Enhancement on the Performance of Refrigeration System Using the Nano-Refrigerant

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Abstract: The purpose of the present experimental work is to investigate the performance (1 ton) refrigeration system using nano-refrigerant. Nano-refrigerant is alumina (γ - Al_2O_3) nanoparticle with size (20-30) nm is dispersed into R-134a with volume fraction 0.01% and 0.02%. The experimental test rig consists of horizontal double tube counter flow heat exchanger fabricated of copper. The nano-refrigerant is evaporated inside the inner tube because of the heat gain from hot water passing in the annulus surrounding the inner tube. The experimental results indicate, when increasing the volume concentration of Al_2O_3 refrigerant by 0.01% and 0.02%, the heat transfer coefficient increases by 0.54% to 1.1%. The thermal conductivity increases by 11.5% and 14.2%, respectively, while the coefficient of performance increases by 3.33% to 12%, respectively. The heat transfer rate in the refrigeration side is enhancement about 6.7% to 21.4% compared with conventional refrigerant, and the power consumption by compressor is decreased by nearly 1.6% and 3.3%, respectively.

Key words: Nano-refrigerant, R134a, alumina (Al_2O_3), tube in tube heat exchanger, heat transfer enhancement.

Nomenclature

C_p	Specific heat ($\text{J/kg}\cdot^\circ\text{C}$)
k	Thermal conductivity ($\text{W/m}\cdot^\circ\text{C}$)
h	Heat transfer coefficient ($\text{W/m}^2\cdot\text{K}$)
Q	Heat transfer rate (W)
$\dot{m}$	Mass flow rate (kg/s)
m	Mass of the nanoparticle (g)

Greek Letter

ρ	Density (kg/m^3)
μ	Dynamic viscosity ($\text{kg/m}\cdot\text{s}$)
ϕ	Nanoparticle volume fraction

1. Introduction

Most of the refrigeration systems use Vapour Compression Refrigeration with used double tube heat exchanger and suspended Al_2O_3 nanoparticle in the R134a with many concentration to enhance the thermal performance of nano-refrigerant because better thermal conductivity on nanoparticle and more

heat transfer reduced the power consumption.

Senthilkumar and Praveen [1] studied experimentally the performance of a domestic refrigeration by using CuO -R600a nano-refrigerant. In this investigated refrigeration a method used the natural gas to improve the energy efficiency of refrigeration. The average particle diameter is 50 nm and the purity is 99.5%, the concentration of the nano in the refrigeration is 0.1 and 0.5 g/L. The result indicated that the freezing velocity is quick than the pure R600a, and the saving energy consumption is about 11.83% and 17.88%.

Bi et al. [2] studied experimentally the performance of a domestic refrigerator using TiO_2 -R600a nano-refrigerant as working fluid. Thermal conductivity and heat transfer characteristics were increasing when using the nanoparticle, the concentration when suspended in the R600a is 0.1 and 0.5 g/L and the average diameter is 50 nm. The test results indicated that TiO_2 -R600a can work normally and efficiently in refrigerator. Compared with

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refrigerator using pure R600a as working fluids, it can save 5.94% and 9.60% energy consumption respectively and the freezing velocity of nano-refrigerant system was more quickly than the pure R600a system. Kuljeet and Kundan [3] studied the performance of a refrigeration system when using nano-refrigerant (R134a+Al₂O₃). The purpose in this study is to improve thermal physical properties over the conventional refrigerants, using domestic refrigerator. The results presented that coefficient of performance of domestic refrigerator can be improved by mixing Al₂O₃ nanoparticles in base refrigerant R134. Mahbubul et al. [4] studied about thermophysical properties and heat transfer performance of Al₂O₃/R-134a nano-refrigerant, to determine the thermal conductivity and viscosity of the nano-refrigerant. It used a horizontal smooth tube. The results revealed that thermal conductivity of the nano-refrigerant increases when increasing nanoparticle volume fraction and temperature, but decreases if increasing the particle size. And the viscosity of nano-refrigerant also increases with the augmentation of nanoparticles concentrations. Fadhillah et al. [5] used copper oxide nanoparticles for studied refrigerant thermophysical properties. The design double tube heat exchanger is made of copper. A study proved that the nanoparticles suspension in domestic refrigerators R134a could reduce the energy consumption and improve coefficient of performance of the refrigeration system. The investigation includes enhancing the thermophysical properties.

