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Nanofluids as Heat Transfer Enhancers in Microchannels - A Review

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Abstract: The performance of a microchannel heat exchanger can be enhanced by reducing the hydraulic diameter or by using a working fluid which has better thermal conductivity than conventional working fluids. As the Nanotechnology is progressing, Nanofluids are emerging as potential alternative for working fluid in microchannels. Nanofluids have very high thermal conductivity as suspended Nano-particles enhances thermal conductivity of base fluid and improves the heat transfer performance of Microchannels. In this review paper experimental and numerical investigations carried out by various researchers in this area are critically analyzed. It has been observed that enhancement in heat transfer depends on volume fraction concentration of nanofluid, nanoparticle size and material. Further the average Nusselt number increases with an increase in nanofluid volume concentration and Reynolds number as well as decrease in nanoparticle size. Only an optimum volume fraction of nanofluid concentration enhances heat transfer and a slight increase reported in pressure drop when compared with pure fluid.

Keywords: Microchannels, Nanofluids, Thermal conductivity, Nanotechnology, Nanoparticles, Heat transfer

1. INTRODUCTION

With tremendous increase in computing power of Micro Electro Mechanical Systems (MEMS), an efficient heat dissipation and thermal control management system is required for proper functioning of electronic components. Microchannels which are light in weight, smaller in size handle low amount of coolants and provide higher surface area to volume ratio give higher heat transfer coefficients are efficient cooling devices for various modern electronic systems where higher heat fluxes are encountered. The pioneer work in the field of heat transfer using microchannel heat sink for electronic cooling was first time demonstrated by Tuckerman and Pease [1] by achieving high heat flux removal capacity of up to 800 W/cm^2 with microchannels in single-phase and two-phase flows. They noted that as the hydraulic diameter of the channel decreases, the heat transfer coefficient increases. In a microchannel a coolant is used to carry away heat from the small hot surface by forcing it through small passages having hydraulic diameter ranging from 10µm to 200 µm [2].

The enhancement in heat transfer performance in microchannels can be achieved by(i) using different microchannel geometries such as rectangular, square, circular,trapezoidal and triangular see Fig.1(a) (ii) different materials with high thermal conductivity such as copper, aluminium and silicon see Fig.1(b) (iii) by using alternative coolants with better heat capabilities. The conventional coolants used in microchannels are air, water, ethylene glycol, engine oil and their heat transfer performance is limited because of limited thermal conductivity. So by increasing the thermal conductivity of coolants heat transfer performance of microchannels can be improved. Choi [3] at the Argonne National Laboratory, USA, first time proposed the use of nanoparticles to increase the thermal conductivity of conventional coolants by dispersing an appropriate amount of solid nanoparticles having higher thermal conductivity than base fluid and coined the term ‘Nanofluids, for resulting mixture.

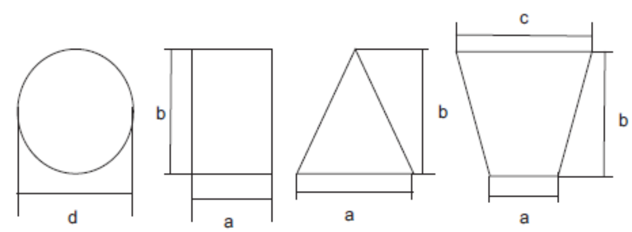

Fig. 1(a). Different microchannel geometries utilised in previous studies.

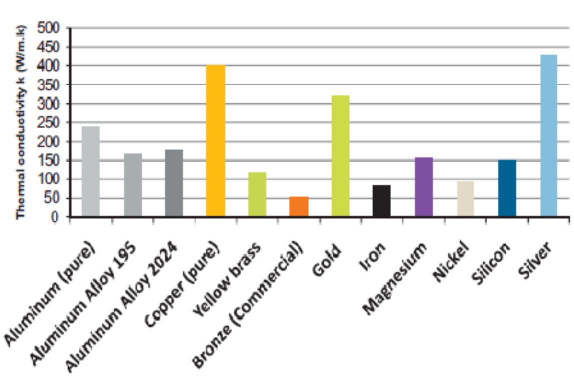

Fig. 1(b). Possible candidates materials for microchannel heat sink fabrication [4]

A nanofluid consists of small nanosized particles of size less than 100 nm in a base fluid such as water, ethylene glycol and engine oil. Recent studies have shown that nanofluids have emerged as potential heat transfer fluids for enhancing thermal performance of microchannels because of their high thermal conductivity and stability. Metallic materials generally used for nanoparticles are Oxide Ceremics (Al_2O_3, CuO), metals (Cu,Au,Ag),Semiconductors and Carbon nanotubes (CNT). The most common materials used are oxide ceremics. The addition of nanoparticles to the base fluid increases the thermal conductivity of the nanofluids and this improves the heat transfer performance of microchannels. Although nanofluids improve the thermal performance 0f microchannels but leaves behind the challenges like sedimentation of particles,fouling, high pressure drop, erosion and even clogging of channels over prolong use [5]. This paper reviews the experimental and numerical studies available in open literature associated with heat transfer enhancement in microchannels using nanofluids. The effect of various parameters of Nanofluids like nanoparticle volume fraction, size of nanoparticles, base fluid, substrate material and Reynolds number on the heat transfer enhancement are critically analysed and reviewed.

