A Review on Heat Transfer Enhancement using Nano Particles

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Abstract— There has been increasing interest in nanofluid and its use in heat transfer enhancement. Nano are suspensions of nanoparticles in that show significant enhancement of their properties at modest nanoparticle concentrations. Nano 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 nano 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.

Index Terms—Nano, Nano-particles, Heat transfer enhancement.

I. INTRODUCTION

Nano consist of a base fluid enriched with nano size particles (less that 100 nm). Nano 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 nano could be classified as TiO_2 in water, CuO in water, Al_2O_3 in water, ZnO in Ethylene glycol. Today nano 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. Low thermal conductivity of process fuid hinders high compactness and effectiveness of heat exchangers, although a variety of techniques is applied to enhance heat transfer. Improvement of the thermal properties of energy transmission fluids may become a trick of augmenting heat transfer. An innovative way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluids. Various types of powders such as metallic, non-metallic and polymeric particles can be added into fluids to form slurries. The thermal conductivities of fluids with suspended particles are expected to be higher than that of common fluids such large particles may cause some severe problems such as abrasion and clogging. Therefore, fluids with suspended large particles have little practical application in heat transfer enhancement. High thermal loads due to miniaturization in a wide variety of applications like microelectronics, transportation, lighting, utilization of solar energy for power generation etc., offers technological challenges in designing efficient thermal management systems.

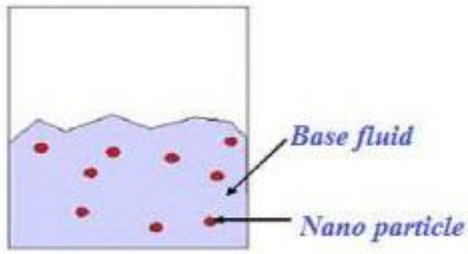

Fig. I: Principle of nanofluid [1]

Traditional heat transfer such as air, water, engine oil, and ethylene glycol (EG) have very low thermal conductivities of 0.03, 0.613, 0.145 and 0.253 $Wm^{-1}K^{-1}$ respectively. This poor thermal conductivity of these is an obstacle in improving heat transfer augmentation and compactness of the heat exchangers. Nanofluid is a new field of scientific research that has grown enormously in the past few years. Still, it is a field in its adolescence, and there are a number of issues which have not been fully investigated. Despite recent advances such as discoveries of unexpected thermal properties, new mechanisms and unconventional models proposed, the mysteries of nano are unsolved. Water is the most cost effective and widely used thermal fluid available with high heat transfer efficiencies and easy to control. However, its main limitation is that at a temperature above 100ºC it starts to boil, become steam and hence can only be used as a pressurized system–imposing restrictions upon its handling and use to ensure safe operation. The introduction of nano sized particles to heat transfer (nano) is an emerging thermal management concept with implications in many disciplines including power generation, transportation, micro-electronics, and chemical engineering, aerospace and manufacturing. The normal fluid has some major disadvantage regarding heat transfer. [5]

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.

Table I: Thermal conductivities of various solids and liquids [1]

	Material	Thermal Conductivity (W/mK)
Carbon	Nanotube Diamond Graphite Fullerenes film	1800-6600 2300 110-19 0.4
Metallic solids(pure)	Copper Aluminium	401 237
Nonmetallic solids	Silicon Alumina(Al_2O_3)	148 40
Metallic liquids	Sodium(644K)	72.3
Nonmetallic liquids	Water Ethylene glycol(EG) Engine oil(EO)	0.613 0.253 0.145

II. SYNTHESIS AND PREPARATION METHODS FOR NANOFLUIDS

Preparation of nanofluids is the first key step in experimental studies with nanofluids. Nanofluids are not just dispersion of solid particles in a fluid. The essential requirements that a nanofluid must fulfill are even and stable suspension, negligible agglomeration of particles, no chemical change of the particles or fluid, etc. Nanofluids are produced by dispersing nano meter scale solid particles into base liquids such as water, ethylene glycol, oil, etc. In the synthesis of nanofluids, agglomeration is a major problem. There are mainly two techniques used to produce nanofluids the single-step and the two-step techniques. And others are given below [4]

1) Direct evaporation
2) Gas condensation (IGC)/dispersion
3) Chemical vapor condensation
4) Chemical precipitation

Gas condensation advantages**:**
- Wide variety of nano powders can be produced
- Powder production process has already been commercialized

Gas condensation disadvantages:
- Agglomeration
- Often poor dispersion properties

Direct Evaporation
- Less agglomeration than gas-condensation
- Restricted to low vapor pressure liquids and materials that can be vaporized at low to moderate T
- Small particle size, but little control over size
- Small sample sizes; slow production rate; scalable?

