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Role of nanoparticle shape in enhancing the thermal conductivity of nanofluids

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ABSTRACT

In present work, five different nanoparticles of three different shapes are used to study the enhancement in thermal conductivity, viscosity and stability of nanofluids. The main objective of present work is to analyze the effect of shape on thermo-physical properties of nanofluids. For this study, spherical, cubic and rod shaped nanoparticles are used. CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 water based nanofluids are prepared by two step method using probe sonication technique. The effect of shape on thermal conductivity of nanofluids is analyzed experimentally by using hot-wire method set up. Results of this study reveal that the cubic shaped Al_2O_3 nanofluid (concentration 2.5 wt%) shows highest thermal conductivity over base fluid by 3.13 times. Effect of nanoparticle shape on the viscocity is also studied in the presnt work. Al_2O_3 nanofluid also has good stability amongst all nanofluids. Also, it is observed that in all five cases of nanofluid cubic shape nanoparticles enhance thermal conductivity at the highest rate than spherical and rod shape. Pumping power study shows that cubic shaped nanoparticles require higher pumping power than spherical and rod shaped nanoparticles.

1. Introduction

Research work done in the past suggests that nanofluids have the ability to be used for efficient heat transfer in thermal engineering applications [1]. For many industrial processes, heat transfer takes place through fluids as a medium. In many modern applications such as indoor ventilation with radiators, cooling of electrical components, and heat exchangers, quick heat transfer results in low energy consumption [2]. Due to this energy saving ability of nanofluids, variation in thermal conductivity of nanofluids because of change in shapof nanomaterial is investigated. Several research reports suggest that thermal conductivity of nanofluids is greatly influenced by shape of nanoparticle impurity used for the preparation of nanofluids. The outcome of this work indicates that spherical shaped solid nanoparticles enhance thermal conductivity of base fluid by a small magnitude, whereas non-spherical nanoparticles have higher ability to enhance thermal conductivity of nanofluid [3]. The heat transfer performance of an oscillating heat pipe is also investigated experimentally and it is concluded that alumina nanoparticle shape plays a very crucial role in enhancement of the heat transfer performance. In this work, it is also demonstrated that alumina nanofluid is not beneficial in laminar or turbulent flow mode [4]. The aggregation has positive effects on the thermal conductivity enhancement. It may be due to the fact that aggregated size offers fast heat transfer path for neighboring particles and it shows appreciable increase in the shape factor of the aggregate [5]. The comprehensive review made by Goharshadi et al considers several parameters, which influence thermal conductivity of nanofluids. Among these parameters, nanoparticle shape has considerable influence on enhancement of thermal conductivity [6,19].

To investigate the effect of shape on thermal conductivity, viscocity, stability and pumping power of nanofluid, five different nano-impurities (CuO, MgO, TiO_2, ZrO_2 and Al_2O_3) have been

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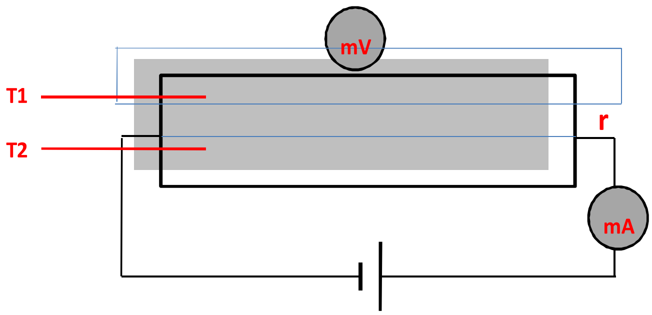

Fig. 1. Schematic sketch of two wire method based setup to determine thermal conductivity of nanofluid.

chosen for the preparation of nanofluids. Two step method is used for forceful dispersion of nanoparticles in base fluid (water) to prepare stable nanofluid.

