Research on Nano Refrigerant and Nano Lubricant to Improve Energy Saving of Refrigeration System

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Abstract—In order to improve the performance of the refrigeration system, researchers have introduced nano-refrigerant and nano-lubricating oil into the latest development of air-conditioning system. However, explaining the role of nano-particles based on the physical phenomena affecting the vapor compression refrigeration system (VCRS) has been limited in experiments. Therefore, this paper reviews the mechanism of using nano-refrigerant and nano-lubricating oil to improve the performance of VCRS, discusses the compression work of the refrigeration system using nano-refrigerant and nano-lubricating oil and VCRS performance parameters such as COP and COF, and relates them to the overall performance of the system. The results show that the main factors affecting the performance of VCRS are heat transfer enhancement, refinement of the characteristics of cold oil mixture and improvement of tribological properties. The influence of nano-refrigerant and nano-lubricating oil on heat transfer, cold oil mixture and tribological properties of VCRS improves the overall performance of VCRS. Therefore, nano-refrigerant and nano-lubricant are expected to be the best choice to improve the efficiency of VCRS.

1. Introduction

Choi et al.[1] first proposed a "nanofluid" to improve the performance and efficiency of thermodynamics and mechanical systems. At present, nano-refrigerants and nano-lubricating oils have been widely used in vapor compression systems (VCRS), which have great potential for improving the thermodynamic and mechanical properties of the system. In addition, nano-refrigerants and nano-lubricants have better tribological properties (lubrication, wear performance), which adds advantages to the compressor. In VCRS, most of the lubricating oil will be mixed with a small amount of refrigerant in the compressor to form a refrigerant-lubricating oil mixture. According to HVAC product manufacturers, the compressor contains an average of 50% lubricating oil, and the remaining lubricating oil will be in the evaporator (20%), dryer (10%), condenser (10%) and hose (10%), etc. Therefore, adding nanoparticles to the refrigerant can improve the heat absorption or cooling performance of the vapor compression system. Generally, nano-refrigerants can be prepared by two methods, as shown in Figure 1. Although nano-refrigerant and nano-lubricant are similar in preparation methods, there are significant differences between the two. From the perspective of tribological properties, the system using nano-refrigerant has better heat transfer characteristics, because nano-particles are more inclined to refrigerant. After adding nanoparticles to refrigerants and lubricants, the energy-saving effect of the system is significantly improved. From this point of view, nano-refrigerants and nano-lubricating oils are good substitutes for improving the heat transfer
characteristics, tribological properties of vapor compression systems and enhancing the solubility characteristics of refrigerant-lubricating oil. Under normal circumstances, the nanoparticle suspension liquid will have a higher thermal conductivity than the base lubricant. The improvement of the heat transfer performance of the working fluid in the vapor compression system is conducive to the improvement of the flow and pool boiling heat transfer characteristics, and it is also conducive to the improvement of the condensation heat transfer performance of the flow pool in the system. Therefore, it is necessary to determine an optimal concentration of nano-lubricating oil and nano-refrigerant in order to provide the best performance for various applications in the vapor compression system. This article reviews the mechanism of nano-refrigerant and nano-lubricating oil to improve the performance of the overall vapor compression refrigeration system (VCRS), and studies the effect of nano-refrigerant and nano-lubricating oil on the performance of the vapor compression system.

This article reviews the mechanism of nano-refrigerant and nano-lubricating oil to improve the performance of the overall vapor compression refrigeration system (VCRS), and studies the effect of nano-refrigerant and nano-lubricating oil on the performance of the vapor compression system.

Fig. 1 Two methods of adding nanoparticles in VCRS

2. Research on the Mechanism of Improving the Performance of VCRS

The mechanism of improving the performance of VCRS is divided into three parts. The first part is the heat transfer performance, the second part reviews its solubility and miscibility, and finally, the research progress of tribology of nano-lubricating oil is reviewed.