Chemical Vapor Condensation Synthesis
- powder can be directly deposited into liquids (less agglomeration than IGC, but more than direct evaporation)
- size control is possible
- scale-up should be straight-forward (but hasn't been done)
- layered oxide nanoparticles can be produced (e.g., for biomed. applications) Pump

Chemical Synthesis
- Chemical synthesis techniques can produce small, monodisperse nanoparticles with no agglomeration
- Effect of surface molecules on thermal properties?
- Few existing nanofluid thermal properties studies have used this type of particle

Two Step Technique

Two-step method is the most widely used method for nanofluids [1]. Nanoparticles, nanofibers, nanotubes, or other nano materials used in this method are first produced as dry powders by chemical or physical methods. Then, the nano sized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing ,homogenizing, and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications. Due to the difficulty in preparing stable nanofluids by two-step method, several advanced techniques are developed to produce nanofluids, including one-step method. In the following part, we will introduce one-step method in detail.

Single Step Technique

The single step simultaneously makes and disperses the nanoparticles directly into a base fluid; best for metallic nanofluids. Single disperses [1]. Various methods have been tried to produce different kinds of nanoparticles and nano suspensions. The initial materials tried for nanofluids were oxide particles, primarily because they were easy to produce and chemically stable in solution. Various investigators have produced $Al_2O_3$and CuO nano powder by an inert gas condensation process and found to be 2–200 nm-sized particles. The major problem with this method is its tendency to form agglomerates and it sun suitability to produce pure metallic nano powders. The problem of agglomeration can be reduced to a good extent by using a direct evaporation condensation method.

III VARIOUS TYPES OF NANOFLUIDS

Oxide Nanofluids

- Saw smaller enhancement for Al_2O_3-in-H_2O than Masuda [4]
- Nanoparticles produced by IGC; dispersed in H_2O ultrasonically, but no pH adjustment
- Larger effect for ethylene glycol than for water-based nanofluids.
- Larger improvement for CuO than Al_2O_3 is surprising

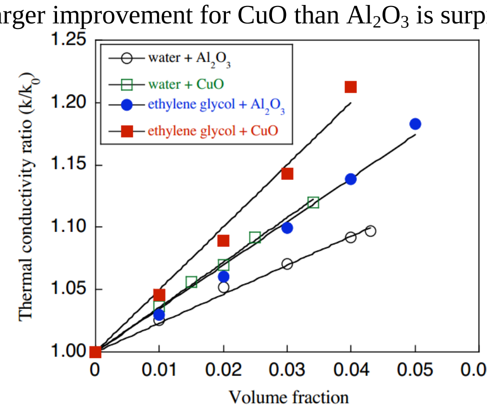

Fig. II: Comparison of various oxide nanofluids [4]

Copper-Containing Nanofluids

- 10 nm diameter Cu nanoparticles produce much larger increase in k than 30 nm diameter oxide nanoparticles [4]
- thioglycolic acid improves dispersion behaviour (but adding acid alone does not affect k)
- Is larger k enhancement due to smaller particle size or larger particle conductivity?

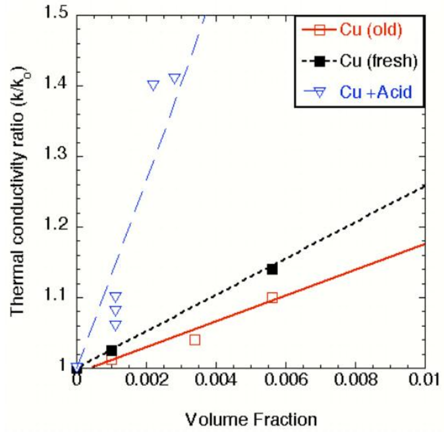

Fig. III: Comparison of various copper containing nanofluids [4]

IV DISCUSSION ON NANOFLUID HEAT`TRANSFER TECHNOLOGIES AND THEIR APPLICATIONS

Thermo-physical and transport properties of nanofluids are very important in nanofluid heat transfer technologies on single- and two-phase flow (boiling, flow boiling and condensation) [1]. So far, most studies on nanofluid thermal properties have focused on thermal conductivity and limited studies have concerned viscosity. For single-phase convective heat transfer, it is clear that single-phase heat transfer coefficient can be enhanced by nanofluid due to its higher thermal conductivity compared to the base fluid. It should also be noted that the viscosity of a nanofluid is generally higher than that of the base fluid. Therefore, frictional pressure drops of single phase flow of nanofluid are generally higher than those of the base fluid.

