Experimental Study on the Effect of Header Shape on Flow Maldistribution in Microchannels

C. Anbumeenakshi[*1], A. Hemalatha[*], M. Arikesavan[□] ,K.Premgopi [□], A. Aravindh [□]
[*]*Associate Professor,* [□]*U.G Scholar,*

Department of Mechanical Engineering, K.L.N. College of Engineering,

Madurai, Tamil Nadu, India

Abstract

The microchannel cooling technique shows promise as a solution for the high heat rejection requirements of today's high-power electronic devices. As global trends push towards compact sizes, components become smaller while the heat generated increases. Optimizing the thermal design of small electronic cooling devices is crucial to maintain system temperatures within acceptable levels. To dissipate the heat in these components, innovative cooling technologies are being developed, with microchannel cooling emerging as a top choice. Therefore, the need for microchannel cooling has become essential.An experimental investigation was conducted to analyze flow maldistribution in a microchannel heat sink using deionized water as the coolant. The study utilized an aluminum microchannel heat sink with 25 rectangular microchannels, with a hydraulic diameter of 763 µm. The primary focus was to identify the most suitable header shape to minimize flow maldistribution. Experiments were conducted with three types of header shapes: circular-ended, conical-ended, and trapezoidal, all with a center inlet flow configuration. The results indicated that the trapezoidal header shape resulted in the least flow maldistribution. Additionally, as the flow rate increased, maldistribution decreased. Overall, the study found that flow distribution in the microchannel significantly depends on both the header shape and the flow rate.

Keywords: microchannel, flow maldistribution, header, flow inlet

1. Introduction

Thermal management is a critical aspect of engineering, particularly in fields like electronics, aerospace, and automotive industries, where efficient heat dissipation is essential for the performance, reliability, and longevity of components and systems. Among various cooling techniques, microchannels have emerged as a highly effective solution due to their ability to handle high heat fluxes with compact designs. In many applications, excessive heat can lead to performance degradation, failure, and reduced lifespan of components. Effective thermal management ensures that heat is efficiently removed from critical areas, maintaining optimal operating temperatures. The effective thermal management is suitably attained with incorporating microchannel with liquid cooling .

Heat transfer is influenced by flow distribution. When the coolant flows uniformly in to the channels it dissipates the heat uniformly by allowing the coolant to flow on the surface of the electronic equipment by the use of micro channel. In general coolant does not flow uniformly in to the channels and leads to non-uniformity in temperature distribution in the device leading to reduced efficiency/failure due to hotspots. The non-uniformity in flow is called flow maldistribution, defined as non-uniform distribution of mass flow rate through different channels.

The most pioneering research in microchannel heat sink was started in early 1980’s by Tuckerman and pease [1]. A Microchannel heat sink, first proposed by him, pointed out that decreasing liquid cooling channel dimensions to the micron scale will lead to increase the heat transfer rate. They demonstrated experimentally a forty-fold improvement in heatsinking

Chu et al. [2] conducted an experimental and numerical study on fluid flow characteristics of rectangular microchannels and the experimental results identified that the geometrical channel aspect ratio has a significant influence on pressure drop. Xia et al. [3] performed a numerical study with different inlet /outlet configurations and header shapes and found that ‘I’ type inlet/outlet arrangement shows better flow uniformity and rectangular header shape provides the better flow uniformity than the trapezoidal and triangular headers.

Anbumeenakshi and Thansekhar [4] conducted an experimental investigation on flow maldistribution in microchannels and found that flowmaldistribution depends on header shape and flow inlet configuration.

Zhu et al. [5] carried out a numerical study on fluid flow and heat transfer characteristics of microchannel heat sinks with different groove shapes. The results indicated that the overall performance can be greatly improved by arranging grooves on channel side walls. Joseph et al. [6] conducted a numerical and experimental study of microchannel performance on flow maldistribution and the findings are recirculation zones in the collector influenced the flow maldistribution

Fadi and Bobby [7] performed a detailed numerical analysis on flow distribution in microchannel devices with U shaped manifolds. It is observed that microchannel width has a stronger influence on flow distribution compared with microchannel spacing width. Amirah et al.[8] carried out a numerical study on flow distribution in parallel rectangular multi channels and identified that a uniform flow distribution is achieved when the maldistribution factor value approaches zero.

