Thermo Physical Properties of Nanofluids

Naveen Kumar Gupta, Subrata Kumar Ghosh

Abstract: ***Nanofluids are new generation of thermo fluids. Researchers are attracted towards their application in various thermal energy systems. Before employing nanofluids in the heat exchangers, it is necessary to ensure superior thermo physical properties of nanofluids. In the present work, different thermo physical properties of nanofluids like thermal conductivity, viscosity, specific heat and density have been studied for a wide range of volume concentration (0.25-2.0 %) and temperature (30-60°C). TiO_2/ H_2O and CeO_2/ H_2O nanofluids show good stability for 0.25-2.0 volume %. The temperature range 30-60°C is considered because above 60°C the convection heat transfer may affect the accuracy of measurements. De-ionized water (D.I. water) is considered as base fluid. TiO_2/H_2O and CeO_2/H_2O nanofluids show superior thermal properties as compared to D.I. water.***

Keywords: **Nanofluids, Thermal conductivity, Specific heat, Density.**

I. INTRODUCTION

Choi et al [1] invented the term nanofluids (NFs) in 1995. Researcher dispersed the nanoparticles (size < 100nm) in base fluid. After sonicating the mixture the thermophysical properties are found to be superior to the base fluid. Researchers are continuously working to find out the new application in various domains of life. In last two decades many hundreds of research papers have been published. Researchers used different materials (nanoparticles) and base fluids to obtain a large variety of nanofluids. Majority of nanofluids shows higher thermal properties and thermal performance of the device using nanofluids as working fluid is increased. In some cases the thermal is decreased also. The enhancement/deterioration depends upon many factors. Researchers are trying to figure out those reasons. In case of thermal energy system, enhanced thermal conductivity plays main role. Almost all researchers accept that enhancement in thermal conductivity is main reason behind the improvement in thermal performance. Gupta et al [2] provide review of such mechanisms. Authors highlight the various causes or mechanisms accepted by the researchers.

In different characterization studies, researchers considered the low concentration (less than 5.0 % by wt.) of nanofluids because beyond that sedimentation of nanoparticles take place. Agglomeration and sedimentation of nanoparticles is the main problem which restrict their applications. Gupta et al [3] discussed the sedimentation of nanoparticle. Sedimentation causes deterioration in thermal performance. Therefore, researchers are working on sedimentation of nanofluids and found some surfactants which reduce the tendency of sedimentation. But addition of surfactant leads to the change in thermal properties of nanofluids. The continuous (inline) sonication might be solution of the sedimentation but power consumption in sonication will decrease the thermal efficiency of the system. The operating cost might be new challenge also. Research in nanofluid application is in nascent stage. Research in terms of publication is increasing exponentially. Many empirical correlations and research outcomes are available but due to large number of variables, they are applicable for limited conditions only. More experimental studies are required to establish the new models. Hence in present work authors made an attempt to provide characterization of TiO_2/ H_2O and CeO_2/ H_2O nanofluids for a wide range of volume concentration (0.25-2.0 %) and temperature (30-60°C).

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II. CHARACTERIZATION OF NANOFLUIDS

2.1 Preparation of Nanofluids

Nanoparticles (TiO_2 and CeO_2) were procured from Alfa Aesar, USA. In the present study water was considered as the base fluid. Nanofluids were prepared by dispersing the required amount of nanoparticles in water. The mixture of nanoparticles and water was sonicated by an ultra-sonic liquid processor (Model VCX-500, M/S Sonics, U.S.A) for at least 4 hours, to obtain the good stability of nanofluids [1]. Nanofluids having low concentration (0-3%) shows good stability [2]. Therefore, in present investigation, 0-2.0 volume % nanofluid concentration has been considered.

2.2 Stability Analysis of Nanofluids

Stability of nanofluids was checked through Sedimentation test. After 30 days, no sedimentation of nanoparticles was observed. Sedimentation test give very approximate results on dispersion ability of nanofluids. Zeta potential and Dynamic Light Scattering (DLS) analysis gives more accurate results. The tendency of agglomeration of nanoparticles, dispersed in base fluid, is generally measured by Dynamic light scattering analysis.

