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Investigations on thermal properties of CeO_2/water nanofluids for heat transfer applications

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ABSTRACT

At present, the nanofluids are being considered to be new emerging area of research which has lot of benefits in heat transport applications over traditional heat transport fluids. Since, nanofluids showcases an enhanced thermo-physical properties over the conventional fluids, they give better performance when compared with conventional working fluid. The current study evaluates the thermophysical properties of CeO_2/water nanofluids by experimentally by varying the temperature and volume concentrations. The volume concentration of CeO_2/water nanofluids is varied in five different values ranging from 0.01 to 0.3. The elemental composition of cerium oxide nanoparticles is analysed with the aid of EDX. The surface characteristics of the CeO_2 nanoparticles are explored with scanning electron microscope. It is evaluated that thermal conductivity, co-efficient of viscosity and co-efficient of density of CeO_2/water nanofluids with 0.3 vol fractions have been increased by 35.97%, 1.76% % and 1.56% respectively when compared to that of 0.01 vol concentration. It has also been evaluated that specific heat of CeO_2/water nanofluids is decreased by 5% with 0.3 vol concentrations when compared to 0.01 vol concentrations.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advances in Design, Materials and Manufacturing.

1. Introduction

Heat transport fluids such as water based fluids, oil, and glycols are having deprived thermo physical properties due to which the thermal performance enhancement cannot be improved to optimal level to meet the current requirements of the solar collectors. In order to meet these requirements, nanofluids could be employed as operational fluids in place of conventional fluids to increase the absorption of solar energy. Thermal conductivity, specific heat, effective density, co-efficient of dynamic viscosity, and capacity are the important factors which controls their heat shifting characteristics [1,2]. Further, the thermal properties of nanofluids are relying on size of particle, volume fraction, operating temperature, etc. Therefore, it is essential to assess the temperature dependent properties of nanofluids as they are important for estimation of heat transport coefficient.

The term 'nanofluid' had been first coined by Choi [3] as mentioned in his work. The nanoparticles disbanded in the base fluid show enduring stability and greater thermal conductivity when compared to micro-level particles in addition to little pressure drop. A lot more investigations have been conceded in order to acknowledge the variation in heat conductivity in the past. It is found that the assimilation of nanoparticles in a base fluid augments their heat transport property owing to the Brownian motion which influences the thermal behavior of nanofluid [4,5,6]. Masuda et al. [7] performed the experiments for exploring the opportunity of shifting the characteristics of conventional heat transport fluids by disbanding nano level particles such as Al_2O_3 and TiO_2 particles with the water based fluid. It was observed that the enhancements in the effective thermal conductivities were found to be 32.0% and 11.0%, respectively for the fluids containing of 4.3% volume concentration.

Murshed et al. [8] accomplished an experiment to gauge the thermal conductivities by using dissimilar shaped nano-TiO_2 particles in water by hot-wire technique. It was perceived that the heat

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conductivity augmented with the rise of particle's volume percentage. Further, the particle's shape, size, pH value and viscosity are other features considered which manipulates the intensification of heat conductivity of the nanofluids. Wang et al. [9] revealed that 11.3% enrichment in the thermal conductivity, with 0.01% volume fraction of CNT in water. Beck et al. [10] experimented with ethylene glycol/alumina nanofluids within the temperature of 298 K to 411 K and revealed ultra enrichment in thermal conductivity of all their particle concentrations.

Lee et al. [11] acknowledged that the co-efficient of viscosity and thermal conductivity are linearly related properties with increase in the nanoparticle concentration when evaluated Al_2O_3/water nanofluids. Li et al. [12] premeditated the collective effects of deviation in pH and surfactant on copper based nanofluids and reported that the heat conductivity is a having a direct association with the mass fraction of nanoparticle, proportion of surfactant and nanofluid's pH value. They also reported that appropriate surfactant and best possible pH value are the key factors in improving the heat conductivity of base fluids for heat shifting purposes. Mintsa et al. [13] acknowledged that the comparative amplification in thermal conductivity was a principal factor at the modest temperatures.

