The Experimental Investigation and Comparison of Thermal Conductivities of Cobalt and Silica Nano fluids in Glycerol Water Mixture as Base fluid

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

Abstract: ***The present work is intended to bring out the comparison between the enhancements of thermal conductivities of cobalt and silica nanofluids. A nanofluid is a dispersion of solid nano-sized particles in a carrier liquid called basefluid. The experimental study has been done on thermal conductivities of Cobalt (Co) and Silica (SiO_2) nanofluids in Glycerol-Water (GW) mixture as basefluid. The average particle size of Cobalt nanoparticles was 80nm and that of $SiO_2$is 50nm. The initiation of the work started with the optimal mixture ratio selection of GW solutions. The selected optimal ratio of GW solution is used as basefluid for Co and SiO_2nanofluids preparation. Both nanofluids are prepared at concentrations of 0.5, 1 and 2% of nanoparticles by weight. The zeta potential test is conducted for the prepared nanofluids to ensure stability. The thermal conductivities of Co and SiO_2 nanofluids increased with nanoparticle concentration and temperature. The thermal conductivity enhancement of Co nanofluids is greater than that of SiO_2nanofluids at any given concentration and temperature.***

Keywords: Nanofluid, GW mixture, Zeta potential, Thermal conductivity.

I. INTRODUCTION

In the present world of miniaturization of the various heat transfer equipment, the major inconvenience encountered is poor conductance of conventionally used heat transfer fluids like water, refrigerants and engine oil. Enhancement of thermal characteristics may be the key to enhance the heat transfer rates of the fluids being used. Application of nanotechnology in the present case could be a convenient method. Adding nanosized solid particles to heat transferring fluids to form a uniform dispersion titled as nanofluid can improve their thermal conductivities. A variety of nanoparticles like metals, nonmetals, ceramics and oxides can be used for dispersion [1].Das et al. [2] in their report claimed that stable dispersions of CuO and Al_2O_3 in water improved the thermal conductivity, and the thermal conductivity of the nanofluid rises with increase in the temperature and concentration of nanoparticles. The nanofluids containing dispersed metallic nanoparticles sh1ow better elevation in thermal conductivities than non-metallic or metal oxide nanoparticles at a given temperature and concentration [3, 4]. A thermal conductivity enhancement of 23.8% by dispersion of just 0.1%by volume of copper nanoparticles in water was reported by Liu et al.[5] and an enhancement of 22% in thermal conductivity was published by Saterlie et al. [6] in water by adding 0.55% copper nanoparticles in the presence of sodium Dodecyl benzene sulfonate (SDBS) as dispersant. Paul et al. [7] in a similar work had shown an enhancement of 48% in water by adding just 0.00026% (by volume) of gold nanoparticles of mean diameter 21nm.On the other hand the research report published by Guo et al. [8] stated that the thermal conductivity enhancement of just 3.4% with a suspension of 1% volume of silica (SiO_2) nanoparticles in deionized water. In a similar investigation done on SiO_2 nanofluids, Ranjbarzadeh et al. [9] reported that for an enhancement of 38.2 % in thermal conductivity it took an addition of 3% of silica nanoparticles in water. A glance at the previous research on nanofluids clearly demonstrates that metallic nanoparticles are at the forefront in superiority of thermal conductivity enhancement of nanofluids. In some countries where subzero temperatures can be prevailed, a mixture of 60:40 ratio by weight of water and ethylene glycol is used in heat exchangers like car radiators to avoid freezing inside the equipment [10]. Selvam et al. [11] in their research work done with basefluid of 30% ethylene glycol by volume in water dispersed with silver nanoparticles of size less than 100nm has shown improvement of thermal conductivity of nearly 12% at 50^0Cand particle concentration of 0.15% by volume. Guo et al. [12] has investigated the variation of thermal and electrical conductivities of SiO2 nanofluids of particle concentration of 0.3% by mass in water and ethylene glycol mixtures of increasing glycol percentages from 0-100% by volume. Yu et al [13] reported the complete essence of the concept of stability of nanofluids. The drawback in the practical application of nanofluids is their dispersion stability. The nanoparticle because of their higher densities than basefluids they tend to form sediments and increase the possibility of forming agglomeration.

