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Application of Nano-Fluids as Coolant in Heat Exchangers: A Review

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Abstract – *Nanofluids are important because they enhance heat transfer. Nanofluids are colloidal mixtures of nanometric metallic or ceramic particles in a base fluid, such as water, ethylene glycol or oil. Nanofluids possess immense potential to enhance the heat transfer character of the original fluid due to improved thermal transport properties. In this article, a brief overview has been presented to address the unique features of nanofluids, such as their preparation, heat transfer mechanisms, conduction and convection heat transfer enhancement, etc. About 55 published studies (1976-2015) are reviewed in this paper. It is marked from the literature survey articles that nano fluids performance are the most frequently studied as an efficient coolant for heat exchangers.* ***Copyright © 2016 Penerbit Akademia Baru - All rights reserved.***

Keywords: Nanofluids, Nanoparticles, Heat Transfer Enhancement, Applications of Nanofluids

1.0 INTRODUCTION

This review gives an overview of Nano-fluid, synthesis of nano-fluid, heat transfer through nano-fluids and problems associated with their applications. Nanofluids are a new class of fluids engineered by dispersing nanometer-sized materials (nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets) in base fluids [1-3]. In general, materials can have different properties at the nanoscale (nanometer is one billionth of a meter) than they do at larger size. Some materials become stronger, lighter increased stability or better at conducting electricity or heat or at reflecting light. Others display different magnetic properties or become chemically active in special ways [4] .Nanofluids are nanoscale colloidal suspensions containing condensed nanomaterials. Nanofluids have been found to possess enhanced thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water [5-12]. Researchers have measured the thermo physical properties of nanofluids while many others used well-known predictive correlations. Their works have been both experimental and theoretical [13]. Applications of nanofluids in industries such as heat exchanging devices appear promising with these characteristics. It has demonstrated great potential applications in many fields.

However, the development and applications of nanofluids may be slowed down by several factors such as long term stability, increase pumping power and pressure drop, nanofluids' thermal performance in turbulent flow and fully developed region, lower specific heat of nanofluids and higher production cost of nanofluids [13]. One of the most important issues is the stability of nanofluids, and it remains a big challenge to achieve desired stability of nanofluids. This paper, we will review the new progress in the methods for preparing stable nanofluids and summarize the stability mechanisms.

In recent years, nanofluids have attracted more and more attention. The main driving force for nanofluids research lies in a wide range of applications. Although some review articles involving the progress of nanofluids investigation were published in the past several years, most of the reviews are concerned of the experimental and theoretical studies of the thermo physical properties or the convective heat transfer of nanofluids. The purpose of this paper will focuses on the new preparation methods and stability mechanisms, especially the new application trends for nanofluids in addition to the heat transfer properties of nanofluids.

2.0 SYNTHESIS OF NANOFLUIDS

Preparation of nanofluids is the first key step in applying nano phase particles to changing the heat transfer performance of conventional fluids. The nanofluid does not simply refer to a liquid–solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles and no chemical change of the fluid. Generally, these are effective methods used for preparation of suspensions: (1) to change the pH value of suspensions; (2) to use surface activators and/or dispersants; (3) to use ultrasonic vibration. All these techniques aim at changing the surface properties of suspended particles and suppressing formation of particles cluster in order to obtain stabile suspensions. It depends upon the application case how these techniques are used.

Different methods have been developed to prepare nanofluids, such as the dispersing method [14, 6, 15-17] , physical vapor condensation [18, 19], and one-step chemical method [20] etc. However, preparation of a uniformly dispersed nanofluid is essential for obtaining stable reproduction of physical properties or superior characteristics of the nanofluids [21, 22].

2.1 Two-Step Method

Two-step method is the most widely used method for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the nano sized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling [23]. Two-step method is the most economic method to produce nanofluids in large scale, because nano powder synthesis techniques have already been scaled up to industrial production levels [24].

Literature review reveals that the initially nanofluids, used a two-step process [14], In which nanoparticles or nanotubes are first produced as a dry powder, often by inert gas condensation [25]. Chemical vapor deposition has also been used to produce constituents for use in nanofluids, particularly multi walled carbon nanotubes [21]. The nanoparticles or nanotubes are then dispersed into a fluid in a second processing step. Simple techniques such as ultrasonic agitation or the addition of surfactants to the fluids are sometimes used to minimize particle aggregation and improve dispersion behavior. Such a two-step process works well in some cases, such as nanofluids consisting of oxide nanoparticles dispersed in deionized water [14]. Less success has been found when producing nanofluids containing heavier metallic nanoparticles. Since nano powder synthesis techniques have already been scaled up to industrial production levels by several companies[26], there are potential fiscal advantages in using two-step synthesis methods that rely on the use of such powders.

