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Mechanism for improvement in refrigeration system performance by using nanorefrigerants and nanolubricants – A review

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ABSTRACT

In order to improve the refrigeration system performance, researchers are introduced nanorefrigerants and nanolubricants in the recent development of HVAC system. However, the explanations of the nanoparticles contribution on the basis physical phenomena which affecting the vapor compression refrigeration system (VCRS) are limited in the literature. Hence, this paper presents a review on mechanism for improvement in VCRS performance by using nanorefrigerants and nanolubricants. The heat transfer augmentation, the refinement of refrigerant-oil mixture characteristic, and the tribology properties enhancement are among the major mechanisms that affect the VCRS performance. The performance parameters of VCRS such as compressor work and COP of refrigeration system using nanorefrigerants and nanolubricants have been discussed to relate between the mechanisms with overall system performance. The results showed that the utilization of nanorefrigerants and nanolubricants in the system was increased the heat transfer coefficients from 12 to 101% and the thermal conductivity enhancement for up to 4%. The solubility and miscibility of refrigerant-oil mixture with nanoparticles additives was enhanced for up to 12% although some reported that it was remained unchanged. The nanolubricants were behaved better tribology characteristics with 32% and 13% reduction of friction coefficient and wear rate, respectively. The effect of nanorefrigerants and nanolubricants on heat transfer, refrigerant-oil mixture and tribology had increased the overall performance of VCRS with 11% compressor work reduction and 24% of COP enhancement. Therefore, the nanorefrigerants and nanolubricants are expected to become the best candidate towards improving the efficiency of the VCRS.

1. Introduction

An improved thermal fluid or known as “nanofluids” was initially introduced by Masuda et al. [1] and Choi [2]. The base idea is using nanomaterials in the form of particles and suspends them in a fluid. The main goal of nanofluid is to increase the heat transfer performance by using the smallest possible concentrations with uniform dispersion and stable suspension of nanoparticles in the base fluid. At present, nanofluid has been developed by many researchers with the main objective to improve the performance and efficiency of the thermodynamic and mechanical systems. This advanced liquid has been used in many applications with the intention to provide an efficient energy system, energy savings, reduce the dependency towards fossil fuels and to reduce greenhouse gas emissions to the environment.

Nanolubricants and nanorefrigerants have been widely used in vapor compression system and shown to have high potential to increase the efficiency of the thermodynamic and mechanical performance of the system. Specifically, the heat transfer properties of the working fluid (refrigerant and lubricant) which can be improved through the use of nanotechnology. Also, nanorefrigerants and nanolubricants have an improved tribological characteristic (lubrication, the wear properties, high-pressure conditions) which an added advantages for the compressor. In the vapor compression system, most of the lubricant will be in the compressor with a small amount mixed with the refrigerant to form the refrigerant-lubricant mixture. According to the manufacturer of HVAC products, an average of 50% of the lubricant will be in the compressor, while the rest is in the evaporator (20%), drier (10%), condenser (10%), and hoses (10%) [3]. Thus, with the addition of nanoparticles into refrigerant improves the heat absorption or cooling in the vapor compression system. Whereas, a mixture of nanoparticles in the lubricant improves compressors efficiency.

Typically nanorefrigerants can be prepared via two methods as

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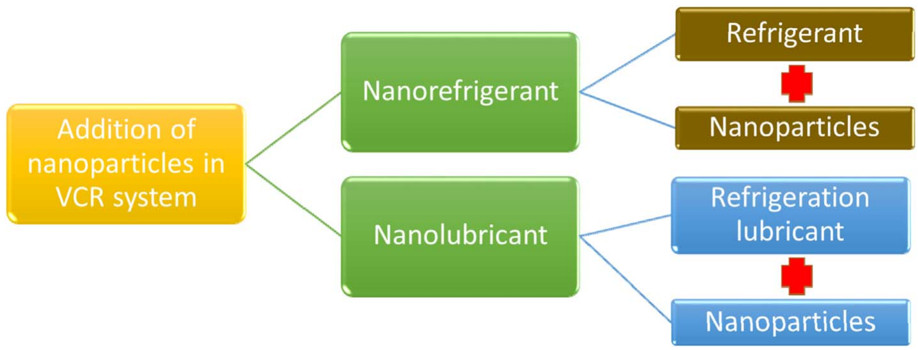

Fig. 1. Two methods to utilize the addition of nanoparticles in VCRS.

shown in Fig. 1. The first method is by dispersing the nanoparticles into the refrigerant. While the second method is by dispersing the nanoparticles into the compressors lubricant. Oftenly researchers declare that the resultant products from both approaches as nanorefrigerants, however, some researchers differentiate the products from the first method as nanorefrigerants and the second method as nanolubricants. Although nanorefrigerants and nanolubricants are similar in the way they operate, there are significant differences between both. For instance, the system uses nanorefrigerants will have improvement in the heat transfer characteristics compared to tribology characteristics as the nanoparticles are more towards the refrigerant. Whereas, nanolubricantss provides a superior improvement in terms of tribology as the nanoparticles more concentrated in the compressor lubricant compared to the refrigerant. However, till date, there is limited experimental work performed to explain the difference between nanorefrigerants and nanolubricants. These are due to the difficulties in the preparation of stable nanorefrigerants. However, the addition of nanoparticles in both the refrigerant and lubricant proved to improve the energy-saving in the system significantly.

