Study of Parameters of Liquid Cooling for Microscale Heat Transfer: A Review

Sagar Mittal[*], Amandeep Singh Wadhwa[**], Harry Garg[***]

Abstract

In an electronic component, high processing power in compact chips results in large heat dissipation. The aim of this article is to study and analyze the parameters of liquids for microscale heat transfer as it is an evolving trend from research point of view. Further, the range of coolants used for microscale heat transfer can vary from water, ethylene glycol, and liquid metal to nanofluids. Heat transfer in microchannel using nanofluid as coolant is highly efficient as it has higher heat dissipation capacity than water used as coolant. Microchannel cooling with liquid metal poses tough challenge with regard to corrosion and blocking problems in the cooling system. The heat transfer characteristics of the nanofluids for microchannel applications would be studied and the parameters like thermal conductivity of different nanofluids compared in the present article.

Keywords: Micochannels, Nanofluids, Thermal conductivity, Convective heat flow, Thermal resistance.

Introduction

The growth and lot of advancement in new technologies, e.g., electrical, electronics, computer technologies, communication, etc., leads to the problem of heat dissipation. This problem arises due to large storage data in small chip size and more power generation. Same problem is also experienced by optical devices. The current air-cooling technologies limit the dissipation rate as air has less heat convective coefficient than liquids. The advanced cooling solution, i.e., heat flux beyond the limit of 100 W/cm^2 is required by some applications. Conventional heat-transfer fluids such as water, mineral oil, and ethylene glycol play an important role in many industrial sectors including pulp and paper, petrochemical, chemical, food, textile and other processing plants. However, these fluids are inadequate for some applications which need high-heat-flux such as superfast computing, superconducting magnets, novel supersonic jet aircraft, and high-power microwave tubes due to their low thermal conductivity.

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To develop advanced heat transfer fluids, significant higher thermal conductivities are needed than presently available fluids. However, fluids at room temperature that have metals in solid form at room temperature have thermal conductivity of high orders of magnitude than conventional fluids. Copper has thermal conductivity at room temperature700 times greater than that of water and 3000 times greater than that of engine oil. Also thermal conductivity of the metallic liquids is much more than non-metallic liquids. Therefore, conventional heat transfer fluids have less thermal conductivity than fluids that contain suspended solid metallic particles. Therefore, for the thermal management of electronic and optical devices, the efficient method is microchannel heat sinks using liquid fluids.

Microchannel is the channel of hydraulic diameter below 1 mm. Microchannel heat sinks are very effective for heat dissipation from devices due to their high area-to-volume ratio. These heat exchangers can be manufactured from ceramic, metal and even low-cost plastics. Microchannels can be manufactured by different techniques such as silicon etching or electroplating, micromolding, micromilling in different shapes such as like trapezoidal, rectangular, rectangular-trapezoidal, etc. Microchannels that can be used for various applications are automotive and aerospace, heat pumps, refrigeration air conditioning, heat recovery ventilators, cooling of gas turbine blades, microelectronics, thermal control of film deposition, power and processing industries, infrared detectors, powerful laser mirrors, superconductors, etc.

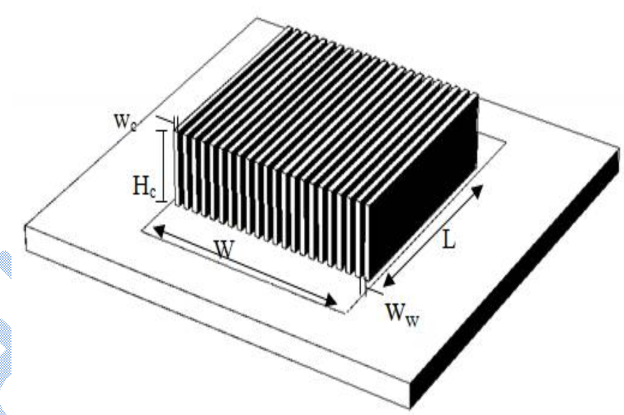

Figure 1.Schematic of Microchannel Geometry for High Heat Flux Cooling Applications [19]

Nanofluids are made by putting nanoparticles (size <100 nm) made of metal oxides, carbides or carbon nanotubes, etc. (eg., copper, copper oxide, aluminum oxide) in base fluid.

The features such as large surface area, high mobility will be achieved by suspending the nanoparticles in fluids. Starting from copper, we can go up to multi-walled carbon nanotubes (MWCNTs) for need of higher conductivity. Nanofluids are classified according to their applications as heat transfer nanofluids, chemical nanofluids, surfactants and coating nanofluids, tribological nanofluids, environmental (pollution cleaning) nanofluids, bio-and pharmaceutical nanofluids, and medical nanofluids (drug delivery, functional and tissue-cell interaction).

