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Study and Behavior of Nanofluids on Heat Transfer

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Abstract: As a new research and technology frontier, nanofluids are used to enhance heat transfer including single-phase heat transfer, nucleate boiling heat transfer, flow boiling heat transfer and critical heat flux. This paper presents an overall review of a number of patents on nanofluid heat transfer technologies and their applications for the energy efficiency improvement in various thermal systems in recent years. Although a number of patents on nanofluids heat transfer technologies (more than 20 patents) have been invented, the fundament mechanisms of nanofluid heat transfer have not yet well understood so far. Thus, the applications of these technologies are greatly limited. According to this review, the future developments of these technologies are discussed. In order to be able to put the nanofluid heat transfer technologies into practice, fundamental studies are greatly needed to understand the physical mechanisms.

Keywords: Nanofluid, Nanoparticles, heat transfer. Dispersion of particles

I. INTRODUCTION

Nanofluid a term coined by Choi in 1995 is a new class of heat transfer fluids which is developed by suspending nanoparticles such as small amounts of metal, nonmetal or nanotubes in the fluids. The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably<1% by volume) by uniform dispersion and stable suspension of nanoparticles (preferably<10 nm) in host fluids.

Nanofluids are engineered colloids made of a base fluid and nanoparticles (1-100 nm). Common base fluids include water, organic liquids (e.g. ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymeric solutions and other common liquids. Materials commonly used as nanoparticles include chemically stable metals gold, copper), metal oxides (e.g., alumina, silica, zirconia, titania), oxide ceramics (e.g. Al2O3, CuO), metal carbides (e.g. SiC), metal nitrides (e.g. AIN, SiN), carbon in various forms (e.g., diamond, graphite, carbon nanotubes, fullerene) and functionalized nanoparticles. Solids have thermal conductivities which are orders of magnitude larger than those of conventional heat transfer fluids as shown in Table 1. By suspending nanoparticles in conventional heat transfern fluids, the heat transfer performance of the fluids can be significantly improved [1-5]. As a fluid class, nanofluids have a unique feature which is quite different from those of conventional solid-liquid mixtures in which millimeter and/or micrometer-sized particles are added. Such particles settle rapidly, clog flow channels, erode pipelines and cause severe pressure drops. All these shortcomings prohibit the application of conventional solid-liquid mixtures to microchannels while nanofluids instead can be used in micro-scale heat transfer [5, 6]. Furthermore, compared to nucleate pool boiling enhancement by addition of surfactants, nanofluids can enhance the critical heat flux (CHF) while surfactants normally do not [7]. Thus, nanofluids appear promising as coolants for dissipating very high heat fluxes in various applications.

II. SYNTHESIS OF NANOFLUIDS

The thermal conductivity of heating or cooling fluids is a very important property in the development of energy-efficient heat transfer systems. At the same time, in all processes involving heat transfer, the thermal conductivity of the fluids is one of the basic properties taken account in

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designing and controlling the process. Conventional heat transfer fluids have inherently poor heat transfer properties compared to most solids which is due to the higher thermal conductivities of solids (in orders of magnitude) compared to traditional heat transfer fluids. To overcome the rising demands of modern technology and also to reduce the limitations there is a need to develop new types of fluids that will be more effective in terms of heat exchange performance (Assael etal.,2006). Long ago the basic concept of dispersing solid particles in fluids (mm or µm sized) to enhance the thermal conductivity was introduced by James Clerk Maxwell. Although these fluids showed improved thermal conductivities but due to problems such as: sedimentation, erosion, fouling, increased pressure drop of the flow channel and also clogging of microchannels and flow passages they have never been of interest for practical applications (Trisaksri & Wongwises,2007; Wang & Wei, 2009). However for this reason finding other ways to improve heat transfer properties of conventional fluids became a serious challenge for many researchers. By the introduction of nanotechnology which involved the synthesis of nanoparticles new ideas such as dispersing nanoparticles instead of mm or µm particles in conventional fluids arised. Nanoparticles (1-100nm) have unique properties such as: size dependent physical properties (color, conductivity), large surface area (the specific surface area of nanoparticles is 3 orders of magnitude greater than that of microparticles). There are two different approaches for the synthesis of nanoparticles. The bottom-up approach which is the formation of nanoparticles from constituent atoms and the synthesis of nanostructures from bulk referred to the topdown approach. Also nanoparticles can be classified by the technique that has been used for their synthesis which are:

1- Physical methods
1-1 Mechanical grinding
1-2 Inert gas condensation
2- Chemical methods
2-1 Chemical precipitation
2-2 Chemical vapor deposition
2-3 Micro-emulsions
2-4 Spray pyrolysis
2-5 Thermal spraying

III. FABRICATION FLUIDS

3.1 Methods for producing nanofluids

The delicate preparation of a nanofluid is important because nanofluids need special equirements such as an even suspension, durable suspension, stable suspension, low agglomeration of articles and no chemical change of the fluid. There are two fundamental methods to obtain nanofluids .

