A Review on Heat Transfer Enhancement of Nanofluids

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Abstract
Nanofluids are suspensions of nano particles in fluids that show significant enhancement of their properties at modest nano particle concentrations. In heat exchanger utilization of nano fluid will improve the performance of particular heat exchanger. This paper focuses one explaining the basic mechanisms of improvement in heat transfer by addition nano particles.

Keywords: Nano fluid, Heat Transfer, Thermal conductivity.

1.1 Introduction
Due to the limitation of fossil fuel in the world, subject of energy consumption optimization in various industrial processes becomes very important. In chemical processes one of the most important devices related to energy and heat transfer is heat exchanger. For decades, efforts have been done to enhance heat transfer, reduce the heat transfer time, minimize size of heat exchangers, and finally increase energy and fuel efficiencies. These efforts include passive and active methods such as creating turbulence, increasing area, etc. Most of them are limited by inherent restriction of thermal conductivity of the conventional fluids (such as water, mineral oil and ethylene glycol). The poor heat transfer properties of the employed fluids in the industries are obstacles for using different types of heat exchangers. Since solid particles have thermal conductivity higher than that of common fluids, when they are dispersed in the fluids result in higher heat transfer characteristics. There are many types of particles such as metallic, nonmetallic and polymeric. However, due to large size of micro and macro-sized particles, they will face some problems in using of these suspensions, such as clogging of flow channels due to poor suspension stability, erosion of heat transfer device, and increasing in pressure drop. Nanofluids are engineered colloids made of a base fluid and nano particles (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 nano particles include chemically stable metals (e.g. gold, copper), metal oxides (e.g., alumina, silica, zirconia, titania), oxide ceramics (e.g. Al_2O_3, CuO), metal carbides (e.g. SiC), metal nitrides (e.g. AIN, SiN), carbon in various forms (e.g., diamond, graphite, carbon nano tubes, fullerene) and functionalized nano particles. Solids have thermal conductivities which are orders of magnitude larger than those of conventional heat transfer fluids. By suspending nano particles in conventional heat transfer fluids, the heat transfer performance of the fluids can be significantly improved [1-5].

A decade ago, with the rapid development of modern nanotechnology, particles of nano meter-size (normally less than 100 nm) are used instead of micro meter-size for dispersing in base liquids, and they are called nano fluids. This term was first suggested by Choi [1] in 1995, and it has since gained in popularity. Heat transfer nano fluids 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 single phase and boiling heat transfer performance (mainly single phase heat transfer). It has been demonstrated that nano fluids can have significantly better heat transfer characteristics than the base fluids. Several good comprehensive reviews have summarized the available studies on heat transfer of nano fluids [1-2]. From these reviews, the following key features of nano fluids have been found:

(i) They have larger thermal conductivities compared to conventional fluids;
(ii) They have a strongly non-linear temperature dependency on the effective thermal conductivity;
(iii) They enhance or diminish heat transfer in single-phase flow;
(iv) They enhance or reduce nucleate pool boiling heat transfer;
(v) They yield higher critical heat fluxes under pool boiling conditions.

Choi and Eastman [3] invented a method and apparatus for enhancing heat transfer in fluids such as deionized water, ethylene glycol and oil by dispersing nano crystalline particles of substances such as copper, copper oxide, aluminum oxide and the like in the fluids. Nano crystalline particles are produced and dispersed in the fluid by heating the substance to be dispersed in a vacuum while passing a thin film of the fluid near the heated substance. The fluid is cooled to control its vapor pressure. Figure (**1**) shows a plot of conductivity as a function of particle volume in deionized water.

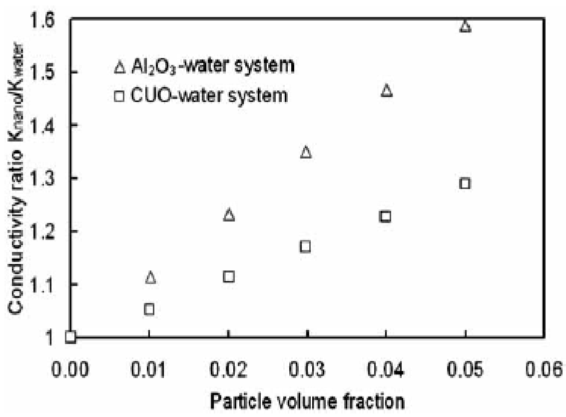

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FIG.1 Conductivity ratio of nano fluid to base fluid versus particle volume fraction

Maes *et al*. [4] and Mae [5] invented nano fluids containing nano-particles and carboxylates for improving the heat transfer characteristics of heat transfer fluids or antifreeze coolants. The carboxylates from a stable physisorbedor chemisorbed carboxylate protective layer on metallic nano-particles that does not hinder heat transfer. The combination of carboxylates and metallic nano-particles provide excellent corrosion protection, improved heat transfer and enhances the stability of the nano-particles in suspension. Nano particles treated with carboxylates to form a chemisorbed carboxylate protective layer are used in heat transfer fluid or lubricate or hydraulic fluid or soap.

