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Numerical Investigation On The Heat Transfer In Micro-Channels With Trapezoidal Ribs- A Review

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Abstract*—The three-dimensional study of a rectangular microchannel with trapezoidal ribs is considered to identify the heat transfer, temperature contour, velocity contour, and pressure drop at different Reynolds number, in channels at different inclination angles of ribs. The rib angles are 30°, 45°, 60° and 90° are taken. In this study, the investigation is done numerically. The fluid flow as water is used and three trapezoidal ribs are taken at different angles. The dimension of the microchannel is the length, height, and width of the channel are 10 mm, 0.5 mm, and 0.45 mm, and in the middle of the channel, three trapezoidal ribs were placed. These dimensions are taken from Wang et al. [19] and Yuan et al. [20]. The geometry is created in SOLIDWORKS 2019 and the investigation is done by ANSYS FLUENT 2020 R2.

***Keywords*— Microchannel, Reynolds number, Nusselt number, trapezoidal ribs, Pressure drop**

I. INTRODUCTION

In this investigation, we considered a rectangular microchannel with trapezoidal ribs. The length of trapezoidal ribs is 0.1 mm, the height is 0.1 mm and the width from the bottom is 0.1 mm and the top is 0.05 mm. The inclination angle of the ribs is 75°. The three ribs are collinear in nature. The water fluid is flowing inside of the channel and ribs are used as obstacles to creating turbulence and mixing of fluid to provide a greater amount of heat transfer.

$$\nabla \cdot \rho V = 0$$

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial y}(\rho w) = 0$$

ρ is the density of the fluid and the unit of density is kg/m^3. Throughout the channel the density of the fluid is constant. The fluid particles travel in the x-direction, y-direction and z-direction. The velocity in the x-direction is represented as u, the velocity in y-direction is represented as v and the velocity in the z-direction is represented as w.

Dimensional numbers show a central role in fluid flow such as Reynolds number, Nusselt number Froude number, etc. in this study Reynolds number and Nusselt number are considered.

Here the flow is assumed to a laminar flow through the pipe. At the entry, the velocity of the fluid is calculated using the Reynolds number which can be mathematically shown below

$$Re = \frac{\rho V D}{\mu}$$

Where ρ is the density of the fluid and it is measured in kg/m^3. V is the velocity of the inlet fluid in (m/s), D is the diameter of rectangular channel and viscosity is the properties of fluid, It is denoted by μ (Pa-s.)

$$D = 2W_l H_l / (W_l + H_l)$$

Where W_l is the width of the channel and H_l is the height of the channel.

The Heat transfer performance is depends on Nusselt number. The Nusselt number was calculated by using equation-

$$Nu = \frac{hD}{k}$$

Where h represents the convective heat transfer coefficient in W/m^2-K, and the thermal conductivity of the fluid is material properties which denoted by k. The unit of thermal conductivity is w/m-k.

Fig.1- Rectangular Microchannel with three trapezoidal ribs

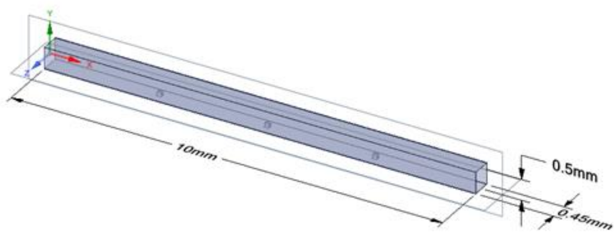
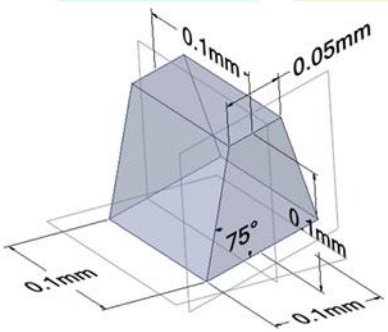


Fig.2 Trapezoidal ribs



II. LITERATURE REVIEW

Tuckerman et al.[1] demonstrate a better option to supply higher energy storage density in small temperature differences. He takes a micro-electro-mechanical system-based Heat exchanger. The Slurry as a cold fluid is used.

Adams et al. [2] have investigated on circular microchannel. The diameters of microchannel are D1 and D2, it is 0.76mm and 1.09 mm respectively. The setup was arranged like constant temp bath tub, it is full of distilled water and the temperature of this bath tub is constant. A pump is provided to supply the water to test section. Before test section two valves are attached, one is called bypass valve and other is called needle valve. The both valve is responsible for coarse control flow rate and fine flow rate. As a final results, when diameter decreases, then Reynolds number increases and extent of enhancement increases.

Ambatipudi et al. [3] have experimented on microchannel which has varying parameters such as channel width and channel depth. The calculation mass transfer is taken place inside the channels. If we increase the number of channels and flow rates of fluid varies with length of microchannel. They seen that when fluid velocity rises, the heat-transfer coefficient also rises through the channels. The Nusselt number also rises along the dimension of microchannels.