2.3. Measurement of thermal conductivity:

In present work, thermal conductivity of nanofluids (TCNFs) were measured by thermal properties analyzer (KD 2 PRO, Decagon Devices, Inc., USA) working on transient hot wire principle. TCNFs were measured at 30°C to 60°C temperatures at an interval of 5°C. KS-1 Sensor gives accurate result up to 50°C. Above 50°C convection heat transfer may cause of error in measurements. Researchers [7] measured thermal conductivity up to 60°C by transient hot wire method. To eliminate the forced convection, sample must be in absolutely still condition in relation to KS-1 sensor. The read time should be less. The sensor should be oriented vertically to avoid free convection. Therefore, following the above guidelines the error in measurement can be minimized. In present work, five measurements have been taken for each experiment and their mean value has been considered for further study.

Standard deviation for thermal conductivity measurement has been found approximately 3.0%.

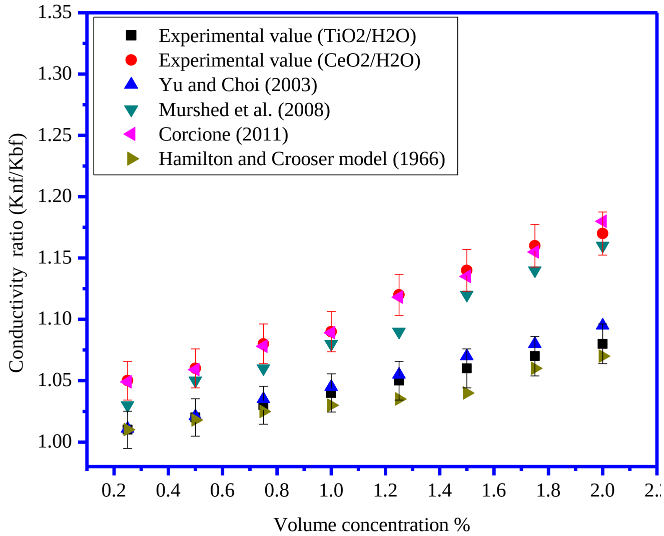

Figure 1: Variation of TCNFs ratio with concentration

The thermal analyzer was calibrated by measuring the thermal conductivity of water at 25°C. The difference in measured value and the value available in open literature (ASHRAE handbook) was within ±2.0%. As per the KD2 pro manual, the inaccuracy of the measurements is around 5%. Hence maximum possible inaccuracy of the results lies within 7% limit.

The TC ratio means the ratio of TCNF to the base fluid (water). Figure 1 shows that the TC of TiO_2/H_2O and CeO_2/H_2O nanofluid increases with a volume concentration (0.25-2.0%) of nanofluid. The trend in the enhancement of TCNFs (TiO_2/H_2O and CeO_2/H_2O) were very close to results obtained by Yu and Choi [8] and Corcione [9] respectively. Yu and Choi have modified the Maxwell model after considering the role of interfacial layer in the enhanced TCNFs. Massimo Corcione proposed empirical correlation based on large number of experiments. According to Corcione model TC ratio increases with concentration and temperature.

The TCNFs (TiO_2/H_2O and CeO_2/H_2O) is 7-10% and 10-12% as compared to water respectively. The slight difference in measured and results obtained using mathematical models available in literature for thermal conductivity may be due to the difference in shape, size, PH value, purity of materials and instrumentation error.

Figure 2 shows that the TC of CeO_2/H_2O nanofluids increases with temperature. The enhancement in TCNF lies in the range of 8-10%.

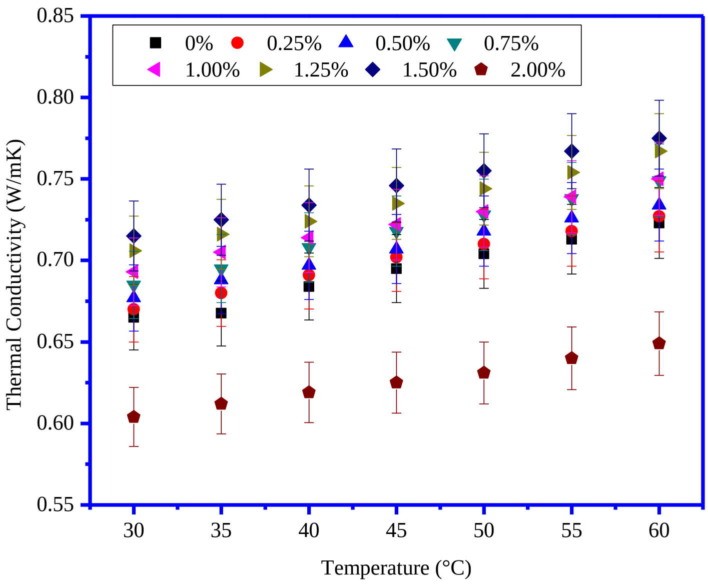

Fig 2: Variation of thermal conductivity with temperature for CeO_2/H_2O nanofluid

