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Computational Fluid Dynamics Investigation of Flow Dynamics and Thermal Performance on Pin Fin Heat Exchanger

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Abstract - The increasing demand for compact cooling systems for high-performance electronic devices has sparked interest in thermal enhancement techniques. While previous studies have individually explored microchannel and pin fin heat sinks, limited research has investigated their combined effects. This study investigates the synergistic impact of pin fin and microchannel heat sinks on fluid flow and heat transfer characteristics across various Reynolds numbers and heat flux conditions. Experimental and numerical analyses were conducted to compare different heat sink configurations, with experimental results demonstrating good agreement with theoretical correlations, albeit with slight deviations. Computational Fluid Dynamics (CFD) simulations were employed to analyze various heat sink configurations, revealing that square pin fin arrangements exhibited superior heat transfer performance.

Additionally, the influence of the porous medium on heat sink performance was examined, showing significant impacts on heat transfer. Moreover, microchannel pin-fin heat sinks demonstrated superior performance to conventional pin-fin heat sinks, indicating potential for further enhancement in microchannel pin-fin heat exchangers. Optimization studies utilizing entropy generation minimization techniques highlighted opportunities for enhancing overall heat sink performance. These findings offer valuable insights for designing efficient cooling systems for electronic devices.

Keywords: Heat Transfer, Pin Fin, Microchannel, Cooling System, Electronic Devices, Optimization

1. INTRODUCTION

The ongoing pursuit of high-performance electronic systems has led to a relentless drive for miniaturization, intensifying the challenges associated with heat dissipation. As electronic devices become increasingly compact and powerful, the demand for efficient cooling solutions has never been more pressing. Traditional heat dissipation methods, such as air cooling, cannot manage the escalating thermal loads generated by densely packed electronic components. Consequently, there has been a growing emphasis on exploring novel thermal management techniques to address these challenges. In recent years, considerable attention has been directed towards enhancing the thermal performance of electronic chips. With the ever-increasing transistor density within integrated circuits, the need for effective heat dissipation mechanisms has become paramount. This has spurred a surge in research focusing on microscale heat exchangers, particularly microchannel and pin fin configurations. These microscale structures offer promising avenues for improved heat transfer due to their enhanced surface area-to-volume ratios and increased convective heat transfer coefficients. Microchannel heat sinks, characterized by their intricate network of small fluid passages, have garnered significant interest for their ability to remove heat from electronic devices efficiently. Likewise, pin fin heat sinks, featuring arrays of closely spaced elongated fins, have emerged as a popular choice for thermal enhancement. The design flexibility afforded by pin fins allows for tailored heat transfer performance, making them highly adaptable to diverse cooling requirements. While extensive studies have individually explored the performance of microchannel and pin fin heat sinks, there remains a notable gap in the literature regarding their combined effects. This underscores the need for comprehensive investigations into the synergistic interactions between these two heat transfer enhancement techniques. By elucidating the combined influence of microchannel and pin fin configurations on fluid flow and heat transfer characteristics, this study aims to develop more effective cooling solutions for advanced electronic systems.

