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A Review on Performance of Vapour Compression Refrigeration System Using Nano Additive Refrigerants

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Abstract: Now a days, researchers focused on use of Nano additive refrigerants in vapour compression refrigeration system (VCRS) because of their remarkable improvement in thermo-physical and heat transfer capabilities to enhance the Coefficient of Performance (COP) and reliability of refrigeration system. Based on results available in the literatures, it has been found that Nano additive refrigerants have a much higher and strongly temperature-dependent thermal conductivity at very low particle concentrations than conventional refrigerant. This can be considered as one of the key parameters for enhanced performance for refrigeration systems. In this review, we summarized the performance enhancement of vapour compression refrigeration system using Nano additive refrigerants reported by different researchers. Moreover, challenges and future directions of performance enhancement of VCRS using Nano additive refrigerants were presented.

Keywords: VCRS, COP, Nano Additive Refrigerants, Performance, Thermal Conductivity

1. Introduction

The coefficient of performance (COP) of a refrigeration system is defined as the ratio of heat removal rate on the evaporator side to the mechanical work input on the compressor side. The COP can be upgraded in two ways: firstly, by increasing the heat removal rate at the evaporator side, and secondly, by decreasing the compressor work. Many researchers have investigated the possibility of introducing nanoparticles in refrigerants to develop a new class of Nano fluids called "Nano refrigerants". Use of Nano-refrigerants will increase the heat transfer in refrigeration systems and thus enhance the system performance with the rapid advancement in nanotechnology; it becomes possible to obtain Nano sized particles (1 to 100 nm.) of metals, oxides and carbides. These nanoparticles having high thermal conductivity are suspended in conventional heat transfer fluids which lead to emerging of new generation of heat transfer fluids called nanofluids. Nanofluids have been introduced by Steve Choi of Argonne's Energy Technology Division and Jeff Eastman of the Materials Science Division on Argonne National Laboratory in 1995. Thermal systems like refrigerator, air conditioners etc. consume large amount of electric power. Many researchers have been carried out in last decade to enhance the heat transfer rate, to improve performance of the systems. To improve thermo physical and heat transfer capabilities of the system, nanoparticles are either suspended in the refrigerant or lubricating oil. Nano fluids have the following characteristics as compared to normal solid liquid suspensions.

A) Higher heat transfer between the particles and fluid due to high surface area of the articles.
B) Better dispersion stability.
C) Reduces particle clogging.
D) Reduces pumping power as compared to base fluid to obtain equivalent heat transfer.

Nanoparticles could be of metal like copper, nickel, aluminum. Oxides like aluminum oxide, titanium oxide, copper oxide, silicon oxide. Base fluids are the thermo fluids like water, ethylene glycol, propylene glycol, engine oil and refrigerants. [2] Nano fluids are prepared by production of nanoparticles and then its dispersion in the base fluid. There are two methods used for the preparation of Nano fluids namely single step method and two step method. In single step method, nanoparticles are simultaneously produced and dispersed, while in two step method, nanoparticles are first produced and then dispersed in the base fluid. [3] Nanofluids are not simply the solid-liquid mixtures but they are the even suspension, stable suspension and durable suspension. There should not be any agglomeration of particles and no chemical change in the base fluid. To achieve all this, there are three ways

(i) To change pH value of suspension.
(ii) To use surface activators/dispersants.
(iii) To use ultrasonic vibration.

All these techniques change the surface properties of the suspended particles and suppress clustering. It depends on the application how these techniques are used. [21] Nanofluids have vast application in different fields like engine cooling, engine transmission oil, cooling electronic circuits, refrigeration, drilling lubrication, thermal storage, solar water heating, nuclear cooling system, defense space application, biomedical application, drilling and lubrication. [17] This paper review application of Nano fluidsas lubricants in vapor compressor refrigeration system. The below figure 1 shows the different types of Nano-particles with Length scale and some examples related to it.

