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Study of thermal characteristics of energy efficient micro channel heat sinks in advanced geometry structures and configurations: A review

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The sustainability and economic development is intertwined with the energy consumption and conversion processes. To suffice the ever-increasing demand of energy consumption amid environmental concerns, energy conservation and recovery along with the harnessing of renewable energy has been mandated by the policy regulators. In any energy conversion process, heat exchangers are vital operation component and has been part of any energy conversion process since the Nineteenth century. However, due to the increased energy demand, requirement of high efficiency and space and material constraints, the need for miniaturized light-weight heat exchangers with adequate heat transfer characteristics persists. Traditional heat exchangers are outdated because of its large space requirements and comparatively less heat removal rate. The miniaturized micro channel heat sink (MCHS) with tubes of about less than 1 mm have a tremendous potential to further enhance the heat transfer performance. However, its simple design doesn't cope with the modern requirements of heat removal. Therefore, many researchers have tried to improve its performance using different techniques. The present study reviews some of the most important techniques applied to MCHS. These techniques include, coolant types used in MCHS, MCHS shapes, flow conditions, numerical methods used for this research, and materials used to manufacture MCHS. Moreover, some recommendations have been given to provide opportunities to researchers for future aspects.

KEYWORDS

MCHS, analytical, experimental, CFD, energy, heat

Abbreviations: MCHS, microchannel heat sink; MEMS, microelectronic mechanical systems; CMCHS, corrugation microchannel heat sinks; KKL, Koo-Kleinstreuer-Li technique; AFR, aligned fan-shaped ribs; OFR, offset fan-shaped ribs; IoT, internet of things; CNT, carbon nano-tubes; 2D, two dimensional; 3D, three dimensional; CFD, computational fluid dynamics; NSGA, non-dominated sorting genetic algorithm.

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Highlights

- Microchannel heat sink is one of the promising candidate for removing high heat flux in a small area.
- Various methods of heat transfer improvements in microchannel heat sink are discussed.
- Flow and heat transfer characteristics in microchannel heat sink are reviewed.
- Future recommendations are given for the ease of new researchers in the field of microchannel heat sink.

Introduction

Micro Channel Heat sinks (MCHS) have been the preferred choice for thermal management control experts for decades due to their performance in electronic cooling applications. Improving MCHS performance to counteract the rapid rise in the rate of heat produced by current electronic circuits is a promising area for future study. The microelectronic mechanical systems (MEMS) are one of the most practical MCHS applications. MCHS is made up of numerous connected microchannels with a covering plate composed of a low thermal conductivity material (adiabatic) such as glass to keep the coolant flowing. The coolant eliminates the heat created by the electronic chip as it passes through the microchannel. Tuckerman and Pease (1981) was the first to employ a microchannel heat sink for electronic cooling. This paved the way for further research on the subject. Since then, tremendous work has gone into enhancing microchannel heat sinks' ability to remove the heat created by electronic chips. To maximize the surface available for heat transmission, several microchannel geometries such as circular, rectangular, triangular, and trapezoidal designs (Figure 1) have been used in the creation of microchannel heatsinks (Liu et al., 2022; Zhang et al., 2022). They also employed high-thermal-conductivity materials including copper, aluminum, and silicon to build the microchannel heatsinks (Figure 2) (Japar et al., 2018; Jennings and Smith, 2020; Shamsuddin et al., 2021). A mixture of two materials was also examined in order to overcome the attachment flaws with electronic chips.

