Experimental Investigations on the impact of Lower Aspect Ratios for Thermal Performance of a Microchannels

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Abstract – *Microchannel heat sinks are used widely for cooling electronic devices to extract the heat and improve the reliability of the devices. Microchannels are small in scale, light in weight, large surface to volume ratio. In this work, the experiments are conducted to analyze the impact of the geometry parameters (width and heights) on microchannels' thermal performance. The obtained result shows that the heat transfer coefficient (4.51, 5.10, 5.57, and 6.30 kW/m^{2}K) and Nusselt Number increased as aspect ratios increases. The thermal resistance is decreased with an increase in aspect ratios of the channel (AR; 0.23, 0.45, 0.68 AND 0.91) for different flow rates. The microchannel's thermal performance is increased by 27.95% compared to the plane channel for an aspect ratio of 0.91.*

Key Words: Microchannel, Thermal Performance, Aspect Ratio, Heat transfer Coefficient, Reynolds Number, Thermal Resistance, etc

1. INTRODUCTION

Due to the constant development of the miniaturization of electronic equipment in the current years, the production of heat per unit area has increased quickly. It leads to the development of effective cooling techniques are required to improve the life of the equipment. The conventional methods, e.g., fins with fan, heat pipes, thermoelectric cooling, were applied, and these techniques are no longer in use as effective cooling. The water-cooled microchannel heat sink has appeared as the most promising technology for enhancing heat transfer as an alternative. It has superior thermal characteristics with the ratio of surface to volume, attracts more and more attention to apply as a cooling method [1,2,3]. It is because the thermohydraulic behaviors of the Microchannel are different as compared with the conventional channels. Much research was done on the behaviors of a microchannel by the researchers in the last decade.

In the 1980s, Tuckerman and Pease were experimented on the thermal performance of the microchannel heat sink. The source has opened the gateway in the area of fluid dynamics and heat transfer in microscale geometries. Various factors can influence the thermohydraulic behaviors in the microchannels.

There are various methods available to enhance the heat transfer in the conventional heat exchanger equipment or sinks. Those are to be classified as active methods and passive methods. Active methods are like electrodynamics, impingement of jet, fluid spray, and vibration effect require external power to trigger. Also, passive methods are such as extended fins, rough surfaces, winglets, twisted tapes, etc., can be implemented without external power.

Prior research was focused on the performance of microchannel by varying the geometric parameters (shape and dimensions), design of manifold, and arrangement of the source. In line with that, the numerical study was done with fin heights (0.4 -0.6 mm) on the channel's thermal-hydraulics performance at a various range of Reynolds Number (100 to 400). It was observed that the channel's geometry change and shape have a noticeable effect on the working fluid's thermal characteristics. It was noticed that the heat transfer coefficient increases with an increase in fin height. The pressure drop also was increased with increase fin height of microchannel [1].

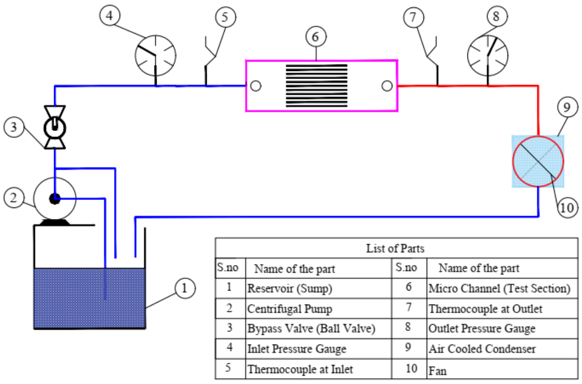
The experimental investigation was conducted on the heat transfer analysis on ribbed channels for various Reynolds Numbers ranges (185 to 1800). It was seen that the pressure drop increased with the ribbed channel as compared with a flat medium. Despite this, there was an increase in heat transfer coefficient with the ribbed channel [2].

It was focused on the characteristics of heat transfer and fluid flow in a microchannel with micro ribs by experimentally with the working fluid as water. The results showed that the channel's thermal performance with ribs on both sides was higher than the ribs at one side and without ribs on the channel. The friction factor was decreased with increase in the inlet temperature; however, the pressure drop was more in channels with ribs than the without ribs channel [3].

The researchers were implemented passive methods in microscale devices because of the cost-effectiveness and reliability of the method [4, 5, and 6]. But the usages of these methods are limited. In this work, an experimental study has been carried out to find the impact of low range aspect ratios on the thermal performance in a microchannel at various ranges of mass flow rates.

