Advanced Heat Transfer Enhancement by using Nanofluids: A Review

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Abstract— *The purpose of this review article is to summarize the important published articles on the enhancement of the convection heat transfer with Nanofluids. Over the last 2-3 decades, there has been intensive research into the behavior of substances that contain extremely small particles. Nanotechnology is the science and engineering of working at the Nano-scale, where the individual particles are 1-100 nanometers in size. It's hard to imagine the size of nanoparticles, but there are about 2, 54, 00,000 nanometers in an inch. Nanofluids which are less than even a micron (nearly 10^{-9} times smaller) in diameter, highly reactive and efficient material which can be used to increase factor like rate of heat transfer, thermal conductivity of any metal or material, they are that much reactive and strong. The thermal conductivity increases with decreasing the grain size of the material. As the thermal conductivity increases the heat transfer rate increases.*

Keywords— *nanotechnology, Nanofluids, thermal conductivity, heat transfer enhancement, convectional heat transfer.*

I. INTRODUCTION

Heat is a form of energy called thermal energy that is primarily due to the motion of molecules and atoms within the medium. Heat transfer is the transfer of heat due to a temperature difference. The flow of heat is always from a warm surface to a cold surface. Scientists and engineers who are interested in heat transfer are often interested in the heat transfer rate. The amount of heat transfer is increased by using Nanofluids. Nanotechnology is the science and engineering of working at the Nanoscale, where the each particle size in the range of 1-100 nanometers [1, 4, 5]. It's hard to imagine the size of nanoparticles, but there are about 2,54,00,000 nanometers in an inch (2.54 cm) [8]. It is the smart application of Nanofluids that will carry about a revolution in the heating and cooling. Dispersing particles of as metals, oxides, carbides, or carbon nanotubes, Al, Zn, Si etc into base fluid through this Nanofluids is prepared. (generally less than 5% in volume) with sizes of 1 to 100 nanometers in a base fluids such as water, ethylene glycol, and engine oil [1, 4, 5, 14]. Nanofluids are considered to offer important advantages over conventional heat transfer fluids. Researchers focused on measuring and modeling viscosity and thermal conductivity of Nanofluids from the last decades [20]. The purpose of using Nanofluids is to achieve higher values of heat transfer rate compared to the base fluid. This is achieved by dispersion of solid nanoparticles, which have higher thermal conductivity than the base liquid. The rate of heat transfer of Nanofluids increases by increase in concentration of nanoparticles in base fluid. A new challenge for thermal science is Nanofluid and it is provided by nanotechnology [2]. Properties that mainly determine the thermal performance of a liquid for heat transfer applications are the thermal conductivity, viscosity, specific heat and density [2]. Thermal conductivity of Nanofluids increases with increase in concentration of nanoparticles in base fluid [1]. A nanofluid is a suspension of ultrafine particles in a conventional base fluid which tremendously enhances the heat transfer characteristics of the original fluid [16, 17]. The mode of heat transfer is convection because the base fluid which chosen as a medium for transferring heat is a liquid. Convective heat transfer can be enhanced passively by changing the flow geometry, boundary conditions, or by enhancing thermal conductivity of the fluid. Various techniques have been proposed to enhance the heat transfer performance of fluids. [18]. Heat transfer in convection mode is given by Newton's law of cooling ($q=hA\Delta T$) [2].