2. EFFECT OF VARIOUS PARAMETERS OF NANOFLUID ON HEAT TRANSFER

2.1 Effect of Particle Volume Fraction

The increase in heat transfer coefficient is not merely affected by increase in thermal conductivity but also by increase in Reynolds number and particle volume fraction [6]. Addition of nanoparticles into the base fluid improves the heat transfer when particle volume concentration is lower than 2%. Increase in particle volume concentration increases the pressure drop slightly [7]. Lee and Mudawar [8] investigated the single phase and two phase heat transfer characteristics of Alumina based naonofluids in microchannels. They observed that higher single phase heat transfer coefficients are obtained in the entrance region of microchannels with increased particle concentration.

However enhancement is weaker in fully developed region. They further suggested that nanoparticles should not be used in two-phase microchannel heat sinks (MCHS). The reason given is once boiling starts, particles begin to deposit into relatively large clusters near the channel exit due to localised evaporation. This clustering phenomenon quickly propagates upstream to fill the entire channel, thus preventing coolant from entering the heat sink and causing failure of the cooling system. Jang and Choi [9] numerically investigated a nanofluid-cooled microchannel and reported that heat transfer by using nanofluids containing diamond (1%,2 nm) at fixed power of 2.25 W was enhanced by about 10 % compared with that of microchannel with pure water. Mohammed et al. [10] have numerically investigated the MCHS performance using alumina-water nanofluid with volume fraction ranged from 1 % to 5 %. They observed that nanofluids can improve the heat transfer coefficient of MCHS as is volume fraction increase from 0 to 2.5 %. However nanofluid with 5 % volume fraction could not able to enhance the heat transfer or performing almost the same result as pure water, because the particles would be too big in content to flow smoothly on the extremely narrow cooling channels. Zhang et al. [11] experimentally investigated heat transfer characteristics of alumina –water nanofluids in a circular microchannel and reported that Nusselt number of alumina-water nanofluids is higher than that of pure water,and increases with Reynolds number and particle concentration as shown in Fig.2(a & b). The maximum enhancement achieved is 10.6 % for nanosfluids with particle concentration of 0.77 %, moreover the heat transfer enhancement effect is more apparent at higher Reynolds numbers in the case of laminar flow.

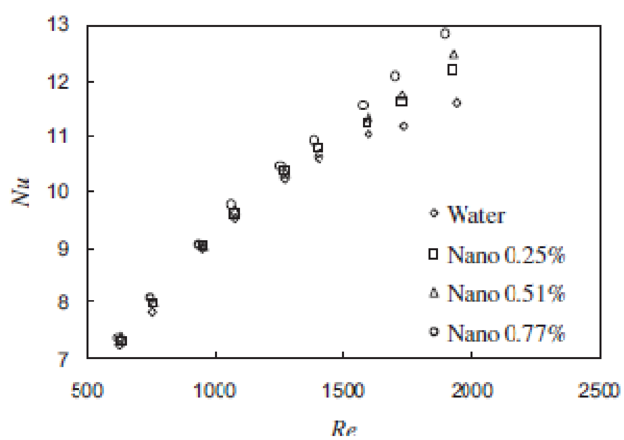

Fig. 2(a). Influence of Reynolds number and particle concentration on Nun at heat flux of 69. 9 kW m^{-2} [11]

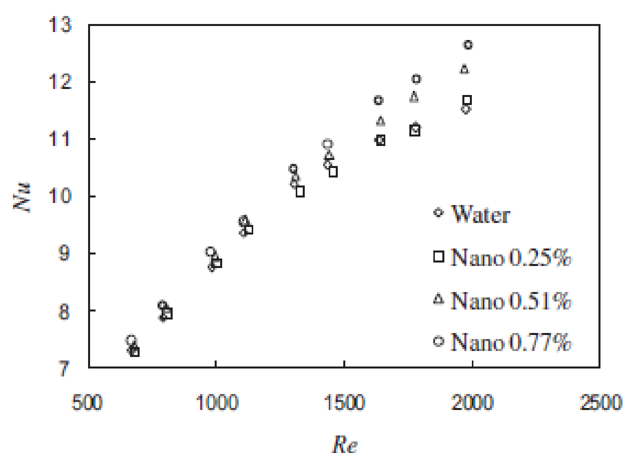

Fig. 2(b). Influence of Reynolds number and particle concentration on Nun at heat flux of 108. 9 kW m^{-2} [11]

Numerical investigations conducted by Manay et al. [12] on heat transfer characteristics of nanofluids in square microchannels have reported that heat transfer increased with increasing Reynolds number and particle volume concentration. CuO-water nanofluid provided higher heat transfer than that of Alumina –water nanofluid and best heat transfer enhancement is achieved at 2 % particle volume concentration and Reynolds number (Re =100) for CuO-water nanofluid.

