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# A Review Paper on Experimental Heat Transfer Enhancement using Nanofluids

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***Abstract -- Properties that mainly determine the thermal performance of a liquid for heat transfer applications are the thermal conductivity, viscosity, specific heat and density. Fluids such as air, water, ethylene glycol, and mineral oils are typically used as heat transfer media in applications such as power generation, chemical production, automobiles, air conditioning and refrigeration. However, their heat transfer capability is limited by their very low thermal conductivity. For enhancement of thermal conductivity of these fluids, much attention has been paid in the past decade to a new type of composite material i.e. nanofluids. Nanofluids are the suspensions of nanoparticles in base fluids. Nanoparticles have unique features different from conventional solids liquid mixtures in which mm or micrometer sized particles of metals and non-metals are dispersed. Due to their excellent characteristics nanofluids find wide applications in enhancing heat transfer. A nanoparticles suspension is considered as a three phase system including the solid phase (Nanoparticles), the liquid phase (fluid media), and the interfacial phase, which contributes significantly to the system properties because of their extremely high surface-to-volume ratio in nanofluids. The system engineering approach was applied to nanofluid design resulting in a critical assessment of various parameters in the multivariable nanofluid systems. Understanding the relative importance of nanofluid parameters for heat transfer allows engineering nanofluids with desired set of properties. This review provides an experimental review on the historical evolution of nanofluid concept, heat transfer enhancement of base fluid with nanoparticles and scope of applications of nanofluids.***

***Keywords: refrigeration, interfacial phase, nanoparticles, nanofluids, surface to volume ratio***

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## I. INTRODUCTION

Efficient transfer of energy in the form of heat from one body to another is often required in almost all industries. Thermal and nuclear power plant, refrigeration and air conditioning system, chemical and processing plants, electronic devices, space shuttles and rocket-launching vehicles, satellites are a few to name where the productivity as well as safety depends on efficient transfer of heat. Often a fluid is chosen as a medium for transferring heat and accordingly the mode of heat transfer is convection. The rate of heat transfer in convection is given by an apparently simple looking relationship; popularly known as Newton's law of cooling.

$$q = hA\,\Delta T$$

where the $q$ is the rate of heat transfer, $h$ is coefficient of convective heat transfer, $A$ is the surface area and $\Delta T$ is the temperature difference across which the transfer of thermal energy take place. It has been always the pursuit of the thermal engineers to maximize $q$ for given $\Delta T$ or $A$. This can be done by increasing $h$. However, this is easier said than done. Heat transfer coefficient is a complex function of the fluid property, velocity and surface geometry. Out of different fluid properties, thermal conductivity influences the heat transfer coefficient in the most direct way as this is the property that determines the thermal transport at the micro-scale level. [6] It is well known that metals in solid form have much higher thermal conductivity than that of fluids. Heat transfer by conduction through solid is orders of magnitude larger than that by convection/conduction through a fluid. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. [1] Therefore, fluids containing suspended solid particles are expected to display significantly enhanced thermal conductivities relative to those of conventional heat transfer fluids. [2] In fact, numerous studies about the effective thermal conductivity of fluids that contain solid particles in suspension have been conducted. Such fluids are called as nanofluids. Thus, 'nanofluid' is a new class of heat transfer fluid that utilizes dispersion of fine scale metallic particles in a heat transport liquid in appropriate size and volume fraction to derive a significant enhancement in the effective heat transfer coefficient of the mixture. In comparison to dispersing micron-size ceramic particles, nanofluids consist of suspension of ultra-fine or nanometric metallic particles with much smaller size and volume fraction, and yet offer higher efficiency of heat transport. The main excitement of using nanofluid arises due to the following features [10] :(a) Enhancement of thermal conductivity far beyond the level any theory could predict, (b) Dependence of thermal conductivity on particle size apart from concentration, (c) Greater stability of suspension using a stabilizing agent [11] , and (d) Retention of Newtonian behavior at small concentration without much pressure drop. The above mentioned potentials provided the thrust to begin research in nanofluid, with the expectation that these fluids will play an important role in developing the next generation of cooling technology. The result can be a highly conducting and stable nanofluid with exciting newer applications such as secondary refrigerants in the future.

## II. LITERATURE REVIEW

Suspension of nanoparticles like Al, Zn, Si etc. in base fluids are called nanofluids. Nanofluid is the new challenge for thermal science provided by nanotechnology. These nanofluids have unique features different from conventional solid liquid mixtures. They contain mm or micrometer sized particles of metals and non-metals. Due to their excellent physical and chemical characteristics they find wide applications in enhancing heat transfer.