2. EXPERIMENTAL APPARATUS

Experiments are conducted on an aluminum rectangular microchannel, as shown in figure.1 and Figure.2. A monoblock 0.5 HP centrifugal pump is used to circulate the working fluid in the test rig. A ball valve varies the flow of fluid. The flow rate is measured by using a one-letter measuring jar and stopwatch at the end of the pipe outlet [7].



List of Parts

S.no	Name of the part	S.no	Name of the part
1	Reservoir (Sump)	6	Micro Channel (Test Section)
2	Centrifugal Pump	7	Thermocouple at Outlet
3	Bypass Valve (Ball Valve)	8	Outlet Pressure Gauge
4	Inlet Pressure Gauge	9	Air Cooled Condenser
5	Thermocouple at Inlet	10	Fan

Figure: 1 Schematic diagram of an experimental setup

Figure: 2 Experimental setup

An electric heater is fixed at the bottom to raise the temperature of a channel. A dimmer is attached to a heater to maintain constant heat flux. Temperature is measured at inlet and outlet by using K- Type thermocouples. Also, the pressure is measured with pressure gauges at the inlet and outlet, respectively. An air cooled condenser is connected to cool the working fluid and reused.

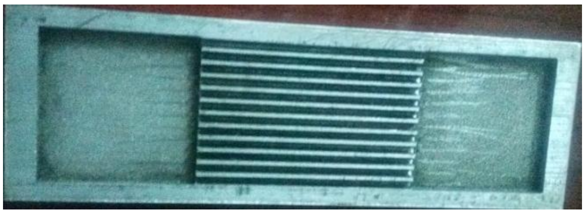


Figure: 3 A Micro Channels with Aspect Ratio 0.93

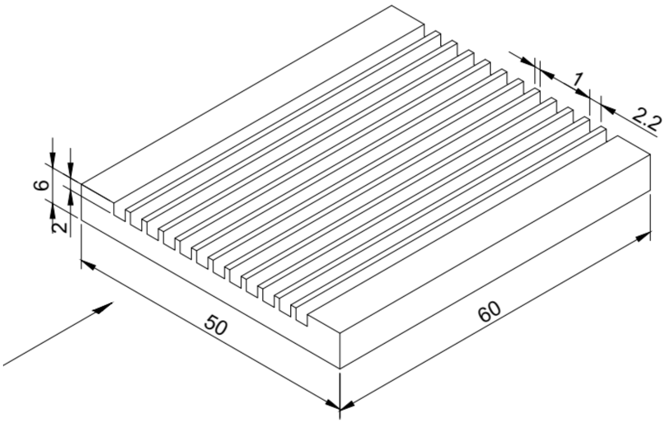


Figure: 4 Physical geometry of Micro Channel

The microchannel is manufactured by using a Spark Electric Discharge Machine (EDM), as shown in figure.3. The model length (L), width (W), and height (H) are 60mm, 50mm, and 6 mm. it is consisted of 12 parallel channels with various heights (H_C), and fixed width (W_C) are 2mm, 1.5mm, 1mm and 0.5 mm, and 2.2 mm, respectively.

3. DATA ANALYSIS

The amount of heat extracted from the channel by the single-phase working fluid can determine by the energy balance below[2,7,10].

$$Q = mC_P(T_{out} - T_{in}) \tag{1}$$

Where m is the mass flow rate, T_{in} and T_{out} are the inlet and outlet temperatures, respectively, and Cp is the fluid's specific heat.

The heat transfer coefficient of a fluid can be determined by using Newton's law of cooling

$$h = \frac{Q}{(T_w - T_f)A_{Ch}} \tag{2}$$

Where, T_w and T_f are the average wall temperature along the channel, average fluid bulk temperature.

$$T_f = \frac{T_{in} + T_{out}}{2} \tag{3}$$

$$T_w = \frac{T_{wtc1} + T_{wtc2} + T_{wtc3} + T_{wtc4} + T_{wtc5}}{5} \tag{4}$$

The total heat transfer area of the microchannel is calculated by the fin analysis method as follows

$$A_{ch} = A_b + \eta_{fin}A_{fin} \tag{5}$$

A_b and A_{fin} are the base surface area at the bottom of the channel and area of the fin, respectively. The fin efficiency is denoted by the symbol η_{fin}. The fin condition is assumed as a shortfin adiabatic tip condition and calculated the fin efficiency by using the below expression

$$\eta = \frac{\tanh(mH_{fin})}{mH_{fin}} \quad (6)$$

Where m is the fin parameter, given by

$$m = \sqrt{\frac{h_{sp} P_{fin}}{k_m A_{fin}}} \quad (8)$$

Where, P_{fin} is the perimeter of the fin, Afin area of the fin. Nusselt number is calculated by the average heat transfer coefficient as follows.

$$Nu = \frac{hD_h}{k_f} \quad (9)$$

Where k_f is the thermal conductivity of the fluid, D_h the hydraulic diameter of the channel.