The rise in the amount of heat created by more powerful electronics that continued to shrink in size compelled designers to look for alternate coolants that could remove heat more effectively than air. Liquid coolants were one option (Rehman and Seong, 2018). Because of their comparatively strong heat removal capabilities, and because some gases like N_2, He, NH_3, etc. have certain disadvantages like flammability, Toxicity, Corrosiveness, Reactivity, and high Cost. Conversely, liquid coolants, such as water, have been employed in electronics cooling. However, using water as a coolant can increase the risk of leakage and high power demand. Moreover, recent advancements in nanoparticle production technologies have prompted an upsurge in nano fluid research in an effort to create viable alternative coolants with improved heat removal capabilities. However, the disadvantages associated with nanofluids include particle sedimentation, passage clogging, and high-power demands Recently, impressive work on microscale heat transfer devices to disperse heat flux more than 1 kW/cm^2 has been described (Faulkner and Shekarriz, 2003; Zhang et al., 2015; Bazkhane and Zahmatkesh, 2020; Hu et al., 2022). Adding parallel type micro-channels, on the other hand, will not be enough to fulfil the needs of modern multicore processors (Dewan and Srivastava, 2015). Choi and Eastman (1995) showed that high thermal conductive fluids with highly distributed nano size metallic or oxide in the base fluid improved heat transmission. The use of nano fluid in microscale devices resulted in significant thermal increase at a high cost of pressure loss, resulting in inferior performance. Furthermore, the topic of nanofluids' stability and dependability is hotly debated (Keblinski et al., 2005; Das et al., 2006). Due to integration challenges in two-phase flow, a large number of research on microchannels by Kandlikar (2005), Han et al. (2016) have highlighted the need for unique microscale devices for enhanced heat dissipation. Because we are in the golden era of microfabrication, an innovation in microchannel heat sink

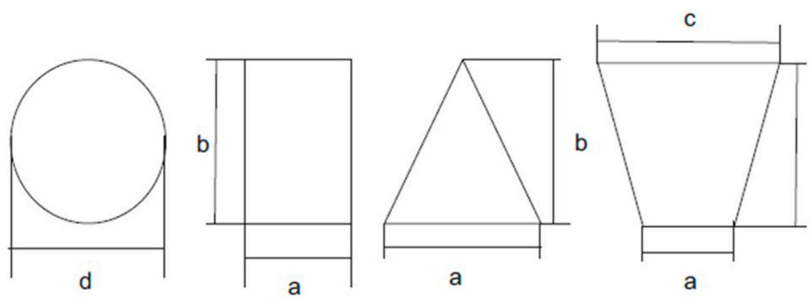

FIGURE 1
MCHS geometries.

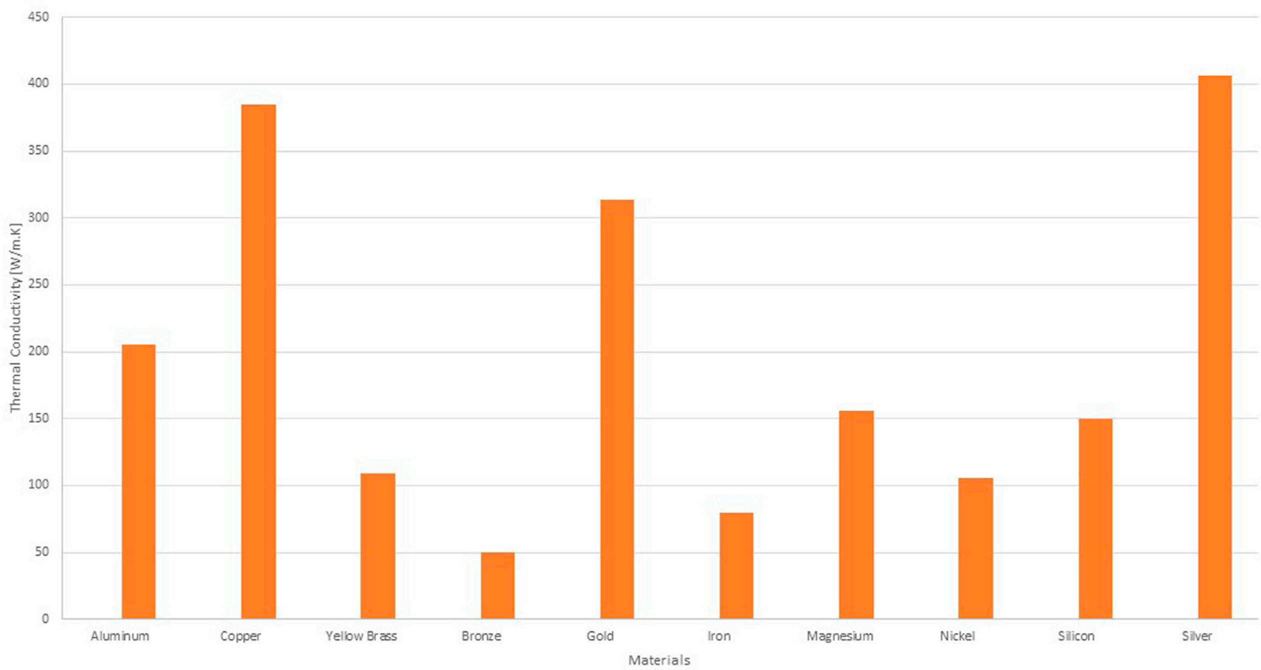

FIGURE 2
Thermal conductivity of commercial materials.