2.1 Heat transfer performance

The current development of nanotechnology helps to improve the heat transfer performance of vapor compression refrigeration systems. Adding nano particles to conventional compressor oil and refrigerant to form nanolubricating oil and nano refrigerant is one of the methods to enhance the heat transfer of the system[2]. One of the earliest studies on the enhanced heat transfer effect of nano-refrigerant or nano-lubricating oil was proposed by Kedzierski and Gong[3]. Their experiments showed that, compared with pure R134a/POE, the mass fraction of CuO/R134a is 0.5%/POE has a high heat transfer rate (50% ~ 275%). When the mass fraction of CuO/R134a/POE nano-refrigerant is 2%, the boiling heat transfer increases by 12% on average. In another experiment, Bartelt et al.[4] also studied the flow boiling process of R134a/POE/CuO nano-refrigerant in a horizontal tube, and showed that when the mass fraction is 2%, the heat transfer coefficient increases by about 50~101%. These results indicate that nano-refrigerant or nano-lubricating oil helps to improve the boiling heat transfer process. Akhavan-Behabadi et al.[5] studied the condensation effect of CuO/R600a/POE nano-refrigerant in a smooth horizontal tube, and reported that the addition of CuO nano-particles enhanced the condensation heat transfer compared with the benchmark refrigerant lubricant mixture. When the mass fraction of CuO/R600a/POE is 1.5%, the maximum heat transfer increment can be increased by about 83%. Sharif et al.[6] also studied the relationship between thermal conductivity, viscosity and volume concentration of Al2O3/PAG nano-lubricating oil for automotive air conditioning (AAC) systems. The results show that when the volume concentration is 1%, the thermal conductivity can be increased to 4%. However, at a volume concentration of 0.4%, the viscosity is 7.58 times higher than that of PAG
lubricants. One year later, Zawawi et al.\textsuperscript{[7]} continued this work by dispersing SiO\textsubscript{2} nanoparticles in PAG lubricants, and the results showed that the thermal conductivity and viscosity of nano-lubricants increased with increasing volume concentration, and with increasing temperature and reduce. However, since the nano-lubricant is specifically designed for the AAC system, the author recommends the use of specific concentrations of SiO\textsubscript{2}/PAG and Al\textsubscript{2}O\textsubscript{3}/PAG. This is because too high lubricating oil viscosity will affect the performance and power consumption of the refrigeration system compressor. Table 1 summarizes the research on enhanced heat transfer of nano lubricating oil and nano refrigerants.

| References          | Type of experiment | Nanolubricants/ nanorefrigerant | Conclusion                                                                                      |
|---------------------|--------------------|---------------------------------|------------------------------------------------------------------------------------------------|
| Kedzierski and Gong\textsuperscript{[3]} | Boiling heat transfer | CuO/R134a/POE                   | When the mass fraction of CuO/R134a/POE nano-refrigerant is 2%, the boiling heat transfer increases by an average of 12% |
| Bartelt\textsuperscript{[4]}              | Flow boiling heat transfer | R134a/POE/CuO                   | Experimental results show that when the mass fraction of nano-lubricating oil is 2%, its heat transfer coefficient can be increased by about 50% to 101%. |
| Akhavan-Behabadi\textsuperscript{[5]}      | Flow, condensation, boiling, heat transfer | CuO/R600a/POE                   | Compared with the benchmark refrigerant lubricant mixture, the addition of CuO nanoparticles can enhance condensation heat transfer. Under the same experimental conditions, when the mass fraction of CuO/R600a/POE is 1.5%, the maximum heat transfer increase can be increased by 83% |
| Sharif\textsuperscript{[6]}         | Thermal conductivity and viscosity | Al\textsubscript{2}O\textsubscript{3}/PAG | When the volume concentration is 1%, the thermal conductivity can be increased by 4%. At a volume concentration of 0.4%, the viscosity is 7.58 times higher than that of PAG lubricants. |
| Zawawi\textsuperscript{[7]}              | Thermal conductivity and viscosity | SiO\textsubscript{2}/PAG \# Al\textsubscript{2}O\textsubscript{3}/PAG | The thermal conductivity and viscosity of nano-lubricants increase with the increase of volume concentration, but decrease with temperature. |