In another work, Murshed et al. [14] determined that the nanofluid's thermal conductivity is an outcome of particle shape, size, particle fraction, temperature and interfacial layer. Gupta et al. [15] established that the haet conductivity of nanofluid relies on many factors namely, particle mean size, shape, base fluid, pH value, additives, clustering, and temperature of the nanofluids. Li et al. [16] evaluated the co-efficient of viscosity of CuO and water based nanofluid using the capillary viscometer. They revealed that the co-efficient of viscosity gradually diminishes with the escalating temperature. Further, surface morphology, volume proportion, particle size and rate of shear are the other factors which influence the viscosity. Vajjha and Das [17] proposed a mathematical model for the specific heat of the nanofluids consisting of nanometer level Al_2O_3, ZnO and SiO_2 particles immersed in the base fluid containing 60% ethylene glycol with water. When the theoretical data was compared with the experimental data, they observed only 2.7% of error in the experimental work. They also indicated that the nanofluid with minimum specific heat can carry the thermal energy easily.

Two numerical models were developed by Hanley et al. [18] reported that the specific heat of the base fluid is diminished with the raise in the volume proportion of nanoparticles. Yousefi et al. [19] performed the experiments in order to envisage the density for Al_2O_3 disbanded-water and discovered that the density amplified with the proportion of nanoparticles but reduced with the raise in temperature. It is discerned from the previous studies that the high conductivity nanometer particles encompasses the inherent capability of boosting thermal properties of the base fluids [20,21]. In this current investigation, the influence of CeO_2 nanoparticles on the thermal conductivity, co-efficient of viscosity, specific heat and density of nanofluids of the base fluids by varying the particle volume concentrations and temperature is evaluated experimentally for heat transport purposes such as for solar thermal components.

2. Materials and methods

Cerium oxide nanoparticle (CeO_2) is a type of earth metal oxide which plays a pivotal role in heat shifting applications due to its versatile characteristics. Fig. 1 represents the powder of CeO_2 nanoparticles. CeO_2 nanoparticles have several benefits like good availability and easy to prepare, possess good thermal properties, good economic potential, good stability with water when comparing to other nanoparticles, no toxicity or flammability and environmental friendly. Some of the properties of CeO_2 are listed in Table 1.

Fig. 1. Cerium oxide nanoparticles.

Table 1
Thermo-physical properties of CeO_2 nanoparticles.

S.No	Properties	CeO_2 nanoparticles
1	Density	7.132 g/cm^3
2	Specific heat	460 J/kgK
3	Thermal conductivity	12 W/mK

2.1. Analysis on elemental composition

EDX is a method which gives elemental proportion of different constituents present in a chemical. This method analyses X-rays emitted from the sample after assailing by the beam of electrons. The ionization energy is represented by abscissa of the EDX spectrum whereas ordinate signifies the counts. From the Fig. 2, it was observed that the crests obtained rely on the cerium and oxygen molecules alone.

2.2. Determination of shape of nanoparticle

Scanning Electron Microscope (SEM) is a influential method used for learning the shape of nanoparticle and suspension uniformity. Morphology test was carried out by allowing a superior grin of elevated energy electrons on the sample surface of the nanoparticle for viewing the morphology of the CeO_2 nanoparticles. The images of the nanoparticles with two magnifications have been shown in Fig. 3. The prepared nanoparticles looked in spherical

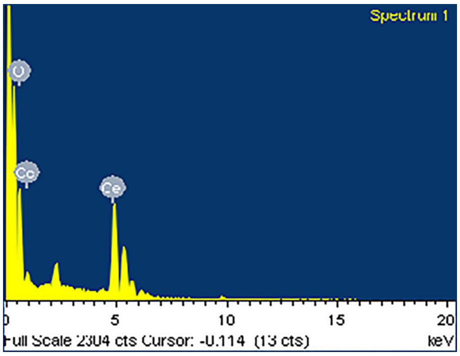

Fig. 2. EDX graph of CeO_2 nanoparticles.