3.1.1 Two step process:

This technique is also known as Kool-Aid method which is usually used for oxide nanoparticles. In this technique nanoparticles are obtained by different methods (in form of powders) and then are dispersed into the base fluid. The main problem in this technique is the nanoparticle agglomeration due to attractive Van der Waals forces.

3.1.2 One step process:

In this process the dispersion of nanoparticles is obtained by direct evaporation of the nanoparticle metal and condensation of the nanoparticles in the base liquid and is the best technique for metallic nanofluids such as Cu nanofluids. The main problems in this

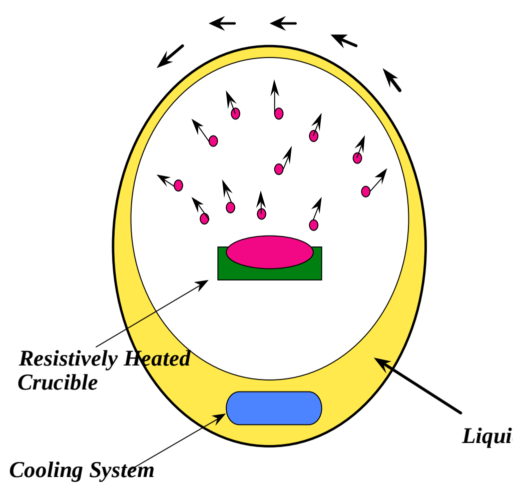

Fig: 1 Schematic diagram of nanofluid production on one step process.

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Techniques are low production capacity, low concentration of nanoparticles and high costs. While the advantage of this technique is that nanoparticle agglomeration is minimized. The suspensions obtained by either case should be well mixed, uniformly dispersed and stable in time. Also it should be noted that the heat transfer properties of nanofluids could be controlled by the concentration of the nanoparticle and also by the shape of nanoparticles.

3.2 Methods for dispersing particles

Due to the high surface energy of nanoparticles they tend to agglomerate to decrease their surface energy. The agglomeration of nanoparticles causes rapid settling which deteriorates the properties of nanofluids. To keep the nanoparticles from agglomeration they are coated with a surfactant (steric dispersion) or charged to repulse each other in a liquid.
Although the addition of the dispersant could influence the thermal conductivity of the base fluid itself, and thus, the real enhancement by using nanoparticles could be over shadowed. There are other dispersion methods

Fig: 2 Schematic diagrams of dispersion nanofluid particles.

such as using a high-speed disperser or an ultrasonic probe/bath and also changing the pH value of the suspension (Chopkar etal., 2006). The selection of suitable dispersants depends mainly upon the properties of the solutions and particles and the use of these techniques depends on the required application of the nanofluid. However metallic nanofluids due to their low thermal conductivity have limited interest but metallic nanofluids especially Cu nanofluids and Ag nanofluids due to there high thermal conductivity are the common nanofluids. More specifically we can say that all the metallic nanofluids compared to oxide nanofluids show much more enhancements so that metallic nanofluids and their volume percent is reduced by one order of magnitude at comparable K enhancements. There are a number of factors other than the thermal conductivity of the dispersed phase which should be considered such as the average size of the nanoparticles, the method employed for the preparation of the nanofluids, the temperature of measurements and the concentration of the dispersed solid phase.

IV. CHARACTERISTICS OF NANOFLUIDS

Pioneering nanofluids research in ANL has inspired physicists, chemists, and engineers around the world.Promising discoveries and potentials in the emerging field of nanofluids have been reported.

