Experimental Study on Thermal Conductivity and Viscosity of Al₂O₃-Nanotransformer Oil

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Abstract – Nanotransformer oil is a type of nanofluid in which nanomaterial is mixed with transformer oil as a base fluid. Nanotransformer oil has potential of better heat transfer characteristics as compared to conventional transformer oils used for cooling purposes. Thermal conductivity and viscosity are the important thermophysical properties of any nanofluid which affect its heat transfer performance. In this study, an experimental attempt has been made to know about thermal conductivity and viscosity of nano-transformer oil. Experiments have been conducted at different temperature (20°C-50°C) and with varying volume concentrations (0.1%, 0.3% & 0.5%) of nanoparticles in the transformer oil. Research is already going on where researchers are using either water or ethylene glycol as base fluid. A very limited investigation have been reported for the transformer oil as a base fluid. Here attempt has been made to investigate the nanomaterial based transformer oil, called nanotransformer oil.

Keywords – Conductivity, Viscosity, Nanotransformer oil, Nanoparticles, Volume concentration, Agglomeration

I. INTRODUCTION

Conventional oils shows poor heat transfer characteristics compared to coolants and engine oil. It has been investigated that their performance can be increased by adding nanoparticles and these nanomaterial based oils have great potential to meet out the lubrication and cooling requirements of the given system. The concept of nanofluid was proposed by Choi and his team by dispersing nanoparticle of higher thermal conductivity in to the base fluid [1]. Earlier investigations shows that dispersion of millimeter or micrometer size particles in to the base fluid which causes particle agglomeration and settling, block the channels in which such type of fluid are used. Moreover, their pumping power is increased and because of these problems with a mixture millimeter or micrometer based fluids was never been a good choice for heat transfer applications. Investigations on nanofluids show that they have potential to overcome these problems. Main function of the nano transformer oil is to avoid excessive heating caused by overloading conditions on transformer. It is required that in addition to good heat transfer properties transformer oil should have good electrical insulating property which insulate the primary winding from secondary winding. Agglomerations and settling of nano fluids which is a major challenge to make stable nanofluid can be avoided by using proper dispersing techniques and by adding surfactants which thereby help in improving the stability of nano-transformer oil. Few Studies have already been performed on oil based nanofluids. Xie.H et al. [2] measured thermal conductivity of nanofluids containing Al₂O₃, nanoparticles with two different base fluids: ethylene glycol and pump oil. Results showed a 30 % & 40 % improvement in the thermal conductivity as compared to the corresponding base fluids for 5 vol. % of nanoparticles and the size of the nanoparticles used with both the fluids is 60 nm.

Investigations are carried out by various researchers at different temperatures to see the effect on thermal conductivity of nano transformer oil by using CuO, Al₂O₃, Cu, Al nanoparticles of 45, 31, 80, 60 nm sizes respectively. Conductivity enhancement was found to be by 7.5, 6, 5, 3, and 4 % respectively [3]. Xie et al. [7] had also investigated the thermal conductivity of pump-oil by using Al₂O₃ nanoparticles. The size of nanoparticle used was 60 nm and the conductivity enhancement was found to be 11 %. Xuan et al. [8] studied thermal conductivity of Cu and Transformer oil at 100 nm size and found a 6% enhancement in the thermal conductivity. A limited literature is available about viscosity of oil based nanofluids. Therefore, our attempt is to see the performance of oil based

nanofluids. Reported research shows that water and ethylene glycol have been used widely as a host/ base fluids in making nanofluids.

The objective of this experimental study is to discuss the dependence of thermal conductivity and viscosity of Al$_2$O$_3$–nanotransformer oil in temperature ranges from $(20$-$50^\circ\text{C})$ under different weight fractions of nanoparticles from $0.1, 0.3$ & $0.5\% \text{ (vol.)}$ In subsequent sections the preparation and characterization of nanofluids along with results have been discussed in detail.

II. FUNDAMENTAL THEORIES & CONCEPTS

Maxwell derived an equation for calculating the effective thermal conductivity of solid-liquid mixtures consisting of spherical particles. Later on this equation was modified and explained to obtain different mathematical models for thermal conductivity of nanofluids. Few models have been shown in Table 1.