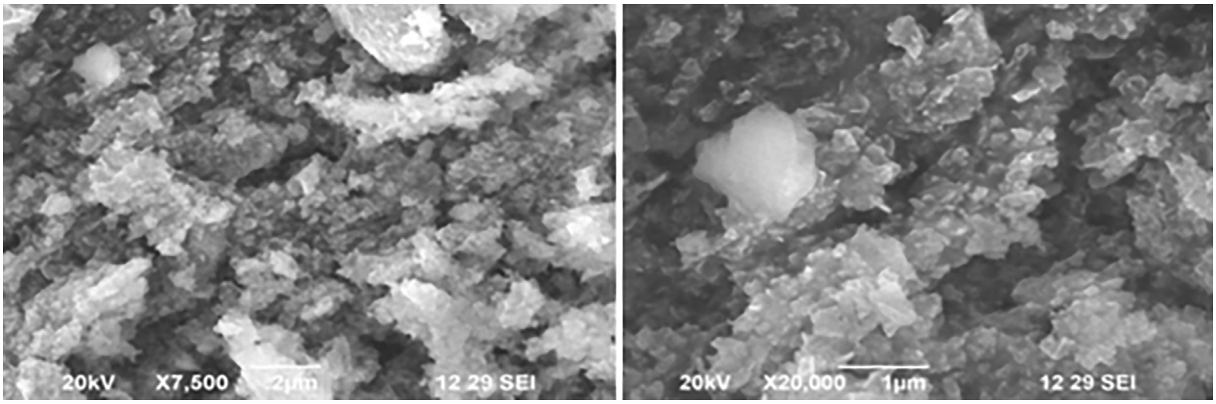

Fig. 3. SEM images of CeO_2 nanoparticles.

shape and the image confirms that the highly agglomerated particles are in the size range of micrometer under ambient condition.

2.3. Assessing volume concentration of nanoparticle

To evaluate the quantity of CeO_2 nanoparticles for preparation of nanofluid, the law of mixture formula has been used. A perceptive balance having a 0.1 mg resolution is utilized to quantify the nanoparticles precisely. The required weight quantity of the nanoparticles for preparing 1000 ml water base is calculated by using the following relation.

$$\%\,\text{volume concentration of CeO}_2 = \frac{\left[\frac{W_{CeO_2}}{\rho_{CeO_2}}\right]}{\left[\frac{W_{CeO_2}}{\rho_{CeO_2}} + \frac{W_{bf}}{\rho_{bf}}\right]} = \frac{\left[\frac{W_{CeO_2}}{7132}\right]}{\left[\frac{W_{CeO_2}}{7132} + \frac{1000}{1000}\right]} \tag{1}$$

Table 2
Volume proportions of CeO_2 nanoparticle in different nanofluids.

S.No	Volume proportion, φ (%)	Weight of nanoparticle in gms
1	0.01	0.713
2	0.05	3.57
3	0.1	7.13
4	0.2	14.26
5	0.3	21.39

Table 2 summarizes the quantity of CeO_2 nanoparticles used to synthesize the nanofluids with different volume proportion with a 1000 ml of base fluid.

