Preparation of nanorefrigerants using mono-, bi- and tri-layer graphene nanosheets in R134a refrigerant

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Preparation of Nanorefrigerants using Mono-, Bi- and Tri-layer Graphene Nanosheets in R134a Refrigerant

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Abstract. Nano-refrigerants are a special class of nanofluids, prepared by addition of nanoscale impurity in refrigerants. The nano-refrigerants have a wide range of applications in many fields of thermal engineering including rapid refrigeration, air conditioning and heat pumps. In the present work, nanorefrigerants are prepared by forcefully dispersing Mono-, Bi- and Tri-layer graphene nanosheets in R134a refrigerant (as base fluid) at low temperature (278 K). To analyze the effect of number of layers of graphene, three types of graphene layers namely mono-, bi- and tri-layer graphene nanosheets are chosen. The result of the research work shows that thermophysical and heat transfer properties are strongly influenced by the number of layers of graphene. The nanorefrigerant prepared using mono-layer graphene shows outstanding heat transfer property in terms of ~96.14 % enhancement in thermal conductivity over the pure refrigerant.

INTRODUCTION

The cooling and heating in domestic and industrial applications mainly depends on the thermo–physical properties such as thermal conductivity, viscosity, specific heat and density of fluids which are used in system. Conventional fluids have poor heat transfer capacity due to low thermal conductivity. Hence, it consumes more energy, which indirectly results in the emission of large amount of CO_2. Therefore, the development of nanorefrigerants is very much necessary for the improvement in performance of refrigeration technology. The key advantages of nanorefrigerants are,

- Nanorefrigerants will lead to compact and lighter refrigeration systems.
- Nanorefigerant based refrigeration systems will consume low energy.
- Nanorefrigerants have virtue of low global warming and zero ozone depletion potential.

But the nanorefrigerant exhibits some unresolved issues such as particle clogging, large pressure drop, corrosion of components, still required to be addressed. Anand et al reviewed comprehensively the recent developments in the field of nanorefrigerants. The review is mainly focused on the domestic use of nanorefrigerants for improvement in coefficient of performance, energy saving and green environment. In the present work, after rigorous research authors have concluded that the refrigerant R134a has zero ozone depletion potential. During the experimentation with nanoparticles and lubricant mixture in refrigeration system, Anand et al demonstrated that the power consumption is significantly reduced [1]. Nair et al summarized the recent developments in the nanorefrigerants field in the context of its preparation, thermophysical properties and application. This study pointed out that the

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research on the nanorefrigerant is slow and needs more attention of scientific community. In this review, many cases-studies are discussed, which shows that addition of nanoparticles in refrigerant improve performance of refrigeration system and energy efficiency [2].

Kumar et al reported the preparation of Al_2O_3-R134a nanorefrigerant to analyze the performance in refrigeration system. In this work, Al_2O_3 nanoparticles firstly mixed with poly alkylene glycol (PAG). Results of the investigation show that Al_2O_3nanorefrigerant performs efficiently in the refrigeration system. It is observed that refrigeration system performance is better than pure lubricant with R134a as working fluid. The use of nanorefrigerent reduces the energy consumption by 10.32% [3]. Kushwaha et al experimentally investigated the performance of (R134a + Al_2O_3) nanorefrigerent in refrigeration system. This study reports some motivating results, such as temperature drops significantly across the condenser for R134a+Al_2O_3nanorefrigerant and improvement in coefficient of performance. Work of Kushwaha et al proposed R134a+Al_2O_3nanorefrigerant for practical application in refrigeration system [4].

Ozturk et al formulated a new category of nanorefrigerants, which comprises graphene nanosheets. The graphene based nanorefrigerant shows outstanding thermal conductivity enhancements over carbon nanotube suspension with practical value of viscosity. The experimental study shows that graphene based nanorefrigerant is potential category of nonorefrigerant to achieve efficiency in many thermal management applications [5]. Fadhilah et al studied the thermophysical properties of CuO nanoparticle loaded nanorefrigerent through mathematical modelling. In this work, the physical properties of R-134a are used for mathematical modelling. The thermal conductivity, dynamic viscosity and heat transfer rate were the main parameters studied in this work. The mathematical modelling-based results show that nanorefrigerant will be the potential working fluid, which saves energy usage and environment [6].

Mahbubul et al investigated the heat transfer and pressure drop characteristics of Al_2O_3-R141b nanorefrigerant as a function of different volume concentrations. The results of the study show that heat transfer and pressure drop characteristics increased with the concentration of nanoparticle. The optimized nanorefrigerant improved the performance of cooling capacity of refrigeration system. This results in low energy consumption [7]. Ajayi et al studied the performance of 0.04%Ni/R134a nanorefrigerant as working fluid in refrigeration system. For the nanorefrigerant application, nanoparticles were prepared by one step method and dispersed into the mineral oil. The results of the study show that nanorefrigerant performed better with improved coefficient of performance of the order of 7.05% [8]. Mahbubul et al investigated the thermophysical properties of 5 vol.% Al_2O_3 nanoparticles loaded R-134a refrigerant and its effects on the coefficient of performance in the temperatures range 283–308 K. The result shows that thermal conductivity improved over pure refrigerant by 28.58%, whereas specific heat of nanorefrigerant is slightly reduced compare to R-134a [9]. Sanukrishna et al reported the thermophysical, heat transfer and pressure drop properties of TiO_2 nanoparticle loaded R134a nanorefrigerants. The results of study show that thermophysical and heat transfer characteristics improved due to the addition of nanoparticles in pure refrigerant. In this work, heat transfer coefficient got increased by 30.2% [10].