The hydraulic diameter is defined as the ratio of four times the channel area to the wetted perimeter and expressed as

$$D_h = \frac{2W_C \times H_C}{W_C + H_C} \quad (10)$$

Here, Hc and Wc are the height, width of the channel

The Reynolds Number is defined as the inertial force ratio to viscous force and used to determine the channel's type flow. It is expressed by

$$Re = \frac{\rho u D_h}{\mu} \quad (11)$$

Here, ρ, μ are the density and dynamic viscosity of the working fluid, respectively. u is the average velocity of the liquid, which is expressed by

$$u = \frac{V}{NA_c} \quad (12)$$

Here, V is the fluid flow rate, and A_c is the cross-section area of the fluid flow in the channel. N represents the number of channels

Thermophysical properties of the working fluid are taken at bulk mean temperature in the above calculations.

Thermal resistance is the material property, which can resist a heat flow. It can be expressed.

$$R_t = \frac{T_{max} - T_{in}}{Q} \quad (13)$$

T_{max} is the maximum temperature in the five thermocouples connected to the channel wall, T_{in} fluid inlet temperature, and the q is the heat extracted by the fluid.

The total pressure drop is measured by the pressure gauges or differential manometer at the channel's inlet and outlet. It includes the pressure drop in the channel, in the manifolds at the inlet and outlet, and the loss of pressure at the channel's contractions and expansions. It is calculated by using the following expression.

$$\Delta p_{ch} = \frac{3\mu_f L_{ch} V_{ch}}{b^2 F\left(\frac{a}{b}\right)} \quad (14)$$

4. RESULTS AND DISCUSSIONS

The experiments are conducted on the microchannel's for various aspect ratios at constant heat flux while maintaining the room temperature at 28°C approximately. For each test, the mass flow rate of fluid assortments are varied from 0.004 to 0.017 kg/sec in every channel.

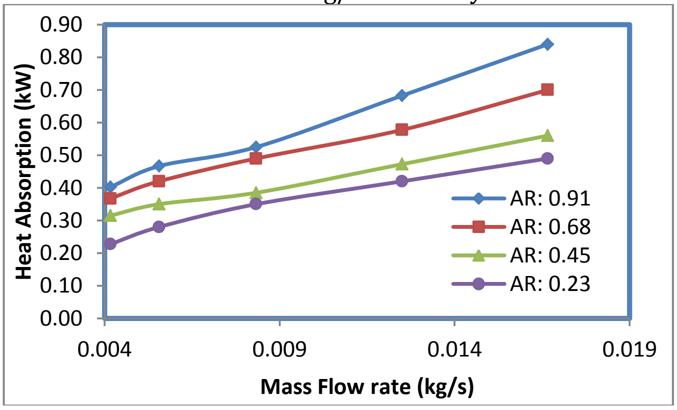


Figure: 5 Variation of Hat Absorption with a mass flow rate

Figure 5 depicts the amount of heat is absorbed by the fluid channels at various flow rates concerning aspect rations. It is increased with mass flow rates from 0.42 to 0.84 kW in a channel of an aspect ratio of 0.91. It is observed that there is an increase in the fluid heat absorption as mass flow rate increases. It is also seen that the rate of heat absorption increased with the increase of aspect rations. The slopes of the curves are increased with increase aspect ratio. It indicates that the higher aspect ratio channels can dissipate more heat transfer than the lower aspect ratio channels. It is also evident that the rate of heat transfer is more at higher flow rates. The reported values of heat absorption Q are 0.35, 0.42, 0.51, 0.58 kW respectively for aspect ratio of 0.23, 0.44, 0.68 and 0.91. This is due to more surface to volume ratio of fluid and less working fluid film thickness in the channel. The channel height is also influenced on the rate of heat transfer.

