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Thermo physical property of nano-refrigerant: preparation, thermal characteristics, and applications

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Abstract

Nano fluids, is a fluid/liquid containing nanometer-sized particles that are called nanoparticles. Similarly Nano refrigerant is a refrigerant which contains nanometer-sized particle. These refrigerant are engineered colloidal suspensions/mixture of nanoparticles in a base refrigerant. The nanoparticles used in Nano-refrigerant are typically made of oxides, metals, carbides, or carbon nanotubes. The refrigerant suspension of Nano nanomaterials, have shown many unpredicted properties, and the thermal characteristics offer unprecedented potential for many applications. This paper represent theoretical analysis of thermal characteristics of Nano refrigerant with respect to size and concentration of Nanoparticles and presents the broad range of current and future applications in different fields including mechanical, energy and biomedical fields. At last, the paper identifies the opportunities for future research.

Keywords: Nano Refrigerants, Ecofriendly refrigerants, performance evaluation, Energy-Exergy analysis.

1. Introduction

Nano refrigerant are a new kind of fluids engineered by colloidal/mixture of nanometer-sized materials (nanofibers, nanotubes, nanoparticles, nanowires, Nano sheet, Nano rods, or droplets) in base refrigerant. In other words, Nano refrigerant are nanoscale colloidal suspensions containing condensed nanomaterials. Nano refrigerant have been found to possess enhanced thermo-physical properties such as thermal conductivity, density, dynamic viscosity, and convective heat transfer coefficients compared to those of base refrigerant like R134a, R407c, R404, R134a etc. It has demonstrated great potential applications in many fields.
For a two-phase system, there are some important issues we have to face. One of the most important issues is the stability of nano refrigerant, and it remains a big challenge to achieve desired stability of nano refrigerant. All of us we know that approx major refrigerant have vapour phase at atmospheric temperature, so it is a challenging work to mix nanoparticle into the base refrigerant. Refrigerant which have liquid phase at zero degree i.e. R114, R12 is easy to mix with nanoparticles. In this paper, we will theoretically analyze the performance characteristics of Nano refrigerant.

In recent years, Nano refrigerants have attracted more attention. The main driving force for Nano refrigerant research lies in a wide range of applications.

2. Preparation methods for Nano fluid

2.1. Two-Step Method

Two-step method is the most widely used method for preparing nano fluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the Nano sized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the most economic method to produce Nano fluids in large scale, because Nano powder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature

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applications.
Due to the difficulty in preparing stable Nano fluids by two-step method, several advanced techniques are developed to produce Nano fluids, including one-step method. In the following part, we will introduce one-step method in detail.

2.2. One-Step Method

To reduce the agglomeration of nanoparticles, Eastman et al. developed a one-step physical vapor condensation method to prepare Cu/ethylene glycol Nano fluids [1]. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased [2]. The one-step processes can prepare uniformly dispersed nanoparticles, and the particles can be stably suspended in the base fluid. The vacuum-SANSS (submerged arc nanoparticle synthesis system) is another efficient method to prepare Nano fluids using different dielectric liquids [3, 4]. The different morphologies are mainly influenced and determined by various thermal conductivity properties of the dielectric liquids. The nanoparticles prepared exhibit needle-like, polygonal, square, and circular morphological shapes. The method avoids the undesired particle aggregation fairly well.
One-step physical method cannot synthesize Nano fluids in large scale, and the cost is also high, so the one-step chemical method is developing rapidly. Zhu et al. resented a novel one-step chemical method for preparing copper Nano fluids by reducing $CuSO_4{\cdot}5H_2O$ with $NaH_2PO_2{\cdot}\ H_2O$ in ethylene glycol under microwave irradiation [5]. Well-dispersed and stably suspended copper Nano fluids were obtained. Mineral oil-based Nano fluids containing silver nanoparticles with a narrow-size distribution were also prepared by this method [6]. The particles could be stabilized by Korantin, which coordinated to the silver particle surfaces via two oxygen atoms forming a dense layer around the particles. The silver nanoparticle suspensions were stable for about 1 month. Stable ethanol-based nanofluids containing silver nanoparticles could be prepared by microwave-assisted one-step method [7]. In the method, polyvinylpyrrolidone (PVP) was employed as the stabilizer of colloidal silver and reducing agent for silver in solution. The cationic surfactant octadecylamine (ODA) is also an efficient phase-transfer agent to synthesize silver colloids [8]. The phase transfer of the silver nanoparticles arises due to coupling of the silver nanoparticles with the ODA molecules present in organic phase via either coordination bond formation or weak covalent interaction. Phase transfer method has been developed for preparing homogeneous and stable graphene oxide colloids. Graphene oxide nanosheets (GONs) were successfully transferred from water to n-octane after modification by poleylamine, and the schematic illustration of the phase transfer process is shown in Figure 1 [9].