Fluid dynamics in general, is an empirical science that relies heavily on experimentation to determine the effects of changes in flow parameters. When compared to numerical studies, an experimental study on flow maldistribution in multiple microchannels is less. A comprehensive experimental investigation of effect of header shape and centre inlet configuration on flow maldistribution in microchannel heat sink has not been reported in the literature. A header is a major part in the microchannel which distributes the fluid evenly along the channels. There are varies shapes in the headers. Flow uniformity greatly relies on header shape and flow inlet configuration.

In the present work, a detailed experimental investigation is carried out to examine the effect of shape of headers and flow inlet configuration on flow distribution through the microchannel heat sink and hence to identify the optimal header shape for minimizing the flow maldistribution effects in microchannel heat sink. The experimental data generated will also be useful for validating the numerical findings in microchannel flows.

2. Experimental Setup and measurement procedure

The microchannel cooling system employed in the experimental study consists of a microchannel test section and a peristaltic pump (RH-P120L, Ravel Hiteks Pvt. Ltd.) as shown in Fig.1. A closer photographic view of the microchannel test section is shown in Fig. 2. It consists of 25 parallel microchannels of rectangular cross section and inlet header, both made up of aluminium. The channels are numbered from 1 to 25 starting from the right end of the header.

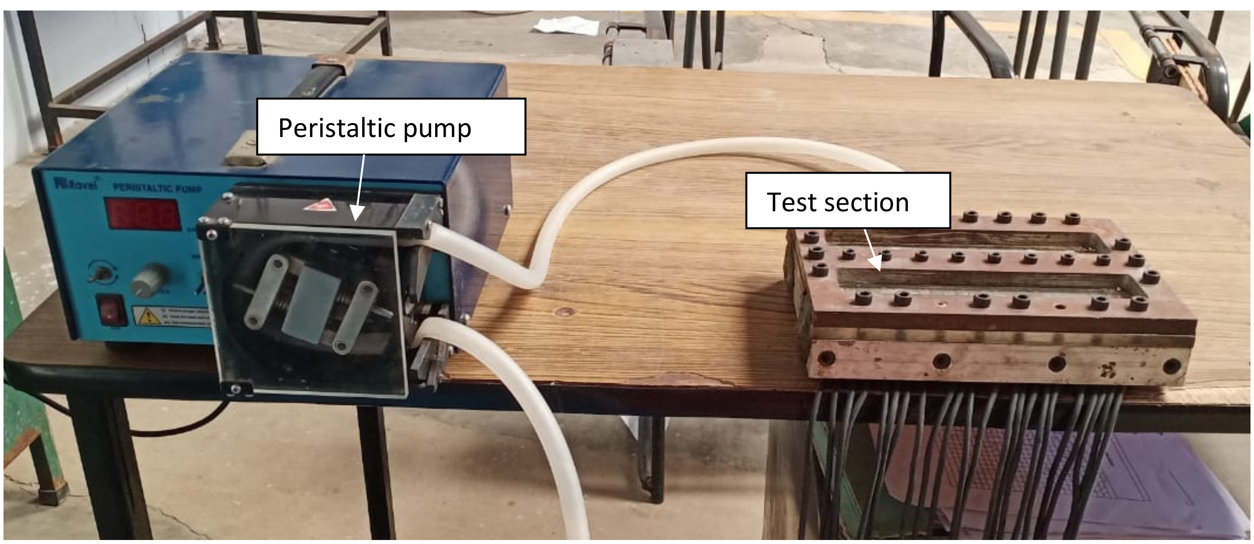

Fig.1. Photographic view of Experimental setup

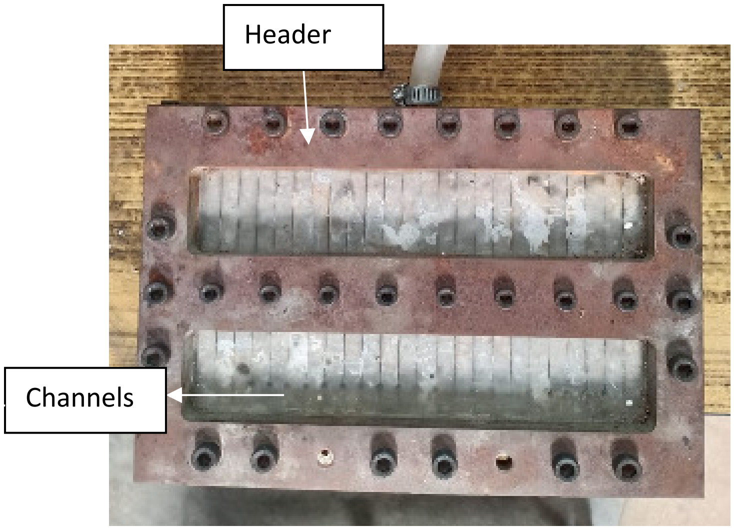

Fig.2. Microchannel Test section

In order to study the effect of shape of the header, three different headers namely circular ended, conical ended and trapezoidal shaped headers were used. jet type inlet configuration was used. The dimensions of the channel and various headers employed are given in Table 1.To visualize the flow inside the header and channels, the top of the test section is covered with a transparent acrylic sheet. Before starting the experiments, the microchannel test section is subjected to leak tests. Firstly, with the test section immersed in water, high pressure air is forced through it to ensure that there is no leak. Then it is ensured that the fluid flows only through the microchannels without spilling over the channels by passing Potassium permanganate – water solution.

Table 1

Geometrical parameters of microchannel and headers

Parameter	Value
Length of the channel, L_c	100 mm
Width of the channel, W_c	0.42 mm
Depth of the channel, D_c	4.2 mm
Number of channels, n	25
Length of the header, L_h	196 mm
Depth of the header, D_h	5 mm
Width of the header , W_h	10 mm(Circular ended) 10 mm(Conical ended) 10-5 mm (Trapezoidal)