2.4. Measurement of Viscosity

Viscosity affects the heat transfer capability and pumping cost of the working fluids. Stabinger viscometer (Make: Antan Par, Model-SVM 3000) has been used to measure the dynamic viscosity and density of nanofluids at 7 different temperatures between 30°C to 60°C at 5°C interval. The measurements were performed at atmospheric pressure and steady state condition. Figure 3 and 4 shows the variation of shear stress with respect to shear rate for TiO_2/H_2O and CeO_2/H_2O nanofluids respectively. The tests were conducted at 30°C temperature

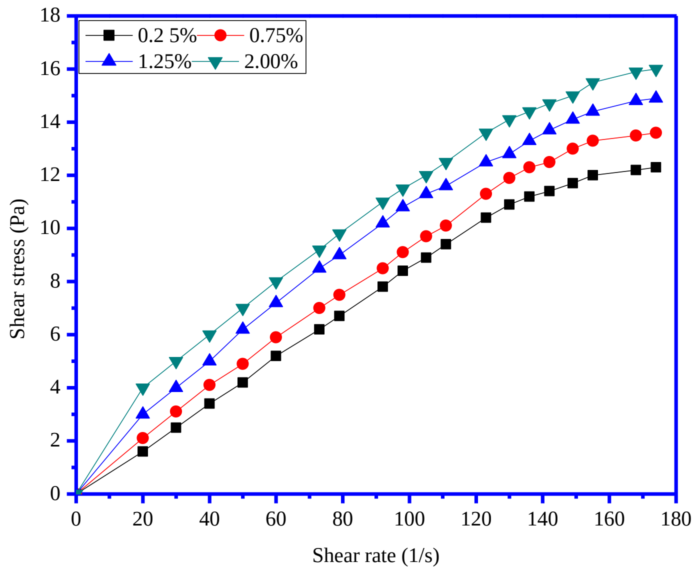

Figure 3: Variation of shear stress with shear rate for TiO_2 /H_2O nanofluid

The rheology of non-Newtonian fluid is represented by the power law: $\tau = K\gamma^n$

Where τ, K and n represents shear stress, index of flow consistency and flow behavior.

The larger deviation of n from 1 shows more non-Newtonian behavior of fluids.

The values of n in present study are less than1. It means both the nanofluids possess the shear-thinning behavior i.e. nanofluids exhibit a pseudo plastic rheological behavior. The shear thinning phenomenon means on increasing the shear rate the viscosity decreases nearly linearly.

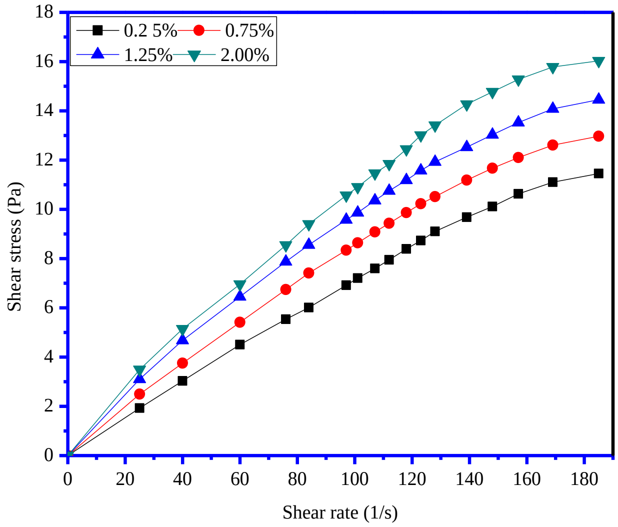

Figure 4: Variation of shear stress with shear rate for CeO_2/H_2O nanofluid

Figure 5 shows the variation of viscosity ratio with volume concentrations. Viscosity ratio means the ratio of viscosity of nanofluid to the base fluid. It was observed that the measured values are slightly higher than the values predicted by Pak and Cho [12] and Corcione *et al* [9]. The difference may be due to the parameters like shape, PH value, ultrasonic time, clustering and dispersion behavior of nanoparticles etc. The present test values of viscosity ratio for CeO_2/H_2O nanofluid are in good agreements with Tiwari *et al*. The viscosity ratio of TiO_2 /H_2O nanofluid is deviated by 10% from Corcione *et al* [9]. In present work, five measurements have been taken for each experiment and their mean value has been considered for further study. Standard deviation for viscosity measurement has been found approximately 2.25 %.