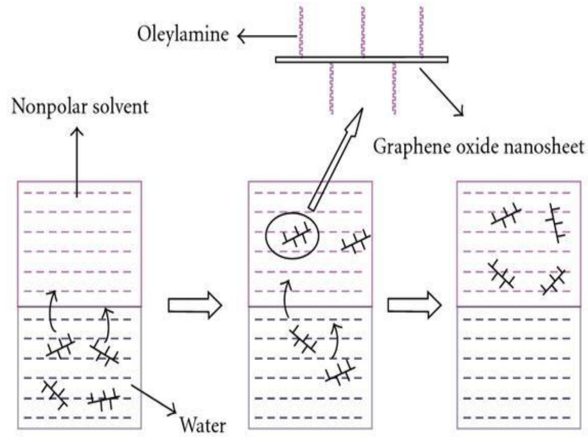

Figure 1: Schematic illustration of the phase transfer process

However, there are some disadvantages for one-step method. The most important one is that the residual reactants are left in the nanofluids due to incomplete reaction or stabilization. It is difficult to elucidate the nanoparticle effect without eliminating this impurity effect.

2.3. Other Novel Methods

Wei et al. developed a continuous-flow microfluidic micro reactor to synthesize copper Nano fluids. By this method, copper Nano fluids can be continuously synthesized, and their microstructure and properties can be varied by adjusting parameters such as reactant concentration, flow rate, and additive. CuO Nano fluids with high solid volume fraction (up to 10 vol%) can be synthesized through a novel precursor transformation method with the help of ultrasonic and microwave irradiation [10]. The precursor Cu $(OH)_2$ is completely transformed to CuO nanoparticle in water under microwave irradiation. The ammonium citrate prevents the growth and aggregation of nanoparticles, resulting in a stable CuO aqueous Nano fluid with higher thermal conductivity than those prepared by other dispersing methods. Phase-transfer method is also a facile way to obtain monodisperse noble metal colloids [11]. In a water-cyclohexane two-phase system, aqueous formaldehyde is transferred to cyclohexane phase via reaction with dodecylamine to form reductive intermediates in cyclohexane. The intermediates are capable of reducing silver or gold ions in aqueous solution to form dodecylamine-protected silver and gold nanoparticles in cyclohexane solution at room temperature. Feng et al. used the aqueous organic phase-transfer method for preparing gold, silver, and platinum nanoparticles on the basis of the decrease of the PVP's solubility in water with the temperature increase [12]. Phase-transfer method is also applied for preparing stable kerosene-based Fe_3O_4 Nano fluids. Oleic acid is successfully grafted onto the surface of Fe_3O_4 nanoparticles by chemisorbed mode, which lets Fe_3O_4nanoparticles have good compatibility with kerosene [13]. The Fe_3O_4 Nano fluids prepared by phase-transfer method do not show the previously reported "time dependence of the thermal conductivity characteristic". The preparation of Nano fluids with controllable microstructure is one of the key issues. It is well known that the properties of Nano fluids strongly depend on the structure and shape of nanomaterials. The recent research shows that Nano fluids synthesized by chemical solution method have both higher conductivity enhancement and better stability than those produced by the other methods [14]. This method is distinguished from the others by its controllability. The Nano fluid microstructure can be varied and manipulated by adjusting synthesis parameters such as temperature, acidity, ultrasonic and microwave irradiation, types and concentrations of reactants and additives, and the order in which the additives are added to the solution.

3. Theoretical result of Nano refrigerant

A computational program has been developed to solve nonlinear equation related to Nano refrigerant and its thermal properties and various respective graph has been plotted with different concentration of nanoparticles and refrigerant shown below.

3.1. Thermo physical property of Nano refrigerant

In this section variation of thermo physical property of base refrigerant using nanoparticle suspended into base refrigerant at 5 Vol % are shown below.

3.1.1. Thermal conductivity of Nano refrigerant using different nanoparticle and base refrigerant

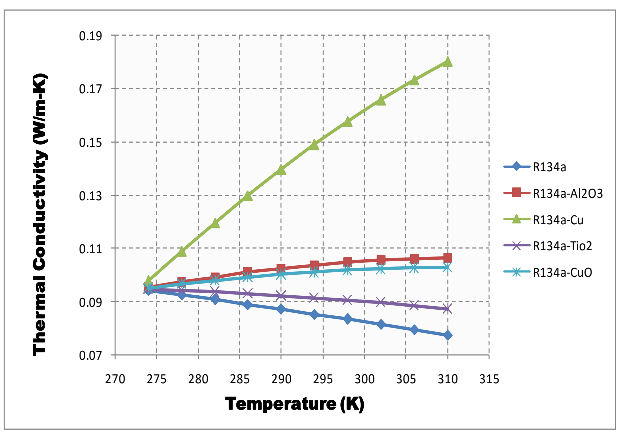

Fig.2. Variation of Thermal conductivity with Temperature of R134a using different nanoparticles

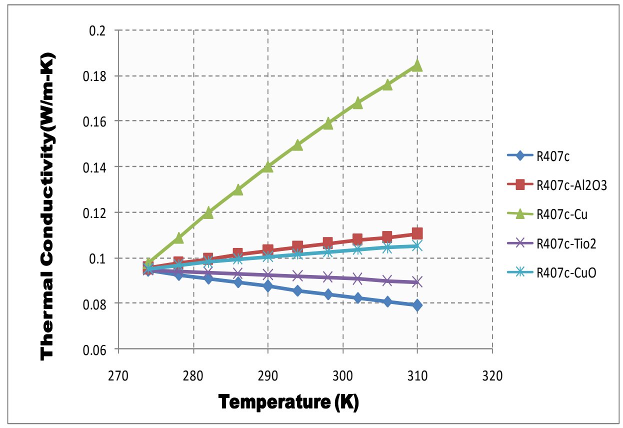

Fig.3. Variation of Thermal conductivity with Temperature of R407c using different nanoparticles

