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Computational Investigations on Heat Transfer Enhancement Using Nanorefrigerants

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Abstract – Nanofluid has become one of the interesting topics for engineers working for decades to develop more efficient heat transfer in different applications. Nanorefrigerant, as a combination of nanoparticles and refrigerant, is a new concept that has been recently investigated by number of researchers. Electricity consumption usually varies from one sector to another. Generally, residential sector is one of the biggest electricity consumers in Malaysia. Based on the literature, 26.3% of electricity consumption in the residential sector in Malaysia is allocated to refrigerator–freezers.

Keywords: Nanorefrigerant, Refrigerator–freezers, Annulus, ANSYS

1.0 INTRODUCTION

1.1 Concentric and Eccentric Annular Passage

Environmental and economic sustainability have drawn the attention of researchers and prompted them to seek alternative methods that offer maximum energy at low cost. Thermal system channel configuration and heat transfer fluid type are significant to providing the greatest required energy transport. Investigating forced, natural and mixed heat transfer to fluid flow in an annular passage is among the most important heat transfer studies, owing to its presence in several applications from heat exchangers, to reactors, packed beds, gas turbines, chemical industries, etc. There are numerous published investigations that were initiated decades ago, comprising experimental and numerical explorations that deal with different types of fluid and boundary conditions [1].

Rohsenow et al. [2] distinguished four fundamental thermal boundary conditions with the potential to be applied in annular passages, as follows:

First kind: Uniform temperature at one wall (different from the incoming fluid temperature), while the other wall is at uniform entering fluid temperature.

Second kind: Uniform heat flux at one wall (i.e., adiabatic with zero heat flux) and the other wall is insulated.

Third kind: Uniform temperature at one wall (unlike the entering fluid temperature) and the other wall is insulated.

Fourth kind: Uniform heat flux at one wall, and the other wall maintains entering fluid temperature.

There are also other types of boundary conditions represented by varying and non-zero uniform heat flux at both walls of an annular passage. In the last decade, the demand for energy has increased due to global development. Techniques used for saving energy and cost are provided by changing the flow channel configurations besides introducing high thermal conductivity fluid, such as nanofluid, which enhances thermal performance. Throughout the present review, the subject matters of interest are investigated systematically, such as temperature distribution, thermal stresses, thermal length, heat transfer coefficient, pressure drop, and velocity profile. Some studies have also addressed the effect of a rotating inner and/or outer pipe and the effect of eccentricity on heat transfer processes in an annular passage. The geometry of annular passages in engineering applications is available in various configurations, including circular, rectangular, elliptical, conical, polygonal, rhombic, triangular, square, and non-uniform, as found in concentric and eccentric configurations. A number of researchers have employed a concentric annular passage, meaning that the center line of the inner pipe has the same coordinates as that of the outer pipe, while others have used an eccentric annular passage whereby the inner pipe's center line does not have the same coordinates as that of the outer pipe [1].

1.2 Performance Analysis of a Refrigeration System using Nanorefrigerants

Many investigators have conducted studies on vapour compression refrigeration systems and to study the effect of nanoparticle in the refrigerant as well as lubricant on its performance. Pawel et al. [3] conducted studies on nanofluids and found that there is the significant increase in the thermal conductivity of nanofluid when compared to the base fluid and also found that addition of nanoparticles results in significant increase in the critical heat flux. Bi et al. [4] found that there is remarkable reduction in the power consumption and significant improvement in freezing capacity. They pointed out the improvement in the system performance is due to better thermo physical properties of mineral oil and the presence of nanoparticles in the refrigerant. Jwo et al. [5] conducted studies on a refrigeration system replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant and mineral lubricant. The mineral lubricant included added Al_2O_3 nanoparticles to improve the lubrication and heat-transfer performance. Their studies show that the 60% R-134a and 0.1 wt % Al_2O_3 nanoparticles were optimal. Under these conditions, the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%.

Bi et al. [6] conducted an experimental study on the performance of a domestic refrigerator using TiO_2-R600a nanorefrigerant as working fluid. They showed that the TiO_2-R600a system worked normally and efficiently in the refrigerator and an energy saving of 9.6%. Kumar and Elansezhian [7] conducted an experimental study on the performance of a domestic refrigerator using Al_2O_3-R134a nanorefrigerant as working fluid. They found that the Al_2O_3-R134a system performance was better than pure lubricant with R134a working fluid with 10.30% less energy used with 0.2%V of the concentration used and also heat transfer coefficient increases with the usage of nano Al_2O_3. Krishna Sabareesh et al. [8] conducted an experimental study on the performance of a domestic refrigerator using TiO_2-R12 nanorefrigerant as working fluid. They found that the freezing capacity increased and heat transfer coefficient increases by 3.6 %, compression work reduced by 11% and also coefficient of performance increases by 17% due to the addition of nanoparticles in the lubricating oil.

