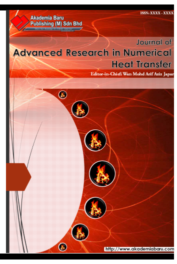
Penerbit Akademia Baru

Journal of Advanced Research in Numerical Heat Transfer

Journal homepage:
http://www.akademiabaru.com/submit/index.php/arnht/index
ISSN: 2735-0142



Influence of Volume Fraction of Titanium Dioxide Nanoparticles on the Thermal Performance of Wire and Tube of Domestic Refrigerator Condenser Operated with Nanofluid

Nizamuddin Razali[1], Mohd Bekri Rahim[1], Sri Sumarwati[1,*]

[1] Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400 Johor, Malaysia

ABSTRACT

Many researchers have used nanoparticles that have remarkable improvements in thermophysical and heat transfer capabilities to improve the efficiency and reliability of refrigeration and air conditioning systems. The case study was driven to investigate the thermal draft performance of natural wire-and-tube condensers of domestic refrigerators using TiO_2 nanoparticles suspended in HFC134a as refrigerants. Relevant input data, nanofluid properties, empirical correlations, and operating conditions were obtained from the previous literature to numerically investigate the heat transfer performance improvement of wire-and-tube condensers using nanofluids as coolant. The overall heat transfer coefficient and heat transfer rate in the condenser cooling system increase with nanofluids used (HFC134a + TiO_2) compared to the basis of the fluid (HFC134a) alone. It reported that for case study conditions with Reynolds numbers of air and refrigerant at 150 and 25400 severally, the overall heat transfer conductance increased by only 1.2% with adding 5% TiO_2 particles in the base fluid. However, at optimum conditions with the Reynolds number of air augment to 4400 and the Reynolds number of refrigerants decreasing to 12,000, the overall heat transfer conductance increases by up to 10%. In addition, frontal area reduction wire and tube condensers can be estimated.

Keywords:
TiO_2 Nanoparticles, Thermal Performance, Domestic Refrigerator, Nanofluid

1. Introduction

The sustainability of energy is crucial to driving Malaysia's economic development. The government has introduced various energy efficiency regulations and initiatives to make consumers smarter in their energy use. In Malaysia, the demand for electricity for residential electricity is 20.7% [1]. The rapid increase in the number of household appliance ownership, especially refrigerators. Almost every household in the country has a freezer for daily use. Therefore, any increase in the efficiency of these appliances will result in a significant amount of electricity consumption savings in the residential sector. Condensers and refrigerants are critical parts of the refrigeration system that affect energy consumption [2]. An integrity condenser design will increase energy efficiency and reduce space and material for a certain cooling capacity reducing manufacturing costs. The use of nanofluids in refrigeration systems will significantly improve the energy efficiency and reliability of

* *Corresponding author.*
E-mail address: sri_fatoni78@yahoo.com

refrigeration systems [3] due to the high increase in thermophysical and heat transfer capabilities that have been demonstrated by many previous researchers specializing in this field.

There are many heat exchangers of various types designed to fully meet the needs of heat transfer technology [4]. For example, in refrigeration systems, the most commonly used condenser is a wire-and-tube type consisting of a single steel tube carrying a heat transfer medium such as coolant and a solid steel wire that serves as an extension surface to direct the secondary heat transfer of liquids such as air across the tube. Moreover, the relatively inexpensive manufacturing cost of wire and tube condensers is the reason why it has been used in refrigerators and household refrigerators. From a heat transfer point of view, this type of condenser is assumed to consist of a variety of horizontal tubes, with wires acting as an extension surface to enhance heat transfer from the wall to the external environment [5].

