Chapter

Effect of Nanoparticles on Performance Characteristics of Refrigeration Cycle

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Abstract

Since few years, researchers are introduced nanorefrigerant in the recent development of refrigeration systems. This chapter briefly summarizes the behavior of different nanoparticles in vapor compression refrigeration cycle. The nanoparticles' infusion in refrigeration cycle affects the viscous behavior of the refrigerant. It is found that very limited studies have been done on viscosity characteristics of nanolubricants, but few reports states that viscosity increases with nanoparticles additive which improves the tribology of compressor. But inversely, the increment of viscosity promotes to the possible pressure drop in the system which eventually drops the cycle performance. The optimum contribution of nanorefrigerant with high thermal conductivity and low viscosity is the success key of system performance with nanoparticles. However, it is found that the contribution of nanoparticles on the basis of physical phenomena that are affecting the vapor compression cycle is limited in the literature. This chapter aims to make a review on the mechanism of improving vapor compression cycle by using nanorefrigerants.

Keywords: nanorefrigerants, nanolubricants, compressor work, coefficient of performance, heat transition

1. Introduction

Nanorefrigerant was defined to complete the objective of improving thermal performance using little possible fraction of nanoparticles in the base refrigerant. An improved term of refrigerant known as "nanorefrigerant" firstly introduced and experimentally implemented by Wang et al. [1]. The addition of nanoparticles in refrigerant improves the system performance in terms of improvement in flow and pool boiling heat transfer characteristics as well as flowing pool condensation heat transfer [2, 3]. Nowadays, nanorefrigerant and nanolubricant became a great alternate to enhance the performance of cooling cycles in terms of tribology performance, heat mass transfer properties and refrigerant/oil mixture relations [4–7]. Specifically, nanorefrigerant improves the heat transfer coefficient at evaporation and condensation whereas a nanolubricant improves the tribology characteristics which ultimately increase the compressor performance. The expected volume concentration of nanoparticles is calculated using Eq. (1).

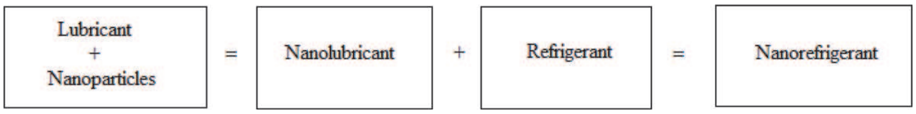

Figure 1.
Formation of nanorefrigerant in VCR cycle.

$$ø = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p} + \frac{m_L}{\rho_L}} \times 100 \quad (1)$$

where, ø is the volume fraction in percentage, ρ_p and ρ_L are the density of nanoparticles and density of the lubricant respectively; and m_p and m_L are the masses of nanoparticles and lubricants respectively. The formation of nanorefrigerant is possible as shown in **Figure 1**.

The present chapter aims to define the mechanism that steers towards improvement in overall VCR cycle performance using nanolubricants and nanorefrigerants. The authors' hope that this paper will be useful to define the research gaps and understands the contribution of nanorefrigerants and nanolubricants in refrigeration cycle.

2. Improvement in VCR system performance

The section consists of four sub-sections. First part concerns research findings related to Al_2O_3 nanoparticles and the other parts deals with review studies related to CuO, TiO_2 and CNT nanoparticles. The schematic diagram of refrigeration cycle is shown in **Figure 2**.

2.1 Studies related to Al_2O_3

Till date, researchers developed various methods to improve heat transfer characteristics of refrigerants inside the vertical and horizontal tubes. Adding nanoparticles to base refrigerant is one of the most efficient methods to enhance the thermal characteristics of refrigerant.

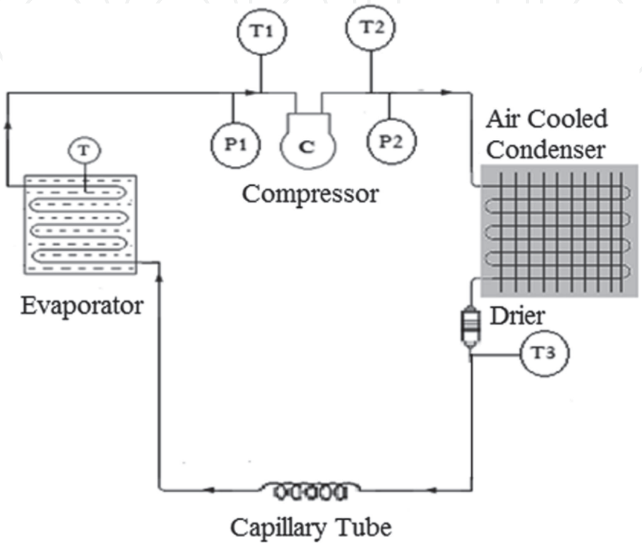

Figure 2.
Schematic diagram of vapor compression refrigeration cycle.