2. Experimentation

A set up of hot-wire method is built to measure the thermal conductivity. The wire, which is immersed in the investigated sample is heated by passing a constant electrical current through it, and its temperature change ΔT, is measured as a function of time t, for several values of the current. The set up consists of chemically-inert cylindrical hallow tube of Teflon with special arrangement of wire and thermocouple. The schematic representation of set up is as shown in Fig. 1. The silver wire of 200 mm length and 2 mm diameter is used as the metal wire. Thermal conductivity of nanofluids was estimated by using relation

$$K = (q/4\pi K) \quad (1)$$

Where, K is Slope between ΔT and Time, k is thermal conductivity (W/m^0K)

q- Power generated by heating wire per unit length (W/m)

As the present work deals with the effect of nanoparticle shape on thermal conductivity of nanofluids, CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanoparticles were procured in three different shapes i.e. spherical, cubic and rod from Sigma-Aldrich (AR-grade). Two step method is used to prepare nanofluids of CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanoparticles. The water of electrical resistivity of the order of 18.2 MΩ.cm is used as base fluid. While preparing nanofluids concentration of nanofluids was kept constant (2.5 wt %) for three different shapes. In this way, three samples for every nanofluid were prepared for thermal conductivity investigation. For forceful dispersion, probe sonication technique was used to achieve stable nanofluids.

