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Heat Transfer and Numerical Analysis in Microchannel Heat Exchanger Using Nanofluids : A Review

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ABSTRACT

Nanofluids are gaining lot of importance in thermal applications due to its excellent heat transfer characteristics. Micro-scale heat transfer devices are used on large scale in electronics industry which leads to the development of compact size heat exchanger with high heat transfer coefficient. Recent development in the field of nanotechnology involves the use of suspended nanoparticles in base fluids which leads to the improvement in the heat transfer coefficient of base fluids. This paper summarizes the articles published on enhancement of convective heat transfer in microchannel heat exchanger using nanofluids and effect of various thermophysical properties on heat transfer performance. Theoretical and experimental results for different geometries and effects on Nusselt number are reported in this paper. The results show outstanding increase in the importance of nanofluid application in microchannels. The effects of use of different nanofluids and their performance as compared to base fluids are shown.

Keywords: Nanofluids, Microchannel Heat Sink (MCHS), Microchannels, Thermal conductivity, Heat transfer

I. INTRODUCTION

Conventional heat transfer fluids like oil, water and ethylene glycol are used on a large scale in many industries, including power generation, chemical processes, heating and cooling processes, transportation, microelectronics and other micro-sized applications. The thermal conductivity of heat transfer fluids has great significance in developing equipments with high heat transfer. To improve heat transfer rate, the use of extended-surface (fins and microchannels), the vibration of the surface, suction/injection of fluids and using electrical/magnetic fields has reached to the standstill. Industrial survey indicates the need to develop equipments which are highly compact and leads to increase in heat flux. So development of high efficiency heat transfer fluid is a difficult task. Recently many researchers have attempted to develop special classes of heat transfer fluids so as to increase their heat transfer properties. New method involves the suspension of small solid particles in the base fluid. Different types of solid particles, such as metallic, non-metallic and polymeric can be added into base fluids. However, the earlier studies indicated that the use of suspended particles of millimetre or even micrometre-size leads to high heat transfer enhancement, but some major problems such as poor stability of the suspension, clogging of flow channels, eroding of pipelines and increase in pressure drop in thermal equipments are also experienced [1].

Choi [2] suggested first the term nanofluid in 1995 and it specifies the use of particles of average size of 10 nm for dispersing in base liquids so as to increase thermal conductivity of base fluid and since then this term has gained popularity.

II. PRODUCTION OF NANOPARTICLES AND SUSPENSIONS

Nanoparticles are prepared by gas phase condensation or using chemical synthesis technique as suggested by Siegel [3]. The gas phase condensation process consists of evaporation of source material. Then rapid condensation of vapour into nanometer sized crystals takes place in a cool, inert, reduced-pressure atmosphere. Researchers use one-step and two-step methods to produce nanofluids. One-step method involves simultaneous making and directly dispersion of particles in the base fluid. Processes such as drying, storage, transportation, and dispersion of nanoparticles are not used in this method [4-8]. Nikkam et al. [9] investigated the one-step fabrication of copper nanoparticles. Di-ethylene glycol was used as base fluid for this process. Suspension of copper nanoparticles in Di-ethylene glycol resulted in highly stable nanofluids. The second most commonly used technique for preparing nanofluids is Two-step method. This process involves formation of nanoparticles as dry fine particles chemical/physical process. Then the next step makes use of various techniques like ultrasonic agitation, high-shear mixing. These nanosized powders are then suspended in base fluid. Due to the small sizes and high surface area, these nanoparticles have the tendency to combine which is not suitable. To improve the stability of nanoparticles in fluids the use of surfactants is the most important technique [10]. Two step method was used by several researchers to prepare CNTs, hybrid nanoparticles and different types of nanofluids.

III. THERMOPHYSICAL PROPERTIES OF NANOFLUIDS

Thermophysical properties such as thermal conductivity, viscosity and specific heat are affected with the addition of nanoparticles in base fluids which results in change in heat transfer coefficient. Thermophysical properties are affected by Concentration of nanoparticles, shape and size of nanomaterials.

