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Measurement of Overall Heat Transfer Coefficient and Friction Factor in a Plate Fin Heat Exchanger with Nano MgO-based Transformer Oil

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Abstract

This experimental investigation is carried out to assess the thermal performance of nano Magnesium Oxide (MgO) based transformer oil in a plate-fin heat exchanger for applications in the electrical transformers manufacturing industry. The Overall Heat Transfer Coefficient (UHTC) and friction factor are determined experimentally using a unique test rig designed and developed for this investigation. Nano MgO-based transformer oil is prepared and characterised in the laboratory for its thermo-physical properties. While the viscosity and density of nanofluid are determined experimentally, the specific heat and thermal conductivity are estimated theoretically as functions of temperature. Experiments were conducted on nano MgO-based transformer oil with different volume concentrations ranging from 0.002% to 0.008%. The mean bulk temperature of the nanofluid is varied from 30 C to 70 C with a flow rate from 1.2 L/min to 4.2 L/min. The Reynolds numbers for the flow are varied from 600 to 7100. The UHTC is determined and presented as a function of mean bulk temperature and mass flow rate. The results of UHTC are also presented as a function of volume concentration, taking mass flow rate and temperature as parameters. It is found that the UHTC, Convective Heat Transfer Coefficient (CHTC), improved by 53.43% and 13.79%, respectively. The friction factor decreased by 28.87% when the Reynolds number increased from 600 to 7100. In the present experiment, it is observed that the pumping power increased by 28.26% with respect to mass flow rate, while the pumping power decreased with an increase in temperature from 30 to 70 °C to an extent of 45 to 50 %. The novelty of the present investigations comes from two aspects: 1) the selection of nano MgO as a colloidal substance, and 2) the use of a plate-fin heat exchanger for testing the thermal performance of nano MgO-based transformer oils.

Major Findings: *From the present investigation, it is found that pumping power increases with the volume concentration, when compared to the base fluid, to a maximum extent of 2%, which does not contribute significantly to the penalty in pumping power. Hence, it is recommended that MgO based nano transformer oil is a potential candidate in electrical industry.*

Keywords: *Friction Factor, Heat Exchangers, Heat Transfer Coefficient, MgO, Pumping Power*

1.0 Introduction

Electric transformers generate considerable heat during their operation. The electrical conductivity of the transformer coils gets reduced as a function of temperature. Transformer oils (Mineral oils) are generally employed to dissipate heat generated in the coils and maintain the operating temperature within the acceptable limits. In the transformers, mineral oil performs two functions, i.e., cooling and electrical insulation. These functions are interrelated in defining the life of the transformer. If the mineral oil has high breakdown strength and the best cooling, it will lead to an increase in the life of the transformers. To cope with the increasing

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demand for power in the future, the need of the hour is to develop transformers of small size. While there is a variety of coolants available in the market commercially, the selection criterion of transformer oils is based on their dielectric properties, thermal stability, specific heat, and thermal conductivity. From the literature, it is known that transformer oil has a thermal conductivity of 0.126 W/m.K and a specific heat of 1860 J/kg. K. Therefore, any improvement in the thermal transport properties of transformer oil is expected to improve the electrical performance of transformers. In the present work, contrasting the properties of nanoparticles is carried out to select the most suitable combination of nanoparticles with transformer oil. The selection of MgO nanomaterials is based on compatibility with transformer oil. It is found that the development of good mineral oil is most critical in terms of dielectric and thermal properties.

There have been several research papers on transformer oils/Mineral oils in combination with a variety of nano materials. However, there is a research gap in nano MgO-based transformer oil coolants, which has not been explored extensively for their thermal performance. Attractive thermo-physical properties of MgO motivate in-depth investigations in the direction of applications in the electrical transformer industry.

The pertinent literature published by other investigators is presented, and some significant highlights of their findings are discussed. MgO, as a nano-material, is eco-friendly, economically feasible and industrially important due to its unique physical and chemical behaviour[1-5] such as its excellent corrosion resistance[6] high thermal conductivity[7] physical strength, stability, flame-resistance, dielectric resistance, mechanical strength[8-11]. Further, the self-cleaning ability of MgO is an attractive property for fluids in circulation[1].

It was reported in the literature that transformer oil-based nanofluids are known to have higher thermal conductivity and heat transfer performance compared to conventional transformer oils. Four different types of transformer oil-based nanofluids are synthesised using the well-known two-step method[12]. The first nanofluid contains pure Multi-Walled Carbon Nanotubes (MWCNTs), while other samples consist of 20 vol% of MWCNTs and 80 vol% of different oxide nanoparticles (i.e., Al_2O_3, TiO_2, and SiO_2). The stability, thermo-physical properties, and electrical properties of pure transformer oil (naphthenic), palm oil methyl ester and blended oils suspended with SiO_2-graphene nanoparticles were reported in[13]. Thermal conductivity and dielectric strength of the Ag-WO_3 hybrid were reported in[14]. There are many research studies to determine and evaluate the dielectric strength of pure transformer oils and nano- based transformer oils. However, there are only limited studies with a focus on determining the cooling performance of nano-based transformer oils.

The main objective of this study is to determine the thermal performance of nano MgO-based transformer oil with different volume concentrations of nano particles.

