ENHANCEMENT OF THERMOPHYSICAL PROPERTIES OF NANO REFRIGERANT

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ABSTRACT

In modern days, refrigeration systems have become our daily usage in many applications. These systems consume more electricity as compared to other appliances and also releases harmful chlorofluoro carbons which causes global warming. A new emerging heat transfer fluid called nanofluid has been introduced in many applications. In recent years, refrigerant-based nanofluids and nano refrigerants have been introduced as significant effects of nanoparticles in heat transfer performance and energy consumption reduction. Many types of materials could be used as the nanoparticles to be suspended into the conventional refrigerants. In this study, the effect of the suspended copper oxide (CuO) nanoparticles into the R-600a which has Zero ODP and 3 GWP is investigated by using mathematical modelling. The investigation includes the thermal conductivity, dynamic viscosity, and heat transfer rate of the nano refrigerant in a tube of evaporator. The results show enhanced thermophysical properties of nano refrigerant compared to the conventional refrigerant. These advanced thermophysical properties increased the heat transfer rate in the tube which is helpful for reduction in energy consumption.

Keywords: Nano refrigerant, thermal conductivity, dynamic viscosity, heat transfer coefficient.

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1. INTRODUCTION

Nanorefrigerants, which are a new class of nanofluids, are mixtures of nanoparticles and refrigerants. They have several potential applications in various fields, such as for refrigeration and air-conditioning systems and heat pumps, among others.

Nanorefrigerants can be made either by dispersing the nano particles directly into the refrigerant with the help of single step process or by mixing the nanoparticles with the lubricant in the compressor and then the refrigerant is flown.

There were different literature reviews on various nano refrigerants [1,6]. The usage of Copper oxide nanoparticles blending with R22 refrigerant and the results shows that the addition of nano particles, 0.05% by volume, has improved heat transfer properties of the refrigerant and reduced power consumption when relative COP has increased from 0.58 to 0.62 when R22 with 0.05% concentration of nano particles [2]. The thermophysical properties like thermal conductivity, dynamic viscosity, and heat transfer rate of the nano refrigerant (CuO+R134a) in a tube of evaporator are determined and concluded that suspending 1% vol. fraction of nanoparticles into the refrigerant has increased the thermal conductivity about 3121.05% enhancements. The viscosity of nano refrigerant is showing great percentage of enhancement which is about 44.45% and the heat transfer rate of a tube of nano refrigerant with 5% vol. fraction is about 1% enhancement [3]. Blending of Al₂O₃ nanoparticles with their pure fluids: R12, R134a, R430a, R436a, and R600a is experimented and the coefficient of performance (COP) and compressor work for various evaporation and condensation temperatures are investigated. Although R12 showed the lowest compressor work, it cannot be used in the applications anymore because of its ODP and GWP values. Instead of this refrigerant, R134a can be used as it has the second lowest compressor work in the analysis. Results obtained using theoretical analysis were compared with the results available in the literature, and deviations were 22.5% and 28.6% for pure R134a and R134a/Al₂O₃ mixtures when the density of particles is 3,690 kg/m³, respectively. The deviation was 20.8% for the R134a/Al₂O₃ mixture when the nanoparticle density was 2,200 kg/m³ [4]. Comparison with refrigerator using pure R600a as working fluids, 0.1 and 0.5 g/L concentrations of TiO₂-R600a can save 5.94% and 9.60% energy consumption respectively. It is also proved that the freezing velocity of nano refrigerant system was more quickly than the pure R600a system and the refrigerator performance was investigated using energy consumption test and freeze capacity test [5]. Long term stability of nanoparticles dispersion affects the thermal conductivity of the nano refrigerant since better dispersion behaviour showed higher thermal conductivity of nano refrigerant [7].