Jwo et al. [8] dispersed 0.1% mass fraction of Al_2O_3 particles in polyester oil and reported 2.4% reduction in compressor work. Mahbubul et al. [9, 10] reported significant increment in thermal conductivity and viscosity with Al_2O_3 nanoparticles dispersed in R141b. Later, the author observed increment in heat transfer coefficient and pressure drop up to 383 and 181%, respectively using particle volume fraction between 1 and 5% with fixed mass flux of 100 kg/m^2 s. Mahbubul et al. [11] reported large frictional pressure drop of R134a/Al_2O_3 nanorefrigerant as compared to R113/CuO nanorefrigerant flows inside horizontal smooth tube due to higher vapor quality [12].

Sun and Yang [13] studied the effect of Alumina-R141b, Cu-R141b, Al-R141b and CuO-R141b with mass fractions 0.1–0.3 wt% in a computer aided test rig on flow boiling heat transfer in horizontal tube and reported that Cu-R141b nanorefrigerant had the highest heat transfer coefficient as compared to other mixtures. Kedzierski [14] dispersed 1.6% volume fraction of Al_2O_3 in R134a/POE mixture flows on a horizontal and rough flat surface and found that higher volume fraction of nanoparticles with low average diameter has greater positive effect on heat transfer characteristics of base refrigerant. Further, Kedzierski [15] investigated the effect of Al_2O_3 nanoparticles on the pool boiling characteristics of R134a/POE mixture inside the rectangular finned surface and reported that 3.6% nanoparticle volume fraction enhanced the boiling heat transfer performance up to 113%. Tang et al. [16] reported that using δ-Al_2O_3 with R141b significantly improved pool boiling heat transfer coefficient in the system but adding surfactant at higher concentration corrupted the heat transfer process.

Mahbubul et al. [17] dispersed Al_2O_3 in R141b refrigerant for thermal conductivity and viscosity investigation. The author reported that viscosity and thermal conductivity of R141b/Al_2O_3 nanorefrigerant at 2% volume fraction are 179 and 1.626 times greater than pure refrigerant. Jwo et al. [8] used 0.05–2% weight fraction of Al_2O_3 particles with R134a and R12, respectively and reported that R134a refrigerant replaces R12, as polyester oil replaces mineral oil. Further, 0.1 wt% fraction of nanoparticles in R134a refrigerant reduced the energy consumption by 2.4% which significantly improved the COP of refrigerator. Kumar and Elansezhian [18] experimentally investigated the effect of R134a/Al_2O_3/PAG blend on the overall performance of VCR cycle and observed lower energy consumption by 10.32%. Author stated that using nanoparticle in refrigeration system is a cost effective method which improve its COP and length of capillary tube is reduced.

Subramani and Prakash [19] observed 25% less energy consumption and 33% overall COP enhancement in VCR cycle using Al_2O_3 nanorefrigerant. The freezing capacity of the cycle was also improved. Yusof et al. [20] dispersed 0.2% Al_2O_3 particles in polyester (POE) lubricant and reported 7% improvement in system COP and 2.1% reduction at compressor energy consumption. Cremaschi et al. [21] studies that alumina nanoparticles did not improve the solubility between refrigerant and lubricant, while addition of nanoparticles had slightly lowered the solubility of R410a/POE.