2.0 Materials and Methodology

In this study, MgO nano materials that are commercially available in the market are purchased from Sigma Aldrich. As per the materials specification data sheet, the average size of MgO nanoparticles is ≤50 nm. The purity of the material is specified to be >99.99%. In the preparation of nanofluids, a surfactant called CTAB, which weighs one-tenth of the MgO nanoparticle, is used. Different volume concentrations such as 0.002%, 0.004%, 0.006%, and 0.008% are used in this present experiment. A precision digital micro-balance (supplied by Labotech) with a resolution of 1 micro-gram is employed to determine the weight of nanoparticles to be added to the base fluid. Measured quantities of MgO nanoparticles and CTAB are added to the base fluid. Here two-step approach was implemented for the preparation of. The mixer is kept on a magnetic stirrer (model no EINS SCI E-MS20-H3-T) for 8 hr at 470 rpm and further sonicated for 6hr to achieve uniform dispersion of nanoparticles.

Thermophysical properties of MgO and transformer oil reported in the literature by different researchers are collected and summarised in Table 1. It is observed that there has been some inconsistency in the thermal conductivity values of MgO reported. For example,[15] reported 54.9 W/m K,[16] reported 48 W/m K whereas,[17] Reported 51.12 W/m K. As a result, in the present investigation, the maximum thermal conductivity value is taken as a typical representative.

Table 1. Thermo-physical properties of MgO and TrO as reported in the literature by researchers

Property	Magnesium Oxide (MgO)				Transformer oil (TrO) Meysam Nazari, (2023)[22]
	Amin Asadi (2019)[15]	S.M. Mousavi (2019)[17]	Sadeq R. Nfawa (2021)[16]	Gabriela Huminic, Angel Huminic, (2019)[19]	
Thermal Conductivity, k (W/m K)	54.9	51.12	48	-	0.126
Specific Heat, Cp, (J/kg K)	937	852	-	964	1860
Density, ρ (kg/m^3)	3580	3570	145	3588	880
Viscosity, μ (Pa.s)	-	-	-	-	13.7

Table 2. Thermo-physical properties and specifications of nanoparticles

Thermo- Physical Properties	TiO_2 [Bock Choon Pak and Young I. Cho 1998][28]	ZnO [Amin Asadi, 2019][30]	Al_2O_3 [Ebrahim dardan, 2016][29]	MgO [Amin Asadi, 2019][15]
Thermal Conductivity, k (W/m K)	8.4	29	46	54.9
Specific Heat, Cp (J/kg K)	710	514	385	937
Density, ρ (kg/m^3)	4157	5606	3890	3580
Purity	99+%	99+%	-	-
Size (nm)	27	35-45	20	-
Specific surface area	56.1	>60	>138	-
(SSA) m^2/g				
Colour	White	White	White	-

The superior thermophysical characteristics of MgO and its compatibility with transformer oil are displayed in Table 2 in contrast to other nanoparticles like TiO2, ZnO, and Al_2O_3. The inherent compatibility, stability, purity, and good dispersion nature of nano MgO particles into transformer oil can yield a robust and reliable nanofluid. Addition of MgO does not deteriorate the transformer oil, and no hazardous byproducts are produced by the reaction of MgO with the oil.

3.0 Experimental Test Rig

An experimental test rig shown in Figure 2 is designed and developed to determine the performance of MgO nano-thermo-fluids. The test rig consists of a plate-fin heat exchanger, which is shown in Figure 1, that is available commercially in the market. The constructional details and the dimensions of the heat exchanger are shown in Table 3. The test rig has two

circuits: one to carry the hot fluid and the second one to carry cold air that flows through the finned structure. Six thermocouples are employed to measure 1) inlet/outlet liquid temperature, 2) air inlet/outlet temperature, 3) atmospheric air temperature, and 4) plate surface temperature, as shown in Figure 2. Two pressure sensors are installed to measure the inlet and outlet oil pressure. One rotameter is incorporated to measure the flow rate of hot fluid. In this work, ambient air is taken as the cold fluid. A suction fan is attached at the end of a duct that draws atmospheric air through the heat exchanger. The air velocity is measured using an anemometer installed between the heat exchanger and the suction fan. The flow rate of the cold fluid (air) flowing through the heat exchanger is estimated from the air velocity measurements. A high-temperature, durable pump is installed to drive the hot fluid through the circuits. All the temperature sensors are pre-calibrated and connected to the data acquisition system using software installed on the computer (laptop) as shown in Figure 2. Experimental data are collected for different volume concentrations at different flow rates of nano-fluids. Further, a schematic diagram is shown in Figure 3.



Figure 1. Plate fin heat exchanger.

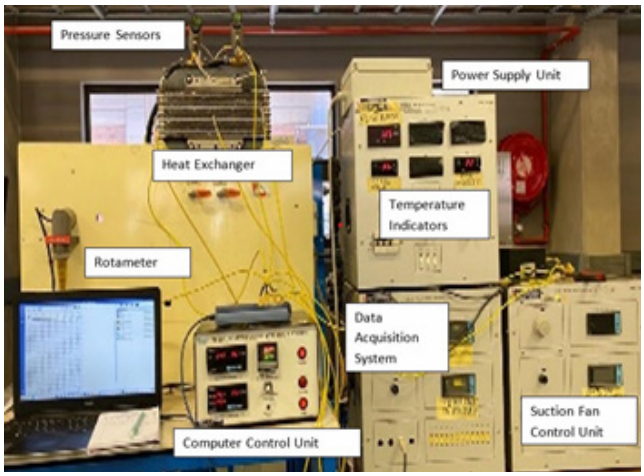


Figure 2. Test rig in the laboratory.

