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NANOFLUIDS: A CONCEPT TO ENHANCE HEAT TRANSFER

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ABSTRACT

In process industries, heat transfer is the key operation to optimize the process. Conventional methods used to enhance heat transfer rates have been exploited beyond their limits. Hence, recent technologies & advanced fluids with a capacity to modify thermal as well as flow characteristics are of great importance to over come the limitations poised by conventional methods. Nanofluids, one of the advanced fluids, are containing suspension particles of metals, oxides & carbides. Application of nano particles help in improving heat transfer characteristics of fluids. These suspended particles are significantly smaller than 100 nm, and have a bulk solids thermal conductivity of orders of magnitudes greater than the base fluids. Thus, nanofluids are promising to meet and enhance the challenges as the surface area per unit volume of nanoparticles is much larger than that of microparticles. Nanoparticle materials like oxides and metals and base fluid such as water and organic liquid are used to prepare nanofluids. The suspended nanoparticles alter the transport characteristics and heat transfer characteristics of the base fluid to a considerable extent. Nanofluids have exhibited that they possess great potential for heat transfer rate enhancement. The thermal conductivity of nanofluid is measured by hot-wire apparatus. This review paper explains the reasons for enhanced flow and heat transfer characteristics of nanofluids. It also describes the methods available to prepare nanofluids and utility of nanofluids in current heat exchangers.

Key words:
Nanofluids; Enhanced heat transfer; Thermal conductivity

INTRODUCTION

In 1857 Michael Faraday introduced the concept of nano fluids. Faraday reported the study on the synthesis and colours of colloidal gold. The efficient and effective transfer of heat energy , from one object to another is often required in almost all industries. Mostly 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.

$$q = hA\Delta T \qquad (1)$$

Where the q is the heat transfer rate in (W), h is convective heat transfer coefficient (W/m^2 K), A is the surface area in (m^2) and ΔT is the temperature difference (K) across which the transfer of thermal energy take place.

It has been always the pursuit of the thermal engineers to maximize q for given ΔT or A. This can be done by increasing h. 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 [1-3]. The conventional process fluid with low thermal conductivity can no longer fullfill the need of increasing heat transfer rate.Low thermal characteristic of heat transfer of a fluid is the main issue to the development of heat exchangers which are having high compactness and effectiveness. The potent way to increase the thermal conductivity of traditional fluids is by the suspension of solid particles, such as millimeter- or micrometer-sized particles [1-3]. But these millimeter or micrometer sized partilces are not of due practical interest as they cause erosion and fouling. Which results in enhanced pressure drop of the flow channel? Sedimentation is also an issue.The idea and development of nanofluids is straight forwardly concerned to trends in miniaturization and nanotechnology. The pioneering efforts at Argonne National Laboratory (ANL) are keyed to potential commercial applications of nanofluids in many diverse industries [4]. The progress in the field of nanotechnology has resulted in the development of a group of fluids termed nanofluids. Nano fluids are the mixture base fluid and metal & non metal particles which are greatly smaller than 100 nm, and exhibits a bulk solids thermal conductivity of orders of magnitudes higher than the base liquids and also, under stationary conditions, the effective thermal conductivity enhances. Lee et al., under laminar flow conditions with nanofluids in micro channels, have shown that drop in thermal resistance is twice and dissipation of heat energy is thrice that of pure water. Several studies carried out using water-Cu nanofluids of concentrations approximately 2% by volume. It was shown that heat transfer coefficient of nano fluid was 60% more than that of pure water was used [2].

Nanofluids can be utilized to increase rate of heat transfer as well as energy efficiency in a variety of thermal systems, comprising the main application of vehicle cooling or transportation, microelectronics, nuclear power generation, and rocket launching vehicles. Their potential benefits are improvement in heat transfer, reduction in pumping cost, minimal clogging, etc [5].

NANOFLUIDS

Nano fluids are the mixture of nano particles in base fluids.The size of solid nanoparticles or nanofibers is typically of 1-100 nm suspended in liquid These nano particles are made of oxides, nitrides, carbides and various metallic materials. As the thermal conductivity of soild particles is much more than liquids. So, the thermal conductivity of mixture is greater than base fluid. Owing to this unique feature of increased thermal conductivity of nano fluids are of great interest in industiral processes. The concept of nanofluids refers to a new kind of heat transport fluids by suspending nanoscaled metallic or nonmetallic particles in base fluids. Nanofluids are more suits for practical application than the existing techniques for enhancing heat transfer by adding millimeter and/or micrometer-sized particles in fluids [2].