2.2 Studies related to CuO

Kedzierski and Gong [22, 23] observed heat transfer improvement between 50 and 275% using 0.5% mass fraction of CuO particles with R134a/RL68H and R134a/POE blend. Moreover, R134a/RL68H blend shows higher heat transfer enhancement as compared to the R134a/POE blend. In Later study, the author used 2 Vol% fraction of CuO particles in R134a refrigerant and reported nanorefrigerant has higher heat flux. Bartelt et al. [24] dispersed 0.5–1% mass fraction of CuO nanoparticles in R134a/polyester blend in horizontal flow boiling conditions and found 42–82% and 50–101% heat transfer enhancement for 1 and 2% mass fraction respectively. Peng et al. [25] dispersed 0.1 and 0.5 wt% CuO nanoparticles in R113 refrigerant to study heat transfer performance inside a horizontal rough pipe and reported 29.7% HTC using nanoparticles in base refrigerant. Henderson et al. [26] reported lower heat transfer performance with 0.5 and 0.05 vol% of CuO and SiO_2 nanoparticles dispersed in R134a and R134a/POE blend during boiling flow conditions in horizontal tube. Further, the author used 0.02, 0.04 and 0.08 vol% of CuO nanoparticles in R134a/POE blend and observed that nanoparticle with 0.04 and 0.08 vol% improved heat transfer performance up to 52 and 76%, respectively. Kedzierski and Gong [27] dispersed 0.5% mass fraction of CuO nanoparticles in polyester oil and observed 275% improvement in heat transfer with base refrigerant R134a.

Later, Bartelt et al. [28] extended the experiment of Kedzierski and Gong [27] and observed that 2% concentration of CuO nanoparticles gives the highest improvement up to 101% (**Tables 1** and **2**) [29, 46].

Abdel-Hadi et al. [30] experimentally found that CuO nanoparticles with average size 25 nm and concentration 0.55% is an optimum value which significantly enhanced the evaporative heat transfer coefficient. Kumar et al. [29] observed 7% reduction in compressor energy consumption and 46% enhancement in COP with dispersion of 0.2–1 wt% fraction of CuO nanoparticles in compressor lubricant. Moreover, the author reported reduction in friction and wear in compressor using nanoparticles in base lubricant. Peng et al. [31] used Cu nanoparticle in R113/VG68 (ester oil) mixture. It was observed that using Cu nanoparticles with average size of 20 nm strongly improved the heat transfer performance up to 23.8% as compared to other particles sizes of 50 and 80 nm. Akhavan-Behabadi et al. [32] found 83% increment in heat transfer rate with 1.5% mass fraction of CuO nanoparticles dispersed in R600a/polyester oil condensed inside the smooth horizontal tube (**Figures 3** and **4**) [29, 41, 46].

2.3 Studies related to TiO_2

Wang et al. [1] performed among the first experimental study using nanorefrigerant which proves that cooling speed and COP of domestic refrigerator significantly enhanced by utilizing TiO_2 nanoparticles in R134a based system. Further, Jiang et al. [33] studied the thermal conductivity using new theory and compared with the experimental data using different R22 nanorefrigerant fractions. The investigation proved that particle aggregation theory and the resistance network is a useful method

Nanoparticles concentration	0%	0.2%	0.4%	0.6%	0.8%	1.0%
Energy consumption (kW)	0.113	0.112	0.10	0.107	0.105	0.105
Energy saving (%)	—	0.79	3.37	5.55	7.31	7.31

Table 1.
Compressor energy consumption using distinct nanoparticle fractions [29].

Nanoparticles concentration	0%	0.2%	0.4%	0.6%	0.8%	1.0%
Energy consumption (kW)	0.1323	0.1278	0.1250	0.1236	0.1224	0.1224
Energy saving (%)	—	3.40	5.51	6.57	7.48	7.48

Table 2.
Compressor energy consumption of LPG/MO mixture using distinct nanoparticle fractions [46].