design (Goodling and Knight, 1994) or a hybrid approach is needed to take the microchannels' existing cooling performance to the next level.

However, it is important to emphasize that the usefulness of revolutionary microchannel technologies is not limited to cooling data centers, workstation computers, nozzle cooling for 3D printers, super capacitor thermal management, and artificial organ cooling. As a result, the need for a new sink design to improve current cooling is compelling for a variety of reasons, and it may bring fresh insight into a variety of multidisciplinary domains. Designing unique microscale devices for electronic cooling, microscale hybrid cooling devices (involves a mix of two or more cooling technologies), design improvements in existing microchannels, and so on may all be used to meet the aforementioned criteria.

There have only been a few review studies accessible in the open literature linked with microchannel heatsink performance since Goodling and Knight (1994). These studies only looked at a few factors. For instance, Morini (2004) published a review paper focused on experimental investigations, while Mohammed et al. (2011a) published a review article focused on experimental and theoretical studies employing nano fluids. The many methodologies used to study and optimize overall performance as well as the geometrical characteristics of microchannel heat sinks with non-circular forms are included in this paper's systematic review of the literature (Table 1). Table 1 may also be used as a reference to identify the coolant and materials utilized, as well as the flow types, optimization technique, and study results. A comparison research is also reviewed, which emphasized the disparities between the various parts of prior investigations as well as their results. There are also suggestions for further research.

Literature review

Microchannel heat sinks and coolant types

Microchannel heat sinks having non-circular cross sections, especially rectangular microchannel heatsinks, have been widely explored (Jia et al., 2018; Kose et al., 2022). Different researchers have used different approaches, such as experimental (Peng et al., 1994), numerical (Choquette et al., 1996), and analytical (Zhimin and Fah, 1997), as well as models such as fin (Zhao and Lu, 2002; Hameed et al., 2020; Hussein et al., 2022) porous medium (Kim, 2004), and thermal resistance (Liu and Garimella, 2005), to analyze and optimize the geometrical parameter combinations that have resulted in the best performance for microchannel heatsinks. To increase the heat removal capacities of microchannel heatsinks, different coolants, materials, flow conditions, and microchannel geometries were explored. These research'

TABLE 1 Comparative study of MCHS.

