FACTORS AND MECHANISMS RESPONSIBLE FOR HEAT TRANSFER ENHANCEMENT USING NANO FLUID

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Abstract:A colloidal mixture of Nano fluid particles in a base fluid is called Nano fluid which is a new generation of Heat transfer fluid for various heat transfer applications. This paper analyses and summarizes the various factors affecting Nano-fluid thermal performance such as particle size, fluid type, temperature, volume concentration, PH, particle shape and the latest developments regarding the mechanisms that influences the enhancement of Heat transfer by using Nano fluids.

IndexTerms - Nano fluid, Thermal conductivity, Brownian motion

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I. INTRODUCTION

Nano fluids are a new class of fluids, developed by dispersing Nano meter sized materials (Nano particles, Nano fibres, Nano tubes, Nano wires, Nano rods, Nano sheets) in the base fluids. Common base fluids include water, organic fluids, oils lubricants and bio fluids etc. Materials commonly used as Nano particles include chemically stable metals (Ex: - Ag, Au, Cu), Metal oxides (Ex:-Alumina, silica, MgO) ceramic oxides (Ex:-Al_2O_3, CuO) etc. Preparation of Nano-fluids is the first key step in experimental studies with Nano-fluids. Nano fluid is not simply liquid-solid mixtures. Some special requirements are essential, e.g., even and stable suspension, durable suspension, negligible agglomeration of particles, no chemical change of the fluid, etc. Nano fluid are produced by dispersing Nanometre-scale solid particles into base liquids such as water, ethylene glycol (EG), oils, etc. In the preparation of Nano-fluids agglomeration is a major problem. There are mainly two techniques used to produce Nano-fluids. The single-step and the two-step method. The single-step direct evaporation approach was developed by Akoh[1] et al. (1978) and is called the VEROS (Vacuum Evaporation onto a Running Oil Substrate) technique. The original idea of this method was to produce Nanoparticles, but it is difficult to subsequently separate the particles from the fluids to produce dry Nanoparticles. A modified VEROS process was proposed by Wagener[2] et al. (1997). They employed high pressure magnetron sputtering for the preparation of suspensions with metal Nanoparticles such as Ag and Fe. Eastman[3] et al. (1997) developed a modified VEROS technique, in which Cu vapour is directly condensed into Nanoparticles by contact with a flowing low-vapour-pressure liquid (EG).

Zhu[4] et al. (2004) presented a novel one-step chemical method for preparing copper Nano-fluids by reducing $CuSO_4{\cdot}5H_2O$ with $NaH_2PO_2{\cdot}H_2O$ in ethylene glycol under microwave irradiation. Results showed that the addition of $NaH_2PO_2{\cdot}H_2O$ and the adoption of microwave irradiation are two significant factors which affect the reaction rate and the properties of Cu Nano-fluids.

A vacuum-SANSS (submerged arc Nanoparticle synthesis system) method has been employed by Lo[5] et al. (2005) to prepare Cu-based Nano-fluids with different dielectric liquids such as de-ionized water, with 30%, 50%, 70% volume solutions of ethylene glycol and pure ethylene glycol. They found that the different morphologies that are obtained are mainly influenced and determined by the thermal conductivity of the dielectric liquids. CuO, Cu_2O, and Cu based Nano-fluids can also be efficiently prepared by this technique. An advantage of the one-step technique is that Nanoparticle agglomeration is minimized, while the disadvantage is that only low vapour pressure fluids are compatible with such a process. Recently, a Ni Nano-magnetic fluid and silver Nano fluid were also produced by Lo[6] et al. (2006) using the SANSS method. The spherical silver Nanoparticle formed in the ethylene glycol and the mean particle size is about 12.5 nm, which more closely resembles Newtonian fluids.

