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Heat Transfer Improvement by Nano Fluids.

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Abstract: *There has been increasing interest in nanofluid and its use in heat transfer enhancement. Nanofluids are suspensions of nanoparticles in fluids that show significant enhancement of their properties at modest nanoparticle concentrations. Nanofluids are quasi single phase medium containing stable colloidal dispersion of ultrafine or nanometric metallic or ceramic particles in a given fluid. This article covers recent advances in the last decade by researchers in heat transfer enhancement with nanofluids as the working fluid. A brief overview has been presented to understand the evolution of this concept, possible mechanism of heat conduction by nanofluid and areas of application. In order to put the nanofluid heat transfer technologies into practice, fundamental studies are greatly needed to understand the physical mechanisms.*

Keywords*: Nanofluids, Nano- particles, Heat transfer enhancement, Applications of Nanofluid.*

I. INTRODUCTION

Nanofluids consist of a base fluid enriched with nano size particles (less that 100 nm). Nanofluids are characterized by an enrichment of a base fluid like Water, Ethylene glycol or oil with nanoparticles in variety of types like Metals, Oxides, Carbides, Carbon. Mostly commonly recalled Nanofluids could be typified as TiO_2 in water, CuO in water, Al_2O_3 in water, ZnO in Ethylene glycol. Today Nanofluids have got wide range of applications in transportation, power generation, nuclear, space, microelectronics, biomedical and many areas where heat removal is involved.

The normal fluid has some major disadvantage regarding heat transfer.

1. The particle settles rapidly, forming a layer on the surface and reducing the heat transfer capacity of the fluid.
2. If the circulation rate of the fluid is increased, sedimentation is reduced, but the erosion of the heat transfer device, pipe line etc increased rapidly.
3. The large size of the particle tends to clog the flow channels, particularly if the cooling channels are narrow.
4. The pressure drop in the fluid increases considerably.

Chandrasekhar et. al [1] conducted experimental and theoretical investigations of the effective Thermal conductivity and viscosity of Al_2O3/water nanofluids. The nanoparticles in this study, was prepared using microwave assisted chemical precipitation method and then dispersing them in distilled water using sonicator. During the experimental investigation it was noticed that both the thermal conductivity and viscosity values increase with that of the nanoparticle volume concentration. Theoretical values obtained were in good agreement with the experimental results.

Suresh et. al [2] investigated the heat transfer and pressure drop characteristics through a uniformly heated circular tube using Alumina-Copper /water hybrid nanofluids under fully developed laminar flow conditions. In this study, the hybrid particle was synthesized in a thermo chemical route. The volume concentration used was 0.1% and the composition used was 90% Alumina and 10% Copper. The nano-composite powder was obtained using hydrogen reduction method and the nanofluids were prepared with the base fluid as water. A maximum enhancement of 13.56% in Nusselt number was obtained for a Reynolds number of 1730 when compared to Nusselt number of water. The friction factor was compared with that of alumina-water nanofluids and was found to be slightly more.

Hwang et al [3] investigated the pressure drop and convective heat transfer coefficient of water based alumina nanofluids flowing through a uniformly heated circular tube in fully developed laminar flow regime. The experimental results show that the data for nanofluid friction factor show a good agreement with analytical predictions from the Darcys equation for single-phase flow. However, the convective heat transfer coefficient of the nanofluids increases by up to 8% at a concentration of 0.3 vol% compared with that of pure water and this enhancement cannot be predicted by the Shah equation. Furthermore, the experimental results show that the convective heat transfer coefficient enhancement exceeds, by a large margin, the thermal conductivity enhancement. In this study, based on scale analysis and numerical solutions, they have shown the flattening of velocity profile induced from large gradients in bulk properties such as nanoparticle concentration, thermal conductivity and viscosity.

Suresh et al [4] synthesized Al_2O3-Cu hybrid particles by hydrogen reduction technique from powder mixture of Al_2O3

and CuO in 90:10 weight proportions obtained from a chemical route synthesisAl_2O3–Cu/water hybrid nanofluids with volume concentrations from 0.1% to 2% were then prepared by dispersing the synthesized nano-composite powder in deionised water. The experimental results have shown that both thermal conductivity and viscosity of the prepared hybrid nanofluids increase with the nanoparticles volume concentration. The thermal conductivity and viscosity of nanofluids have been measured and it has been found that the viscosity increase is substantially higher than the increase in thermal conductivity. The experimental measurement of thermal conductivity showed a maximum enhancement of 12.11% for a volume concentration of 2%. The experimental results have been compared with the classical theoretical models available in literature.