The application of nanofluids in heat transfer technology to improve the thermal performance of heat exchangers has been discovered by many researchers and can be used in many devices today [6]. These nanofluids have been shown to have superior heat transfer capabilities and have been a popular research topic in the field of heat transfer [7]. Nano liquids are a relatively new class of liquids by suspending nano-scale materials in conventional base liquids and having a higher thermal conductivity than base liquids. Nano refrigerant is a type of nano liquid, and the basic liquid is a refrigerant. Nano refrigerants have a higher heat transfer coefficient than refrigerants (without nanoparticles), and they can be used to improve the performance of refrigeration systems. At the same Nusselt number, the heat transfer coefficient for fluids with higher thermal conductivity is higher than for fluids with lower thermal conductivity [8]. Therefore, studies to improve the thermal conductivity of nano-coolers are necessary. The effect of lubrication and material compatibility of refrigeration systems due to the addition of nanoparticles into the refrigerant should be noted [9]. This is because the use of nanofluids in domestic refrigerator condensers as nano fuel will affect condenser performance but also the entire refrigeration system [9]. Therefore, TiO2 nanoparticles can be used as additives to increase the solubility of mineral oils in hydrofluorocarbon coolant (HFC) [10]. Moreover, cooling systems using a mixture of HFC134a and mineral oil with TiO2 nanoparticles appear to provide better performance by returning more lubricating oil to the compressor than systems using HFC134a and POE oils [11]. This research was conducted to investigate the thermal performance of a local refrigerator condenser type wire and tube which uses TiO2 nanoparticles mixed according to a specific method into HFC134a as the refrigerant.

2. Methodology

The data that used in this case study consists of into several categories, which are:

i. Data design parameters and geometrical data of the wire and tube condenser.

Table 1
Design parameters and geometrical data of current wire and tube condenser

Tubing Material	Copper tubing powder-coated with white
Tube outer diameter, $d_{t,o}$ (mm)	4.8
Tube inner diameter, $d_{t,i}$ (mm)	3.6
Tube pitch, p_t (mm)	50
Total length of tube, L_t (m)	11
Inner flow area (m^2)	9.62×10^{-6}
Inner wetted area (m^2)	0.124407
Outer heat transfer area (m^2)	1.1614
Number of rows, N_t	25
Wire diameter, d_w (mm)	1.5

Wire pitch, p_w (mm)	4.94
Number of wires (pairs) N_w	90
Length of wire, L_w (m)	1.25
Condenser height, H (m)	1.2
Condenser width, W (m)	0.44

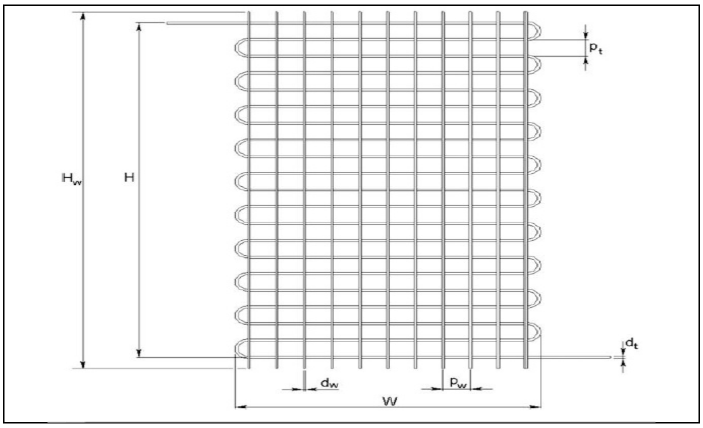


Fig. 1. Parameters of wire and tube condenser

ii. Operating condition of the condenser and the refrigerant

Table 1
Operating condition of the condenser and the refrigerant

Operating Condition	Value
Air surrounding temperature, T_a (°C)	32
Temperature of inlet refrigerant, $T_{ref,in}$ (°C)	71.2 assume T_{ave} = 70°C
Refrigerant volumetric flow rate, ν_{ref} (m^3/s)	8.1×10^{-6}
Mass flow rate of air, $\dot{m}_a$ (kg/s)	36.797×10^{-3}

iii. The thermal physical properties of HFC134a and air

Table Error! No text of specified style in document.
Thermal physical properties of HFC134a and air

Thermal physical property	HFC134a (at 70°C)	Air (at 32°C)
Density, ρ (kg/m^3)	995.6	1.1764
Specific heat, C_p (J/kg.K)	1806	1005.25
Viscosity, μ (Ns/m^2)	120.3×10^{-6}	1.85×10^{-5}
Conductivity, k (W/m.K)	61.2×10^{-3}	26.475×10^{-3}

iv. The thermal properties of TiO_2 nanoparticles

Table 2
Thermal physical properties of Nanoparticles of TiO_2

Thermal physical property	Nanoparticles of TiO_2
Density, ρ (kg/m^3)	4200
Specific heat, C_p (J/kg.K)	0.528
Conductivity, k (W/m.K)	8.32

The test conditions for each analysis are explained below:

(a) Influence of volume fraction of titanium dioxide nanoparticles on the thermal performance of wire and tube condenser in the domestic refrigerator (case study condition).