Nanorefrigerants and nanolubricants is a good alternative to improve the performance of the vapor compression system in term of improved heat transfer characteristics, tribological performance, and enhanced refrigerant-lubricant solubility characteristic [4–7]. Usually, the nanoparticles suspended liquid will have an increase thermal conductivity compared to its base lubricant [8–11]. The increase in the heat transfer properties of the working fluid in the vapor compression system help in flow and pool boiling heat transfer characteristics and as well as the flowing pool condensation heat transfer in the system. Moreover, the increase in the thermal conductivity properties is advantageous to the heat exchanger in the system as the higher heat transfer coefficient benefits the system through a minimum increase in pumping power [12,13]. Whereas, the improvement in tribological properties improves the coefficient of friction and wear rate of the compressor. These lower the compressor load and provides better wear characteristics, and eventually improves the mechanical components life cycle. However, the increase in the concentration of nanoparticles will also significantly upsurge the viscosity of the nanofluid. Therefore, an optimum nanolubricants and nanorefrigerants concentration required to be identified to provide the best performance in vapor compression system for the various application.

The present review paper aims to highlight the mechanism that leads towards enhancement of overall vapor compression refrigeration system (VCRS) performance by using nanorefrigerants and nanolubricants. These mechanisms mainly involving the heat transfer, solubility and tribology of nanorefrigerants and nanolubricants in VCRS. The influence of nanorefrigerants and nanolubricants towards the performance of the vapor compression system is also presented. Till date, numerous works had been done related to nanorefrigerants and nanolubricants [4–6,14–18]. However, to the best of authors' knowledge, there is no comprehensive literature on the nanorefrigerants and nanolubricants prospective to highlight the mechanisms that contribute towards enhancement of VCRS. It is authors' hope that this review paper will be useful to fill the identified research gaps and to promote a better understanding on the contribution of nanorefrigerants and nanolubricants in VCRS.

2. Development of nanorefrigerants and nanolubricants

The development of nanorefrigerants and nanolubricants is divided into two sections. The first section focuses on the research progress of nanorefrigerants from the early years. Further, the research progress on nanolubricants is presented in the second section.

2.1. Progress on nanorefrigerants

Wang et al. [19] had performed among the first experiment using nanorefrigerants in the VCRS. Their experimental result shows the performance of the COP and cooling speed of the refrigerator system enhanced by using TiO_2/MO/R134a nanorefrigerants. This experiment proved that by adding the nanoparticles to the working fluid of the system, the vapor compression system could be improved. Nevertheless, the initial development studies on the nanorefrigerants and its rudiment property were done by Wang et al. [20]. Later, Jiang et al. [21] have improved the theory of nanorefrigerants by introducing the prediction thermal conductivity based on particles aggregation theory. Five concentration of R22 based nanorefrigerants thermal conductivities were predicted by using the new theory and compared with the experimental data. The finding shows that the resistance network method and the particles aggregation theory is a useful method to calculate the thermal conductivity properties of nanorefrigerants.

Lin [22] in counterpart has performed the dispersion stability study of the nanorefrigerants. The sedimentation ratio and light transmission index ratio methods were used to test the stability and the dispersion of nanoparticles in the nanorefrigerants. As a result, they have shown that the properties of the refrigerants greatly affected by the dispersion and stability of the nanoparticles in the nanorefrigerants. Besides, the dielectric constant and the refrigerant polarity has also shown to be affected by the nanorefrigerants dispersion and its stability. In another study conducted by Li et al. [23], on the impact of TiO_2/R11 on pool boiling heat transfer demonstrated that TiO_2 enhances the boiling heat transfer coefficients of R11 refrigerants. Their study verified that the nanorefrigerants has great potential in improving the evaporator performance in a VCRS. Trisaksri and Wongwises [24] had experimented the nucleate pool boiling HTC using TiO_2/R141b refrigerant-based-nanofluid. The nucleate pool boiling HTC was studied at various concentrations and pressures. The outcomes show that the nucleate pool boiling HTC decreases with the increase of nanorefrigerants concentration, particularly at high heat fluxes. Later, Jiang et al. [25] conducted experimental work to establish the thermal conductivity model for the carbon nanotubes (CNT) based nanorefrigerantss. A modified Yu–Choi model proposed by Jiang et al. showed a decent deviation about 5.5% from the experimental result. Whereas, Saidur