2.2 Effect of Nanoparticle size

The experimental study conducted by Anoop et al. [13] using Alumina water nanofluid flow in the developing region of a tube with nanoparticle diamerters 45 nm and 150 has found an increase in heat transfer enhancement with decrease in particle size. Lee et al. [14] used Alumina (38.4 nm) and CuO (23.6 nm) particle size to increase the thermal conductivity of water and ethylene glycol. They observed that increase in thermal conductivity is not only a function of concentration and conductivities of particles material and liquid but also a function of particle size and shape.

Further experimental and numerical investigations conducted by Kalteh et al. [15] to study heat transfer of Alumina –water nanofluid inside a rectangular microchannel have reported that average Nusselt number increases with a decrease in nanoparticle size as shown in Fig.3. for 1 % nanofluid with 100 nm and 30 nm particle size, the average Nusselt number is 8.669 and 15.14 respectively. Hung et al. [16] performed numerical study with an Alumina-water nanofluid cooled Microchannels and reported that for smaller particles,the overall thermal resistance decreases with decreasing particle size. However, particle size has an insignificant effect on cooling performance above a certain value(>23 nm). Further the improvement in heat transfer performance obtained by decreasing the particle size is limited compared to that achieved by varying the particle volume fraction.

2.3 Effect of Base Fluid

Various studies have suggested that dynamic viscosity of nanofluid is very important to heat transfer performance, and base fluids with lower viscosity such as (water< ethylene glycol < engine oil) gives better heat transfer performance in microchannels using nanofluids. [16].

2.4 Effect of substrate material

The thermal conductivity of various subsbstrate material used is in the order Copper· Aluminium · Silicon· Steel. As copper substrate has the highest thermal conductivity it may produce smallest temperature increase and thus increases the thermal performance of the microchannel heat sink. So to increase the heat transfer performance of MCHS a substrate material with higher thermal conductivity is preferable [16].

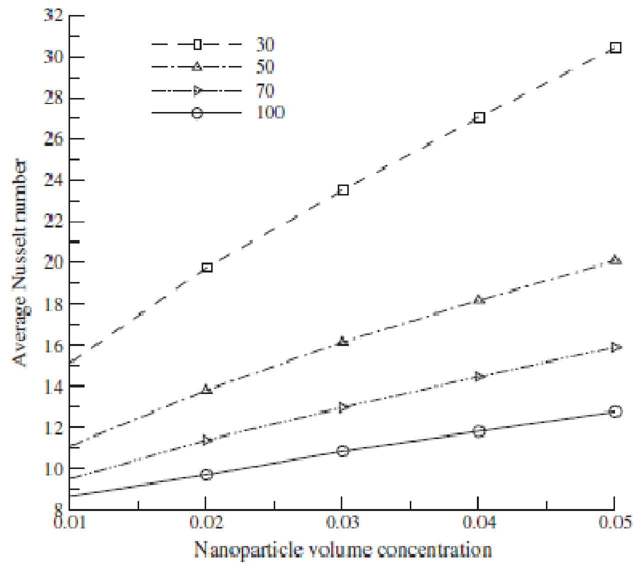

Fig. 3. Effect of the nanoparticle size on the nanofluid average Nusselt number (*Nu*) for Re=300 [15]

3. CONCLUSIONS

This paper has critically reviewed the literature pertaining to heat transfer enhancements in microchannels by using nanofluids. Various experimental and numerical studies conducted by researchers in this area are analyzed. The effect of using nanofluids with different particle volume fractions, particle size, base fluid and substrate material on enhancement of heat transfer in MCHS.The following conclusions can be drawn from the review conducted:

- Nanofluid cooled Microchannel heat sink gives enhanced heat transfer performance when compared with pure fluid.
- Use of nanofluids as coolant is advantageous in single-phase heat transfer when used in two-phase MCHS it s performance falls and causes failure of cooling system.
- The advantage of increased heat transfer with increasing particle volume fraction of (Al_2O_3 – water) nanofluid is obtained upto a certain limit (2-2.5 %).However particle volume fraction at 5 % yielded the same result as with pure water.
- Base fluids having lower viscosity like water (water< ethylene glycol < engine oil) should be preferred to get enhanced heat transfer performance in microchannel using nanofluids.
- A substrate material with higher thermal conductivity (Copper· Aluminium · Silicon· Steel) is preferable for fabrication of microchannel heat sink to increase the thermal performance.

- Alhough use of nanofluids improve the thermal performance of microchannels but leaves behind the challenges like sedimentation of particles,fouling, high pressure drop, erosion and even clogging of channels over prolong use yet to be overcome in future.

4. NOMENCLATURE

Re	Reynold Number
Nu	Nusselt Number
MCHS	Microchannel Heat Sink
MEMS	Micro-Electro Mechanical Systems

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