This research was performed by increasing the nanoparticles concentration from 0%-5%. Besides, air and refrigerant Reynolds numbers were kept constant based on each operating condition (≈ 150 and ≈ 25400). Refrigerant mass and volume flow rate, refrigerant Prandtl and Nusselt number, overall heat transfer conductance based on the airside, and total heat transfer rate of the condenser was then determined.

(b) Influence of air Reynolds number on the thermal performance of a wire and tube condenser of a domestic refrigerator.

Air Reynolds number was varied from 100 to 30,000 while refrigerant Reynolds number was kept constant at 25,400. The analysis also included a comparison of the thermal performance of a wire and tube condenser with nanofluids at different volume fractions. In this section, the effect of air Reynolds number on the thermal performance of the condenser in terms of air heat transfer coefficient, overall heat transfer conductance based on airside, and total heat transfer rate were analyzed and studied. However, for the case study, the wire-and-tube condenser was naturally draft and the air Reynolds number was about at 150 only.

(c) Influence of refrigerant Reynolds number on the thermal performance of a wire and tube condenser of a domestic refrigerator.

Refrigerant Reynolds number was varied from 2,000 to 40,000 while air Reynolds number was kept constant at 150. The analysis also included a comparison of the thermal performance of the wire-and-tube condenser with nanofluids at different volume fractions. This analysis focused on the overall heat transfer coefficient based on the airside and total heat transfer rate of wire and tube condenser.

(d) Optimum operating condition

This part focused on the optimum operating condition of the wire and tube condenser based on air and refrigerant Reynolds number and the effect of volume fraction of nanoparticles on the thermal performance. The improvement of thermal performance for this condition has been studied.

(e) Comparison of refrigerant pressure drop and pump power.

In this section, all the operating condition was kept at constant value except for the volume fraction of titanium dioxide nanoparticles that were varied. It focused on the effects of the volume fraction of titanium dioxide nanoparticles on the refrigerant pressure drop and pumping power.

Therefore, the thermal performance of wire and tube condensers can be measured by investigating its heat transfer rate Q, total thermal conductivity k, pressure drop, and other related parameters that can indicate increased use of nano coolants in wire and tube condensers compared to conventional coolers (without nanoparticles). The comparison also considers not only the influence of the use of nanoparticles but also the influence of the volume fraction of titanium dioxide (TiO2) nanoparticles on the heat transfer rate of the condenser. Calculation and thermal analysis of wire and tube condenser performance consist of two parts, namely air side calculation and nano coolant side calculation.

3. Findings

In this section, analysis of the thermal performance of domestic refrigerator condenser (wire and tube) at constant Reynolds number of air and refrigerant at 150 and 25400 respectively have been carried out. With the increase of volume fraction, 4 main parameters will be influenced which are: dynamic viscosity of nanofluids μ_{nf}, the specific heat of nanofluids $C_{p,nf}$, density of nanofluids ρ_{nf}, and thermal conductivity of nanofluids k_{nf}. Besides, the dynamic viscosity of nanofluids increased as the volume fraction of nanoparticles increased, and this condition will influence the mass velocity of nanofluids G_{nf} in the domestic refrigerator. Investigation for this section also found that refrigerant HFC134a dispersed with titanium dioxide nanoparticles achieve higher thermal conductivity and heat transfer coefficient of nanofluid. However, this phenomenon is clarified due to the lower value of the air heat transfer coefficient. The air heat transfer coefficient affects the value of the air Reynolds number. Next, the influence of the air Reynolds number on the thermal performance wire and tube condensers is discussed.

