Experimental Testing of Thermo Physical Properties of Novel Water and Glycerol Mixture-Based Silica Nano Fluids

T. Rajendra Prasad, K. Rama Krishna, K. V. Sharma

Abstract*: The main objectives of the present work embrace the preparation of cobalt nanofluids, amalgamation of silica nanofluid with optimum glycerol-water (G-W) mixture ratio and estimation of its thermal properties like thermal conductivity and viscosity experimentally. Optimum ratio of base liquid (G-W mixture) was selected for the preparation of nanofluids. Subsequently, thermophysical properties of the hybrid nano mixture have been determined experimentally using KD2Pro thermal properties analyzer and Brookfield viscometer at different volume concentrations of silica nanofluids. Attained results reveal that, the dynamic viscosity and thermal conductivity are found to be growing remarkably with the increase in nanoparticle weight concentration in base liquid mixture. The results are found to be in good agreement with the available data from the literature.

***Index Terms*: Water-Glycerol mixture, Nanofluid concentration, Thermal conductivity, Viscosity.**

I. INTRODUCTION

Conventional energy transfer fluids like water, transformer oil and refrigerants have limited heat transfer capabilities because of their low thermal conductivities. Several methods have been proposed by investigators to improve thermal conductivities of the conventional energy transfer fluids. One such method to improve thermal conductivity of the conventional fluids is by dispersing solid nanoparticles in to these fluids and the resulting dispersion is named as nanofluid. The thermal conductivity of nanofluid is expected to be greater than the basefluid because the solid nanoparticles have higher thermal conductivity than that of basefluid. A variety of solid nanoparticles can be dispersed in the basefluids like metals, metallic oxides, non-metallic oxides and ceramics.

Masuda et al. [1] was the first to start investigations regarding the dispersion of ultrafine solid particles in traditional liquids. Choi [2] investigated the improvement in thermal conductivity after dispersing solid nanoparticles in traditional heat transfer liquids and called the dispersion as nanofluid. Various investigators have found similar improvement of thermal conductivities by forming stable dispersions of nanoparticles in traditional fluids [3, 4]. An increment of 22% in heat transfer coefficient than water is reported by suspending TiO_2 nanoparticles in water by Sajadi and Kazemi [5]. Eastman et al. [6] reported a good amount of increment in thermal conductivity of 40% than basefluid by suspending copper oxide nanoparticles in base ethylene glycol. In a similar investigation, the improvement in thermal conductivity of alumina and silica nanofluids have been published [7]. The thermophysical properties of stable alumina and silica nanofluids are investigated by Sahoo et al. [8, 9]. The heat transfer coefficient improvement through alumina, copper oxide and silica nanofluids in ethylene glycol water mixture as basefluid [10]. Various nanofluids dispersed in different types of basefluids are investigated by several researchers [11-13]. The thermal conductivity of the nanofluids increases with rise in nanoparticle concentration and temperature [14-17]. The dynamic viscosity of the nanofluid increases with rise in concentration and decreases with rise in temperature [18]. Pham Van Trinh et al. [19, 21] have reported investigations and found 50% and 41% increase in thermal conductivity with hybrid nanofluids dispersed with 0.07% volume concentration of Gr-CNT and 0.07% volume concentration of Gr–MWCNT/Cu in ethylene glycol basefluid. The thermal conductivity of water improved by 40% by suspending 0.25% volume concentration of copper nanowires [20]. A stable suspension of 1.5% weight concentration of the copper nanoparticles coated with carbon has improved the thermal conductivity of basefluid propylene glycol by 49% [22]. Dahai Zhu et al. [23] in their investigation found the thermal conductivity enhancement of 60.78% by adding 0.75 vol % CuO nanowires in dimethicone based nanofluid. S. Iyahraja et al. [24], in their research on suspended polyvinyl pyrrolidone coated silver nanoparticles in distilled water, seen that the thermal conductivity increases up to 69 % with a low volume fraction of 0.1 vol % of nanoparticles. Sundar et al. [25] had done the evaluation of thermal conductivity and viscosity of alumina nanofluids in ethylene glycol water mixture as basefluid. Usri et al. [26] have estimated the convective heat transfer coefficient of TiO_2 nanoparticles with particle size in the range of 30-50 nm suspended in EG-water in 40:60 ratios at 70°C. Few investigators have developed correlations for the calculation of thermophysical properties of the nanofluids [27, 28].