**Sarit Kumar Das, Stephen U.S. Choi & Hrishikesh E. Patel** [1]presented a paper on "Heat Transfer in Nanofluids-A Review". In this paper they presented an exhaustive review of nanotechnology study and suggest a direction for future developments in nanotechnology. The conclusion drawn in this paper is that nanofluids show great promise for use in cooling and related technologies. They observed maximum enhancement (~160%) with 1% volume fraction with multi-walled carbon nanotubes dispersed in engine oil.

**Elena V. Timofeeva, Wenhua Yu et. al.** [2]presented a paper on " Nanofluids for Heat Transfer: An Engineering Approach". In this paper the factors contributing to the fluid cooling efficiency were discussed first, followed by a review of nanofluid engineering parameters and a brief analysis of their contributions to basic thermo-physical properties.

**Pawel Keblinski, Jeffrey A. Eastman and David G. Cahill** [3]presented a paper on "Nanofluids for Thermal Transport". In this paper a brief discussion was given about synthesis of nanofluids, thermal transport in stationary fluids, and thermal conductivity of nanofluids.

**P. Keblinski, S.R. Phillpot, S.U.S. Choi & J.A.Eastman** [4]presented a paper on "Mechanism of Heat Flow in Suspensions of Nano-sized Particles (nanofluids)". In this paper they explained different mechanisms of heat flow in nanofluids.They explained Brownian motion of the particles, molecular level layering of the liquid at the liquid/particle interface, the nature of heat transport in the nanoparticles, and the effects of nanoparticle clustering.

**Seok Pil Jang and S.U.S.Choi** [5]presented a paper on "Role of Brownian Motion in the Enhanced Thermal Conductivity of Nanofluids". In this paper they devised a theoretical model that accounts for the fundamental role of dynamic nanoparticles in nanofluids. The model not only captures the concentration and temperature dependent conductivity but also predicts strongly size-dependent conductivity.

**S.U.S.Choi and J.A.Eastman**[6] presented a paper on "Enhancing Thermal Conductivity of Fluids with Nanoparticles". They provided information related to technology for production of nanoparticles and suspensions and theoretical study of thermal conductivity of nanofluids.They estimated potential benefits of nanofluids with copper nanophase materials.

**Indranil Manna**[7] in his paper "Synthesis, Characterization and Application of Nanofluid—An Overview" reviewed an update on the historical evolution of nanofluid concept, possible synthesis routes, level of improvements reported, theoretical understanding of the possible mechanism of heat conduction by nanofluid and scopes of application.

**J. A. Eastman, S. U. S. Choi,W. Yu and L. J. Thompson**[8] presented paper on "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles". They experimentally found that a ''nanofluid'' consisting of copper nanometer-sized particles dispersed in ethylene glycol has a much higher effective thermal conductivity than either pure ethylene glycol or ethylene glycol containing the same volume fraction of dispersed oxide nanoparticles.

**C.Choi, H.S.Yoo and J.M.Oh** [9]presented a paper on "Preparation and heat transfer properties of nanoparticles –in-transformer oil dispersions as advanced energy efficient coolants". They investigated three kinds of nanofluids prepared by dispersing $Al_2O_3$ and AIN nanoparticles-in-transformer oil. They found that the thermal conductivity of the nanoparticle oil mixtures increases with particle volume fraction and thermal conductivity of itself.

**Ji-Hwan Lee, Seung-Hyun Lee, Chul Jin Choi, Seok Pil Jang and Stephen U. S. Choi**[10] in their paper "A Review of Thermal Conductivity Data, Mechanisms and Models for Nanofluids" presented a critical review of the classical and new models used to predict the thermal conductivity behavior of nanofluids. They discussed some controversial issues such as data inconsistencies, the sufficiency and suitability of classical and new mechanisms, and the discrepancies between experimental data and model predictions.

**M.T. Naik and L. Syam Sundar**[11] published a paper "Investigation into Thermophysical Properties of Glycol based CuO Nanofluids for Heat Transfer Applications". They presented experimental work on thermal conductivity and viscosity of water-propylene glycol based CuO nanofluids at different temperatures for five different concentrations. They showed that thermal conductivity of CuO nanofluids increases with increase in the CuO nanoparticle concentration in the base fluid.

**Yulong Ding, Haisheng Chen et. al.** [12]presented a paper on " Heat Transfer Intensification Using Nanofluids". This paper summarized some recent work on the heat transfer of nanofluids. It covered heat conduction, convective heat transfer under both natural and forced flow conditions, and boiling heat transfer in the nucleate regime.

**Sandipkumar Sonawane, Kaustubh Patankar, Ankit Fogla et.al.**[13] published a paper on "An Experimental Investigation of Thermophysical Properties and heat transfer performance of $Al_2O_3$-Aviation Turbine Fuel Nanofluids". They investigated aviation turbine fuel - $Al_2O_3$ for better heat transfer performance in a potential application of regeneratively cooled semi-cryogenic rocket engine thrust chambers. They experimentally measured the thermophysical properties of aviation turbine fuel - $Al_2O_3$ nanofluid. They varied volume concentration of $Al_2O_3$ nanoparticle between

 

0 to 1%. They found that at 1% particle volume concentration the enhancement in the thermal conductivity was 40% and the increase in the viscosity was found to be 38%.