Revised Manuscript Received on May 10, 2019

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The particle sedimentation velocity (V), particle diameter (d), density difference between nanoparticle and basefluid (Δρ), basefluid viscosity (η) and acceleration due to gravity (g) is given by well-known equation of Stoke's as shown below:

$$V = \frac{d^2}{36\eta}\Delta\rho g \quad (1)$$

From the above equation it is clear that to minimize sedimentation and to increase dispersion stability it is evident to increase viscosity of basefluid for a given particle size. The stability of a prepared nanofluid can be analyzed by the zeta potential test which is the mutual amount of repulsion between the dispersed nanoparticles in the dispersion medium. The nanofluids having the value of zeta potential above 30mV are considered to be stable. The zeta potential of the nanofluids changes with mixing of acid or base [14]. The dispersion stability increases with the increasing in the sonication time for the nanofluid [15].The major research reports on the properties of nanofluids are concentrated on basefluids like water, ethylene glycol, glycerol or the combinations of water and glycol. The glycerol having a boiling point of 290^{0}Cand viscosity of 612cp [16] at room temperature, when mixed with water can have more operating range of temperatures when used in heat transfer equipment. As mentioned earlier an increased viscosity of basefluid enhances the stability, glycerol being a high viscous fluid increases the viscosity of glycerol water mixture. Hence, the mixture of glycerol and water enhances stability and operating range of temperatures for a nanofluid when used as a basefluid. A detailed survey of the literature indicates no publication reported on the nanofluids using glycerol water as basefluid dispersed with cobalt and silica nanoparticles.

II. MATERIALS AND METHODS

Samples of volume 100ml were prepared having different weight percentages of glycerol in water ranging from 10 to 90%. The samples are named as GW10 to GW90 indicating glycerol as G, distilled water as W and numerical to be weight percentage of glycerol. The thermal conductivity and viscosity of the GW samples of different mixture ratios were tested using KD2Pro thermal properties analyzer (Decagon Devises Inc.) and Brookfield digital rheometer model LVDV-III respectively. The KD2pro thermal properties analyzer uses the concept of transient hot wire, containing KS-1 sensor and a digital controller. The KS-1 sensor operates on an incorporated algorithm which fabricates time and temperature data through an exponential integral function using least squares technique. The readings of KD2pro devise are validated by measuring the thermal conductivity of calibration liquid Glycerin having thermal conductivity of 0.286W/mK. The temperature of the samples is maintained constant by an automatically controlled constant temperature water bath, the testing equipment is mounted on vibration free table and the sensor is kept vertical to arrest the convection effects. To avoid errors in the measured values of thermal conductivity the testing is repeated for six times and the average of the measured value is considered. The measured data were only considered and taken for averaging if the error percentage of the result is below 0.01% as prescribed by Decagon Devises Inc. The viscosity of the samples is measured with Brookfield digital rheometer model LVDV-III (Brookfield Engineering Laboratories Inc.) having a measurement range of 1cp to 6x10^{6}cp. The operating temperature ranges of the instrument are -20^{0}C and 100^{0}C and the accuracy of the devise is ±1.0%. The cobalt and silica nanofluids are prepared by two step method. The cobalt nanoparticles of average particle size 80nm and silica nanoparticles of average particle size 50nm are procured from Nano Wings Private Limited, India and Nano Research Labs, India respectively. Both the nanofluids samples of 0.5%, 1%, and 2% weight percentages of 100ml each were prepared by mixing carefully weighed amounts of nanoparticles. The nano-dispersion was magnetically stirred for 30 minutes at room temperature. Finally the nano dispersion was probe sonicated for 120 minutes. No surfactants were used during the preparation of the nanofluids. The dispersion stability of the prepared nanofluids was found by the analysis of zeta potential. Five different samples of varied pH were prepared from cobalt and silica nanofluids from highest concentration of 2%. The zeta potential of the prepared nanofluid samples was found by Zetasizer Nano ZS90 (Malvern Instruments Ltd).