II. LITERATURE REVIEW

S. K. Das et. al. [11] they presented a paper on "Heat Transfer in Nanofluids-A Review". In that paper they explained study of nanotechnology and they suggested a proper direction for future developments in nanotechnology. The outcome drawn from their paper is that Nanofluids shows greater promise for use in cooling and cooling related technologies. **J. A. Eastman et. al. [12]** they presented a paper on "Anomalously increased effective thermal conductivities of ethylene glycol-based Nanofluids containing copper nanoparticles". They did experimental work and found that ''Nanofluids'' consisting of copper nanometer-sized particles dispersed in ethylene glycol has a much higher thermal conductivity than either pure ethylene glycol or ethylene glycol containing the same volume fraction of dispersed oxide nanoparticles. **C. Choi et. al. [13]** they presented a paper on "Preparation and heat transfer properties of nanoparticles–in transformer oil dispersions as advanced energy efficient coolants". They investigate three kind of Nanofluids prepared by disperse Al_2O_3 and AlN nanoparticles in transformer oil. They observed that thermal conductivity of nanoparticles oil mixtures increases with particle volume fraction and thermal conductivity. **Yulong Ding et. al. [14]** they presented a paper on "Heat Transfer Intensification Using Nanofluids". They summarized some recent work on the heat transfer of Nanofluids. It covered heat conduction, natural and forced flow convection and boiling heat transfer in nucleate regime. **A. K. Singh [15]** he presented a paper on "Thermal Conductivity of Nanofluids". This study provides a review of nanotechnology and thermal conductivity of Nanofluids. He concluded that Nanofluids have great potential for thermal management and energy control. **Yimin Xuan and Qiang Li [19]** they presented a paper on procedure for preparing Nanofluids which is a suspension consisting of nanophase powders and a base liquid. By means of the procedure, some sample Nanofluids are prepared. They introduced the theoretical study of thermal conductivity of Nanofluids. They used the hot-wire apparatus to measure thermal conductivity of Nanofluids with suspended copper nanophase powders. Some important factors are discussed. **Mostafa Keshavarz Moraveji et. al. [21]: -** This paper deals with the thermal enhancement of the grooved heat pipe performance by charging Al_2O_3 Nanofluid as the working fluid inside a 1 mm wick-thickness sintered circular heat pipe which is experimentally tested. The tested concentration levels of nanofluid are 0%, 1% and 3% wt.. The more Al_2O_3 nanoparticles were dispersed in the working fluid, the performance of heat pipe was enhanced. In the heat pipe with charged nanofluid as the working fluid, the wall temperature decreased with respect to pure water thus providing a better performance. Also with higher concentrations of the nanofluid, wall temperature decreased. **Seok Pil Jang et. al. [22]: -**In this paper the effects of Various Parameters on Nanofluid thermal Conductivity are studied. Experiment were conducted using ethylene glycol-based Nanofluids containing copper and water-based Nanofluids containing 6 nm copper of volume fraction of 0.5%, 1%, 2%. The results show that with smaller diameter of nanoparticles thermal conductivity increases. **Omer A. Alawi et. al. [23]: -**This paper describes the research results of heat transfer characteristics of various types of heat pipes using Nanofluids as working fluids. It has shown that Nanofluids have great application prospects in various heat pipes. For the majority of micro-grooved heat pipes, mesh wick heat pipes, oscillating heat pipes and most closed two-phase thermosyphon, adding nanoparticles to the working liquid can significantly enhance the heat transfer, reduce the total heat resistance and increase the maximum heat removal capacity. At the same time, there are still some problems and challenges on the mechanisms of the heat transfer enhancement and the actual applications. **Cheol Bang et. al. [24]:** - Boiling heat transfer characteristics of nano-fluids with nanoparticles suspended in water were studied using four different volume concentrations of alumina nano-particles. Pool boiling heat transfer coefficients of Nanofluids measured on a flat surface in the pool were compared to the coefficient of pure water. Alumina-water nano-fluids show different performance and phenomena compared to pure water in terms of natural convection and nucleate boiling. The heat transfer coefficient was decreased by increasing particle concentration. On the other hand, CHF performance has been enhanced to 32% and 13%, respectively, for both horizontal flat surface and vertical flat surface in the pool due to delayed boiling activity. **Haisheng Chen et. al. [25]: -** Titanate nanotubes were synthesized, characterized and dispersed in water to form stable Nanofluids The titanate nanotube nanofluids show a small thermal conduction enhancement of 3%at 25 °C and 5% at 40 °C with the 2.5 wt. % nanotube loading. The titanate Nanofluids exhibit shear thinning behavior with the shear viscosity decreasing rapidly with increasing shear rate. **Lazarus Godson et. al. [26]** the heat transfer coefficient of Nanofluids is much higher than that of the common-base fluid and gives little or no penalty in pressure drop. **Dongsheng Wen et. al. [27]** the effect on the heat transfer properties of nanoparticles suspensions flowing through small channels has been investigated by mathematical modeling. The model considers particle migration due to spatial gradients in both the viscosity and the shear rate, as well as the Brownian motion. Particle migration due to these effects could result in a significant non-uniformity in particle concentration over the tube cross-section, in particular, for large particles at high concentrations. The non-uniform particle concentration has a significant influence on the local thermal conductivity. Compared with the constant thermal conductivity assumption, the non uniform profile resulting from particle migration leads to a higher Nusselt number, which depends on the Peclet number and the mean particle concentration. **Gilles Roy et. al. [28]** in this paper they have investigated, by numerical simulation, the hydrodynamic and thermal characteristics of a laminar forced convection flow of Nanofluids inside a straight heated tube and a radial space between coaxial and heated disks. Two particular Nanofluids were considered, namely Ethylene Glycol- cAl_2O_3 and water–cAl_2O_3. Results have clearly revealed that the addition of nanoparticles has produced a remarkable increase of the heat transfer with respect to that of the base liquids. Such heat transfer enhancement that appears to be more pronounced with the increase of the particle volume concentration is accompanied, however, by a drastic adverse effect on the wall shear stress. It has been found that the Ethylene Glycol–cAl_2O_3 mixture yields, so far, a better heat transfer enhancement than water–cAl_2O_3. **S. Kumar et. al. [29]** this paper shows that Nanofluids have great potential for heat transfer enhancement and are highly suited to application in heat transfer processes. Nanofluids are a new class of heat transfer fluid engineered by dispersing metallic or non-metallic nanoparticles less than 100 nm in size in a liquid.