Authors	Nature of the work	Materials	Channel geometry	Analysis methods	Flow condition	Coolant types	Optimization schemes
Peng et al. (1994)	Experimental	Stainless steel	Rectangular	—	Laminar turbulent	Water methanol	—
Harley et al. (1995)	Experimental analytical	Silicon	Rectangular trapezoidal		Laminar	Nitrogen helium argon	—
Peng and Peterson (1996)	Experimental	Stainless steel	Rectangular	—	Laminar turbulent	Water	—
Choquette et al. (1996)	Numerical analytical	Aluminum	Rectangular	Thermal resistance	Laminar turbulent	Water	Numerical
Zhimin and Fah	Analytical	Silicon	Rectangular	Thermal resistance	Laminar turbulent	Water	Self-developing software
Hetsroni et al. (2005a)	Analytical	—	Rectangular	Mathematical model	Laminar	Water	—
Perret et al. 1998	Analytical	Silicon	Rectangular hexagonal diamond	Thermal resistance	Laminar	Water	—
Tso and Mahulikar (1998)	Analytical	—	Rectangular	—	Laminar turbulent	Water	—
Harms et al. (1999)	Experimental	Silicon	Rectangular	—	Laminar turbulent	Deionized water	—
Kim and Kim (1999)	Analytical	Silicon	Rectangular	Porous medium	Laminar	Water	Numerical
Rahman (2000)	Experimental	Silicon	Rectangular	—	Laminar turbulent	Water	—
Fedorov and Viskanta (2000)	Numerical	Silicon	Rectangular	3D Numerical	Laminar	Water	Numerical
Choi and Cho (2001)	Experimental	Copper silicon	Rectangular	—	Laminar turbulent	Paraffin water	—
Tunc and Bayazitoglu, (2002)	Numerical	—	Rectangular	Numerical	Laminar turbulent	—	—
Qu and Mudawar, (2002)	Numerical experimental	Oxygen free copper	Rectangular	3D numerical	Laminar	Deionized water	Numerical
Ryu et al. (2002)	Numerical	Silicon	Rectangular	2D numerical 3D nmerical	Laminar	Water	Numerical
Zhao and Lu, (2002)	Analytical numerical	Copper silicon	Rectangular	Porous medium Fin model	Laminar	Water	Numerical
Toh et al. (2002)	Numerical	Silicon	Rectangular	3D numerical	Laminar	Water	Numerical
Wu annd Cheng (2003)	Experimental	Silicon	Trapezoidal	—	Laminar	Deionized water	—
Tiselj et al. (2004)	Numerical experimental	Silicon	Triangular	Numerical	Laminar	Water	Numerical
Kim (2004)	Numerical analytical	—	Rectangular	Fin model Porous medium Numerical	Laminar	—	—
Gamrat et al. (2005)	Numerical	Bronze	Rectangular	3D numerical 2D numerical	Laminar	Water	Numerical
Liu and Garimella (2005)	Numerical	Silicon	Rectangular	Thermal resistance Fin model Porous medium Fin–fluid coupled Numerical	Laminar	Water	—
Lee et al. (2005)	Experimental	Copper silicon	Rectangular	Numerical	Laminar turbulent	Deionized water	—
	Experimental	Copper silicon		—		Water Deionized water	—

(Continued on following page)

TABLE 1 (*Continued*) Comparative study of MCHS.

Authors	Nature of the work	Materials	Channel geometry	Analysis methods	Flow condition	Coolant types	Optimization schemes
Hetsroni et al. (2005b)			Rectangular trapezoidal triangular		Laminar turbulent		
Kim and Kim (2006)	Analytical numerical	—	Rectangular	Averaging model	Laminar	—	Numerical
Li and Peterson (2006)	Numerical	Silicon	Rectangular	3D numerical model	Laminar	Water	Numerical
Wang et al. (2006)	Numerical	Silicon	Rectangular (treeshape)	3D numerical	Laminar	Water	SIMPLE Algorithm
Iyengar and Garimella (2006)	Analytical	Copper	Rectangular	Thermal resistance model	Laminar	Water Air	—
Khan et al. (2006)	Analytical	Silicon	Rectangular	Entropy generation minimization	Laminar	Air	Numerical
Li et al. (2007)	Numerical	Copper silicon stainless steel	Rectangular	3D Numerical	Laminar	Water	SAMPLER Algorithm
Chen (2007)	Numerical analytical	—	Rectangular	Porous medium model	Laminar	—	Finite difference method
Tsai and Chein (2007)	Analytical	Silicon	Rectangular	Porous medium model	Laminar	Cu–water CNT–water	Numerical
Kou et al. (2008)	Numerical	Silicon	Rectangular	Simulated annealing model	Laminar	Water	Numerical
Chen et al. (2008)	Numerical	Silicon	Rectangular	Simulated annealing model	Laminar	Water	3D Numerical
Husain and Kim (2009)	Numerical	Silicon	Rectangular	Surrogate analysis methods	Laminar	Water	Evolutionary algorithm Plot
Husain and Kim (2008)	Numerical	Silicon	Rectangular	Surrogate analysis method	Laminar	Water	Hybrid evolutionary algorithm
Ighalo et al. (2009)	Numerical	Silicon	Rectangular	3D Numerical	Laminar	Water	DYNAMIC-Q algorithm
Xie et al. (2009)	Numerical	Copper	Rectangular	3D Numerical	Laminar	Water	Numerical
Hu and Xu (2009)	Numerical analytical	Silicon	Rectangular	Thermal resistance	Laminar	Water	Sequential quadratic
Biswal et al. (2009)	Analytical	Cu Al Si	Rectangular	Thermal resistance	Laminar	Water	—
Wang et al. (2009)	Experimental Numerical	Silicon Pyrex glass	Trapezoidal	3D numerical	Laminar	Water	—
Hong and Cheng (2009)	Numerical	Silicon	Rectangular (Offset strip–fin)	3D numerical	Laminar	Water	FLUENT
Husain and Kim (2010)	Numerical	Silicon	Rectangular	Improved surrogate analysis	Laminar	Water	Evolutionary algorithm
Deng et al. (2010)	Analytical	Silicon	Rectangular	Improved porous medium	Laminar	Water	—
Koşar (2010)	Numerical	Cu Al Si steel silica glass quartz polyimide	Rectangular	3D numerical	Laminar	Water	—
Mohammed et al. (2011a)	Numerical	Aluminum	Rectangular	Numerical	Laminar	Alumina–water	Finite volume
Cho et al. (2010)	Experimental	Silicon	Rectangular trapezoidal	—	—	R-123	—
McHale and Garimella (2010)	Numerical	Silicon	Trapezoidal	3D numerical	Laminar	—	Finite volume
	Experimental	Polycarbonate-Al	Square	—		Water	—

