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Heat Transfer Properties of Metal Nanoparticle in Heat Exchanger

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Abstract The review of previous studies indicates the influence of Nano-fluids on improving heat transfer and cooling systems performance. Although there are different Nano-fluids with different properties, selecting the best fit Nano-fluid with respect to considered conditions is a difficult process. Considering fan coil system as a shell and tube heat exchanger, this paper studies the effect of each influential parameter of Nano-fluids i.e. density, viscosity, thermal conductivity and constant pressure specific heat on heat transfer. Studies were conducted on 13 Nano-fluids (volume fraction of different metallic nanoparticles=0.2 and the minimum and maximum specific heat coefficients of 737.35Kj/kg.K and 2854.10 Kj/kg.K, respectively) with water as the base fluid. It was revealed that there is a direct relationship between specific heat coefficients, as the most effective parameter of Nano fluids, average Nusselt number (the minimum and maximum average Nusselt numbers are 5.15 and 7.81, respectively) and heat transfer. Given this relationship, it is possible to select the best Nano fluid offering the maximum time and cost save with respect to conditions. In addition, it is possible to take more effective steps in the way of discovering new Nano fluids with better performance without conducting practical tests and only by simple calculations. This, in turn, results in a remarkable progress in Nano Industry.

Keywords: Air conditioning system, Nusselt number, Nanoparticles, Shell-tube heat exchanger, and specific heat coefficient

خواص انتقال حرارت نانوذرات فلزی در مبدل‌های حرارتی

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چکیده: مروری بر کارهای انجام شده اهمیت نانوسیال‌ها را در افزایش انتقال حرارت و کارآئی سامانه‌های گرمایش و سرمایش را نشان می‌دهد. گرچه نانوسیال‌های مختلف با خواص مختلف وجود دارد، با وجوداین انتخاب نانوسیال بهینه برای شرایط معینی عموماً یک فرآیند پیچیده‌ای می‌باشد. در این مقاله با درنظرگرفتن یک سیستم فن کوئیل همانند یک مبدل حرارتی پوسته و لوله، تأثیر خواص مختلف نانوسیال از قبیل دانسیته، وزیسکوزیته، رسانائی حرارتی و گرمای ویژه را بر روی انتقال حرارت مطالعه می‌شود. مطالعه بر روی ۱۳ نانوسیال با کسر حجمی ۰/۲٪ و گرمای ویژه در حدود ۷۰۰ الی ۳۰۰۰ کیلوژول بر کیلوگرم کلوین با سیال پایه آب انجام گردید. نتایج نشان می‌دهد که رابطه مستقیمی مابین گرمای ویژه بعنوان پارامتر مهم نانوسیال، عدد نوسلت و میزان انتقال حرارت وجود دارد. با معلوم بودن این رابطه، انتخاب یک نانوسیال بهینه که در شرایط معینی همراه با هزینه پائین می‌باشد، میسر می‌باشد.

واژه‌های کلیدی: سامانه تهویه مطبوع، عدد نوسلت، نانوذرات، مبدل حرارتی پوسته و لوله و گرمای ویژه.

1. Introduction

The development of urbanization with the ever-increasing growth of constructing residential complexes and tall buildings on the one hand and the economic supply of pleasant air with respect to residents' needs and building condition on the other hand, have attracted the attentions of researchers to the improvement of air conditioning systems.