Wu et al. [4] have tried on trapezoidal microchannel(silicon) to quantity friction factor.

Laminar flow is taken for deionized water as the fluid. The range of hydraulic diameter is 25.9–291.0 μm. He concluded that when the shape of channels changes friction factor also changed. Navier stokes theorem is still valid for trapezoidal microchannel(silicon) for the laminar flow of deionized water.

Rosaguti et al. [5] have studied serpentine circular cross-section pipes using computational fluid dynamics. Reynolds number are taken upto 200 for analysis purpose, and they found that due to establishment of Dean vortices, separation occurs. Heat transfer rate throughout the channel are negligible because a low Reynolds number.

Chein et al. [6] have considered a rectangular channel of 10mm x 6.2mm x 0.5mm (LxWxH) and examined the fluid flow and heat transfer characteristics in microchannel heat flow sink and resolved them by finite volume scheme. They focused on three-dimensional laminar fluid flow in channel and heat transfer are steady. The rectangular channels are I-type, N-type, D-type, S-type, U- type, and V-type are taken and studied. They concluded that it gives better performance and velocities.

Sui et al. [7] have investigated rectangular cross-sections, wavy microchannel, and three-dimensional laminar flow. To analyze the fluid mixing dynamic section techniques are used. The results show that when fluid passes through a wavy microchannel, Heat transfer increases, The secondary flow is generated. This secondary flow is called Dean Vortises.

Mohammed et al. [8] has considered a rectangular microchannel. Inside the channel there are 25 wavy microchannels are attached. water flow and heat transfer in wavy microchannel. They takes wavy amplitude from 125 to 500 μm. As a results it was found that the increase in temperature of wavy microchannel increases then amplitude of wavy microchannel is decreases.

Chai et al. [9] have investigated on rectangular microchannel with interrupted ribs. The dimension of microchannel is 10mm x 0.25mm x0.35mm are considered,. They change the dimension and orientation of rectangular ribs for differebt types of studies. It is observed that the heat transfer for the interrupted microchannel is best for Re< 600. At this Reynolds number heat transfer is maximum.

Wang et al. [10], have investigated on multiport hydrodynamic channel. Its diameter is 825μm.They usages the dielectric fluid HFE-7100 and studied the convective heat transfer characteristics. The inclination angel is -90° to +90° are taken as vertically downward and vertically upward respectively. They concluded that 45° is the best

orientation for heat transfer, a with rise in heat flux, heat transfer decrease.

Nandi et al. [15] have investigate by numerically on wavy rectangular microchannel. They considered laminar flow in two-directions. The length of microchannel is 21 mm and length of wave is 20 mm and diameter of wave is 1 mm are considered. To numerical analysis some assumption are taken out such that fluid should be Newtonian and steady flow. The solving equation are Navier-stokes are used. The Reynolds number are 0.1 to 100 are considered. The amplitude and frequency of wave equation are (0.2, 0.5, 0.8) and (1, 5, 10) are considered respectively.

Odesola et al. [16] have investigated flow in microchannels inclined at angles 0°, 30°, and 60°.They found that the fluid flow through microchannels of hydraulic diameter Dh=1587 μm inclined at 30° and 60° is highly optimized and heat transfer capacity was increased in a microchannel of hydraulic diameter Dh =199 μm inclined at 60°.

Gholami et al. [17] have investigate on rectangular microchannel. The dimension of rectangular microchannel is in proportion of length and diameter. The ratio of length and diameter is 100. They take mainly rectangular, oval, and triangular ribs. For analysis purpose they considered two-dimensional analysis. The inlet temperature of microchannel is 298 k and heat flux is 10,000 w/m^2. The Reynolds are 1, 10, 50, and 100 are considered. The graph Reynolds number verses volume fraction of Nano particles are shows that when Reynolds number increases, volume fraction of Nano particle also increases.

Mohammed et al. [18] have considered a conical rings of two type first one is convergent rings and second is divergent rings. Convergent and divergent parts also divided into three part, inlet, exit and main part. The length of inlet part is 3312 mm and exit part length is 1246 mm and main part is 1100 mm respectively. The Nano fluid particle are is Al2O3, CuO, SiO2, and ZnO taken. The diameter of Nano particle is 20 mm to 50 mm are consider. For analysis purpose reynols number are between 2000 to 10000 are considered and inlet temperature and heat flux are 300 k and 1500 w/m^2 are taken. The graph of average Nusselt number vs number of cells are shows that when number of cells increases, Nuselt number is decreases.

