Influence of Cavities with Staggered Configuration on Heat Transfer Characteristics of a Micro-channels

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Abstract – *The reliability of the cooling electronic device is improved by using micro-channel heat sinks by extracting heat generated in it. Micro-channels are compact in size, light in weight, large surface to volume ratio. In this work, the experiments are conducted to analyze the influence of the cavities with staggered arrangement on micro-channels' thermal performance. The obtained result shows that the heat transfer coefficient (15.19, 11.44, and 7.87 kW/m²K) and Nusselt Number increased as pitch of the cavities increases. The micro-channel's thermal performance is increased by 39.13% compared without cavities .*

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

1. INTRODUCTION

Due to the rapid development of the in integrated circuits, of circuits are manufactured into one miniaturized of electronic chip. However the constant increase in generated heat flux requires more effective cooling. It leads to the development of techniques are required to improve the life of the equipment. Compared with the heat exchangers in conventional scale, micro-channel heat exchangers are of higher heat transfer rate while the volume and weight are small.

The traditional methods, e.g., fins, thermoelectric cooling, were applied, and these techniques are not effective cooling methods. The micro-channel heat sink has emerged as the most promising technology for enhancing heat transfer as an alternative [1, 2, 3]. Much research was done on the behaviors of a micro-channel by the researchers in the last decade.

In the 1980s, Tuckerman and Pease was conducted experiment on the thermal performance of the micro-channel heat sink. This was leads to the area of research on the fluid dynamics and heat transfer in micro-scale geometries. Influence of parameters are more on the thermo-hydraulic behavior in the micro-channels and need to study with understanding.

There are various methods available to enhance the heat transfer in the conventional heat exchanger equipment or sinks. Those are 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.

The Previous research was focused on the heat transfer characteristics of micro-channel by using the heat transfer augmentation methods. Binghuan Huang et.al was done experimental investigation of the flow and heat transfer performance in micro-channel heat exchangers with cavities for a range of Re 40-120. It was noticed that the channel with cavities was performed high thermal performance as compared with the straight channel [1].

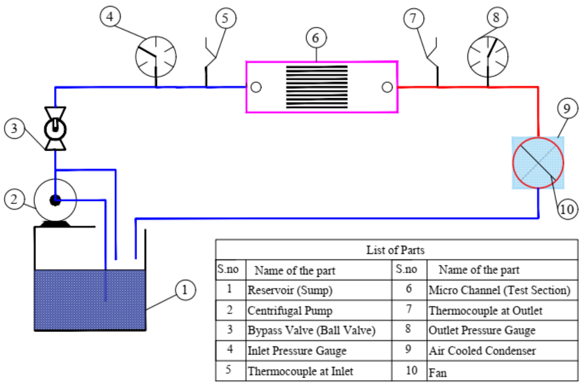
Fang Li et.al was done numerical analysis on micro-channel with three different internal spoiler cavities flow and heat transfer performance based on filed synergy principle to obtained optimum condition for various range of operating parameters. [2].

Aparesh Datta et.al was done a numerical analysis on performance of rectangular micro channel with trapezoidal cavities with ribs by using conjugate heat transfer method for various arrange of Reynolds Number 300-900. It was notices that the best thermal performance with diamond rib combination and the height entropy generation with backward triangular rib combination. [3].

From the above literature survey, it was noticed that there need to be conducted more work on the channel with various combinations of cavities. In this work, an experimental study has been carried out to find the influence of cavities on the heat transfer characteristics of a micro-channel with various arrangements for various flow rate of working fluid.

2. EXPERIMENTAL APPARATUS

Experiments are conducted on an aluminum rectangular micro-channel, with triangular cavities with staggered arrangement with three different pitches as shown in figure.1 and Figure.2. A mono-block centrifugal pump is used to circulate the working fluid in the test rig. A flow meter with control valve is used to control flow rate and as well as to measure the volume flow rate in litter per minute. [4].



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 constant heat flux is maintained by the dimmer at the bottom of the heater. K Type thermocouples are used to measure the temperature at inlet, out let and wall temperature of the channel at five sections with each distance of 10mm. Two bourdon pressures are connected at inlet and outlet to measure the pressure. Fan is attached to the condenser, which is used to cool the fluid while flowing though the condenser and it can be reused in the circuit.