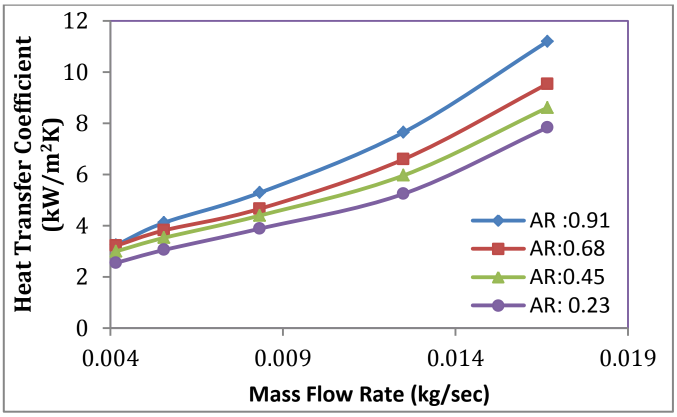


Figure: 6 Effect of Heat transfer Coefficient with flow rates.

Figure 6 shows the effect of heat transfer coefficient with various mass flow rates and also various linearly. It is observed that the coefficient of heat transfer increases with increase aspect ratio. It is due to fin height and the rate of fluid flow in the channel. Reported average values of h are 4.51, 5.10, 5.57 and 6.30 kW/m²K respectively for aspect ratio of channels ($AR=H_C/W_C$) 0.23, 0.45, 0.68 and 0.91. It is noticed by that the height heat transfer coefficient (6.30 kW/m²K) with the aspect ratio of 0.91 channel. It confirms that the heat transfer coefficient is the same in every channel irrespective of aspect ratio at a low flow rate. It is due to uniform temperature distribution and the low flow rate of fluid flow in the channel [8].

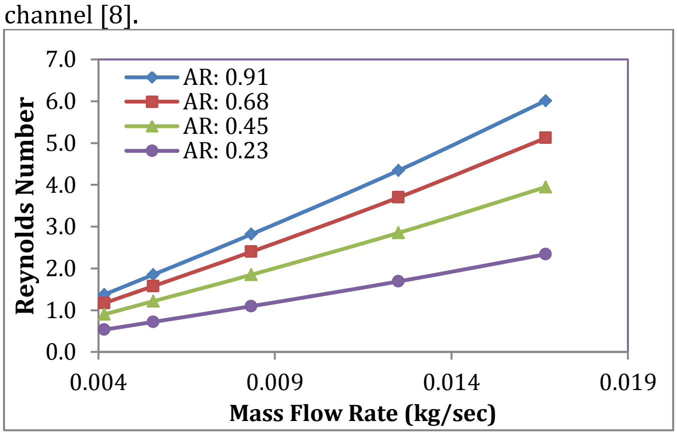


Figure: 7 Variation of Reynolds Number with flow Rates

Figure 7 shows the variation of Reynolds Number for various aspect ratios of channels with different mass flow rates of fluid in channels. It is observed that the Reynolds Number increased linearly with increase in mass flow rate. Also, it shows that the Reynolds Number increases with increasing aspect ratios. It is due to the effect of the channel's hydraulic diameter and fluid velocity in the channel. Reynolds Number is directly propositional to the hydraulic diameter and velocity fluid. The average values of Re 1.3, 2.2, 2.8, and 3.3 with their aspect ratios (AR), which are 0.23, 0.45, 0.68, and 0.91, respectively.

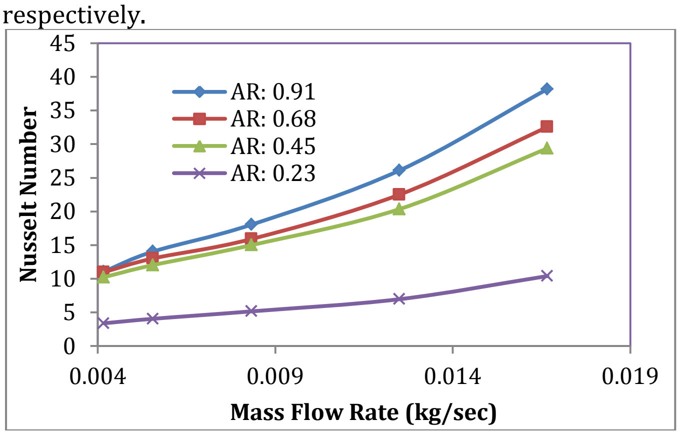


Figure: 8 Effect of Nusselt Number with the mass flow rate

Figure 8 shows Nusselt Number's effect with low mass rates for different aspect ratios of all channels. It is noticed that Nu increases with the increased mass flow rate of fluid and aspect ratio, respectively. It is due to that the Nu depends on heat transfer coefficient and hydraulic diameter. The Variation of Nu is similar to the variation of the heat transfer coefficient. Also, it depends on the aspect ratio. It is seen the higher Nu at the aspect ratio of 0.91 channel. There is an increase in heat transfer area with an increase in aspect rations. It is also observed that these are lower Nu values in a channel with the aspect ratio of 0.23 compared with the other channels aspect ratios (AR: 0.43, 0.68, and 0.91).