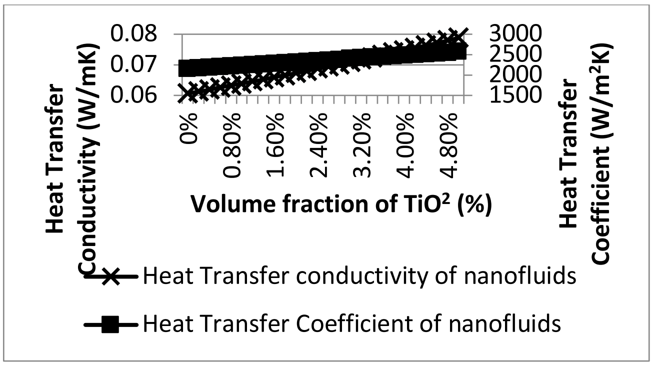


Fig. 2. Effect of titanium dioxide volume fraction to heat transfer conductivity and heat transfer coefficient at constant Reynolds number

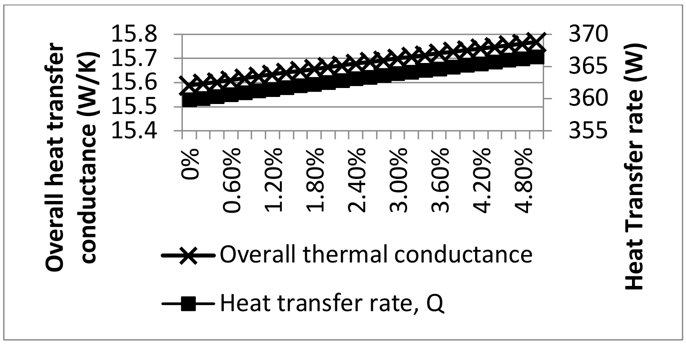


Fig. 3. Effect of titanium dioxide volume fraction to overall heat transfer conductance, UA (W/K) and Overall Heat Transfer rate (W)

It can be concluded that the efficiency of the condenser increases with the use of nano liquids. However, the percentage of effectiveness did not increase significantly. The effect of air Reynolds number on the thermal performance of a wire and tube condenser is discussed. Even though in this study case the condenser was naturally drafted, the effect of air Reynolds number is still needed to be considered to investigate the most effective method for improvement. The refrigerant's volumetric and mass flow rates, Nusselt, and Prandtl numbers did not experience any change since the refrigerant Reynolds number was kept constant at 29,600. Only air Reynolds number and volume fraction of titanium dioxide nanoparticles were varied in this section.

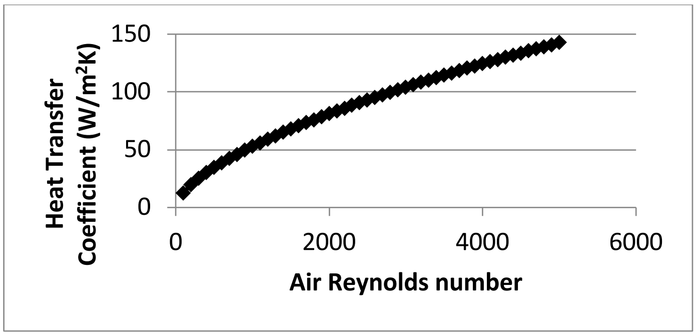


Fig. Error! No text of specified style in document.. Effect of air Reynolds number to air heat transfer coefficient

However, the improvement percentage was very small at the lower air Reynolds number, and it became higher when the air Reynolds number increased. This is the reason why is a case study of the wire and tube condenser that operates at 150 air Reynolds number did not show significant enhancement when using 5% TiO2 in nanofluids. About 6% improvement of overall heat transfer coefficient was obtained when the air Reynolds number is increased to 5000 using nanofluid with 5% TiO2 nanoparticles.

This indicates that to get the optimum enhancement using nanofluids in wire and tube condenser systems a forced convection heat transfer method needs to be used such as using a fan to increase the air Reynolds number.

