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Effect of Shape on Thermophysical and Heat Transfer Properties of ZnO/R-134a Nanorefrigerant ☆

P.B. Maheshwary[a], C.C. Handa[b], K.R. Nemade[c]*

[a]Department of Mechanical Engineering, JD College of Engineering and Management, Nagpur 441 501, India.
[b]Department of Mechanical Engineering, KDK College of Engineering, Nagpur 400 049, India.
[c]Department of Physics, Indira Mahavidyalaya, Kalamb 445 401, India.

Abstract

Presently, nanorefrigerant becoming the important class of nanofluids due to its heat transfer performances of refrigeration and air-conditioning systems. In the present study, we analyze the effect of shape on the thermophysical and heat transfer properties of ZnO/R-134a nanorefrigerant. The spherical and cubic shape ZnO nanoparticles used in this study for addition in refrigerant. The results of study indicate that the thermophysical and heat transfer properties significantly affected by shape of ZnO nanoparticles. In case of cubic ZnO nanoparticles, 42.5 % of increment observed over the pure refrigerant. This preliminary study about the effect of shape on thermophysical and heat transfer properties shows that ZnO/R-134a nanorefrigerant suitable for refrigeration and air-conditioning systems.

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Keywords: thermophysical properties; heat transfer; nanorefrigerant; R-134a refrigerant

1. Introduction

Nanorefrigerant is adulterate suspension of solid particles and refrigerant as base fluid. Nanorefrigerants have been found great application in the field of refrigeration and air-conditioning systems because of tunable thermal

* Corresponding author. K.R. Nemade, Tel.: +091-9049703051
E-mail address: krnemade@gmail.com

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conductivity of refrigerants by addition of nanoparticles. Higher thermal conductivity of nanorefrigerants can extract maximum output from the refrigeration and air-conditioning systems [1]. Addition of metal oxide nanoparticle as an impurity significantly enhances the thermal conductivity of nanorefrigerant [2].

Mahbubul et al analyzed the volumetric effects of thermal conductivity, viscosity and density of Al_2O_3/R141b. The results of this study show that an optimum concentration of nanoparticles in refrigerant can enhance the performance of a refrigeration system [3]. Bi et al investigated the performance of TiO_2-R600a nano-refrigerants in a domestic refrigerator without any system reconstruction. The refrigerator performance was analyzed by using energy consumption test and freeze capacity test. The results of this study show that 9.6% less energy used with 0.5 g/L TiO_2-R600a nano-refrigerant [4]. Sarkar et al reported the thermodynamic properties and optimization cascade system with different natural refrigerants. Their study gives two selection charts along with tables one for higher coefficient of performance and the other for highest volumetric capacity [5]. Jiang et al study shows that the thermal conductivities of carbon nanotube based nanorefrigerants are much higher than those of carbon nanotube -water Nanofluids or spherical nanoparticle-R113 nanorefrigerants [6].

In light of above discussion, it is observed that most of the researchers analyzed the effect of concentration on performance of nanorefrigerants. Thus, in the present study effect of nanoparticle shape on thermal conductivity of nanorefrigerants studied for spherical and cubic shape ZnO nanoparticles loaded R-134a refrigerant. The main accomplishment of the present work is that thermal conductivity of R-134a refrigerant increase by 42.5 % for cubic shape ZnO nanoparticles.

2. Experimental

In the present work, ZnO/R-134a nanorefrigerant was prepared by two step method. In this method, 0.1 (10 %) volume fraction of ZnO added in pure R-134a refrigerant and kept for 2 h under probe sonication process for forceful dispersion of ZnO nanoparticles. All thermophysical and heat transfer properties of ZnO/R-134a nanorefrigerant measured in the temperature range 283-307 K. The viscosity of nanorefrigerant of different particle shape was determined using AR-1000 Rheometer, TA Instrument. The thermal conductivity and specific heat measurements were carried out by using KD2 pro thermal analyzer (Decagon Devices).