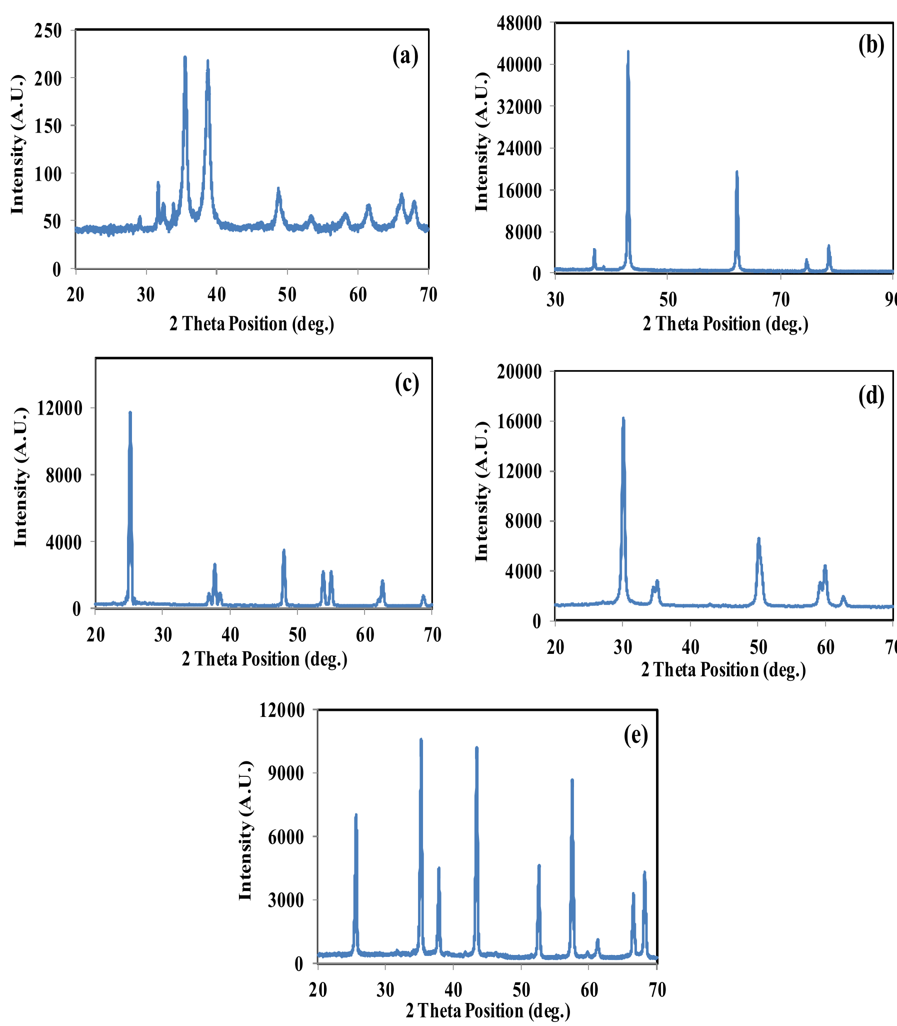

Fig. 2. XRD pattern of (a) CuO (b) MgO (c) TiO_2 (d) ZrO_2 and (e) Al_2O_3 nanoparticles.

X-Ray diffraction (XRD) analysis is used to ensure the structural purity of nanoparticles. For XRD analysis, related data was collected on Rigaku, Miniflex-II (Japan) X-ray diffractometer in the 2θ range 20-70° with step height of 0.02°. The present study deals with the effect of shape on thermal conductivity of nanofluids, morphology analysis plays a very important role. Therefore, morphology of all samples was confirmed using scanning electron microscopy (SEM) technique. SEM images of nanoparticles of different shapes were captured using JEOL JSM-7500F SEM.

The viscosity of nanofluids loaded with different shapes was analyzed by using AR-1000 Rheometer, TA Instrument. Thermal conductivity of nanofluids under investigation was measured using hot-wire method with the help of home built set up. All data related to viscosity and thermal conductivity was measured thrice to verify deviation in results. However no considerable deviation was observed in results. Stability of nanofluids is a crucial parameter which indicates quality of nanosuspension. This information of nanofluids was collected using dynamic light scattering technique (NanoZS, Malvern).

The experiments are repeated three times for each case and the average value is reported. No significant deviation is observed in the study.

3. Results and discussion

Fig. 2 (a) exhibits the pattern of XRD for CuO nanoparticles used for the preparation of nanofluids. Fig. 2 (a) shows the structural purity of CuO nanocrystals and it is in good agreement with JCPDS card No. 01-080-1268. The signature peaks mentioned in this card exactly match with XRD data of CuO nanocrystals. Fig. 1 (b) depicts XRD pattern of MgO nanoparticles, which represents that MgO has cubic phase with a lattice parameter of a = b = c = 4.213 Å and space group (Fm-3 m (2 2 5)). The XRD data of cubic MgO is in good agreement with JCPDS card No. 04-829. Fig. 2(c) shows the XRD pattern of TiO_2 nanocrystals, which exhibits anatase phase. All characteristic peaks of TiO_2 exactly with JCPDS card No. 21-1272 and no other impurity peak observed in XRD pattern. Fig. 2(d) shows the XRD patterns of ZrO_2 nanocrystals which exhibits tetragonal phase and is indexed to JCPDS card No. 79-1771. Fig. 1 (e) shows the XRD pattern of Al_2O_3 nanocrystals, which exhibits α-phase with no other impurity peak. The XRD data of Al_2O_3 nanocrystals shows good matching with JCPDS card No. 46-1212. All signature peaks and their marginal intensity are in good agreement with JCPDS card.