2. LITERATURE SURVEY

This literature is based on MPFHE with and without nanofluids and thermal and hydrodynamic behaviour. Peles [1] and colleagues examined the thermal, hydraulic, and geometrical factors that impact the MPFHE's thermal resistance through low temperature and high heat flux dissipation. When Zhong Qian [2] et al. examined the heat transfer analysis of a microchip cooler, they found that the differential in thermal conductivity led to a uniform temperature distribution in copper and a non-uniform distribution in silicon nitrate. The pressure differential and single-phase MPFHE heat transfer rate were investigated by Siu-Ho [3] et al. It has been discovered that as the Reynolds number and the coefficient of heat transfer increase, so does the frictional force. Rubio et al.'s analysis [4] of MPFHE with various fin forms demonstrated that the fin's shape significantly influences temperature and pressure variations. Using water as the slogging fluid, Kosar [5] et al. investigated the pressure differential and heat removal of MPFHE. The result demonstrates that heat removal becomes increasingly important as mass flow rates increase. Furthermore, an increase in flow ratios encourages improved pressure drop. According to Prasher et al. [6], the analysis of the hydrodynamic and thermal behaviour enactments of MPFHE reveals that Nusselt's number varies with the fin diameter, reaching 1.35 for Re $<$ 100 and 73 for Re $>$ 100. The hydrodynamic and thermal effects of water-based nanofluids in a single-stage MPFHE were investigated by Mohammadian et al. [7]. The findings demonstrate that in a hot surface heat exchanger, the overall entropy production decreases, and the COP of the system increases as the total volume proportion of nanoparticles added to the base fluid increases at low Reynolds numbers. Similarly, when nanoparticles are added to the base fluid at high Reynolds numbers during cold surface heat exchange, the COP increases, and total entropy production decreases. Additionally, decreasing the diameter of the nanoparticles has little effect at low Reynolds numbers; nevertheless, at higher Reynolds numbers, there is a noticeable increase in COP and a decrease in the total entropy output in cold surface heat exchangers. When

Mohammadian et al. [8] examined the entropy and heat transfers in a CFMCHE (Counter Flow Microchannel Heat Exchanger), they found that adding Al2O3 nanoparticles in water enhanced the CFMCHE's efficacy. Moreover, rising volume concentrations result in rising pressure and heat transmission. The effects of nanoparticle assembly and distribution on the thermal characteristics of aqueous nanofluids were examined by Haitao Zhu [9] et al. After comparing several water-based nanofluids, it was found that Fe3O4water nanofluids had a higher thermal conductivity. The literature has further comparable work references [10–12]. In order to make the analysis more understandable, a single proportional piece of the MPFHE was considered when performing CFD analysis on the MPFHE using ANSYS 18.1. The assignment of suitable boundary conditions and nanofluid properties has developed geometric modelling, meshing, and analytical solution processes. Al2O3-water and CuOwater have also been examined as nanofluids for the investigation in this study, in addition to water. The reason is that Al2O3-water and CuO-water nanofluids have better heat transfer characteristics and are less expensive than other nanofluids. They show improved thermal conductivity and convective heat transfer coefficient compared to their base fluid. While previous research concentrated on a single nanofluid and one heat transfer study parameter, the current study compares three distinct fluids and a range of hydrodynamic parameters at varying volume fractions. Based on empirical correlations, the thermophysical characteristics of nanofluids have been investigated.

3. METHODOLOGY

A finned heat sink measuring 11.5 x 6 x 1 mm is considered a three-dimensional heat sink. Figure 1 illustrates the CAD model of the untinned heat sink.

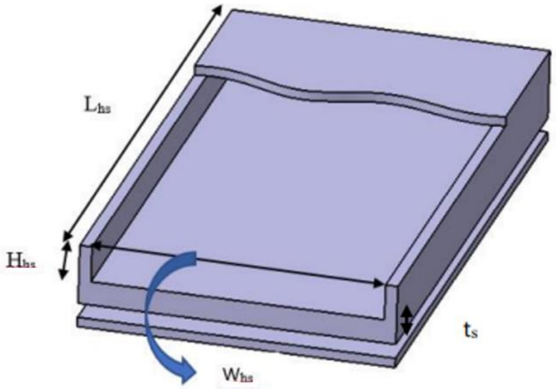


Figure 1. CAD Model of the un-finned heat sink.

A three-dimensional heat sink of 11.5 x 6 x 1 mm is considered for the parallel pinfin heat sink. Five straight pin fins with 0.5 mm thickness and 0.5 mm height were considered for the parallel pinfin heat sink. Figure 2 shows the CAD model of the parallel pinfin heat sink.