III. RESULTS AND DISCUSSION

A. Selection of Optimum Mixture Ratio of GW mixtures

To optimize the basefluid mixture ratio of glycerol and water solutions, the thermal conductivity and viscosity of all the samples from GW10 to GW90 were found. The viscosity test was conducted at a shear rate of 200s^{-1} and the results were compared with those values reported by Cheng [17]. The thermal conductivity results are compared with data reported by Bates [18]. The thermal conductivity and viscosities of the GW mixtures are in good agreement with data reported in the literature. The average deviations of the measured viscosity and thermal conductivity data compared to that of data reported by Cheng [17] and Bates [18] is found to be 2.27% and 6.13%.The measured data of viscosity and thermal conductivity and their comparison with reported data in the literature are given in Table.1 and Table.2. A close observation of the Table.1 and Table.2 suggests us that the viscosity of the mixture increases and thermal conductivity decreases with the increase in weight percentage of glycerol in the mixtures. An increase in the basefluid viscosity increases the pumping power needed and increases the dispersion stability of the nanofluid. The increase in viscosity of the basefluid has its pros and cons. The thermal conductivity is decreased with increase in glycerol percentage of the mixture.

Hence, a compromise should be set for the weight percentage of the glycerol in the mixtures. The viscosity and thermal conductivity of 30% glycerol solution (GW30) is 1.91cp and 0.428W/mK respectively. The viscosity of GW30 mixture is almost double that of water which can be considered as better in stability point of view and there is no major loss in the thermal conductivity compared to that of pure water. As discussed earlier in previous article, a higher viscosity of basefluid is always desirable but increase in the viscosity basefluids increase the pumping power required for the allied nanofluids. Also increasing glycerol percentage lessens the thermal conductivity of the mixture. Hence, as a compromise limit between thermal conductivity and viscosity, GW30 have selected as the basefluid for the preparation of the cobalt and silica nanofluids.

Table.1 The measured viscosity data of GW mixtures and their comparison with reports in literature

% Glycerol (by weight)	Viscosity Data (cp)		
	Present Work	Cheng[19]	%Deviation
10	1.1	1.02	7.83
20	1.29	1.34	-4.20
30	1.91	1.85	2.94
40	2.63	2.70	-2.60
50	3.92	4.22	-7.20
60	7.63	7.28	4.79
70	15.66	14.36	8.98
80	46.84	34.51	6.74
90	171.6	112.04	3.19

Table.2 The measured thermal conductivity data of GW mixtures and their comparison with reports in literature

% Glycerol (by weight)	Thermal Conductivity Data		
	Present Work	Bates[20]	%Deviation
10	0.533	0.573	-7.61
20	0.482	0.531	-10.31
30	0.428	0.489	-14.45
40	0.409	0.452	-10.55
50	0.387	0.418	-8.18
60	0.373	0.380	-2.14
70	0.351	0.355	-1.38
80	0.317	0.326	-3.01
90	0.309	0.301	2.44

B. Stability Evaluation of Cobalt and Silica Nanofluids

Five different samples of pH 2, 5, 7.5, 9.2 and 12.3 were prepared from cobalt nanofluid and five other samples of pH 1.5, 4.6, 8, 9.62 and 12.09 were prepared from silica nanofluid both having highest concentration of 2%. The variation of zeta potential for maximum weight percentages (2%) of nanoparticles with respect to pH for both the nanofluids is shown in **Fig.1**. For the preparation of different pH samples of 10ml each, strong solutions of HCL and NaOH are taken and adding them just by a drop changed the pH consistently. The zeta potential of cobalt nanofluid has a maximum of 38.2mV at a pH of 7.5, and for silica nanofluid the maximum zeta potential is 34.6mV at a pH of 8. As discussed earlier the value of zeta potential of which is above ±30mV represents stable nanofluids and the magnitude of zeta potential is a measure of dispersion stability, the thermal conductivities for cobalt and silica nanofluids are measured by maintaining their pH values of 7.5 and 8 respectively to ensure better dispersion stability and to get an accurate result for thermal conductivity at each trail.