Tsujii [6] and Egawa and Tsujii [7] invented a heat transfer medium composition excellent in dispersion stability of metal and/or metal oxide particles and high in the thermal conductivity characterized by comprising water and/or alcohol as the main component, and (a) one kind or two or more kinds selected from metal and or/ metal oxide particles having an average particle diameter of from 0.001 to 0.1 um,(b) one kind or two or more kinds selected from polycarboxylic acids and/or salts thereof, and (c) at least one kind of a metal corrosion inhibitor. The heat transfer medium liquid composition that can be used as a coolant for an internal-combustion engine, a motor and the like, a heat transfer medium for a hot water supply, heating, cooling and freezing system, or a heat transfer medium for a snow melting system, road heating and the like. In particular, the invention relates to a heat transfer medium liquid composition
which is excellent in dispersion stability of metal and/or metal oxide particles and high in thermal conductivity.

Davidson and Bradshaw [8] invented heat transfer compositions and methods for using same to transfer heat between a heat source and a heat sink in a transformer, and in particular to the utilization of nano-particle size conductive material powers such as nano-particle size diamond powders to enhance the thermal capacity and thermal conductivity of heat transfer compositions such as transformer oil. The thermal conductivity was greatly improved with same volume fraction nano particles addition.

Ohira [9] and Ohira *et al*. [10] invented a technique for reducing the reactivity or toxicity of a fluid in a liquid state, or for improving the flow resistance or thermal conductivity thereof. The inventors have accomplished their invention on the basis of the findings that the dispersion of nano size ultrafine particles (about 1 to 100 nanometers in diameter) such as metals, alloys or metallic compounds in a liquid fluid such as a liquid metal coolant or heat transfer medium for a heat exchanger can reduce the reactivity or toxicity thereof, and can improve the flow resistance or thermal conductivity thereof. The flow resistance of the liquid fluid can be raised, and the leakage of the liquid fluid from minute cracks cab be reduced. By using the liquid fluid as a heat transfer medium, of a heat exchanger, the heat transfer performance equivalent to or higher that the heat transfer performance of the original heat exchanger can be obtained.

Jeffcoate *et al*. [11] invented a fluid composition having enhanced heat transfer efficiency, by the addition of nano particles in coolants to enhance heat transfer efficiency. (a fluid composition includes a coolant and a plurality of nano particles dispersed within the coolant. The plurality of nano particles includes glass, silica, pumices, metal compounds adapted to react by providing a fluid composition including a coolant and a plurality of nano particles dispersed within the coolant. The plurality of nano particles includes glass, silica, pumices, metal compounds adapted to react with chloride in the coolant and /or mixtures thereof. The plurality of nano particles substantially increases heat capacity of the coolant, thus enhancing the fluid composition's heat transfer efficiency.

1.2 Influencing factors of thermal conductivity enhancement

In the experiment of the study, it was found that the thermal conductivity enhancements of nanofluids might be influenced by multi-faceted factors including the volume fraction of the dispersed NPs, the tested temperature, the thermal conductivity of the base fluid, the size of the dispersed NPs, the pretreatment process, and the additives of the fluids. The effects of these factors are presented in this section.

Particle Volume Fraction

Particle volume fraction is a parameter that is investigated in almost all of the experimental studies and the results are usually in agreement qualitatively. Most of the researchers report increasing thermal conductivity with increasing particle volume fraction and the relation found is usually linear. However, there are also some studies which indicate nonlinear behaviour. According to the some authors, such a nonlinear relation is an indication of interactions between particles. It was concluded that despite the fact that particle volume fraction is very small, nanotubes interact with each other due to the very high particle concentration (1011 particles/cm3)

Particle Material

Most of the studies show that particle material is an important parameter that affects the thermal conductivity of nanofluids. At first glance, it might be thought that the difference in the thermal conductivities of particle materials is the main reason of this effect. However, studies show that particle type may affect the thermal conductivity of nanofluids in other ways. For example, Lee et al. considered the thermal conductivity of nanofluids with Al2O3 and CuO nano particles and they found that nanofluids with CuO nano particles showed better enhancement when compared to the nanofluids prepared using Al2O3 nano particles. It should be noted that Al2O3, as a material, has higher thermal conductivity than CuO.