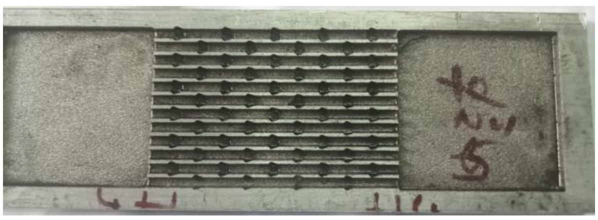


Figure: 3 A Micro Channels with Cavities

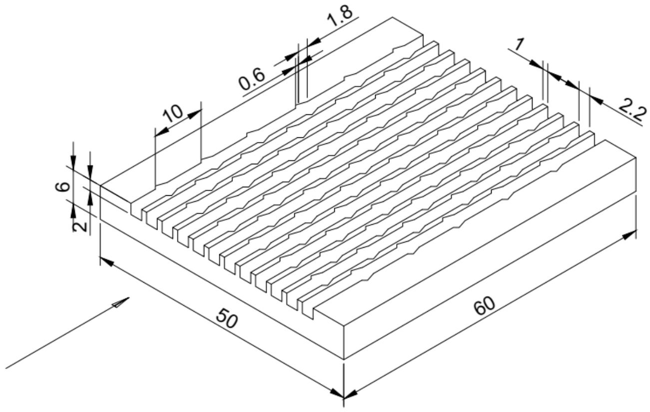


Figure: 4 Physical geometry of Micro Channel

An EDM is used to manufacture the micro-channel with cavities with various positions as shown in figure 3. The channel dimensions are as flows as length (L), width (W), and height (H) are 60mm, 50mm, and 6 mm. it is consisted of 12 parallel channels with height (H_C), and width (W_C) are 2mm, and 2.2 mm, respectively. The dimensions of cavities are as flows as height 0.6mm, length 0.6 mm at entry and exit height 0.6 and length 1.8mm.

3. DATA ANALYSIS

The rate of heat absorbed from the channel by the working fluid is calculated by using the following expression [5, 6, 7].

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

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 convective heat transfer coefficient of a fluid can be calculated by using Newton's law of cooling

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

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

$$T_f = \frac{T_{in} + T_{out}}{2} \qquad (3)$$

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

The total heat transfer area of the micro-channel is calculated by the fin analysis method as follows

$$A_{ch} = A_b + \eta_{fin} A_{fin} \quad (5)$$

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 micro-channel's for various pitch conditions of cavities at constant heat flux while maintaining the room temperature at 28°C approximately. For each test, the Reynolds Number is varied in the range of 1.4 to 6.

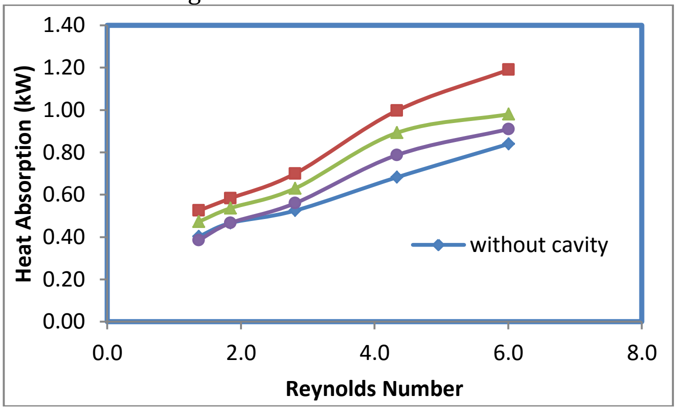


Figure: 5 Variation of Hat Absorption with Reynolds Number

Figure 5 depicts the amount of heat is absorbed by the fluid channels at various ranges of Reynolds Numbers. It is increased with Reynolds Numbers from 1.4 to 6 in a channel with cavity for a pitch of 10mm. It is observed that there is an increase in heat absorption by the working fluid as Reynolds numbers increases. It is also seen that the rate of heat absorption decreased with the increase of pitch of the cavities. It indicates that the channel with cavities at lower pitches can dissipate more heat transfer than other conditions. this is due to formation of eddies or Dean vortices by the cavities in the channels. The reported values of heat absorption Q are 0.8, 0.7, and 0.62 kW respectively for different pitches of cavities 10mm, 15 mm and 20 mm.

