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A Comprehensive Review of Nano-Fluid Heat Transfer Mechanism

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ABSTRACT

In this paper, a comprehensive review of nano-fluid heat transfer mechanism and its thermo-physical properties are done. Different nano-fluid preparation techniques, heat transfer mechanism and their thermo-physical properties are discussed in detail. As we know, heat transfer in nano-fluid depends on parameters such as Brownian motion of particle, molecular layering of the liquid-particles interface and nano particle clustering. Also, the effect of metal oxides nano particles in heat transfer enhancement of the nano-fluid is enormous. It is also known that, the coolants have high thermal conductivities at low volume concentration of nano-fluid. The thermal conductivity and viscosity of nano-fluids mostly depend on their size, volume concentration, shape and material. The increase or decrease of nano-fluid viscosity depends upon the material of nano particle. It is also observed that the viscosity of nano-fluid increases with increase in volume of nano particle.

Keywords: Nano particles, Nano- fluid, Thermal Conductivity, Viscosity, Volume Concentration, Heat Transfer.

1. INTRODUCTION

The resources in nature are limited, with these fast depleting resources, maximizing efficiency is very important. Most of the Industries face the severe problem of heat transfer enhancement of thermal systems on account of limited resources, confined space etc. In electronic industries the electronic devices are manufactured into smaller volumes and major problem arises due to this is how to dissipate the heat generated from these devices. Therefore there is an increased emphasis on maximizing heat transfer rate. The minimization of energy waste by increasing the effectiveness of heat transfer is a trending area of research. The conventional fluids used for heat transfer purpose have low thermal conductivity. The increase of heat transfer through extended surfaces has already reached its limit. Therefore, we need to look for alternatives to achieve our objective. Nano fluid is looks to fill this gap and have been the recent advancement to increase heat transfer. Fluids with nano particles (diameter less than 100 nm) suspended inconventional fluids are called Nano fluids. Proper dispersion of nano particles into base fluid forms stable Nano fluids this exhibits several beneficiary features. The introduction of few nano particles in the base fluid increases thermal conductivity of the base fluid significantly. Their enhanced thermal conductivity in-turn can improve the heat transfer rate and energy efficiency in various fields like defence, transportation, space, power generation etc.

2. NANO FLUID PREPARATION

The preparation of Nano fluid is the first step for experimental studies. Nano fluid consists of metals, carbides, oxides and carbon nano tubes well dispersed in conventional fluids. Researchers are studied and used a two-step process to produce nano-tubes via inert gas condensation process [1-2]. This process involves the vaporization of a source material under

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vacuum conditions. An advantage of this technique is that nano particle agglomeration is minimized. The disadvantage is that only low vapour pressure fluids are compatible with the process [3] and the pure metallic nano particles cannot be produced. The formation of such a problem can be reduced by using a direct evaporation condensation method [4-6].This method produces stable Nano fluids without surfactants by regulating the size of particle. Alumina Nano fluids can be synthesized by laser ablation method [7]. Gold and silver Nano fluids can be produced by pure chemical synthesis [8]. Nano fluids with copper nano particles dispersed in ethylene glycol are prepared using one-step pure chemical synthesis method [9].

3. NANO FLUID HEAT TRANSFER MECHANISM

The heat transfer mechanism is altered in the coolants by adding the Nano fluids. Importantly the thermal conductivity of the coolant is enhanced. The reasons for higher thermal coefficients in Nano fluids are brought out by Keblinski et al. [10]. The theories behind the enhancements are discussed in the following sections.

3.1. Brownian motion of a Particle

In the Brownian motion of nano particles, particles move through liquid and collide, thereby enabling direct solid to solid transfer of heat. This is essential for thermal conductivity enhancement along with increase in temperature and decrease in nano particles sizes [11]. Based on the experimental study the Wangetal. [12] Found that the microscopic forces such as Vander Walls force, electro static force and stochastic force are responsible for increase in the Brownian motion of particles, this result in enhancing the heat transfer rate. As mentioned in the Stokes-Einstein formula [13], the Brownian motion depends on the particle diffusion constant (D).

3.2. Molecular Layering of the Liquid-Particles Interface

An interface effect of liquid around the particles could enhance thermal conductivity. Also this helps to get more ordered atomic structure of liquid layer than that of the bulk liquid [10]. A liquid shell around the particles behaves like solids, this helps to achieve high thermal conductivity.

