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Application of Nanofluids for Heat Transfer Enhancement in Heat Exchangers - A Review

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ABSTRACT

Nanofluids are potential heat transfer fluids with enhanced thermo physical properties and heat transfer performance can be applied in many devices for better performances (i.e. energy, heat transfer and other performances). The forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of nanofluids flowing in horizontal heat exchangers under different flow conditions are investigated. The purpose of this review summarizes the important published articles on the enhancement of the convection heat transfer in heat exchangers using nanofluids. Because of its superior thermal performances, latest up to date literatures on this property have been summarized and presented in this paper as well.

Keywords - *Nanofluids, Thermal conductivities, Heat transfer, Heat Transfer Applications, Heat exchanger*.

1. INTRODUCTION

Heat exchangers are widely used in many engineering applications, for example, applications in chemical industry, power production, food industry, environment engineering, waste heat recovery, air conditioning, and refrigeration. Nowadays high prices of energy motivate industry to apply energy saving methods as much as possible in their facilities. For decades, efforts have been made to enhance heat transfer of heat exchangers, reduce the heat transfer time and finally improve energy utilization efficiency. These efforts commonly include passive and active methods such as creating turbulence, extending the exchange surface or the use a fluid with higher thermo physical properties. A decade ago, with the rapid development of modern nanotechnology, particles of nanometer size (normally less than 100 nm) are used instead of micrometer-size for dispersing in base liquids, and they are called nanofluids. This term was first suggested by Choi [1] in 1995, and it has since gained in popularity. Many researchers have investigated the heat transfer performance and flow characteristics of various nanofluids with different nanoparticles and base fluid materials. Several following existing published articles which associate with the use of nanofluids are described in the following sections. Abu-Nada, et al. [2] used an efficient finite volume method to study the heat transfer characteristics of natural convection for CuO/EG/water nanofluid in a differentially heated enclosure. His results show that the dynamic viscosity and friction factor increased due to dispersing the alumina nanoparticles in water.

2. PROPERTIES OF NANOFLUIDS AND DIMENSIONLESS NUMBERS

The effectiveness of heat transfer is described by the convective heat transfer coefficient, which is a function of a number of thermo- physical properties of the nanofluid, the most significant ones being thermal conductivity, specific heat, viscosity and density. Thermophysical properties of nanofluids Thermophysical properties of the nanofluids can be computed using classical formulas derived for a two-phase mixture.

$$\rho_{NF} = (1-\phi)\rho_{BF} + \phi\rho_{NP}, \quad (1)$$

The density and specific heat of the nanofluids are assumed to be a linear function of volume fraction due to lack of experimental data on their temperature dependence.

$$C_{pNF} = \frac{(1-\phi)(\rho C_p)_{BF} + \phi(\rho C_p)_{NP}}{(1-\phi)\rho_{BF} + \phi\rho_{NP}}, \quad (2)$$

Thermal conductivity and dynamic viscosity of the nanofluids are dependent not only the volume concentration of nanoparticle, but other parameters such as particle shape (spherical, disk shape or cylindrical), size, mixture combinations and slip mechanisms, surfactant, etc. Experimental studies [4–10] showed that the thermal conductivity as well as viscosity both increases with the addition of nanoparticles.

Several theoretical and experimental studies on nanofluid single-phase heat transfer have been reported in literature. The correlations based on the experimental data for finding the Nusselt number of nanofluids from laminar to turbulent flows reported in literature are presented. The different dimensionless numbers are computed using following equations:

Reynolds number:

$$Re = \frac{\rho u_m D}{\mu} \qquad (3)$$

Prandtl number:

$$Pr = \frac{C_p \mu}{k} \qquad (4)$$

Grashof number:

$$Gr = \frac{\beta g D^3 \rho^2 (T_S - T_\infty)}{\mu^2} \qquad (5)$$

Rayleigh number:

