 0.001 and 0.005 vol.% into fresh naphthenic oil enhanced the flash point temperature by 13.81% and 17.1% and fire point temperature by 11.11% and 12.96% respectively. Similarly, naphthenic oil enhanced the flash point temperature by 3.7% and 6.6% and the fire point temperature by 4.7% and 8.1% respectively.

The addition of hybrid nanoparticles of 0.001 and 0.005 vol.% concentrations into fresh naphthenic oil enhanced the kinematic viscosity by 3.1% and 4.3% respectively, in used naphthenic oil enhanced by 3.4% and 2.2% respectively.

The addition of hybrid nanoparticles into fresh naphthenic oil decreases the breakdown strength by 25.6% and 17.6% respectively for 0.001 and 0.005 vol. %. But adding to used naphthenic oil increases the breakdown strength by 18.5 % and 28.1% respectively.

The thermal conductivity of fresh naphthenic oil is enhanced by 34.7% and 47.7% respectively and for used naphthenic oil improved by 27.5% and 52.9% respectively for 0.001 and 0.005 vol.%.

The pH value of fresh naphthenic oil increases with increasing the nanoparticle concentration and temperature. The average enhancement is 5.5% and 7.3% respectively for 0.001 and 0.005 vol.%. Similarly, for sed, naphthenic oil the pH value increases with increasing nanoparticle concentration but decreases with increasing temperature. That is 5.6% and 7.9% respectively for 0.001 and 0.005 vol.%.

It is advisable to add nanoparticles to used naphthenic oil, it will enhance the breakdown voltage strength and all other thermophysical properties.

8.0 Acknowledgement

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9.0 References

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