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The literature on nanofluid research has been mostly on water as basefluid. To the best of the knowledge, very few studies have determined the influence of base liquid mixture ratio on the characteristics of nanofluid heat transfer flow and no study has been reported on the influence of water-glycerol based liquid mixtures with dispersed silica nanoparticles. Therefore, this work endeavours to determine the thermal properties of nanofluids in optimizing the performance of heat transfer. In the present research, first the optimum ratio of base liquid (glycerol-water mixture) was selected for the preparation of nanofluids based on thermophysical properties of glycerol-water solutions. Later, the thermal properties like thermal conductivity and viscosity have been determined experimentally. The KD2 pro thermal properties analyzer and Brookfield viscometer are used to find thermal conductivity of glycerol-water solutions and silica nanofluids at different weight concentrations of nanofluids. The present work will be very useful for designing the nanofluids based heat exchange devices.

II. MATERIALS AND METHODS

Various samples of 100ml each were prepared by mixing glycerol and water containing different weight percentages of glycerol. In such a way different glycerol and water solutions containing 10% to 90% of glycerol by weight are prepared. The KD2 Pro thermal property analyzer (**Fig.1**) is used for measuring thermal conductivity of prepared glycerol water solutions.

Fig.1. KD2Pro Thermal Property Analyzer

The Brookfield digital rheometer model LVDV-III (**Fig.2**) is used for measuring viscosity of prepared glycerol water solutions. Both the instruments were calibrated and tested for accuracy of the results of the instruments with standard liquids like water and glycerin whose thermal conductivity and viscosity are already established. The tests done on both the instruments with the standard liquids are successful and results were very close to the actual established values of thermal conductivity and viscosity. After testing the accuracy of KD2Pro and Brookfield rheometer, the instruments are used to test the thermal conductivity and viscosity of prepared glycerol water mixtures. The results of these properties are used to identify the better mixture ratio of the glycerol water solutions. Silica Nano powder having average particle size of 50nm is purchased from Nano Research Labs, India. Silica nanopowder of appropriate amount is taken to prepare 0.115%, 0.23% and 0.92% volume concentrations of silica nanofluids in selected optimum basefluid ratio. The corresponding weight concentrations of nanoparticles are 0.25%, 0.5% and 2%.

Fig.2. Brookfield Rheometer

The silica nanopowder is then dispersed in the basefluid by magnetic stirring for an hour at room temperature. Then the prepared nanofluid solutions are moved for probe sonication. According to Suganthi and Rajan [29] a minimum of two hours of sonication is suggested for proper results of the measured thermophysical properties of nanofluids. Hence, the prepared nanofluids are sonicated for two hours and stable nanofluids were prepared without mixing any surfactant.

The dispersion stability analysis is vital because the test results of thermophysical properties like viscosity and thermal conductivity is affected by the dispersion stability of nanofluids [30]. Various testing methods are available for checking the dispersion stability of nanofluids [31-33]. Zeta potential tests were employed in this work for the analysis of dispersion stability of prepared silica nanofluids. A variety of techniques are available to test the nanofluid thermal conductivity [34]. KD2Pro is used to test the nanofluid thermal conductivity and previously various researchers used the same instrument for same tests [35-38]. The silica nanofluid viscosity is measured by Brookfield digital rheometer model LVDV-III, the same instrument is employed previously by various researchers [39-41] for measuring nanofluid viscosity.

III. RESULTS AND DISCUSSIONS

The two thermophysical properties called thermal conductivity and viscosity of glycerol-water mixtures having different weight percentages of glycerol from 10-90% is measured initially for selecting an optimum percentage of glycerol in the solutions. The samples are prepared having 100ml quantity with varying proportion of glycerol in water. The prepared mixtures of glycerol and water are mixed well by a mechanical stirrer to ensure the complete homogeneity. The mixture having optimum percentage of glycerol in water is to be used as a basefluid.