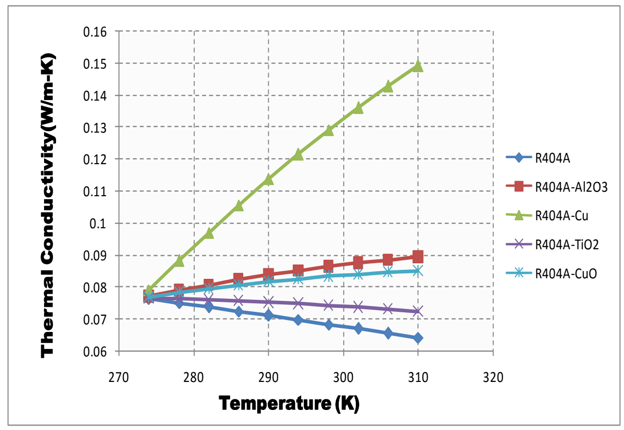

Fig.4. Variation of Thermal conductivity with Temperature of R404A using different nanoparticles

Fig.2. to Fig.4. Show the enhancement in thermal conductivity of Nano refrigerant when different kind of nanoparticle is suspended into the host refrigerant. The enhancement factor varies from 0.06 to 2 for different nanoparticle. From the Fig-4 we can see that cu nanoparticle have more EF at higher temperature which value is approx. 2.

3.1.2. Density of Nano refrigerant with different nanoparticle and base refrigerant

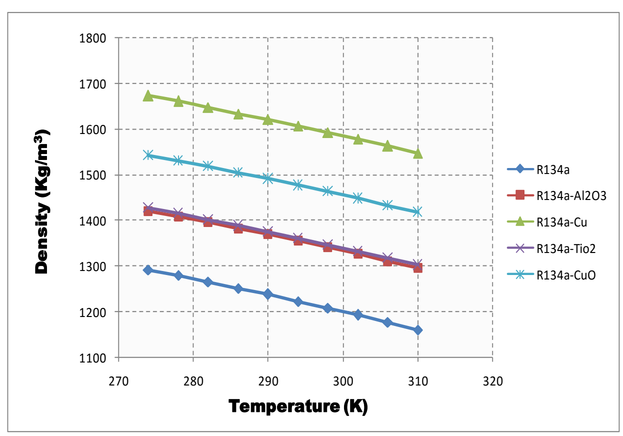

Fig.5. Variation of Density with Temperature of R134a using different nanoparticles

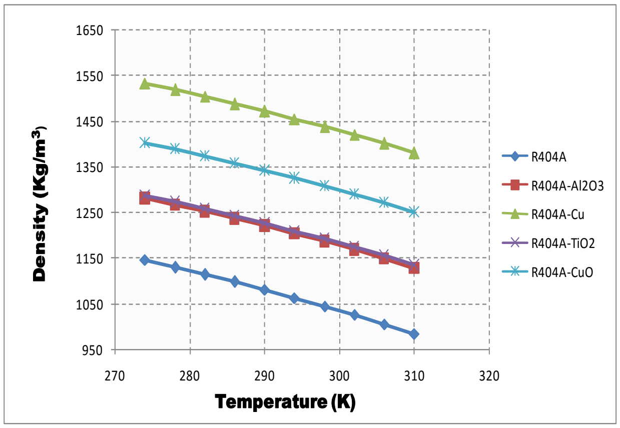

Fig.6. Variation of Density with Temperature of R404A using different nanoparticles

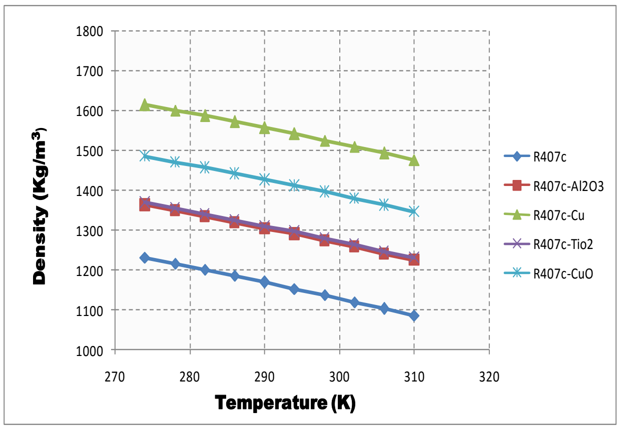

Fig.7. Variation of Density with Temperature of R407c using different nanoparticles

Fig.5. to fig.7. Shows variation in density of Nano refrigerant subject to temperature variation. Fig shows that density variation of Nano refrigerant is similar to pure refrigerant as higher temperature low density and lower temperature high.