2.4. Preparation of CeO_2/water nanofluid

The cerium oxide nanopowder having purity of 99.5% for the experimental study was purchased from Alfa Aesar. The crystallographic structure of CeO_2 nanoparticle is spherical [22]. The average spherical diameter of all the nanoparticles is approximately 25 nm. Water based CeO_2 nanofluid was prepared in the present work using two-step method [23]. CeO_2 nanoparticles were first weighed precisely based on the profound volume proportions i.e. 0.01%, 0.05%, 0.1%, 0.2% and 0.3%, respectively evaluated using the Equation (1). Table 2 represents the quantity of nanoparticles needed to synthesize various volume proportion of the nanofluid. Preparation of nanofluids had done for a flat plate type solar collector with ladder type heat exchanger having 8.5 L intake capacity of working fluids. It was estimated that 0.7132 g of nanoparticles is required to synthesize a CeO_2/water nanofluid containing 0.01% volume proportion. With the help of, the required quantity of CeO_2 nanoparticles was added at a snail's pace in the water employing a magnetic stirrer, maintaining constant stirring for around thirty minutes. Using ultrasonicator (QSonica model of Q500-110, with the probe diameter of 12.7 mm), the prepared solution was once again sonicated continuously for about thirty minutes in order to get homogeneous mixture with a frequency

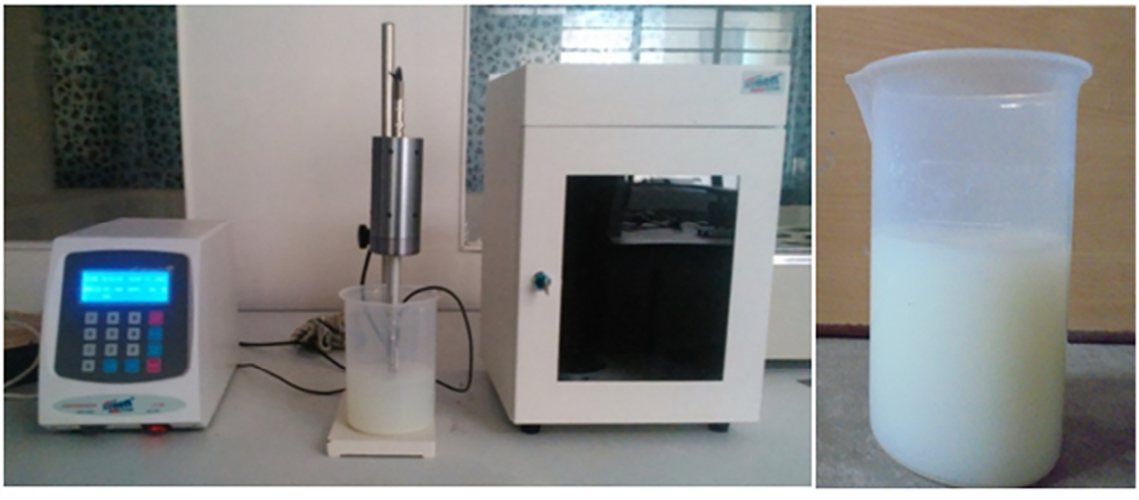

Fig. 4. Nanofluid preparations using ultrasonicator.

range of 45 kHz [24,25]. Similarly CeO_2/water nanofluid for other volume concentrations was prepared following the same procedure. The prepared nanofluid solutions are depicted in Fig. 4.

2.5. Determination of CeO_2/water characteristics

The thermo-physical characteristics of CeO_2/water nanofluid are evaluated experimentally for all the concentrations. The mass of nanofluid increases per unit volume because of the totaling of nanoparticles in the nanofluid. A digital density meter with a predetermined uncertainty of ± 0.034% was used to find the densities of CeO_2/water nanofluid for all the volume concentrations under investigation. Dynamic viscosity is one of the main parameter for determining Rheological behaviour of the nanofluid and the heat transport rate of nanofluids mainly relying on its viscosity. The co-efficient viscosity of nanofluids for all the volume concentrations has been deliberated with the help of Brookfield viscometer with the manufacturer specified uncertainty of ±1.0%.

The specific heat is another vital thermo-physical property as mentioned in earlier sections and it is measured with the aid of DSC (with an accuracy of ±0.15%), which uses the thermo analytical technique [26,27]. Thermal properties analyzer was exploited to compute thermal conductivity of CeO_2/water nanofluid (with an instrument uncertainty of ±0.5%).