Synthesis of nanofluids

Nano fluids are the mixtures of nanoparticles of metals and non metals in base fluids. The particles of ceramics, metal carbides, and nitrides are blended into base fluids. Thes particles remain in suspension. Water, ethylene or tri-ethylene-glycols, bio fluids, polymer solutions are used as base fluids. Different combinations of nano particles and base fluids can be prepared depending upon specific applications. Particles of nitrided, oxides with surfactant molecules are dispered into fluids. These fluids are water, ethylene glycol and oils. Two step process and single step process [2, 4, 6] are the techniques which are generally used for the synthesis of nanoparticles.

Two step process

First from metal and non metals, powders of nanoparticles are produced by gas condensation technique. Another technique which is used for formation of powder is chemical vapor depostion process. In second step nanoparticles or nanotubes are dispersed into base fluid. To prevent the agglomeration of particles ultrasonic agitation technique is used. Surfactants are also added into base fluids to minimize the agglomeration. These processes improve dispersion behavior of synthesis of nanofluids consisting of nanoparticles of oxides mixed in deionized water. Such type of two step [2] process works well in the synthesis of Nanofluids consisting of oxides nanoparticles dispersed in deionized water.

Single step process

Direct evaporation approach is a type of single step process. It was first developed by Akoh et al [4]. It is known as vacuum evaporation technique.Dispersed particles of nanofluids are produced by a technique known as direct evaporation. As an example, Eastman et al [6] established a process of vacuum evaporation onto oil technique. In this technique vapors of Cu were directly condensed into nanoparticles by contact with a flowing low vapor pressure liquid ethylene glycol. In single step process nano particle agglomeration is minimum. This is the added advantage of single step process. The only demerit of this process is that it is suitable for low vapor pressure fluids.

The sophisticate production of a nanofluid is vital. There are some special attributes related to nanoparticles such as even, durable and stable suspension, low agglomeration of particles. These attributes should be met by a nanofluid. There should be chemical change of the fluid [7]. The procedures employed for the stabilization of the suspensions are: (1) Altering the pH value of suspension, (2) using surface activators (3) using dispersants, (4) using ultrasonic vibration. As the dispersants may affect the thermal conductivity of base fluids [7] so they are not preferred.

PROPERTIES OF NANOFLUIDS

Some of the important properties of Nanofluids are: (1) Suspension duration of nanoparticles much longer than micro-particles (2) suspension duaration can be enhanced indefinitely with enhancement by surfactants and stabilizers (3) In comparision to micro partilces the ratio of surface area to volume for nanofluids is much more (3) it has been proved experimentally that nanoparticles improves thermal conductivity of base fluids by more than 150%. (4) Since the size of the nanoparticles is very minute there is no clogging of pipes and hence they do not block flow of fluids [8]. But the most important and desired property of nanofluid is thermal conductivity which is explained as below:

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Thermal conductivity of nanofluids

By increasing thermal conductivity of a fluid its heat tranfer performance can be boosted. Thermal conductivity of solid metal particles is many times more than the fluid molecules. Since, nanofluids are the mixture of naoparticles dispersed into base fluids. Owing to suspension of metal particles the conductivity of nano fluids is much higher than the base fluids. To understand the thermal behavior of nano fluids extensive experimental works have been done by several researchers. Das et al. [9] presented that thermal conductivity of alumina oxides and cuprous oxides nanofluids vary with the temperature. These are the water based nano fluids. The volume weighted average particle diameters was 38.4 nm for Al_2O_3 while that was 28.6nm for CuO. It was proved experimentally that thermal conductivity increase with temperature rise. The smaller size nano particle (CuO) showed more response to temperature than larger size particles (Al_2O_3). It happens owing to easeness in mobilization by smaller particles. Smaller size particles cause a higher level of motion. Lee et al. [2] conducted experiments to measure the conductivity of nano fluids. The number-weighted particle diameter and the area weighted particle diameter used were 18.6 and 23.6nm for CuO, and 24.4 and 38.4nm for Al2O3, respectively. Different base fluids were used for aluminium oxide particles and cuprous oxide particles. With the use of water and ethylene glycol as a base fluids four combinations of nanofluids were obtained. Remarkably higher thermal conductivity was exhibited by thes nano fluids in comparision to, base fluids. To know the variation in the thermal conductivity of nanofluids conataining copper suspension in ethylene glycol Eastman et al. [5] reported an experimental study. The results were vey anomalous. The thermal conductivity of nano fluids were very high. For nano fluids consisting of 0.3% (by volume) of Cu nanoparticles of a mean diameter less than 10nm dispersed in ethylene glycol as a base fluid the hike in thermal conductivity was 40%. It was observed that increase in conductivity of nano fluid is a function of several variables. The size of dispersed particles in base fluid affects the thermal conductivity. Other variables which affect the thermal conductivity of nano fluids are: type of base fluids, shape and size of naoparticles and surface area of nanoparticles. The Maxwell proposed a model for solid-liquid mixtures. It is applicable for mixture of relatively larger particles.The Maxwell model, is used to calculate thermal conductivity of nanofluids. According to this model the effective thermal conductivity, keff is