The study also proved that concentration of the Al₂O₃ nanoparticles influenced the pressure drop, pumping power, and heat transfer coefficient of the nano refrigerant in a horizontal smooth tube. Heat transfer coefficient influenced the heat transfer rate in the cooling system. The enhancement of the heat transfer coefficient due to Al₂O₃ nanoparticle concentration is obtained for single-phase laminar flow in microchannel, although there are surface deposition, nanoparticles clustering, and agglomeration in the two-phase regime [8].

This study aims to investigate the thermal conductivity and viscosity of the CuO/R-600a nano refrigerant and the heat transfer rate in an evaporator tube is determined by using the thermophysical properties of the nano refrigerant.

2. MATERIAL THERMOPHYSICAL PROPERTIES AND MATHEMATICAL MODELLING

2.1. Nano refrigerant and Tube Design

In this study, the thermophysical properties of nano refrigerant are investigated by considering the CuO nanoparticles and the conventional refrigerant, R-600a. Table 1 shows the physical properties of the nanoparticles and refrigerant. A copper horizontal smooth tube of an evaporator is designed by using a CATIA software with the inner diameter, D_i , and length, L , being 0.00772 m and 1.4 m, respectively. Figure 1 shows the copper tube of evaporator. Constant parameters of initial condition in evaporation process have been determined in

calculating the properties of nano refrigerant. Table 2 shows the constant parameters used in this study

Table 1 Physical properties of CuO nanoparticle.

Nanoparticles and Conventional refrigerant	Thermal conductivity (W/m·K)	Density (kg/m ³)	Diameter (nm)	Viscosity (Pa·s)
CuO (Copper Oxide)	32.9	6320	30	-
R-600a	0.02586	564	-	9.43017e ⁻⁶

Table 2 Specification values in determining nano refrigerant properties.

Constant parameter	Value
Refrigerant velocity, V	1.5m/s
Diameter of nanoparticles, d _p	30nm
Thermal conductivity of copper, k _{copper}	401W/mk
Heat transfer coefficient for air, h _{air}	50W/m ² k
Temperature inlet, T _i	26°C
Temperature outlet, T _o	-10°C

2.2. Mathematical Model of Nano Refrigerant

The thermal conductivity of nano refrigerant is calculated by using data from Table 2 and mathematical modelling from Vasu et al., [9] as follows

$$\frac{k_{nf}}{k_m} = c Re_m^{0.175} \phi_p^{0.05} \left(\frac{k_p}{k_m} \right)^{0.2324} \quad (1)$$

where k_{nf} is the thermal conductivity of nanofluid, k_m is the thermal conductivity of refrigerant, k_p is the thermal conductivity of nanoparticles, c is constant in the equation (1.298), ϕ_p is the particle volume fraction, v_m is the velocity of the refrigerant, ρ_p is the density of nanoparticles, d_p is the diameter of nanoparticles, and T_{in} is the temperature inlet. The Reynolds number of nano refrigerant is calculated by using (2) as follows:

$$Re_m = \left(\frac{1}{v_m} \right) \left(\frac{18k_p T_{in}}{\pi \rho_p d_p} \right)^{0.5} \quad (2)$$

Mahbubul et al. (2013) introduced the Brinkman formula to determine the viscosity of nano refrigerant, as in (3) which has been used to determine the nanofluid's viscosity.

$$\mu_{r,n,L} = \mu_{r,L} \frac{1}{(1-\phi)^{2.5}} \quad (3)$$

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

$\mu_{r,L}$ is the viscosity of liquid pure refrigerant, and ϕ is the particle volume fraction of nano particles. The viscosity of nano refrigerant has been influenced by the viscosity of the conventional refrigerant. A general equation of conduction is used in determining the heat transfer rate of flowing nano refrigerant, meanwhile the heat transfer rate equation is stated in

$$q = Un_f A (\Delta T) \quad (4)$$

where q is the heat transfer rate, Un_f is the heat transfer coefficient for nano refrigerant, A is the area of the tube, and ΔT is the temperature different between inlet and outlet of the tube. The temperature of the nano refrigerant in the tube is considered at 26°C with the velocity of 1.5m/s.

