HEAT TRANSFER ENHANCEMENT TECHNIQUES OF MINICHANNEL HEAT SINK USING NANOFLUIDS: A REVIEW

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ABSTRACT

Heat transfer augmentation technique refers to different methods used to increase rate of heat transfer without affecting much the overall performance of the system. Minichannel heat sink widely used as a heat exchanger to remove heat from electronic chips. As because of higher generation of heat in the electronic chips, there have been widely using liquid cooling systems. But as the technology growing day by day, more effective coolant needed for these systems. The invention of nanofluid has promised to enhance the effectiveness of the new liquid coolant. The mixture of solid particles to the liquid generally increases the thermal conductivity of the liquid because of its higher thermal conductivity itself. This paper contains review of different techniques used for heat transfer enhancement of minichannel heat sink using nanofluids.

***Keywords:* Heat Transfer Enhancement, Minichannel Heat Sink, Nanotechnology, Need of Nanofluids, Passive Method.**

I. INTRODUCTION

The heat exchangers have an important role in the energy conservation, conversion, and recovery. Due to the rapid development of modern technology, heat exchangers used by various industries require high heat-flux cooling. Cooling with conventional fluids such as water and ethylene glycol and so forth, (Because of poor conductivity) is challenging.

Therefore, it is necessary to increase the heat transfer capabilities of working fluids in the heat transfer devices. Heat transfer augmentation techniques are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, cooling of electronic circuits etc.

Heat transfer augmentation techniques refer to different methods used to increase these techniques and broadly divided in two groups, passive and active. Active techniques involve some external power input for the enhancement of heat transfer. Passive heat transfer augmentation method does not use any external power input. The passive methods are based on the principle, one of the way to enhance heat transfer rate, is to increase the effective surface

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area and residence time of the heat transfer fluid. Use of this technique causes the swirl in the bulk of the fluids an disturbs the actual boundary layer so as to increase effective surface area, residence time and consequently heat transfer coefficient in existing system.

II. DIFFERENT METHODS OF HEAT TRANSFER ENHANCEMENT

Heat transfer enhancement deals with the improvement of thermo-hydraulic performance of heat exchangers. Different enhancement techniques have been broadly classified as active and passive techniques.

2.1 Active method

Active method involves some external power input for heat transfer enhancement. Some examples of active methods include induced pulsation by cams and reciprocating plungers, use of a magnetic field to disturb the seeded light particles in a flowing stream, mechanicals aids, surface vibration, fluid vibration, electrostatic fields, suction or injection and jet impingement.

2.2 Passive method

Passive heat transfer enhancement method as stated earlier does not need any external power input. In the convective heat transfer one of the ways to enhance heat transfer rate is to increase the effective surface area and residence time of the heat transfer fluids. The passive methods are based on the same principle. Use of this technique causes the swirl in the bulk of the fluids and disturbs the actual boundary layer so as to increase effective surface area, residence time and consequently heat transfer coefficient in existing system.

2.3 Compound method

If any two or more techniques i.e. passive and active may be employed simultaneously to enhance the heat transfer of any device, which is greater than that of produced by any of those techniques separately, the term known as Compound enhancement technique.

This paper focuses on reviewing the passive methods in minichannel heat sink. The passive heat transfer augmentation methods as stated earlier do not need any external power input. For the convective heat transfer, one of the ways to enhance heat transfer rate is to increase the effective surface area and residence time of the heat transfer fluids. The passive methods are based on this principle, by employing several techniques to generate the swirl in the fluids and disturb the actual boundary layer so as to increase effective surface area, residence time and consequently heat transfer coefficient in existing system.

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III. MINICHANNEL HEAT SINK

With the advancement in miniaturization technology and need for higher efficient equipments, mini-scale and micro-scale devices are proving to be beneficial and advantageous.

The trend towards miniaturization is mainly driven by:

- Emergence of micro scale devices that require cooling.
- Increased heat flux dissipation in microelectronic devices.
- The need of heat transfer enhancement.

Currently, minichannel heat sink is used in industries such as microelectronics, robotics, telecommunications etc. These micro scale devices, commonly known as Micro Electromechanical Systems (MEMS) are getting more advanced and complex as the micro fabrication technology is progressing well with the trend. However, there are two factors that limit the heat transfer coefficients in a mini heat exchanger: the reduction in the channel dimensions was accompanied by higher pressure drop, and the amount of heat transfer was limited by the heat transfer fluid used.