2.0 METHODOLOGY

2.1 The Numerical Study

The 3D model geometry is built by using Gambit v 2.4.6. Then the model geometry is meshed to split the domain into sub domains (i.e., cells or elements) using tetrahedral cells. In this study, the geometry was meshed by using Gambit and ANSYS 12.1.0. The boundary conditions such as inlet, outlet, walls, fluid properties and operating conditions are defined after mesh creation. The mesh of laminar flows cases is created in Gambit while the mesh of turbulent flows cases is built in ANSYS due to its increased complexity and near wall treatment requirement. Generally, the solution using FLUENT includes setting the boundary conditions, defining the fluid properties, executing the solution and viewing and post processing the results.

However, when the geometry is built, mesh is created and boundary conditions are prescribed, many meshes are examined in order to get an appropriate grid system. This is well known as "grid independence test" (GIT). Dense mesh needs very long time to simulate the problem and low density mesh provides incorrect results. Therefore, the GIT specifies the sufficient density for grid and save the time of simulation.

As shown in Fig.1, an evaporator annulus was studied for this work. The inner_cylinder with diameter (D = 20 mm), the thickness of cylinder wall (t = 5 mm) and the hydraulic diameter is (D_h = 10 mm). The computational length of annulus (L) is 400 mm. Pure refrigerants, various nanoparticles and various nanoparticle shapes are selected as the working fluid and the thermophysical properties assumed to be temperature independent. The right side of annulus is subjected to velocity inlet based on Reynolds number and the exit side of the annular cylinder is subjected to pressure outlet. The outer pipe of the annular space is maintained under constant heat flux. Whereas the inner pipe of the annular space is kept isothermally at a constant temperature (Ti).

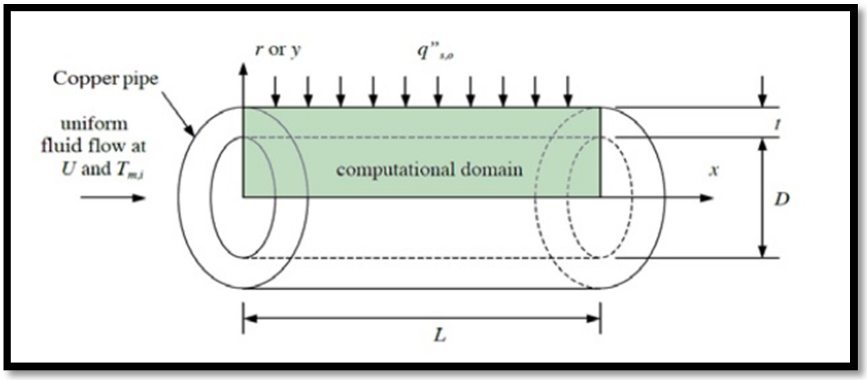

Figure 1: Evaporator test section.

2.2 The Experimental Study

The vapour – compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Fig. 2 depicts a typical, single – stage vapour – compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve and an evaporator. Circulating nanorefrigerant enters the compressor in the thermodynamic state known as a saturated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. The hot vapour is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool air flowing across the coil or tubes.

The condensed liquid nanorefrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid nanorefrigerant. The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold nanorefrigerant liquid and vapours mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature.

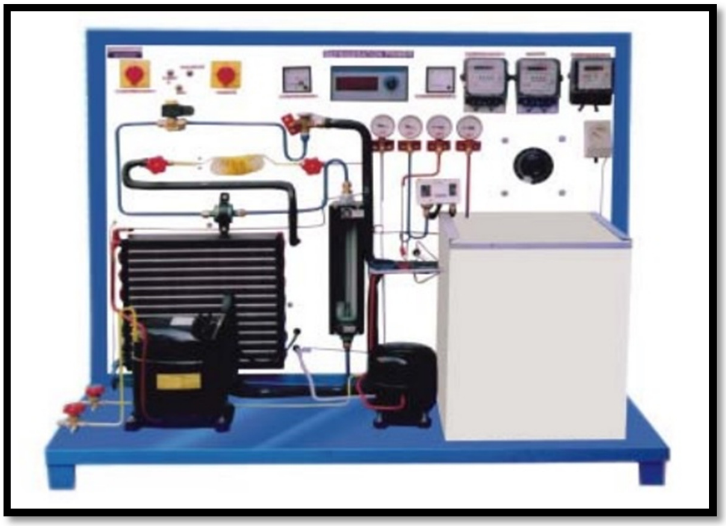

Figure 2: Experimental Setup of the refrigeration test rig

3.0 RESULTS AND DISCUSSION

3.1 Effect of Nanorefrigerant Type

Nanorefrigerants are proven to enhance the heat transfer characteristics. However, there is no research done on finding which nanofluid is the best among other Nanorefrigerant. The effect of using various nanofluids is presented in Fig. 3. SiO_2 could transfer most energy compared to other nanofluids and water. For Nusselt number, SiO_2 has the best enhancement followed by Al_2O_3, ZnO, CuO and finally pure water has the worst heat transfer. This is because SiO_2 has the highest thermal conductivity compared to other nanofluids. Thermal conductivity has the major role in determining the amount of the heat enhanced in a working fluid. Water with lowest thermal conductivity has the worst heat transfer enhancement.