3.1.3. Dynamic viscosity of Nano refrigerant using different nanoparticle and base refrigerant

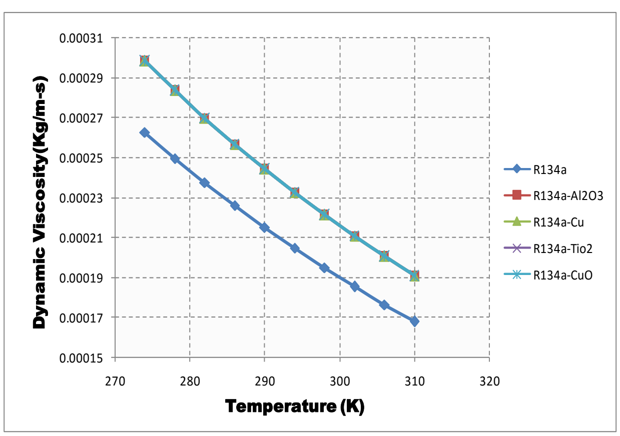

Fig.8. Variation of Dynamic viscosity with Temperature of R134a using different nanoparticles

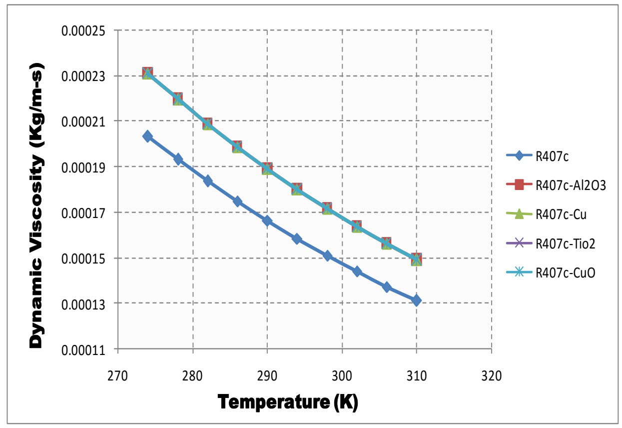

Fig.9. Variation of Dynamic viscosity with Temperature of R407c using different nanoparticles

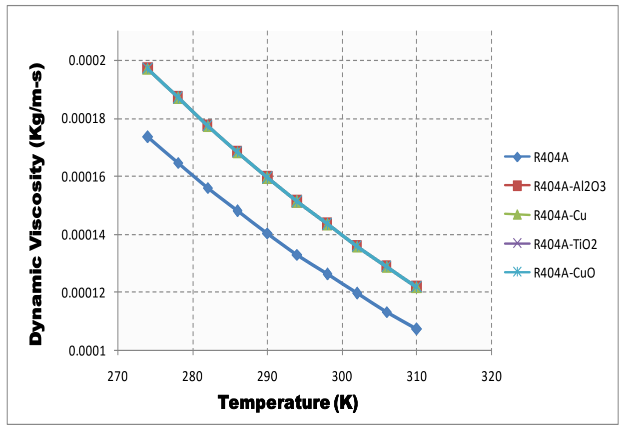

Fig.10. Variation of Dynamic viscosity with Temperature of R404A using different nanoparticles

Fig.8 to fig.10. Shows variation in Dynamic viscosity of Nano refrigerant subject to temperature variation. Fig shows that Dynamic viscosity variation of Nano refrigerant is similar to pure refrigerant as higher temperature low viscosity and lower temperature high.

3.1.4. Specific heat of Nano refrigerant using different nanoparticle and base refrigerant

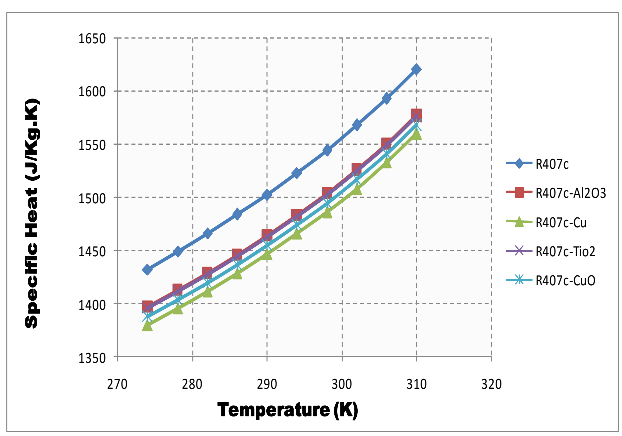

Fig.11. Variation of Specific heat with Temperature of R407c using different nanoparticles

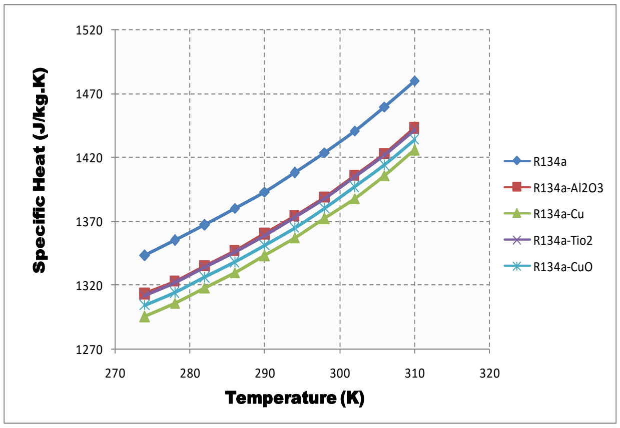

Fig.12. Variation of Specific heat with Temperature of R134a using different nanoparticles

