Review on Heat Transfer Enhancement Using Nanofluids in Heat Exchangers

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Abstract. ***The motivation of heat transfer enhancement is to develop the compact heat exchangers in order to attain the high efficiency, low cost, light weight, and size as small as possible. Nanofluids have induced vast interest to researchers of multi-disciplines due to their fascinating thermo physical properties and numerous potential benefits. In this paper, an attempt has been made to summarize the theoretical and experimental investigations on enhancement of heat transfer using nanofluids in heat exchanger applications. Since the nanofluids are effective heat transfer medium, the latest literatures on the nanofluids properties have been presented in this paper. Moreover few obstacles and challenges on nanofluid application are acknowledged and guidelines for further research have been summarized.***

Keywords: nanofluids, heat transfer enhancement, heat exchangers

1. Introduction

The initiation of high heat flow processes has created significant demand for new technologies to enhance heat transfer. An example is in automotive systems where improved heat transfer could lead to smaller heat exchangers for cooling resulting in reduced weight of the vehicle. Nanotechnology is a fast developing technology and its applications are extended in most of the engineering and medical fields [1-4]. Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids shows better results. Companies have started to observe the potential of nanofluids technology and their focus for specific industrial applications are increased. For example, the transportation industry, nanocars, GM and Ford, among others are focusing on nanofluids research projects [5-7]. Researchers proved that better enhancement of thermal conductivity using nanofluids compared to conventional cooling fluids [8-12]. Enhancement of convective heat transfer was reported by ZeinaliHeris et al. [13], Kim et al. [14], Sharma et al. [15]. Heat transfer coefficient is the determining factor in forced convection cooling or heating applications of heat exchange equipment.As a result, the heat transfer enhancement mainly depends upon factors such as particle volume concentration, particle material, particle size, particle shape, base fluid material temperature, and additives [18]. In general, reviews on thermal and rheological properties, different modes of heat transfer have been reported by many researchers. It is hope that this review will be useful to find other applications with better performances and solutions to overcome the challenges. It is also expected that performances of these identified applications can be improved further.

2. Nanofluids heat transfer characteristics enhancement

2.1 Enhancement of thermal conductivity

Thermal conductivity of nanofluids is found to be an attracting characteristic for many applications. It represents the ability of material to conduct or transmit heat. Considerable investigations have been carried out on this topic.Masuda et al. [4], Xuan and Roetzel [16] and Xuan and Li [17] stated that with low nanoparticles concentrations (1–5 Vol%), the thermal conductivity of the fluids can increase more than 20%. Eastman et al. [19], found that thermal conductivity of 0.3% copper nanoparticles of ethylene glycol nanofluids is increased up to 40% compared to base fluid. Authors stressed that, this property plays an important role in construction of energy efficient heat transfer equipment. Table 1 also shows the enhanced thermal conductivities of metallic and non-metallic nanofluids as reported by Shen [20]. Choi et al. [21], reported a 150% thermal conductivity enhancement of poly olefin oil with the addition of multi walled carbon nanotubes (MWCNT) at 1% volume fraction. Similarly, Yang et al. [22], reported a 200% thermal conductivity enhancement for poly olefin oil containing 0.35% (v/v) MWCNT. Lee et al. [23] revealed thermal conductivity of nanofluids is affected by pH level and addition of surfactant during nanofluids preparation stage. Better dispersion of nanoparticles is achieved with addition of surfactant such as sodium dodecyl benzene sulfonate.