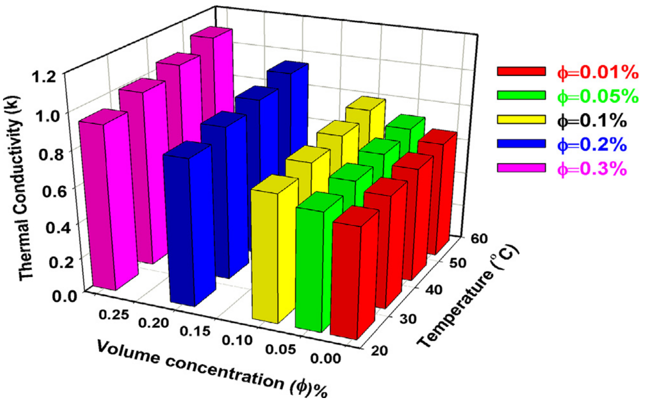

Fig. 5. Thermal conductivity of nanofluid with temperature rise.

3. Results and discussion

3.1. Thermal conductivity of nanofluids

The nanofluids having good thermophysical properties are significant to boost-up the heat shifting behaviour [28,29]. The heat conductivity of the any nanomaterials is solely relying on the nanoparticles size, shape, materials and base fluid corresponding to temperature. Fig. 5 illustrates the variation of heat conductivity of CeO_2/water fluids at various nanoparticle proportionss of 0.01%, 0.05%, 0.1%, 0.2% and 0.3% respectively by varying the temperature. It is evaluated that the heat conductivity of CeO_2/water fluids is augmented with raise in particle volume concentrations by changing the temperature. The heat conductivity of CeO_2/water nanofluids with the proportion of 0.3 vol% is 35.97% higher than that of 0.01% volume concentration at temperature of 350 °C. This is due to the totaling of nanoparticles inside the base fluid in consequence of the Brownian motion, which influences the thermal behaviour of nanofluid [30,31]. Besides, the raise in nanoparticle volume proportion augmented the thermal conductivity because of interfacial layers.

Fig. 6 compares the experiemntal thermal conductivity with a proposed analytical method by Mahian et al. [32]. The deviation between the measured and a calculated value are within the limit, which validates the experimental results.

3.2. Specific heat of nanofluids

Specific heat is one of the important thermal characteristics of nanofluids which is considered to be the prominent factor in the heat transport applications. Fig. 7 shows the relationship between specific heat with various particle volume concentrations of CeO_2/water nanofluids by varying the temperature. It is noted that specific heat of CeO_2/water nanofluids is diminished with raise in particle proportion and increase in temperature. It is also perceived that the CeO_2/water nanofluids having 0.3% volume fraction was having specific heat of about 5% lesser than the base fluids at the temperature of 35 °C. It is seen from the Fig. 7 that the nanofluids with 0.3% volume fraction are possessing 2% lower specific heat than that of 0.01% volume concentration. This is due to the fact that the raise in the volume concentrations resulted in the enrichment of the density of nanofluids which effectively transferred the