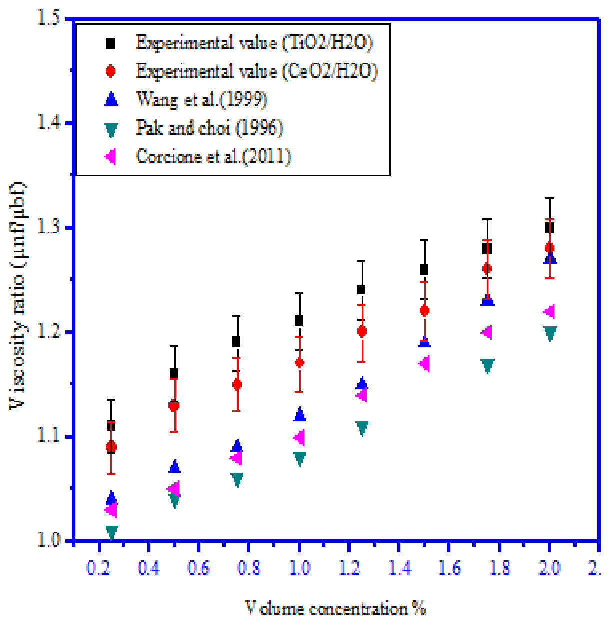

Figure 5: Variation of viscosity ratio with volume concentration for nanofluids

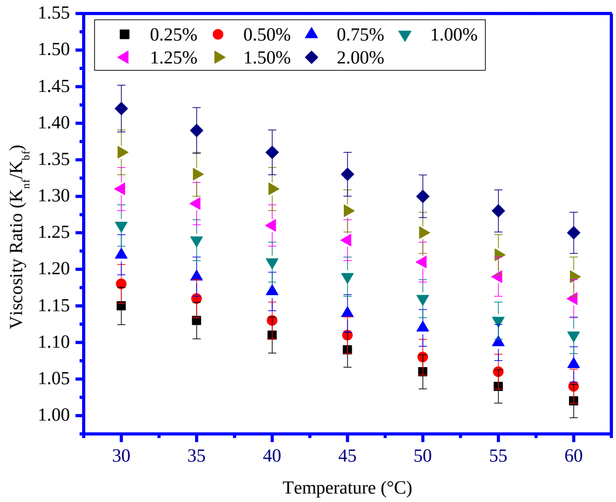

Figure 6: Change in viscosity of TiO_2/H_2O nanofluid

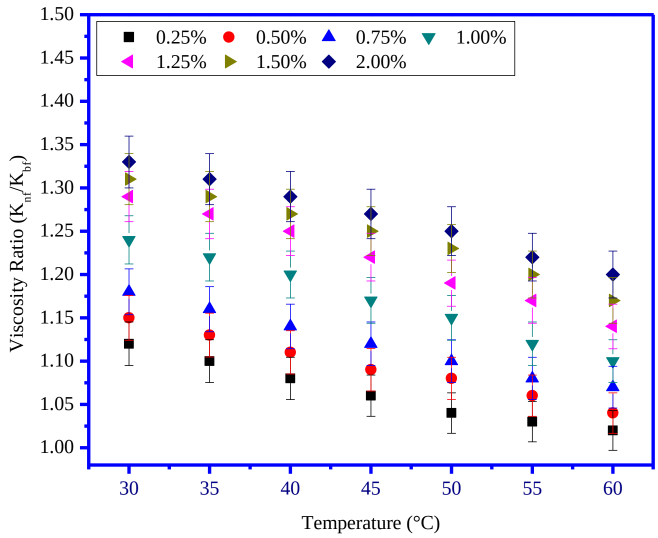

Figure 7: Change in viscosity of CeO_2/ H_2O nanofluid

Figure 6 and 7 shows the variation of viscosity ratio with temperature for TiO_2/H_2O and CeO_2/H_2O nanofluids respectively. It has been observed that viscosity ratio decreases with temperature for both the nanofluids. In liquids cohesive force and molecular interchange contribute to the viscosity of liquids. The increment in temperature reduces the cohesive forces between the molecules. But molecular interchange increases with rise in temperature. The net effect of reduction in cohesive force and rise in molecular interchange decides the viscosity of nanofluids. The temperature rise of nanofluid causes significant enhancement in kinetic energy of nanoparticles. Therefore, increment in mobility of nanoparticles and reduction in cohesive forces causes decrement in kinematic viscosity of nanofluids.