Literature shows that, there are three effective procedures used to achieve stability of suspension against sedimentation of nanoparticles. Some of the researchers applied all of these methods to gain better stability [27-29], but others just applied one [30] or two techniques with satisfaction [31-33]. There is no standard to recognize the superlative mix up of combining methods. This area acquires more experiments to be clarified.

2.2 One-Step Method

To decrease the cluster of nanoparticles, Eastman et al. developed a one-step physical vapor condensation method to prepare Cu/ethylene glycol nanofluids [19]. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased [34]. The one-step processes can prepare uniformly dispersed nanoparticles, and the particles can be stably suspended in the base fluid.

However, there are some disadvantages for one-step method. The most important one is that the residual reactants are left in the nanofluids due to incomplete reaction or stabilization. It is difficult to elucidate the nanoparticle effect without eliminating this impurity effect. The preparation of nanofluids with controllable microstructure is one of the key issues. The nanofluid microstructure can be varied and manipulated by adjusting synthesis parameters such as temperature, acidity, ultrasonic and microwave irradiation, types and concentrations of reactants and additives, and the order in which the additives are added to the solution [35, 36].

3.0 HEAT TRANSFER CHARACTERISTICS OF NANO FLUIDS

3.1 Conduction

Since thermal conductivity is the most important parameter responsible for enhanced heat transfer many experimental works been reported on this aspect. The transient hot wire method[37], the steady-state parallel-plate technique [38] and the temperature oscillation technique have been employed to measure the thermal conductivity of nanofluids [39]. Among them the transient hot wire method has been used most extensively. Because in general nanofluids are electrically conductive, it is difficult to apply the ordinary transient hot-wire technique directly. A modified hot-wire cell and electrical system was proposed, Coating the hot wire with an epoxy adhesive which has excellent electrical insulation and heat conduction. However, researcher pointed that possible concentration of ions of the conducting fluids around the hot wire may affect the accuracy of such experimental results.

Oscillation technique was developed and later modified [40, 41]. This method is purely thermal and the electrical components of the apparatus are removed from the test sample. Hence ion movement should not affect the measurement.

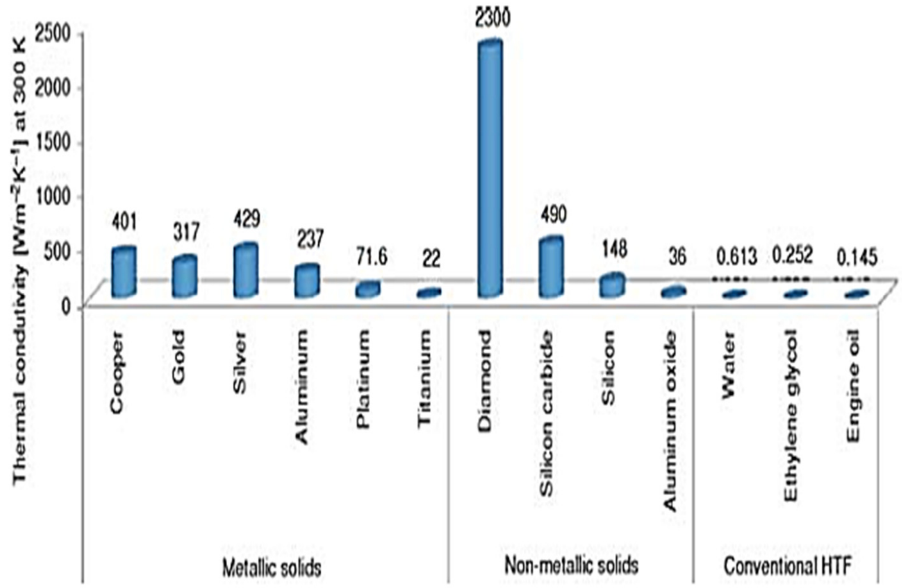
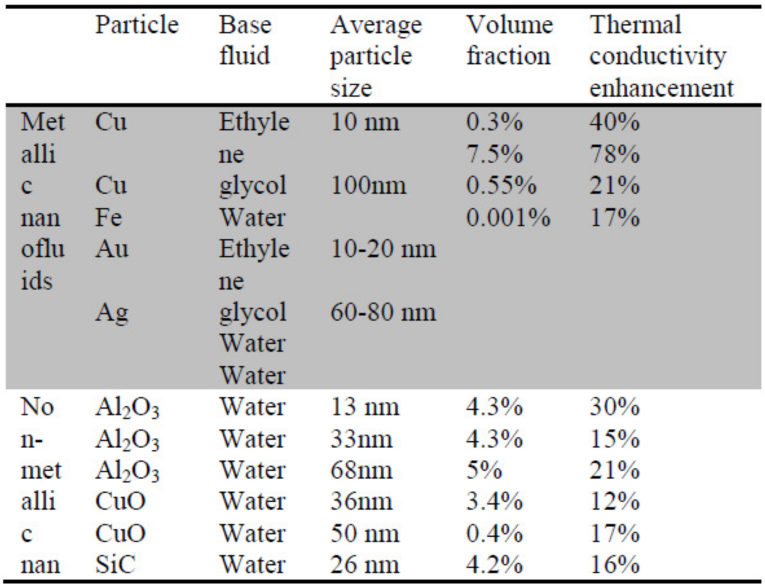