<table>
<thead>
<tr>
<th>Author</th>
<th>Thermal Conductivity model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxwell model $[4]$</td>
<td>$k_{nf} = \frac{k_p + 2k_f + 2(k_p - k_f)\varphi}{k_p + 2k_f - (k_p - k_f)\varphi} k_f$</td>
</tr>
<tr>
<td>Hamilton model $[5]$</td>
<td>$k_{nf} = \frac{k_p + (n-1)k_f + (n-1)(k_p - k_f)\varphi}{k_p + (n-1)k_f - (k_p - k_f)\varphi} k_f$</td>
</tr>
</tbody>
</table>

Einstein $[7]$ proposed the model to study the dynamic viscosity of dilute suspensions that contain spherical particles. In the model, the interactions between the particles are neglected. Few more model given by other researchers are also given in table 2.

Table 2: Viscosity Models and their applicability

<table>
<thead>
<tr>
<th>Author</th>
<th>Viscosity model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nguyen et al.$[6]$</td>
<td>$\frac{\mu_{nf}}{\mu_f} = 2.1275 - 0.0215T + 0.00027T^2$</td>
</tr>
<tr>
<td>Nguyen et al.$[6]$</td>
<td>Temperature dependent nanofluids viscosity model and valid for 1% to 4%</td>
</tr>
<tr>
<td>Einstein model $[7]$</td>
<td>$\frac{\mu_{nf}}{\mu_f} = 1 + 2.5\varphi$</td>
</tr>
<tr>
<td>White et al.$[8]$</td>
<td>$ln\frac{\mu_{nf}}{\mu_f} = a + b\left(\frac{T_e}{T}\right) + c\left(\frac{T_e}{T}\right)^2$</td>
</tr>
<tr>
<td>White et al.$[8]$</td>
<td>Temperature dependent viscosity of Al203</td>
</tr>
</tbody>
</table>

III. PREPERATION AND CHARACTERIZATION

In nanotransformer oil Al$_2$O$_3$ nanoparticles are dispersed in transformer oil by using two step method. In this technique nanoparticles are prepared and then dispersed in to the base fluid. The stability of nanoparticle suspension in base fluid also depends upon the preparation method used and it is found that sometimes surfactants are also added to stabilize the nanoparticle suspension.

The material of nanoparticles is chosen as Al$_2$O$_3$ because it is chemically more stable and its cost is less than their metallic counterparts and also it is easily available.

The properties of Al$_2$O$_3$ used for investigation are given in Table 2. Photograph of Al$_2$O$_3$ nanoparticles obtained from the transmission electron microscope (TEM) is shown in Fig. 1. The X-ray diffraction and particle size distribution is also shown in Fig.2 and 3. Nanofluids with different concentrations are prepared for the experimental work. Nanoparticles of the required amount and base fluid were then mixed together and their mixture is sonicated for 4 hours in order to obtain stable and uniform suspensions.

Table 3: Properties of Al$_2$O$_3$ (Gamma) nanoparticles

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purity</td>
<td>99.99 %</td>
</tr>
<tr>
<td>Avg. particle dia.</td>
<td>20 nm (gamma)</td>
</tr>
<tr>
<td>Molecular mass</td>
<td>100.96 g/mol</td>
</tr>
<tr>
<td>Density</td>
<td>3880 Kg/m$^3$</td>
</tr>
</tbody>
</table>

Table 4 Properties of “Transol” transformer oil

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity</td>
<td>11.0 cSt</td>
</tr>
<tr>
<td>Density at 20$^\circ\text{C}$</td>
<td>0.89 kg/dm$^3$</td>
</tr>
<tr>
<td>Flash point</td>
<td>140$^\circ\text{C}$</td>
</tr>
<tr>
<td>Interfacial tension (20$^\circ\text{C}$)</td>
<td>0.05 N/m</td>
</tr>
</tbody>
</table>

Fig. 1 : TEM photograph of Al$_2$O$_3$ nanoparticles
IV. EXPERIMENTAL SET UP

KD2 Pro “thermal property analyzer” is used for thermal conductivity measurements. It consists of a handheld microcontroller and sensor needles. The KD2’s sensor needle contains both a heating element and a thermistor. The KS-1 sensor needle can be used for measuring thermal conductivity of fluids in the range of 0.2–2 W/m-k with accuracy of ±5%. At the end of the reading, the controller computes the thermal conductivity using the change in temperature (ΔT)–time data from:

\[ k = \frac{q (\ln t_2 - \ln t_1)}{4\pi (\Delta T_2 - \Delta T_1)} \]