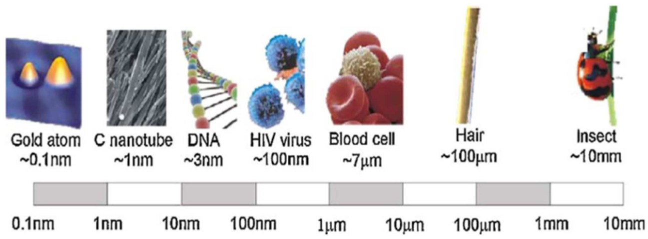

Figure 1. *Length of scale and some examples related to Nano sizes.*

2. Thermal Conductivities of Nano Fluids

Thermal conductivity is the ability of material to conduct or transmit heat. Thermal conductivity plays an important role in construction of energy efficient thermal system. If thermal conductivity is higher than heat transfer coefficient will be higher. Jwo et al. [6] conducted experimental study using Al_2O_3 nanoparticles and lubricant of R134a refrigeration system as a base fluid. They used thermal analyzer to measure thermal conductivity for temperature range between 10-40°C. They concluded that thermal conductivity enhances by 2.0%, 4.6% and 2.5% for 1.0, 1.5 and 2.0 wt.% of Al_2O_3 at 40°C and nano fluids shows better effects for high temperatures. Mahbulul et al. [16] carried out experimental analysis on flow boiling inside horizontal smooth tube using Al_2O_3/R134a nanorefrigerant for 1.0 to 5 vol.%concentration and temperature range was 300 K to 325 K. The velocity of nanorefrigerant was observed to be 5 m/s. and vapour quality was 0.2 to 0.7. The Sitprasert model was used to calculate thermal conductivity and found to be increased with increase in nanoparticle volume fraction and temperature, increased sharply due to concentration of nanoparticles rather than temperature effect. Khedkar et al. [22] investigated thermal conductivity of paraffin based Fe_3O_4 Nano fluid measured using transient hot wire method. The results shows that thermal conductivity increases with particle volume fraction and enhancement observed to be 20% over the base fluid. Mahbulul et al. [20] analyzed the thermal conductivity of Al_2O_3/R141b nanorefrigerant using Sitprasert model and found that increases linearly with increase of particle volume concentration. Experimental value found to be higher when compared with Maxwell, Yu and Choi model. Authors reported that thermal conductivity at 20°C temperature and 0.4% volume concentration was highest and lowest at 5°C and 0.1% volume concentration. The authors agreed that nanofluids have higher thermal conductivity as compared to base fluid. There are two ways to improve thermal conductivity of Nano refrigerants, one is to use nanoparticles with higher thermal conductivity and other is to increase concentration of nanoparticles in base fluid.

3. Viscosity of Nano Fluids

Volume fraction and temperature have significant effect over the viscosity of Nano refrigerants. Sajuman et al. [12] performed analysis on Nano fluid where he used lubricant of compressor of vapor compression refrigeration system as base fluid and TiO_2 nanoparticles. Nano fluid was prepared using mechanical stirrer and ultrasonic agitation for 70 minutes. They measured the viscosity of Nano fluid using Redwood Viscometer and found that viscosity is predominant in lower temperature range. Mahbulul et. al. [14] also conducted experimental study on Al_2O_3/R141b nanorefrigerant and measured the viscosity of Nano refrigerant using LVDVseries ultra-programmable viscometer. They concluded that viscosity increases with the increase of nanoparticle volume concentration and decreases with the increase of temperature, observed to be 179 times greater than the base fluid. Mahbulul et al. [16] also found that viscosity increased due to augmentation of nanoparticle concentration when experimental with the Nano refrigerant flow boiling inside the smooth tube. Khedkar et al. [22] investigated the viscosity of paraffin based Fe_3O_4 (size 25 nm. and 0.01 – 0.1 volume fraction) Nano fluid using TA instrument thermometer. They reported that viscosity increases with increase in particle volume fraction but much less than predicted by Einstein model. Mahbulul et al. [20] investigated viscosity of Al_2O_3/R141b Nano refrigerant using Brinkman Model and found that viscosity increases with nanoparticle volume fraction enhancement and decreases with increase of temperature. High nanorefrigerant temperature intensifies the Brownian motion and reduces the viscosity of nanorefrigerant.

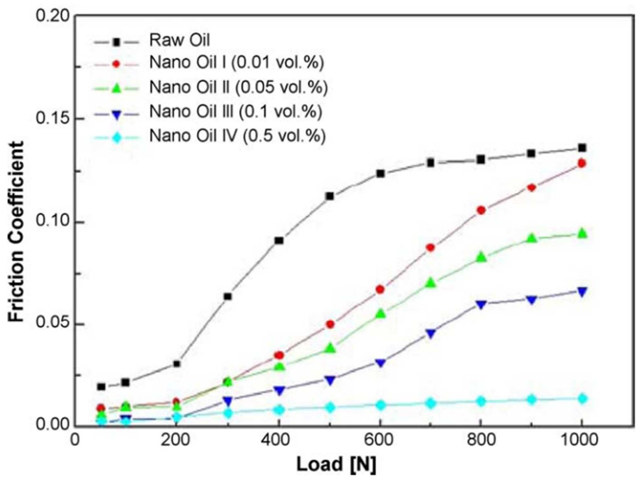

Figure 2. *Lubrication test results on the friction coefficient as a function of the fullerene volume fraction of Nano-oil.*