Andic et al [5] synthesized nano-composite Al_2O3-Cu hybrid powder by thermo chemical method and sintering with a comparative analysis of the mechanical and electrical properties of obtained solid samples. Nano- crystalline Al_2O3-Cu powders were produced by thermo chemical route through the following stages: spray drying, oxidation of precursor powder, reduction by hydrogen and homogenization. Characterization of powders included differential thermal and thermo gravimetric analysis, XRD and AEM coupled with EDS. Size of the produced powders were 20-50nm with noticeable presence of agglomerates. Many researchers have used various nanofluids for the enhancement of heat transfer. The objective of this present investigation is to estimate experimentally the Nusselt number in the turbulent flows of Al_2O3/water nanofluids through a serpentine tube path under constant heat flux condition and to estimate the Nusselt number in the turbulent flows of Al_2O3/water nanofluids through a serpentine tube path with attachment of micro fin under constant heat flux condition.

II. PREPARATION OF NANOFLUID

There are two primary methods to prepare nanofluids: A two-step process in which nanoparticles or nanotubes are first produced as a dry powder. The resulting nanoparticles are then dispersed into a fluid in a second step. Single-step nanofluid processing methods have also been developed.

Two-Step Methods

Several studies, including the earliest investigations of nanofluids, used a two-step process in which nanoparticles are first produced as a dry powder. This method is more extensively used to produce nanofluids because nanopowders are commercially available nowadays. A variety of physical, chemical, and laser-based methods are available for the production of the nanoparticles to be used for nanofluids.

One-Step Methods

The nanoparticles may agglomerate during the drying, storage, and transportation process, leading to difficulties in the following dispersion stage of two-step method. Consequently, the stability and thermal conductivity of nanofluid are not ideal. In addition, the production cost is high.

III. Physics of Nanofluids

In 2004 Eastman assessed the nanofluidic properties of the carbon Nanotubes.[6] The driving force for this study were interesting properties like astonishingly high conductivity, low density and high aspect ratio other factors. As their study did not produce expected results, significance of intervening factors was critically investigated[7]. They found out that alignment of the nanotubes, volume loading, adhesion between the fibers and the matrix, and particle were responsible for deviation of results. According to Eastman 2004, particle coating plays a negative role in performance of nanoparticles towards increasing the thermal conductivity of the base fluid at only 3% weight loading of the Nanotubes.

As another example Choi et al. [8] in 2003 observed a 300 % increase of thermal conductivity of the Nanofluid compared to the based fluid. Alignment factor was proved important by Choi at al. in 2003 after an additional 10% thermal conductivity to the already increased thermal conductivity (300%) was observed with tubes aligned with the fluid movement direction. As of their conclusion Choi et al. considers the interaction between matrix and tubes as an important factor as well as interfacial resistance, aspect ratio. Surprisingly they used molecular dynamic and Atomistic simulation in their as a tools for better understanding and analysis of the governing phenomena.

III. HEAT TRANSFER APPLICATIONS

Amazing capability of Nanofluids in heat transfer enhancement has encouraged researcher in recent decades to develop concepts and technologies advocated by manufacturers of ultra-compact, miniaturized and intrinsic electronic chips. The uplifting demand for higher speed, multiple functioning, more powerful and smaller sized boards has almost doubled number of transistors on electronic chips with production of localized heat flux over 10 MW/m2and the total power exceeding 300 W. Promising to fulfill this critical need, technologies like “Nanofluid in Oscillating Heat Pipe” and “Nanofluid With Tunable Thermal Properties” emerged by Ma et al. 2006 and Philip et al 2008 respectively [9](Fig. 1 top and bottom rows respectively). According to

Ma et al. “there is no exiting low cost cooling mechanism that can effectively manage this amount of heat effectively”.

According to Philip et al., the observed reversible tunable thermal property of Nanofluid with advantage of %300 increase in thermal conductivity of the based fluid may find many technological applications for this fluid in nanoelectromechanical system (NEMS) and microelectromechanical system (MEMS) based devices.

For example, depending upon the cooling requirement, the current or magnetic field can be precisely programmed to obtain the desired level of TC enhancement or cooling.

Although no typical answer exists to explain the odd behavior of the Nanofluid material to date, researcher could properly explain the great privilege of the Nano particles over micro particles in formation of enriched fluid for their super-efficient heat removal capability. He et al[10]. 2008 explains that on one hand micro/macro particle bring about little thermal enhancement to the base fluid while on the other hand abrasion, channel clogging and higher pressure drop are comparably higher than those of Nanofluids. Furthermore according to Eastman et al. 2004, to achieve such an enhancement concentrations above %10 of volume fraction must be applied which very readily face stability and rheological disorders. He et al. further highlights Nanofluids by their excellent stability, higher thermal conductivities than that predicted by currently available macroscopic models as well as their advantage of little pressure drop. Interestingly Eastman et al. has pointed out similar properties accompanying the advantages of strong temperature dependent effects and significant increase of critical heat flux (up to 3 times greater than the base fluid).

