Effect of Cu-Water Nanofluid on Heat Transfer Rate of a Minichannel Heat Exchanger

•**Abhay Kumar Singh**[1]
[1]Assistant Professor, Department of Mechanical Engineering
Bakhtiyarpur College of Engineering, Bakhtiyarpur, Bihar, India
Email id-kumarabhay347@gmail.com

Abstract-

Since they have such high heat transmission properties, nanofluids are becoming increasingly important in thermal applications. The electronics industry uses micro-scale heat transfer devices extensively, which has led to the creation of tiny heat exchangers with high heat transfer coefficients. The use of dispersed nanoparticles in base fluids is a recent invention in the field of nanotechnology that improves the heat transfer coefficient of base fluids. This study provides an overview of the literature on the use of nanofluids to improve convective heat transfer in microchannel heat exchangers and the impact of different thermophysical parameters on heat transfer performance. In this study, theoretical and experimental findings for various geometries and their impacts on the Nusselt number are presented. The findings indicate a remarkable rise in the significance of using nanofluids in microchannels. Effects of using various nanofluids and how they perform in comparison to basic fluids.

Keywords— *Effect of Cu-Water, Nanofluid on Heat Transfer Rate, Minichannel Heat Exchanger.*
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INTRODUCTION

Many sectors, including power generation, chemical operations, heating and cooling processes, transportation, microelectronics, and other micro-sized applications, employ conventional heat transfer fluids like oil, water, and ethylene glycol extensively. The development of equipment with high heat transfer requires careful consideration of the thermal conductivity of the heat transfer fluids. The usage of extended-surface (fins and microchannels), surface vibration, suction/injection of fluids, and the use of electrical/magnetic fields to speed up heat transfer have all come to a halt. An industrial assessment reveals the necessity to create very compact equipment that increases heat flow. Therefore, it is challenging to design high efficiency heat transfer fluid. In recent years, several researchers have worked to create unique classes of heat transfer fluids in an effort to improve those fluids' heat transfer capabilities. Small solid particles are suspended in the base fluid in the new approach. Base fluids can contain a variety of solid particles, including metallic, nonmetallic, and polymeric ones. However, earlier research revealed that while the use of suspended particles can significantly improve heat transfer, there are also some significant drawbacks, including poor suspension stability, clogged flow channels, pipeline erosion, and an increase in pressure drop in thermal equipment. The term "nanofluid" was initially proposed by Choi in 1995, and since then it has grown in popularity. It refers to the usage of particles with an average size of 10 nm that are dispersed in base liquids to boost heat conductivity. For their own safety, liquid cooling systems have been used extensively due to the increasing heat generation in electronic devices. However, the advancing technology necessitates a more potent coolant for these systems. The development of nanofluid has the potential to improve the performance of the new liquid coolant. A nanofluid is typically described as a suspension of nanoscale particles (up to 100 nm) in the base fluid. Due to the liquid's higher intrinsic thermal conductivity, the addition of solid particles often enhances the liquid's thermal conductivity. Another method to improve the cooling system's efficiency is to make the heat sink smaller. Since the previous two decades, several computational, analytical, and a few practical investigations of the capabilities of nanofluids applied to the miniature heat sink for cooling electronics have been carried out.

Keblinski et al. investigated the movement of nanofluids thermally. They claimed that the thermal conductivity of the nanofluids was significantly increased by a layer of liquid cluster around the nanoparticle. Additionally, it is said that Brownian motion did not significantly contribute to bettering the thermal transit of the nanofluids. However, Tokit et al. emphasised that by aiding the cluster formation of the nanoparticle at a lower velocity itself, the Brownian motion plays a significant role to boost the thermal conductivity. Alumina-water and titania-water nanofluids for cooling electronic circuits were examined by Putra et al. The study included the need to create a novel cooling method rather than a traditional one for cooling microchips. Nanofluid was used to provide a notable improvement in heat rejection from the electronic chip. The effects of temperature on the heat transmission capabilities of nanofluids were examined by Das et al.

LITERATURE REVIEW

X. L. Xie et al. 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/cm2 at the pumping power of 0.205 W.

Saad Ayub Jajja et al. 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 40.50 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 440C 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/m2 K and 2156 W/m2 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. experimentally investigated the behavior and heat transfer enhancement of Al2O3–H2O 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 Al2O3–H2O 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. experimentally studied thermal performance of Al2O3–H2O nanofluid in a minichannel heat sink. They performed various experiments to explore the forced convective heat transfer performance of using Al2O3–H2O 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. 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%.

Ali Ijam et al. analyzed a minichannel heat sink with a 20×20 cm bottom for $SiC–H_2O$ nanofluid and TiO_2–H2$_O$ 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 TiO2–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. 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. experimentally investigated the heat transfer enhancement of a minichannel heat sink using Al2$_O$3–H_2O nanofluid. The thermal performances of a minichannel heat sink were experimentally investigated for cooling of electronics using nanofluid coolant instead of pure water. The Al2$_O$3–H2$_O$nanofluid 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 2.70C) 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. 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 TiO2 particles. The results obtained from the nanofluids cooling in mini-rectangular fin heat sink were compared with those from the de-ionized water cooling 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. examined the influence of $Al2_{O}3$–$H2_{O}$ 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.