(Continued on following page)

TABLE 1 (*Continued*) Comparative study of MCHS.

Authors	Nature of the work	Materials	Channel geometry	Analysis methods	Flow condition	Coolant types	Optimization schemes
Betz and Attinger (2010)					Laminar (segmented flow)		
Zade et al. (2011)	Numerical	—	Rectangular	3D numerical	Slip	Air	—
Chiu et al. (2011)	Experimental Numerical	—	Rectangular	3D numerical (CFD)	Laminar	Water	—
Chen and Ding, (2011)	Analytical	Copper	Rectangular	Porous medium	Laminar	Water Alumina–water	—
Moharana et al. (2011)	Experimental Numerical	Copper	Rectangular	3D numerical (CFD)	Laminar	Deionized water	—
Escher et al. (2011)	Experimental Analytical	Silicon	Rectangular	Thermal resistance model	Laminar	SiO2–water	—
Ijam and Saidur (2012)	Analytical	Copper	Rectangular	Thermal resistance model	Turbulent	SiC–water TiO2–water	—
Mohammed et al. (2011d)	Numerical	Copper aluminum steel titanium	Trapezoidal	3D numerical	Laminar	Diamond–water Diamond–EG Diamond–oil Diamond–glycerin	Finite volume
Lelea (2011)	Numerical	Copper	Rectangular	3D numerical	Laminar	Alumina–water	Finite volume
Xia et al. (2011)	Numerical	Silicon	Rectangular (triangular cavities)	3D numerical	Laminar	Water	FLUENT
Saenen and Baelmans (2012)	Numerical	Silicon	Rectangular	3D numerical	Laminar	Air	SIMPLE algorithm
Ijam et al. (2012)	Analytical	Copper	Rectangular	Thermal resistance model	Laminar	Al2O3–water TiO2–water	—
Adham et al. (2012)	Analytical	Aluminum	Rectangular	Thermal resistance model	Laminar	Ammonia gas	NSGA-II
Sharma et al. (2013)	Numerical	Copper	Rectangular	3D numerical	Turbulent (manifolds)	Hot water	Ansys. CFX
Ahmad et al. (2019)	Numerical	Copper	Rectangular	3D numerical	Laminar	Water	Ansys. Fluent
Rehman et al. (2020b)	Numerical	Copper	Rectangular	Entropy generation minimization	Laminar	Water	Fluent
Ali et al. (2021b)	Numerical	Copper	Rectangular	Thermal enhancement factor	Laminar	Water	Ansys
Rehman et al. (2020a)	Numerical	Copper	Rectangular	3D numerical	Laminar	Water	Ansys. Fluent
Ahmad et al. (2021)	Numerical	Copper	Rectangular	Thermal resistance	Laminar	Water	Ansys
Ahmad et al. (2022)	Numerical	Copper	Rectangular, circular, elliptical, trapezoidal, hexagonal, novel (Plus shape)	Entropy generation minimization, thermal resistance	Laminar	Water	Ansys. Fluent
Ali et al. (2021a)	Numerical	Copper	Rectangular	Thermal enhancement factor	Laminar	Water	Ansys

final results were presented in a variety of ways, including graphical representations (Lee et al., 2005), quantitative data (Hetsroni et al., 2005b), and empirical correlations (Peng et al., 1994).