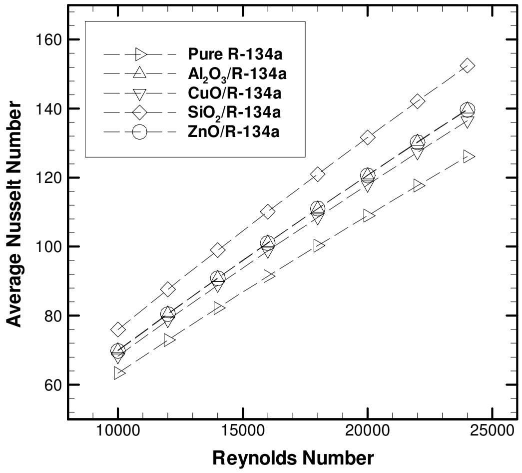

Figure 3: The effect of nanorefrigerant types on the average Nusselt number (Using φ = 4%, dp = 20 nm and q_w = 5000 W/m^2).

3.2 Effect of Base Fluid Type

The simulation is performed for four different types of base fluid which is (R-12, R-22, R-134a and R-141b) with SiO_2 nanoparticle, concentration volume 4% and particle diameter 20nm. The annulus used has a 400 mm length with hydraulic diameter 10 mm. The heat flux value was 5000 W/m^2 and the Reynolds number in the range of $10\times10^3 \leq Re \leq 24\times10^3$. Fig. 4 shows the average Nusselt number for different Reynolds number. It can be obtained from this Figure that SiO_2/R-141b has the highest Nusselt number comparing to other types of nanorefrigerants. This is because the R141b base fluid has highest viscosity which leads to increase the velocity for the nanorefrigerants since the velocity proportional directly with the viscosity of the base fluid. However, second base fluid is R-134a then R-12 and finally R-22 according to their viscosity.

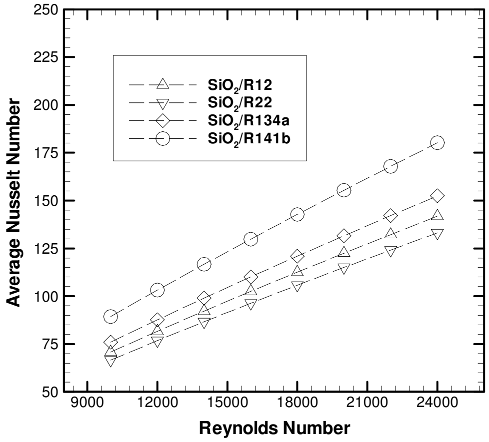

Figure 4: The effect of different types of pure refrigerants on the average Nusselt number (Using SiO_2, dp = 20 nm, φ = 4% and q_w = 5000 W/m^2).

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3.3 Effect of Heat Flux Ratio (q_i/q_o)

Different values of heat flux ratio ranged from 0 to 2 were used in this study. The other parameters were fixed at volume fraction $\varphi = 4\%$ and nanofluid is silicon oxide SiO_2 with the particle diameter dp = 20 nm. It was noticed that the Nusselt number along the tube decreased with increasing the heat flux ratio value as shown in Fig. 5 and this is because the wall temperature proportional directly with the heat fluxes.

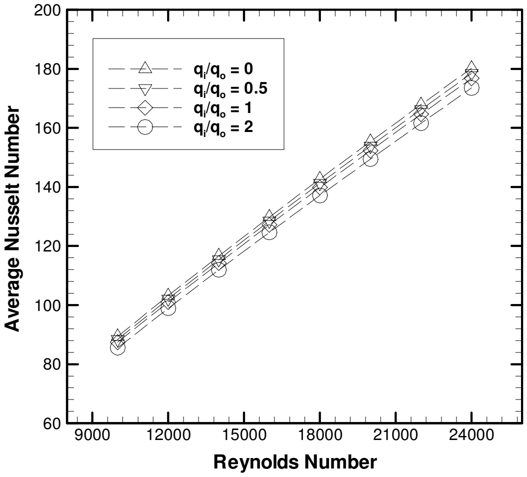

Figure 5: The Effect of Heat Flux Ratio (q_i/q_o) on the average Nusselt number (Using SiO_2/R-141b, dp = 20 nm, $\varphi = 4\%$ and $q_w = 5000\ W/m^2$)

4.0 CONCLUSSION

Numerical simulations for turbulent mixed convection heat transfer in concentric annulus using various Nanorefrigerants were presented. A three-dimensional grid setup was built in order to simulate the geometry using Computational Fluid Dynamics (CFD) software. Using finite volume method (FVM), the governing equations were deciphered and correlated to case study, provided with some particular assumptions. Conclusions are made after detailed investigation on mixed convection in 3D different annulus type using Nanorefrigerants as follows:

- SiO_2 has the greatest Nusselt number followed by Al_2O_3, ZnO, CuO and lowest values for pure refrigerant.
- SiO_2/R-141b has the highest Nusselt number comparing to other types of nanorefrigerants.
- The effect of heat flux on the inner and outer walls of the annulus on heat flows was significant.

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