The two-step method is extensively used in the synthesis of Nano-fluids considering the available commercial Nano powders supplied by several companies. In this method, Nanoparticles are first produced and then dispersed in the base fluids. Generally, ultrasonic equipment is used to intensively disperse the particles and reduce the agglomeration of particles. For example, Eastman et al. (1997), Lee et al. (1999), and Wang et al. (1999) used this method to produce Al_2O_3 Nano-fluids. Also, Murshed[7] et al. (2005) prepared TiO_2 suspension in water using the two-step method. Other Nanoparticles reported in the literature are gold (Au), silver (Ag), silica and carbon Nanotubes. As compared to the single-step method, the two-step technique works well for oxide Nanoparticles, while it is less successful with metallic particles.

While most Nano fluid productions to date have used one of the above-described (one-step or two-step) techniques, other techniques are available depending on the particular combination of Nanoparticle material and fluid. For example, Nanoparticles with specific geometries, densities, porosities, charge, and surface chemistries can be fabricated by templating, electrolytic metal deposition, layer-by-layer assembly, micro droplet drying, and other colloid chemistry techniques. Another process, the chemical vapour condensation technique, appears to offer advantages in terms of control of particle size, ease of scalability, and the possibility of producing novel core-shell Nanostructures (Srdic[8] et al, 2001). Still another technique is the shape- and size-controlled synthesis of Nanoparticles at room temperature (CaO[9] et al, 2006). The structural characteristics of Nanoparticles such as the mean particle size, particle size distribution, and shape depend on the synthesis method, and there is potential for good control. These characteristics for Nanoparticles in suspensions are not easily measured. This fact could account for some of the discrepancies in thermal properties reported in the literature among different experiments.

In addition to ultra sonification, some other techniques such as control of pH or addition of surface active agents are also used to attain stability of the suspension of the Nano-fluids against sedimentation. These methods change the surface properties of the suspended particles and thus suppress the tendency to form particle clusters. It should be noted that the selection of surfactants should depend mainly on the properties of the solutions and particles. Xuan and Li[10] (2000) chose salt and oleic acid as the dispersant to enhance the stability of transformer oil-Cu and water-Cu Nano-fluids, respectively. Oleic acid and cetyltrimethylammonium bromide (CTAB) surfactants were used by Murshed et al. (2005) to ensure better stability and proper dispersion of TiO_2-water Nano-fluids. Sodium dodecyl sulphate (SDS) was used by Hwang[11] et al. (2005) during the preparation of water-based multi-walled carbon Nanotube (MWCNT) Nano-fluids since the fibres are entangled in the aqueous suspension.

By suspending Nano-particles in the base fluid heat transfer rate can be improved due to following reasons

- The suspended Nanoparticles increase the surface area and heat capacity of the fluid.
- The suspended Nanoparticles increase the effective thermal conductivity of the fluid.
- The interaction and collision among particles, fluids and the flow passage surface are intensified.
- The dispersion of Nano particles flattens the transverse temperature gradient of the fluid in its flow passage.
- The pumping power is low when compared to that of pure fluids to achieve equivalent heat transfer enhancements.
- There is reduced particle clogging when compared to conventional slurries.

II. MECHANISMS

2.1 Heat conduction Mechanisms in Nano fluids

Keblinski[12] presented four possible mechanisms in Nano fluids which may contribute to thermal conduction.

(a) Brownian motion of Nano particles.
(b) Liquid layering at the liquid/particle interface.
(c) Ballistic nature of heat transport in Nanoparticles.
(d) Nano particle clustering in Nano fluids.