Table.1 The Measured Viscosity And Thermal Conductivity Data Of GW Mixtures

% Glycerol (by Weight)	Measured data	
	Viscosity, cp	Thermal conductivity, W/mK
10	1.1	. 0533
20	1.29	0.482
30	1.91	0.428
40	2.63	0.409
50	3.92	0.387
60	7.63	0.373
70	15.66	0.351
80	46.84	0.317
90	171.6	0.309

The literature data available for viscosity by Cheng [42] and thermal conductivity by Bates [43] of glycerol and water mixtures are compared to the measured data. Both the test results of viscosity and thermal conductivity of glycerol water solutions closely matches with the literature reports. For instance the viscosity measured and literature data [42] at 30% glycerol mixture are 1.91cp and 1.855cp respectively. The average deviation percentage between measured and reported viscosity data is 11.04%. Similarly, for 30% glycerol mixture the measured and literature data [43] of thermal conductivity are 0.428W/mK and 0.489W/mK respectively.

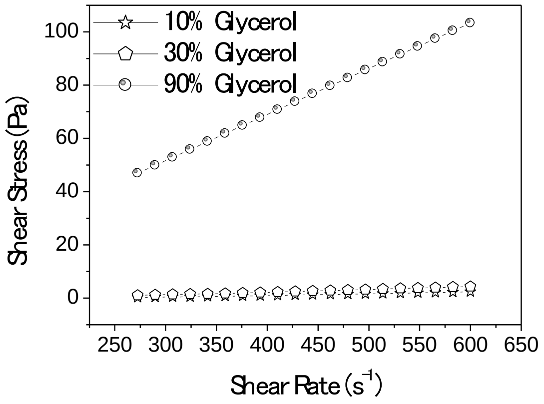

Fig.3. Variation Of Shear Stress With Shear Rate At Different Glycerol Concentrations

The average deviation percentage between measured and reported viscosity data is 6.13%. By the comparison of thermal conductivity and viscosity data of glycerol and water mixtures with data reported in the literature reflects that the reliability of the measuring instruments KD2 Pro and Brookfield rheometer is reflected. Moreover the procedure followed while taking the measurements is validated. The Shear stress Vs Shear rate graphs for different concentrations of glycerol in the mixtures prove that the mixtures behave as a Newtonian fluid as shown in **Fig.3**.

As we know glycerol is a high viscous and low thermal conducting liquid compared to water, increasing glycerol percentage in the mixture will decrease the thermal conductivity and increases the viscosity of the mixtures and the same trend reflected in the measured data. As per the stability of a nanofluid is concerned a higher value of viscosity is desirable [44]. For the basefluid mixture containing 30% of glycerol the viscosity is nearly 2cp which is double than pure water. The thermal conductivity at this basefluid mixture ratio is also slightly less compared to that of water, which shows us that without compromising on the decrement of thermal conductivity the desired viscosity for stability of nanofluid is achieved from the 30% glycerol in water basefluid mixture ratio. So, for this reason we have selected the 30% glycerol in water baseflid mixture ratio for the preparation of nanofluids with different concentrations of cobalt nanoparticles.

The silica nanofluids of 0.115%, 0.23% and 0.92% concentrations by volume (0.25%, 0.5% and 2% Wt%) are prepared in the selected mixture ratio of the basefluid and sonicated for about 60 minutes to ensure better stability and to give accurate results while measuring their viscosity and thermal conductivity. The SEM image (**Fig.4**) shows that the silica nanoparticles are spherical and the maximum percentage of silica nanoparticle sizes matches with that of average size proposed by the vendor.