$$K_{eff,Maxwell} = \left[\frac{\left(K_p + 2K_l + 2\left(K_p - K_l\right)\right)\phi}{\left(K_p + 2K_l - 2\left(K_p - K_l\right)\right)\phi} \right] K_l \quad (2)$$

Where Kp is the thermal conductivity of the particle, K_1 is the thermal conductivity of the liquid and φis the particle volume fraction of the suspension.

According to Maxwell's model the spherical suspension particles have impact on the effective thermal conductivity of suspension particle, base liquid and the volume fraction of the solid particles [6]. Shape of particles affects the thermal conductivity of non-spherical particles. Volume fraction also affects the thermal conductivity of non sperical particles [8]. To measure the effective thermal conductivity of two component mixture Hamilton and Crosser model can be used. The model is a function of the conductivity of both the particle and base fluid, and the shape of the particles [6]. The thermal conductivity of two component mixture can be determined by:

$$K_{eff,Hamilton} = \frac{\left[K_p + (n-1)K_l - K_p\right]\phi}{\left[K_p + (n-1)K_l + \left(K_l - K_p\right)\right]\phi} \quad (3)$$

where n is the empirical shape factor given by n = 3 / ψ where ψ is the sphericity.

APPLICATIONS AND POTENTIAL BENEFITS

Nano fluids are of great interest in industrial processes. This industrial interest shows that nanofluids can be widely in different sectors. Nao fluids are used in cooling of reactor of nuclear power plants, refinery, process equipment, and textile and paper production industries. It has wide scope in Heating Ventilation and Air Conditioning (HVAC) and energy production and supply to electronics. These industries are restricted by heat transfer and so have a strong need for improved fluids that can transfer heat more efficiently and effectively. The impact of this new heat transfer technology is estimated to be great, assuming that heat exchangers are

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ubiquitous in all types of industrial applications and that heat transfer effectiveness is key point in several multibillion-dollar enterprises. The potential benefits of nanofluids are: (1) Enhanced convective heat transfer and stability of suspension for longer duration as they provide large surface area. (2) Reduced pumping power as nanofluid has high thermal conductivity so the velocity by which the fluid flows is low. (3) Sever clogging of micrometer-sized particles put limitations at heat transfer equipment but with the use of nanoparticles clogging of heat transfer equipments can be prevented as are small enough that they are expected to behave like molecules of liquid (4) With the proper utilization of nano fluids, the size of heat excahnger can be reduced which results in energy and cost savings [3,8].

CONCLUSION

Various techniques have been developed in the field of nano technology capable of producing particles of nano size. Mixing of these particles in fluid alter the thermal properties of the mixture known as nano fluid. The thermal conductivity of this fluid is much more than the base fluid. The size of the nano partilces has great impact on this change in properties. The surface area to volume ratio increases. This nano fluid is of great interest in various industrial processes. The size and shape of nao particle has great influence upon the thermal characteristics of mixture known as nano fluid. The alteration in thermal conductivity of nanofluids depends on the particle volume fraction, type of base fluid and nano particles. Though nanofluids have shown tremendous potential in enhancing heat transfer, commercial aspects of the techniques are to be considered for industrial acceptance.

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