Particle Size

Particle size is another important parameter of thermal conductivity of nanofluids. It is possible to produce nano particles of various sizes, generally ranging between 5 and 100 nm. Eastman et al. concluded that the size of the nano particles is an important factor that affects the thermal conductivity enhancement, which is contrary to the predictions of conventional models such as Hamilton and Crosser model, which does not take the effect of particle size on thermal conductivity into account. The general trend in the experimental data is that the thermal conductivity of nanofluids increases with decreasing particle size. This trend is theoretically supported by two mechanisms of thermal conductivity enhancement; Brownian motion of nano particles and liquid layering around nano particles. However, there is also a significant amount of contradictory data in the literature that indicate decreasing thermal conductivity with decreasing particle size. In fact, for the case of nanofluids with Al2O3 nano particles, such results are more common than the results showing increasing thermal conductivity with decreasing particle size.

Particle Shape

There are mainly two particle shapes used in nano fluid research, spherical particles and cylindrical particles. Cylindrical particles usually have a large length-to-diameter ratio. Two types of nano particles were used by Xie et al., for the preparation of nanofluids; spherical particles with 26 nm average diameter and cylindrical particles with 600 nm average diameter. It was found that 4.2 vol. % water-based nano fluid with spherical particles had a thermal conductivity enhancement of 15.8%, whereas 4 vol. % nano fluid with cylindrical particles had a thermal conductivity enhancement of 22.9%. In addition to these experimental results, the fact that nanofluids with carbon nanotubes (which are cylindrical in shape) generally show greater thermal conductivity enhancement than nanofluids with spherical particles should also be considered. As a result, one can conclude that cylindrical nano particles provide higher thermal conductivity enhancement than spherical particles. One of the possible reasons of this is the rapid heat transport along relatively larger distances in cylindrical particles since cylindrical particles usually have lengths on the order of micrometers.

Temperature

In conventional suspensions of solid particles (with sizes on the order of millimeters or micrometers) in liquids, thermal conductivity of the mixture depends on temperature only due to the dependence of thermal conductivity of base liquid and solid particles on temperature .However, in case of nanofluids, change of temperature affects the Brownian motion of nano particles and clustering of nano particles, which results in dramatic changes of thermal conductivity of nanofluids with temperature.

Effect of Acidity (PH)

The number of studies regarding the pH value on the effect of fluid acidity on the thermal conductivity enhancement of nanofluids is limited when compared to the studies regarding the other parameters. A significant decrease in thermal conductivity ratio with increasing pH values as reported in literature. It was also observed that the rate of change of thermal conductivity with particle volume fraction was dependent on pH value. Thermal conductivity enhancement of 5 vol. % Al2O3/water nano fluid was 23% when pH is equal to 2.0 and it became 19% when pH is equal to 11.5. The authors related the dependence of thermal conductivity on pH to the fact that as the difference between the is electric point of Al2O3 nano particles and pH value of the solution increases, mobility of nano particles increases, which improve the micro-convection effect. It is obtained optimum values of pH (approximately 8.0 for Al2O3/water and 9.5 for Cu/water nanofluids) for maximum thermal conductivity enhancement. At the optimum value of pH, surface charge of nano particles increases, which creates repulsive forces between nano particles. As a result of this effect, severe clustering of nano particles is prevented.

Particle Material and Base Fluid

Many different particle materials are used for nano fluid preparation. Al2O3, CuO, TiO2, SiC, TiC, Ag, Au, Cu, and Fe nano particles are frequently used in nano fluid research. Carbon Nano tubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene glycol and engine oil. According to the conventional thermal conductivity models such as the Maxwell model, as the base fluid thermal conductivity of a mixture decreases, the thermal conductivity ratio (thermal conductivity of nano fluid (*knf*) divided by the thermal conductivity of base fluid (*kf*)) increases. It is seen that poor conductive fluid serve best then highly conductive ones. Hence water is generally is avoided. When it comes to nanofluids, the situation is more complicated due to the fact that the viscosity of the base fluid affects the Brownian motion of nano particles and that in turn affects the thermal conductivity of the nano fluid.