2.2 Solubility and miscibility
In the vapor compression system, nano-lubricating oil can improve the solubility and miscibility of refrigerant and lubricating oil to a certain extent. Wang et al.\textsuperscript{[8]} reported the improvement of the solubility and miscibility of nano-lubricating oil for the first time. Subsequently, a group of researchers used mineral oil to mix TiO\textsubscript{2} and Al\textsubscript{2}O\textsubscript{3} nanoparticles with R134a refrigerant to study the performance of domestic refrigerators. Their research shows that with the addition of TiO\textsubscript{2} and Al\textsubscript{2}O\textsubscript{3} nanoparticles in POE oil, the recovery rate of oil increases. Wang et al.\textsuperscript{[8]} also studied the performance of residential air-conditioning (RAC) using R410a as the refrigerant and adding nanoparticles (NiFe\textsubscript{2}O\textsubscript{4}) to B32 mineral oil. The results showed that in the four different refrigerants, NiFe\textsubscript{2}O\textsubscript{4}/R410 The solubility can be increased by 12%. At the same time, Bobbo\textsuperscript{[9]} studied the influence of nanoparticles on the lubricity and solubility of POE oils and refrigerants. Experiments have found that nano-lubricating oil has little effect on the solubility and thermodynamic properties of the refrigerant. However, whether the addition of nanoparticles in lubricating oil will definitely affect the solubility between refrigerant and lubricating oil is controversial. Therefore, Cremaschi et al.\textsuperscript{[10]} found in their study that nanoparticles added to lubricants did not hinder the oil solubility of POE, although their research showed that the solubility of nano-lubricating oils compared with the R410A/POE combination It seems slightly lower. In this experiment, the solubility of the nanoparticles is low, which may be due to the remaining nanoparticles in the recovery tank at the end of the refrigerant recovery process to measure the solubility. Table 2 summarizes the promoting effects of nano-lubricating oil and nano-refrigerant on solubility research.
Table 2 Research on the promoting effect of nano lubricating oil and nano refrigerant on solubility

| References | Type of experiment | Nanolubricants/ nanorefrigerant | Conclusion |
|------------|--------------------|---------------------------------|------------|
| Wang [2]   | Solubility and miscibility | TiO$_2$/R134a/MO | By adding TiO$_2$ nanoparticles, the solubility between mineral oil and hydrofluorocarbon (HFC) refrigerant can be improved. |
| Wang [8]   | Residential air conditioning performance (RAC) | NiFe$_2$O$_4$/R410 | Through the solubility test in this study, it is found that the solubility of NiFe$_2$O$_4$/R410 can be increased by 12% in four different refrigerants. |
| Bobbo [9]  | Lubricity and solubility | TiO$_2$/POE | Nano-lubricating oil has no obvious effect on the solubility of the refrigerant. Even with nano-lubricating oil, the thermodynamic properties of the refrigerant are independent. |
| Cremaschi [10] | Solubility | Al$_2$O$_3$/POE | Although the research results show that the solubility of nano-lubricating oil is slightly lower than that of R410A/POE, the nanoparticles added to the lubricating oil do not actually interfere with the oil-soluble properties of POE. |

2.3 Tribological study of nano lubricating oil

The coefficient of performance (COP) of VCRS can be improved by reducing the workload required for the operation of the system compressor. Reducing the workload required by the compressor operating system can improve the COP of the system. In the previous work, some researchers have effectively improved the friction performance and reduced the friction by adding nanoparticles, so as to achieve better lubrication effect. Although friction is an important source of energy in mechanical systems, high friction can cause wear and may shorten the life cycle of mechanical components. Therefore, studying the optimal concentration of nano-lubricating oil is of great significance to improve the mechanical durability and energy efficiency of VCRS.

By dispersing different content of nanoparticles into compressor oil such as PAG (polyalkyl glycol), POE (polyolefin oil) and MO (mineral), several methods to improve the performance of VCRS have been studied. In addition, the experiment also reduced frictional heat, thereby maintaining a higher viscosity than crude oil. Krishna Sabareesh et al. [12] studied the effect of TiO$_2$/MO nano lubricants on the performance of vapor compression systems. They found that using TiO$_2$/MO nano-lubricant for preliminary tests on a disc pin tester, the COF was reduced by 32%, and the optimal volume concentration was 0.1%. And the TiO$_2$/MO nano lubricating oil was tested on the actual VCRS. The results show that the compressor work is reduced by 11% and the COP is increased by 17%. Bobbo et al. [9] studied the effect of POE nano lubricating oil on the tribological improvement of carbon nanohorn (SWCNH) and TiO$_2$ nanoparticles. In order to further understand the potential applications of nano-lubricating oil in refrigeration systems, the lubrication properties of its extreme pressure performance and anti-wear properties were compared with those of the base fluid. However, studies have shown that the impact of nano-lubricating oil on anti-wear performance is not significant, although TiO$_2$ nanoparticles perform best in extreme pressure performance. Subsequently, Zawawi et al. [7] studied the COF and wear efficiency characteristics of Al$_2$O$_3$ and SiO$_2$ nanoparticles combined with PAG compressor oils of different volume contents. The results show that when the volume concentration of the mixed nano-lubricating oil is 0.06%, the COF can be reduced by 4.78%, and the wear efficiency can be reduced by 12.96%. Therefore, the application of hybrid nano-lubricating oil has great potential to improve the tribology and COP of the refrigeration system.