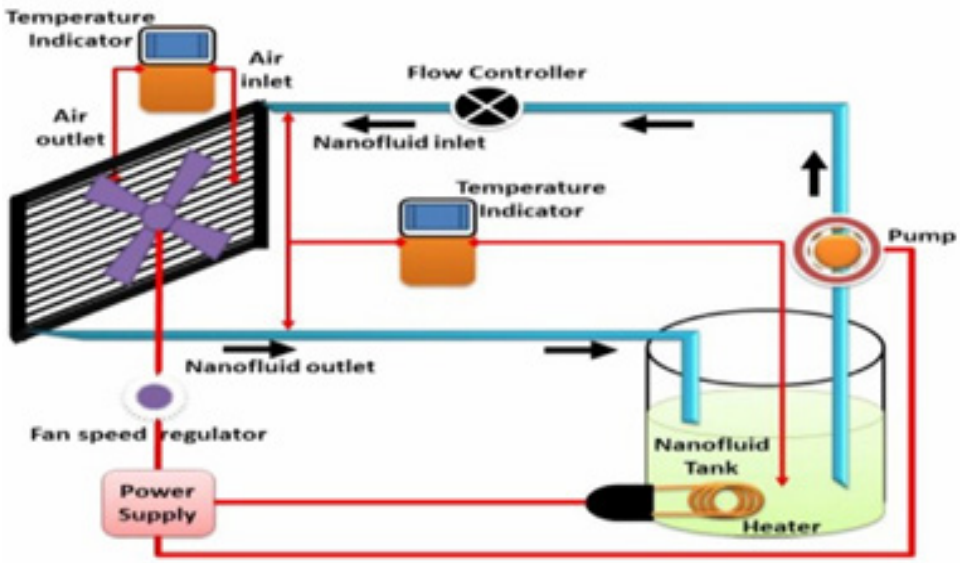


Figure 2. Schematic Diagram[23].

Table 3. Constructional details of the radiator used

Radiator Length, RL	0.325 m
Radiator Width, RW	0.115 m
Tube Width, TW	0.025 m
Tube Height, Th	0.003 m
Fin Width, FW	0.028 m
Fin Height, Fh	0.009 m
Fin Thickness, FT	0.0001 m
Distance between the fins, FD	0.005 m
Number of tubes, n-tubes	9

4.0 Preparation of Nanofluids

The sequence of steps involved in the preparation of is shown in Figure 4. The two-step method is employed and is shown in Figure 5. MgO nanoparticles are dispersed into a base fluid, such as transformer oil, using techniques like mechanical stirring, ultrasonication to ensure even distribution. To maintain a stable suspension and prevent the nanoparticles from agglomeration, surfactants, or stabilising agents such as Cetyltrimethylammonium bromide (CTAB) are added. The incorporation of CTAB modifies interfacial interactions and aids in the prevention of particle aggregation by disrupting the attractive forces at play. Given that surfactants enhance the dispersion of nanoparticles via various mechanisms, it is imperative to take into account factors such as the nature of the base fluid, the selection of surfactant, and its concentration during the formulation of stable nanofluids. Frequently employed surfactants encompass oleic acid, CTAB, stearic acid, and sorbitan monooleate[31]. Thismethod is known to be cost-effective and flexible that allowing the preparation of nanofluids with various volume concentrations required for the present investigation. Required quantities of nanoparticles were calculated by using Equation (1). A precision digital micro- balance (supplied by Labotech) with a resolution of 1 μm was employed to determine the weight of MgO nanoparticles of different concentrations that were added to the base fluid transformer oil (from

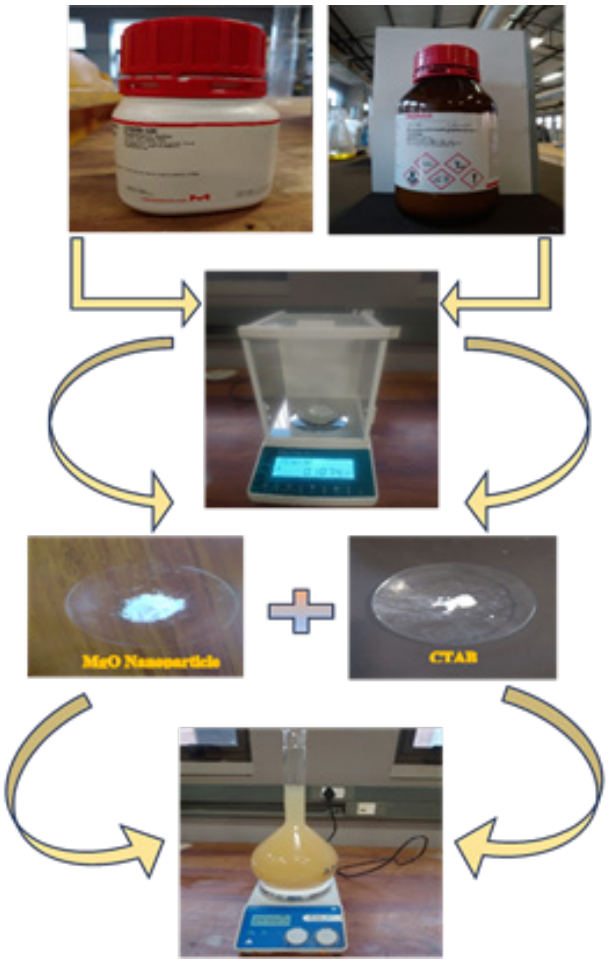


Figure 4. Preparation of nano MgO-based transformer oil.