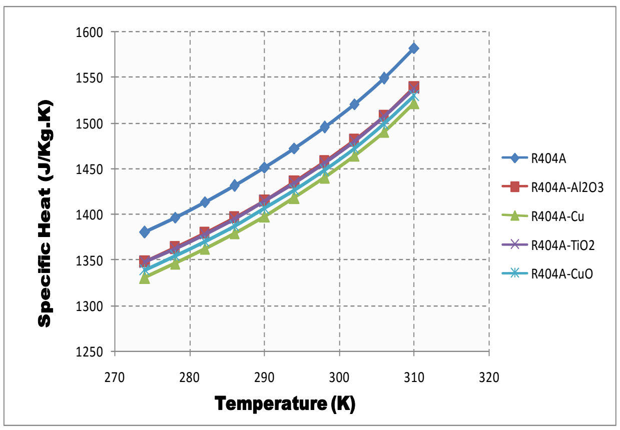

Fig.13. Variation of Specific heat with Temperature of R404A using different nanoparticles

Fig.11-13 shows variation in Specific heat of Nano refrigerant subject to temperature variation. Fig shows that Specific heat variation of Nano refrigerant is similar to pure refrigerant as higher temperature High Specific heat and lower temperature low. But when we go for higher vol % concentration of nanoparticle Specific heat will reduce.

3.1.5. Effect of volume fraction on Thermo physical property of Nano refrigerant with different nanoparticle and base refrigerant (at 280K temperature)

Density ratio shown Fig 14. is defined as the ratio of density of Nano refrigerant (nanoparticle mixed with pure refrigerant) to the density of pure refrigerant.
Thermal conductivity shown in Fig 17. is defined as the ratio of thermal conductivity of Nano refrigerant (pure refrigerant mixed with nanoparticle) to the thermal conductivity of pure refrigerant.

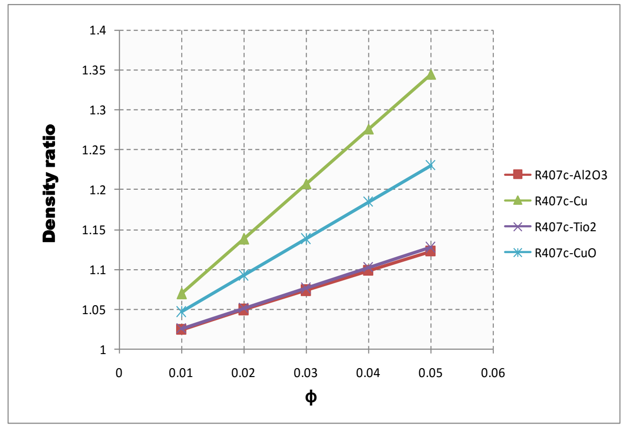

Fig.14. Variation of Density Ratio with volume fraction (ϕ) of R407c using different nanoparticles

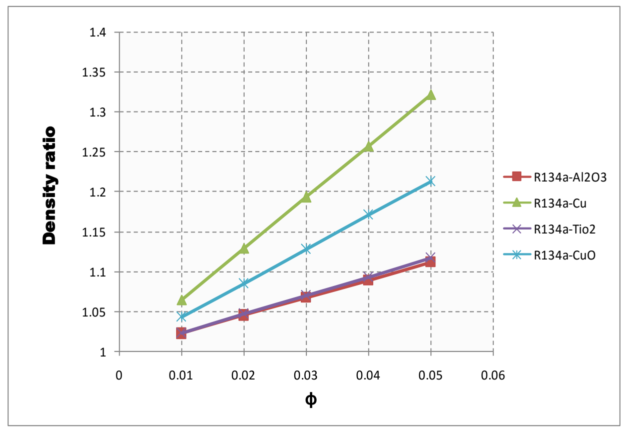

Fig.15. Variation of Density Ratio with volume fraction (ϕ) of R134a using different nanoparticles

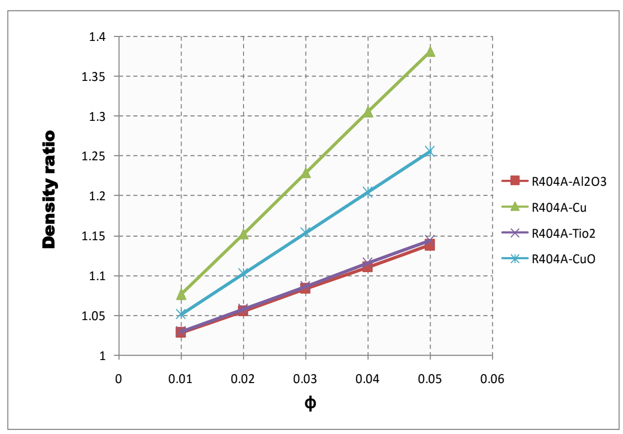

Fig.16. Variation of Density Ratio with volume fraction (ϕ) of R404A using different nanoparticles