3. Results and Discussion

Figure 1(a) shows the SEM image of spherical ZnO nanoparticles. SEM image revealed that ZnO used for the dispersion in R-134a refrigerant is nearly spherical. The average particle size of spherical ZnO nanoparticles estimated using the SEM images was found to be 29.1 nm. Figure 1 (b) represents the SEM image of cubic shape ZnO nanoparticles dispersed in R-134a refrigerant. The average particle size of cubic ZnO nanoparticles was found to be 21.4 nm. Figure 1 (c) depicts the XRD pattern of ZnO nanoparticles. The diffraction peaks position in XRD pattern of ZnO reflects the crystalline purity of used ZnO nanoparticles. The peak position in XRD pattern of ZnO nanoparticles shows excellent agreement with JCPDS file no.36-1451. The JCPDS data card shows that ZnO has hexagonal wurtzite structure. The lattice parameters of ZnO nanoparticles are with a = 3.25 Å and c = 5.2 Å and its ratio is c/a ~ 1.60. The data card also shows that ZnO nanoparticles belongs to space group C6mc. The average particle size was computed using Debye-Scherrer equation. The average crystallite size for ZnO nanoparticles estimated using this information was found to be 25.7 nm.

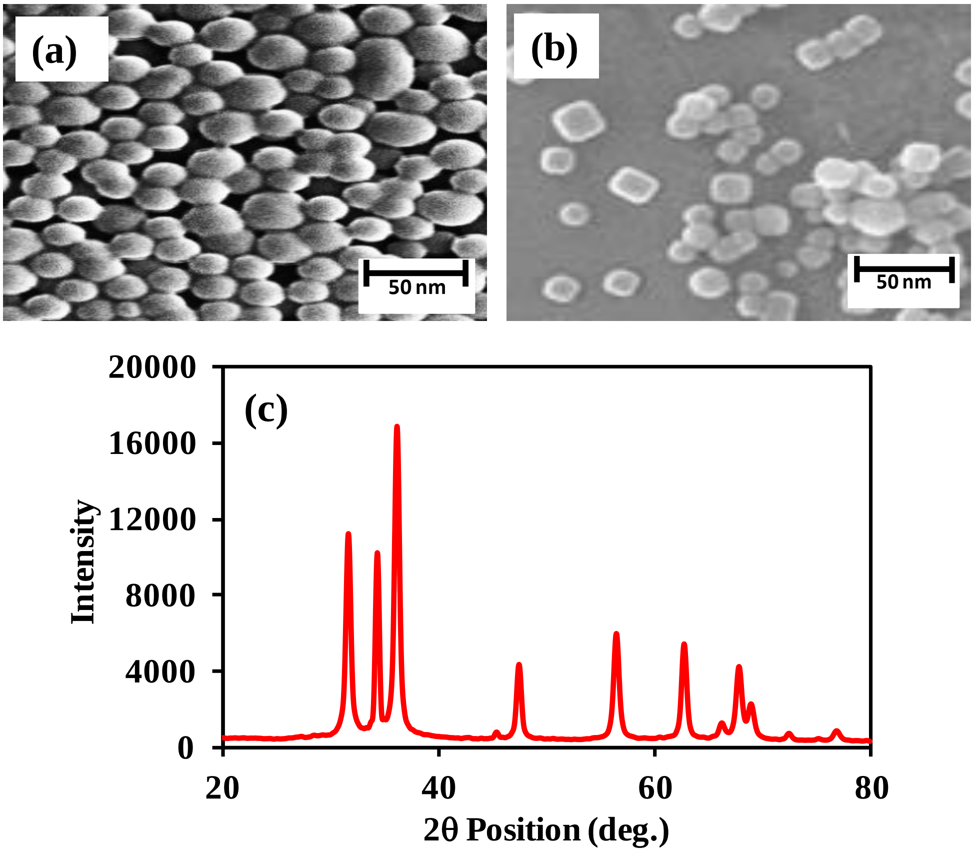

Figure 1. SEM images of (a) Spherical and (b) Cubic shape ZnO nanoparticles and (c) XRD pattern of ZnO nanoparticles.