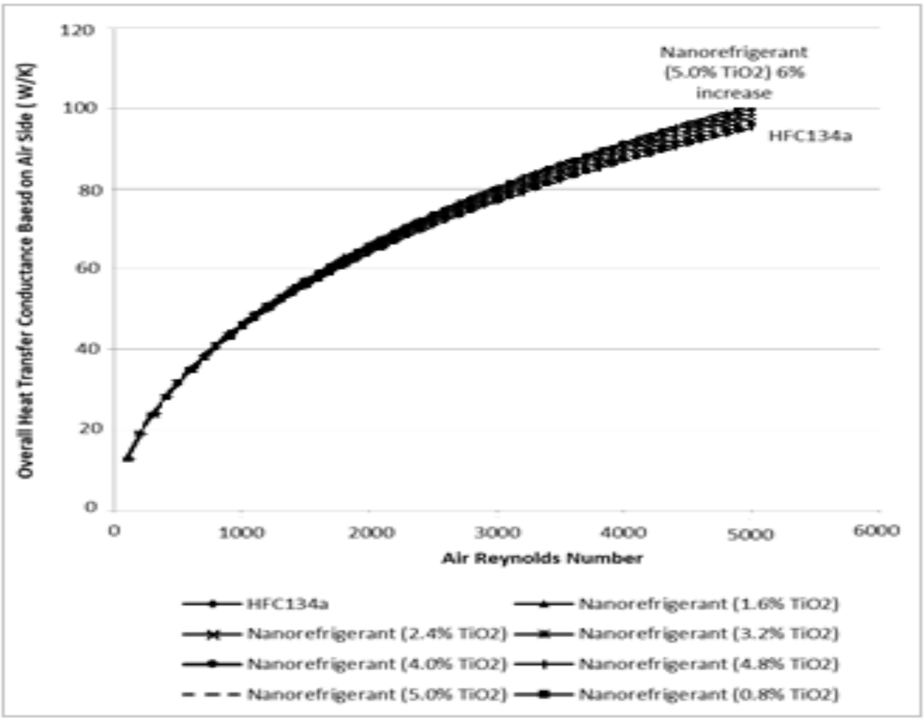


Fig. 6. Effect of air Reynolds number and titanium dioxide volume fraction to overall heat transfer coefficient based on air side

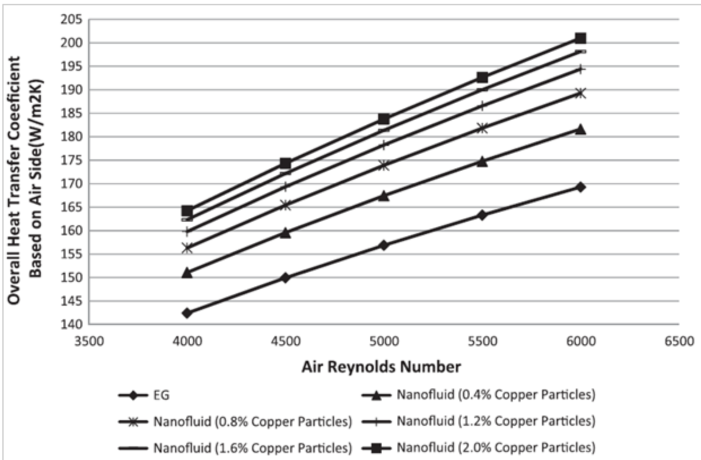


Fig. 7. Effect of air Reynolds number and copper volume fraction to overall heat transfer coefficient based on air side

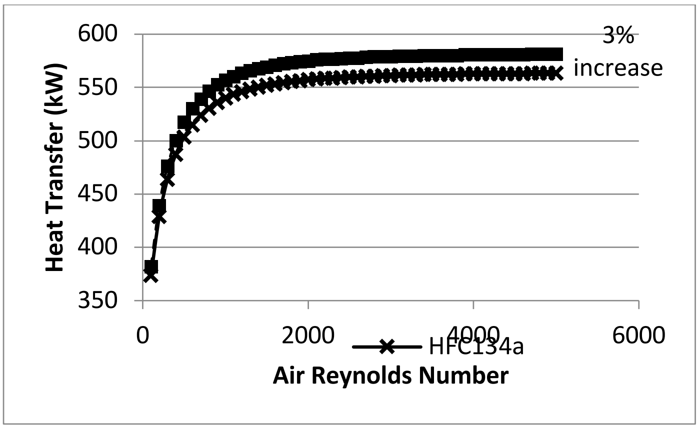


Fig. 8. Effect of air Reynolds number and titanium dioxide volume fraction to heat transfer rate of condenser

Approximately a 3.2% increase in heat transfer can be achieved with the addition of 5% titanium dioxide particles to the Reynolds 4400 air. Based on the overall heat transfer conductance and the increase in heat transfer rate, the percentage reduction of the air front area can be estimated. The percentage in heat transfer rate increases with the Reynolds number of air, but after 4400, the increase in heat transfer rate decreases slightly. Therefore, the optimal Reynolds air number for a wire-and-tube condenser of this type in the case of this study is 4400. This value will be used for optimal conditions.

