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Experimental investigation of header shape and inlet configuration on flow maldistribution in microchannel

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A R T I C L E I N F O

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A B S T R A C T

A detailed experimental investigation has been carried out to analyze the flow maldistribution in a microchannel heat sink by using deionized water as the coolant in an aluminum microchannel heat sink with 25 numbers of rectangular microchannels of hydraulic diameter 763 μm, for Reynolds number range of 200–650. The prime focus of this experimental study is to find the suitable combination of header shape and flow inlet configuration to minimize the flow maldistribution effect. Experiments have been carried out with three types of header shapes rectangular, trapezoidal and triangular and two types of inlet configurations viz. vertical flow inlet configuration and inline flow inlet configuration. It is found that vertical flow inlet configuration gives less maldistribution than inline flow inlet configuration. Trapezoidal and triangular headers give less flow maldistribution at low flow rate while rectangular header gives less flow maldistribution at higher flow rates. As the flow rate increases maldistribution decreases. In general, it is found that flow distribution in the microchannel significantly depends on flow inlet configuration, header shape and flow rate.

1. Introduction

With the rapid development of very large-scale integration technology (VLSI) and Micro Electro Mechanical Systems (MEMS), the application of microchannel heat sinks is drawing more attention as the most compact and efficient method of transferring heat from a power source to a fluid. These microchannel heat sinks, as one of the basic devices in micro fluidic system, can be broadly applied to the cooling of electronic devices, photo voltaic cells, piping systems, chemical reactors, automotive heat exchangers, laser process equipments, aerospace technology, fuel cell, sensor technology and other applications in bio mechanics. The energy conversion efficiency of concentrating type photovoltaic cells drops significantly with rise in surface temperature of the cell. In computers and electronics, the heat generated by the electrical circuit is a limiting factor in how small you can make it. Hence, as the power of the chip increases, the heat generation from the chip also increases. To remove the heat generated from the chip, liquid is used as a coolant. These applications necessitated the need for clear understanding of liquid flow in microchannels. The coolant flow should be uniform throughout the heat transfer area. Otherwise it will lead to non-uniformity in temperature distribution in the chip leading to 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 maldistribution effects may be spatial, temporal, or a combination.

The most pioneering research in microchannel heat sink was started in early 1980's by Tuckerman and pease [1]. It was identified that the microchannel heat sink would be able to dissipate with a maximum substrate temperature rise of 71 °C above the water inlet temperature.

Single phase experiments on single microchannel [2–4] reveal that the experimental and theoretical friction factor data are in good agreement. But early experiments on multiple microchannels [5,6] exhibit inconsistent results with regard to friction factor and flow transition which are attributed to maldistribution effects not being accounted for properly. Flow maldistribution depends on several factors such as heat exchanger geometry (mechanical design, channel and header geometry and dimensions, manufacturing tolerances or imperfections), operating conditions (such as flow velocity changes along the headers, fluid viscosity, and multiphase flow) [7].

Several numerical studies in flow maldistribution have been carried out in the past by varying the header shape, geometrical dimension of the channel, and inlet and outlet configuration. Teng

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Nomenclature

D	depth (mm)
L	length (mm)
n	number of channels
Re	Reynolds number
W	Width (mm)

Greek symbol

φ	flow non-uniformity factor

Subscripts

c	channel
h	header

et al. [8] performed a numerical study in microchannel and concluded that as the flow rate increases maldistribution decreases. Numerical studies were carried out by Dharaiya et al. [9] and by Tong et al. [10] and found that tapered header configuration exhibit less flow maldistribution in microchannels. Pan et al. [11] and Mohammadi et al. [12] studied numerically the effective geometrical dimension of a channel and found that tall and narrow channels exhibit better flow uniformity. A numerical study of flow in rectangular microchannels was presented by Kumaraguruparan et al. [13] and reported that recirculation near the upstream of the inlet header causes flow maldistribution. Siva et al. [14,15] carried out numerical investigations to understand the flow in microchannel and the influence of geometric parameters on flow maldistribution and found the best possible configuration to minimize the flow maldistribution and hot spot formation in microchannel cooling system using optimization tools.

Few numerical studies have been reported, which analyze the effect of inlet and outlet arrangement in microchannel heat sink. Lu and Wang [16] carried out a numerical study and observed that ']' type inlet and outlet arrangement provides better uniform flow distribution and lowest pressure drop. Chein and Chen [17] carried out numerical study to identify the suitable inlet and outlet configuration for microchannel heat sink and found that better heat sink performance can be achieved if the coolant is supplied and collected vertically. Kumaran et al. [18] performed a numerical investigation and found that 'C' type inlet and outlet arrangement gives better flow distribution and 'U ' type arrangement gives minimum pressure drop. Xia et al. [19] 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.

When compared to numerical studies, only a few experimental works have been carried out in multiple microchannels. Experimental and numerical study was performed by Wang et al. [20,21] in mini tubes of circular cross section with rectangular header and with modified inlet headers and found modified inlet header such as baffle tube gives better flow uniformity. Jones et al. [22] used micro PIV technique to measure flow distribution, at different flow rates 10 ml/min and 100 ml/min and a general expression for PIV measurement depth was presented. Siva et al. [23] performed an experimental work in microchannel and estimated maldistribution from the pressure drop of the microchannel. It was found that channels with small hydraulic diameter give more uniform flow distribution. Recently Barreto et al. [24] reported a visualization study on flow of air–water in parallel microchannels to analyze the flow pattern map.

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 inlet configuration on flow maldistribution in microchannel heat sink has not been reported in the literature. Enhancement of energy conversion efficiency of concentrating type photovoltaic cells by providing uniform coolant distribution in microchannel heat sink is the motivation for the present experimental work. 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 with suitable inlet configuration 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 aluminum. The channels are numbered from 1 to 25 starting from the inlet of the header.

In order to study the effect of shape of the header, three different headers namely rectangular, trapezoidal and triangular headers are used. Two types of flow inlet configurations viz. Inline flow inlet and vertical flow inlet are used. In the case of inline flow inlet, the fluid enters the inlet header in a direction parallel to the length of the header. In the case of vertical inlet, the fluid enters the header in a direction perpendicular to the length of the header. Various combinations of headers and flow inlet configurations used for the parametric study are shown in Figs. 3–8. The dimensions of the channel and various headers employed are given in Table 1.

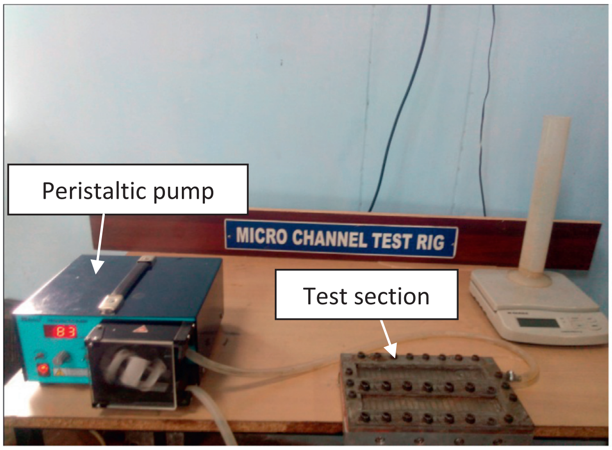

Fig. 1. Photographic view of experimental setup.