To offer a basic overview of the development phases for microchannel heat sinks, the different components of past research were grouped in a comparison study, or table form, in the following section. The tabular format makes it easy to retrieve the data supplied by these investigations. Selected publications covering various experimental, analytical, and numerical research were chosen for this part in order to highlight the various development stages and approaches used for studying and optimizing the overall performance of microchannel heatsinks.

Microchannel heat sinks shapes

Novel MCHS with triangular chambers and rectangular ribs were studied by Li et al. (2016). Heat transfer and flow properties were investigated, and it was discovered that heat transfer was improved, and heat was evenly distributed at the substrate owing to a combination of multiple interruptions and flow disturbances caused by the new design. The width of the rib is also related to the frictional factor and Nusselt number, according to the research. Rectangular, triangular backward, diamond, forward triangular, and ellipsoidal geometries were examined by Chai et al. (2016). The mixing of cold and hot water in the micro chamber, which leads in the expansion of the thermal boundary layer in the MCHS area, is primarily responsible for the improved heat transmission in this study. This resulted in an increase in Re and Nux in the MCHS inlet, which tends to decrease as the MCHS progresses. The properties of fluid flow and heat transmission in MCHS with rectangular ribs and sinusoidal cavity were investigated by Ghani et al. (2017). The prototype with ribs and cavities combined resulted in a lower pressure drop, according to this research. The flow mixing is aided by the creation of a transverse vortex in the cavity. The length and breadth of the ribs are directly related to the Nusselt number and friction factor. Zhou et al. (2016) investigated a novel MCHS prototype with wavy channels. Re, wavelength, and wave amplitude are among the characteristics being investigated. According to this research, wavy channels perform 2.8 times better than standard channels. In addition, shorter wavelength wavy channels have a higher convective heat transfer coefficient. Wang et al. (2018) investigated the effects of porous fins and double-layered MCHS in combination.

The study and comparison of traditional as well as integrated prototypes has been completed. Even though all systems have identical Reynolds numbers ranging from 65 to 200, the combined model shows a 45.3%–48.5% decrease in total power for pumping. Coolant's "slide effect" on the channel wall is blamed for the loss in pumping power. The increased MCHS with sectional oblique fin was experimentally confirmed by Lee et al. (2015), who discovered that MCHS with a lower oblique angle had superior heat transmission characteristics. It is backed by the fact that when the oblique angle is less, flow resistance is lower, resulting in a higher secondary flow rate. The performance features of MCHS with wavy channel and Nano fluids were investigated by Sakanova et al. (2015). Traditional rectangular MCHS prototype offers superior performance characteristics than wavy MCHS prototype. It is also been discovered that when Re is greater in Wavy MCHS, performance improves significantly. The impact of reduced thermal and hydrodynamic boundary layer thickness improves heat transfer properties.

Coolant types

Since the invention of MCHS at 1981, a lot of researcher have used plenty of coolant types to see their effect on thermal and hydraulic effect of MCHS. These coolant types include but not limited to water (Tuckerman and Pease, 1981; Kim and Kim, 1999; Gamrat et al., 2005), Air (Khan et al.; Kleiner et al., 1995), Nitrogen, Helium, Argon (Harley et al., 1995), Deionized water (Harms et al., 1999; Qu and Mudawar, 2002; Moharana et al., 2011), Paraffin water (Choi and Cho, 2001), Alumina-water (Mohammed et al., 2010), R-123 (Cho et al., 2010), SiO2–water (Escher et al., 2011), Diamond–water, Diamond–EG, Diamond–oil, Diamond–glycerin (Mohammed et al., 2011b), and aluminium oxide (Al_2O_3) nanofluids (Baig et al., 2021).