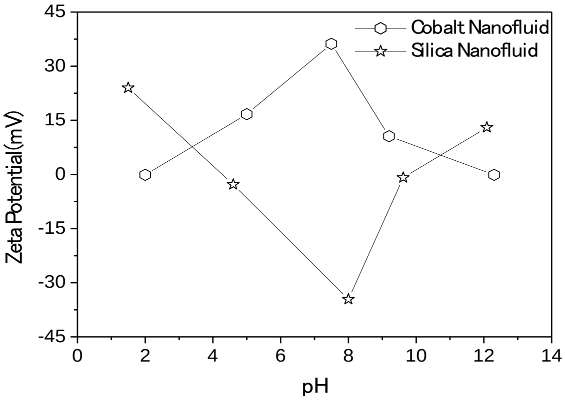

Fig.1. Variation of Zeta potential with pH for cobalt and silica nanofluids

C. Scanning Electron Microscopic imaging of Cobalt and Silica nanoparticles

To visualize the nanoparticle size and morphology various techniques like scanning electron microscopy (SEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM) are available.

In the present investigation, to verify the particle size and shape of the cobalt and silica nanoparticles, scanning electron microscope (SEM) images were taken. To test cobalt and silica nanoparticles through SEM the nanofluids highest weight concentration of 2% were considered. Before SEM testing of both the nanoparticles the nanofluid samples are probe sonicated and the samples are dried in oven. The SEM images of cobalt and silica nanoparticles are shown in **Fig.2** and **Fig.3** respectively. A clear observation of the SEM images shows that the particle shapes are almost spherical and most of the sizes of the cobalt and silica nanoparticles tally with those prescribed by the nanoparticle suppliers. The particle size analysis done based on SEM images suggests that the average nanoparticle sizes of cobalt and silica are closely equal to 80nm and 50nm respectively.