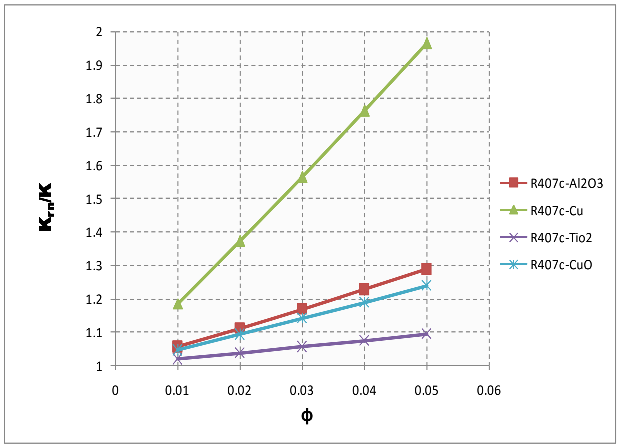

Fig.17. Variation of Thermal conductivity Ratio with volume fraction (ϕ) of R407c using different nanoparticles

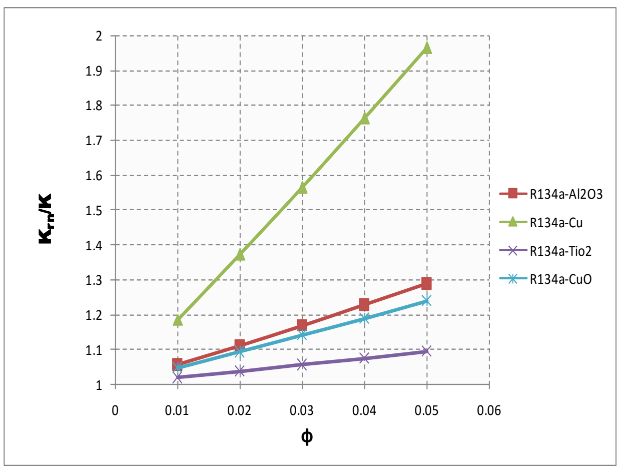

Fig.18. Variation of Thermal conductivity Ratio with volume fraction (ϕ) of R134a using different nanoparticles

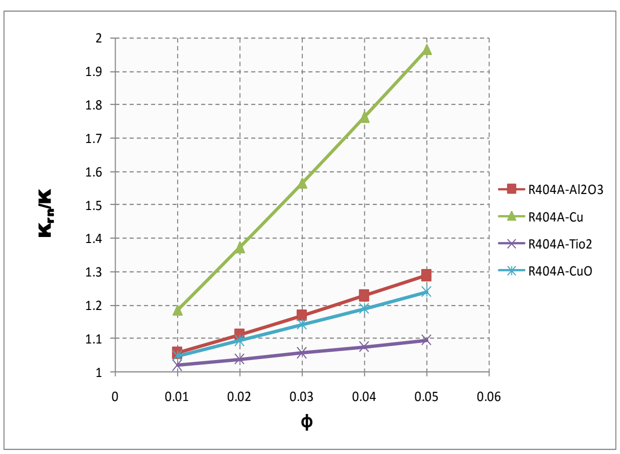

Fig.19. Variation of Thermal conductivity Ratio with volume fraction (ϕ) of R404A using different nanoparticles

Fig 17 to Fig. 19. Shows that conductivity ratio of pure refrigerant to Nano refrigerant increases with increasing concentration of nanoparticle into the host refrigerant. From the fig we can see that Cu nanoparticle based Nano refrigerant have higher cond. Ratio than other nanoparticle and have approx. two times higher than base refrigerant at 5 vol % concentration.

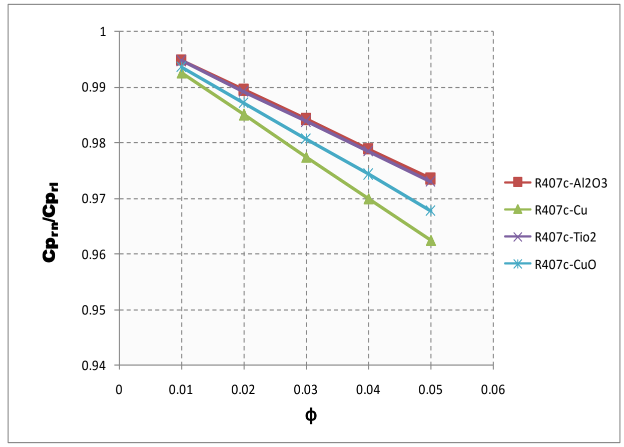

Fig.20. Variation of Specific heat ratio with volume fraction (ϕ) of R407c using different nanoparticles

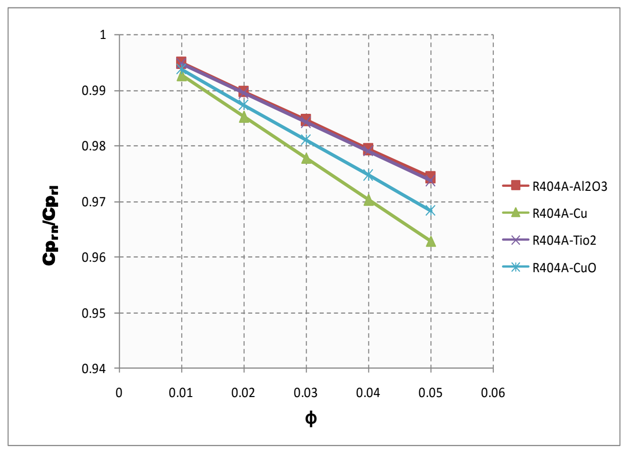

Fig.21. Variation of Specific heat ratio with volume fraction (ϕ) of R404A using different nanoparticles

Specific heat ratio shown in Fig 20-22. Is defined as the ratio of specific heat of Nano refrigerant (nanoparticle mixed with pure refrigerant) to the specific heat of pure refrigerant.