SABS-approved SANS EnvirOil). The due processes are followed for stirring and sonication to ensure a homogeneous mixture of nanofluids. This prepared nano MgO mixer is now ready to pour into the stainless-steel tank, which is insulated with asbestos, with a cubic capacity of 20 litres.

$$\emptyset\% = \frac{\left(\frac{wt_{np}}{\rho_{np}}\right)}{\left(\frac{wt_{np}}{\rho_{np}} + \frac{wt_{bf}}{\rho_{bf}}\right)} \quad (1)$$

A small quantity of MgO prepared for this investigation is kept separately in a conical flask for 7 days, as shown in Figure 6. It is observed that there is

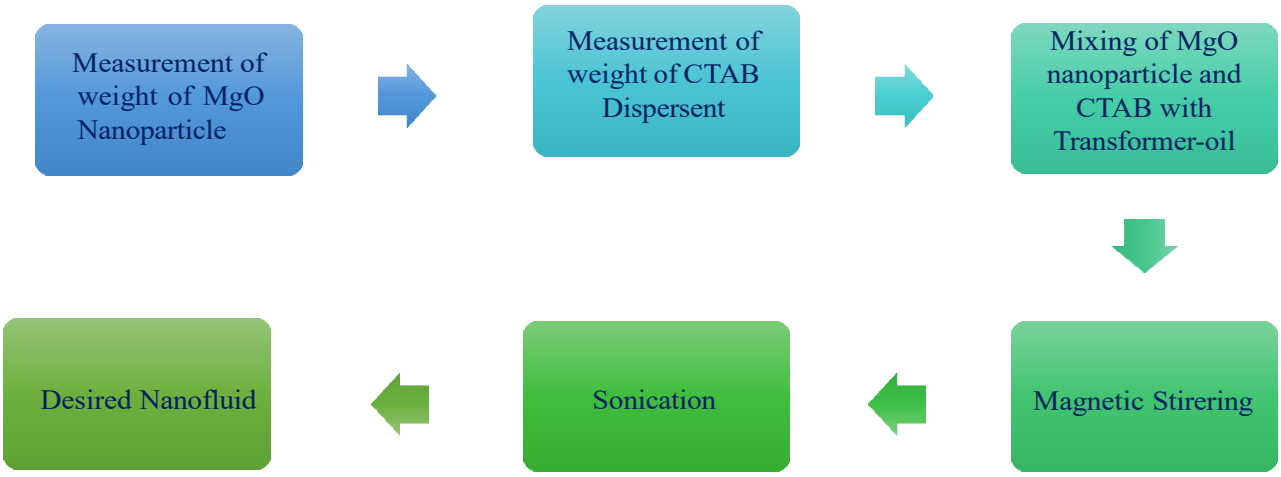


Figure 5. Two-step method.

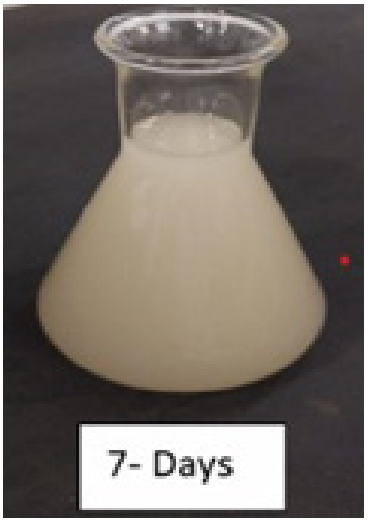


Figure 6. Stability of the nanofluid was observed.



Figure 7. Viscometer Anton and Paar.

no settlement of nanoparticles at the bottom of the flask. It is believed that MgO nanoparticles continue to be in a colloidal state in the base fluid. Hence, it is assumed that the nanofluid is considerably stable for the intended purpose.

5.0 Data Reduction

The thermo-physical properties such as viscosity, density, specific heat capacities, and thermal conductivity of MgO-TrO based nanofluids were estimated for different concentrations at different temperatures, respectively, using the standard Equations (2), (3), (4), and (5). Viscosity was measured by using an Anton Paar viscometer shown in Figure 7, for the temperatures ranging from 30 to 70 °C in the present investigation.

$$\mu_{nf} = (1 + 2.5\varphi)\mu_{bf} \quad [20] \tag{2}$$

$$\rho_{nf} = (1 - \varphi)\rho_{bf} + \varphi\rho_{np} \quad [20] \tag{3}$$

$$C_{pnf} = (1 - \varphi)C_{pbf} + \varphi C_{pnp} \quad [18] \tag{4}$$

Maxwell's equation is used to determine its thermal conductivity.

$$\frac{k_{nf}}{k_{bf}} = \frac{k_p + 2k_{bf} - 2(k_{bf} - k_p)\varphi}{k_p + 2k_b + (k_b - k_p)\varphi} \quad (5)$$

5.1 Liquid Side Calculation

The Reynolds number was calculated using Equation (6).

$$Re_{liquid} = \frac{\rho_{liquid} V_{liquid} D_h}{\mu_{liquid}} \quad (6)$$

Where Dh liquid, Vliquid, ρliquid and μliquid are the hydraulic diameter of the tube, the flow velocity, density, and viscosity of the working fluid, respectively. The velocity of the fluid through each tube must be found to calculate the Reynolds number. The number of tubes is given by the manufacturer who supplied the heat exchanger. The velocity can be calculated by the following Equation (7).