All-water air conditioning system is a type of such systems. It is advantageous to other systems in terms of low-sized facilities and low-cost operations and maintenance processes. In this system, the heat-carrying fluid, cold or hot water, is supplied in a separate location and then is sent to the coils of heat exchangers installed in rooms (such as fan coils). The fluid, then, cools downs or warms up the air passing through coils by the aid of a ventilator. Selecting the maximum possible amount of a proper type of fluid has been the subject of many studies in recent decades. As a new attempt in thermal sciences area, Nano-fluid, which is a product of nanotechnology, has attracted attentions due to its advantages to convective heat transfer. Choi and Eastman (1995) was the first person who named fluids containing particles in nanometer scales as Nano-fluids in his set of studies in the national laboratory of Oregon, USA and showed the dominant thermal properties of them by measuring the convective heat transfer of the fluids. Pak and Cho.(1998) studied turbulent convective heat transfer using water-aluminum oxide Nano-fluid with a volume percentage of 1%-3% in laboratory. They found that the Nusselt number of Nano-fluid increases as the Reynolds number and volume concentration of it increases. Heriset al. (2006) studied the heat transfer of water-aluminum oxide laminar flow under constant wall temperature with a 0.225 volume fraction of nanoparticles. They derived a lower Nusselt number for this Nano-fluid compared with the water-based fluid where the heat transfer rate increased as the concentration of nanoparticles increased. Lai et al. (2006) studied the behavior of water-aluminum oxide Nano-fluid in a stainless steel tube (in millimeter scale) exposed to a constant heat flux. In lower Reynolds number (Re<270) the maximum improvement in Nusselt number was 8% in the volume concentration of 1%. "Jung et al. (2006) conducted convective heat transfer test on water-aluminum oxide Nano-fluid under laminar flow condition in a rectangular microchannel. The maximum increase in convective heat transfer was 32% in the volume concentration of 1.8%. "Ho et al. (2009) conducted cooling test on a horizontal tube under laminar flow of water-aluminum oxide Nano-fluid with a volume concentration of 1% and 2%. Surprisingly, their results showed a 51% increase in heat transfer coefficient. "Eastman et al. (1997) reported that the thermal conductivity of ethylene glycol Nano-fluid (volume fraction of copper particles=0.3%) is higher than ethylene glycol base fluid by more than 40%.Yu and Choi (2003) studied the thermal conductivity of zinc oxide-ethylene glycol as a Nano-fluid.

By adding zinc-dioxide nanoparticles to ethylene glycol with a volume ratio of 5%, they obtained an increase in thermal conductivity by 26.5%. Mintsaet al. (2009) studied the effects of temperature, particle size and volume ratio on the thermal conductivity of water-based copper oxide and aluminum oxide Nano-fluids. The results revealed the increase of thermal conductivity of the Nano-fluids.

The review of previous studies and results indicates the possibility of improving fan coil performance using Nano-fluids compared with water-base fluids. However, there are different Nano-fluids with different properties and selecting the best fit Nano-fluid with the maximum efficiency in considered conditions is a difficult process.

This study considers fan coil as a shell and tube heat exchanger and numerically studies the effects of influential factors of Nano-fluids, including density, viscosity, thermal conductivity coefficient and constant pressure specific heat, on heat transfer rate.

2. Geometry and Equations

Figure 1 shows the studied geometry. Only parts of tubes were studied for simulation simplification purposes. The studied cross section is 4 cm in length and 1 cm in width with an inlet mass flow of 0.05 kg/s. The radius of semicircle is 0.5 cm and the temperatures of heat resources and inlet air is 450 K and 300 K, respectively.

Thermo-physical properties of a fluid are necessary for thermal and hydraulic designs. The density of Nano-fluid is determined via Pack and Cho Eq. (1). The specific heat is determined via Xuan and Roetzel Eq. (2) Xuan and Roetzel. (2000), viscosity is determined via Brinkman Eq. (3) Brinkman.(1952) and thermal conductivity is determined via Maxwell model Eq. (4) Maxwell. (1881).

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_f \tag{1}$$

$$(\rho Cp)_{nf} = \varphi(\rho Cp)_p + (1-\varphi)(\rho Cp)_f \tag{2}$$

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}} \tag{3}$$

$$K_{nf} = \left[\frac{K_p + 2K_f + 2\emptyset\,(K_p - K_f)}{K_p + 2K_f - \emptyset\,(K_p - K_f)}\right]K_f \tag{4}$$

Nusselt number is calculated by the following Equation:

$$Nu = \frac{hD}{K_{nf}} \tag{5}$$

Table (1) shows the physical specifications of nanoparticles and water as the base fluid. Gambit and Ansys Fluent 15.0 were used for simulation.