In study of Nanofluids researchers like Jeyhooni et al.[11] 2012, Hea 2006 and 2012, Madhusree et al. 2012 concluded that up to an optimum point there exists a direct ascending trend of conductivity of Nanofluid with increase of concentration of particles and decrease of particle size.

IV. ADVANTAGES OF NANOFLUIDS

Spectacular capability of Nanofluids in heat transfer/removal enhancement can properly address the energy demand and emission issues of the present world. In United State only, utilization of Nanofluids for industrial cooling could result in great energy savings and resulting emissions reductions. For U.S. industry, the replacement of cooling and heating water with Nanofluids has the potential to conserve 1 trillion Btu of energy. For the U.S. electric power industry, using Nanofluids in closed-loop cooling cycles could save about 10– 30 trillion Btu per year (equivalent to the annual energy consumption of about 50,000–150,000 households). The associated emissions reductions would be approximately 5.6 million metric tons of carbon dioxide; 8,600 metric tons of nitrogen oxides; and 21,000 metric tons of sulfur dioxide.

In more localized end points, faster and more robust data servers and computers, electronic devices, sensors and actuators can appreciably boost the businesses, reduce the instances of circuit burns and electricity cut-offs and hence save a significant amount of money to end users and service providers. Consequently a potential of 2-billion dollar-per-year investment is estimated to flow into this great technology. Figure 2 shows a surprising advantage of %60 more efficiency in server cooling which is expected to bring about a significant boost of efficiency for the service provider.

1. **Knowledge in atomic levels**

According to Eastman et al.[12] 2004, although the potential for the use of Nanofluids in a wide range of applications is promising, a seriously hindering fact in development of the fields and applications is that a detailed atomic-level understanding of the mechanism(s) responsible for the observed property changes remains elusive. In the absence of this treasury of knowledge people rely on few simplistic models and in some cases large discrepancies between prediction and measurement remains a secret. As an instance, different scenarios have been proposed by [6] et al 2004 to explain the true reason for remarkably lower measured conductivity of Nanotubes in water.

b. Toxicity and disposal problems

Nanoparticles like silicon are extremely health threatening and presence of these particles in aquatic environment will severely endanger life of humans and animals through digestion and inhalation of these contaminants. Therefor some issues regarding the use of Nanofluids in a power plant system include the unpredictability of the amount of nanoparticles that are carried away by the boiling vapor. One other concern is what extra safety measures that have to be taken in the disposal of the Nanofluid. Hence extra caution must be taken in regards to the concentration and disposal of the material which calls for development of standards and procedural instructive and training sessions.

3. **Erosion and abrasion**

In the light of advantages of Nanoparticles over micros particles, still abrasion and erosion problems issues exist with these extremely fine particles. In particular, consideration of possible chemical reactions and oxidation with materials of the media (walls and the fluid base) must be carefully accounted for. As a practical measure, Wong and Leon 2009[13] refer to the fact that application of Nanofluid coolant to boiling water reactors (BWR) is predicted to be minimal because nanoparticle carryover to the turbine and condenser would raise erosion and fouling concerns.

d.Cost inhibition

Use of diamond, gold, silver, and has been studied in study of researchers like Patel and coworkers 2003[14], Eastman 2004, Ma et al. 2006. Associate cost of integration of gold in water as a Nanofluid with volume fraction loading of 0.011%vol for a system containing 200 milliliter of the fluid will be $40351. As another instance, the price of 200 milliliter of a 1% volumetrically loaded water-carbon nanotube fluid will be $65002[15]. In the view of the author of this paper, insurability about cost effectiveness besides technical aspects explained above will confine the development of systems to laboratory scale experiments and prototypes still for a considerable time.

VI. CONCLUSION

Nanofluid cooling has variety of application in power generation, industrial, information technology[16], and business sections. Promising advantages of Nanofluids through enhancement of heat transfer have been summarized as efficiency and safety boos in power generation, product size, cost and waste reduction, product quality and aesthetic improvement, energy consumption and emission reduction, faster communication and computation and ultimately in one word prosperity of the society. Besides research and communication not only will invaluably advance the science but will also bring the researcher form different parts of the word closer together for an enjoyable participation and collaboration.

Finally dangerous and many unknown sides of the Nanofluids utilization must be addressed to ensure about impressive role of this advanced technology in driving the life on planet earth towards more prosperity[17]. This end will be met thorough years of extensive research and development of models, experiments and patents.

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