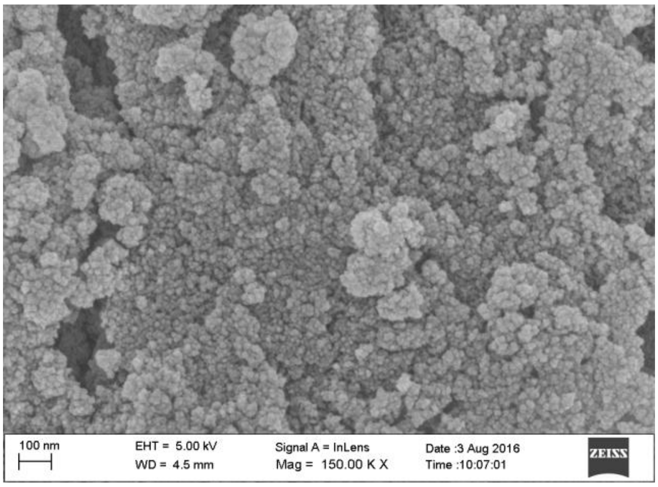

Fig.4. SEM Image Of Silica Nanoparticles

To analyze the dispersion stability the zeta potential test of prepared nanofluids, the nanofluid of maximum concentration of 0.92% by volume is considered. The zeta potential is a measure of mutual repulsion between two particles in a suspension. If the zeta potential is more than 30mV the nanofluid is a stable dispersion [45]. Five different samples of different pH values each of 10ml were prepared by mixing drops of strong HCl and NaOH solutions accordingly from the considered nanofluid. The prepared samples have the ranges of pH from 1.5 to 12.04. The change in the zeta potential of the nanofluid with variation of pH is shown in Table.2. A close observation of the Table.2 indicate that the maximum value of the zeta potential of -34.6mV is obtained at a pH of 8.

Table.2 The Measured Zeta Potential Data With Ph Of The Nano Fluid

pH	Zeta potential, mV
1.5	24
4.6	-2.8
7.7	-34.6
9.62	-0.9
12.04	13

The viscosity and thermal conductivity were found for nanofluids of 0.115%, 0.23% and 0.92% concentrations of silica by volume at different temperatures. Accuracy and validation of experimental results of the thermal properties of KD2 Pro and viscosity calculations of rheometer were done with standard liquids like water, glycerol and ethylene glycol whose values of thermal conductivity and viscosity are already established.

The viscosity of nanofluid for all concentrations decreased with raise in temperature as shown in **Fig.5.** The percentage increment in the viscosity of nanofluids with temperature is shown in **Fig.6**. In **Fig.6** the nanoparticle concentrations are shown in weight percentages. The maximum enhancement of 100.9% in viscosity is found for 0.92% silica nanofluid at a temperature of 40^{0}C.

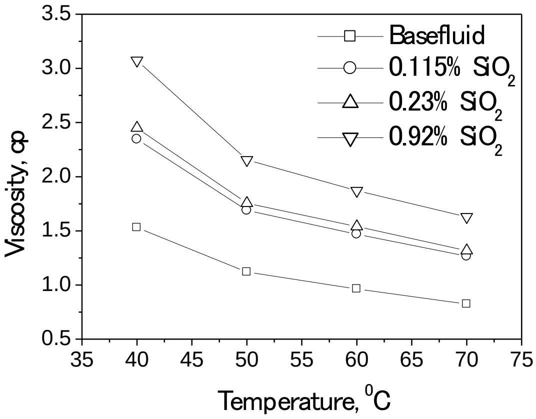

Fig.5. Variation Of Viscosity With Temperature At Different Silica Volume Concentrations

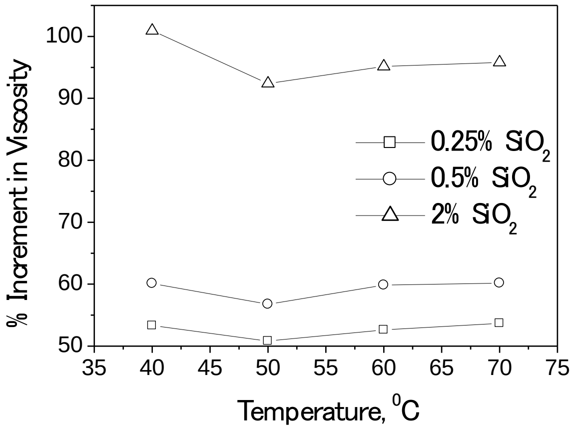

Fig.6. Percentage Increment Of Thermal Conductivity With Temperature (Sio$_2$ Concntrations Are Shown In Wt%)