IV. NANOFLUID

4.1 History

The nanotechnology is new, but it is existence of the functional devices and structure of nanosized devices are not new in this world. In 1905, experimental data on the diffusion theory showed that the molecule has nano meter diameter, which is considered as the notable landmark in the scientific history of nanotechnology. In 29 December 1959: Visionary statement by Prof. R.P. Feynman, "There is enough space at the bottom". A carbon nano tube is a tube shaped material, made of carbon, having a diameter measuring on the nano meter scale. Carbon nano tubes are allotropes of carbon with a cylindrical nanostructure. The cylindrical carbon molecules have unusual properties which are valuable for nanotechnology. In particular owing to their extraordinary thermal conductivity and mechanical and electrical properties carbon nano tubes find application as additives to various structural materials.

4.2 Need of Nanofluid

- Nanofluids are most reliable for continuous cooling & heating systems
- With nano size particles, fluid is considered as integral fluid
- It reduces pumping power as compared to the pure liquid to achieve the better heat transfer enhancement
- It reduces particle clogging as compared to conventional slurries and hence heips the system miniaturization
- High specific surface area, hence more heat transfer surface between particles and fluids
- Having high dispersion stability with motion of particles

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4.3 Applications of Nanofluid

The concepts of nanofluids are used for the heat transfer characteristics which are applicable for many systems for better performance. There are many researches did on the heat transfer properties using nanofluids especially on thermal conductivity and convective heat transfer. Applications of nanofluids in many industries such as heat exchanging devices appear promising with these characteristics. Nanofluids can be used in following specific areas:

- Refrigeration
- Nuclear system cooling
- Solar water heating
- Bio- and pharmaceutical
- Electronic circuits cooling
- Drilling and lubrication
- Chemical
- Engine cooling and Engine transmission oil nanofluids
- Process/extraction

V. REVIEW OF WORK CARRIED OUT

X. L. Xie et al. [1] numerically studied laminar heat transfer and pressure drop characteristics in a water-cooled minichannel heat sink. They analyzed numerically a minichannel heat sink with bottom size of 20 mm × 20 mm for the single phase laminar flow of water as coolant through small hydraulic diameters. They also analyzed the effect of channel dimensions, channel wall thickness, bottom thickness and inlet velocity on the pressure drop, thermal resistance and the maximum allowable heat flux. The results indicate that there is improvement in heat transfer performance with a relatively high but acceptable pressure drop by using a narrow and deep channel with thin bottom thickness and relatively thin channel wall thickness. They found nearly-optimized configuration of heat sink which can cool a chip with heat flux of 256 W/cm^2 at the pumping power of 0.205 W.

Saad Ayub Jajja et al. [2] experimentally investigated water cooled minichannel heat sinks for microprocessor cooling. They investigated five different heat sinks with fin spacing of 0.2 mm, 0.5 mm, 1.0 mm, and 1.5 mm along with a flat plate heat sink. Microprocessor heat was simulated by a heated copper block with water as a coolant. At heater power of 325 W, the lowest heat sink base temperature of 40.5^0 C was achieved by using a heat sink of 0.2 mm fin spacing which was about 9% lower than the best reported base temperature of 44^0C using a nanofluid with commercial heat sink. The base temperature and thermal resistance of the heat sinks were found to drop by decreasing the fin spacing and by increasing volumetric flow rate of water circulating through the heat sink. For a flat plate heat sink, the maximum thermal resistance was 0.216 K/W that was reduced to as little as 0.03 K/W by using a heat sink of 0.2 mm fin spacing. The overall heat transfer coefficient was found to be 1297 W/m^2 K and

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2156 W/m^2 K for the case of a flat plat and 0.2 mm fin spacing heat sinks, respectively, the latter showed about two-folds enhancement compared to the former.

Cong Tam Nguyen et al. [3] experimentally investigated the behavior and heat transfer enhancement of Al_2O3–H_2O nanofluid, which was flowing inside a closed system that is destined for cooling of microprocessors or other electronic components. The experimental data, obtained for turbulent flow regime, have clearly shown that the inclusion of nanoparticles into distilled water has produced a considerable enhancement of the cooling block convective heat transfer coefficient. For Al_2O_3–H_2O nanofluid with 6.8% particle volume concentration, heat transfer coefficient has been found to increase as much as 40% compared to that of the base fluid i.e. water. They also found that an increase of particle concentration has produced a clear decrease of the heated component temperature. The experimental data have clearly shown that nanofluid with 36 nm particle diameter provides higher heat transfer coefficients than the ones of nanofluid with 47 nm particle size.

