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# The Stability and Thermal Conductivity of Cobalt Nano fluids in Base Liquid Water and Glycerol Mixture

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***Abstract*: The present work involves in determination of a suitable ratio of glycerol-water (GW) mixture for the preparation of nanofluid. The base liquid with 30% weight of glycerol is selected, based on the thermo-physical properties for dispersion of spherical cobalt (Co) nanoparticles of 80nm size, for a maximum concentration of 2% by weight. The stability investigation of prepared nanofluids is done by measuring Zeta potential and SEM imaging. The prepared cobalt nanofluid thermal conductivity is measured by maintaining 7.5pH as that concerned value has maximum Zeta potential. The maximum increment in thermal conductivity is found to be 38.4% for 2% nanofluid concentration is determined at a temperature of 60°C. The data obtained for the base liquid are in fine concurrence with the published data.***

***Keywords* : Water and Glycerol mixture; Stability; Zeta Potential; SEM analysis; Thermal conductivity.**

## I. INTRODUCTION

Traditional heat transport fluids like water, glycols and synthetic oils are used commercially with utilization found in transportation, power production, chemical processing and electronics. The heat transfer capacity of the above mentioned fluids is limited due to their lower thermal conductivities. Various approaches are reported by researchers to increase the heat transfer capacity of these fluids. Recent studies targeted on the increasing the thermal conductivity by dispersing solid particles having dimensions of nanometer level because solids have high thermal conductivity compared to liquids/gases. Generally, these ultrafine particles of metal or metal oxide particles of various shapes are dispersed in the conventional single-phase fluids. Nanoparticles that are frequently used for the preparation of nanofluids are silver, alumina, copper oxide, silica, carbon nano tubes etc.

Masuda et al. [1] initiated the studies on the suspension of super micron sized particles in heat transport fluids. Nanosized particles suspended in conventional fluids are referred as nanofluids by Choi [2] which showed enhanced thermal properties compared to base liquid. Jang and Choi [3], Lee et al. [4] elucidated the ability to improve thermal conductivity by stable suspension of nanoparticles in conventional fluids. In the past two decades, the accelerating pace of research on nanofluid utilization in achieving heat transfer enhancement reflects its impact and recognition in heat transfer applications.

The investigation done by the Singh et al. [5] clarified that metallic nanofluids have high improvement in thermal conductivity than metal oxide nanofluids, which makes them more applicable for high heat transfer rates. In other works, Ismael and Sultan [6], Patel et al. [7] and Das [8] have found that metallic nanoparticles in base fluids have shown greater increment in thermal conductivity compared to oxide nanoparticles. Wilk et al. [9] suspended Copper nanoparticles inside water and found an increment of 11.5% in thermal conductivity with 0.1% (by vol.) nanofluid than water. Saterlie et al. [10] in their study reported an increment of 48% in the thermal conductivity in the nanofluid containing 1% (by vol.) of Cu in water. Bhanushali et al. [11] in their work proved that suspension of Cu nanowires resulted in increased thermal conductivity of nanofluid of 40% with nanoparticle loading of 0.25% (by vol.) in water. Parametthanuwat et al. [12] in their experiments found a maximum of 28% of growth in thermal conductivity by suspending Ag nanoparticles of 0.5 (by vol.) in water with 1 wt% potassium oleate surfactant. Godson et al. [13, 14] in their work found an increment in thermal conductivity of 80% with 0.9 vol% and 115% for 1.2 vol% of Ag nanoparticles in water. Iyahraja and Rajadurai [15], in the study on polyvinylpyrrolidone coated on silver nanoparticles dispersed in distilled water found an enhancement in thermal conductivity of 69 % with a low volume percentage of 0.1%. As proven by other researchers, Bashirnezhad et al. [16] in their review article reported that the viscosity enhances with nanoparticle concentration and decreases with increase in the temperature.