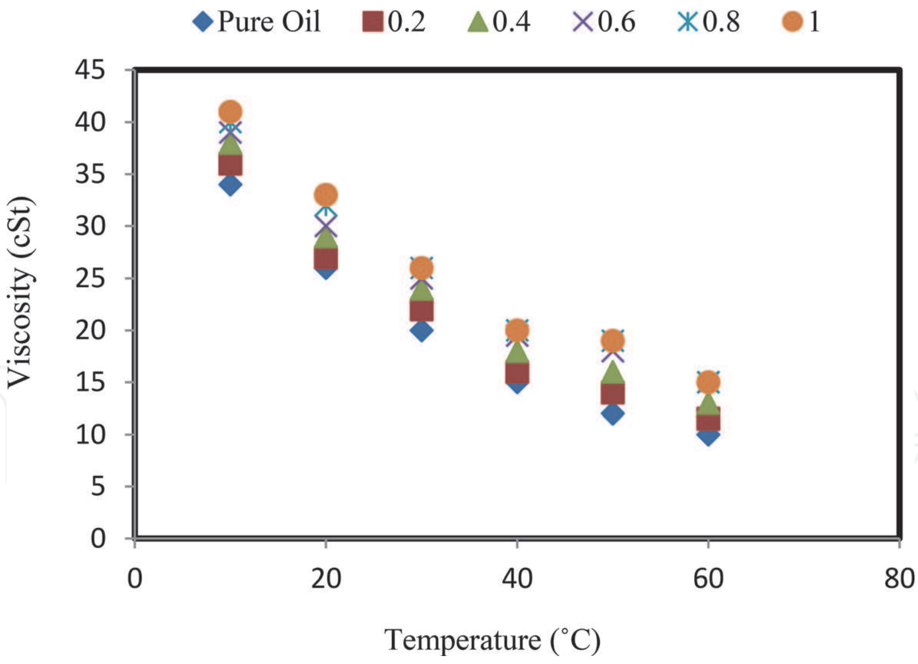

Figure 3.
Viscous behavior of mineral oil appended with CuO nanoparticles [29].

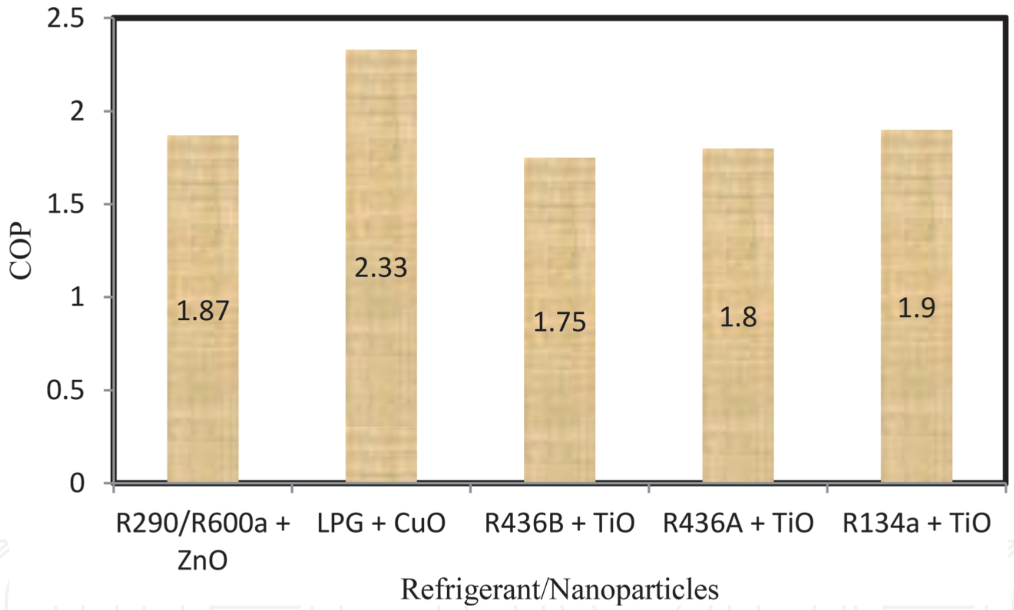

Figure 4.
COP comparison of the refrigerant cycle appended with different refrigerants/nanoparticles.

to calculate the thermal conductivity properties of nanorefrigerant. Li et al. [34] observed that significant improvement at heat transfer coefficient of R11 refrigerant using TiO_2 particles. Trisaksri and Wongwises [35] experimentally observed that nucleate pool boiling heat transfer coefficient (HTC) of using R141b refrigerant decreases with increment of TiO_2 nanoparticle fractions at high heat fluxes.

Mahbubul et al. [36] found that pressure drop increases with the addition of TiO_2 gradually in base refrigerant. Trisaksri and Wongwises [37] reported that increasing the particle volume fraction decreased the boiling heat transition rate and adding TiO_2 particles in base refrigerant R141b deteriorated the heat flow. Bobbo et al. [38] experimentally investigated a study in order to define the effect of TiO_2/carbon nanohorns (SWCNH) dispersion on the tribology of compressor polyester oil (SW32). The author reported better performance of TiO_2/SW32 blend compared to pure SW32 and SW32/SWCNH mixtures. Bi et al. [39] dispersed TiO_2 nanoparticles in R600a refrigerant through compressor lubricant and observed significant increment in freezing capacity about 9.60% by reducing energy consumption up to 5.94% using 0.1 and 0.5 g/L TiO_2 nanoparticle. Sabareesh et al. [40] used 0.05–0.015 vol% TiO_2 nanoparticles in compressor lubricant and observed that 0.01 vol% is optimum fraction value for better tribological properties. The author reported 17% improvement in COP and 11% reduction compressor energy consumption using nanoparticles with R12. Adelekan et al. [41] observed better COP in refrigerant cycle using TiO_2/MO nanolubricant instead of R134a/MO.