Brownian motion is the random motion of particles suspended in a fluid (a liquid or a gas) resulting from their collision with the fast-moving atoms or molecules in the gas or liquid. The Brownian motion of Nano-particles could contribute to the thermal conduction enhancement through two ways, a direct contribution due to motion of Nano-particles that transport heat, and an indirect contribution due to micro-convection of fluid surrounding individual Nano-particles. In the second kind of modelling, the structure of the Nano fluid is considered analogous to the structure of a composite material. This composite material would present a core composed of the Nanoparticle, an interface layer containing intermediate properties surrounding this core, and a matrix composed of the base fluid that immerses these two regions. The composition of these regions could form a multiphase system, in which the phase superposition would be the main factor responsible for enhancing the thermal conductivity of the mixture. According to Ding et al. [30], at the interface between the solid particles and the base fluid, the liquid molecules could be significantly more ordered than along the rest of the base fluid. This can directly influence the thermal behaviour of the Nano-fluids, approaching the behaviour of crystalline solids, the conductivity of which is greater than that observed in liquids fig. 1, extracted from Keblinski[12] et al. shows that the rise of the interface layer results in an enhancement in the thermal conductivity proportional to the size of this layer. In this case, κ represents the dimensionless enhancement of the thermal conductivity. However, it is important to notice that the effect of the formation of an interface layer can deteriorate the thermal conductivity of a Nano fluid. In cases in which the interface presents a significant thermal resistance, (e.g., when the size of the Nano-particles is small as compared to a characteristic length of the flow), the use of Nano-fluids is not recommended. Several researchers used the interface layer concept in order to explain the great enhancement obtained in the thermal conductivity of Nano-fluids. Yu and Choi [31, 32] suggested models considering an interface layer of Nano metric dimensions formed by a base fluid around the Nano-particles.

A third kind of modelling is the study of the formation of particle clusters and of the distribution of these clusters. A study involving these concepts was presented by Wang and Mujumdar [15]. Ding et al. [30] also presented the use of a mechanism of structuring and clustering

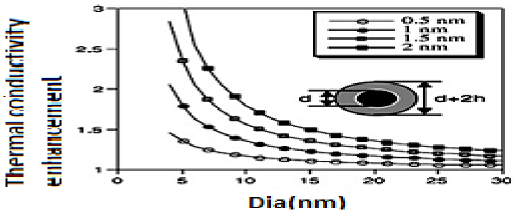

fig 1 effect of the thickness of the interface layer on thermal conductivity enhancement

This mechanism proposes the use of particle clusters with equivalent thermal conductivity. The results from the application of this model have good agreement with the experimental results. Several studies presented in Kakac and Pramuanjaroenkij[19] also reported that excessive particle clustering in Nano-fluids deteriorates the thermal conductivity so that an optimum level of clustering must be evaluated in order to achieve a maximum enhancement.

Fig. 2, reproduced from Keblinski[12] et al. shows that particle clusters with less compact structures allow a greater enhancement in heat transfer than compact arrangements. In this case, κ represents the dimensionless enhancement of thermal conductivity and ϕ represents the dimensionless particle clustering.