The effect of the refrigerant Reynolds number on the thermal performance of a domestic refrigerator condenser is discussed in this section. The refrigerant Reynolds number in this research was changed from 2000 to 40000. Refrigerant Reynolds numbers play a crucial role, in determining the condenser's thermal performance. The refrigerator might be overcooled or overheated if the refrigerant is not controlled properly. The main function of a condenser is to ensure that the refrigerant is operating at optimum temperature.

As a result, with the addition of 5% titanium dioxide particles, a 1.2% improvement of heat transfer rate has been achieved at 12,000 refrigerant Reynolds numbers. It is also observed that the percentage of improvement is increased with the increase of the refrigerant Reynolds number, but after 12000 refrigerant Reynolds numbers, the heat transfer rate decreases as shown in Figure 10.

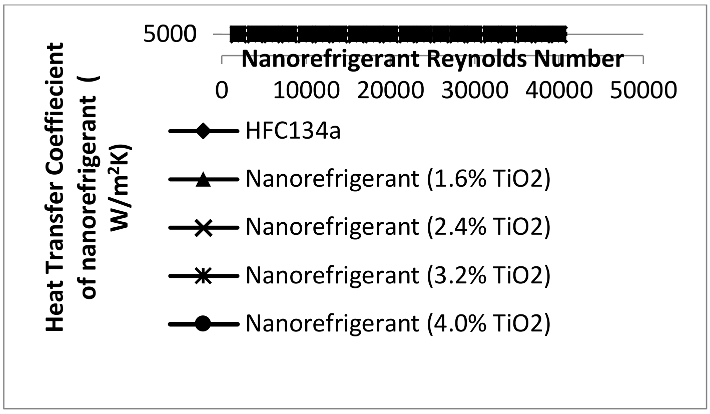


Fig. 9. Effect of refrigerant Reynolds number to heat transfer coefficient of nanofluids

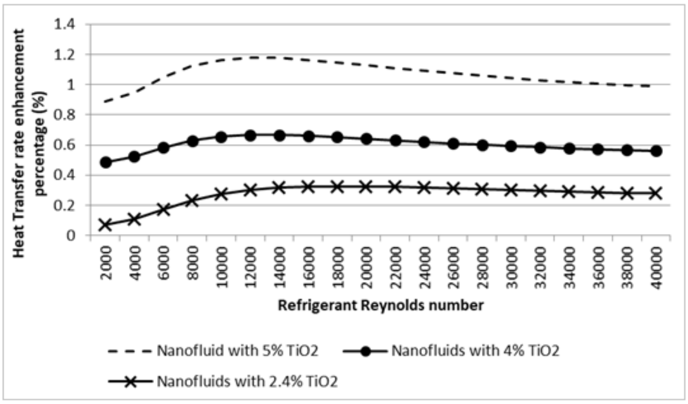


Fig. 10. Effect of refrigerant Reynolds number to heat transfer rate of wire-and-tube condenser

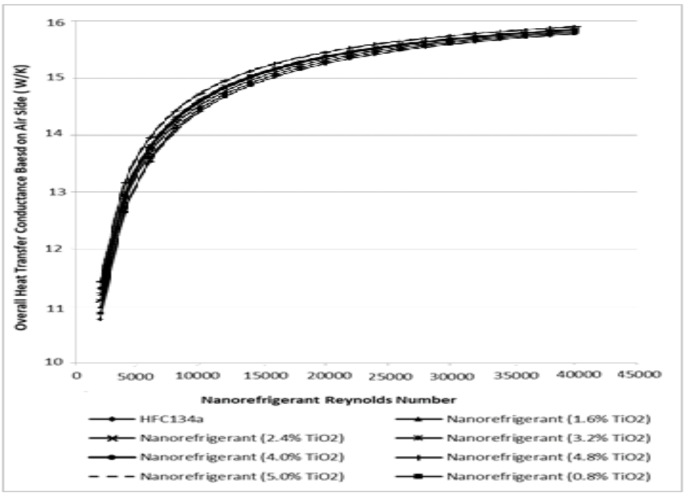


Fig. 11. Effect of refrigerant Reynolds number to overall heat transfer coefficient