Tarun and Kundan [6] investigated the performance of refrigeration system with nano-refrigerant to reduce the power consumption and enhance the heat transfer capacity of refrigerant. It used in this study Al₂O₃ with 20-30 nm mixed with R134a. The test rig evaporator section coil type is load with water. The experimental results are enhancement in the thermo physical properties, and heat transfer characteristics of the refrigeration system, enhancement in COP, a reduction in the power consumption (10.87% &

13.04%), faster cooling from (41c-25c), and more temperature drop in the condenser.

The aim of the present paper is to investigate the performance of (1 ton) refrigerant system when using Al₂O₃ with R-134a as a refrigerant, and to study enhancing the thermophysical properties of nano-refrigerant, power consumption, and the heat transfer rate.

2. Experimental Test Rig

The experimental test rig consists of reciprocating hermetic compressor condenser, expansion valve and the evaporating is counter flow double tube heat exchanger as shown in Fig. 1. The refrigerant used in the system is R-134a. The experimental test section is a straight double tube counter flow heat exchanger which is made of copper. The length of test section is 1,100 mm, the inner diameter and the thickness are 21 mm and 1 mm, respectively. The outer tube diameter and the thickness are 44 mm and 1 mm respectively as shown in Fig. 2. The refrigerant is flow in the inner tube and the hot water passes through annulus. The hot water circuit consists of water tank with electrical heater (2,000 Watt), water pump pipes insulated and fitting, and rotameter to measure the flow rate.

3. Preparation of the (Al₂O₃-R134a) Nano-Refrigerant

Nano-refrigerant was prepared in a recommended method for nanofluid. The nanoparticle Al₂O₃ was mixed with refrigerant R-134a by using vibrated ultrasonic oscillator. The average particle of Al₂O₃ diameter is about 20-30 nm and the mass purity is 99.5% in this investigation using some correlation of thermo physical properties of Al₂O₃/R-134a. Some constant properties of Al₂O₃ are shown in Table 1 [8]

Table 1 The properties of Al₂O₃.

Density (kg/m ³)	3,970
Thermal conductivity(W/m·K)	40
Specific heat (J/kg·K)	765

Fig. 1 Schematic diagram for the experimental test rig.

Fig. 2 The test section.

that the concentration is 0.01%-0.02% and the average diameter is 20-30 nm [7].

The thermo-physical properties of nano-refrigerant are the following.

The volume fraction (ϕ) of nano-refrigeration can be estimated by the following Eq. (1) [9].

$$\phi = \frac{m_n/\rho_n}{m_n/\rho_n + m_r/\rho_r} \quad (1)$$

where, n and r refer to nanoparticle, pure refrigerant liquid phase.

The viscosity of nano-refrigerant has been influenced by the particle size of nanoparticle and the concentration and conventional refrigeration. It can be calculated by using the following Eq. (2) [10].

$$\mu_{r-n,L} = \mu_{r,L} \frac{1}{(1 - \phi)^{2.5}} \quad (2)$$

where, $\mu_{r-n,L}$ is the viscosity of liquid nano-refrigerant, $\mu_{r,L}$ is viscosity of liquid pure refrigerant.

The thermal conductivity of nano-refrigerant is calculated by mathematical model as follows [11].

$$\frac{K_{nf}}{K_r} = C \text{Re}_m^{0.175} \phi_P^{0.05} \left(\frac{K_p}{K_m}\right)^{0.2324} \quad (3)$$

where, nf refers to nanofluid, r is pure of refrigerant, C is constant in this equation (1.298).