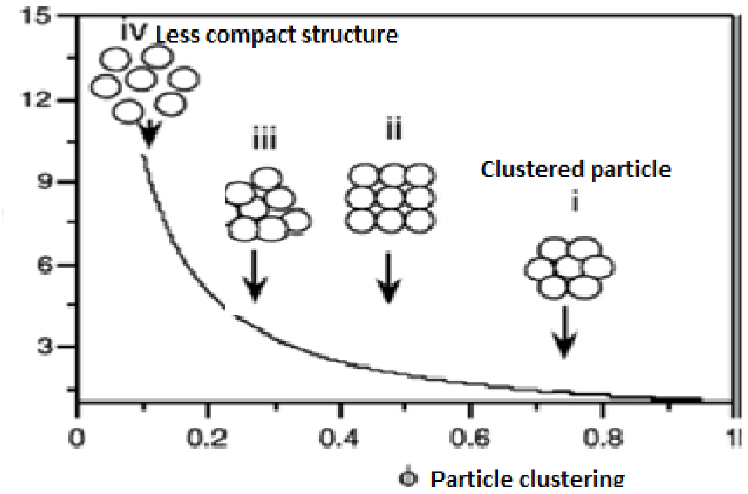

fig 2 effect of clustering of particles on thermal conductivity enhancemen

2.2 Formation of Chain Structure:

Studies of Nano-particles by Xinweiwang and Xianfauusing transmission electron microscopy (TEM) show that the Al2O3 particles used in the work are spherical. Particles in the liquids are not separated completely. Using TEM, it is found that some particles adhere together to form a chain structure. According to Hamilton and Crosser, [20] heat transfers could be enhanced if the particles form chain structures because more heat is transported along those chains oriented along the direction of the heat flux. The effect of the particle size is not considered in their treatment. Assuming that an average chain consists of three particles, the thermal conductivity of particles is 10 times that of the base liquid, and there is 5 vol % particles in liquid, the thermal conductivity will increase 3% according to Hamilton and Crosser's equation[20] if the thermal conductivity ratio is taken as infinity, the increase of thermal conductivity is about 7%. Therefore, it is possible that the chain structure contributes to a thermal conductivity increase in Nanoparticle admixtures

A brief summary of previous research on thermal conductivity enhancement is as fallows in the early phase of research period, the research group in Argonne National Laboratory made crucial contribution to start the study. Eastman[21] et al. reported that they prepared stable water based CuO Nano-fluids of 5 volume%, and observed 60% thermal conductivity enhancement. Wang[22] et al. measured thermal conductivity of water based CuO and Al_2O_3 Nano-fluids using a steady-state parallel plate method, and reported that their thermal conductivity was higher than those of conventional predictions.

Xian and Li prepared water based Cu Nano-fluids using two-step method, and investigated the effects of particle volume fraction, shape, size, and material properties on effective thermal conductivity. They reported that particle Brownian motion, sedimentation and dispersion would enhance convection heat transfer performance. Choi [23]et al. measured the thermal conductivity of oil based CNT Nano-fluids, and reported the large and non-linear increase of thermal conductivity with volume fraction. Eastman[24]et al. measured the thermal conductivity of ethylene glycol (EG) based Cu Nano-fluids of 0.3 volume%, and reported 40% thermal conductivity enhancement. Xie[25] et al. measured thermal conductivity of water/EG based Sic Nano-fluids using transient hot-wire method, and concluded that the thermal conductivity enhancement is independent of base fluid type, and it is a function of particle size and shape. Das[26] et al. measured thermal conductivity of Nano-fluids using temperature oscillation technique at different temperature and reported it increased linearly with temperature.

Findings report that particle size, nature of material, operating temperature Thermal conductivity and pH value of base fluid all have an influence on Thermal conductivity enhancement in Nano fluids.

III. Convective Heat transfer Enhancement with Nano Fluids:

The past decade has seen many research activities in the experimental heat transfer characteristics of various Nano-fluids. For forced convective heat transfer, Lee and Choi[27] (1996) studied the heat transfer behaviour in parallel channels using an unspecified Nano fluid and observed a reduction in thermal resistance by a factor of 2. Xian and Li[28] (2003) experimentally investigated flow and convective heat transfer characteristics for Cu-water based Nano-fluids through a straight tube with a constant heat flux at the wall. Results showed that the Nano-fluids give substantial enhancement of the heat transfer rate compared to pure water. They also claimed that the friction factor for the Nano-fluids at low volume fraction did not produce an extra penalty in the pumping power.

Wen and Ding[29] (2004b) reported experimental results for the convective heat transfer of γ -Al_2O_3 (27-56 nm)/water based Nano-fluids flowing through a copper tube (D = 4.5 mm, L = 970 mm) in laminar regime. They found that the inclusion of Al_2O_3 particles can significantly enhance the convective heat transfer coefficient, which increases with increasing Reynolds number and particle concentrations. Furthermore, the improvement of the heat transfer coefficient was particularly large in the entrance region, and decreased with the axial distance. Apart from the improved effective thermal conductivity, they also attributed the improvement of heat transfer to particle migration, which caused a non-uniform distribution of thermal conductivity and viscosity field along the cross-section in the tube.