The heat transfer coefficient of nanofluids is increased up to 20% at 40,000 refrigerant Reynolds numbers with 5% TiO2 in nanofluids compared to the base fluid. Overall heat transfer conductance based on airside is increased polynomial with refrigerant Reynolds number as shown in Figure 11. However, the enhancement value of this property for nanofluids is not significantly higher than that of a base fluid which is 0.8% at 40,000 refrigerant Reynolds numbers. Based on previous literature reviews, it should have a significant improvement for the overall heat transfer conductivity by using nanofluids. The aim is to achieve a significant reduction for the entire heat transfer area. Besides, this value has a peak point of improvement in the range of 10000 to 15000 refrigerant Reynolds numbers. The heat transfer rate improvement was observed with the change of refrigerant Reynolds number.

4. Discussions

Heat transfer rate is valuable with the increase of volume concentration of nanoparticles (ranging from 0% to 5%). Approximately 1.8%, a quantity that is added at heat transfer rate was achieved, with the addition of 5% titanium dioxide nanoparticles in the air and refrigerant, Reynolds number respectively. However, this achievement is lower than what is expected, compared to the result from [12] that using nanofluids to investigate the performance of automotive car radiators, the authors can achieve improvement at 3.8% heat transfer rate enhancement. Several factors can influence the significant enhancement of thermal performance using nanofluids. The main factors that contribute to this lower increment of thermal performance enhancement are the air and the refrigerant Reynolds number. In conclusion, the application of nanofluids in a heat exchanger using natural draft does not significantly improve thermal performance. These findings are in line with studies [13] show that the addition of nanoparticles in the base fluid is crucial to avoid obtaining higher thermal performance.

The thermal performance of a wire-and-tube condenser using nanofluids (HFC134a refrigerant dispersed TiO2 nanoparticles) is increased significantly with the air Reynolds number. However, at low air Reynolds number (0 – 1000), the enhancement of using nanofluids is not very significant until at high air Reynolds number (>1000). About 3% and 6% enhancement of total heat transfer rate and overall heat transfer conductance were observed, respectively the 5000 air Reynolds number using 5% of titanium dioxide nanoparticles compared to the pure HFC134a refrigerant. The optimum air Reynolds number of this type of wire-and-tube condenser is 4400. The influence of refrigerant Reynolds number also increases the thermal performance of wire and tube condensers using nanofluids, when the refrigerant Reynolds number increase. The optimum refrigerant Reynolds number is at 12,000, and this Reynolds number the overall heat transfer conductance and total heat transfer rate increase 2.0% and 1.2% respectively.

Thermal performance of wire and tube condensers at optimum conditions; air and Reynolds refrigerant numbers at 4400 and 12000, respectively, showed a significant increase. Approximately 9.5% increase in overall heat transfer conductance was measured at this condition using 5% of titanium dioxide nanoparticles. An estimated 8.7% reduction of the air front area for the wire and tube condenser can be achieved in this study using optimal conditions. This study has proved that the application of nanofluids as a working refrigerant in the domestic refrigerator can enhance the thermal performance of wire and tube type condensers but need to use force convection heat transfer. The results of this study are supported by the findings of [14], which found that the Nusselt number average increases with increasing Reynolds number and particle concentration. However, the exact percentage of enhancement is still unknown as this study used numerical calculation and correlation from previous research to predict the improvement. Error due to unsuitable use of correlation and mathematical modeling and experiment data from other researcher experiments might occur and will influence the results. Therefore, an experimental investigation needs to be conducted to verify these results.