Xia et al. (2015) used experimental and analytical approaches to evaluate the flow and heat transfer properties of a corrugated MCHS prototype to a standard MCHS model. Rectangular Microchannel Heat Sinks (RMCHS) have a lower pressure drop than Corrugation Microchannel Heat Sinks (CMCHS). The pressure decrease is caused by a vortex that forms in the reentrant cavity, which periodically reduces and redevelops the boundary layer. The thermal enhancement factor, which reaches 1.24 for the Reynolds number of 611, characterizes the benchmarking performance. For chip cooling systems, the CMCHS proved to be the most cost-effective option. Using Al2O3 and TiO2 Nano Fluid, Xia et al. (2016) examined the fluid flow and heat transmission properties in MCHS. The volume percentage of the nano fluid is found to be directly related to the thermal conductivity and dynamic viscosity of the fluids in this study. In addition, the TiO_2 nanofluid outperforms the Al_2O_3 nanofluid. The heat transmission properties of Al_2O_3 with a volume fraction of 1.0% are improved. The combination of Al_2O_3 and the new MCHS structure results in dramatic performance improvements. The convective transfer coefficient and pressure difference in a 25 mm cylindrical MCHS containing Cu nanoparticle were examined by Azizi et al. (2015). With a mass fraction of 0.3%, the nanofluid has a higher heat transfer coefficient and a smaller pressure difference.

For larger Re numbers, there is a reduction in heat transfer co-efficient and thermal efficacy. Arshad and Ali (2017) looked at the heat transmission and pressure drop characteristics of MCHS with a 1 mm hydraulic diameter. For the power of 100, 125, and 150 W, the coolant utilized for analysis is distilled water and TiO_2. When distilled water is employed as a coolant, Nusselt number has no connection with heating power, however TiO_2 nanofluid has better performance at lower heating power. In comparison to distilled water, TiO_2 Nanofluid improves heat transmission by 12.75%. Heating power has been shown to be inversely related to pressure differential over MCHS. Duangthongsuk and Wongwises (2017) investigated heat transmission and pressure decrease in numerous zigzag flow channels using nanofluids. In comparison to Zigzag, the CCZ-HS pattern exhibits a 2%–6% increase in heat transmission (CZ-HS). Also established are relationships to characterize heat transfer and pressure decrease. The influence of a magnetic field on the nanofluid that flows through the MCHS was investigated by Hosseini et al. (2018). The viscosity and heat transport are calculated using the Koo-Kleinstreuer-Li (KKL) technique. According to this research, when nanoparticle size reduces, the temperature differential between the wall and the coolant diminishes, increasing the Nusselt number. Furthermore, introducing a magnetic field to MCHS causes nanoparticles to gain velocity, increasing the Nusselt number.

Numerical methods employed

To establish a link between performance and other aspects listed above, Xia et al. (2016) quantitatively evaluated numerous parameters such as header shapes, MCHS shapes, entrance and exit positions. The traditional design of a rectangular header gives greater flow homogeneity, whereas the MCHS with offset fan shaped reentrant cavities and triangular reentrant cavities has superior heat transfer properties, according to this research. With different fan-shaped ribs, Chai et al. (2016) investigated laminar flow and heat transmission properties in MCHS. The width, height, spacing, and alignment characteristics were investigated in this study. According to their findings, aligned arrangements had a greater heat transfer co-efficient for Re values ranging from 187 to 715.

Heat transfer correlation for the MCHS has also been calculated using the suggested innovative methodologies, with a mean absolute error of 2.5 percent for aligned fan-shaped ribs (AFR) and 3.8% for offset fan-shaped ribs (OFR). Mohammed et al. (2011c) used numerical simulation to investigate the impact of the MCHS channel shape on thermal and fluid fluxes. The zigzag, step, and curved profiles were investigated. The zigzag channel has a higher heat transmission coefficient than the wavy channel, while the curvy channel has superior heat transfer properties than the wavy channel. Finally, it is discovered that step geometry improves hydraulic performance while zigzag MCHS improves thermal performance. Furthermore, the pressure drop for all suggested channels is larger than for traditional rectangular channels, according to the research. The impacts of geometric characteristics such as sinusoidal and zigzag MCHS and their connection with Nusselt number were quantitatively explored by Toghraie et al. (2018). The volume fraction of nanoparticles has been discovered to be directly related to the Nusselt number. The zigzag prototype performs better in terms of heat transfer and flow than its counterpart. In order to examine the sectional properties of rectangular, trapezoidal, and triangular cross section MCHS, Wang et al. (2016) did numerical simulations in rectangular, trapezoidal, and triangular cross section MCHS. When the hydraulic diameter is in the region of 0.349 mm scale, the Navier-Stokes equation remains true. The number of channels has a significant impact on heat resistance and pressure drop. Thermal resistance is inversely proportional to the number of channels.