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.

(i) 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.

(ii) 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.

(iii) 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.

CU-WATER NANOFLUID EXPERIMENTATION

(i) Preperation of Nanofluid- Gamma For the preparation of CuO nanofluid using water as the base material, copper oxide was employed. CuO nanoparticles were distributed in 3.5 litres of ultra pure, double-distilled water using different volume fractions, such as 0.01, 0.02, 0.03, 0.1, 0.2, and 0.3, and their ability to transfer heat in a microchannel was examined.

(ii) Characterisation of Nanofluid- Scanning Electron Microscope (SEM) and Energy Dispersive Atomic X Ray (EDAX) were used for the Characterization Analysis.

(iii) Micro channel heat sink experimental setup- Figure 1. displays a schematic representation of the experimental setup. The Ultrasonic Vibration Bath, Pump, Filter, Flow Metre, Micro-Channel, Heater, and Air Cooled Heat Exchange comprise the test loop. CuO nanofluids are kept in the ultrasonic vibration bath in the current work. This bathtub serves as a sonificator and reservoir.On the microchannel's surface, a heater is permanently placed. Between the bath and the microchannel, a pump is affixed to move nanofluids throughout the whole system. Utilising filters, the undesirable micron-sized particles are eliminated. Between the pump and the micro channel is a flow metre. The valve, which is situated between the pump and channel, regulates the rate of fluid flow. The micro channel's inlet and exit have fixed pressure gauges that are used to gauge the pressure decrease in the channel. The nano fluid absorbs part of the heat from the heater as it moves through the microchannel. When the nano fluid flows through the heat exchanger that is cooled by the air, the extra heat it was carrying is discharged. The cycle is then repeated with the fluid moving to the bath. In order to avoid any fluid leakage, the complete setup is maintained in an airtight state.

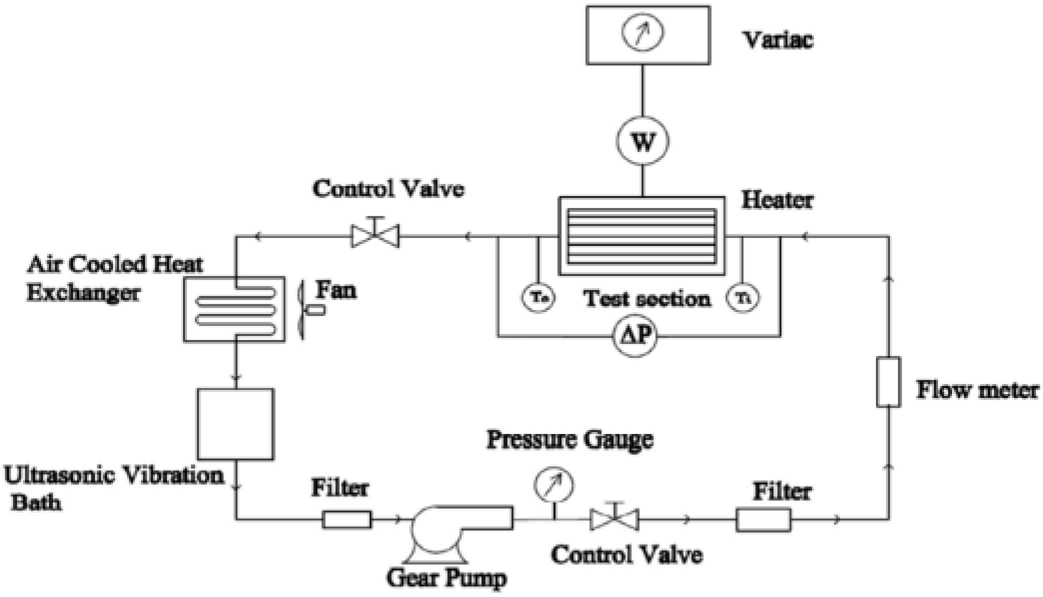

Figure 1- Schematic diagram of the experimental setup

METHODOLOGY

To gain a deeper understanding of the concepts involved in the study of the hydrothermal analysis of nanofluids in minichannel thermal devices with a focus on heat transfer enhancement mechanisms and techniques used, and achievement of thermal improvement, a thorough review of related works and expression of researches in this area was conducted. The approaches utilised to improve heat transmission as well as the study's methodology (either experimental or numerical) were reviewed after discussing a categorization of nanofluids first.