Figure 1: Effect of Different Materials on thermal conductivity [42]

The experimental results for different nanofluids by researchers are summarize in Fig. 2 illustrated the conductive heat transfer coefficient nanoparticles in liquid and shows overall trend of heat transfer enhancement



	Particle	Base fluid	Average particle size	Volume fraction	Thermal conductivity enhancement
Metallic nanofluids	Cu Cu Fe Au Ag	Ethylene glycol Water Ethylene glycol Water Water	10 nm 100nm 10-20 nm 60-80 nm	0.3% 7.5% 0.55% 0.001%	40% 78% 21% 17%
Non-metallic nan	Al_2O_3	Water	13 nm	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	50 nm	0.4%	17%
	SiC	Water	26 nm	4.2%	16%

Figure 2: Effect of Different particles on thermal conductivity [43]

The maximum measured thermal conductivity enhancement for different nanofluids is summarized in Table 1.

Table 1: Summary of the maximum measured thermal conductivity enhancement for nanofluids contacting nanoparticles

Base Fluid	**Nano Particle**	**Size of particles (nm)**	**Maximum Concentration (vol %)**	**Maximum Enhancement In k (%)**	**Reference**
Water	Al_2O_3	13nm	4.3	30	[44]
Water	Al_2O_3	33	5	30	[5]
Water	CuO	36	5	60	
Pump Oil	Cu	35	0.055	45	
Water	Al_2O_3	13	4.3	32	[45]
Water	TiO_2	27	4.35	10.7	
Water	Al_2O_3	28	4.5	14	[38]
Ethylene Glycol	Al_2O_3	28	8	40	
Pump Oil	Al_2O_3	28	7	20	
Engine Oil	Al_2O_3	28	7.5	30	
Water	CuO	23	10	35	
Ethylene Glycol	CuO	23	15	55	
Water	Al_2O_3	24.4	4.3	10	[14]
Ethylene Glycol	Al_2O_3	24.4	5	20	
Water	CuO	18.6	4.3	10	
Ethylene Glycol	CuO	18.6	4	20	
Water	Al_2O_3	38	4	25	[39]
Water	CuO	28.6	4	36	
Water	Al_2O_3	60	5	20	[46]
Ethylene Glycol	Al_2O_3	60	5	30	
Pump Oil	Al_2O_3	60	5	40	
Water	Al_2O_3	10	0.5	100	[47]
Water	Al_2O_3	20	1	16	[48]
Ethylene Glycol	CuO	25	5	22.4	[49]
Water	TiO_2	15	5	33	[50]
Toluene	Au	15	0.011	8.8	[22]
Water	Au	15	0.00026	8.3	
Water	Ag	70	0.001	4.5	
Ethylene Glycol	Fe	10	0.55	18	[51, 52]

3.2 Convection

Researchers presented an experimental system to investigate the convective heat transfer coefficient and friction factor of nanofluids for laminar and turbulent flows in a tube [53, 54]. The working fluid used was 100 nm Cu particles dispersed in deionized water. Experiments with different concentrations of nanoparticles were conducted. The Reynolds number of the nanofluids varied in the range of 800-25000. The nanofluid used consisted of Fe_3O_4 magnetic nanoparticles with an average diameter of 13 nm dispersed in water with six volume fractions (0, 0.6, 0.8, 1, 1.5 and 2%). The results revealed that as volume fraction and Reynolds number increased, Nusselt number increased, and friction factor decreased as Reynolds number increased[55] .The experimental results concluded that the convective heat transfer coefficient of the nanofluids varied with the flow velocity and volume fraction. Also, the values were higher than those of the base fluid in the same conditions. The Nusselt number of the nanofluids with 2% volume fraction of Cu particles was 60% higher than that of water. From the experimental data of [54, 53], the new heat transfer correlations for the prediction of the heat transfer coefficient of nanofluids flowing in a tube were given as follows:

Laminar flow:

$$Nu_{nf} = 0.4329[1.0 + 11.285\phi^{0.754} Pe_d^{0.218}]\mathrm{Re}_{nf}^{0.33}\,\mathrm{Pr}_{nf}^{0.4} \qquad (1)$$