In the regions of the world having water freezing temperatures, a mixture of water-ethylene glycol mixture is used as heat transfer liquid in thermal systems like heat exchangers [17]. Sahoo et al. [18, 19] measured the thermal conductivity and dynamic viscosity of silica and alumina nanofluids. The valuation of nanofluid thermo physical properties were done by Sundar et al. [20] for $Al_2O_3$/Ethylene glycol-Water in 40/60 ratio with particle size of 36 nm in the temperature range of 20-60°C.

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Namburu et al. [21] developed the correlation for viscosity for CuO/Ethylene glycol-Water nanofluids and Kulkarni et al. [22] estimated the dynamic viscosity of $SiO_2$/Ethylene glycol-water nanofluid and reported an exponential type of correlation for viscosity.

Most of the researchers investigated nanoparticles dispersed in single base fluids like water.

It was reported that the nanofluid dispersion stability depends on nanoparticle dimensions, base fluid viscosity and pH of the nanofluid. Water has lower viscosity than alcohols and glycerol however, greater value of thermal conductivity. Alcohols and glycerol have greater range of liquid phase with temperature than water for use as engine coolant. It is intended to select an optimum mixture of glycerol and water which possess greater viscosity than water even at higher temperature for nanofluid stability, while compromising on the mixture thermal conductivity to a lesser extent. The mixture ratio is determined for dispersion of cobalt nanoparticles.

As per the best of the knowledge, in the literature very few reports are available on the effect of the base fluid on the thermo physical properties of the nanofluids. The effect of glycerol and water mixture ratio on thermo physical properties of nanofluid suspended with cobalt nanoparticles is not available in the literature. Hence, in the present study an optimum mixture ratio of glycerol and water is experimentally evaluated to be used as a base fluid for the synthesis of cobalt nanofluids. Further, the thermal conductivity of the prepared nanofluids are measured at different concentrations.

## II. MATERIALS AND METHODS

Glycerol in the range of 10 to 90% (by weight) is mixed with 90 to 10% (by weight) of distilled water and nine samples of 100ml each is prepared. The samples are designated with mixture ratio as GW10, GW20, … GW90, where GW10 indicate glycerol of 10% and the remaining 90% distilled water. The properties of mixture vary significantly with the percentage of glycerol in the mixture and the temperature. The thermal conductivity and viscosity of the mixtures of different GW mixture ratios are measured by KD2 Pro thermal properties analyzer and Brookfield viscometer.

The thermal conductivity of liquids may be tested by numerous techniques like transient hot-wire technique (THW), steady-state parallel-plate technique and cylindrical cell technique [26]. In the present work, KD2 Pro is utilized to find the thermal conductivity of the cobalt nanofluids also. Various investigators [27-30] previously used KD2 Pro to measure the thermal conductivity of the fluids.In the literature reports indicate that a number of researchers [31-33] used Brookfield viscometer to test the viscosity of the fluids.

The cobalt nanofluid is prepared by Nano Wings Private Limited, India. The particles are dispersed in the selected GW mixture for a maximum concentration of 2%. Suganthi and Rajan [23] reported the influence of time of ultrasonication on the thermo physical properties of nanofluids and recommended that the sonication process for a minimum of two hours for nanofluids to exhibit maximum thermal conductivity. Co nanofluids have been homogenized by intensive ultrasonic vibrations at amplitude of 40 kHz for 120 minutes. Thus, stable cobalt nanofluids were successfully prepared without mixing any surfactants. The dispersion stability influences the thermo physical properties of the prepared nanofluids. Hence, the analysis of the nanofluid stability is crucial [24] in the determination of properties. Different stability evaluation methods are available such as Sedimentation photographing, UV-Vis Spectrophotometry, Scanning Electron Microscope imaging (SEM), Transmission Electron Microscope imaging (TEM), Zeta potential measurement and Dynamic light scattering method. The magnitude of Zeta potential indicates a measure of repulsive forces between similarly charged particles. The SEM image shows the state of dispersion in nanofluid [25]. In the present work, the cobalt nanoparticle dispersion stability was determined by measuring Zeta potential of the prepared nanofluid at various pH values and through SEM imaging in which the sample is prepared from drying the nanofluid dispersion.