2.5 Measurement of Specific heat

Specific heat is one of the most important thermophysical properties of any heat transfer fluid. It reflects the heat transfer capacity of the fluid. The specific heat capacity can be predicted by equation 1 (Xuan and Roetzel, 2000).

$$(\rho C_p)_{nf} = (1-\varnothing)(\rho C_p)_f + (\rho C_p)_p \quad (1)$$

Equation (1) is based on energy balance equation. Figure 8 shows the variation of specific heat with volume concentration. Specific heat of nanofluid was measured using differential scanning calorimeter (Setaram C80D) at 25°C.

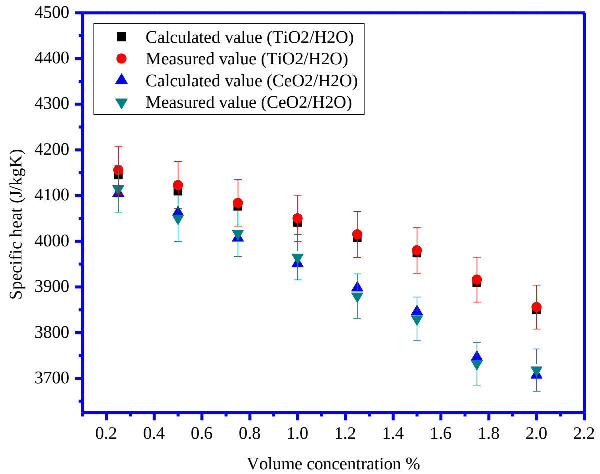

Figure 8: Variation of specific heat with volume concentration for nanofluids

Figure 9 and 10 shows the variation of specific heat for TiO_2/H_2O and CeO_2/H_2O nanofluid with temperature respectively. In present work, five measurements have been taken for each experiment. Standard deviation for specific heat measurement has been found approximately 1.25%.

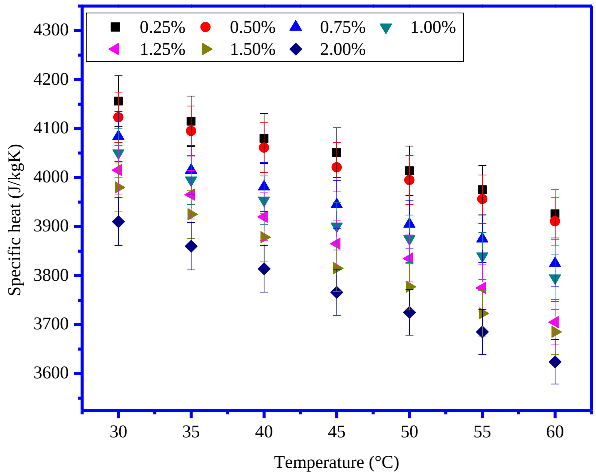

Figure 9: Change in specific heat of TiO_2/H_2O nanofluid

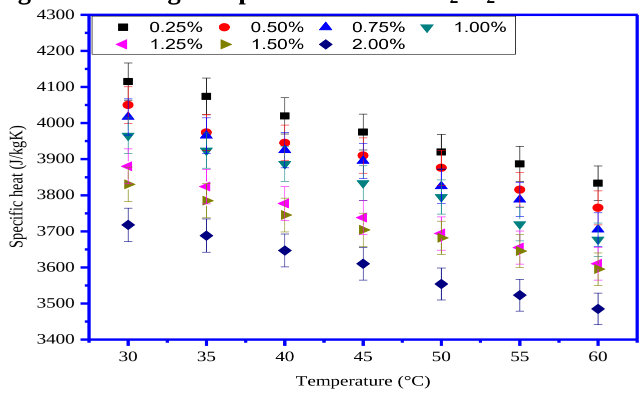

Figure 10: Change in specific heat of CeO_2/H_2O nanofluid

It shows that the specific heat of nanofluids decreases with the increase in temperature. It is quite obvious that as the temperature of nanofluid increases, the average kinetic energy of nanoparticles increases. Due to the increment in average kinetic energy, the collision of nanoparticles in all possible direction increases. So, the increment in kinematic energy of nanoparticles leads to the decrement in specific heat of nanofluids.