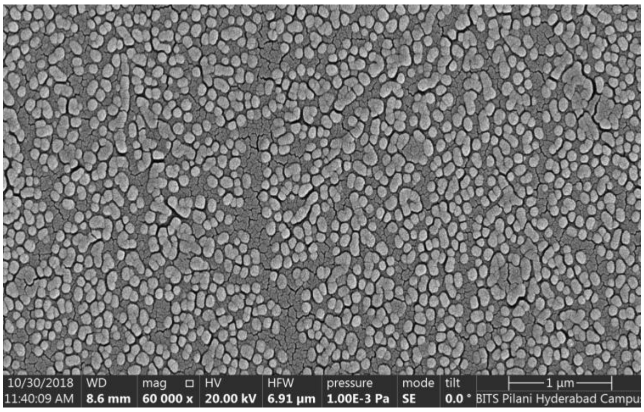

Fig.2. SEM image of Cobalt nanoparticles

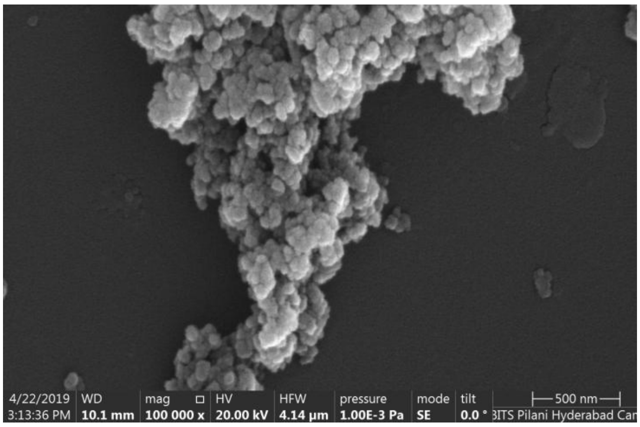

Fig.3. SEM image of Silica nanoparticles

D. Thermal conductivity testing of Cobalt and Silica nanofluids

The thermal conductivity of cobalt and silica nanofluids at prepared nanoparticle weight concentrations of 0.5%, 1% and 2% is measured with KD2Pro thermal properties analyser. To ensure correctness of the test results meticulous care taken to avoid aggregation of the nanoparticles as the phenomenon of aggregation in nanofluids affects the thermal property test results [13].To avoid aggregation of nanoparticles the cobalt and silica nanofluids are probe sonicated for 120 minutes and the pH of cobalt nanofluids are maintained at 7.5 and that of silica nanofluids are maintained at 8, as they have maximum zeta potential at these pH values. The thermal conductivities of cobalt and silica nanofluids at all prepared concentrations are measured between the temperature ranges of 30^0C to 60^0C. The variations of the thermal conductivities of cobalt nanofluids with respect to temperature at different concentrations are shown in **Fig.4**. The variations of the thermal conductivities of silica nanofluids with respect to temperature at different concentrations are shown in **Fig.5.** As observed from the mentioned figures the thermal conductivities of cobalt and silica nanofluids both increases with raise in temperature and concentration. The measured thermal conductivities of both the cobalt and silica nanofluids at any given temperature and concentration are greater than that of the basefluid.

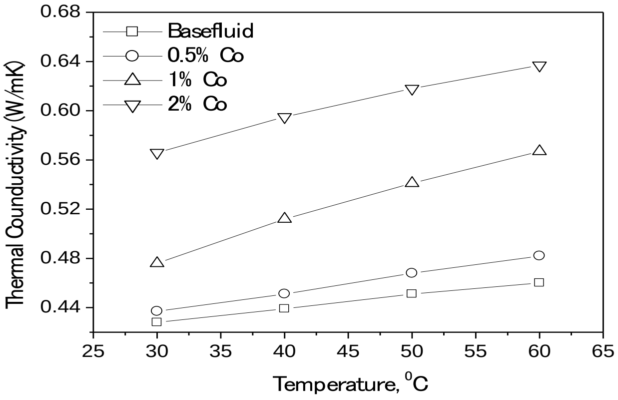

Fig.4. Variation of thermal conductivity of Cobalt nanofluids

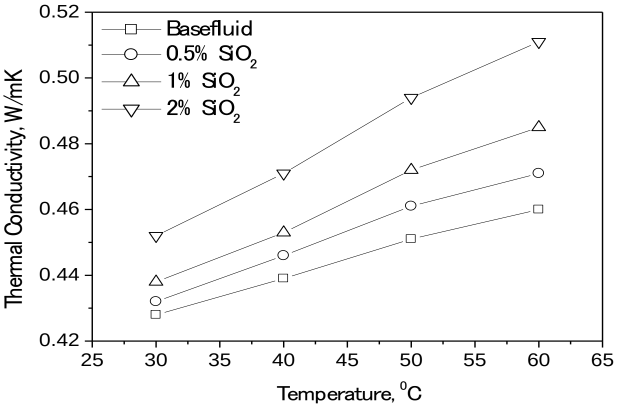

Fig.5. Variation of thermal conductivity of Silica nanofluids

A comparative graph between percentage increments in thermal conductivities with temperature at considered nanoparticle concentrations for both cobalt and silica nanofluids is drawn in **Fig.6**. For instance at 0.5% concentration and 30^0C the increment in thermal conductivity of cobalt nanofluid is 5.66% than that of basefluid and that of silica nanofluid is 0.93%.