## III. RESULTS AND DISCUSSIONS

The nanofluid procured at 2% weight concentration has been subjected to sonication for 2 hours. The sample is diluted to various concentrations of 0.5, 1.0 by weight. The thermal conductivity and viscosity of Glycerol Water mixtures of weight percentages 10-90% glycerol in water are utilized for selection of ideal mixture ratio to be used as base liquid. The test data of viscosity (at shear rate of 200/s) is compared with the data reported by Cheng [34] and thermal conductivity data with those reported by Bates [35]. The viscosity values of the present test results closely relate to the values proposed by Cheng (Fig.1) with percentage differences less than 9% for GW70 glycerol weight percentage in water, however for the viscosity values for concentrations more than 70% the differences are higher and those may be due to loading errors in the instrument.

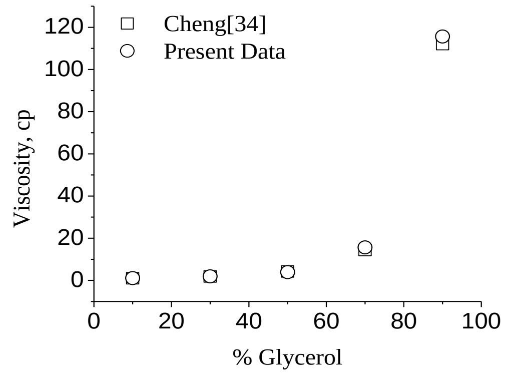


**Figure 1. Variation in Viscosity of GW mixtures**

The thermal conductivity data of the present test results when compared to the values proposed by Bates (Fig.2) the maximum percentage difference is about 13 for all concentrations of glycerol in water.

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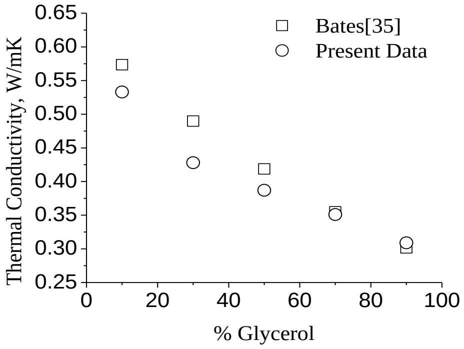


**Figure 2. Variation in Thermal Conductivity of GW mixtures**

The variation of Shear stress with respect to Shear rate for different concentrations of glycerol in the GW mixtures proves that the mixtures behave like a Newtonian fluid as shown in Figure 3. The viscosity of the base fluid plays an important role in the dispersion stability of nanofluid, the nanoparticles moving in the fluid is subjected to the viscous forces which tend to reduce their sedimentation [36]. Hence, higher viscosity of base fluids increases the dispersion stability of nanofluids, but higher viscosity of the fluids requires more pumping power for their use in heat transfer equipment. So, a compromised limit should be set for the viscosity of the nanofluid which consists of good dispersion stability and requiring low pumping capacity. The viscosity of basefluid mixture at 30% glycerol in water is nearly 2 cP which was reported in literature [37] as a most desirable viscosity value in the stability point of view as increment in viscosity favors dispersion stability.

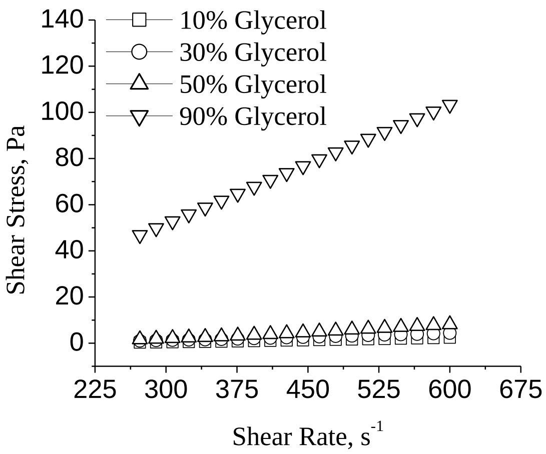


**Figure 3. Shear stress Vs Shear rate of GW mixtures**

At GW30 the mixture has a thermal conductivity of nearly 0.4W/mK which is slightly less than water, indicating that with out loosing a great deal in thermal conductivity the viscosity of the mixture increased twice compared to water. Hence, GW30 has better viscosity value in the stability point of view. Due to the above reason GW30 is selected as ideal mixture ratio to be as base fluid to prepare the cobalt nanofluids at various concentrations of 0.5%, 1% and 2% by weight.