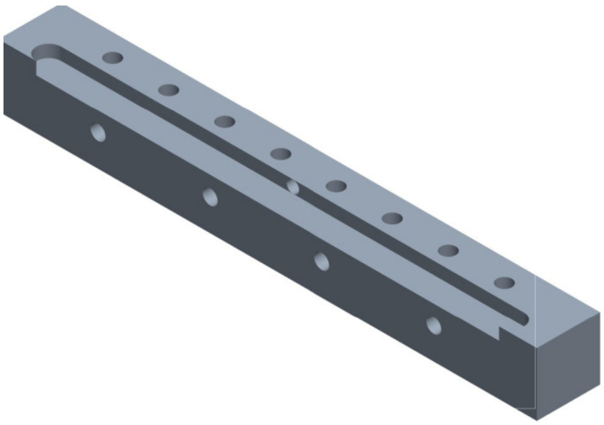

Fig 3: Circular ended header

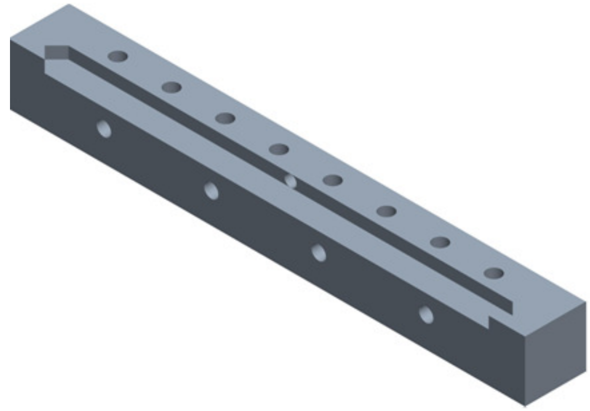

Fig 4: Conical ended header

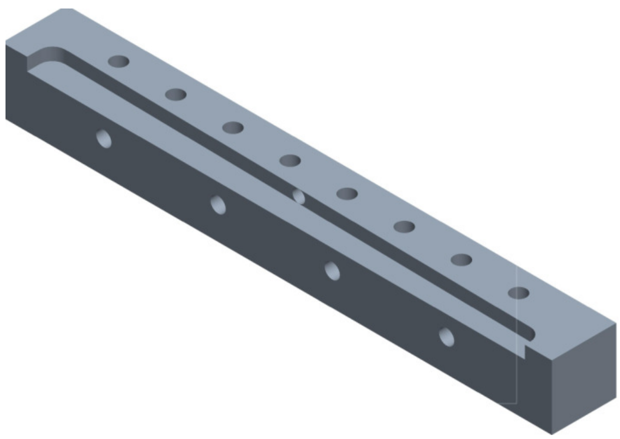

Fig 5: Trapezoidal header

Experiments were carried out by using deionized water as the working fluid. Water is pumped with the help of a peristaltic pump, in which the discharge is varied by adjusting the speed of rotation. Water enters the inlet header, from where it is distributed among the microchannels. After ensuring steady flow of water, water from each channel is collected individually and measured by the conventional method of using a measuring jar and a stop watch with an uncertanity of ± 0.025 %. Experiments were repeated a few times on different days to ensure the repeatability of the data measured. The geometric parameters of the microchannel and the headers were measured by Rapid-I Machine Vision Inspection System. The maximum uncertanity in the measurement of channel width, channel depth, channel length, header width, header length and header depth is of ± 1.71 %.

3.