The Reynolds number of nano-refrigerant is calculated by using

$$\text{Re}_m = \left(\frac{1}{v_m}\right) \left(\frac{18 K_p T_{in}}{\pi \rho_p d_p}\right)^{1/2} \quad (4)$$

where, v_m is the velocity of refrigerant, ρ_p is the density of nanoparticle.

The coefficient of performance of refrigerant system is shown by the following Eq. (5).

$$\text{COP}_{n-r} = \frac{h_1 - h_4}{h_2 - h_1} \quad (5)$$

The heat transfer rate of nano-refrigerant can be obtain by the following Eq. (6) [12].

$$Q_{r-n} = \dot{m}_{r-n} C_{p_{r-n}} \Delta T \quad (6)$$

where, ΔT is different temperature of nano-refrigerant in double tube heat exchanger.

To obtain the power consumption of the test rig it is calculated by using the following Eq. (7) [13].

$$\text{Power consumption} = V \times I \quad (7)$$

4. Result and Discussion

Fig. 3 shows that the viscosity increases 1.4% and 5.2% respectively with the increase of volume fraction, compared with conventional refrigerant. The suspended Al_2O_3 nanoparticles have increased the surface area that offers more contact between R-134a/ Al_2O_3 .

Fig. 4 shows the relationship between the thermal conductivity and volume fraction. Thermal conductivity K_{nf} is influenced by the particle volume fraction. The enhancement of thermal conductivity of two volume concentration 0.01 and 0.02% increases about 11.5% and 14.2%.

Fig. 5 observes that $\text{Al}_2\text{O}_3/\text{R}-134\text{a}$ mixture is highest COP when compared with pure refrigerant.

COP is related to power consumption, the higher COP is, the less power consumption of the system. The COP increment is about 3.33% to 12% compared without nano-refrigerant, when the volume concentrations are 0.01% and 0.02% respectively.

Fig. 6 indicates the influence of the Al_2O_3 nanoparticle volume fraction on the heat rate of nano-refrigerant which is transferred from center tube of refrigerant to the wall. It can be demonstrated that the heat rate is proportional to the particle volume fraction. It is indicated that the increase of the heat rate is from 6.7% to 21.4% compared without nanoparticle.

Fig. 7 demonstrates the influence of the Al_2O_3 nanoparticle concentration on the convective heat transfer coefficient. It can be showed that the heat transfer coefficient is proportional to the particle volume fraction. When increasing the particle concentration of the nanoparticle in R134a, the heat transfer increases from 0.54% to 1.1% from table R134a due to the thermal conductivity effect. This is due to mobility of particles near the wall, migration of them to the center of the tube.

Fig. 8 shows that the power consumption of the compressor can observe the reduction in power consumption when mixed the nanoparticle with pure refrigerant compared to pure refrigerant. A reduction of the power consumption is from 1.6% to 3.3%.

Fig. 3 Viscosity as a function of volume concentration Al_2O_3 .

Fig. 4 Thermal conductivity as a function volume concentration.

Fig. 5 Variation of COP with volume concentration.

Fig. 6 Effect of volume concentration on the heat transfer rate.

Fig. 7 Heat transfer coefficient as a function of volume concentration.

Fig. 8 Comparison of power consumption.

5. Conclusions

- (1) The viscosity of nano-refrigerant also increases 1.4% and 5.18% with the increase of nanoparticle concentration compared with conventional refrigerant.
- (2) The heat transfer coefficient increases significantly 0.54% and 1.1% respectively.
- (3) The coefficient of performance for 0.01% and 0.02% of refrigerant are increased by 3.33%, 12% respectively.
- (4) The heat transfer rate with volume fraction 0.01% and 0.02% is enhancement about 6.7% and 21.4% respectively.
- (5) A reduction of the power consumption is 1.6%

- and 3.3% respectively.
- (6) Fast cooling is from 42 °C to 16 °C.
- (7) Thermal conductivity of the nano-refrigerant increases with the increased volume fraction and temperature, and decreases with increasing nanoparticle size, which is about 11.5% and 14.2% respectively.

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