$$Ra = Pr \times Gr \qquad (6)$$

Peclet number

$$Pe = \frac{u_m d_p}{\alpha} \qquad (7)$$

where the thermal diffusivity of nanofluid is

$$\alpha = \frac{k}{(\rho C_p)} \qquad (8)$$

3. APPLICATION OF NANOFLUIDS

Convective heat transfer is one of the most widely investigated thermal phenomena in nanofluids, relevant to a number of engineering applications. Due to the observed improvement in the thermal conductivity, nanofluids are expected to provide enhanced convective heat transfer coefficients. However, as the suspensions of nanoparticles in the base fluids affect the thermo- physical properties other than thermal conductivity also, such as the viscosity and the thermal capacity, quantification of the influence of nanoparticles on the heat transfer performance is essentially required. [11-20] From the observed results it is clearly seen, that nanofluids have greater potential for heat transfer enhancement and are highly suited to application in different types of heat exchangers. This section explains application of nanofluids in heat exchangers used in industries, such as plate heat exchangers, shell-and- tube heat exchangers, compact heat exchangers and double-pipe heat exchangers, based on available literatures.

Pantzali et al. [21] studied numerically and experimentally the effects of nanofluids on the performance of a miniature plate heat exchanger with modulated surface. Their thermo physical measurements of the nanofluid (CuO in water, 4 vol %) reveal that the increase in thermal conductivity is accompanied by a significant drop in heat capacity and an increase in viscosity. The results suggest that, for a given heat duty, the nanofluid volumetric flow rate required is lower than that of water causing lower pressure drop, resulting in lower pressure drop and less pumping power. Also, Pantzali et al. [22] performed a study on plate heat exchangers (PHE) using nanofluids (CuO nanoparticles and water) as coolants. The results from the measurement of the Thermophysical properties of the nanofluids yielded these findings: increase of thermal conductivity; increase of density; decrease of heat capacity; increase in viscosity; and possible non-Newtonian behavior.

Mare et al. [23] investigated the thermal performances of two types of nanofluids (oxides of alumina dispersed in water and aqueous suspensions of nanotubes of carbons) in two plate heat exchangers. The results showed a significant enhancement in laminar mode of the convective heat transfer coefficient of about 42% and 50% for alumina and carbon nanotubes, respectively compared to that of pure water for the same Reynolds number. Also, the results showed that the impact of the viscosity and the pressure drop at low temperatures is important and has to take into account before to use nanofluids in heat exchanger.

Experimental investigations on the heat transfer characteristics and pressure drop of the ZnO and Al2O3 nanofluids in a plate heat exchanger have been reported by Kwon et al. [24]. Experimental results showed that, according to the Reynolds number, the overall heat transfer coefficient for 6 vol% Al2O3 increased to 30% because at the given viscosity and density of the nanofluids, they don't have the same flow rates.

The characteristics of Al2O3/ethylene glycol nanofluid and ethylene glycol fluid which cross a rectangular arrangement of tubes in a shell and tubes heat exchanger have been reported by Khoddamrezaee et al. [25] The results showed that by using of nanofluids, the stagnation and separation points of flow were postponed and the amount of heat transfer coefficient and shear stress increased but the effect of shear stress increase can be neglected in compare of unusual heat transfer rising.

Farajollahi et al. [26] performed an experimental analysis to study of the heat transfer characteristics of nanofluids in a shell and tube heat exchanger. The results have indicated that addition of nanoparticles to the base fluid enhances the heat transfer performance and results in larger heat transfer coefficient than that of the base fluid at the same Peclet number. It was noticed that heat transfer characteristics of nanofluids increase significantly with Peclet number.

Lotfi et al. [27] conducted a experimentally study on heat transfer enhancement of multi-walled carbon nanotube (MWNT)/ water nanofluid) in a horizontal shell and tube heat exchanger. The results indicate that the presence of multi-walled nanotubes enhances the heat transfer rate in a shell and tube heat exchanger.

Leong et al. [28] investigated the application of nanofluids as working fluids in shell and tube heat recovery exchangers in a biomass heating plant. The results showed that the convective and overall heat transfer coefficient increased with the application of nanofluids compared to ethylene glycol or water based fluids.

Compact heat exchanger is a unique and special class of heat exchanger having a large heat transfer area per unit volume. These have been widely used in various applications in thermal fluid systems including automotive thermal fluid systems In addition, flat tubes are more popular in automotive applications due to the lower drag profile compared to round tubes.

Vasu et al. [29] studied the thermal design of flat tube plain fin compact heat exchanger with the e-NTU rating method using Al2O3/water nanofluid as coolant. The results showed that the pressure dropof4%nanoparticlesof Al2O3 is almost double of the base fluid.