Figure 1 A tube of evaporator with CuO/R-600a nano refrigerant

Working fluid: CuO/R-600a

Nano refrigerant Fluid velocity: 1.5m/s

Inlet temperature: 26°C

Tube length: 1.4m

Inner diameter: 0.00772m

Outer diameter: 0.00952m

Material: copper

3. RESULTS AND DISCUSSION

Figure 2 and Table 3 show the relationship between the thermal conductivity of the nano refrigerant, refrigerant R-600a, and nanoparticle volume fraction. The thermal conductivity of nano refrigerant, Kn_f , is directly proportional to the nanoparticle volume fraction. The thermal conductivity of the conventional refrigerant, 0.02586 W/mK, is increased with nanoparticle volume fraction with the increment being about 0.01 W/mk for each 1% CuO nanoparticle concentration addition.

Figure 2 Thermal conductivity as a function of nanoparticle volume fraction.

Figure 3 Viscosity as a function of nanoparticle volume fraction.

Figure 4 Heat transfer as a function of nanoparticle volume fraction.

As the nanoparticle concentration increases there is an enhancement in thermal conductivity of about 3625.1%, as the thermal conductivity increases from 0.02586W/mk to 0.9633W/mk. However, the viscosity of the nano refrigerant must also be considered since it may affect the overall performance of refrigeration system. The increments of nano refrigerant viscosity due to nanoparticle suspension are shown in Figure 3. The viscosity is directly proportional to the CuO nanoparticle volume fraction. The viscosity of R-600a at 26° C is 9.43017e-6 Pa-s. After suspending the nanoparticles into the refrigerant at 1% nanoparticle volume fraction, the viscosity increased to 9.670e-6 Pa-s, about 2.54% of enhancement as shown in Table 3. The suspended CuO nanoparticles have increased the surface area that offered more contact between the R-600a refrigerant and the nanoparticles. The thermal conductivity of nano refrigerant increases with the increment of surface areas. Thus, calculating heat transfer rate by considering the enhanced thermal conductivity of the nano refrigerant proved that the heat transfer rate is proportional to the nanoparticle volume fraction as shown in Figure 4. The heat transfer rate of the R-600a refrigerant increased by 1.744% and the increment of the heat transfer rate for 1% to 5% volume fraction is about 1.00% to 8.890%.

Table 3: Nano refrigerant thermal conductivity enhancement.

Nanoparticle volume fraction, ϕ (%)	Thermal conductivity efficiency, $(\frac{k_{nf}}{k_m})$	Nano refrigerant thermal conductivity enhancement (%)	Nano refrigerant viscosity enhancement (%)	Heat transfer rate enhancement (%)
0.01	34.44	3344.7	2.54	1.744
0.02	35.58	3458.0	5.18	3.521
0.03	36.31	3530.7	7.91	5.275
0.04	36.83	3583.3	10.71	7.085
0.05	37.25	3625.1	13.68	8.809

4. CONCLUSION

The thermal conductivity of refrigerant R-600a is 0.02586 W/mK at temperature of 26° C. Suspending 1% vol. fraction of nanoparticles into the refrigerant has increased the thermal conductivity about 3344.7% enhancements. Additional increment in vol. fraction has increased the thermal conductivity. The viscosity of nano refrigerant is also showing great percentage of enhancement which is about 2.54% once compared to the conventional refrigerant with only 1% of nanoparticles volume fraction. The heat transfer rate of a tube of nano refrigerant with 5% vol. fraction is about 9% enhancement. This study helps to other researchers to investigate the thermophysical properties of nano refrigerant experimentally. It is important to have superior thermal properties of the nano refrigerant that could withstand the variation of temperature and pressures and the nanoparticles would not cause the clogging, corrosion, or pressure drop in the overall performance of refrigeration system. And researchers can try different concentrations along with different mass flow rates.

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