$$V_{liquid} = \frac{Q_{Liquid}}{N_{Tube} A_{Tube}} \quad (7)$$

The hot fluid travels through the tubes of the radiator. The hydraulic diameter Dh can be calculated by Equation (8).

$$D_h = \frac{4.A_{Tube}}{P_{Tube}} \quad (8)$$

The liquid side heat transfer coefficient was attained by evaluating Equation (9).

$$h_{exp} = \frac{Nu_{exp}.k_{nf}}{D_h} \quad (9)$$

The Nusselt number was found for a rectangular cross-section from a fully developed laminar flow. For laminar flow, Dittus Equation (10) is used to determine the Nusselt number.

$$Nu = 0.023 * Re^{0.8} * Pr^{1/3} \quad (10)$$

5.2 Air Side Calculation

The air flows between the radiator tubes and fins and, in the process, absorbs heat by the convective heat transfer mechanism. The velocity can be calculated by the following Equation (11).

$$V_{Air} = \frac{Q_{Air}}{A_{radiator} - (N_{Tube} H_{Tube} L_{radiator})} \quad (11)$$

The Reynolds number was calculated using Equation (12).

$$Re_{Air} = \frac{\rho_{Air} V_{Air} D_{hAir}}{\mu_{Air}} \quad (12)$$

Where DhAir, VAir, ρAir and μAir are the hydraulic diameter of the tube, the flow velocity, density, and viscosity of the working fluid, respectively. The velocity of the air through each passage must be found to calculate the Reynolds number. Looking at the geometry of fins, it can be assumed that the flow of air is in the laminar region. Equation (13)[24] is used to determine the Nusselt number.

$$Nu = 0.664 * Re_{Air}^{1/2} * Pr_{Air}^{1/3} \quad (13)$$

The air-side heat transfer coefficient was determined using Equation (14).

$$h_{Air} = \frac{Nu_{Air}.k_{Air}}{D_{hAir}} \quad (14)$$

UHTC19 is calculated using Equation (15).

$$UHTC = \frac{Q}{A\,\Delta T_m} = \frac{mC_p(T_{in} - T_{out})}{A\left(\frac{(T_w - T_{in}) - (T_w - T_{out})}{\ln\left(\frac{T_w - T_{in}}{T_w - T_{out}}\right)}\right)} \quad (15)$$

A - Total internal surface area of the tube.

ΔTm - logarithmic mean temperature difference.
Number of Transfer Units calculated by Equation (16).

$$NTU = \frac{UA}{Cmin} \quad (16)$$

Effectiveness calculated by using Equation (17)[24].

$$\varepsilon = 1 - \exp\left[\left(\frac{1}{Cmax}NTU^{0.22}\right)\left(\exp^{(-CmaxNTU^{0.78})}-1\right)\right] \quad (17)$$

6.0 Experimental Results and Discussions

6.1 Overall Heat Transfer Characteristics of Nano MgO-Based Transformer Oil as a Function of Mean Bulk Temperature

The variation of UHTC of nano MgO-based transformer oil flowing through the tubes of the heat exchanger as a function of temperature is shown in Figure 8. Figure 8 represents four sets of experiments conducted at four different flow rates from 1.2 L/min to 4.2 L/min in the range of temperature from 30 to 70 °C. In each set of graphs, the volume concentration of nanoparticles is increased progressively from 0.002% to 0.008%. it is observed that the UHTC increases with the mean bulk temperature. Further, the UHTC increased with an increase in volume concentration. In Figure 8, it is visible that the overall heat transfer coefficient is a very strong function of temperature. The effect of volume concentration of nanoparticles appears to be predominant for the set of graphs that corresponds to 3.2 L/min and 4.2 L/min, whereas the effect is not so much visible at 1.2 L/min and 2.2 L/min flow rate. It is concluded that the dispersion of nanoparticles improved the UHTC to an extent of 53.43% at a higher volume concentration of 0.012% when compared to the base fluid.

6.2 Overall Heat Transfer Characteristics of Nano MgO-Based Transformer Oil as a Function of Mass Flow Rate

In the following Figure 9, the UHTC is shown as a function of the mass flow rate of the nano-based transformer oil. Figure 9 again represents four sets of experiments conducted at four different temperatures in the range of 30 to 70 °C. In the present experimental test facility, there is a provision to measure the volume flow rate of the fluid with the help of a rotameter and a digital flow meter coupled with a display unit. The mass flow rate of the nano MgO-based transformer oil is determined considering the density of the nanofluid estimated using Equation (3) proposed by Einstein[20]. Again, in each set of graphs, the volume concentration of nanoparticles is increased progressively from 0.002% to 0.008%. From these experiments, it is observed that the UHTC increases with the mass flow rate of the nanofluid. It is found that the overall heat transfer coefficient improved with the increase in the mass flow rate and volume

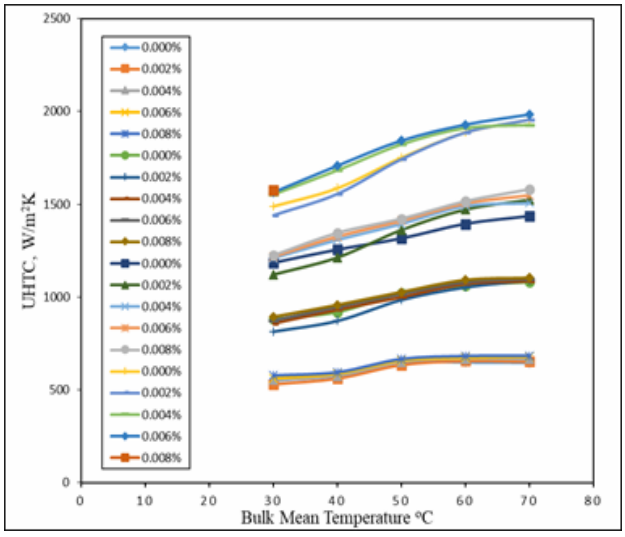


Figure 8. Overall heat transfer coefficient as a function of mean bulk temperature.