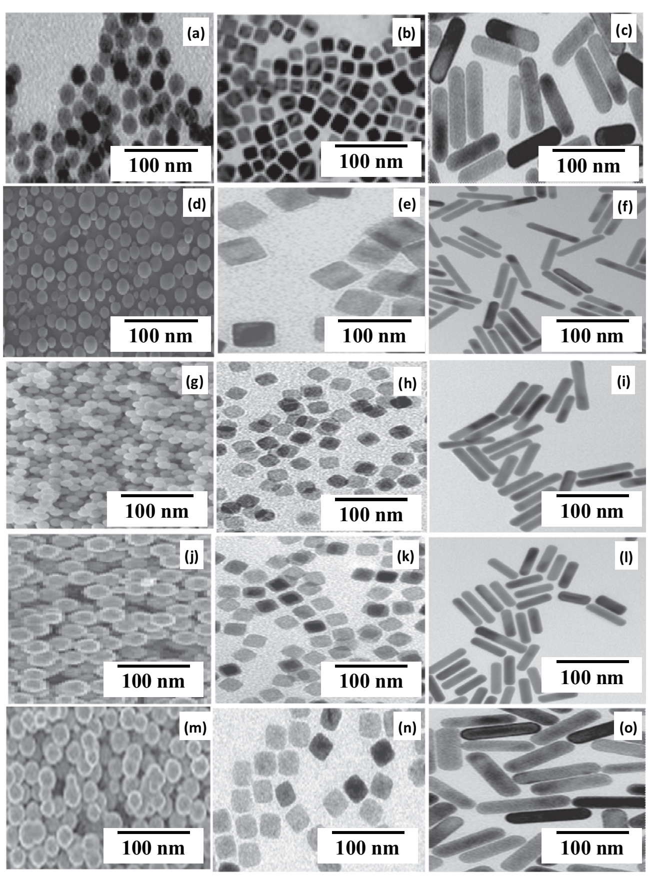

Fig. 3. SEM images of (a) spherical CuO, (b) cubic CuO, (c) rod CuO, (d) spherical MgO, (e) cubic MgO, (f) rod MgO, (g) spherical TiO_2, (h) cubic TiO_2, (i) rod TiO_2, (j) spherical ZrO_2, (k) cubic ZrO_2, (l) rod ZrO_2, (m) spherical Al_2O_3, (n) cubic Al_2O_3 and (o) rod Al_2O_3.

Present study deals with the effect of shape on thermal conductivity of nanofluids, three shapes i.e. spherical, cubic and rod shape have been chosen. To confirm the shape of nanoparticles, SEM analysis for all samples under investigation was performed. The SEM images of all samples were captured at same magnification (100 nm). Fig. 3(a–c) shows the SEM images of CuO nanoparticles of spherical, cubic and rod shape, respectively. Fig. 3(d–f) represents the SEM images of spherical, cubic and rod shape of MgO nanoparticle respectively. Fig. 3(g–i) depicts the SEM images of spherical, cubic and rod shape of TiO_2 nanoparticle respectively. Fig. 3 (j–l) shows the SEM images of spherical, cubic and rod shape of ZrO_2 nanoparticles respectively. Fig. 3 (m–o) shows the SEM images of spherical, cubic and rod shape of α-Al_2O_3 nanoparticles respectively. All SEM images of nanoparticles show that no agglomeration is presents between nanoparticles.

Fig. 4 (a–e) shows the variation of viscosity with temperature as a function of nanoparticle shape. All figures show that viscosity decreases with temperature due to lack of immobile fluid molecules [7]. It is also observed that cubic shaped nanoparticles of CuO (Fig. 3-a), MgO (Fig. 3-b), TiO_2 (Fig. 3-c), ZrO_2 (Fig. 3-d) and Al_2O_3 (Fig. 3-e) have higher magnitude of viscosity than spherical and rod shaped nanoparticle. This might happen due to the fact that cubic shaped nanoparticles are difficult to rotate given that they possess a higher surface area than rod and spherical shaped nanoparticles [8]. This result is in agreement with the investigation made by Gaganpreet et al which says that eccentricity of the particle increases relative viscosity [9,18]. According to the model proposed by Kreiger Dougherty, shape factor of nanoimpurity dispersed in base fluid has great influence on the viscosity [10,17].

A recent work published by Timofeeva et al established the relation between thermal conductivity of nanofluids and shape of nano-impurity and is given by (Eq. 1) [11,15],

$$\frac{k_{eff}}{k_o} = 1 + (C_k^{Shape} + C_k^{Surface}) \tag{2}$$

where, $\underline{C_k^{shape}}$ is thermal conductivity enhancement coefficient function of shape and $C_k^{Surface}$ is thermal conductivity enhancement coefficient function of surface.