2.6 Measurement of Density:

Density of nanofluid also has an important role in present heat pipe application. It plays key role in fluid flow behavior inside the heat pipe. Density of nanofluid can be calculated with the help of following relation [12]:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np} \quad (2)$$

Equation (2) is based on mixing theory without considering the effect of temperatures on density. The density of TiO_2 and CeO_2 nanoparticles are higher as compared to water. Therefore, according to equation 2 it is clear that density of TiO_2/H_2O and CeO_2/H_2O nanofluid increases with the rise in volume concentration. Figure 11 shows the density variation with volume concentrations for both the nanofluids. Densities of nanofluids were measured at 30°C temperature. The increment in density of CeO_2/H_2O nanofluid is higher as compared to TiO_2/H_2O nanofluid due to more density of CeO_2 than TiO_2 nanoparticles. The measured values of densities of nanofluids were in good agreements with the calculated values. Standard deviation for density measurement has been found approximately 0.5%.

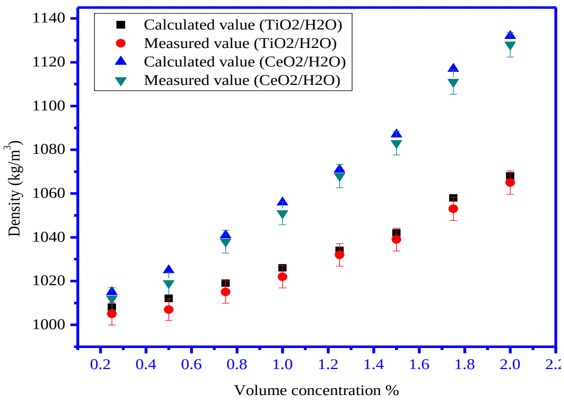

Figure 11: Variation of density with volume concentrations for nanofluids

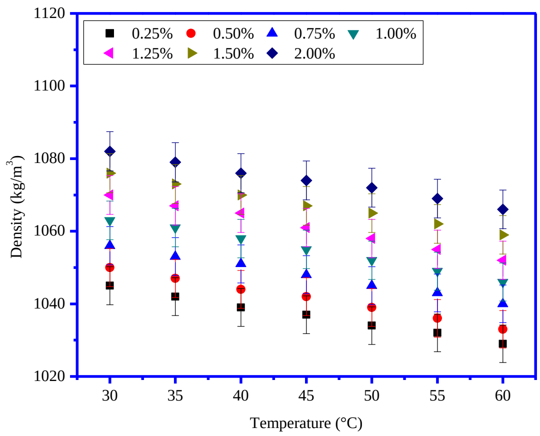

Figure 12: Change in density of TiO_2 /H_2O nanofluid

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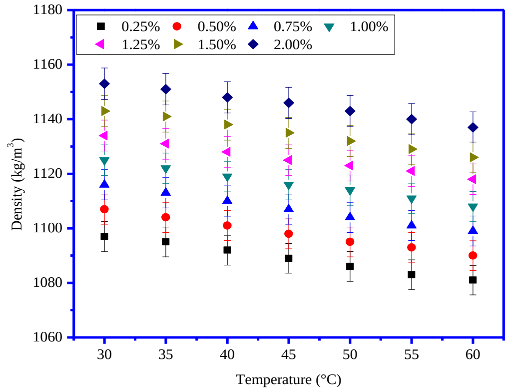

Figure 13: Change in density of CeO_2/H_2O nanofluid

Figure 12 and 13 shows the variation of density with temperature for TiO_2/ H_2O and CeO_2/H_2O nanofluid respectively. The temperature rise causes the reduction in cohesive forces among the molecules of base fluid which further decreases the density of base fluid. The Brownian motion of nanoparticles increases with rise in temperature. Therefore, the cumulative effect of reduction in cohesive forces among the molecules of base fluid and increment in Brownian motion of nanoparticles causes decrement in density of nanofluids.

III. CONCLUSION

In the present investigation, the characterizations of nanofluids have been done. The changes in thermo physical properties of nanofluids with respect to concentration and temperature have been reported. It has been observed that an addition of nanoparticles into the base fluids, leads to the enhancement of the thermo physical properties of nanofluid. But for better stability, the low concentrations are preferred. More experimental studies are required to establish new empirical correlations.

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