1.3Mechanisms of Heat Transfer Enhancement

Apart from the basic reason of improvement in thermal conductivity in nano fluids, the suspension of nano particles alters the flow behaviour in general. Following section describes several of the proposed mechanisms

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Enhancement of heat transfer by improvement in thermal conductivity.

Liquid molecules close to a solid surface are known to form layered structures. the layered molecules are in an intermediate physical state between a solid and bulk liquid. With these solid like liquid layers, the nano fluid structure consists of solid nano particles, solid-like liquid layer, and a bulk liquid. The solid-like nano layer acts as a thermal bridge between a solid nano particle and a bulk liquid and so is key to enhancing thermal conductivity.

Effect of Brownian Motion

It is a seemingly random movement of particles suspended in a liquid or gas and the motion is
due to collisions with base fluid molecules, which makes the particles undergo random-walk motion? Thus, the Brownian motion intensifies with an increase in temperature as per the kinetic theory of particles. Some researchers have suggested that the potential mechanism for enhancement of thermal conductivity is the transfer of energy due to the collision of higher temperature particles with lower ones. The effectiveness of the Brownian motion decreases with an increase in the bulk viscosity.

Thermophoresis

Thermophoresis or the Soret effect is a phenomenon observed when a mixture of two or more types of motile particles (particles able to move) is subjected to the force of a temperature gradient. The phenomenon is most significant in a natural convection process, where the flow is driven by buoyancy and temperature. The particles travel in the direction of decreasing temperature and the process of heat transfer increases with a decrease in the bulk density.

Clustering of nano particles

Nano particles are known to form clusters. These clusters can be handled by using fractal theory. Evans et al. proposed that clustering can result in fast transport of heat along relatively large distances since heat can be conducted much faster by solid particles when compared to liquid matrix. This phenomenon is illustrated schematically in below.

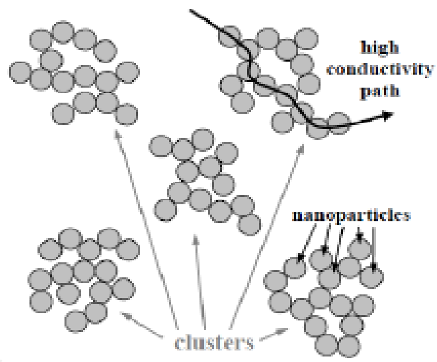

Fig.Schematic illustration representing the clustering phenomenon.

High conductivity path results in fast transport of heat along large distances, It was shown that the effective thermal conductivity increased with increasing cluster size. However, as particle volume fraction increased, the nano fluid with clusters showed relatively smaller thermal conductivity enhancement. When it comes to interfacial resistance, it was found that interfacial resistance decreases the enhancement in thermal conductivity, but this decrease diminishes for nanofluids with large clusters.

Intensification of turbulence

Xuan and Li proposed that the enhancement could also come from intensification of turbulence due to the presence of the nano particles. However, pressure drop measurements by Xuan and Li, Pak and Cho clearly show that turbulent friction factors in their nanofluids can be very well predicted by the traditional friction factor correlations for pure fluids, if the measured nano fluid viscosity is used. This suggests that, beyond the obvious viscosity effect, turbulence is not affected by the presence of the nano particles. This conclusion is corroborated by a comparison of the time and length scales for the nano particles and the turbulent eddies.

1.4 Current & Future Developments

Researchers have given much more attention to the thermal conductivity of nanofluids rather than their heat transfer characteristics. Most of the available heat transfer studies are related to single phase flows and some are related to nucleate pool boiling. However, the study of flow boiling and two-phase flow of nanofluids is very limited in the literature so far. None of the available reviews has specifically mentioned this new important research frontier although all have presented studies of nucleate pool boiling heat transfer of nanofluids with very brief descriptions. Apparently, there are many challenges in nano fluid two phase flow and thermal physics which is a new interdisciplinary research frontier of nanotechnology. Much work is needed to achieve the fundamental knowledge and practical applications.

1.5 Conclusion

As we will increase the particle diameter the thermal conductivity of the nano fluid will increase. Because as the particle size increase the Brownian motion will decrease and the Brownian motion will decrease the randomness will decrease and as we know that decrease in randomness will increase the thermal conductivity. But there is some controversies regarding this thermal conductivity will increase by increase in particle size. As we increase the particle volume fraction of the nano fluids the thermal conductivity will increases simultaneously. The chaotic movement of nano particles increases fluctuation and turbulence of the fluids, which increases the heat exchange process. Convective heat transfer coefficient is enhanced by increasing the particle concentration and the Reynolds number.

1.6 References

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