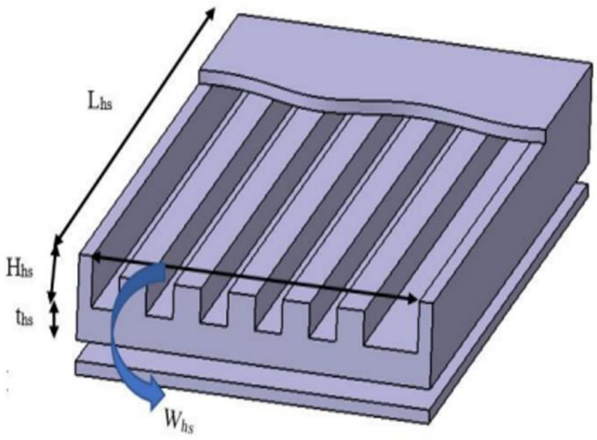
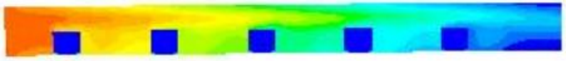


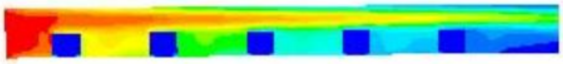
Figure 2. CAD model of parallel pin fin heat sink.

4. RESULT AND DISCUSSION

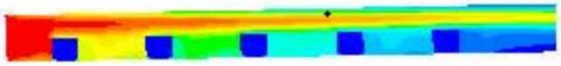
Figure 3 and Figure 4 represent the pressure contour along the Centre line of the circular pin fin heat sink and square pin fin heat sink, respectively, for different Reynolds numbers. It can be seen that the pressure contour is affected by the pinfin shape.



i) Reynolds Number =100



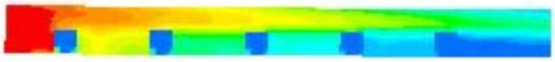
ii) Reynolds Number =500



iii) Reynolds Number =900

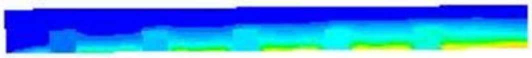
Figure 3. Pressure contour along the centre line of circular pin-fin heat sink for different Reynolds number

i) Reynolds Number =100

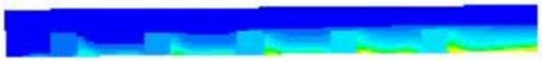


ii) Reynolds Number =500

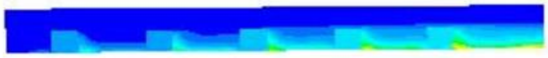
Figure 4. Pressure contour along the centre line of square pin fin heat sink for different Reynolds number



(a) Reynolds Number =100



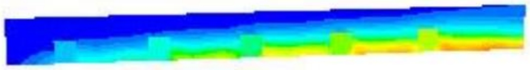
(b) Reynolds Number =500



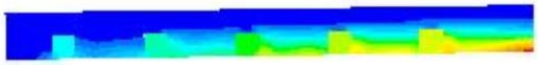
(c) Reynolds Number =900

Figure 5. Growth of thermal boundary layer along the centre line of circular pin fin heat sink for different Reynolds numbers.

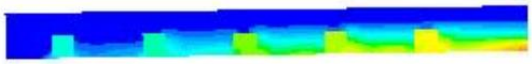
The growth of the thermal boundary layer for HS-SPF and HS-CPF at various Reynolds numbers is shown in Figures 5 and 6, respectively. As both figures show, the pin fin's presence alters the temperature profile, preventing the thermal boundary layer from reaching its fully evolved condition. Heat transport is improved by fluid mixing and thermal boundary layer regeneration. Compared to circular pin fin heat sinks, square pin fin heat sinks have a greater temperature gradient, improving heat transfer.



i) Reynolds Number =100



ii) Reynolds Number =500



iii) Reynolds Number =900

Figure 6. Growth of thermal boundary layer along the centre line of square pin fin heat sink for different Reynolds number