Thermal conductivity of nanofluids: The thermal conductivity increases with the addition of nanoparticles in a base fluid. This is due to Brownian motion which leads to particle movement through liquid and collision with other particles which enables direct solid to solid contact and leads to heat transfer. The second reason is the layering of the liquid molecules at the solid interface. Therefore there exists more ordered atomic structure of liquid layer than bulk liquid. This ordered structure leads to high thermal conductivity. It is found that these layered molecules occur in an intermediate physical state between a solid particle and bulk liquid. Gupta et al. [11] described effect of particle volume fraction, particle material, particle size, particle shape, base fluid material, and temperature on thermal conductivity of nanofluids. It was observed from the experiment results that with decrease in particle size the thermal conductivity of nanofluids increases. There are two types of particle shapes used in case of nanofluids, they are cylindrical particles and spherical particles. The cylindrical shapes of nanoparticles exhibits large length-to-diameter ratio. Besides this the different types of material for nanoparticle which are used for nanofluids preparation are Oxide ceramics, Metal carbides, Nitrides, Metals, Nonmetals. Carbon nanotubes (single or multiwall) are also used as particle material and it exhibits high thermal conductivity and hence used in solar applications. The thermal conductivity of the nanofluids can be determined on the basis of the thermal conductivity of base fluid and particles. Crystalline solid structure is found in nanofluids. In such structures heat is carried by phonons. Such phonons propagate in random direction, scattered by defects and leads to heat transport. Brownian motion and nanoparticles clustering are affected by the change in temperature and shows the changes in thermal conductivity of nanofluids. Clustering of nanoparticles leads to high movement of heat within such clusters, also volume fractions of highly conducting phase are higher than that of volume of solids and exhibits higher thermal conductivity. The effective volume of cluster increases with decreasing packing fraction which leads to increase in thermal conductivity. The thermal conductivity of nanofluids increases with increase in temperature. Duangthongsuk et al.[1] investigated experimentally the thermal conductivity of nanofluids. In this study, TiO_2 nanoparticles were used having volume concentration of 0.2 – 2 vol % and are dispersed in water. It was found that with increasing nanofluids temperatures the measured thermal conductivity of nanofluids increases.

IV. EXPERIMENTAL WORK

Peng et al. [12,13] performed experimental investigations on the pressure drop and convective heat transfer of water flow in rectangular microchannels. It was found that the flow friction and convective heat transfer are greatly affected by the cross sectional aspect ratio in both laminar and turbulent flows.

Qiang et al. [14] experimentally investigated the use of Cu-water nanofluids flowing through a straight tube under laminar and turbulent flow regimes. Constant heat flux boundary condition was used in this case and the effect on the convective heat transfer was studied and flow was analysed. It was found from the results that with the addition of nanoparticles into the base liquid, the heat transfer performance of the base liquid increases. The friction factor of nanofluids was found to be similar as that of the water. New convective heat transfer correlation was proposed for calculating the heat transfer coefficients of the nanofluid. Correlation exists for both laminar and turbulent flow conditions.

Ding et al. [15] experimentally investigated the use of CNT-distilled water nanofluids flowing through a tube. Laminar flow was selected and its effect on the local heat transfer coefficient was analysed. The local heat transfer coefficient of CNT nanofluids was found to be much greater than that of pure water. The enhancement depends on the flow conditions, CNT concentration and the pH value. The effect of pH value was found to be less as compared to other parameters. In order to increase the heat transfer performance of CNTs based nanofluids, aspect ratio should be associated with it.

Nguyen et al. [16] experimentally investigated the heat transfer coefficient of Al_2O_3 nanoparticles dispersed in water flowing through a liquid cooling system of microprocessors. Turbulent flow condition was selected for analysis. The nanofluid was found to have a higher heat transfer coefficient than the base liquid. The nanofluid with a 36 nm particle diameter and 47 nm particle diameter were compared. It was found that 36 nm particle diameter gave higher heat transfer coefficient than the nanofluid with a 47 nm particle diameter. It was seen that with the increase in particle concentration the heated component temperature decreases.

Xuan et al. [17] experimentally investigated the flow and convective heat transfer of nanofluid flowing in a tube. The nanofluids for the experimentation are prepared by mixing Cu particles with diameter less than 100 nm and deionized water. It was found that the suspended nanoparticles increase heat transfer performance and has larger heat transfer coefficient than that of base fluid at same Reynold's number. Heat transfer performance of nanofluid increases with the volume fraction of nanoparticles. On studying the factors affecting the heat transfer coefficient by the use of nanofluids, a new correlation for Nusselt number was proposed. It was observed that friction factor for nanofluid consisting of water and Cu-nanoparticles is same as that of water. With increasing particle volume fraction, the viscosity of dispersed fluid was found to increase and was much higher than that of base liquid. This higher volume fraction of solid particles may suppress the heat transfer enhancement of suspension.