C.J. Ho et al. [4] experimentally studied thermal performance of Al_2O_3–H_2O nanofluid in a minichannel heat sink. They performed various experiments to explore the forced convective heat transfer performance of using Al_2O_3–H_2O nanofluid to replace the pure water as the coolant in a copper minichannel heat sink. Hydraulic and thermal performances of the nanofluid cooled minichannel heat sink have been assessed from the results obtained for the pumping power, the averaged heat transfer coefficients based on the inlet and bulk temperature difference, respectively, with the Reynolds number ranging from 133 to 1515. Compared with the results for the pure water, they found that the nanofluid cooled heat sink has significantly higher average heat transfer coefficients and hence outperforms the water cooled heat sink. The heat transfer efficiency of using the nanofluid in the heat sink was further evaluated against the accompanied pumping power penalty.

P. Selvakumar et al. [5] experimentally investigated the convective performance of CuO–H_2O nanofluid in an electronic heat sink. In this work CuO–H_2O nanofluid of volume fractions 0.1% and 0.2% were prepared by dispersing the nanoparticles in deionised water. A thin channeled copper water block of overall dimension 55 × 55 × 19 mm was used for the study. The interface temperature of the water block is measured and a maximum reduction of 1.15 °C was observed when nanofluid of 0.2% volume fraction was used as the working fluid compared to deionised water. Convective heat transfer coefficient of water block was found to increase with the volume flow rate and nanoparticle volume fraction and the maximum rise in convective heat transfer coefficient was observed as 29.63% for the 0.2% volume fraction compared to deionised water. Pumping power for the deionised water and nanofluids were calculated based on the pressure drop in the water block and the average increase in pumping power is 15.11% for the nanofluid volume fraction of 0.2% compared to deionised water. A correlation is proposed for Nusselt number which fits the experimental Nusselt number within ±7.5%.

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Ali Ijam et al. [6] analyzed a minichannel heat sink with a 20×20 cm bottom for SiC–H_2O nanofluid and TiO_2–H_2O nanofluid turbulent flow as coolants through hydraulic diameters. The results showed that enhancement in thermal conductivity by dispersed SiC in water at 4% volume fraction was 12.44% and by dispersed TiO_2 in water was 9.99% for the same volume fraction. They found that by using SiC–H_2O nanofluid as a coolant instead of water, an improvement of approximately 7.25% and 12.43% could be achieved and by using TiO_2–H_2O 7.63% and 12.77%. The maximum pumping power by using SiC–H_2O nanofluid at 2 m/s and 4% vol. was 0.28W and at 6 m/s and 4% volume equal to 5.39 W. By using TiO_2–H_2O nanofluid at 2 m/s and 4% vol it was found to be 0.29 W and 5.64 W at 6 m/s with the same volume of 4%.

N. A. Roberts et al. [7] experimentally investigated the convective Performance of Nanofluids in Commercial Electronics Cooling Systems. In this work they investigate the performance of different volume loadings of water-based alumina nanofluids in a commercially available electronics cooling system. The commercially available system was a water block used for liquid cooling of a computational processing unit. The size of the nanoparticles in the study was 20–30 nm. They found enhancement in convective heat transfer due to the addition of nanoparticles in the commercial cooling system with volume loadings of nanoparticles up to 1.5% by volume. The enhancement in the convective performance observed was similar to what has been reported in well controlled and understood systems and is commensurate with bulk models. The nanoparticle suspensions showed visible signs of settling which varied from hours to weeks depending on the size of the particles used.

M.R. Sohel et al. [8] experimentally investigated the heat transfer enhancement of a minichannel heat sink using Al_2O_3–H_2Onanofluid. The thermal performances of a minichannel heat sink were experimentally investigated for cooling of electronics using nanofluid coolant instead of pure water. The Al_2O_3–H_2Onanofluid including the volume fraction ranging from 0.10 to 0.25 vol. % was used as a coolant. The effects of different flow rates of the coolant on the overall thermal performances are also investigated. The flow rate was ranged from 0.50 to 1.25 L/min as well as the Reynolds number from 395 to 989. The coolant was passed through a custom made copper minichannel heat sink consisting of the channel height of 0.8 mm and the channel width of 0.5 mm. The experimental results showed the higher improvement of the thermal performances using nanofluid instead of pure distilled water. The heat transfer coefficient was found to be enhanced up to 18% successfully. The nanofluid significantly lowered the heat sink base temperature (about 2.7^0C) while it also showed 15.72% less thermal resistance at 0.25 vol.% and higher Reynolds number compared to the distilled water.