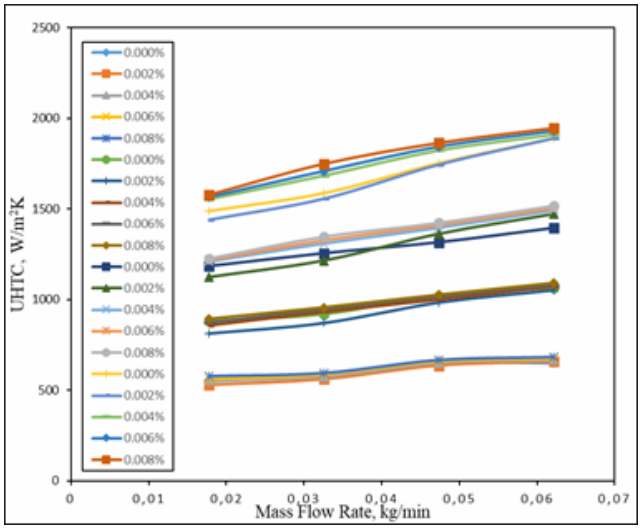


Figure 9. Overall heat transfer coefficient as a function of mass flow rate.

concentration as well. The effect of mass flow rate and volume concentration is relatively more significant on the heat transfer. It can be concluded that the increase in UHTC is due to the combined effect of mass flow rate, mean bulk temperature and volume concentration of the nanoparticles.

6.3 Reynolds Number of Nano MgO-based Transformer Oil as a Function of Mean Bulk Temperature

It is observed from the experimental results that the Reynolds number is generally influenced by the mean bulk temperature and volume concentration as parameters.

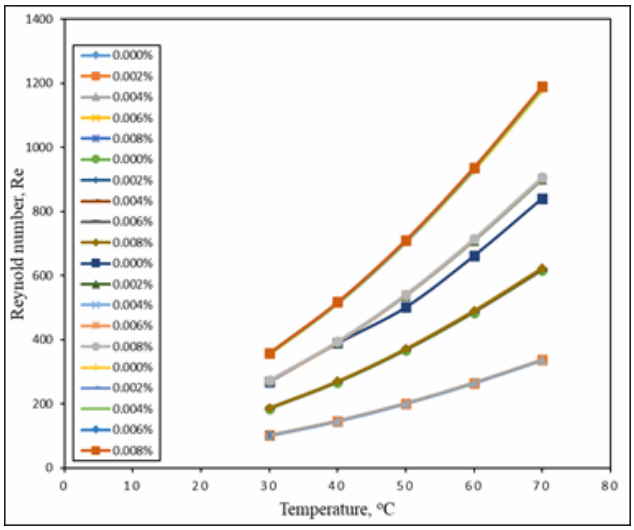


Figure 10. Reynolds number as a function of mean bulk temperature

As the temperature increases, the density and viscosity decrease, leading to an increase in Reynolds number up to 1180, as shown in Figure 10.

6.4 Nusselt Number of Nano MgO-Based Transformer Oil as a Function of Mean Bulk Temperature

There is an increase in Nusselt number as a function of mean bulk temperature, shown in Figure 11, varying from 30 to 70 °C. As temperature increases, the viscosity of most fluids decreases, leading to enhanced fluid

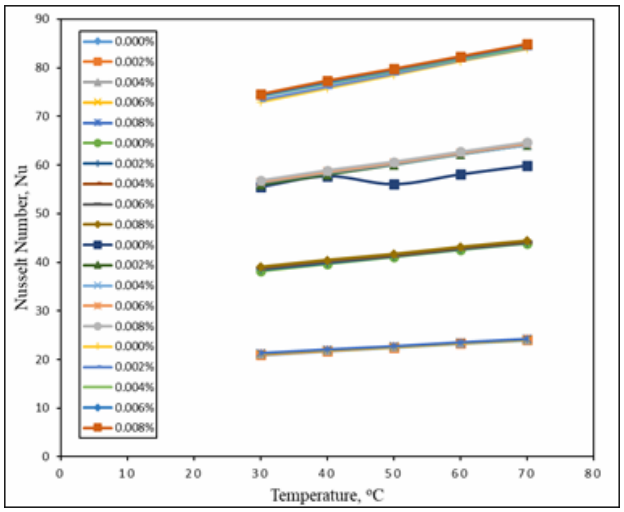


Figure 11. Nusselt number as a function of temperature.

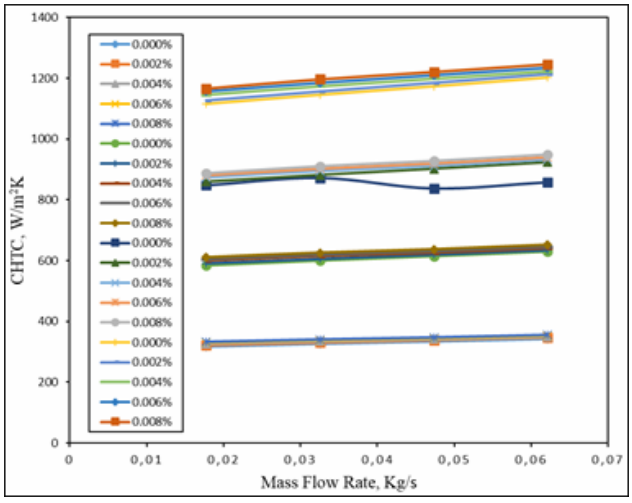


Figure 12. Convective heat transfer coefficient as a function of mass flow rate.

movement. This reduction in viscosity facilitates greater molecular interaction, which increases the convective heat transfer coefficient shown in Figure 12.

