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NUMERICAL INVESTIGATION OF COUNTER FLOW ISOSCELES RIGHT TRIANGULAR MICROCHANNEL HEAT EXCHANGER

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ABSTRACT

Effectiveness of counter flow isosceles right triangular microchannel is calculated with different values of Reynolds number. The water is taken as working fluid for both hot and cold fluid. By using the single phase liquid flow the thermal performance of microchannel heat exchanger is analyze. By solving the energy, continuity, and momentum equations the results are achieved all the equations are solved in FLUENT 16.0. The heat transfer rate, effectiveness, total pressure drop, friction factor, and the hydraulic and thermal performance of the channel are calculated for Reynolds between 100 to 400. The results shows that effectiveness, friction factor, and performance index of microchannel heat exchanger are decreasing with increased values of Reynolds number, whereas the pressure drop and heat transfer rate are increasing as increased in Reynolds number.

Key words: Counter flow, Microchannel, No-slip, Performance index, Reynolds number.

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1. INTRODUCTION

Heat transfer in circular/straight tubes and channels was the topic of plentiful researches for the last century. In latest years, there is a quick development of applications which necessitate high heat transfer rates and fluid flows in comparatively small channels. The hydraulic diameters of microchannel is smaller than 1mm they can easily made and can easily utilized to increase the compactness of the heat exchanger. The microchannel heat exchanger is exclusively encouraging for its superior thermal performance. The microchannel heat exchangers produce high heat transfer area per unit volume as compared with conventional channels. Al-bakhit and Fakheri [2] numerically calculated the effectiveness of parallel flow rectangular microchannel heat exchanger with high conductivity material. The results showed that effectiveness of heat exchanger is not affected by using high conductivity material and independent on the thermal conductivity of the wall. Rahman and Gui [4] experimentally find the friction factor in trapezoidal cross section microchannel using water as a tested fluid. The results showed the good agreement with the obtainable friction factor to the conventional theory. Wu and Little [5] dignified the heat transfer features in laminar and turbulent regimes for gas flow. The results showed that at Reynolds approximate 1000 the turbulent convection occurs. Agrawal et al.[1] using the diverging microchannel with dissimilar divergence angle to calculate the pressure drop with boiling and results showed that at the existence of the acute angle which can decrease the mean pressure Drop

Greek Symbol

f : friction factor

η : performance index

ε : effectiveness

ρ : density

μ : dynamic viscosity

Subscript

h : hot fluid

c : cold fluid

i : inlet

o : outlet

max: maximum

Dimensionless group

Reynolds number, Re : $\frac{D_h}{u}$

Hasan et al. [3] study the axial heat conduction in parallel flow rectangular microchannel using water as a working fluid they showed that different parameters such as thermal conductivity ratio, Reynolds number, hydraulic diameter, channel volume, and wall thickness affect the axial heat conduction rate in a rectangular microchannel heat exchanger.

In the present work the numerical investigation of heat transfer in an isosceles right triangular counter flow microchannel is carried out. The various parameters such as effectiveness, heat transfer rate, friction factor, total pressure drop, and the performance index are calculated.

2. NUMERICAL FORMULATION

Continuity, momentum, and energy equations are solved by using CFD tool ANSYS 16.0. The following physical and geometrical assumptions are accounted during the whole analysis

- The flow is 3-dimensional, steady, and laminar.
- No heat transfer to or from ambient.
- The energy dissipation is negligible.
- The fluid is a continuous medium (no-slip)
- The pressure gradient in axial direction only.
- The fluids are incompressible.

The geometrical configuration of the isosceles right triangular channel is shown in figure 1.

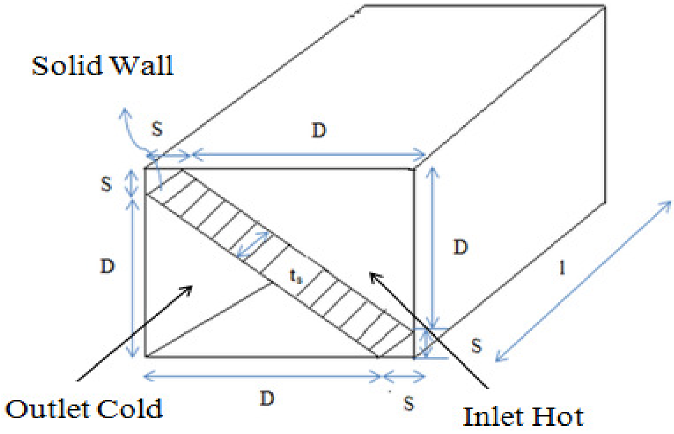

Figure 1 Schematic of isosceles right triangular microchannel heat exchanger

The length of the channel (l) is 20 mm, height and base of the channel (D) is 0.2 mm thickness of the solid wall is (t) 0.005 mm and S is the projected distance of solid wall.