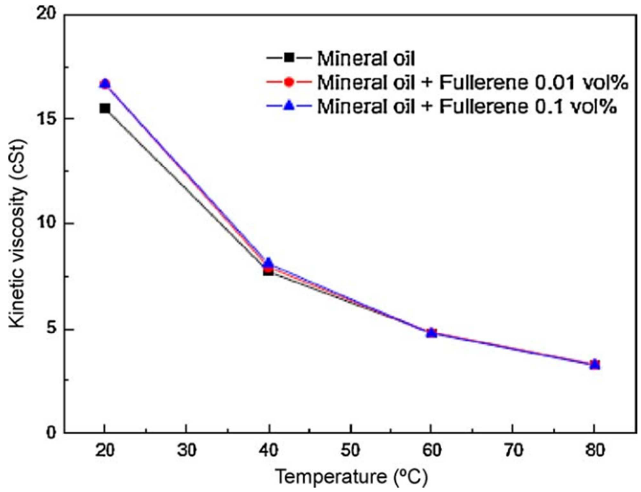

Figure 3. *Kinetic viscosity of fullerene-in-oil as a function of particle concentration and temperature.*

4. Heat Transfer Performance

Heat transfer performance is an important factor to be considered to evaluate the overall performance of the system. The phase change characteristics of the refrigerant based Nano fluids are the governing factor in the heat transfer phenomenon. T. Coumaresssin and K. Palaniradja [7] analyzed the refrigeration system using double pipe heat exchanger and CuO/R134a as Nano refrigerant. The CFD heat transfer analysis was done using FLUENT software and mesh of test section was designed using GAMBIT software. The authors reported that the evaporating heat transfer coefficient increases with the increase in CuO nanoparticle concentration up to 0.55% and then decreases for all values of heat flux. Eed Abdel et al. [9] carried out experimental analysis on vapour compression refrigeration system using CuO/R134a nanorefrigerant. They analyzed the evaporator test section constructed as tube in tube type heat exchanger for nanoparticle concentration of 0 to 1% and for heat flux of 10 to 40 kWm^{-2}. The result shows that evaporating heat transfer coefficient increases with the increase of heat flux, but after 0.55% of CuO nanoparticle concentration, it decreases. They also reported that the evaporating heat transfer coefficient increases up to 25nm. Size of CuO nanoparticle for all values of heat flux. H. Peng etal. [15] Investigated the heat transfer characteristics of CuO/R113 Nano refrigerant flow boiling inside the horizontal smooth copper tube. They carried out experimental analysis for various concentrations of CuO nanoparticles, various mass fluxes and different vapour qualities. They found out that for mass flux of $100kgm^{-2}s^{-1}$ and 0.1 wt.% of CuO nanoparticle concentration, the enhancement in heat transfer is found to be 70.2% compared with the pure refrigerant. Mahbulul et al. [16] used Al_2O_3/R134a nanorefrigerant in flow boiling inside horizontal smooth tube and found out that the convective heat transfer coefficient and flow boiling heat transfer coefficient increases with the increase in nanoparticle volume concentration. Mahbulul et. al. [18] investigated the heat transfer performance of Al_2O_3/R141b nanorefrigerant in horizontal smooth circular tube using mathematical models. They concluded that heat transfer coefficient increases with increase in particle volume fraction. They observed that highest value of heat transfer coefficient to be1755.82 $kWm^{-2}k^{-1}$ for 5 volume% of particle concentration and at vapour quality of 0.2. The minimum heat transfer coefficient enhancement with 1 volume% and 0.3 vaporqualities was foundto be 383% relative to pure R141b refrigerant. H. Peng et al. [19] conducted the experimental analysis using R113/ VG68 oil mixture and carbon nanotubes. Different combinations of refrigerant/oil/CNT was experimented and found that nucleate pool boiling heat transfer coefficient enhancement can reach up to 61% when compared with, without carbon nanotube refrigerant-oil mixture. They also proposed the correlation for predicting nucleate pool boiling heat transfer coefficient of refrigerant-oil mixture with carbon nanotubes and predicted values agreed up to 96% of the experimental data within deviation of ±10%.