4. CONCLUSION

In conclusion, this study demonstrates the significance of integrating pin fin and microchannel heat sink designs to enhance heat transfer in electronic cooling systems. Experimental and numerical analyses revealed that square pin fin configurations outperformed circular ones, with microchannel pin fin heat sinks exhibiting superior heat transfer characteristics compared to traditional pin fin heat sinks. The influence of porous media on heat sink performance was notable, highlighting the importance of its placement and thickness. Furthermore, the transition from microchannel pin fin heat sinks to heat exchangers showed potential for improved heat dissipation, albeit with increased pressure drop. Optimization studies using entropy generation minimization techniques underscored avenues for further enhancing heat sink performance. These findings offer valuable insights for designing efficient cooling solutions for electronic devices, addressing the growing demand for effective thermal management in compact systems.

REFERENCES

[1]. Y. Peles, A. Kosar, C. Mishra, C.J. Kuo, B. Schneider, Forced convective heat transfer across a pin fin micro heat sink, Int. J. Heat Mass Transfer 48 (17) (2005) 3615–3627.
[2]. Z. Qian, H. Wang, Numerical study of the performance of a microchip cooler, Energy Procedia 16 (2012) 314–319.
[3]. A.M. Siu-Ho, W. Qu, F.P. Fefferkorn, Pressure drop and heat transfer in a singlephase micro-pin-fin heat sink, ASME Int. Mech. Eng. Congress and Exposition 2006 (IMECE2006).
[4]. C.A. Rubio-Jimenez, S.G. Kandlikar, A. Hernandez-Guerrero, Numerical analysis of novel micro pin fin heat sink with variable fin density, IEEE Trans. Components Pack. Manuf. Technol. 2 (2012) 825–833.
[5]. A. Kosar, Y. Peles, Thermal-hydraulic performance of MEMS-based pin fin heat sink, J. Heat Transfer 128 (2) (2006) 121–131.
[6]. Ravi S. Prasher, John Dirner, Je-Young Chang, Alan Myers, David Chau, Dongming He, Suzana Prstic, Nusselt number and friction factor of staggered arrays of low aspect ratio micro pin-fins under cross flow for water as a fluid, J. Heat Transfer (ASME) 129 (2) (2007) 141–153.
[7]. Shahabeddin K. Mohammadian, Yuwen Zhang, Analysis of nanofluid effects on thermoelectric cooling by micro-pin-fin heat exchangers, 2014, 70, pp. 282290.
[8]. Shahabeddin K. Mohammadian, Yuwen Zhang, Performance augmentation and optimization of aluminium oxide-water nanofluid flow in a two-fluid microchannel heat exchanger, J. Heat Transfer (ASME) 136 (2) (2014), pp. 02170–9.
[9]. Haitao Zhu, Canying Zhang, Effects of nanoparticle clustering and alignment on thermal conductivities of Fe3O4 aqueous nanofluids, Appl. Phys. Lett. 89 (2006) 023–123.
[10]. S. Harikrishnan, A. Ameelia Roseline, S. Kalaiselvam, Preparation and thermophysical properties of the water-glycerol mixture based CuO nanofluids as PCM for cooling applications, IEEE Trans. Nanotechnol. 12 (4) (2013) 629635.
[11]. P. Sivasamy, S. Harikrishnan, S. Imran Hussain, S. Kalaiselvam, Improved thermal characteristics of Ag nanoparticles dispersed myristic acid as composite for low-temperature thermal energy storage, Mater. Res. Express (IOP Science) 6 (8) (2019).
[12]. K. Shree Meenakshi, E. Pradeep Jaya Sudhan, Preparation and characterization of titanium oxide-water based nanofluids by one-step method for heat transfer applications. In: Proc. Int. Conf. Nanosci., Emerging Technol., 2011, pp. 84–87.