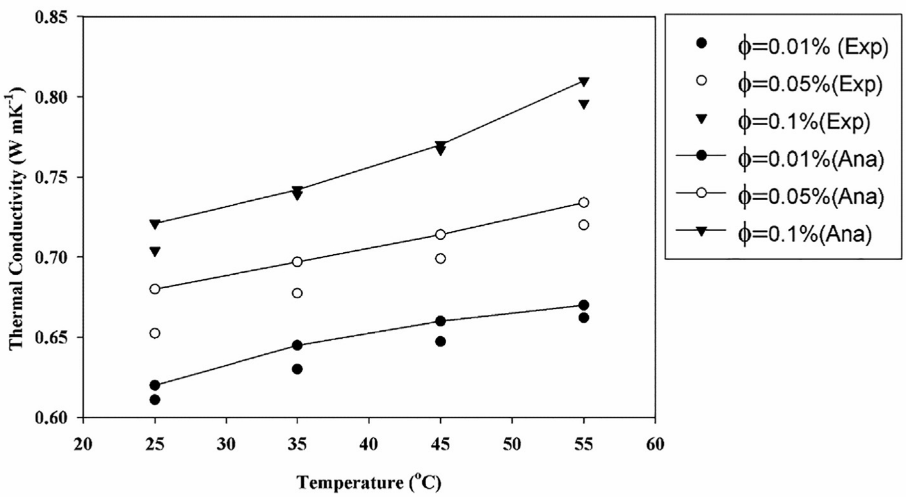

Fig. 6. Validation of measured thermal conductivity values with the analytical model.

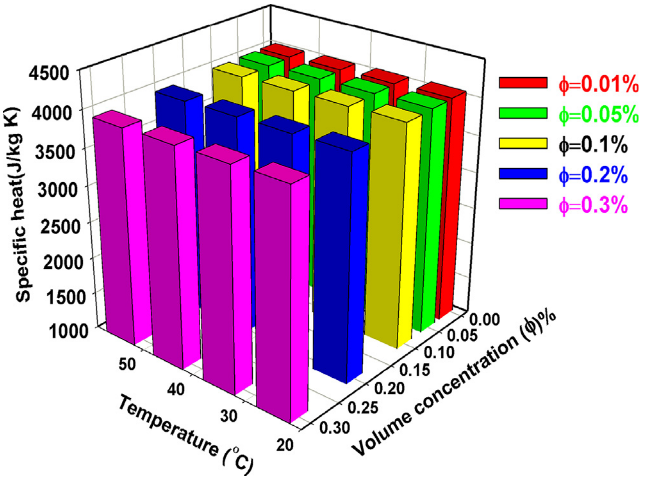

Fig. 7. Specific heat of nanofluids with temperature rise.

energy to nearest fluid molecules thereby reducing their specific heat [5].

3.3. Viscosity of nanofluids

The drop in pressure and the pumping power for heat transfer applications depend on the dynamic viscosity. The co-efficient of viscosity of the traditional base fluid, particle size, temperature, kind of nanoparticles and the particle loading affects the overall viscosity of the systems. Fig. 8 represents the variation of viscosity with different volume concentration of CeO_2/water nanofluid by varying the temperature. It is seen from the graph that the co-efficient of viscosity of nanofluids is linear to volume percentage of nanoparticles whereas it is inversely proportional to the temperature of the CeO_2/water nanofluid. It can be perceived that the co-efficient of viscosity of CeO_2/water nanofluids with 0.3% volume concentration is 1.56% higher than that of 0.01% volume concentration at temperature of 250 °C whereas it is decreased by 1.19% at temperature of 550 °C with similar concentrations. It was proved that the CeO_2 nanofluids up to 0.4 vol% of particle loading would result in Newtonian behaviour with slight variation on the co-efficient of viscosity as there would not be noteworthy communications among the nanoparticles. This may be due to the addition of CeO_2 nanoparticles, which will be resulting in moderately huge disconnection amid the particles. Further, nanofluid with 0.3 vol fraction of CeO_2 has shear-thinning behaviour at lower rate of shear [33]. Hence, it can be concluded that the co-efficient of viscosity of nanofluids is primarily depending on particle size, but it may not be affected significantly by volume concentration and density of nanoparticles.