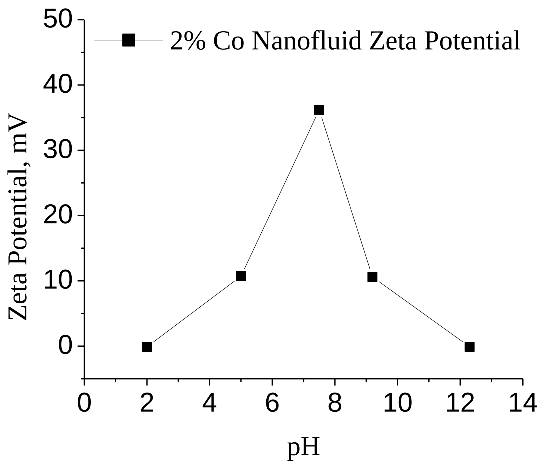


**Figure 4. Zeta potential Vs pH**

The nanofluids of 0.5%, 1% and 2% concentrations of Cobalt by weight are prepared in ideal mixture ratio of GW30. The prepared nanofluids is ultrasonicated for 120 minutes to make sure of having enhanced suspension stability and to result in precise thermal conductivity data while testing. The Zeta potential of nanofluid for the maximum nanoparticle concentration (2%) is tested after 50 days of preparation at various pH values ranging from 2 to 12 (Fig.4). The cobalt nanofluid of 25 concentration is selected for zeta potential testing as it is more susceptible for sediment and particle cluster formation. The measured Zeta potential have a maximum value of above 36mV at a pH value of 7.5, showing that the prepared nanofluids behaves with superior dispersion stability at that pH value even after 50 days of preparation.

The Field Electron Scanning Electron Microscope (FESEM) images were taken by drying the sample taken from nanofluid having highest concentration of cobalt after 50 days of nanofluid preparation. The SEM micrograph as shown in Figure 5 indicate that the cobalt nanoparticles were well dispersed, and agglomeration not observed, these aspects reflects that the nanofluids prepared are having good dispersion stability.