Li & Xuan [30] and Xuan &Li [65] presented an experimental system to investigate the convective heat transfer coefficient and friction factor of Nano-fluids for laminar and turbulent flows in a tube. The working fluid used was 100nm Cu particles dispersed in de-ionized water. Experiments with different concentrations of Nano-particles were conducted. The Reynolds number of the Nano-fluids varied in the range of 800 – 25000. The experimental results concluded that the convective heat transfer coefficient of the Nano-fluids 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 Nano-fluids with 2%volume fraction of Cu particles was 60% higher than that of water. The results are shown in fig. 3.

From the experimental data of Xuan & Li[30] the new heat transfer correlations for the prediction of the heat transfer coefficient of Nano-fluids flowing in a tube were given as follows:

a) For laminar flow $Nu_{nf} = 0.4329(1.0+11.285\emptyset^{0.754}Pe_d^{0.218})Re_{nf}^{0.333}Pr_{nf}^{0.4}$

b) For turbulent flow $Nu_{nf} = 0.0059(1.0+7.6286\emptyset^{0.688}Pe_d^{0.001})Re_{nf}^{0.923}Pr_{nf}^{0.4}$

Researchers have claimed that the heat transfer enhancement of Nano-fluids is not only caused by the thermal conductivity increase, but also attributed to other factors such as dispersion and chaotic movement of Nano-particles, Brownian motion and particle migration, shear-induced enhancement in flow, reduced boundary layer, particle re-arrangement, and high aspect ratio

The introduction of the Nano-particles directly can affect other physical properties of the base fluid, such as specific mass, specific heat, and dynamic viscosity. This causes the enhancement in the convection heat transfer coefficient to be even greater than the enhancement obtained due to the thermal conductivity. The enhancement obtained in the specific mass of the Nano-fluid can be represented by the mixture rule, defined for microscopic dispersions and widely spread among the literature. Experimental results by Pak and Cho [32] and Ho[33] et al. show that the mixture rule can be also used for mixtures containing Nano-sized particles with an excellent agreement.

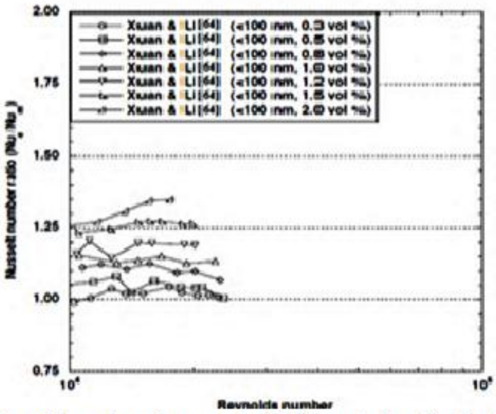

fig 3 nusselt number enhancement with different volume fraction for nano particles

The mixture rule can be represented as:

$$\rho_{nf} = \rho_{np}\emptyset + \rho_{bf}(1-\emptyset)$$

Regarding the specific heat of Nano-fluids, O'Hanley[34] et al. studied the behaviour of the two main correlations used by the majority of the present works to describe this property of a Nano-fluid.

$$c_{p,nf} = \frac{\emptyset(\rho c_p)_{np}+(1-\emptyset)(\rho c_p)_{bf}}{\emptyset(\rho)_{np}+(1-\emptyset)(\rho)_{bf}}$$

Regarding the models used for evaluating the forced convection using Nano-fluids, besides the parameters usually used for determining the flow characteristics, such as the Reynolds number, and the thermal properties of the fluid, such as the Prandtl number, the use of Nano-fluids require additional parameters, so that the correlations take into account the physical phenomena that occur using Nano-fluids. Kakac and Pramuanjaroenkij [35] defined that the convection heat transfer coefficient of a Nano-fluid is expected to be related mainly to the following parameters:

- The thermal conductivities of the base fluid and of the Nanoparticle.
- The specific heat of the base fluid and of the Nanoparticle.
- The flow regime the Nano fluid is subjected to (through the Reynolds number).
- The temperature of the Nano fluid.
- The particle volume fraction of the Nano fluid.
- The dimensions and the geometry of the Nano-particles.