Vajjha et al. [30] numerically investigated the cooling performance of a flat tube of a radiator under laminar flow with two different nanofluids, Al2O3 and CuO, in ethylene glycol and water mixture. Numerical results showed that the Reynolds number of 2000, the percentage increase in the average heat transfer coefficient over the base fluid for a10% Al2O3 nanofluid is94% and that for a 6% CuO nanofluid is 89%. Also, the analysis shows that the average heat transfer coefficient increases with the Reynolds number and the particle volumetric concentration.

Leong et al. [31] studied the application of ethylene glycol based copper nanofluids in an automotive cooling system. The results showed that, overall heat transfer coefficient and heat transfer rate in engine cooling system increased with the usage of nanofluids (with ethylene glycol the base fluid) compared to ethylene glycol (i.e., base fluid) alone . Also, it is observed that, about 3.8% of heat transfer enhancement could be achieved with the addition of 2% copper particles in a base fluid at the Reynolds number of 6000 and 5000 for air and coolant, respectively.

The convective heat transfer enhancement of Al2O3/water and Al2O3/ethylene glycol nanofluids as the coolants inside flat aluminum tubes of the car radiator has been investigated by Peyghambarzadeh et al. [32] Significant increase of total heat transfer rates have been observed with the nanoparticle addition. Also, the results showed that, the heat transfer enhancement of about 40% compared to the base fluids.

Razi et al. [33] studied heat transfer and pressure drop characteristics of the pure base oil and CuO-base oil nanofluid flow inside the round tube and flattened tubes under constant heat flux. Experimental results showed that, for a given flattened tube and at a same flow conditions, there is a noticeable increase in heat transfer coefficient as well as pressure drop of nanofluids compared to that of base liquid. Also, at the same flow conditions and for a given nanofluid with constant particle concentration, flattened tubes enhance the heat transfer rates compared to that of the round tube, significantly.

The cooling performance of an automobile radiator under laminar flow with nanofluids is numerically investigated by Huminic [34] Results showed that at a Reynolds number of 10 the cooling performance of their automobile radiator with Cu- ethylene glycol (2 vol %) nanofluid is enhanced by about 8% compared to that of with ethylene glycol alone.

Chun et al. [35] experimentally analyzed convective heat transfer coefficient of nanofluids (alumina nanoparticles and transformer oil) through a double pipe heat exchanger system under laminar flow regime. The experimental results showed that the addition of nanoparticles in the fluid increases the average heat transfer coefficient of the system in laminar flow.

Duangthongsuk and Wongwises [36] investigated the effect of thermo physical properties models on prediction of the heat transfer coefficient and also reported the heat transfer performance and friction characteristics of nanofluid under turbulent flow conditions. The results showed that the various thermo physical models have no significant effect on the predicted values of Nusselt number of the nanofluid. The results also indicated that the heat transfer coefficient of nanofluid is slightly greater than that of water by approximately 6–11%.The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate of the hot water and nanofluid, and increases with a decrease in the nano fluid temperature.

Zamzamian et al. [37] investigated forced convective heat transfer coefficient in turbulent flow in a double pipe and plate heat exchangerswithAl2O3 nanoparticles and CuO nanoparticles in ethylene glycol. The results showed that homogenously dispersed and stabilized nanoparticles enhance the forced convective heat transfer coefficient of the base fluid significantly.

4. CONCLUSION

Recently important theoretical and experimental research works on convective heat transfer appeared in the open literatures on the enhancement of heat transfer using suspensions of nanometer sized solid particle materials, metallic or nonmetallic in base heat transfer fluids. Thus, this paper presents an overview of the recent investigations in the study the thermo physical characteristics of nanofluids and their role in heat transfer enhancement from heat exchangers. General correlations for the effective thermal conductivity, viscosity and Nusselt number of nanofluids are presented. Compared to the reported studies on thermal conductivity, investigations on convective heat transfer of nanofluids are limited. Most of the experimental and numerical studies showed that nanofluids exhibit an enhanced heat transfer coefficient compared to its base fluid and it increases significantly with increasing concentration of nanoparticles as well as Reynolds number. Further theoretical and experimental research investigations on the effective thermal conductivity and viscosity are needed to demonstrate the potential of nanofluids and to understand the heat transfer characteristics of nanofluids as well as to identify new and unique applications for these fields.

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