From Fig. 5 (a–e), thermal conductivity of nanofluids prepared by using cubic shaped nanoparticles has higher thermal conductivity than other shapes. The results obtained are having concurrence with Timofeeva et al The results obtained for thermal conductivity are supported by Jeong et al [Jeong] and Murshed et al [12,16] too.

Table 1 summarizes the stability data of CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanofluids for different shape at room temperature (303 K). From Table 1, it is observed that settling velocity for cubic shaped nanoparticles is greater than that of spherical and rod

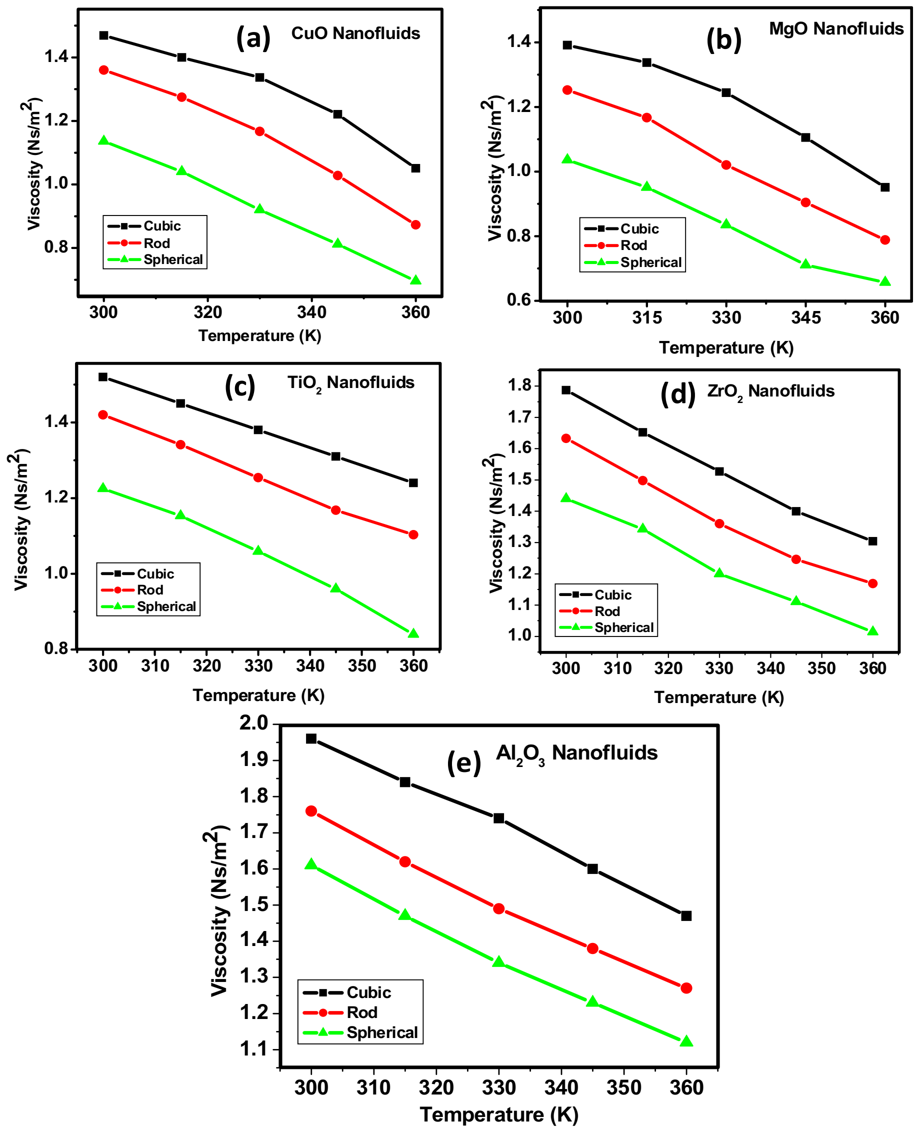

Fig. 4. Variation of viscosity with temperature for different shapes of (a) CuO, (b) MgO, (c) TiO_2, (d) ZrO_2 and (e) Al_2O_3 nanoparticles based nanofluids.

shaped nanoparticles. It also indicates that the base fluid loaded with cubic shaped nanoparticles has lower stability hence lower Brownian velocity. Cubic shaped Al_2O_3 nanofluid has more stability as compared to other cubic shaped nanofluids.