3.3. Nature of Heat Transport in Nano particles

Macroscopic heat transport can be explained using phonons. These phonons are responsible for carrying heat in Nano fluids. These phonons are characterized by randomness in their creation and propagation this gets scattered by each other and results in enhanced heat transfer.

3.4. Nano particle clustering in Nano fluids

Clustering of nano particles play a vital role in thermal conductivity. As the temperature increases, a well diffused percolated structure is formed. Clusters accumulate and form isolated regions at lower temperatures resulting in formation of disconnected cluster networks. This leads to formation of "particle free-zones" and "particle rich-zones" regions [14]. A well diffused thermal pathway at higher temperatures would promote heat transport; while isolated clusters would have inverse effect on heat transport at lower temperature. The variation of cluster formation with respect to temperature can be seen the Fig.1 [15].

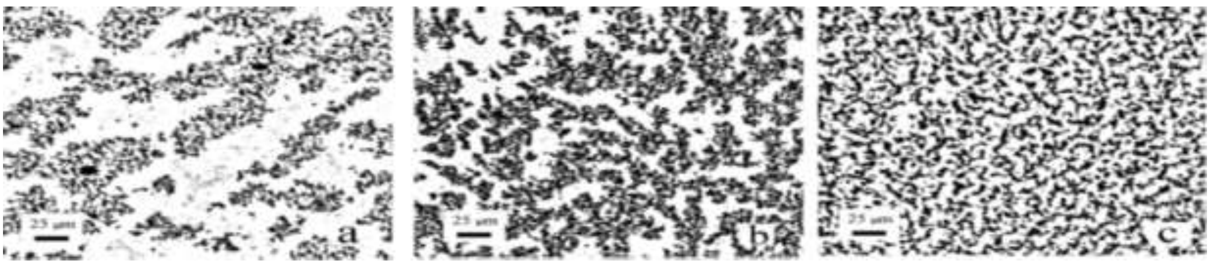

Figure1 Images containing CNT: (a) Frozen sample (b) at room temperature (c) at 100°C [15]

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4. THERMO-PHYSICALPROPERTIES OF NANO FLUIDS

The present day research in Nano fluids is mainly concentrated to study the changes in thermo-physical properties like thermal conductivity and viscosity caused by nano particles.

4.1. Thermal Conductivity

Thermal conductivity enhancement is the most sought after research area in the field of nano particle. Enhanced thermal conductivity is required in many applications and Nano fluids show a great potential in achieving that. It is function of many parameters like, volume concentration of nano fluid, particle material, particle size and temperature etc. The effect of these parameters is discussed in the following sections.

4.1.1. Effect of Volume Concentration

Thermal conductivity is measured initially with oxide nano particles [16, 17]. It is found thatthe copper nano particles increased thermal conductivity significantly [18]. Al_2O_3 as Nano fluid used in different applications resulted in increase of thermal conductivity up to 29% at 5 vol % [19]. Volume fraction of 2, 4 and 6 resulted in enhancement in heat transfer by 12.1%, 11.5% and 11% respectively. The enhancement of 30-45% was found, when 1 vol% of nano particles is added into pure water [20]. Non-linear relationship between particle concentration and thermal conductivity was found with Fe-ethylene glycol nano fluid [21]. Oxides of copper displayed high heat transfer coefficient for a higher volume fraction. Thermal Conductivity enhancement of 8% and 6% was found at 0.4 vol % and 0.15% respectively [22]. Also reported that 37% enhancement occurred in 1% weigh. Therefore, higher volume fraction displayed higher thermal conductivity. Many other researchers reported that the thermal conductivity increases with increase of volume fraction of particles [23-25].

4.1.2. Effect of Particle Material

Particle material has an important role in deciding the thermal conductivity of the nano fluid. Even though the thermal conductivity of Al_2O_3 is higher than CuO nano particle, CuO nano particle causes more heat transfer than the Al_2O_3 nano particles [17]. It is understood that the enhancement of thermal conductivity is decided majorly by Brownian motion [26]. Since Al_2O_3 forms larger agglomerates than CuO, which is responsible for the diminishing of the Brownian motion.