The viscosity of ZnO nanoparticles dispersed refrigerant was calculated using Brinkman model [7],

$$\mu_{nr} = \mu_r \frac{1}{(1-\phi)^{2.5}}$$

where, μnr and μr are the effective viscosity of ZnO nanoparticles dispersed refrigerant and pure refrigerant, respectively. ϕ is the particle volume fraction which is 0.1 (10 %) in present study. Figure 2 depicts the variation of viscosity with temperature for pure R-134a refrigerant, spherical and cubic ZnO loaded R-134a nanorefrigerant. The spherical and cubic ZnO loaded R-134a nanorefrigerant shows typical behavior.

The viscosity of nanorefrigerant decreases with increase in temperature for systems that is spherical and cubic ZnO loaded R-134a nanorefrigerant. This decrease in viscosity assigned to the sub-micron dispersion behaves like a liquid. The obtained results in our case as a function of temperature is parallel to results reported by Mahbubul et al [8]. Another possible reason for decrease in viscosity with increasing temperature is weakening of adhesion forces among the particles and base fluid molecules [9]. From Figure 2, it is also observed that cubic shape ZnO nanoparticles loaded R-134a nanorefrigerant has higher viscosity value than spherical shape ZnO nanoparticles. The higher value of viscosity in case of cubic shape nanoparticles may be due to cubic shape nanoparticles are difficult to rotate. The difficulty in the rotation increases the viscosity of nanorefrigerant.

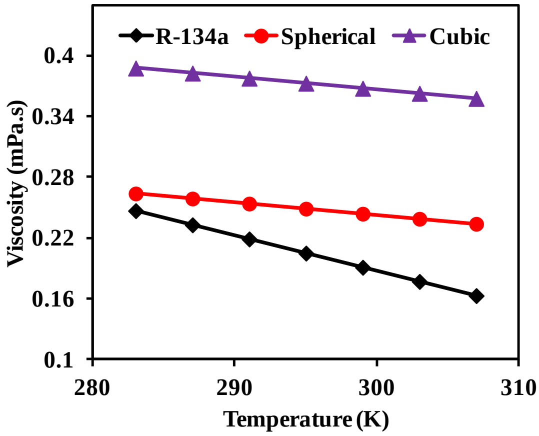

Figure 2. Influence of spherical and cubic shape ZnO nanoparticles on viscosity of R-134a refrigerant.

The variation of density with respect to temperature of pure refrigerant and spherical and cubic ZnO loaded R-134a nanorefrigerant has been shown in Figure 3. The plot shows that density of pure refrigerant and spherical and cubic ZnO loaded R-134a nanorefrigerant decreases moderately with the increase of temperature. The value of density found higher for cubic shape ZnO loaded R-134a nanorefrigerant. All samples show the typical behavior as a function of temperature. At 283 K, cubic shape ZnO loaded R-134a nanorefrigerant show enhancement in density of the order of 22.62 % over pure R-134a refrigerant.

Density is mass and volume based parameter. With increase in temperature, molecules of refrigerant undergoes to vibration which increases volume. Hence the density of refrigerant was decrease monotonically with temperature. The density of solid particles is much greater than liquid or gases. Therefore, spherical and cubic ZnO loaded R-134a nanorefrigerants have higher density than pure R-134a refrigerant. The optimized value of cubic shape ZnO loaded R-134a nanorefrigerants attributed to the higher volume of cubic shape object.