2.4 Studies related to CNTs and other nanoparticles

Jiang et al. [42] reported 50–104% increment in thermal conductivity with distinct particle fractions and diameters of CNTs dispersed in R113 refrigerant. The author declared 1.0 vol% fraction of CNT as optimum value. Park and Jung [43] performed nucleate boiling heat transfer analysis for CNTs with 1 vol% fraction using R123 and R134a refrigerants. The results found that heat transfer rate was improved (up to 36.6%) at low heat fluxes while it starts decreases at large heat fluxes. Peng et al. [44] reported 61% improvement in heat transfer coefficient with CNTs dispersed in R113/oil blend. Moreover, the author found that higher length and smaller outer diameter increased the heat transfer coefficient. Jiang et al. [42] conducted an experimental study on carbon nanotubes (CNTs) based nanofluids and proposed a modified Yu-Choi model which defined a decent deviation about 5.5% from the experimental result. Henderson et al. [45] used SiO_2 particles in polyester oil and reported 55% reduction in flow boiling performance due to the difficulties in nanolubricant dispersion and stability. Whereas, using Al_2O_3/POE nanolubricant results the great heat transfer improvement.

Kumar and Singh [46] reported 7.48% less energy consumption and 48% higher COP with 1.0 wt% of ZnO nanoparticles dispersed in R290/R600a/MO blend. Peng et al. [47] dispersed diamond nanoparticles in R113/VG68 blend to study nucleate boiling heat transfer coefficient. The author reported 63.4% enhancement in HTC using 0.05–0.5 wt% of nanoparticles fractions. Moreover, the study was compared with CuO/oil blend and found that diamond nanoparticles have higher impact on heat transfer characteristics. Kedzierski [48] reported 98% improvement in boiling heat transfer with 0.5%, 1% and 2% mass fractions of diamond nanoparticles dispersed in R134a. Naphon et al. [49] concentrated on the effect of Ti nanoparticles on the efficiency of copper heat pipe using R11 as base refrigerant. The study reported 0.01% nanoparticle fraction give highest efficiency ratio. Wang et al. [50] used a new category of nano oil which is created by mixing $NiFe_2O_4$ nanoparticles into naphthene-based oil B32 as an alternate to polyester VG32 and observed 6% improvement in overall COP.

3. Conclusions and future work

In present chapter, the studies of the previous findings on the heat transition characteristics, solubility and system performance of vapor compression refrigeration cycle has been presented. The literature related to pool boiling heat transfer enhancement of refrigerants and rheological behavior of lubricants using nanoparticles critically reviewed. The use of nanorefrigerants were improved the heat transfer performance of VCR system especially in nucleate and pool boiling heat transfer. CNTs can be considered as a best candidate for heat transfer enhancement of base refrigerants in comparison with the other nanoparticles.

The heat transfer rate increases with decreases nanoparticle dimension while the pressure drop decreases with decreases nanoparticles dimension.

The nanolubricants have great tribology characteristics in terms of wear rate and friction reduction in comparison with base lubricants. TiO_2 and CuO are best nanoparticles especially in improvement in tribology characteristics of compressor. It is reported that COP and freezing speed in cooling cycles is increased through application of nanoparticles in base refrigerants. It is found that improvement in VCR system parameters strongly depends on nanoparticle concentration. Thus, optimum value of particle fraction must be defined for better and stable results.

Furthermore, the below mentioned suggestions can be considering in future works:

1. As the nanoparticles concentration has great effect on thermophysical and tribology properties of refrigerants/lubricants, the study is needed to find the optimum nanorefrigerants and nanolubricants from the perspective of particle size, shapes and flow conditions.

2. The study on analytical models for the prediction of physical properties is so limited. Future works are needed to viral this study.

3. The study on condensation and evaporation flow of nanorefrigerants is very limited. It needs to elaborate.

4. There are no studies available related to effect of nanoparticles on new blend refrigerants such as R1234f.

5. The studies on the use of nanoparticles with natural refrigerants such as NH_3 and CO_2 not performed.

6. As per literature survey, several studies have been done on positive behavior of nanoparticles on heat transfer enhancement of refrigerants. The studies related to effect of nanoparticles on basic physical phenomena are somewhere missing.

7. There are no studies available on the flow of nanorefrigerants inside the microchannels and corrugated tubes.

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