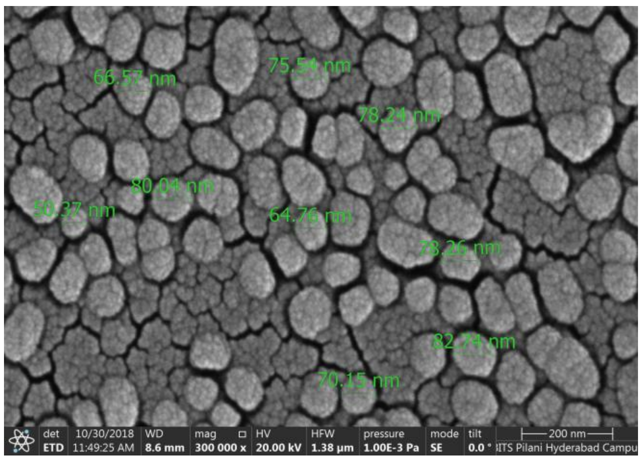


**Figure 5. FESEM image of cobalt nanoparticles**

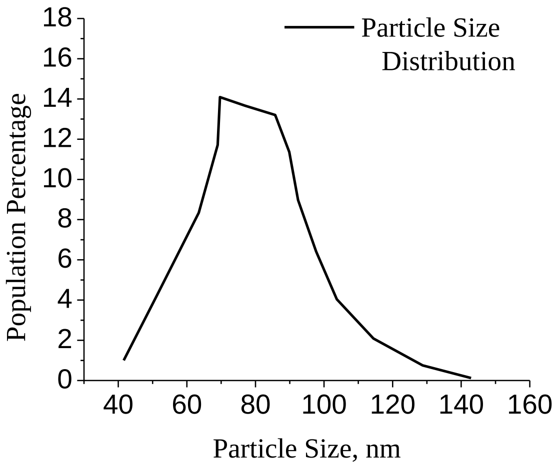


**Figure 6. Particle size distribution of cobalt nanoparticles**

The particle size distribution graph is shown in Figure 6, which results in a mean nanoparticle size of 80nm for the selected Cobalt nanoparticles. The thermal conductivity of cobalt nanofluids at 0.5%, 1%, and 2% concentrations are measured at different temperatures at a pH value of 7.5 as at this value of pH the nanofluids have higher dispersion stability. To validate the accuracy of the measured thermal conductivity data by KD2 Pro is done by measuring the thermal conductivity of standard liquids (Glycerine, water and ethylene glycol) whose property data is previously reported. Figure 7 indicate that the thermal conductivity of the cobalt nanofluids enhances with temperature. The thermal conductivity ratio variation of cobalt nanofluids is represented in the Figure 8. As indicated in Figure 8 it is clear that the thermal conductivity ratio increases with temperature and concentration. The maximum increment of thermal conductivity of 38.4% is seen for Cobalt nanofluids at 2% concentration and 60$^0$C.

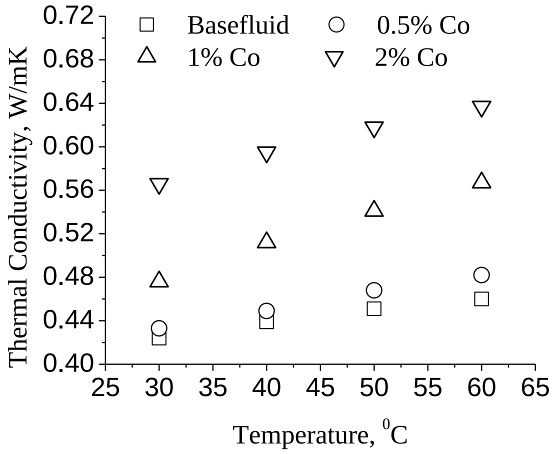


**Figure 7. Variation in thermal conductivity of Cobalt nanofluids**

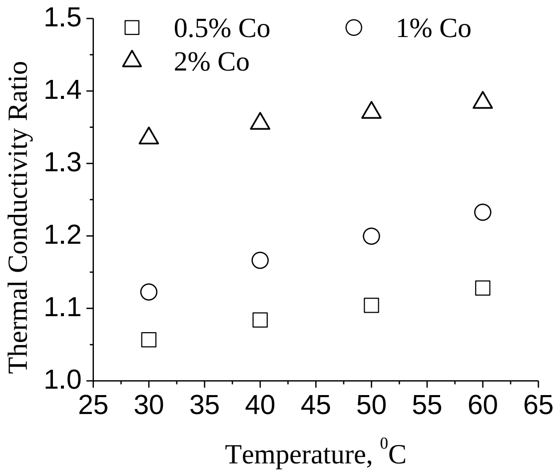


**Figure 8. Variation in thermal conductivity ratio of Cobalt nanofluids**

## IV. COMPARISON OF EXPERIMENTAL DATA WITH THEORETICAL PREDICTIONS

For the comparison of present measured data of cobalt nanofluid thermal conductivity the theoretical equations for predition of nanofluid are considered.

The Maxwell's effective thermal conductivity equation [38]:

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

Where,

$k_{eff}$ = Effective thermal conductivity/ Thermal conductivity ratio,

$k_p$ = Nanoparticle thermal conductivity,

$k_{bf}$ = Basefluid thermal conductivity,

$k_{nf}$ = Basefluid thermal conductivity,

$\phi$ = nanoparticle volume fraction.