In the present work, it was planned to investigate the thermophysical characteristics of graphene/R134a nanorefrigerants. To analyze the effect of graphene and more importantly its layer number on performance of nanorefrigerants, Mono-, Bi- and Tri- layer graphene was used to prepare suspension. The thermo-physical characteristics like viscosity, density, specific heat and thermal conductivity were studied at low temperature.

EXPERIMENTAL

The graphene nanosheets required in this work were procured from Sigma-Aldrich. The procured graphene was characterized by X-ray diffraction (XRD) analysis and transmission electron microscopy (TEM). In the present work, Mono-, Bi- and Tri-layer graphene nanosheets were used for the preparation of nanorefrigerants. As the R134a refrigerant is highly unstable at room conditions, firstly the graphene sheets in three types namely Mono-, Bi- and Tri-layer added separately in lubricant of the compressor system. The preparation of mixture of nano-impurity and lubricant is very important step in the study of nanorefrigerant. The poly alkylene glycol (PAG) lubricant is used in this study, due to its wide acceptability in refrigeration technology and good physical properties. The nanosheets of graphene with the mass fraction of 1% were dispersed in lubricant. The graphene was forcefully dispersed into the lubricant using ultrasonic device for two hours at 150 W and 20 kHz to obtain well dispersed mixture. No surfactant was added in the preparation of graphene-lubricant mixture to avoid the effect of surfactant on heat transfer performance. To prepare nanorefrigerants, the mixture of lubricant and graphene was carefully injected to the pure refrigerant. Three types of nanorefrigerants were prepared in this work using Mono-, Bi- and Tri-layer graphene.

The thermophysical and heat transfer properties of nanorefrigerant studied in the temperature range 283-307 K. The viscosity of nanorefrigerants was determined using AR-1000 Rheometer, TA Instrument. The specific heat and thermal conductivity measurements were carried out by using KD2 pro thermal analyzer (Decagon Devices).

RESULTS AND DISCUSSION

Figure 1 (a) shows the XRD pattern of graphene. The analysis of XRD pattern indicates the structural and phase purity of graphene. XRD pattern comprises two signature peaks of graphene, (002) and (100) at 26.3° and 44.2° respectively. Both these peaks indicate the highly organized structure of graphene. The topography of graphene under study is directly visualized by TEM as shown in Figure 1 (b). The nanosheets of grapheme were used for the preparation nanorefrigerants.

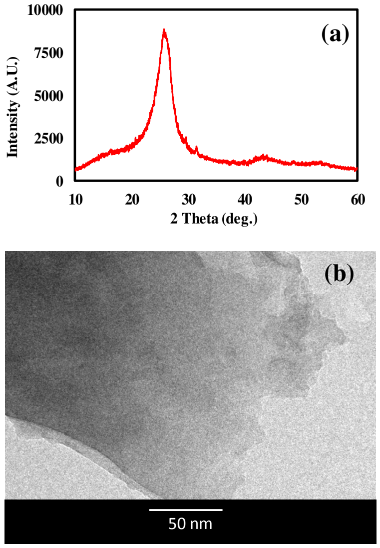

FIGURE 1. (a) XRD pattern and (b) TEM image of graphene.

Viscosity is a critical thermo-physical parameter in refrigeration system, which affects the performance of nanorefrigerant. Viscosity of nanofluids or nanorefrigerant normally increases with increase in concentration of nanoparticles and decreases with temperature. The viscosity of grapheme based R134a nanorefrigerants was studied using Brinkman model (Eq. 1) [11],

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

where, μnr and μr is the effective viscosity of nanorefrigerant and pure refrigerant respectively.ϕ is particle volume fraction. The variation in viscosity of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature is shown in Figure 2.The viscosity of nanorefrigerant decreases with increase in temperature. It is also observed from viscosity plot that trilayergraphene based nanorefrigerant has highest magnitude of viscosity and it decrease with temperature. Similarly, the monolayer graphene based nanorefrigerant has lower values of viscosity than tri- and bi-layer graphene. The decrease in viscosity as a function of temperature is justified as sub-micron dispersion behaves like a liquid. On other hand, decrease in viscosity with increasing temperature is result of diminishing adhesion forces between the particles and base fluid [12].