Table 1: Summary of literature review for thermal conductivity of nanofluids

	Particle	Base fluid	Average particle size	Volume fraction	Thermal conductivity enhancement
Metallic nanofluids	Cu Cu Fe	Ethylene glycol Water Ethylene glycol	10nm 100nm 10nm	0.3% 7.5% 0.55%	40% 78% 18%
	Au	Water	10–20nm	0.026%	21%
	Ag	Water	60–80nm	0.001%	17%

Non-metallic nanofluids	Al_2O_3	Water	13nm	4.3%	30%
	Al_2O_3	Water	33nm	4.3%	15%
	Al_2O_3	Water	68nm	5%	21%
	CuO	Water	36nm	3.4%	12%
	CuO	Water	50nm	0.4%	17%
	SiC	Water	26nm	4.2%	16%
	TiO_2	Water	15nm	5%	30%
MWCNT		Synthetic oil	25nm in diameter 50m in length	1%	150%
MWCNT		Decene/ethylene glycol/water	15nm in diameter 30m in length	1%	20%/13%/7%
MWCNT		Water	100nm in diameter 70m in length	0.6%	38%

Optimum combination of pH and surfactant leads to 10.7% thermal conductivity enhancement of 0.1% Cu/H_2O nanofluids. Thermal conductivity of ethylene glycol based ZnO nanofluids measured by transient short hot wire technique is found to be increased non-linearly with nanoparticles volume fraction [24]. Mintsa et al. [12] added thermal conductivity of nanofluids also depend on the nanoparticles size and temperature. Thermal conductivity value increases with particles concentration, temperature, particles size, dispersion and stability do play important role in determining thermal conductivity of nanofluids [25].The enhanced thermal conductivity of nanofluids offer several benefits such as higher cooling rates and decreased pumping power [26].

2.2 Enhancement of heat transfer coefficient

Beyond the thermal conductivity, convective heat transfer performance under flow conditions of the nanofluids also attracted maximum attention from the researchers. Most of the literatures reported that this property is greatly enhanced with the application of nanofluids. The enhancement of the heat transfer coefficient is a better indicator for nanofluids can be used in the heat exchangers [27]. Heris et al. [28] conducted the experiments with Al_2O_3 and CuO nanoparticles in water under laminar flow up to turbulence. He found that more heat transfer enhancement as high as 40% with Al_2O_3 particles while the thermal conductivity enhancement was less than 15%. Thierry Mare et al. [29] investigated the nanofluids with alumina (γAl_2O_3) and carbon nanotubes (CNTs) dispersed in water under a laminar out-flow mode at low temperature shows an improvement in convective heat transfer coefficient of about 42% and 50% for alumina (γAl_2O_3) and carbon nanotubes (CNTs) nanofluids respectively compared to that of pure water for the same Reynolds number. Substitution of nanofluids instead of conventional coolants seemed to be beneficial for laminar flow compared to turbulent flow[30]. However, the ethylene glycol–γAl_2O_3 nanofluid appears to offer a better heat transfer enhancement than water–γAl_2O_3 because of adverse effects on the wall shear stress [31].

3. Nanofluids in Heat exchangers

Cooling is one of the important challenges faced by many industries. The conventional way to increase cooling rates is increasing the heat transfer area. There is a balance between pumping costs and heat transfer. As the area goes up, so does the energy needed to pass the fluid through the exchanger. Further increase of heat transfer area requires increasing the size of thermal management system. An attractive approach to heat exchanger design is to develop new, high efficiency heat transfer fluids [22].

The new experimental data concerning the use of nanofluids in a commercial heat exchanger confirmed that, besides the physical properties, the type of flow (laminar or turbulent) inside the heat exchanging equipment plays an important role in the effectiveness of a nanofluid. If the heat exchanger operates under laminar conditions, the use of nanofluids seems advantageous, the only disadvantages so far being their high price and the potential instability of the suspension. Ying Yang et.al. [31] investigated the convective heat transfer coefficients of graphitic nanoparticle-in-liquid dispersions (nanofluids) have been measured under laminar flow in a horizontal tube heat exchanger, with aspect ratios significantly different from one (l/d 0.02).