Paisam Naphon et al. [9] studied the heat transfer characteristics of nanofluids cooling in the mini-rectangular fin heat sink. The heat sinks with three different channel heights were fabricated from the aluminum by the wire electrical discharge machine (WEDM) with the length, width and base thickness of 110, 60, and 2 mm, respectively. The nanofluids were the mixture of de-ionized water and nanoscale TiO_2 particles. The results obtained from the nanofluids cooling in mini-rectangular fin heat sink were compared with those from the de-ionized water cooling

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method. Effects of the inlet temperature of nanofluids, nanofluid Reynolds number, and heat flux on the heat transfer characteristics of mini-rectangular fin heat sink were considered. They found that average heat transfer rates for nanofluids as coolant were higher than those for the de-ionized water as coolant. The results of this study are of technological importance for the efficient design of cooling systems of electronic devices to enhance cooling performance.

Tullius et al. [10] examined the influence of Al_2O_3–H_2O nanofluid on enhancing the heat transfer performance of the circular fin structured minichannel heat sink. The nanofluid showed a great enhancement in thermal transportation. In the same time they also got a little surface imperfection problem because of the nanoparticle sedimentation, which was responsible for reducing the heat transfer performances.

Wei-Chen Chen et al. [11] Performed experiment on thermal performance of water-based suspensions of Al_2O_3 nanoparticles and Micro-Encapsulated Phase Change Material (MEPCM) particles in a minichannel heat sink. In this study, experimental efforts have been performed to explore the forced convection heat transfer efficiency of using water-based suspensions of alumina nanoparticles (nanofluid) and microencapsulated phase change material particles to replace the pure water as the working fluids in a minichannel heat sink. The heat sink fabricated from copper consists of 10 rectangular minichannels, each of which has a width of 1 mm, a depth of 1.5 mm, a length of 50 mm, having a hydraulic diameter of 1.2 mm. The minichannel heat sink was heated with a uniform base heat flux with the Reynolds numbers ranged from 133 to 1515. The mass fractions of the nanoparticles and MEPCM particles dispersed in the water-based suspensions were in the ranges of 2–10 wt %, respectively. Experimental results obtained reveal that the heat dissipation effectiveness of the nanofluid and phase change material (PCM) suspension depends significantly on their flow rates through the heat sink. For the nanofluid, the highest enhancement of 57% in the averaged heat transfer coefficient was detected under the highest flow rate; while for the PCM suspension, the highest enhancement of 51% under the lowest flow rate. For the hybrid water-based suspensions, the effect of simultaneous dispersion of the nanoparticles and MEPCM particles in water appears to be supplementary with added benefit of simultaneous increases in the effective thermal conductivity and specific heat such that the heat transfer effectiveness could be further increased up to 56% with little dependence on the flow rate.

C.J. Ho et al. [12] experimentally investigate the thermal performance of Al_2O_3–H_2O nanofluid in a natural circulation loop with a mini-channel heat sink and heat source. In this study, the heat transfer characteristics of Al_2O_3–H_2O nanofluid were investigated experimentally in a rectangular natural circulation loop of 402 mm in height and 205 mm in width. The 120-mm-long heated section and 155-mm-long cooling section in the loop were constructed with mini-channel heat exchangers. The nanometer-sized particles of alumina were dispersed in pure water (the base fluid) to form the Al_2O_3–H_2O nanofluid with mass fractions in the range of 0.1–1 wt. %. The results clearly indicate that Al_2O_3–H_2O nanofluid can enhance the heat-transfer performance of the natural circulation loop considered. The average heat-transfer effectiveness at the heating and cooling sections was approximately 3.5–22% and 9.5–62% respectively.

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VI. CONCLUSION

In this review, various techniques of enhancing the thermal performances of heat sink are explained. Various authors mainly concluded that by using nanofluids as a coolant instead of pure distilled water, enhances the heat transfer rate to a huge extent. It is also concluded that heat transfer rate will be maximum at higher volume concentration of nanoparticals and at higher flow rates of the fluid. Although many analyses have been done on cooling systems for electronics using nanofluids in the open literature, the number of experimental studies conducted is very limited to the best of the author's knowledge. Hence it can be said that the amount of understanding and knowledge is still at the early phase and much research is necessary to fully develope the concepts of nanofluidics and minichannel. Much further analysis is needed to establish the concepts in this field as it is still considered as a novel idea and implementation of nanofluids in industries is still far from being a practical solution at this moment. However, as a general conclusion, it is evident in most cases that minichannel heat exchanger and nanofluids seems like the only possible solution at this moment for the cooling challenge in the mini and nanotechnology era.

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