Table 2 shows the pumping power data of CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanofluids for different shapes of nanoparticles at room temperature (303 K). It is observed that cubic shaped particles require higher pumping power than spherical and rod shaped nanoparticles. This higher pumping power for cubic shaped nanoparticles can be attributed to higher viscosity of nanofluids [13,14].

The data produced in this study was compared with the results of other reports available in the literature. It was observed that many parameters, such as particle concentration, size, shape, viscosity, environmental conditions, base fluid, and methods of nanofluid preparation influence to the measured results. As our study deals with effect of shape on thermal conductivity of nanofluids, no earlier similar reports are available in literature for comparison purpose.

4. Conclusion

The behavior of thermal conductivity, viscosity, stability and pumping power is investigated experimentally for five different nanofluids (CuO, MgO, TiO_2, ZrO_2, Al_2O_3) for three different shapes (spherical, cubic and rod). During this investigation results indicated that nanoparticles having cubic structure based nanofluids have higher viscosity and thermal conductivity compared to rod and spherical shape. The enhancement in viscosity and thermal conductivity is attributed to larger surface area of cubic shaped nanoparticles. However, stability data of CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanofluids indicates that cubic shape nanoparticles based nanofluids have poor stability than spherical and rod shape. Similarly, cubic shape nanoparticle based CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanofluids required higher pumping power. In this study cubic shaped Al_2O_3 nanofluid (concentration 2.5 wt%) has highest thermal conductivity in the order of 3.13 times that of base fluid. Practically, cubic shape nanoparticles based nanofluids are not used in thermal engineering applications due to blocking problem.