Where, \( q \) is constant heat rate applied to an infinitely long and small line source in W/m²

DV-III Ultra Viscometer is used for measuring viscosity of nanofluids. It contains of a small adaptor and adapter further consists of a cylindrical sample holder, a water jacket and a spindle. The viscometer drives the spindle immersed into the sample holder containing the test fluid sample. It measures viscosity by measuring the viscous drag of the fluid against the spindle when it rotates. The spindle CPE-42 is used. The sample holder can hold a small sample volume of 1 mL and the temperature of the test sample is monitored by a temperature sensor embedded into the water bath. Other equipment used is sonicator, which sonicate the solution by using ultrasonic vibrations. Following pictures shows their evidence of existence in the lab.

To prepare a nanotransformer oil, conventional transformer oil is mixed with different volume fractions of nanoparticles (0.1, 0.3, 0.5, 1.0 vol. %).
Following is the procedure adopted to do the experiments with nanotransformer oil:

1. The weight measurement of Al₂O₃ nanoparticles is done to calculate its volume fraction.
2. Al₂O₃-transformer oil is sonicated for 3 hours & checked for any settling of nanoparticles.
3. Thermal conductivity is measured at required temperature by taking nano-transformer oil in test tube and dip KS1 needle of kd2 pro in it properly.
4. Measurement of viscosity is done with sample in Viscometer (Brookfield DV-III Rheometer) and in the temperature range from 20-50°C.
5. Viscosity is measured by changing the r.p.m of the motor from 20 to 70.

V. RESULTS AND DISCUSSION

Experimental data shows that thermal conductivity of nanotransformer oil increase with volume fraction of nanoparticles (0.1, 0.3, and 0.5 % by vol.). Figure 7 shows that thermal conductivity at lower particle volume fraction increases almost linearly with temperature however, at higher particle volume fraction the drop in the value of thermal conductivity is noticed at 45-50°C, this behavior occurs due to the agglomeration and settling of the nanoparticle which increases with increase in volume fraction. Maximum increase in thermal conductivity is up to 4% and is observed in volume concentration ranges from 0.1 to 0.3 % by vol.

Figure 9 shows the comparisons of the thermal conductivity for nanotransformer oil at 0.10 % volume fraction. Maxwell model and Hamilton model have been used to predict this variation in the thermal conductivity. It is found that at in the lower temperature range (up to 35°C), theoretical models predict the thermal conductivity variation accurately but at higher temperature (45-50°C) these predictions deviates from the experimental results. It is proposed that increase in thermal conductivity is mainly due to the Brownian movement of nanoparticles which increase with rise in temperature and this mechanism has not been considered in these models.

Figure 11 shows the effect of temperature on viscosity of nanotransformer oil. The viscosity of nanotransformer oil is tested at temperature from 20 to 50°C and found that viscosity decreases with increase in temperature.
VI. CONCLUSION

In this study, about thermal conductivity and viscosity of nanotransformer oil following conclusions have drawn.

1. Temperature and volume fractions have significant effects on the thermal conductivity and viscosity characteristics of nanotransformer oil.

2. Results show that thermal conductivity increases with increase in temperature up to 40°C however at higher temperature certain deviation is noticed which may be due to Brownian motion of nanoparticles.

3. It is also observed that volume fraction also affects thermal conductivity at higher concentration (0.4-0.5 %) and drop in conductivity is observed due to agglomeration of nanoparticles.

4. The fluids in which shear stress is proportional to shear rate called Newtonian fluid. For 0.1% vol. fraction nanotransformer shows nearly Newtonian behavior but at high temperature it shifts toward non-Newtonian behavior because at higher temperature shear thinning action takes place. For 0.3% vol. fraction shear stress becomes independent of shear strain at higher torque values. Similar kind of behavior is also shown at 0.5 % vol fraction.

There is need to redefine the models for particular category of base fluids as each base fluid has its own physical properties. Nano transformer oil can be good replacement for conventional transformer oil with more validation of the results to predict its thermal performance.

VII. REFERENCES