4.1.3. Effect of Particle Geometry

Particle shape influences the thermal conductivity of Nano fluids [27] for SiC nano particles with spherical and cylindrical shape for water and ethylene glycol. The cylindrical particles of average diameter 600 nm exhibit the enhancement of 22.9% and spherical particles enhanced up to 15.8%. So, cylindrical nano particles give higher enhancement in thermal conductivity than spherical nano particles. Stability of Nano fluids can be increased by fictionalization and also the length of CNT is an important factor in enhancement of thermal conductivity [28].

4.1.4. Effect of Temperature

Temperature plays an important role in determining the thermal conductivity of nano fluid. Temperature dependence of nano fluid is attributed to the change in Brownian movement and clustering with change in temperature [29]. Enhancement of thermal conductivity is governed mainly by two factors namely Brownian motion and thermal carriers inside the particles [30].Hussein et al. [31] reported that if the inlet temperature of SiO_2 is changed from 60°C-80°C, heat transfer was enhanced by 39% to 56% respectively. The introduction of small amount of nano particles to the base fluid in liquid cooling system caused a significant decrease in operating temperature of processor [32]. If the inlet temperature of coolant to

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automobile is varied from 37-49°C for 1 vol%, the heat transfer coefficient gone up by 7% [20, 33]. Thermal conductivity increment with temperature is reported using the coolant, CuO-water nano fluid [34] and Al_2O_3-water nano fluid [35].

4.2. Viscosity

Viscosity is an important parameter for heat transfer in Nano fluids. This is due to the fact that pressure drop directly depends on viscosity. The increase in viscosity leads to increase in pressure drop leads to increase in pumping power. Viscosity highly depends on factors such as volume fraction, particle size and temperature. The internal resistance force offered by the fluid is called viscosity and it is an important factor for all heat transfer application [36]. Many studies have been reported for effect of viscosity on heat transfer and it is discussed in the following sections.

4.2.1. Effect of Volume Fraction

Lu and Fan [37] studied the effect that the volume fraction of Al_2O_3 had on the shear viscosity of water and ethylene glycol Nano fluids. The result concluded that viscosity of pure ethylene glycol and mixture is less than that of the mixture. The shear viscosity increases upon addition of larger amounts of nano particles to the pure fluid. Similar results were reported for shear viscosity of gold-water nano fluid [38]. Prasher et al.[39] stated that the viscosity enhancement and amount of particles are directly proportional and viscosity is found to be higher around ten times that of base fluid. Increase of viscosity ratio is more for water based nano fluid as compared to ethylene glycol based nano fluid [40]. A contrary statement for the viscosityvariation with volume fraction was reported for ethanol based SiO_2 nano fluid [41]. In general, it is accepted that the viscosity of nano fluid enhances with increasing volume fraction.

4.2.2. Effect of Temperature

Most of the studies reported that the decrease in viscosity results increase in temperature. Water based $Al_2O_3$and CuO nano fluid displayed this trend while increasing the temperature from 21°C to 75°C [40, 43]. Water based TiO_2 and SiC Nano fluids also had the same trend of decreasing viscosity with increase in temperature [43, 46, and 47]. Some contradictory results were reported for water based carbon nano tubes. Some studies also concluded that the viscosity may be independent of temperature in the case of nano fluid [39, 48, 49]. Further studies are required involving many nano materials to ascertain the effect of temperature on Nano fluid.

5. CONCLUSION

Present study is a comprehensive review of Nano fluid heat transfer mechanism and thermo-physical properties. The Nano fluid preparation techniques, heat transfer mechanism and thermo-physical properties are discussed in detail. Metal oxides nano particles had a great effect in heat transfer enhancement of the nano fluid. Liquid layering and Brownian motion plays a major role in the mechanism of heat transfer. The major conclusions of these study areas follow

- The coolants have high thermal conductivities at low volume concentration of Nano fluid.
- Nano fluids' thermal conductivity and viscosity greatly depend on their size, volume concentration, shape and material.
- Nano fluid viscosity may increase or decrease depending upon the material of nano particle on lowering the size.
- Viscosity of nano fluid increases with increase in volume fraction of nano particle.
- Further experimental studies are needs to be carried out involving many nano materials to ascertain the effect of temperature on Nano fluid.

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NOMENCLATURE

k_B	Boltzmann Constant
D	Particle Diffusion Constant
d	Particle Diameter
T	Temperature
l	Mean free path
C_p	Specific Heat
T_m	Melting Point
ρ	Density
η	Viscosity
χ	Thermoelectric Conductivity
a	Lattice Constant
γ	Gruneisen parameter

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