At the maximum weight concentration of 2% and 60^0C, the cobalt nanofluid has shown an percentage increment of 38.4% in thermal conductivity than basefluid and silica nanofluid has shown only 11.08% increment than basefluid. As reported by other researchers [3, 4], a metallic nanofluid have higher increment in thermal conductivity than a nonmetallic nanofluid, in the present investigation cobalt nanofluid is showing higher increment than silica nanofluid at any given concentration and temperature.

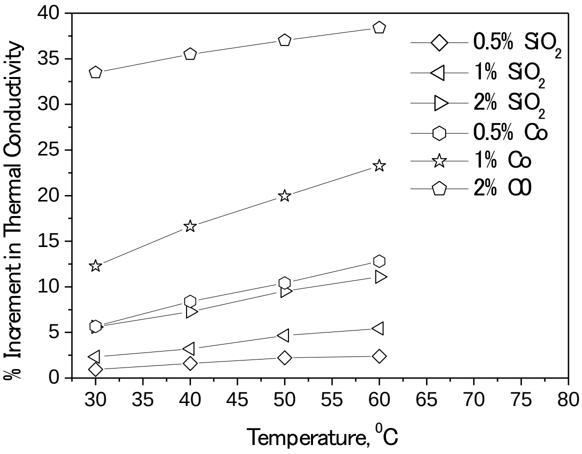

Fig.6. Percentage increment in thermal conductivity of Cobalt and Silica nanofluids

IV. COMPARISON OF MEASURED THERMAL CONDUCTIVITY DATA WITH THEORETICAL PREDICTIONS AND LITERATURE REPORTS

If k_p, k_{bf}, k_{nf} and φ are the thermal conductivities of particle, basefluid, nanofluid and φ represents particle volume fraction, then to predict the thermal conductivity ratio (effective thermal conductivity, k_{eff}) of a bi-phase solution like nanofluid various theoretical equations are available in the literature.

The most commonly used theoretical prediction model is given by Maxwell [19]. According to Maxwell's equation, the effective thermal conductivity is given as below:

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

Jeffery's [20] theoretical model incorporates the effect of molecular interaction between the nanoparticles and the equation proposed to predict effective thermal conductivity is given below:

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

The measured effective thermal conductivities of cobalt and silica nanofluids are compared to Maxwell's and Jeffery's theoretical predictions. For the facility of comparison with theoretical predictions, the cobalt and silica weight concentrations in nanofluids are converted to volume concentratons. The measured data of effective thermal conductivity at 30^0C are compared with theoretical predictions. The predicted data of effective thermal conductivities of both cobalt and silica nanofluids fall well below the measured values as shown in the Fig.7 and Fig.8. It is worthwhile to note that measured dataof effective thermal conductivities and theoretically predicted values for silica nanofluids are little closer than that of the values predicted theoretically for cobalt nanofluids.The differences between measured and predicted data for both the nanofluids may be due to random motion of dispersed nanoparticles in the nanofluid called Brownian motion. The nanofluids which are freshly sonicated having well dispersed particles gives the thermal conductivity test results which are always higher than that of predicted values from the theory [25].

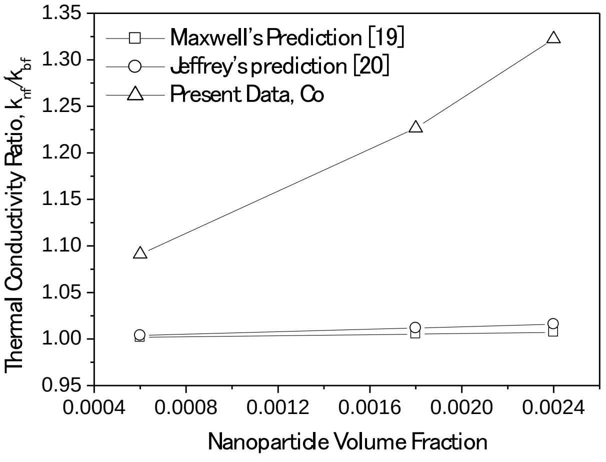

Fig.7. Comparison of thermal conductivity ratio of Cobalt nanofluids with theoretical predictions