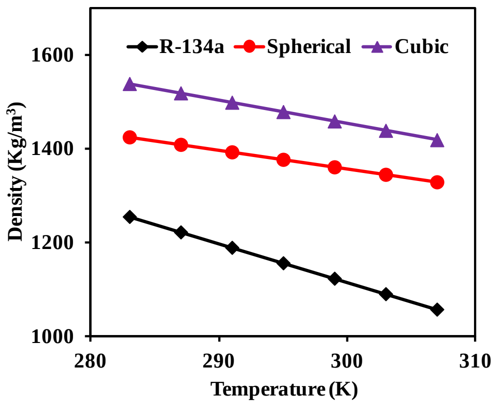

Figure 3. Influence of spherical and cubic shape ZnO nanoparticles on density of R-134a refrigerant.

The specific heat of pure R-134a refrigerant, spherical and cubic ZnO nanoparticle loaded R-134a refrigerant linearly increase with the temperature as shown in Figure 4. For fixed value of concentration of nanoparticles, specific heat of nanorefrigerant decreases than pure R-134a refrigerant. This decrease in specific heat with the addition of nanoparticles is attributed to the lower specific heat of added particles. The increasing temperature results in the fluctuation of refrigerant molecules about their equilibrium value to a higher extent, which increases heat capacity. The increases in heat capacity increases internal energy of the system. The result obtained in our case is parallel with most of the researchers [10].

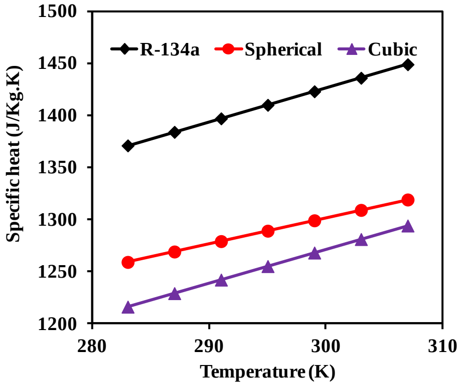

Figure 4. Influence of spherical and cubic shape ZnO nanoparticles on specific heat of R-134a refrigerant.

Figure 4 depicts the variation of thermal conductivity of pure refrigerant and nanorefrigerant with temperature. It can be observed in Figure 1, the thermal conductivity of nanorefrigerant was increases linearly with temperature. The thermal conductivity of pure R-134a refrigerant decreases linearly with increasing temperature. The increase in thermal conductivity of nanorefrigerant is attributed to the higher thermal conductivity of ZnO nanoparticles. The decreases in thermal conductivity of pure R-134a refrigerant may be due to the evaporation of refrigerant molecules. The increment in thermal conductivity due to addition of spherical and cubic ZnO nanoparticles over pure R-134a refrigerant is 25.26% and 42.5 %, respectively.

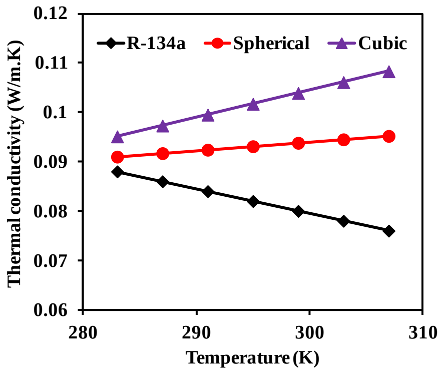

Figure 4. Influence of spherical and cubic shape ZnO nanoparticles on thermal conductivity of R-134a refrigerant.

4. Conclusions

In the summary of present work, thermophysical and heat transfer properties of ZnO/R-134a nanorefrigerant analyzed for two different shapes of ZnO nanoparticles with respect to temperature. The major outcomes of this study could be drawn as follows,

- The addition of spherical and cubic shape ZnO nanoparticles in R-134a refrigerant increases viscosity of nanorefrigerant. Cubic ZnO loaded nanorefrigerant has higher value of viscosity.
- Similar observation is made for density of spherical and cubic shape ZnO nanoparticles loaded in R-134a refrigerant.
- Specific heat of ZnO nanoparticles loaded nanorefrigerant found to be lower than pure R-134a refrigerant.
- The significant enhancement in the thermal conductivity of spherical and cubic shape ZnO nanoparticles in R-134a refrigerant observed of the order of 25.26% and 42.5 % respectively.

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