6.5 Effectiveness of Nano MgO-Based Transformer Oil as a Function of The Number of Transfer Units

From Figure 13, it is observed that the effectiveness increases with respect to the number of transfer units for

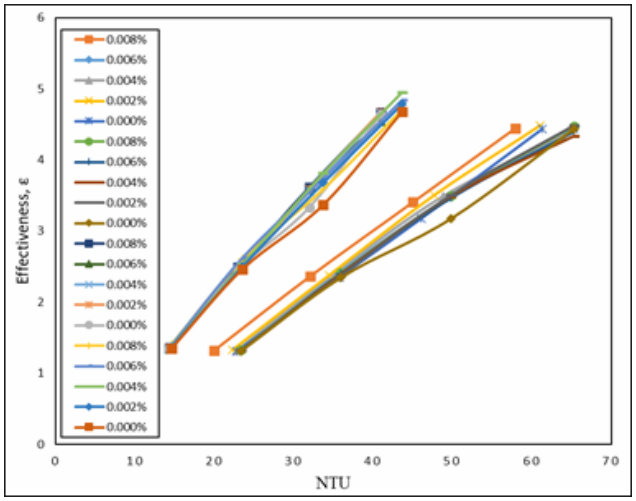


Figure 13. Effectiveness as a function of several transfer units.

different concentrations. The effectiveness increases by 54.08% for the highest concentration.

6.6 Friction Factor of Nano MgO-Based Transformer Oil as a Function of Reynolds Number

Figure 14 shows the variation of the friction factor for various flow rates at different concentrations of MgO nanofluid at fluid inlet temperatures of 30 and 70 °C. As the flow rate of fluid increases, the trend of the lines shows a decrease in the friction factor value by 28.83% compared to the base fluid. The friction factor values reported in the present experimental investigation are, in fact, low when compared to the literature and the range of investigation is confined to the laminar region with a range of Reynolds numbers 70 to 1170. From the literature review conducted, it is found that there is no published research work in combination with MgO and transformer oil. As a result, there are no correlations readily available for friction factor as a function of Reynolds number[25,26].

6.7 Pumping Power of Nano MgO-Based Transformer Oil as a Function of Mean Bulk Temperature and Mass Flow Rate

As temperature increases, pumping power is expected to decrease, due to the reduction in fluid viscosity as shown in Figure 15. Hot fluids generally flow more easily, which reduces the flow resistance encountered by the pump. Thus, a decrease in the viscosity allows the pump to move the fluid with less energy, resulting in lower pumping power requirements, as shown in Figure 15. Pumping power increases with volume concentration 2%. However,

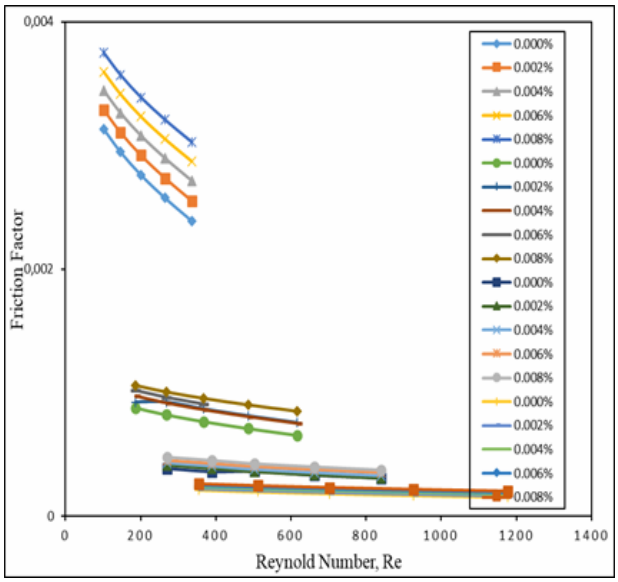


Figure 14. Friction factor as a function of Reynolds number.

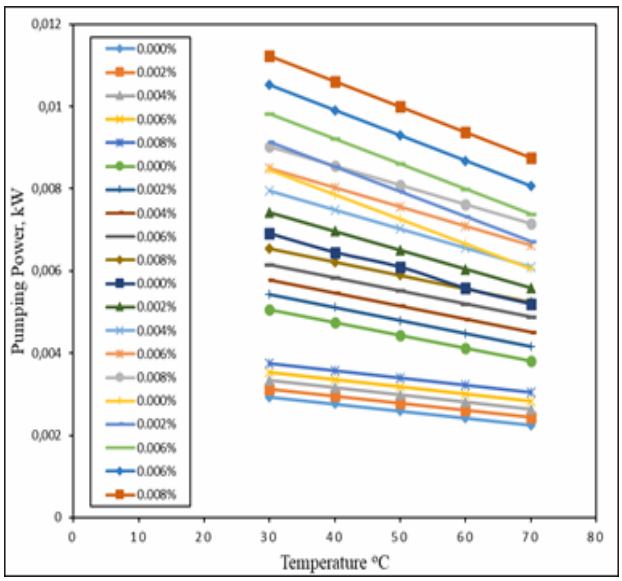


Figure 15. Pumping power as a function of temperature.