III. HOW NANOFLUID WORKS

The transfer of heat depends on the movement of the molecules in the substance. Temperature is a number expressing the movement energy of molecules of substance. To increase temperature, a substance has to be given energy from outside. By changing the density and specific heat, nanofluid increases the heat transfer properties of water. Though water is widely used as a heat transfer medium, water is not a perfect base fluid. The heat transfer of nanofluid is higher when compared to base fluid. Because of this increase in heat transfer nanofluid enables the heat (energy) to be transferred to the target, faster and more efficiently. Nanofluid provides more efficiency with less energy.

Table I: Thermal Conductivity of various materials

[3, 4]

Material	**Material Structure**	**Thermal Conductivity (W/mK)**
Carbon	Nanotubes Diamond Graphite	2000 2300 110-190
Metallic Solid	Silver Copper Aluminum	429 401 237
Nonmetallic Solid	Silicon Alumina (Al_2O_3)	148 40
Metallic Liquid	Sodium (644 K)	72.3
Base Fluids	Water Ethylene glycol (EG) Engine oil	0.613 0.253 0.145
Nanofluids	Water/Al_2O_3 (1.5) EG/Al_2O_3 (3.0) EG-Water/Al_2O_3 (3.0) Water/TiO_2 (0.75) Water/CuO (1.0)	0.629 0.278 0.382 0.682 0.619

IV. PREPARATION OF NANOFLUID

The generation of nanofluid is the first significant step in using nano phase particles to change the rate of heat transfer conventional fluids [19]. The nanofluid does not simply refer to a liquid-solid mixture. Nanofluids are mainly made up of carbides, oxides, metals and carbon nanotubes that can easily be dispensed in heat transferring fluids, such as hydrocarbons, water, ethylene glycol and fluorocarbons by the addition of stabilizing agents. Nanoparticles can also be produced by several processes, namely gas condensation, mechanical attribution or chemical precipitation [8]. These nanoparticles can also be produced under cleaner conditions and their surface can be protected from unexpected coatings which may occur during the gas condensation process [11].

The main limitation of such method is that the particles made by this method occur with some incapability to produce pure metallic nano-powders. The formation of such a problem can be reduced by using a direct evaporation, condensation method [3].

This method is having better control over the particle size and generates particles without surfactants or any electrostatic stabilizers for stable Nanofluids, but has issues of oxidation of pure metals. There are mainly four steps in the process of the direct evaporation-condensation method, also known as one step method.

1. Heat transferring fluid (water or ethylene glycol) containing cylinder is rotated inside so that a thin film of the fluid is constantly expelled out through the topmost of the chamber.
2. The small piece metallic material is evaporated using heat to create the nanoparticles.
3. Fluid is permitted to cool at lowermost to avoid any sort of undesirable evaporated.

V. BENEFITS OF NANOFLUIDS

Nanofluids have following advantages as compared to conventional fluids which make them appropriate for various applications involving heat transfer and heat exchange.

i. The absorption of energy will be maximizing with the change of the particle size, shape, material, and concentration of the nanoparticles.
ii. The suspended nanoparticles increase the surface area and the heat capacity of the fluid due to the very small particle size.
iii. The suspended Nanoparticles enhance the thermal conductivity which results improvement in efficiency of heat transfer systems.
iv. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.
v. To make suitable for different applications, properties of the fluid can be changed by varying the concentration of the nanoparticles.

VI. CONCLUSION

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, recent developments in the study of Nanofluids, including the preparation methods and applications in heat transfer. The review of these studies shows that Nanofluids are very important for many applications. The following conclusions are stated in this review work;

i. The use of nanoparticles increases the heat transfer rate.
ii. Nanoparticles effectively increase the thermal conductivity of the nanofluid.
iii. As a thermal conductivity increases the heat transfer rate increases and vice versa.
iv. The performance of Nanofluids seriously depends upon the size, quantity (volume percentage), shape and distribution.
v. Better characteristics of Nanofluids are important for developing.
vi. The future scope in the Nanofluids research cycle is too concentrated on heat transfer enhancements and determine its physical mechanisms, taking into consideration such items as the optimum particle size and shape, volume concentration of nanoparticles, and base fluid.
vii. The twenty-first century is an era of technological development and has already seen many changes in almost every field or areas.
viii. Finally, it is to suggest that Nanofluids research requires a genuinely multidisciplinary approach with complementary efforts of 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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