**L.Xue, P. Keblinski, S.R.Phillot et. al.**[14] presented a paper on " Effect of liquid layering at the liquid-solid interface on thermal transport". In this paper they showed how the ordering of the liquid at the liquid-solid interface affects the interfacial resistance. Their simulation of a simple monoatomic liquid shwed no effect on the thermal transport either normal to the surface or parralel to the surface. Also their findings suggest that the experimentally observed large enhancement of thermal conductivity in suspension of solid nanosized particles can not be explained by altered thermal transport proprties of the liquid layer.

**A.K.Singh**[15] Defence Institute of Advanced Technology, Pune presented a paper on "Thermal Conductivity of Nanofluids". This study provides a review of nanotechnology with focus on thermal conductivity studies of nanofluids. They concluded that nanofluids have great potential for thermal management and control involved in a variety of applications such as electronic cooling, microelectro mechanical systems (MEMS) and spacecraft thermal management.

## III. Nanofluids with their Thermal conductivities, increase in nanofluids thermal conductivity over base fluid thermal conductivity and synthesis procedure

| Base fluid with conductivity | Nano particles, average diameter and concentration | Method used for synthesis | Max. thermal conductivity ratio | Ref. |
|---|---|---|---|---|
| Water 0.613 | *$Al_2O_3$*, <50 nm, up to 4.3 vol% | 2-step | 1.08 | [2] |
| Water 0.613 | *CuO*, < 50 nm, up to 3.4 vol% | 1-step | 1.10 | [2] |
| Water 0.613 | *C*-MWNT 50 nm, 5 um 3 urn, 0.6 vol% | 2-step | 1.38 | [2] |
| EG 0.252 | *Fe*, <10 nm, 6.0 vol % | 2-step | 1.18 | [2] |
| Water 0.613 | *TiO*2, <15 nm, 5.0 vol % | 2-step | 1.30 | [2] |
| Water 0.613 | *Cu*, 18 nm, up to 5.0 vol% | 2-step | 1.60 | [2] |
| Thiolate | *Au*, 10-20 nm, 0.1 vol % | 2-step | 1.09 | [2] |
| Cirate | *Ag*, 6-80 nm, 0.1 vol % | 2-step | 1.85 | [2] |
| EG 0.252 | *Al*2*O*3, <50 nm, up to 5.0vol% | 2-step | 1.18 | [2] |
| EG 0.252 | *CuO*, 35 nm, up to 4 vol% | 2-step | 1.21 | [2] |

Table:1 Nanofluids with their Thermal conductivities, increase in nanofluids thermal conductivity over base fluid thermal conductivity and synthesis procedure

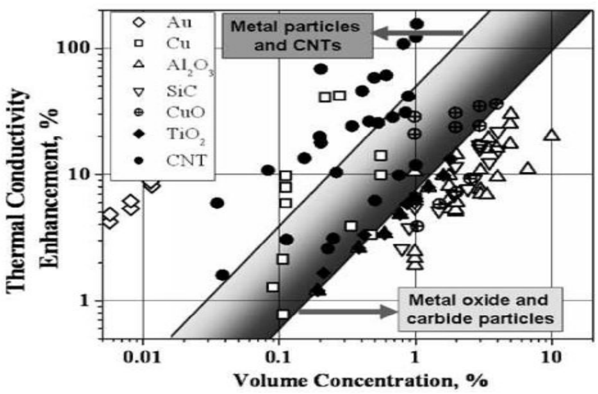


Fig.1 Thermal conductivity of nanofluids: data taken from Lee et al. (1999), Eastman et al. (2001), Choi et al. (2001), Xie et al. (2002a & 2002b), Biercuk et al. (2002), Das et al. (2003a)

 

## IV. CONCLUDING REMARKS

Nanofluids i.e. well dispersed metallic nanoparticles at low volume fractions in liquids; enhance 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 nanofluids, including the preparation methods the evaluation methods for their stability, the stability mechanisms and their potential applications in heat transfer intensification. The performance of nanofluids 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 nanofluids 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 characteristics of nanofluids are also important for developing engineering designs. Finally, it is to suggest that nanofluids research require a genuinely multidisciplinary approach with complementary efforts from material scientists (regarding synthesis and characterization), thermal engineer (for measuring thermal conductivity & heat transfer co-efficient under various regimes and conditions), chemists (to study the agglomeration behavior) and physicists (modeling the mechanism).

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