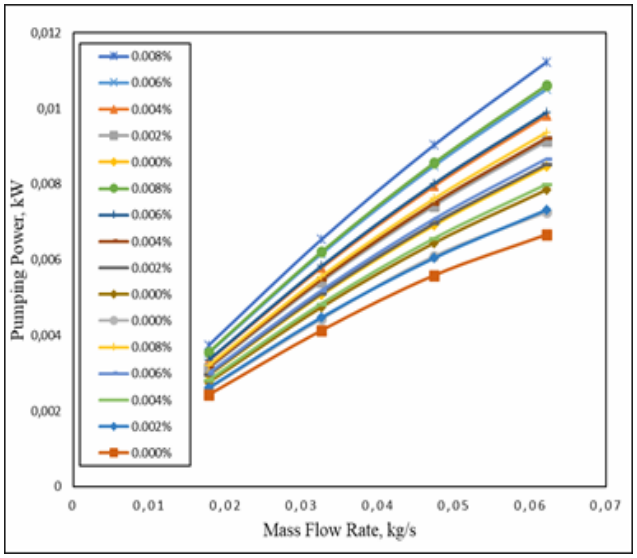


Figure 16. Pumping power as a function of mass flow rate.

it is still beneficial given the improved heat transfer coefficient and thermal performance of the system.
The pumping power is calculated using Equation (18)[27]

$$\dot{W} = \Delta P * Q \quad (18)$$

Where Q is the volume flow rate measured experimentally using a rotameter and a digital flow meter. Pressure drop ΔP across the system (heat exchanger) is measured using two sensitive pressure gauges installed in the circuit.

In Figure 16, it is observed that the pumping power increases proportionately with an increase in mass flow rate. It is also observed that as the volume concentration of nanoparticles increases, there is an incremental increase in the pumping power because of an increase in the density due to the addition of nanoparticles to the base fluid. There is a marginal increase in the pumping power to an extent of 2% due to an increase in the volume concentration of the nano MgO added to the transformer oil.

7.0 Uncertainty Analysis

An uncertainty analysis is conducted for Re, h, Nu, f and W as per[22]. The results of the analysis are presented in the following Table 4.

Table 4. Uncertainty analysis22

Reynolds number, Re	6.2%
Heat transfer coefficient, h	5.9%
Nusselt number, Nu	3.5%
Friction factor, f	4.3%
Pumping Power, PP	3.7%

8.0 Conclusions

The purpose of this experimental study is to evaluate the thermal performance of nano MgO-based transformer oil in a plate-fin heat exchanger for use in the production of electrical transformers. A special test rig created for this study is used to experimentally assess the overall heat transfer coefficient and friction factor. The thermo-physical characteristics of MgO-based materials are determined in laboratory conditions. The following are the key findings from this investigation:

- From the present experimental investigation, it is concluded that UHTC, CHTC improved by 53.43%, 13.79%. The friction factor decreased by 28.87% with an increase in mass flow rate.
- The pumping power increased by 28.26% concerning mass flow rate, while the pumping power decreased with an increase in temperature from 30 to 70 °C to an extent of 45 to 50 %.
- The pumping power increases even with the volume concentration when compared to the base fluid to a maximum extent of 2%, which does not contribute significantly to the additional pumping power requirements.
- The effectiveness as a function of NTU for the heat exchanger showed an improvement with increase in addition of nanoparticles.

From the present experimental investigation, it is concluded that MgO is a suitable candidate for implementation in electrical transformer industries. Future work can focus on different composite nanoparticles with different base fluids to ensure better thermal performance. Research can also be conducted by incorporating advanced optimisation and machine learning techniques into the analysis.

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Nomenclature	**Abbreviation**
RW- Radiator width,	HTC- Heat transfer coefficient
RL- Radiator length	MgO- Magnesium oxide
TW-Tube width,	CuO- Copper oxide
TH -Tube height,	CTAB- Cetyltrimethylammonium bromide
FW- Fin width,	TiO2- Titanium dioxide
FT- Fin thickness,	ZnO- Zinc oxide
FH -Fin height,	Al_2O_3- Aluminium oxide
FD -Distance between the fins,	GNP- Graphene nanoparticles
n-tubes -Number of tubes,	TrO- Transformer oil

Dh- Hydraulic diameter	UHTC- Overall heat transfer coefficient
k - Thermal conductivity, (W/m K)	CHTC- Convective heat transfer coefficient
Cp-Specific Heat, (J/kg K)	CNT- Carbon nanotubes
ρ - Density, (kg/m^3)	
μ -Viscosity, (Pa. s)	
Φ%-Volume concentration	
wtMgO- Weight of Magnesium oxide	
wtCuO- Weight of Copper oxide	
wtTrO- Weight of Transformer oil	
ρMgO- Density of Magnesium oxide	
ρCuO- Density of Copper oxide	
ρTrO- Density of Transformer oil	
ρnf- Density of nanofluid	
ρbf- Density of base fluid	
Φhyb- Hybrid volume concentration	
mbf- Mass of base fluid	
mnf-Mass of nano fluid	
Vnf- Volume of nanofluid	
Vbf-Volume of base fluid	
Re- Reynolds Number	
Nu- Nusselt Number	
Tbulk- Bulk Temperature	
m- Mass flow rate	