Wang et al. [19], In this paper The heat transfer and flow characteristics are investigated they take a rectangular microchannel with bidirectional ribs. The ribs are arranged in vertical and span wise, it is denoted as VR and SR respectively. The length, width and height of microchannel are 21 mm, 11.19 mm and 1.5 mm respectively. For analysis they used ANSYS FLUENT software, the temperature of microchannel at inlet is taken 293 k and pressure is taken 1.013X10^5 Pa and heat flux is taken as 100 w/m^2k . For meshing they used hexagonal type of meshing, during this operation some assumptions are taken like fluid is steady and laminar flow. The experimental setup are arranged like a constant temperature bath tub is taken to store fluid and to transmit it. After filtering the fluid it goes to pump is deliver fluid at rated pressure to test section, after the test section fluid goes to heat exchanger there it exchange the heat and it is collected into the collecting container. From the graph of Nusselt number verses Reynolds number, It is shows that-

- When Reynolds number is lower range the Nusselt number is also lower and the deviation of graph is 7.1 %.
- When Reynold number is in medium range, The Nusselt number is also in medium range and the graph deviation is 8%
- When Reynolds number is at maximum range and Nusselt is also at maximum range and graph deviation is 9.8%.

From the graph of Reynolds number verses normalized Nusselt number it shows that when Reynolds number is in between 200 to 850 the normalized Nusselt number is increases parabolically 1.6 to 2.5.

In the graph of apparent friction factor verses Reynolds number It shows that –

- At apparent friction factor approximate 0.25, at Reynolds number (200 to 300), graph decreases rapidly and then after is decreases at constant slope.
- At apparent friction factor approximate 0.35, at Reynolds number (200 to 300), graph decreases less as compared to above one and then after is decreases at constant slope.
- At At apparent friction factor 0.7, at Reynolds number (200 to 300), graph decreases less as compared to above two and then after is becomes constant.

Yuan et al. [20], have done numerical study on wavy microchannel. It consist of cover plate, threaded hole, locating hole, acrylic plate, sealing grooves etc. The dimensions of microchannel are length width and height are considered. The length of microchannel are L1 and L2 are equal to 15 mm and the whole wavelength of microchannel is addition of $\lambda 1$ and $\lambda 2$. The channel is non-uniform in nature. The solid body of microchannel are considered as copper. The friction factor (f) verses Reynolds number graph shows that when Reynolds number increases, the friction factor decrease. The local Nusselt number verses flow direction graph it shows that when flow direction increases, the Nusselt number decreases. Pressure drop verses Reynolds number graph shows that for different microchannel when Reynolds number increases, pressure drop increses. The graph of Nusselt number verses Reynolds number over all heat transfer is increses for wavy microchannel. In the graph of wall temp verses Reynolds number, when Reynolds number increases, the wall temperature decreases. Heat transfer entropy generation verses Reynolds graph is shows that when Reynolds number increases heat transfer entropy generation decreases. The graph of fluid flow entropy generation verses Reynolds number is shows that when Reynolds number increases, the fluid flow entropy generation also increases.

Wang et al. [21] have considered a rectangular microchannel with truncated ribs. The dimensions of microchannel are length, width, height are 10 mm, 0.55mm and 1.5mm respectively and the ribs dimensions are varied for different types of analysis. For numerical analysis they take Reynolds number between 100 to 200. The heat transfer flow in three-dimensionally, steady and laminar flow is used. The fluid is assumed to be incompressible flow. The material of heat sink is considered as silicon. The inlet temperature of microchannel is 293 k and pressure and heat flux are considered as 1.013X10^5 pa and 100 w/m^2 respectively. For convective medium the heat transfer coefficient is 10 w/m^2 k. The graph of Nusselt number verses Reynolds number for staggered ribs are shows that, For case A1, B1, B2, B3, Reynolds number increases then Nusselt number is very much increases. For SMC, the Reynolds number increase then Nusselt number also increases but very less as compared to above case. For parallel cases approximate same as above case. The graph of apparent friction factor (f) verses Reynolds number for staggered ribs with w = 200 and 250, the Reynolds number increase then apparent friction factor decreases. For parallel ribs case Reynolds increase then apparent friction factor also decrease.

III. OBJECTIVES

In any system heat is main cause to damage the system. The objective of this research are-

- To provide efficient heat transfer to cool any systems.
- To calculate the thermal stresses in micro-channels with trapezoidal ribs.
- To calculate the heat transfer capacity of fluid in micro-channels with trapezoidal ribs.
- To calculate the pressure drop in micro-channels with trapezoidal ribs.

IV. EXPECTED OUTCOMES

- Total heat transfer is depends upon trapezoidal ribs angle and nusselt number, nusselt number should be varied with height and width of ribs. Rib's angle is responsible for heat transfer.
- Overall Pressure drop characteristics is depending on rib's dimensions and the angle of the ribs so pressure drop should vary with different rib's angles.
- Impact of the rib inclination on the temperature contours should be varied with different Reynolds number.
- Impact of the rib inclination on the velocity contours should be varied with different Reynolds numbers.

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