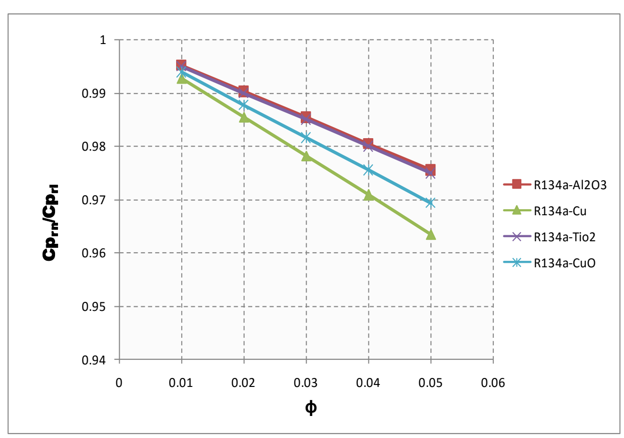

Fig.22. Variation of Specific heat ratio with volume fraction (ϕ) of R134a using different nanoparticles

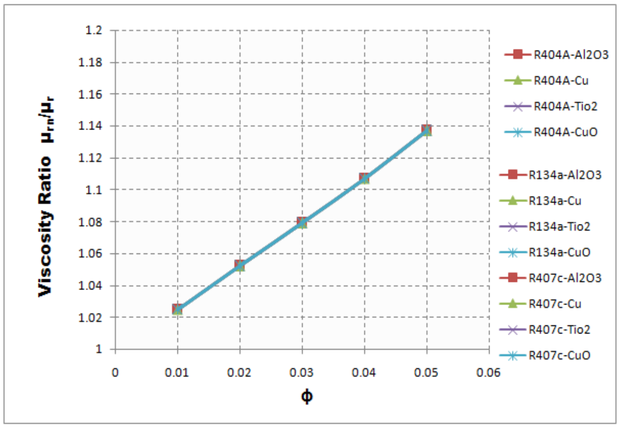

Fig.23. Variation of Viscosity ratio with volume fraction (ϕ) of all Nano refrigerant

Viscosity ratio shown in Fig 23 is defined as the ratio of Viscosity of Nano refrigerant (nanoparticle mixed with pure refrigerant) to the Viscosity of pure refrigerant.

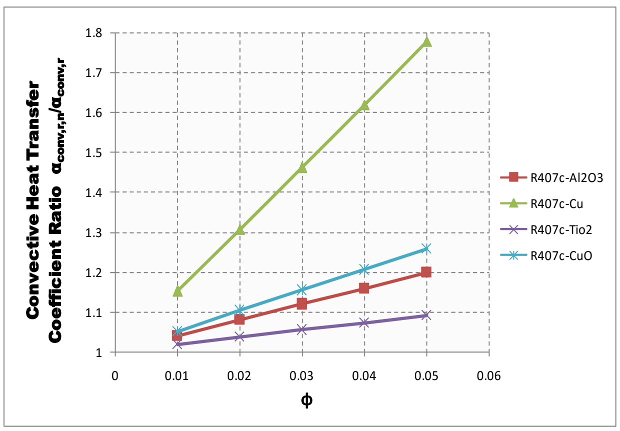

Fig.24.Variation of Convective heat transfer coefficient ratio with volume fraction (ϕ) of R407c using different nanoparticles

Convective heat transfer coefficient ratio shown in Fig 24, 25 and 26 is defined as the ratio of Convective heat transfer coefficient of Nano refrigerant (nanoparticle mixed with pure refrigerant) to the Convective heat transfer coefficient of pure refrigerant.

Heat transfer Enhancement Factor shown in Fig 27-29 is defined as the ratio of heat transfer coefficient of Nano refrigerant (nanoparticle mixed with pure refrigerant) to the heat transfer coefficient of pure refrigerant.

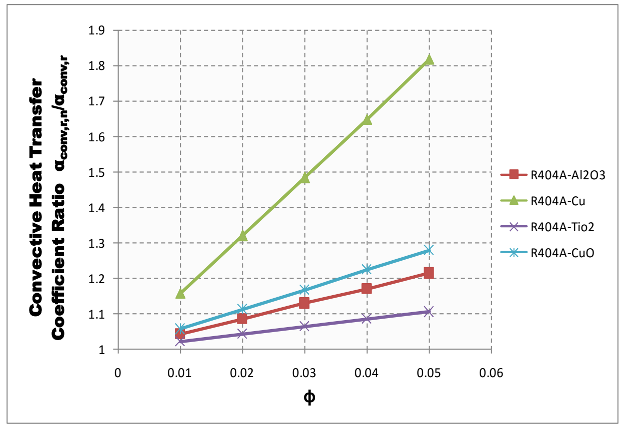

Fig.25. Variation of Convective heat transfer coefficient ratio with volume fraction (ϕ) of R404A using different nanoparticles