Literature Survey

In 1981, Tuckerman and Pease [1] initially proposed microchannels for electronics cooling applications by direct circulation of water in microchannels fabricated in silicon chips. Although pressure drop was high, they were able to remove heat flux up to 790 W/cm^2. Heat transfer was reported firstly by CHOI of the Argonne National Laboratories, USA, in 1995. Peng et al. [2] discussed a series of experimental investigations using water as fluid about all deviations of flow through rectangular microchannels in the range of hydraulic diameters (0.133-0.367 mm) and aspect ratios (0.33:1) using stainless steel substrates. Momoda and Phelps [3] invented a nanofluid composition comprising nano-sized phase change material (PCM) and a base heat transfer fluid for enhancing heat transfer performance. Yin et al. [4] invented the pressure drop measurements in microchannel heat exchangers with parallel circuits and complex headers true single phase. To find out internal manufacturing defects, measurements were done. Xue [5] gave the formula for calculating the effective thermal conductivity of nanofluids. He found that the theoretical results of oil nanofluid/ nanotube and Al_2O_3/ water nanofluid on the effective thermal conductivity are approximate with the experimental data. Withers and Loutfy [6] invented another nanofluid for use in closed heat transfer system in which energy transferred in heat exchanger between condenser and evaporator with heat transfer agent is made to flow from one to another. Kim [7] discussed the application based on 3-D simulation to evaluate the thermal resistance of the microchannel heat sinks of a fin model, a porous medium model and an optimization method was three optimization methods applicable to microchannel heat sinks. Min et al. [8] conducted simulation to know about the influence of tip clearance (the gap between the tip of the microstructures forming the microchannels and the top plate of a heat sink) in a microchannel heat sink. Murshed et al. [9] found in experimental results that nanofluids have much higher thermal conductivities than normal base fluids containing a small amount of nanoparticles. The thermal conductivity of nanofluids increases remarkably with increasing volume fraction of nanoparticles. Particle size and shape also influence the thermal conductivity enhancement of nanofluids. Xu et al. [10] by dividing the flow domain into several independent zones with a number of transverse and longitudinal microchannels made a microchannel sink. In this arrangement, the boundary layer formed interrupted and reattached lead to enhance the heat transfer. Lee [11] discussed about the microchannels heat transfer characteristics which was made of copper with Reynolds numbers in the range of 300 to 3500 and dimensions ranging from 194 to 534 µm. Upadhye and Kandlikar [12] under a given pressure drop limit for selecting microchannel flow geometries presented the results of an optimization procedure. Dixit et al. [13] worked on innovative multilayer water-cooled heat sink using silicon micro-nanopillars. Due to these silicon pillars, the heat dissipation rate was improved. Choi and Eastman [14] developed a method and apparatus for increasing heat transfer in fluids like ethylene glycol, de-ionized water and oil by dispersing nanocrystalline particles. Figures 2 and 3 show a plot of conductivity as a function of particle volume for different nanofluids.

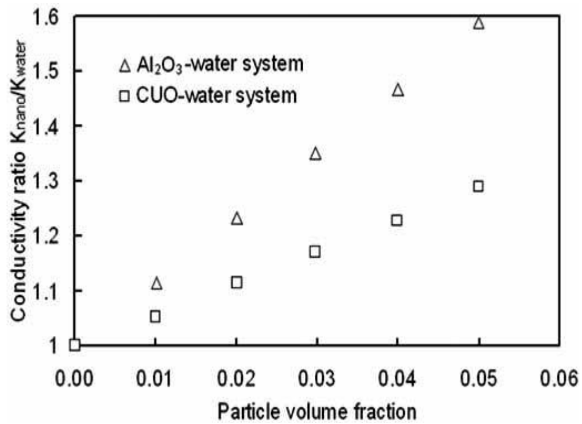

Figure 2.Conductivity Ratio of Nanofluid to Base Fluid versus Particle Volume Fraction [14]

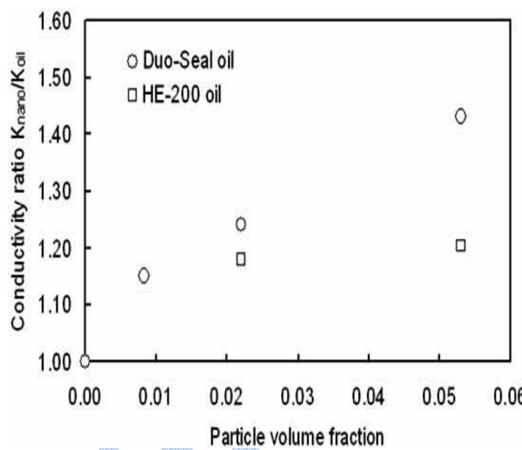

Figure 3.Conductivity Ratio of Nanofluid to Base Fluid versus Particle Volume Fraction [14]

There is up to 50% increase in the thermal conductivity of nanofluids as compared to those of base fluids. Deng at al. [15] in an experiment to evaluate the different flow and heat transfer characteristics in microchannel-used liquid metal instead of water.