3. Numerical Technique

First of all, the geometry and meshes of the studied heat exchanger are determined by Gambit (preprocessing software). Then, the obtained results are introduced to Fluent and the related network is read based on which all next operations, including network adjustment and correction, definition of boundary condition, definition of fluid specification, selection of solution and re-processing, are performed. Since the studied material i.e. water-based Nano-fluid with metallic nanoparticles, has not been defined as a default material in this software, it is necessary to define the material and its specifications. The specifications of this material are calculated through confirmed resources and available theoretical relations and are introduced to the software. This software needs four parameters in order to define the specifications of Nano-fluids: density, specific heat, viscosity and thermal conductivity coefficient. These parameters are calculated from above relations. UDF (User Define Function) code was used to define the studied Nano-fluid in software in order to increase accuracy and decrease errors.

UDF is a set of software designed by the users of Fluent via C programming language and is connected to Fluent after translation in order to enhance the software capabilities to a very precise level on their discretion. When the Nano-fluid is defined by UDF file in Fluent, it is defined by assuming a laminar, two-dimensional and steady stead flow and results are derived.

4. Results

Before studying the obtained results, the maximum wall temperature obtained by our study was compared with Hajighol.*et al*. (2012) results, shown in Table 2, (assuming the same conditions) in order to validate our method.

The comparison showed a good concordance between both results. Relying on the concordance of our results with confirmed ones, the effect of the influential parameters of Nano-fluid, including density, viscosity, thermal conductivity coefficient and constant pressure specific heat, on Nusselt number is studied. Figures (2) to (5) show Density-Nusselt, Viscosity-Nusselt, thermal conductivity-Nusselt and constant pressure specific heat-Nusselt relations in different Nano fluids, respectively.

By reviewing Figures (2) to (5) drawn for water-based Nano-fluids with Nano-metallic particles (with volume fraction of %0.2), it can be concluded that among four important parameters of Nano-fluids, specific heat plays a remarkable role in the selection of nano-particles. According to results, a Nano-fluid gains the maximum Nusselt number and, in turn, the maximum thermal conductivity, by the addition of metallic nanoparticles with the highest specific heat coefficient (transition metals).

5. Conclusion

The importance of nanotechnology, highlighted in recent decades, on the one hand and discovering the remarkable increase of thermal conductivity induced by Nano-fluids on the other hand have emphasized the importance of selecting proper nanoparticles. The review of previous studies reveals that there are studies only on a few number of particular nanoparticles with given thermodynamic specifications and no study has been conducted on other elements as nanoparticle. Thus, this study was conducted to determine the parameter with the highest effect on solid metallic Nano-fluids. In this way it can provide a solution for researchers for selecting the best Nano-fluid, considering their work condition and given effect of any water-based solid metallic nanoparticle. The remarkable advantage of this technique is that in addition to saving time, the selection of nanoparticles with no desired results is avoided. The best nanoparticle can be selected with respect to the considered conditions. This technique can be considered as an effective step in the way of discovering other nanoparticles and achieving a higher thermal conductivity.

The review of obtained results, which can be generalized to all metals of Periodical table ,indicates that in the process of employing solid metals as nanoparticle (with volume fraction of %0.2) with a water-based fluid as the cooling fluid of heat exchanger, the higher the Nano-fluidspecific heat, which is derived from Eq. (2) the higher the Nusselt number.

6. Nomenclature

Ag	Silver
Al	Aluminum
Au	Gold
Cd	Cadmium
Cp	Specific heat coefficient
Cu	Copper
D	Diameter
Ga	Gallium
h	Convective heat transfer coefficient
Hg	Mercury
In	Indium
K	Thermal conductivity
Ni	Nickel
Nu	Nusselt Number
Pd	Palladium

Pt Platinum
Ti Titanium
Zn Zinc
Greek Symbols
ρ Density
μ Dynamic viscosity
Φ Volume friction
Subscripts
F Base fluid
P Particle
nf Nanofluid

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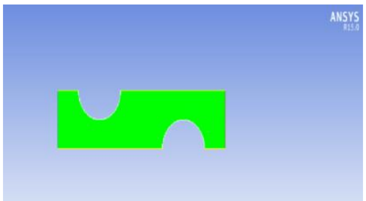