Data Reduction

Normalized flow rate = Individual flow rate/ Average flow rate.

$$\text{Flow non-uniformity factor}, \varphi = \sqrt{\frac{C_1^2 + C_2^2 + C_3^2 + \ldots\ldots\ldots + C_n^2}{n}} \times 100\ \% \qquad (1)$$

Where,

$$C_1, C_2, C_3, \ldots\ldots\ldots, C_n = \frac{(\text{Average flow rate} - \text{Channel flow rate})}{\text{Average flow rate}}$$

4. Results and Discussion

Experiments were conducted with three types of inlet header, namely circular ended , conical ended and trapezoidal header for four different flow rates. The ratio of channel flow rate to the average flow rate is defined as normalized flow rate. If the ratio is one it means that channel flow rate is equal to the average flow rate and it concludes that the channel doesn't have any flow maldistribution. If the ratio is zero it concludes that no flow takes place through the channel. If the ratio is other than zero and one then

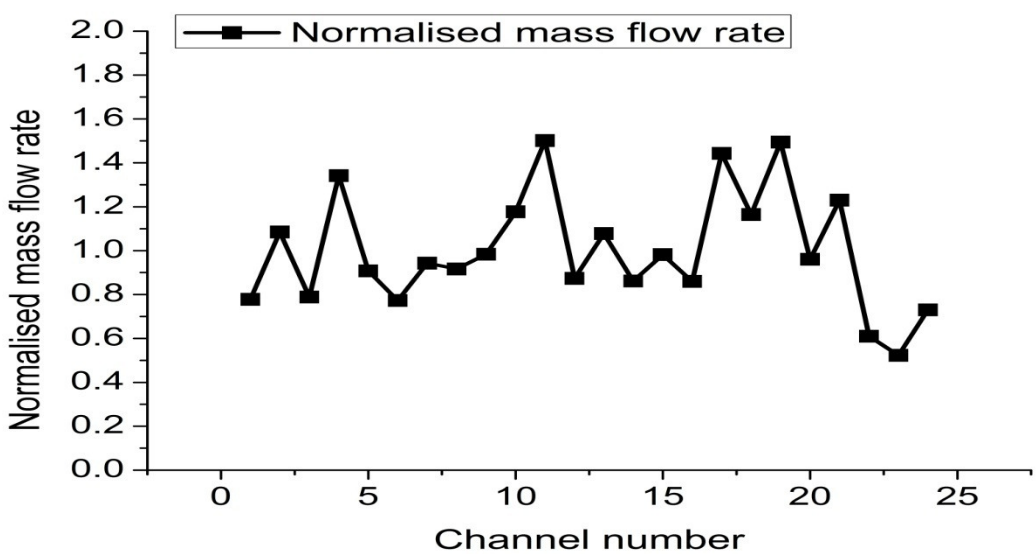

Fig 6: Channel wise flow rate

it concludes that there exists flow maldistribution. Fig 6 shows the channel wise flow rate.