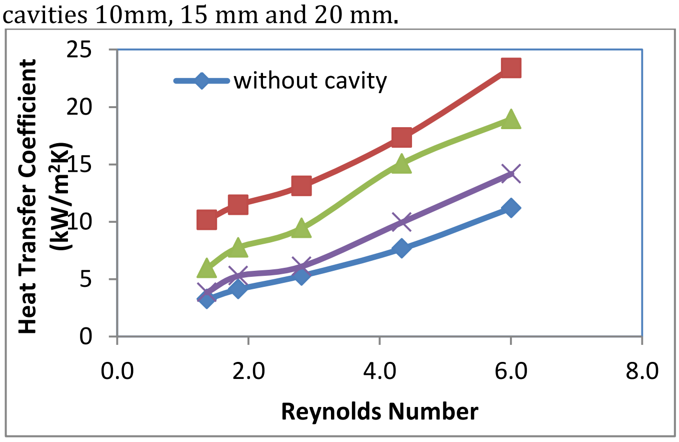


Figure: 6 Effect of Heat transfer Coefficient with Reynolds Numner

Figure 6 shows the effect of heat transfer coefficient with various Reynolds Numbers. It is observed that the coefficient of heat transfer increases with increase pitch of the cavities. It is due to the developments of Dean Vortices and it leads to the mixing of the fluid in the channel and cavities. Reported average values of h are *15.19, 11.44, and 7.87* kW/m²K respectively for various pitch conditions 10, 15, and 20. It is noticed by that the height heat transfer coefficient (15.19 kW/m²K) with the 10 mm pitch of the channel.

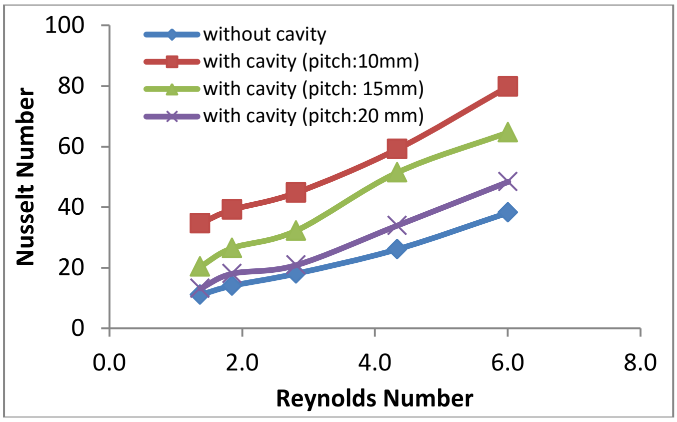


Figure: 7 Effect of Nusselt Number with Reynolds Number

Figure 7 shows Nusselt Number's effect for different Reynolds Numbers of all channels. It is noticed that Nu increases with the increased Reynolds Number respectively. It is due to that the Nu depends on heat transfer coefficient. The Variation of Nu is similar to the variation of the heat transfer coefficient. It is seen the higher Nu with the Pitch 10 mm of channel. .

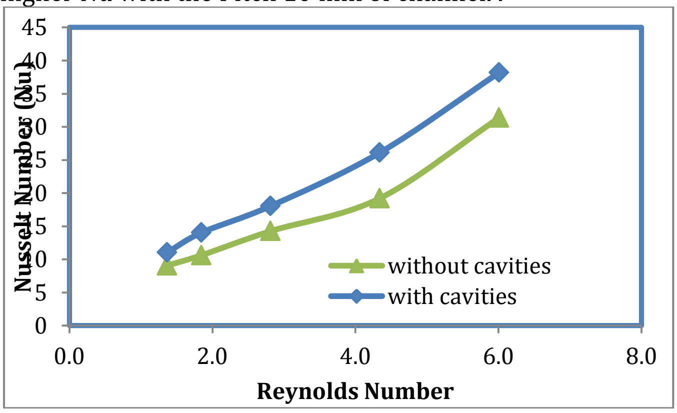


Figure: 8 Nusselt Number vs. Reynolds Number with and without cavities

A comparison between a channel with cavities and without cavities is presented in figure 8. It is noticed that the Nusselt number of micro-channel increased by 39.13% than the plane channel.

5. CONCLUSIONS

In this study, a micro-channel heat sink with different pitch of the cavities are fabricated and tested for various range of Reynolds Numbers at constant heat flux condition. Effect of cavities with a staggered arrangement on the thermal characteristics of micro-channel heat sink is investigated. From the experiments the following conclusions are drawn:

- The rate of heat transfer increases with Reynolds Number linearly and with the pitch of the cavities of channels in the range of 0.8, 0.7, and 0.62 kW. It is due to the dean vortices formed in the channel cavities.
- It is observed that the channel with lowest pitch (P: 10mm) provide the better heat transfer performance (15.19 W/m²K) than the other pitch of the cavities and without cavities of a channel. It is because of proper mixing of the working fluid by the formation of eddies in the channel by the cavities.
- The Nusselt number is increased by 39.15% of micro-channel compared to channel without cavities. It is because of increase in convective heat transfer coefficient, which is depending on the flow conditions.
- It is concluded that better thermal performance is attained cavities with higher pitch (P: 10) in the micro-channel.

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