They evaluated cooling capabilities and characteristics of liquid metal-based microchannel by taking three aspects, i.e., the flow resistance (pressure difference between inlet and outlet) under different coolant volume flow, convective heat transfer coefficient under different coolant volume flow, convection thermal resistance under different pump power using following equations:

- $\Delta p = \rho g \Delta H$
- $h = Q/A(T_w - T_f)$
- $Q = mc_p (T_{out} - T_{in})$
- $T_w = T1 + T2 + T3 + T4/4$
- $T_f = T_{out} + T_{in}/2$

Das et al. [16] studied experimentally enhancement of thermal conductivity of nanofluids (suspending CuO and Al_2O_3 nanoparticles in base fluid) with temperature. They observed that over a temperature range of 21°C to 51°C increase in thermal conductivity enhancement of nanofluids took place two to four times. Rahimi and Mehryar [17] investigated numerically the effects of thermal conductivity, duct wall and thickness on the local Nusselt number at the entrance and ending regions of a circular cross-section microchannel in a conjugate heat transfer problem. Xie et al. [18] recently studied and showed that the thermal characteristics are better in double-layer microchannel. Garg et al. [19] numerically and experimentally analyzed single-layer, double-layer and bi-directional split-channel configuration to increase performance of microchannel heat transfer. They observed high heat transfer coefficient of the order of 14000 W/m^2K in split-layer configuration.

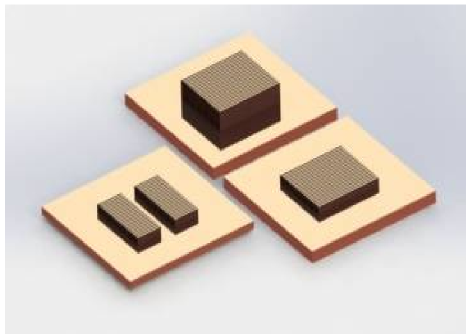

Figure 4.Double, Single and Split-Layered Microchannel [19]

Future Scope

As the improvement of computer performance is rapidly going on, large heat generation in the chip becomes a major serious concern for thermal management. Also the CPU chip size becoming smaller and smaller with almost no room for the heat to escape, there are several engineering challenges that need to be discussed for future applications.

1. The problem of freezing where the ambient temperature is less than the melting-point temperature of liquid coolant is less available in the literature.
2. The analysis of the properties of nanofluid using nanoparticles of diamond powder.
3. Effect of formation of thermal boundary layer on heat transfer rate with increasing length in microchannels using liquid coolant can be studied in addition to other properties.

Conclusion

It can be seen that there is up to 50% increase in the thermal conductivity of nanofluids as compared to those of base fluids. It has been observed with change in temperature the nanofluids show more enhancement of conductivity containing smaller CuO particles. It is also observed that over a temperature range of 21°C to 51°C, there is two to four times increase in thermal conductivity enhancement of nanofluids that takes place. This makes nanofluids even more attractive cooling fluids for devices that have high energy density where the cooling fluid can work at a temperature higher than the room temperature. The heat transfer coefficient of split channel has comparatively greater of the order of 7000 W/m^2K in one side. Moreover, the high heat-transfer coefficient of the order of 14000 W/m^2K can be achieved by heat transfer in two directions. Also the leakage and evaporation problems could be avoided much better by using liquid metal as the coolant of micro channel cooling devices.

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Appendix

- Hc : Height of flow channel (mm)
- L: Length of microchannel (mm)
- Wc: Width of microchannel (mm)
- Ww: Spacing between each fin (mm)
- p: Pressure difference between inlet and outlet, Pa
- p: Fluid density, kg/m^3
- g: Gravity force taken as 10 N/kg
- ΔH: Manometer height difference between the inlet and outlet of the micro channel, m
- Q: Total heat carried away by coolant, J
- A: Heat transfer area, m^2
- T: The wall temperature, K
- Tf: The coolant mean temperature in micro channel, K
- m: Mass flow, kg
- cp: The coolant heat capacity, J/kg K
- Tin and Tout: Inlet and outlet temperatures of micro-channel respectively, K
- T1, T2, T3, and T4: Temperatures of four evenly distributed temperature-measured holes at the bottom of micro channel, K
- h: Convective heat transfer coefficient, W/m^2K