The thermal conductivity of nanofluid for all concentrations increased with raise in temperature as shown in **Fig.7.** The percentage increment in the thermal conductivity of nanofluids with temperature is shown in **Fig.8.** The maximum enhancement of thermal conductivity of 11.08% is found for 0.92% silica nanofluid at a temperature of 60^{0}C.

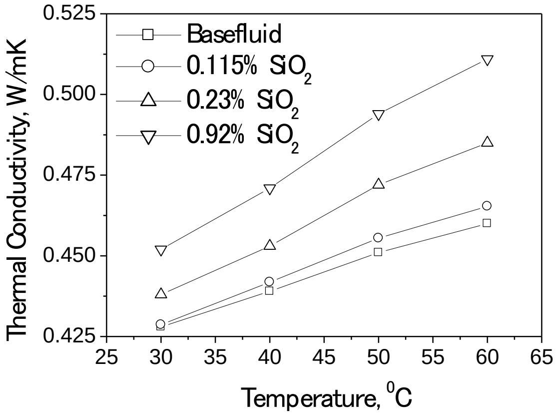

Fig.7. Variation Of Thermal Conductivity With Temperature At Different Silica Volume Concentrations

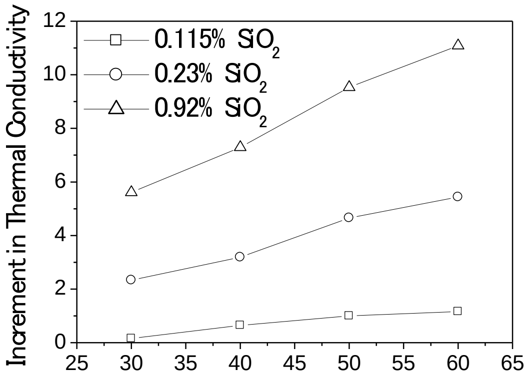

Fig.8. Percentage Increment Of Thermal Conductivity With Temperature

IV. COMPARING MEASURED DATA OF THERMOPHYSICAL PROPERTIES WITH THERORETICAL MODELS

For predicting the thermal conductivity and viscosity of a two phase mixture like a nanofluid, few theoretical models are reported in the literature. The equations to predict effective thermal conductivity (k_{eff}) of a nanofluid in terms of particle volume fraction (φ), thermal conductivity of nanofluid (k_{nf}), thermal conductivity of basefluid (k_{nf}) and thermal conductivity of nanoparticle (k_p) is given by theoretical model equations as follows:

The Maxwell's effective thermal conductivity equation [46]:

$$k_{eff} = \frac{k_{nf}}{k_{bf}} = \frac{k_p + 2k_{bf} + 2\varphi(k_p - k_{bf})}{k_p + 2k_{bf} - \varphi(k_p - k_{bf})} \qquad (1)$$

The Jeffrey's effective thermal conductivity equation [47]:

$$k_{eff} = \frac{k_{nf}}{k_{bf}} 1 + 3\left(\frac{\frac{k_p}{k_{bf}} - 1}{\frac{k_p}{k_{bf}} + 2}\right)\varphi + \left(3\left(\frac{\frac{k_p}{k_{bf}} - 1}{\frac{k_p}{k_{bf}} + 2}\right)^2 + \frac{3}{4}\left(\frac{\frac{k_p}{k_{bf}} - 1}{\frac{k_p}{k_{bf}} + 2}\right)^2\right)\varphi \qquad (2)$$

The equations to predict effective viscosity (μ_{eff}) of a nanofluid in terms of particle volume fraction (φ), viscosity of nanofluid (μ_{nf}) and viscosity of basefluid (μ_{nf}) is given as follows:

The Maxwell's effective thermal conductivity equation [46]:
The Einstein's effective viscosity equation [51]: $\mu_{eff} = \frac{\mu_{nf}}{\mu_{bf}} = (1 + 2.5\varphi)\mu_{bf}$ (3)

The Batchelor's effective viscosity equation [52]:

$$\mu_{eff} = \frac{\mu_{nf}}{\mu_{bf}} = (1 + 2.5\varphi + 6.5\varphi^2)\mu_{bf} \qquad (4)$$

The comparative graph between measured and predicted effective thermal conductivity (k_{eff}) of silica nanofluids is shown in Fig.9. The observation from **Fig.9** is clear that at lower concentration of silica the measured and predicted data of effective thermal conductivity are nearly same but at higher concentrations the measured data are on the higher side by a considerable margin. Hence, the classical models for predicting effective thermal conductivities of silica nanofluids in glycerol water mixture basefluids are not applicable for higher concentrations of the nanoparticles.

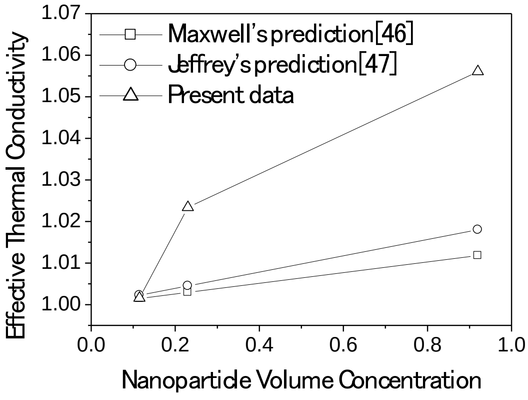

Fig.9. Comparison Between Measued And Predicted Effective Thermal Conductivities

The comparative graph between measured and predicted effective viscosity (μ_{eff}) of silica nanofluids is shown in **Fig.10**. The observation from

Fig.10 is clear that at lower concentration of silica like in the case of thermal conductivity the measured and predicted data of effective viscosity are nearly same but at higher concentrations the measured data are on the higher side by a considerable margin. It is also worthwhile to note here that the Einstein's and Batchelor's predictions result in same values for effective viscosity. In the **Fig.10** we can clearly see that both the lines of predictions coincide with one another. Hence, the classical models for predicting effective viscosities of silica nanofluids in glycerol water mixture basefluids are not applicable for the higher concentrations of the nanoparticles..

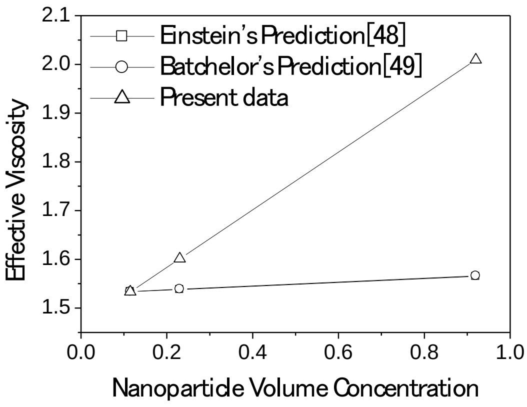

Fig.10. Comparison Between Measued And Predicted Effective Viscosities

V. CONCLUSION

The following conclusions are drawn from this work:

1. The Glycerol-Water basefluid mixture behaves as a Newtonian fluid at all the concentrations of glycerol in water.
2. The thermal conductivity decreases and dynamic viscosity increases with percentage glycerol concentration in base fluid mixture.
3. The 30 % glycerol concentrated base fluid is selected as an optimal choice for the dispersion of different volume fraction nanoparticles for preparing nanofluids.
4. The stable dispersion of the silica nanoparticles in water-glycerol mixture was confirmed by the zeta potential analysis.
5. The thermal conductivity of nanofluids increases with both the percentage of silica nanoparticles concentration and with increase in temperature.
6. The viscosity of nanofluids increases with the percentage of silica nanoparticles concentration and decreases with raise in temperature..

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