5. Energy Performance

Subramani and Prakash [4] carried out the energy consumption test and freeze capacity test to evaluate the performance of refrigeration system using nanoparticles. They found that using SUNISO 3GS oil and Al_2O_3 nanoparticles, coefficient of performance increases by 33% and freezing capacity also increases when compared with pure POE oil/R134a system. Energy enhancement factor was 1.53. D. Kumar and Dr. Elansezhian [5] reported that 10.32% of energy saving was obtained when PAG OIL and Nano Al_2O_3 was used in R134a refrigeration system. Maximum COP of 3.5 obtained for capillary length of 10.5 m. Subramani et al. [8] conducted performance study using three types of Nanolubricants, which are TiO_2 nanoparticles, Al_2O_3 nanoparticles and CuO nanoparticles with SUNISO 3GS oil as base fluid. Authors reported that freezing capacity was higher with TiO_2 Nano lubricant and power consumption reduced by 15.4%, 11.9% and 8.4% with TiO_2, Al_2O_3 and CuO nanoparticles respectively. Kotu and Reji Kumar [10] investigated the heat transfer performance of domestic refrigerator using R134a/mineral oil/ Al_2O_3Nano refrigerant. They concluded that using double pipe heat, increases freezing capacity of the system when compared with the system using Al_2O_3 nanoparticles. Power consumption reduces by 30% with double pipe heat exchanger and coefficient of performance increases by 10% in comparison with pure mineral oil system. R. Kumar et al. [11] investigated R600a/POE oil system in domestic refrigerator. They observed that when POE oil replaced with mineral oil and Al_2O_3 nanoparticles, the power consumption reduced by 11.5%. They showed that, it tookabout 42 minutes to bring cooling load temperature from 28°C to 5°C for Nano refrigerant, 50 minutes for mineral oil and 60minutes for POE oil. Sajuman [12] performed analysis on hermetically sealed compressor using TiO_2 nanoparticles (size 21 nm.) and mineral oil of the refrigeration system. They observed that reduction in power consumption was 9.33% and coefficient of performance increased by 16.08%. Shengshan B. [13] Conducted experimental study on domestic refrigerator using R600a and 0.1 grams/liter and 0.5 grams/liter concentration of TiO_2 nanoparticles. They concluded that 5.94% and 9.60% energy saved respectively using nanorefrigerant. The system shows better performance than pure R600a and returns more lubricant back to compressor.

6. Conclusion

(i) Many Researchers tried performance enhancement of Simple Vapour compression system by using Nano fluids either in the form Nano refrigerant or Nano lubricant, it is clear that Nano refrigerants have high thermal conductivity than traditional refrigerants. Thermal conductivity increases with increase of nanoparticle volume concentration and temperature. Temperature, particle size, dispersion and stability do play an important role in determining the thermal conductivity of Nano fluid.

(ii) Viscosity increases with the increase of nanoparticle volume concentration anddecreases with the increase of temperature.

(iii) Heat transfer performance of the system increases with increasing nanoparticle concentration. In some cases reported, it increases up to specific volume concentration of nanoparticle and then decreases.

(iv) With the use of nanoparticles in refrigerant or lubricant, consumption of power reduces and freezing capacity of the system increases in almost all cases.

(v) For the better performance, dispersion and stability of nanoparticles is the matter of fact. Nanofluids stability and its production cost is the main issue in commercialization of Nano fluids. Exact mechanism of enhanced heat transfer for Nano fluids is still unclear as reported by many researchers.

7. Future Work

Many researchers tried performance enhancement of refrigeration system above mentioned different methods but no one tried it by using the Nano fluid as cooling medium in water cooled condenser refrigeration system so it is decided to experimentally investigate the performance vapour compression system using the Nano fluid as cooling medium in water cooled condenser refrigeration system.

Nomenclature

CNT	Carbon nanotube
EG	Ethylene glycol
Xnp	Mass fraction of nanoparticles
XS	Mass fraction of surfactant
Tsuc	Compressor suction temperature
Tcond	Condenser temperature
Tdis	Compressor discharge temperature
Tdom	Compressor dome temperature
Tfz	Frozen food storage compartment evaporator temperature
Tfd	Fresh food storage compartment evaporator inlet temperature
Tevp	Evaporator temperature
Psuc	Compressor suction pressure
Pdis	Compressor discharge pressure

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