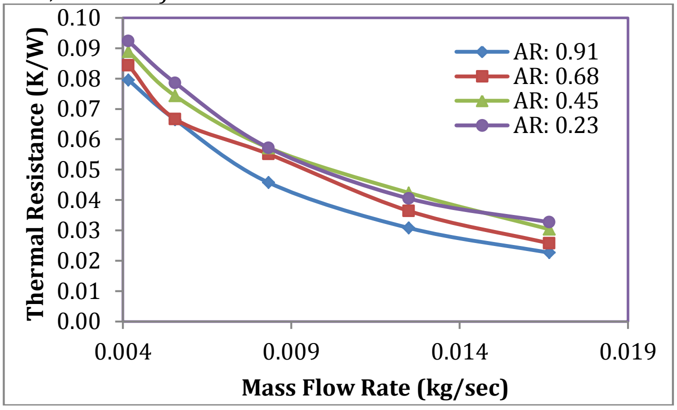


Figure: 9 Effect of Thermal Resistance with the mass flow rate

Figure 9 shows thermal resistance (R_t) with mass flow rates for different aspect ratios of channels. It indicates that the thermal resistance decreases with increasing mass flow rate for various aspect ratios of microchannels. The average values of thermal resistant are 0.06, 0.058, 0.054 and 0.048 (K/W) respectively for aspect ratios 0.23, 0.45, 0.63 and 0.91. It depends on the wall temperature of the channels and the mass flow rate of a fluid. Also observed that the thermal resistance is very low for the higher aspect ratio of the channel (AR: 0.91) and followed by the channel aspect ratios 0.68, 0.45, and 0.23 in the decreasing order. It has inversely proportional relationship with the rate of heat transfer. It also sees the variation of heat transfer rate for different mass flow rates fluid in these results and discussions.

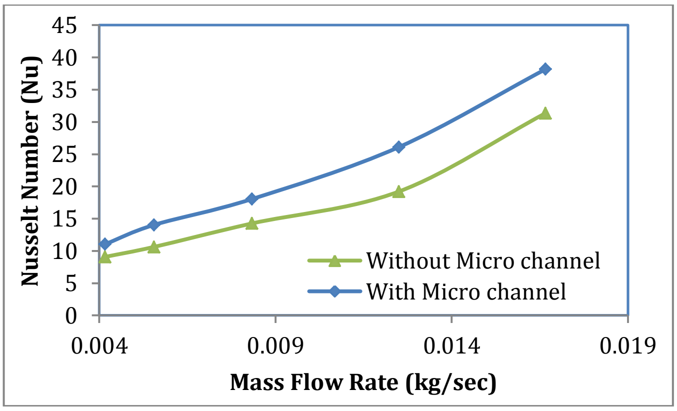


Figure: 10 Nusselt Number vs. mass flow rate for a plane and microchannel

A comparison between a plane channel and the Microchannel for an aspect ratio of 0.91 is presented in figure 10. It is noticed that the Nusselt number of Microchannel increased by 27.59% than the plane channel.

5. CONCLUSIONS

In this study, a microchannel heat sink with different aspect ratios (AR: H_{ch}/ W_{ch}) is fabricated and tested for various mass flow rates at constant heat flux condition. Effect of aspect ratio on the thermal characteristics of Microchannel heat sink is investigated. From the experiments the following conclusions are drawn:

- The rate of heat transfer increases with mass flow rate linearly and with the aspect ratios of channels in the range from 0.35 to 0.58 kW. It is due to the effect of channel height and film thickness of the working fluid in the channel.
- It is observed that the height aspect ratio channel (AR: 0.91) provide the better heat transfer performance (6.30 W/m^2K) than the other aspect ratio of channels (AR: 0.68, 0.45 and 0.23). It is because of more surface to volume ratio of the channel.
- Reynolds Number was increase linearly with mass flow rate rages for 0.004, 0.006, 0.008, 0.013 and 0.017 kg/sec. The reason for this is the hydraulic diameter of the channel and convective heat transfer coefficient.
- The thermal resistance of the channel decreases with an increase in mass flow rate for the values of 0.06, 0.058, 0.054, and 0.048 (K/W). it is due the effect of wall temperature distribution.
- The Nusselt number is increased by 27.59% of microchannel compared to plane channel with working fluid as water. It is because of heat transfer and Hydraulic diameter of channel.
- It is concluded that better thermal performance is attained at a higher aspect ratio (AR: 0.91) in the microchannel.

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BIOGRAPHIES

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