The Hamilton-Crosser's effective thermal conductivity equation [39]:

$$k_{eff} = \frac{k_{nf}}{k_{bf}} = \frac{k_p + (n-1)k_{bf} - (n-1)\phi(k_{bf} - k_p)}{k_p + (n-1)k_{bf} + \phi(k_{bf} - k_p)} \quad (2)$$

Where,

n = Particle shape factor = 3 (Spherical)

The measured data of effective thermal conductivity fall well above the theoretical predictions. The comparison of the predicted data is done with measured data at 30$^0$C. Also for comparing the measured and predicted data the weight concentration of the nanofluids is converted to volume fraction because theoretical models to predict the thermal conductivity are given in terms of volume fractions of suspended particles. It is quite essential to quote here that the predicted data by Maxwell [38] and Hamilton and Crosser [39] in tested range of nanoparticle concentrations resulted in exactly similar data. It is observed that the measured data of effective thermal conductivity of cobalt nanofluids are 1.88%, 9.76%, 18.04% and 23.84% more than predicted data at concentrations of 0.5%, 1% and 2% respectively.

Figure 9 shows the variation between the measured effective thermophysical properties and values predicted by theoretical equations. The variation the measured and predicted data may be due to theoretical predictions not accounting for Brownian movement and particle aggregation observed in nanofluids.

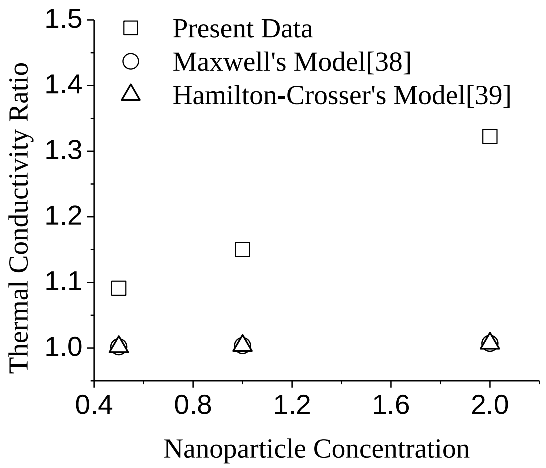


**Figure 9. Comparison of experimental and theoretical of thermal conductivity ratio**

## V. CONCLUSIONS

The conclusions drawn from the present work are as follows:

1. Newtonian fluid behaviour is observed in GW mixtures at all glycerol concentrations.
2. An enhancement in viscosity and drop in thermal conductivity is observed in GW mixtures with glycerol percentage.
3. GW30 is selected as ideal mixture ratio of Glycerol and Water as base fluid for preparing Cobalt nanofluids.
4. SEM micrographs and Zeta potential analysis confirms the dispersion stability of prepared cobalt nanofluids.
5. The prepared nanofluids exhibited good stability even after 50 days from preparation.
6. The thermal conductivity of cobalt nanofluid in GW30 base fluid enhances with temperature and concentration.
7. The maximum increment in cobalt nanofluid thermal conductivity is 38.4% at 2% concentration and 60$^0$C.
8. Finally, it can be concluded that the newly prepared GW mixture-based Co-NPs can be recommended as a best medium in heat transfer applications.

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**K. V. Sharma** joined the Jawaharlal Nehru Technological University Hyderabad, India in 1989 as a lecturer and holds the position of Professor since 2006. He has initiated experimental and theoretical studies with nanofluids since 2003 at the Centre for Energy Studies, JNTUH and later in the Faculty of Mechanical Engineering, Universiti Malaysia Pahang during 2009 to 2012. He was a Full Professor in the Department of Mechanical Engineering, Universiti Teknologi PETRONAS during 2014 - 16. He was involved in various research projects sponsored by the University and the Government of Malaysia. The Universiti Malaysia Pahang has bestowed the Best Researcher Cendekia Bitara Award in 2011 for the contributions made in nanofluid heat transfer. He has published numerous peer reviewed articles in journals dealing with thermal fluid problems having varied thermal applications in the process of guiding 22 doctoral students. He has been instrumental in obtaining U.S. and Malaysia patent on the use of nanoparticles in the manufacture of medium density fiber boards. He has co-authored a book on "Energy Conservation and Management". He is the Chief editor for the book titled "Engineering Applications in Nanotechnology" published by Springer Nature and has authored book chapters of two other publishers.

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