5. Conclusions

Many researchers have used nanoparticles that have remarkable improvements in thermophysical and heat transfer capabilities to improve the efficiency and reliability of refrigeration and air conditioning systems. The case study was driven to investigate the thermal draft performance of natural wire-and-tube condensers of domestic refrigerators using TiO_2 nanoparticles suspended in HFC134a as refrigerants. The overall heat transfer coefficient and heat transfer rate in the condenser cooling system increase with nanofluids used (HFC134a + TiO_2) compared to the basis of the fluid (HFC134a) alone. It reported that for case study conditions with Reynolds numbers of air and refrigerant at 150 and 25400 severally, the overall heat transfer conductance increased by only 1.2% with adding 5% TiO_2 particles in the base fluid. However, at optimum conditions with the Reynolds number of air augment to 4400 and the Reynolds number of refrigerants decreasing to 12,000, the overall heat transfer conductance increases by up to 10%. In addition, frontal area reduction wire and tube condensers can be estimated. This study has proved that the application of nanofluids as a working refrigerant in the domestic refrigerator can enhance the thermal performance of wire and tube type condensers but need to use force convection heat transfer.

Acknowledgements
The research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through TIER 1 (VOT H956).

References

[1] Tenaga, Suruhanjaya. "Energy commission." *Electricity Supply Industry in Malaysia-Performance And Statistical Information 2006* (2020).
[2] Sumeru, Kasni, Mohamad Firdaus Sukri, Muhamad Anda Falahuddin, and Andriyanto Setyawan. "A review on sub-cooling in vapor compression refrigeration cycle for energy saving." *Jurnal Teknologi* 81, no. 5 (2019).
[3] Liu, Li-Hong, Rémi Métivier, Shanfeng Wang, and Hui Wang. "Advanced nanohybrid materials: surface modification and applications." *Journal of Nanomaterials* 2012 (2012): 9-9.
[4] Zohuri, Bahman. *Compact heat exchangers*. Springer, 2017.
[5] Cengel, Yunus A. "Introduction to Thermodynamics and Heat Transfer: Solutions Manual." (2008).
[6] Okonkwo, Eric C., Ifeoluwa Wole-Osho, Ismail W. Almanassra, Yasser M. Abdullatif, and Tareq Al-Ansari. "An updated review of nanofluids in various heat transfer devices." *Journal of Thermal Analysis and Calorimetry* 145 (2021): 2817-2872.
[7] Plant, Robert, Gregory Hodgson, Stefania Impellizzeri, and M. Ziad Saghir. "Experimental investigation of heat transfer with various aqueous mono/hybrid Nanofluids in a Multi-channel heat exchanger." *Processes* 9, no. 11 (2021): 1932.
[8] Pekar, Libor, ed. *Advanced Analytic and Control Techniques for Thermal Systems with Heat Exchangers*. Academic Press, 2020.
[9] Li, Hailong, Wenyan Yang, Zhixin Yu, and Li Zhao. "The performance of a heat pump using nanofluid (R22+ TiO2) as the working fluid–an experimental study." *Energy Procedia* 75 (2015): 1838-1843.
[10] Kong, Dexia, Na Wei, and Min Dong. "Research on Nano Refrigerant and Nano Lubricant to Improve Energy Saving of Refrigeration System." In *Journal of Physics: Conference Series*, vol. 2093, no. 1, p. 012016. IOP Publishing, 2021.
[11] Saidur, Rahman, S. N. Kazi, M. S. Hossain, M. M. Rahman, and H. A. Mohammed. "A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems." *Renewable and Sustainable Energy Reviews* 15, no. 1 (2011): 310-323.

[12] Leong, Kin Yuen, Rahman Saidur, S. N. Kazi, and A. H. Mamun. "Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator)." *Applied Thermal Engineering* 30, no. 17-18 (2010): 2685-2692.
[13] Awais, Muhammad, Najeeb Ullah, Javaid Ahmad, Faizan Sikandar, Mohammad Monjurul Ehsan, Sayedus Salehin, and Arafat A. Bhuiyan. "Heat transfer and pressure drop performance of Nanofluid: A state-of-the-art review." *International Journal of Thermofluids* 9 (2021): 100065.
[14] Akyürek, Eda Feyza, Kadir Geliş, Bayram Şahin, and Eyüphan Manay. "Experimental analysis for heat transfer of nanofluid with wire coil turbulators in a concentric tube heat exchanger." *Results in Physics* 9 (2018): 376-389.