The effect of different shapes of header , and flow rate through the microchannel on flow maldistribution is discussed. Flow non - uniformity factor (φ) is calculated. Smaller the value of flow non-uniformity factor (φ) more uniform the flow is.

4.1 Effect of header shape

The shape of the header is one of the key parameters, which influences flow distribution and pressure drop in the microchannel heat sink with multiple channels. The flow distribution develops as a result of the relative flow resistances experienced by the fluid on its path through the inlet header and the microchannels. Flow distribution through the channels will be uniform, if the pressure in the inlet header is uniform, but maintaining uniform pressure in the inlet header is difficult due to the branching of the fluid, which results in static pressure rise. Fig.7 shows the variation of flow non-uniformity factor (φ) for different header shapes. As far as the effect of header shape on flow uniformity is concerned, the fluid enters in to the header through the centre inlet location, impinges at the side wall and it gets distributed through the channels

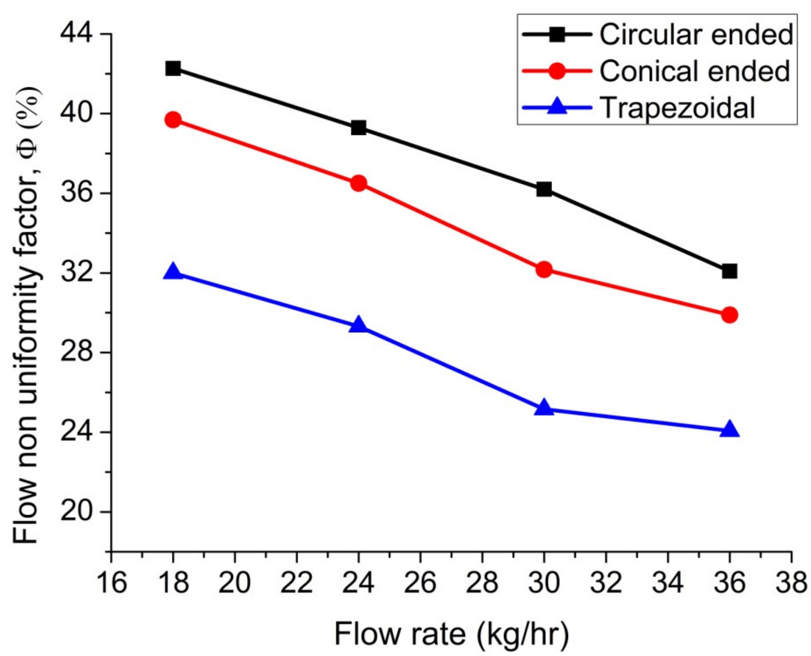

Fig 7: Effect of header shape on flow maldistribution

From the three different shapes of header, the trapezoidal header gives less flow non uniformity than circular and conical ended. The phenomenon in circular ended header is the centrifugal force caused by the circular ended causes large pressure drop compared to other two headers. In the conical ended header includes interruption, redevelopment of boundary layer and vortex formation leads to flow non uniformity. But in the trapezoidal header due to its shape of the header that is the gradual decrease in the width, it reduces the formation of interruption, vortex formation and recirculation and it reduces the flow non uniformity .

4.2 Effect of flow rate

In general, higher the flow resistance through the channels better is the flow distribution among the channels. Fig.8 shows the variation of flow non-uniformity factor (φ) with flow rate for the case of trapezoidal header. It is observed that the flow distribution becomes more uniform at higher flow rates, as the flow resistance through the channels increases with increase in the inlet mass flow rate.