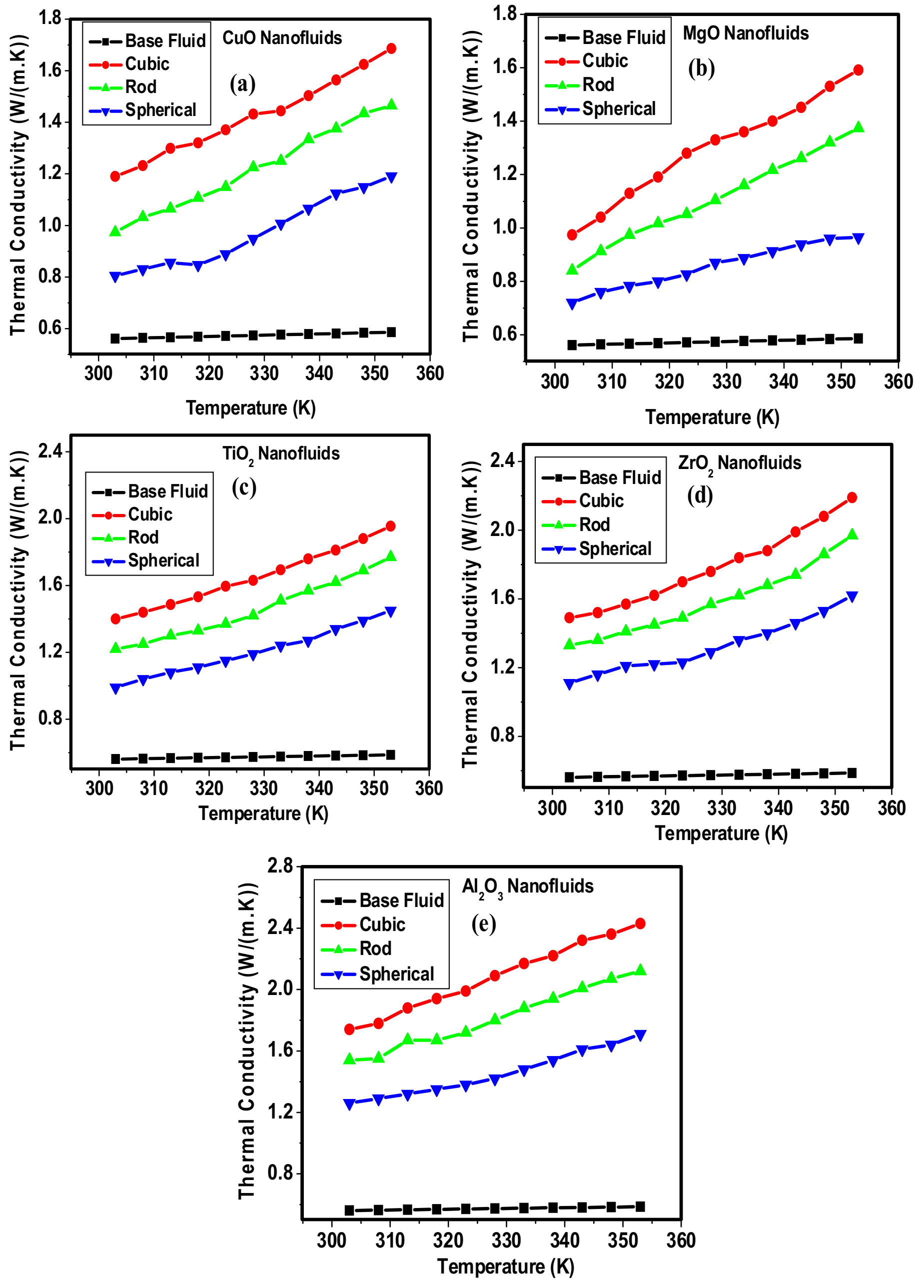

Fig. 5. Variation of thermal conductivity with temperature for different shape of (a) CuO, (b) MgO, (c) TiO_2, (d) ZrO_2 and (e) Al_2O_3 nanoparticles based nanofluids.

Table 1
Stability data of CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanofluids for different shapes at room temperature.

Nanofluid	Shape	Settling velocity (m/s) $\times 10^{-13}$	Brownian velocity (m/s) $\times 10^{-3}$
CuO	Spherical	1.784	7.945
	Cubic	3.241	4.874
	Rod	2.784	6.914
MgO	Spherical	1.874	8.547
	Cubic	5.749	6.749
	Rod	4.412	8.471
TiO_2	Spherical	1.574	8.874
	Cubic	3.541	5.547
	Rod	2.914	7.496
ZrO_2	Spherical	1.418	9.412
	Cubic	2.874	6.324
	Rod	2.147	8.412
Al_2O_3	Spherical	1.342	9.645
	Cubic	2.987	7.145
	Rod	2.007	8.214

Table 2
Pumping power data of CuO, MgO, TiO_2, ZrO_2 and Al_2O_3 nanofluids for different shape at room temperature (303 K).

Nanofluid	Shape	Pumping power (W)
CuO	Spherical	9.21
	Cubic	10.25
	Rod	8.85
MgO	Spherical	8.84
	Cubic	11.89
	Rod	9.57
TiO_2	Spherical	8.14
	Cubic	11.37
	Rod	10.70
ZrO_2	Spherical	9.47
	Cubic	12.14
	Rod	11.74
Al_2O_3	Spherical	10.24
	Cubic	13.11
	Rod	9.57

Therefore for practical applications, spherical shape nanoparticle based nanofluids are suggested. This study shows that spherical shaped Al_2O_3 nanoparticles also have significant thermal conductivity for thermal engineering applications.

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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