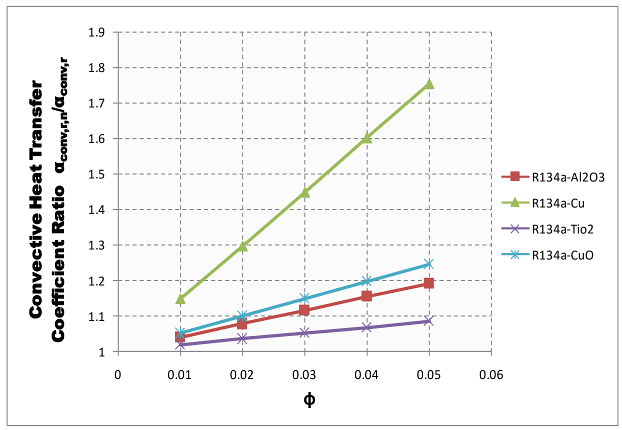

Fig.26. Variation of Convective heat transfer coefficient ratio with volume fraction (ϕ) of R134a using different nanoparticles

Fig 24-26 shows the convective heat transfer coefficient Ratio increases by increasing the concentration of nanoparticle. And copper nanoparticle based Nano refrigerant have highest convective heat transfer coefficient ratio than other particle its value ranges from 1 to 1.7.

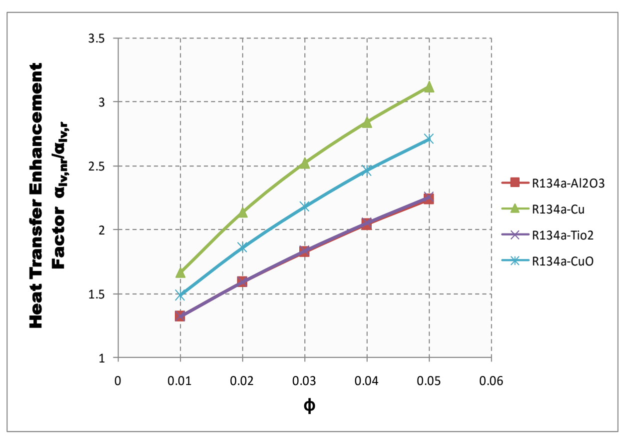

Fig.27. Variation of Heat transfer Enhancement Factor with volume fraction (ϕ) of R134a using different nanoparticles

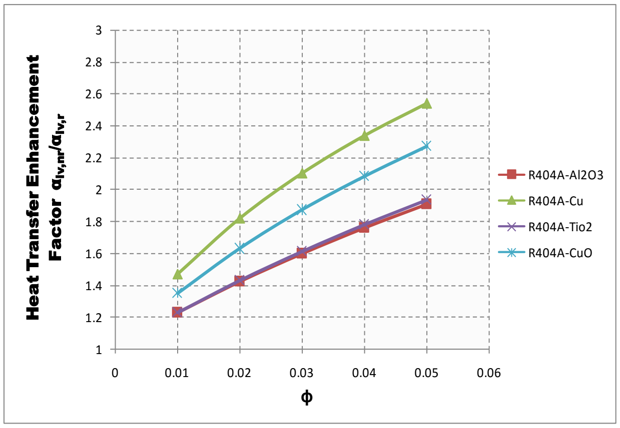

Fig.28. Variation of Heat transfer Enhancement Factor with volume fraction (ϕ) of R404A using different nanoparticles

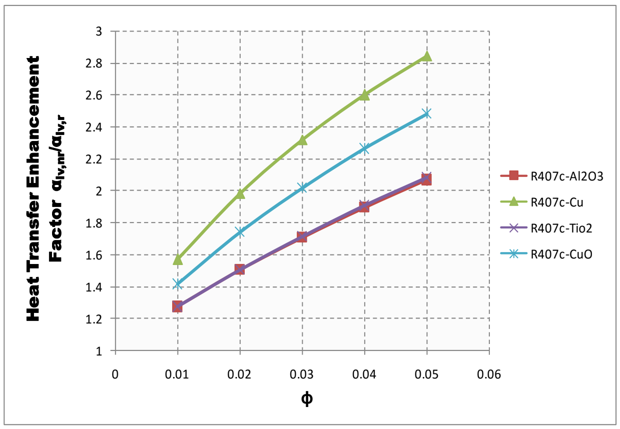

Fig.29. Variation of Heat transfer Enhancement Factor with volume fraction (ϕ) of R407c using different nanoparticles

Fig 27-29 show the heat transfer enhancement factor of Nano refrigerant with different nanoparticle its value ranges from 1.2 to 3.2. As it can be seen that R134 a with cu nanoparticle have highest EF approx. 3.2 at 5 vol %. EF increases with increasing vol %.

4. Conclusion and Future work

Following conclusions have been drawn from present investigations.

(i) The conductivity ratio of pure refrigerant to Nano refrigerant increases with increasing concentration of nanoparticle into the host refrigerant whereas Cu nanoparticle based Nano refrigerant have higher conductivity ratio as compared to other nanoparticle and have approx. two times higher than base refrigerant at 5 vol % concentration.

(ii) The ecofriendly R134a with cu nanoparticle have highest Effectiveness factor approx. 3.2 at 5 vol %. The Effectiveness Factor (EF) increases with increasing vol %.. and the copper nanoparticle based Nano refrigerant have highest convective heat transfer coefficient ratio than other nano particle

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