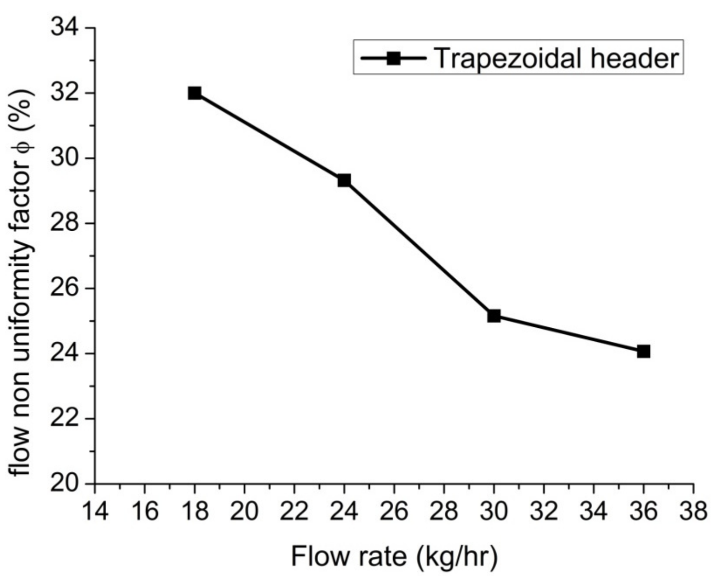

Fig: Effect of flow rate on flow maldistribution

5. Conclusion

This paper presents an Experimental studies in Flow maldistribution in rectangular microchannels of 25 numbers with centre flow inlet configuration and with three various cross sectional shapes of header namely circular ended, conical ended and trapezoidal by varying the flow rates. Deionized water is used as working fluid throughout the experiments. Measurements for flow distribution are done conventionally using a measuring jar and a stop watch for each individual channel. Normalized flow rate was calculated which indicates whether there exists flow maldistribution or not. Flow non – uniformity factor (ϕ) which quantifies degree of maldistribution is presented. Smaller the value of flow non-uniformity factor more uniform the flow is. The significant findings are trapezoidal header results in less maldistribution when compared to other two headers for all flow rates and as flow rate increases maldistribution decreases.

Acknowledgement

The authors extend their gratitude to the Management of K.L.N. College of Engineering for providing the funding and facilities necessary to conduct this research.

References

1. D.B. Tuckerman, R.F.W. Pease, High performance heat sinking for VLSI, IEEE Electron Device Lett. EDL-2 (1981) 126–129.
2. Jiann-Cherng Chu , Jyh-TongTeng , RalphGreif, “Experimentalandnumericalstudyonthe flow characteristicsincurved rectangularmicrochannels”, Applied ThermalEngineering30(2010)1558-1566
3. G. D. Xia, J. Jiang, J. Wang, Y.L. Zhai, D.D.Ma , Effects of different geometric Structures on fluid flow and heat transfer performance in microchannel heat sinks, Int. Journal of heat and mass transfer, 80 (2015) 439-447.
4. C. Anbumeenakshi , M.R. Thansekhar, Experimental investigation of header shape and inlet configuration on flow maldistribution in microchannel, Experimental Thermal and Fluid Science 75 (2016) 156–161.
5. Qifeng Zhu , Huixue Xia, Junjie Chen , Xinmin Zhang ,Kunpeng Chang ,Hongwei Zhang ,Hua Wang Jianfeng Wan, Yangyang Jin, Fluid flow and heat transfer characteristics of microchannel heat sinks with different groove shapes, International Journal of thermal sciences.2020
6. Jojomon Joseph, Danish Rehman , Michel Delanaye ,Gian Luca Morini, Rabia Nacereddine ,Jan G. Korvink , Juergen J. Brandner, “Numerical and Experimental Study of Microchannel Performance on Flow Maldistribution”,micromachines,2020,11,323

7. Fadi Alnaimat, Bobby Mathew, " Flow distribution in microchannel devices with U-shaped manifolds", International journal of thermofluids, 19,2023, 100391
8. Amirah Mohamad Sahar, Mohamad Shaiful Ashrul Ishak, Jan Wissink, Mohamed M. Mahmoud, Tassos G. Karayiannis, "Flow Distribution in Parallel Rectangular Multi Microchannels in Single Phase" *CFD Letters* 15, Issue 1 (2023) 67-75.