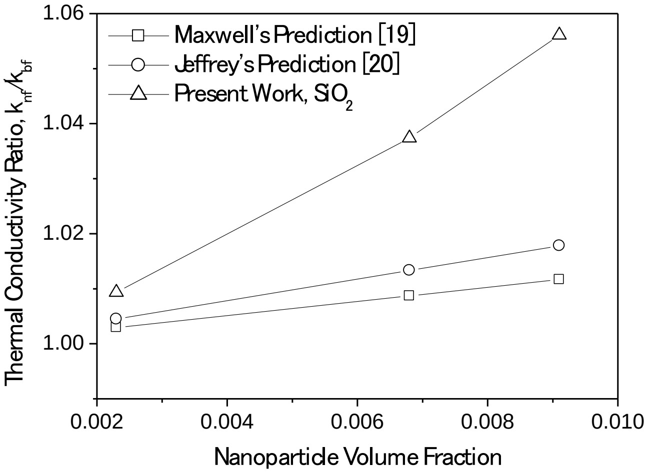

Fig.8. Comparison of thermal conductivity ratio of Silica nanofluids with theoretical predictions

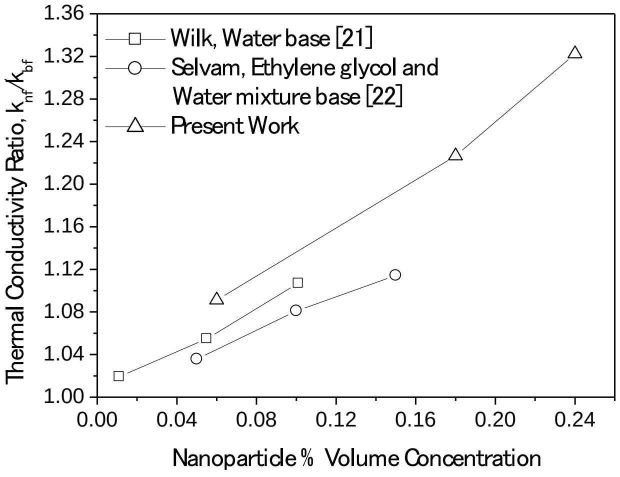

Fig.9. Comparison of thermal conductivity ratio of Cobalt nanofluids with reported literature

The measured effective thermal conductivities of cobalt and silica nanofluids are compared with the reports in the literature. As the thermal conductivity data in literature are given with respect to volume concentrations, for the facility of comparison the cobalt and silica weight concentrations in nanofluids are converted to volume concentratons. The measured data of effective thermal conductivity are compared with literature data at 30^0C at different concentrations. For the purpose of comparison of measured data with literature data of cobalt nanofluids, thenanofluids containing metallic nanoparticles in various basefluids are considered. The reason for this is due to non availability of literature on cobalt nanofluids with GW mixture as basefluid. Fig.9 shows the comparitive graph of measured effective thermal conductivities of cobalt nanofluids with considered literature data. Wilk et al. [21] repoted data on effective thermal conductivities of copper nanofluids with basefluid as water at particle volume concentrations of 0.011%, 0.055% and 0.101%. Selvam et al. [22] repoted data on effective thermal conductivities of silver nanofluids with basefluid as 30% ethylene glycol in water (by volume) at particle volume concentrations of 0.05%, 0.1% and 0.15%. The observation of Fig.9 clearly indicates that measured effective thermal conductivities of cobalt nanofluids in the present work are higher than literature reports. The reason for this is cobalt nanofluids prepared in optimum mixture ratio of GW30 resulted in exibiting good dispersion stability resulting in enhanced Brownian motion.