Turbulent flow:

$$Nu_{nf} = 0.0059[1.0 + 7.6286\phi^{0.6886} Pe_d^{0.001}]\mathrm{Re}_{nf}^{0.9233}\,\mathrm{Pr}_{nf}^{0.4} \qquad (2)$$

where:

$$Pe_d = \frac{u_m d_p}{\alpha_{nf}}; \mathrm{Re}_{nf} = \frac{u_m D}{v_{nf}}; \mathrm{Pr}_{nf} = \frac{v_{nf}}{\alpha_{nf}} \qquad (3)$$

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}} = \frac{k_{nf}}{(1-\phi)(\rho C_p)_f + \phi(\rho C_p)_d} \qquad (4)$$

The results indicated that the friction factor of the nanofluids was equal to that of water under some working conditions, and did not vary with volume fraction. This shows that the nanofluid did not increase the pump power. The friction factor of the nanofluids was determined from the following equation

$$\lambda_{nf} = \cfrac{\Delta p_{nf} D}{\cfrac{L^2 g}{u_m^2}} \qquad (5)$$

Researcher performed experiments with Al2O3 and CuO nanoparticles in water under laminar flow up to turbulence [56].

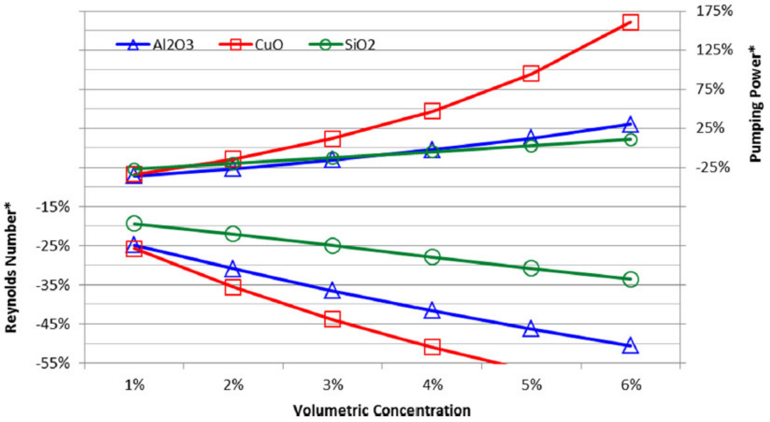


Figure 3: The effect of volumetric concentration of nanoparticle on the Reynolds number and pumping power compared to the base fluid[57]

They found more heat transfer enhancement, as high as 40%, with Al_2O_3 particles, while the thermal conductivity enhancement was less than 15%. The Dittus Boelter equation was not valid for the prediction of the Nusselt number of the nanofluids at various volume fractions. Figs. 3 and 4 show the performance of different nanofluids on the car radiator.

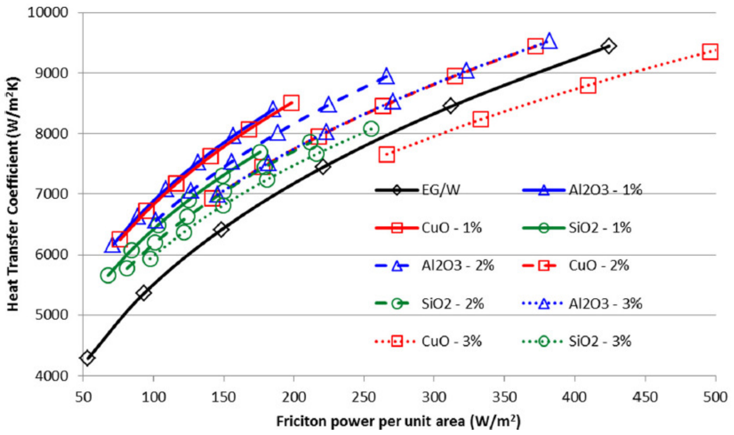


Figure 4: A comparison of the heat transfer coefficient and friction power per unit area with three nanofluids of 1–3% concentration and the base fluid [57].

4.0 CONCLUSION

The current review is a comprehensive outlook on the research progress made in the thermal enhancement process using nanofluids. The aim of the nanofluid research is to develop new methods to augment the synthesis method, novel equipment's for measuring the thermo physical properties and synthesize nanofluids with excellent transport properties. The size of the nanoparticles plays an important role in improving the heat transfer properties. The dispersion behavior of nanoparticles improves, if the nanoparticles can be prevented from agglomeration using appropriate surfactants. The mechanism of the temperature dependence of thermal conductivity continues to be a prime research area, where experimental findings are used to substantiate theory and applications.

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