Industrial Cooling Applications

The application of nanofluids in industrial cooling will result in great energy savings and emissions reductions [4]. For US industry, the replacement of cooling and heating water with nanofluids has the potential to conserve 1 trillion Btu of energy. For the US 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. Experiments were performed using a flow-loop apparatus to explore the performance of polyalphaolefin nanofluids containing exfoliated graphite nanoparticle fibers in cooling. It was observed that the specific heat of nanofluids was found to be 50% higher for nanofluids

Heat Transportation

The mixture of ethylene glycol and water is almost a universally used vehicle coolant due to its lowered freezing point as well as its elevated boiling point [2]. The thermal conductivity of ethylene glycol is relatively low compared to that of water, while the engine oils are much worse heat transfer fluids than ethylene glycol in thermal transport performance. The addition of nanoparticles and nano tubes to these coolants and lubricants to form nanofluids can the increase their thermal conductivity, and give the potential to improve the heat exchange rates and fuel efficiency. The above improvements can be used to reduce the size of the cooling systems or re-move the heat from the vehicle engine exhaust in the same cooling system. have conducted research to study the effects of nanofluids in the cooling of automatic transmission. They dispersed CuO and Al_2O_3 nanoparticles and antifoam agents in the transmission fluid, and then, the transmission fluid was used in real time four wheel automatic transmissions. The results show that CuO nanofluids have the lowest temperature distribution at both high and low rotating speed and accordingly the best heat transfer effect

Electronics Cooling

The power dissipation of IC (integrated circuits) and microelectronic components has dramatically increased due to their size reduction. Better thermal management and cooling flu-ids with improved thermal transport properties are needed for safe operation [2]. Nanofluids have been considered as working fluids in heat pipes for electronic cooling application. were probably the first to show experimentally that the thermal performance of the heat pipe can be enhanced when nanofluids are used. Gold nanoparticles with a particle size of 17 nm dispersed in water were used as a working fluid in a disk shaped miniature heat pipe. The result shows that the thermal resistance of the disk shaped miniature heat pipe is reduced by nearly40% when nanofluids are used instead of deionized (DI) water

Military Applications

Military hardware both mechanical and electrical devices dissipates a large amount of heat and consequently requires high heat flux cooling fluids having sufficient cooling capacity. Nanofluids have the capability to provide the required cooling capacity in such applications, as well as in other military applications, including submarines and high power laser.

Medical Application

Nanofluids are now being developed for medical applications, including cancer therapy [2]. Iron based nanoparticles can be used as delivery vehicle for drugs or radiation without dam-aging the neighboring healthy tissues by guiding the particles up the blood stream to the tumor locations with magnets. Nanofluids could be used to produce higher temperatures around tumours, to kill cancerous cells without affecting the nearby healthy cells. Nanofluids could also be used for safer surgery by cooling around the surgical region, thereby enhancing the patient's health and reducing the risk of organ damage. Nanofluids are currently expensive, partly due to the difficulty in manufacturing them. The development of new synthesis methods is necessary to make nanofluids more affordable before they will see wide-spread applications.

V. PROBLEMS AND DRAWBACKS

Knowledge In Atomic Levels

According to Eastman [4], 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.

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 [3]. Therefore 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.

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 [3]. 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 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.

Cost Inhibition

Use of diamond, gold, silver, 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 [3]. As another instance, the price of 200 milliliter of a 1% volumetrically loaded water-carbon nanotube fluid will be $65002. 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.

REFERENCES

[1] Kavitha T, Rajendran A, Durairajan A, Shanmugam A 2012, "Heat transfer Enhancement Using Nano fluids And Innovative Methods - An

Overview" IJMET Volume 3, Issue 2, May-August (2012), pp. 769-782

[2] Shanthi R, ShanmugaSundaramAnandan and VelrajRamalingam2012, "Heat Transfer Enhancement Using NanofluidsAn Overview" THERMAL SCIENCE: Year 2012, Vol. 16, No. 2, pp. 423-444

[3] B.N.Kharad , G.P.Bhagat, R.M. Ghodkeand A.P.Avhad2014, "Heat Transfer Enhancement Using Nano Fluids- An Overview" IJIRSET Volume 3, Special Issue 4, April 2014

[4] J.A. Eastman 2005, " Mechanisms of EnhancedHeat Transfer in Nanofluids" Supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under contract W-31-109-Eng-38

[5] Dr. K. R. Balasubramanian, Dr. S. Suresh and Dr. S. P. Sivapirakasam2013, "Heat Transfer Enhancement Using Nanofluid In A Serpentine Passage" International Conference on Advance Research in Mechanical , Aeronautical And Civil

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