Materials

Copper (Kleiner et al., 1995), aluminum (Choquette et al., 1996; Hameed and Khaleel, 2020), and silicon (Zhimin and Fah) were used to study the influence of various structural materials on total thermal performance. Other materials such as stainless steel (Peng et al., 1994), glass (Koşar, 2010), and bronze (Gamrat et al., 2005) were used in a few efforts. When channel heights were bigger, the influence of various materials was more noticeable, and when channel heights were less, it was less noticeable. The vast number of microchannel heat sinks produced using silicon instead of copper or aluminum when the microchannel height is merely a fraction of a millimeter attests to this. The use of silicon produces a lighter heat sink that meets current criteria.

Future work

Because of the strong design of today's tiny electronics, there is now greater contact between hardware devices and their environment, which was unthinkable decades before. The combined work of making microfabrication economically viable, developing materials that are compatible with the system, and the most important boom is the software that integrated these devices that allowed us to reach the level of most sophisticated gadgets that we adore today is responsible for this advancement. We are now on the threshold of the Internet of Things (IoT) revolution, which will empower human civilization with smart gadgets that may possibly interact with the environment.

Most of our technologies will be wearable, flexible, biocompatible, and transparent in this new race to the next generation. We are now doing fundamental research into exploiting the limitations, comprehending Multiphysics, defining performance characteristics, and establishing production and design standards. The work of Sitaraman et al. (2017) in creating modelling and experimenting with accelerated test settings for flexible electronics and wearable devices is worth mentioning. Since a result, now is a better time to start working on polymer-based microchannels with improved heat conductivity utilizing nano-additives, as future devices will be primarily flexible and deeply manufactured by additive manufacturing. For insights into polymer-based heat exchangers, a course on the work of Glade et al. (2018) will be useful.

Bioimplants have advanced to new levels in recent decades, with sophisticated customized devices showing promise as a solution for a variety of artificial organs. As a result, these devices are designed to be multipurpose by including a biomedical application that includes self-conditional health monitoring of both the gadget and the human body. This provided new prospects for a variety of bio devices, some of which proved to be life-saving. This necessitates a high-end gadget that is combined with materials that are compatible with localized cooling systems. These devices are used in the treatment of Focal Brain Cooling (Inoue et al., 2017) and Cryosurgery, which uses microchannels to eliminate cancer cells. As a result, future microchannel research is quite promising, and it has the potential to affect our lives *via* a variety of gadgets in the next years. There will undoubtedly be operational challenges to overcome, but the results will be impressive.

Conclusion

Tuckerman and Pease first introduced the forced convention microchannel heat sink in 1981. Since then, a significant number of theoretical and experimental investigation of MCHS has ensued. The researchers examined different channel shapes, study various coolants and material to optimize the performance of the heat sink. The researchers also discussed the analytical mythologies and proposed correlations to ascertain the heat transfer characteristics of the system. The advancement in microfabrication techniques has allowed researchers to experiment with various shapes and materials. For the micro channel systems, laminar flow is favored, the current domain of research in MCHS is investigating the use of nano fluids for better heat transfer properties. The increased interest, tremendous potential, and an increasing number of research outputs for the MCHSs has warranted the need for a thorough review of the topic.

Author contributions

ZR: Conceptualization, methodology, investigation, writing—original draft. FA: Formal analysis, writing—review and editing. HM: Writing—review and editing. HA: Supervision, writing—review and editing. FR: Writing—review and editing. MH: Writing—review and editing. ML: Supervision, writing—review and editing, funding acquisition.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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