Kannadasan et al. [32] compared heat transfer and pressure drop characteristics by experiment in the turbulent flow regimes using CuO/water nanofluids in a helically coiled heat exchanger held in horizontal and vertical positions for 0.1% and 0.2% volume concentrations. The rapid developments of secondary flow enhancing heat transfer due to increase in thermal conductivity of nanofluids when compared with water, the heat transfer enhancement is more in vertical position than in horizontal. Friction factor for vertical position at 0.1% and 0.2% of nanofluids under turbulent flow is found to be higher than the same at horizontal position. This is because of increasing particle volume concentration in turbulent flow conditions. Roghayeh Lotfiet.al. [33] studied that the heat transfer enhancement of multi-walled carbon nanotube (MWNT)/water nanofluid in a horizontal shell and tube heat exchanger experimentally. COOH functional groups were inserted for making the nanotubes hydrophilic and increasing the stability of the nanofluid. The results indicate that heat transfer enhanced in the presence of multi-walled nanotubes in comparison with the base fluid.

Forced convective heat transfer in a water based nanofluids, by increasing the fluid circulating rate can improve the heat transfer performance. As well as application of nanofluid with low concentrations can enhance heat transfer efficiency in comparison with pure water [34,35]. Experimental investigation on a shell and helically coiled tube heat exchanger by using Al_2O_3 / water nanofluids under turbulent flow condition shows the result on tube side experimental Nusselt number of 28%, 36% and 56% with particle volume concentration of 0.1%, 0.4%, and 0.8% nanofluids respectively higher than water and concluded that the Al_2O_3 nanofluid can be applied as a coolant in helically coiled tube heat exchanger to enhance heat transfer with negligible pressure drop [36].

M.M. Elias et al. [37] studied the cylindrical shape nanoparticles, showed that the best performance in respect to overall heat transfer coefficient and heat transfer rate among the other shapes and entropy generation decreases with the increase of volume concentration.

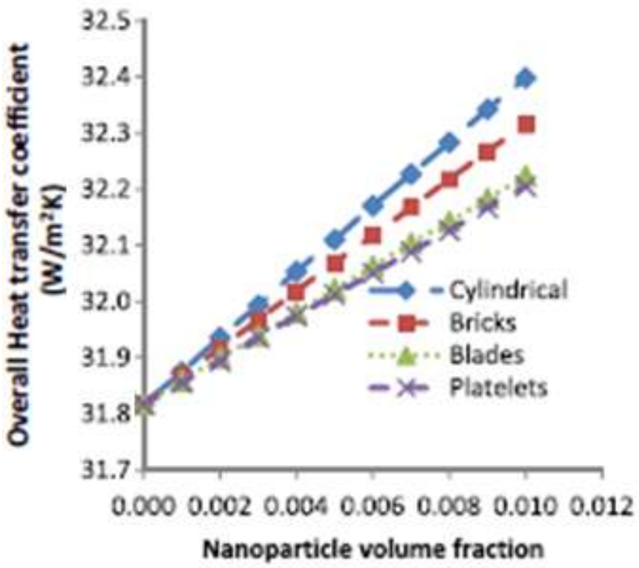

Figure 1: Effect of nanoparticle shapes on overall heat transfer coefficient at segmental baffle [37].

Twisted tape in the fluid flow path of horizontal circular pipe showed enhancement in heat transfer and increase in the pumping power by convective heat transfer analysis of Al_2O_3 nanofluids at different volume concentrations [38-39].

4. Conclusions

- Based on this study, it was reported that the thermal conductivity of nanofluids is one of the driving factors for improving performance in different applications.
- The experimental investigations of literatures show that the nanoparticles increase the heat transfer coefficient of the fluid system in laminar flow, but the increase is much less than that predicted by current correlation based on static thermal conductivity measurements.
- Friction factor increases while increasing particle volume concentration in turbulent flow conditions and hence raise in pressure loss.
- Increase in Reynolds number and volume concentration the average Nusselt number was increased. Diameter of nanoparticles has a small effect on the Nusselt number. Heat transfer rate in heat exchanger has been enhanced using nanofluids by compromising pumping power.
- Key factors that obstruct the commercialization of nanofluids are cost of production and its lower stability. By resolving these encounters, it is anticipated that nanofluids can make considerable impact as coolant in heat exchanging devices.

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