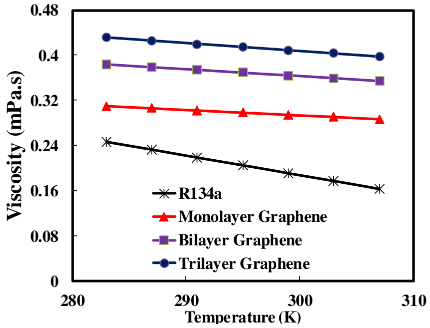

FIGURE 2. Variation in viscosity of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature.

The variation in density of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature is shown in Figure 3. The plot of density shows that with increase in temperature, density of nanorefrigerant decreases. Density is a function of mass and volume. Therefore, with increase in temperature the molecules of nanorefrigerant perform vibration, which ultimately increases volume [13]. Thus, the density of nanorefrigerant is decreases with temperature. The highest magnitude of density is associated with trilayergraphene based nanorefrigerant, whereas monolayer graphene based nanorefrigerant shows lowest magnitude.

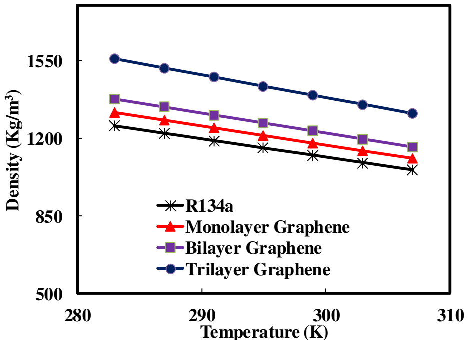

FIGURE 3. Variation in density of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature.

Figure 4 shows the variation in specific heat of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature. The specific heat of nanorefrigerant based on monolayer and bilayer graphene has much lower value than pure R-134a refrigerant. This lower value of specific heat of nanorefrigerant is result of lower specific heat of added particles.

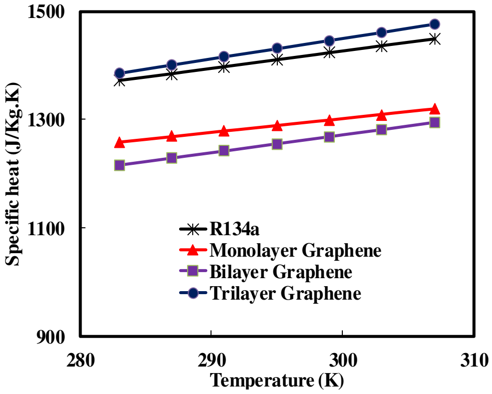

FIGURE 4. Variation in specific heat of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature.

Graphene is a single layer of hybridized sp2 carbon atoms, which is the thinnest and thermally stable material in universe [14]. The graphene nanosheets exhibit the significant thermal conductivity value of the order 5000 W/m.K [15]. Hence, it is expected from graphene that it will display good thermal conductivity enhancement due to the outstanding properties [16].

Figure 5 shows the variation in thermal conductivity of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature. From the plot of thermal conductivity, it is observed that thermal conductivity of R134a refrigerant decreases with increase in temperature. It may be due to the evaporation of refrigerant molecules. From plot, it is also observed that thermal conductivity of nanorefrigerants based on graphene shows increase in thermal conductivity as the temperature increases. This increase in thermal conductivity is assigned to the higher value of thermal conductivity of nanoimpurity that is graphene, in our case [17]. It is also observed that monolayer graphene based nanorefrigerant has highest value of thermal conductivity over the other nanorefrigerant samples. The manolayer based nanorefrigerant shows increase in thermal conductivity of the order 96.14 % over pure R134a refrigerant.

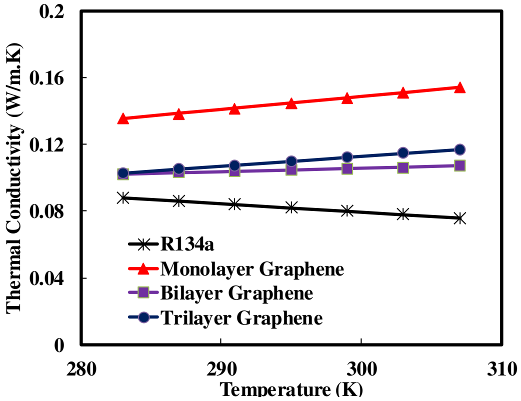

FIGURE 5. Variation in thermal conductivity of mono-, bi- and tri-layer graphenenanosheets based nanorefrigerants as a function of temperature.

CONCLUSIONS

In the present work, the mono-, bi- and tri-layer grapheme nanosheets based nanorefrigerants were successfully prepared and studied their thermophysical properties as a function of temperature. Following are the major concluding remarks made on the experimental investigation undertaken in the present work,

- Among mono-, bi- and tri-layer grapheme nanosheets based nanorefrigerants, it was observed that trilayergraphene based nanorefrigerant had highest magnitude of viscosity and it decreased with increase in temperature.
- The highest magnitude of density was associated with trilayergraphene based nanorefrigerant.
- The specific heat of nanorefrigerant was observed to be lower than the pure R134a refrigerant.
- The monolayer graphene based nanorefrigerant had highest value of thermal conductivity of the order of 96.14 % over the pure R134a refrigerant.

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