Mohammed et al. [18] numerically investigated the effect of use of nanofluids on heat transfer and fluid flow characteristics in rectangular shaped microchannel heat sink (MCHS). Range of Reynolds number selected for above analysis was from 100 – 1000. Alumina–water (Al_2O_3-H_2O) nanofluid with volume fraction ranged from 1% to 5% was used so as to examine the MCHS performance. It was observed that with the increase of particle volume fraction the MCHS wall temperature decreases when the heat flux is 1000 $\frac{W}{m^2}$ as compared to lower heat flux. It was observed that at lower heat flux conditions there is no significant difference between nanofluids and pure water. With the increase of Reynolds number the pressure drop increases. It was found that there is a slight increase in the pressure drop across the nanofluid-cooled MCHS as compared with pure water-cooled MCHS.

V. DATA REDUCTION

The density and specific heat of the nanofluids are calculated by using Pak and Cho [19] correlations, which are given as:

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_w \quad (1)$$

Where $\varphi =$ volume fraction, $\rho_{nf} =$ density of nanofluid, $\rho_p =$ density of particles, $\rho_w =$ density of water (base fluid).

$$Cp_{nf} = \varphi Cp_p + (1-\varphi)Cp_w \quad (2)$$

Where $Cp_{nf} =$ specific heat of nanofluid, $Cp_p =$ specific heat of nanoparticles, $Cp_w =$ specific heat of base fluid.

Heat transfer rate for the base fluid (hot water) is given as:

$$Q_w = \dot{m}_w Cp_w (T_{in} - T_{out})_w \quad (3)$$

Where Q_w is the heat transfer rate of hot water and $\dot{m}_w$ is the mass flow rate of hot water.

Heat transfer rate for nanofluid is given as:

$$Q_{nf} = \dot{m}_{nf} Cp_{nf} (T_{out} - T_{in})_{nf} \quad (4)$$

Where Q_{nf} is the heat transfer rate of nanofluid and $\dot{m}_{nf}$ is the mass flow rate of nanofluid.

The average heat transfer rate is given as:

$$Q_{ave} = \frac{Q_w + Q_{nf}}{2} \quad (5)$$

Where Q_{ave} is the average heat transfer rate between water and nanofluid.

$$h_{nf} = \frac{q_{ave}}{T_{wall} - T_{nf}} \quad (6)$$

Where h_{nf} is heat transfer coefficient, q_{ave} is average heat flux between hot water and nanofluid, T_{wall} is average temperature of wall and T_{nf} is bulk temperature of nanofluid.

$$Nu_{nf} = \frac{h_{nf} D}{k_{nf}} \quad (7)$$

Where Nu_{nf} is Nusselt number of nanofluid, D is the inner diameter of test section and k_{nf} is thermal conductivity of nanofluid.

Friction factor of nanofluid is given as:

$$f_{nf} = \frac{2D\Delta P_{nf} L}{u^2{}_m L \rho_{nf}} \quad (8)$$

Where ΔP_{nf} is the pressure drop of nanofluid, L is the length of test section, u_m is the mean velocity of nanofluid.

VI. CONCLUSION

This review covered some of the basics of nanofluids and literature related to their use and effects in microchannel heat exchanger. There are only few studies available on the use of nanofluids for different engineering applications. Therefore, it is necessary to conduct experimental and theoretical studies on large scale to explore the use and effects of different nanofluids in different thermal applications. From the study of above literature on nanofluids it is concluded that:

[1] Convective heat transfer coefficient of nanofluid is higher than the conventional fluids. The increase of nanoparticle volume fraction enhances the average Nusselt number.

[2] The thermal resistance value decreases as the volume fraction of nanoparticle increases.

[3] The presence of nanoparticles substantially increases the wall shear stress for all values of Reynolds number.

[4] Larger volume fraction and smaller nanoparticle size increase the pressure drop.

[5] New type of nanofluids with high thermal conductivity and low viscosity should be developed so as to be used in various thermal systems.

[6] As nanofluids are costly and difficult to make, new technologies should be developed to prepare cost effective and efficient nanofluids.

[7] More research should be on hybrid nanofluids(combination of two or more nanoparticles) as they have better thermophysical properties for thermal applications.

[8] Carbon nanotubes (CNTs) exhibit high thermal conductivity, unique optical properties and large surface area. Hence they are used in solar collectors and therefore more research should be carried out on use of CNT.

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