(i) Classification of Nanofluids- Normally, two different methods one step and two methods for distributing powdered nanoparticles (NP) into the base fluid are used to create nanofluids. Metals (Cu, Ag, Au), oxide ceramics (Al_2O_3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), semiconductors (TiO_2 and SiO_2), and carbon-based materials (Carbon nanotubes and Graphene) are only a few examples of the various nanoparticle materials employed in the manufacture of nanofluids. A hybrid nanofluid is produced by combining two or more nanofluids, and it exhibits stronger enhancement than the individual nanofluids that made it, while having increased viscosity, which occasionally lowers the amount of enhancement. The majority of researchers found that because nanofluid has a higher surface-to-volume ratio than the base fluid, adding nanoparticles (NPs), typically in sizes between 1 and 100 nm, to a base fluid can significantly increase heat transfer rate and, as a result, increase convective heat transfer coefficient (HTC). This improvement comes at the expense of pressure drop, which necessitates greater working fluid pumping power. Long-term stability and the aggregation of nanoscale to macroscale particles, which may obstruct and degrade the surface of the minichannel, are additional essential considerations. Nanofluid is typically produced using either one step or two step processes. A thorough examination of the creation and synthesis of nanofluids was undertaken.

(ii) Heat transfer enhancement techniques- Simply divided into active and passive approaches, these mechanisms are utilised to improve heat transport without impairing the overall thermo-hydraulic performance of the thermal system. In contrast to the former, which requires some external power input for heat transfer enhancement, the latter modifies the properties and structure of the heating surface by increasing the effective surface area and residence time of the thermal fluid. Because of this method's advanced energy efficiency and material savings, it is frequently used in heat transfer enhancement. Figure 2 shows classifications of active and passive approaches.

(iii) Method of heat transfer analysis- Similar to other science and engineering disciplines, heat transfer analysis uses theoretical approaches, numerical simulations, and experiments as instruments to help research and development. Although the experimental technique is more accurate, simulation is favoured over experimental measurements or theoretical analysis due to considerations including speed, affordability, reproducibility, and safety, as well as current technical advancements and widespread computer access. Some of these strategies' opportunities and difficulties were emphasised.

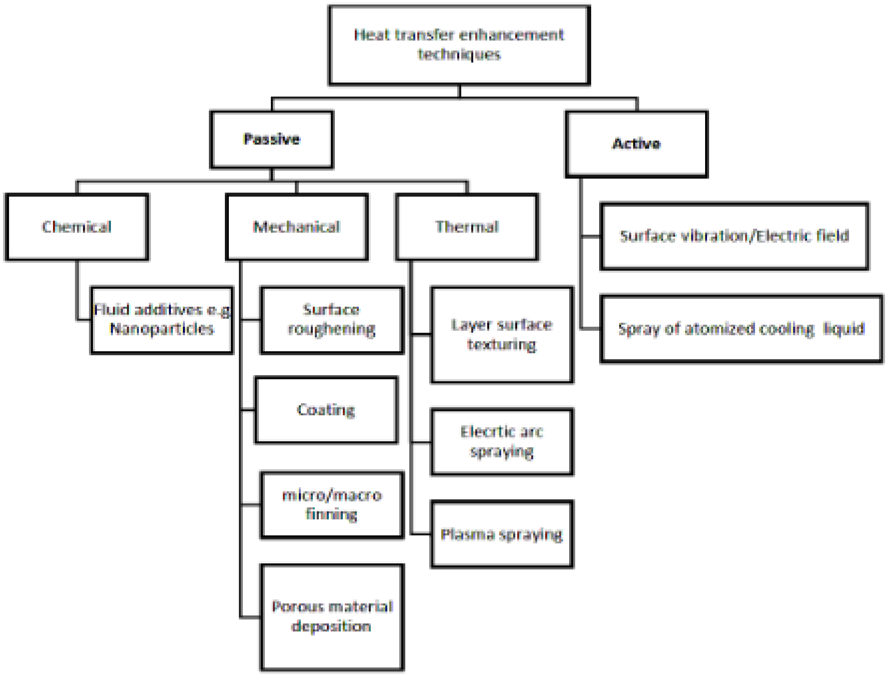

Figure 2- Heat transfer enhancement techniques

CONCLUSION

This study explains numerous methods for improving the thermal performance of heat sinks. In general, writers came to the conclusion that employing nanofluids as a coolant rather than pure distilled water greatly increases the rate of heat transfer. Additionally, it is inferred that with greater fluid flow rates and larger nanoparticle volume concentrations, heat transfer rates will be at their maximum. Although several assessments of cooling systems for electronics utilising nanofluids have been published in the open literature, the author is aware of very few experimental experiments that have been carried out. Therefore, it can be claimed that study is still needed to completely develop the ideas of nanofluidics and minichannel since understanding and knowledge are still in their early stages. Since the use of nanofluids in industries is still regarded as a novel notion and is not yet a feasible option, much more research is required to establish the principles in this sector. As a generalisation, it is clear that minichannel heat exchangers and nanofluids appear to be the only current options for addressing the cooling dilemma in the age of mini and nanotechnology.

This study discussed some of the fundamentals of nanofluids as well as research on their use and outcomes in microchannel heat exchangers. Only a small number of research have been done on the usage of nanofluids in various engineering applications. To investigate the usage and impacts of various nanofluids in various thermal applications, large-scale experimental and theoretical research are thus required. According to the analysis of the aforementioned nanofluids literature.

(i) Nanofluids have a greater convective heat transfer coefficient than traditional fluids. The average Nusselt number improves as the volume percentage of nanoparticles rises.

(ii) As the volume percentage of nanoparticles rises, the thermal resistance value drops.

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