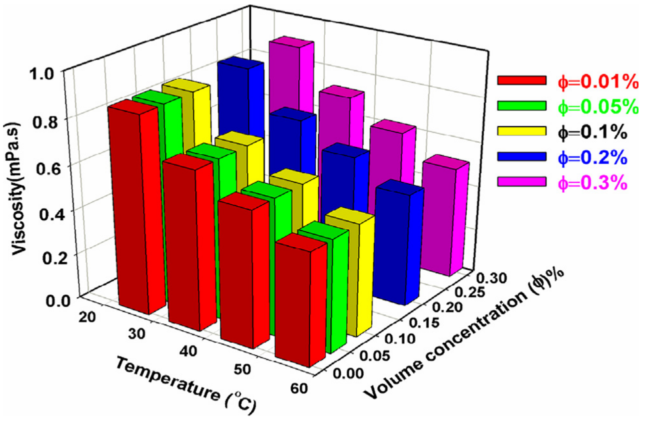

Fig. 8. Viscosity of nanofluids with temperature rise.

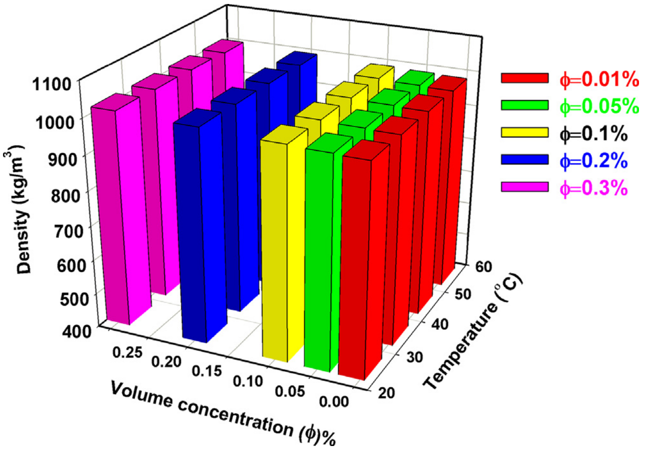

Fig. 9. Density of nanofluids with temperature rise.

3.4. Density of nanofluids

The density of nanofluids unswervingly impinges on the Reynolds number, frictionfactor, pressure loss and Nusselt number. It is considerably affecting the heat transport performance of any nanofluids. Fig. 9 shows the variation of density of CeO_2/water nanofluids with diversified volume fractions with respect to temperature. It is noted from the graph that the density of nanofluids is increased with raise in volume concentrations whereas it is reduced when increasing the temperature of CeO_2/water nanofluids. The density of CeO_2/water nanofluids is 1.76% higher than 0.3% volume concentration when compared to 0.01% volume concentration. It is also revealed that even at higher volume proportion the density and co-efficient of viscosity of CeO_2/water fluids is increased less than 2% due to which the pumping power requirement and drop in pressure is comparatively low for CeO_2/water nanofluid [1].

4. Conclusion

The present analysis concentrates on a comparative study on thermophysical properties of CeO_2/water nanofluids experimentally with respect to particle volume concentrations by varying the temperature. The analysis is carried out for the CeO_2/water nanofluids with five different particle volume percentages of 0.01, 0.05, 0.1, 0.2, and 0.3 respectively. The elemental composition and surface morphology of the CeO_2 nanoparticle was studied with the help of EDX and SEM analysis. The outcomes confirmed that the thermal conductivity has ascending trend whereas the specific heat has descending trend with nanoparticle proportion and temperature. It is validated that the thermal conductivity, density and co-efficient of viscosity of CeO_2/water nanofluids with 0.3% vol. is increased 35.97%, 1.76% and 1.56% respectively when compared to 0.01 vol proportions. It is evaluated that the specific heat competency of CeO_2/water nanofluids is reduced 5% with 0.3%vol. concentrations when compared to base fluids. It is concluded that the thermophysical properties are based on particle size, volume fraction and operating temperature of nanofluids.

CRediT authorship contribution statement

P. Michael Joseph Stalin: Conceptualization, Methodology, Writing - original draft. **T.V. Arjunan:** Supervision. **M.M. Matheswaran:** Formal analysis, Investigation, Validation. **P. Manoj Kumar:** Validation, Visualization. **N. Sadanandam:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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