3. Conclusion

This paper reviews the findings of VCRS heat transfer, solubility, and performance improvements using nano-refrigerants and nano-lubricants as working fluids. You can draw the following conclusions:
In pool boiling and nucleate boiling heat transfer, the use of nano-refrigerant and nano-lubricating oil significantly improves the heat transfer performance of VCRS. Therefore, the optimal concentration of nano-lubricant and nano-refrigerant is the key to improving system performance.

(2) In VCRS, the introduction of nanoparticles improves oil recovery and tribological properties, but the stability of nanoparticles dispersed in fluids is the main issue that needs attention.

(3) Compared with traditional fluids, the addition of nano-refrigerant and nano-lubricating oil can effectively improve the COP, cooling performance, energy-saving performance, solubility and heat transfer performance of VCRS. It has broad development prospects.

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References

[1] U.S. Choi, D.A. Siginer, H.P. Wang, Enhancing thermal conductivity of fluids with nanoparticles, Developments and Applications of Non-Newtonian Flows, American Society of Mechanical Engineers (ASME), New York, 1995, pp. 99 – 105.

[2] R.X. Wang, B. Hao, G.Z. Xie, A refrigerating system using HFC134a and mineral lubricant appended with n-TiO₂ as working fluids, Proceedings of the 4th International Symposium on HVAC, Tsinghua University Press, Beijing, China, 2003, pp. 888–892.

[3] M.A. Kedzierski, M. Gong, Effect of CuO Nanolubricant on R134a Pool Boiling Heat Transfer with Extensive Measurement and Analysis Details, US Department of Commerce, National Institute of Standards and Technology, USA, 2007.

[4] K. Bartelt, Y. Park, L. Liu, A. Jacobi, Flow-boiling of R-134a/POE/CuO nanofluids in a horizontal tube, International Refrigeration and Air Conditioning Conference, Purdue e-Pubs, Purdue, 2008, pp. 1–8.

[5] M.A. Akhavan-Behabadi, M.K. Sadoughi, M. Darzi, M. Fakoor-Pakdaman, Experimental study on heat transfer characteristics of R600a/POE/CuO nanorefrigerant flow condensation, Exp. Thermal Fluid Sci. 66 (2015) 46–52.

[6] M.Z. Sharif, W.H. Azmi, A.A.M. Redhwan, R. Mamat, Investigation of thermal conductivity and viscosity of Al₂O₃/PAG nanolubricant for application in auto-motive air conditioning system, Int. J. Refrig. 70 (2016) 93–102.

[7] N.M.M. Zawawi, W.H. Azmi, A.A.M. Redhwan, M.Z. Sharif, K.V. Sharma, Thermo-physical properties of Al₂O₃-SiO₂/PAG composite nanolubricant for refrigeration system, Int. J. Refrig. 80 (2017) 1–10.

[8] R. Wang, Q. Wu, Y. Wu, Use of nanoparticles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants, Energ. Buildings 42 (11) (2010) 2111–2117.

[9] S. Bobbo, L. Fedele, M. Fabrizio, S. Barison, S. Battiston, C. Pagura, Influence of nanoparticles dispersion in POE oils on lubricity and R134a solubility, Int. J. Refrig. 33 (6) (2010) 1180–1186.

[10] L. Cremaschi, T. Wong, A.A.M. Bigi, Thermodynamic and Heat Transfer Properties of Al₂O₃ Nanolubricants, International Refrigeration and Air Conditioning Conference, Purdue E-Pubs, Purdue, 2014, pp. 1–10.

[11] R. Krishna Sabareesh, N. Gobinath, V. Sajith, S. Das, C.B. Sobhan, Application of TiO₂ nanoparticles as a lubricant-additive for vapor compression refrigeration systems-an experimental investigation, Int. J. Refrig. 35 (7) (2012) 1989–1996.