For the purpose of comparison of measured data with literature data of silica nanofluids, the nanofluids containing silica nanoparticles in various basefluids are considered. The reason for this is due to non availability of literature on silica nanofluids with GW mixture as basefluid. Fig.10 shows the comparitive graph of measured effective thermal conductivities of silica nanofluids with considered literature data. Sahoo et al. [23] repoted data on effective thermal conductivities of silica nanofluids with basefluid as 60% glycerol in water (by volume) at particle volume concentrations of 1%, 2% and 4%. Akilu et al. [24] repoted data on effective thermal conductivities of silica nanofluids with basefluid as 60% glycerol and 40% ethylene glycol (by weight) at particle volume concentrations of 1% and 4%. The observation of Fig.10 clearly indicates that measured effective thermal conductivities of silica nanofluids in the present work lie in between the two considered literature reports. The reason for this is the silica nanofluids prepared Sahoo et al. [23] uses a mixture of 60% ethylene glycol in water (by volume) as basefluid which has a thermal conductivity more than 0.36W/mK and in present work the GW30 basefluid has a thermal conductivity of nearly 0.4W/mK. The thermal conductivities of basefluids are almost similar and Sahoo et al. [23] used volume concentrations much higher than the present work. Hence, the thermal conductivities reported in literature [23] are on the higer side of present work. the silica nanofluids prepared Akilu et al. [23] uses a mixture of 60% glycerol in ethylene glycol (by weight) as basefluid which has a thermal conductivity more than 0.264W/mK and in present work the GW30 basefluid has a thermal conductivity of nearly 0.4W/mK. The thermal conductivity of basefluid used by Akilu et al. [24] is less than GW30 basefluid although they used particle volume concentrations much higher than the present work.

Hence, the thermal conductivities reported in literature [24] are on the lower side of present workat 1% volume concentration and at 4% volume concentration the reported data have higher value because of very high concentration compared to present work.

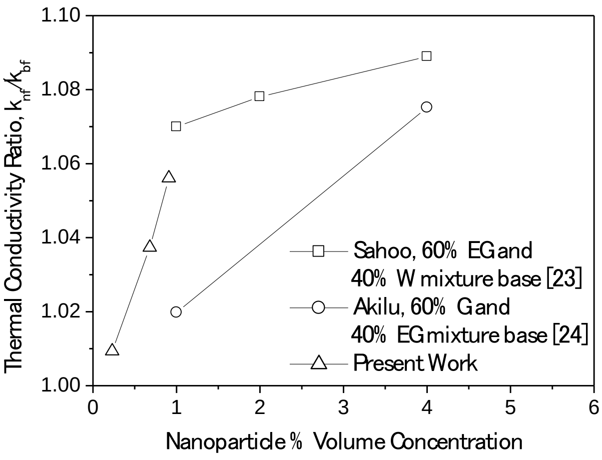

Fig.10. Comparison of thermal conductivity ratio of Silica nanofluids with reported literature

V. CONCLUSIONs

Basing on the measurement of thermophysical properties of glycerol and water mixtures (GW) of various weight concentrations of glycerol, an optimum mixture ratio of GW30 solution is selected as basefluid. It is found that viscosity enhances and thermal conductivity decreases with glycerol percentage in GW solutions. Cobalt and silica nanofluids are prepared in GW30 as basefluid at selected weight concentrations. Zeta potential analysis is done to ensure stabilities of both types of nanofluids. The measured thermal conductivity of both cobalt and silica nanofluids found to be increasing with temperature and nanoparticle concentration. The enhancement in thermal conductivity of cobalt nanofluids is higher than silica nanofluids for a given concentration and temperature. The maximum enhancements in thermal conductivity of cobalt and silica nanofluids are 38.47% and 11.08% at concentration of 2% and 60^0C. The cobalt nanofluid can be a better heat transfer fluid than silica nanofluid.

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