Fig. (1): The geometry of study

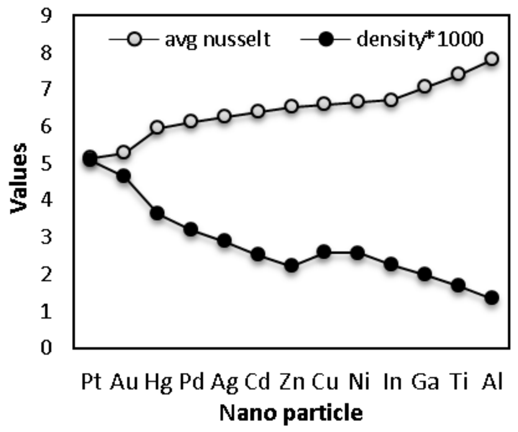

Fig. (2): Density-average Nusselt relation in different Nano-fluids

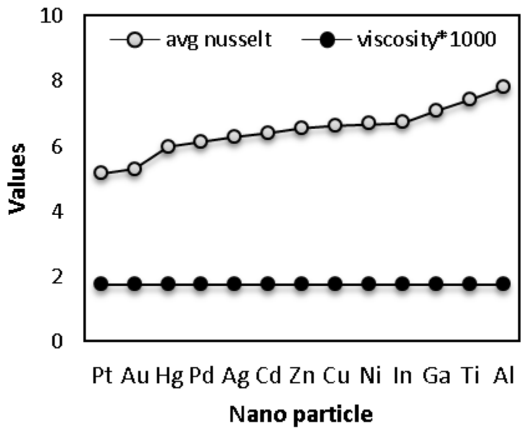

Fig. (3): Viscosity-average Nusselt relation in different Nano-fluids.

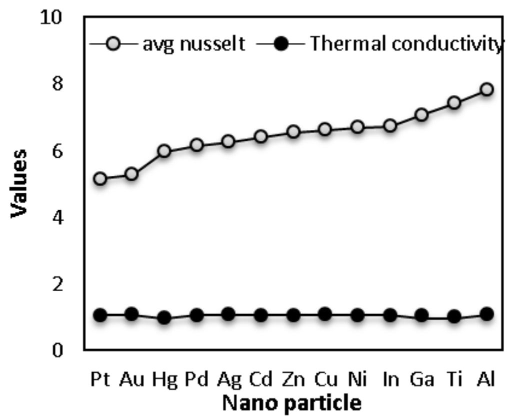

Fig. (4): Thermal conductivity-average Nusselt relation in different Nano-fluids

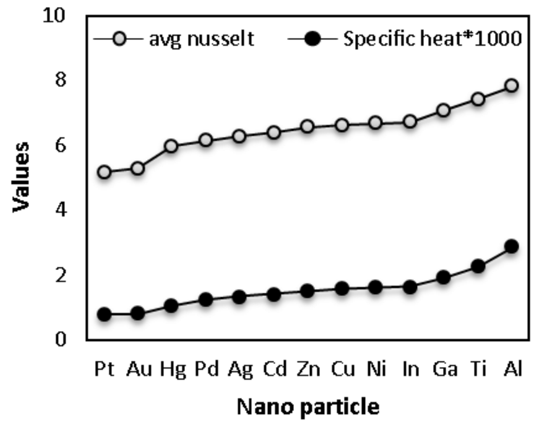

Fig. (5): Specific heat coefficient-average Nusselt relation in different Nano-fluids

Table (1): Specifications of particle used in Nano-fluid

Particle	K (w/m.k)	ρ (Kg/m^3)	C_p (kJ/Kg.k)
Cu	401	8940	0.39
Ag	429	10490	0.23
Au	310	19320	0.13
Ni	91	8908	0.44
Zn	116	7135	0.388
Al	235	2700	0.897
Ga	29	5910	0.371
In	82	7310	0.233
Ti	22	4500	0.54
Hg(L)	8.3	14190	0.1395
Cd	97	8650	0.231
Pd	72	12023	0.244
Pt	70	21450	0.133
Water	0.613	997.1	4.179

Table (2): Comparison of maximum wall temperature

Nanoparticle	Reference Values	Our values
Water	392	387.82
Aluminum oxide	420	391.55
Copper	438	391.28