Buongiorno [36]discussed the influence of these and many other possible mechanisms responsible for the convective heat transfer enhancement using Nano-fluids. The main mechanisms studied were:

- Inertia
- Brownian diffusion

The irregular motion of small particles suspended in a liquid or a gas,caused by the bombardment of the particles by molecules of the medium: first observed by Robert Brown in 1827.

Thermophoresis (Sorbet effect)

Thermophoresis (also thermo migration, thermo diffusion, the Soret effect, or the Ludwig-Soret effect) is a phenomenon observed in mixtures of mobile particles where the different particle types exhibit different responses to the force of a temperature gradient.

Diffusophoresis:

Diffusophoresis is a spontaneous motion of dispersed particles in a fluid induced by a diffusion gradient (also called concentration gradient) of molecular substances that are dissolved in the fluid. This gradient affects structure of the particles in an interfacial double layer and causes sliding motion of the fluid relative to the particle surface.

Magnus effect:

Magnus effect **is** generation of a sidewise force on a spinning cylindrical or spherical solid immersed in a fluid (liquid or gas) when there is relative motion between the spinning body and the fluid.

- Fluid drainage
- Gravity

From the effects presented, it was concluded that, for laminar flow and for the viscous sub layer of the turbulent flow, the effects whose relevance are more significant to the thermal behaviour of a Nano fluid are thermophoresis and Brownian diffusion. However, in the turbulent region, the Nano-particles are dragged by the vortexes without friction, making these mechanisms less relevant.

IV. CONCLUSIONS

Nano fluid, i.e., well-dispersed metallic Nano-particles at low volume fractions in liquids, enhances the mixture's thermal conductivity over the base-fluid values. Thus, they are potentially useful for advanced cooling of micro-systems. This paper presents an overview of the recent developments in the study of Nano-fluids, including the preparation methods, the evaluation methods for their stability, the ways to enhance their stability, the stability mechanisms, and their potential applications in heat transfer intensification, mass transfer enhancement, energy fields, and mechanical fields and so on. The performance of Nano fluid critically depends upon the size, quantity (volume percentage), shape and distribution of dispersoids, and their ability to remain suspended and chemically un-reacted in the fluid. In summary, the future scope in the Nano fluid research cycle are to concentrated on heat transfer enhancements and determine its physical mechanisms, taking into consideration such items as the optimum particle size and shape, particle volume concentration, fluid additive, particle coating, and base fluid. Precise measurement and documentation of the degree and scope of enhancement of thermal properties is extremely important. Better characterization of Nano-fluids is also important for developing engineering designs based on the work of multiple research groups, and fundamental theory to guide this effort should be improved. Finally, it is pertinent to suggest that Nano fluid research warrants a genuinely multidisciplinary approach with complementary efforts from material scientists (regarding synthesis and characterization), thermal engineers (for measuring thermal conductivity and heat transfer coefficient under various regimes and conditions), chemists (to study the agglomeration behaviour and stability of the dispersoid and liquid) and physicists (modelling the mechanism and interpretation of results).

At the end of this review, it becomes quite clear that the most significant mechanisms that influence the thermal transfer behaviour of a Nano fluid are the Brownian motion of Nano-particles, the particle clustering phenomenon and the formation of an interface layer around the Nano-particles. These parameters directly affect many of the correlations defined for the thermal conductivity of a Nano fluid. Also, these mechanisms are directly responsible for many of the practical problems observed with the use of Nano fluid in heat transfer applications. For the convection heat transfer coefficient, the enhancement obtained in some cases was even greater than the enhancement that would be obtained due to the thermal conductivity enhancement; that led the researchers to seek for alternative mechanisms to describe this phenomenon, such as thermal dispersion, particle migration, Brownian diffusion and thermophoresis.

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