- Nanofluids have an unprecedented combination of the four characteristic features desired in energy systems .
- Increased thermal conductivity (TC) at low nanoparticle concentrations Strong temperature-dependent TC Non-linear increase in TC with nanoparticle concentration
- Increase in boiling critical heat flux (CHF)
- These characteristic features of nanofluids make them suitable for the next generation of flow and heat-transfer fluids

4.1. Nanofluids Properties

Nanofluids were found to exhibit higher thermo-physical properties such as thermal conductivity, thermal diffusivity and viscosity than those of base fluids. Heat transfer enhancement in a solid.fluid two-phase flow has been investigated for many years. Research on gas particle flow [8-11]
showed that by adding particles, especially small particles in gas, the convection heat transfer coefficient can be greatly increased. The enhancement of heat transfer, in addition to the possible increase in the effective thermal conductivity, was mainly due to the reduced thickness of

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the thermal boundary layer. In the processes involving liquid.vapor phase change, particles may also reduce the thickness of the gas layer near the wall. The particles used in the previous studies wereon the scale of a micrometer or larger. It is very likely that the motion of nanoparticles in the fluid will also enhance heat transfer. Therefore, more studies are needed on heat transfer enhancement in nanoparticle.fluid mixtures. Thermal conductivities of nanoparticle.fluid mixtures have been reported by Masuda et al. [12], Artus [13], and Eastman et al. [14] adding a small volume fraction of metal or metal oxide powders in fluids increased the thermal conductivities of the particle.fluid mixtures over those of the base fluids. The viscosity of nanofluids, which is the key influencing factor in heat transfer [15−17], has not received as much attention. The experimental and simulation results indicate that nanoparticle size is of crucial importance to the viscosity of the nanofluid due to aggregation. As the nanoparticle size decreases, the viscosity becomes much more dependent on the volume fraction. Moreover,
when the nanoparticle diameter is smaller than 20 nm, the viscosity is closely related to the pH of the nanofluid, and fluctuates with pH values from 5 and Although viscosity influences interfacial phenomena and flow characteristics,

Table 1. Thermal Conductivities of Various Solids and Liquids at Room Temperature

Material	Form	Thermal Conductivity (W/mK)
Carbon	Nanotubes	1800-6600
	Diamond	2300
	Graphite	110-190
	Fullerenes film	0.4
Metallic solids (pure)	Silver	429
	Copper	401
	Nickel	237
Non-metallic solids	Silicon	148
Metallic liquids	Aluminum	40
	Sodium at 644 K	72.3
Others	Water	0.613
	Ethylene Glycol	0.253
	Engine Oil	0.145
	R134a	0.0811

very few studies have been performed on the effective viscosity of nanofluids as a function of volumetric loading of nanoparticles [18.20]. The primary results from these studies indicate that the viscosity of a nanofluid increases with increasing nanoparticle volume fraction. In addition to the very few experimental studies, no theoretical model is available for the prediction of the effective viscosity of nanofluids as a function of temperature and particle volume fraction. It is worthwhile to study temperature-dependent viscosity of nanofluids for their potential applications especially in microfluidic systems.

4.2 Thermal conductivity of nanofluids of solids and fluids

Heat transfer nanofluids were first reported by Choi [1] of the Argonne National Laboratory, USA in 1995. Since then, a number of studies have been conducted on the thermal properties (mainly thermal conductivity) and singlephase and boiling heat transfer performance (mainly singlephase heat transfer). It has been demonstrated that nanofluids can have significantly better heat transfer characteristics than the base fluids. Several good comprehensive reviews have summarized the available studies on heat transfer of nanofluids [1-5]

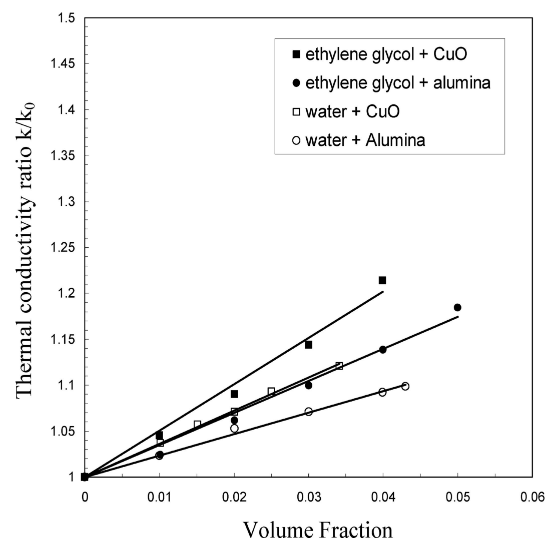

Fig:3 Enhanced thermal conductivity of oxide nanofluids systems as measured by Lee et al. [18]. *k/ko* denotes the ratio of thermal conductivity of nanofluid to that of the base fluid.

V. CONCLUSION

Research work on the concept, its thermo-physical properties, heat transfer enhancement mechanism, and application of the nanofluids is still in its primary stage. This study provides a review of research in this field with focus on thermal properties of nanofluids as well as in heat transfer applications to increase the efficiency.

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