From the geometrical and physical assumption the continuity, momentum and energy equations are as below (Hasan et al. 2014).

x- Momentum equation:

$$\rho_i\,(u_i\frac{\partial u_i}{\partial x} + v_i\frac{\partial u_i}{\partial y} + w_i\frac{\partial u_i}{\partial z}) = -\frac{\partial p_i}{\partial x} + \mu_i\,(\frac{\partial^2 u_i}{\partial x^2} + v_i\frac{\partial^2 u_i}{\partial y^2} + w_i\frac{\partial^2 u_i}{\partial z^2}) \qquad (1)$$

y- Momentum equation:

$$\rho_i\,(u_i\frac{\partial v_i}{\partial x} + v_i\frac{\partial v_i}{\partial y} + w_i\frac{\partial v_i}{\partial z}) = \mu_i\,(\frac{\partial^2 v_i}{\partial x^2} + v_i\frac{\partial^2 v_i}{\partial y^2} + w_i\frac{\partial^2 v_i}{\partial z^2}) \qquad (2)$$

z- Momentum equation:

$$\rho_i\,(u_i\frac{\partial w_i}{\partial x} + v_i\frac{\partial w_i}{\partial y} + w_i\frac{\partial w_i}{\partial z}) = \mu_i\,(\frac{\partial^2 w_i}{\partial x^2} + v_i\frac{\partial^2 w_i}{\partial y^2} + w_i\frac{\partial^2 w_i}{\partial z^2}) \qquad (3)$$

Continuity equation:

$$\frac{\partial u_i}{\partial x} + \frac{\partial v_i}{\partial y} + \frac{\partial w_i}{\partial z} = 0 \qquad (4)$$

Energy equation for fluid:

$$\rho_i c_{p_1}(u_i\frac{\partial T_i}{\partial x} + v_i\frac{\partial T_i}{\partial y} + w_i\frac{\partial T_i}{\partial z}) = k_1\,(\frac{\partial^2 T_i}{\partial x^2} + v_i\frac{\partial^2 T_i}{\partial y^2} + w_i\frac{\partial^2 T_i}{\partial z^2}) \qquad (5)$$

The effectiveness of the heat exchanger can be described as the ratio of actual heat transfer to the maximum possible heat transfer.

$$\varepsilon = \frac{Q_{actual}}{Q_{max}} \qquad (6)$$

Q_{actual}= actual heat transferred in the heat exchanger

Q_{max} = maximum possible heat transfer in the heat exchanger

Now, actual heat transfer rate in a heat exchanger is given by:

$$Q = m_h \cdot C_{ph} \cdot (T_{hi} - T_{ho}) = C_h.(T_{hi} - T_{ho}) \tag{7}$$

and,

$$Q = m_c \cdot C_{pc} \cdot (T_{co} - T_{ci}) = C_c. (T_{co} - T_{ci}) \tag{8}$$

Then the effectiveness is

$$\varepsilon = \frac{C_h(T_{h\,i} - T_{h\,o})}{C_{min}(T_{h\,i} - T_{c\,i})} = \frac{C_c(T_{c\,o} - T_{c\,i})}{C_{min}(T_{h\,i} - T_{c\,i})} \tag{9}$$

Once the effectiveness can obtained, the heat transfer rate can be determined for different value of Reynolds number. After calculation of heat transfer rate the total pressure drop are calculated under different Reynolds number flow condition which is calculated by

$$\Delta P = \Delta P_h + \Delta P_c \tag{10}$$

Where

$$\Delta P_h = (P_{h\,in} - P_{h\,out}) \tag{11}$$

and,

$$\Delta P_c = (P_{c\,in} - P_{c\,out}) \tag{12}$$

Once the total pressure drop are determine the friction factor can be calculated as

$$f = \frac{\Delta P}{\frac{1}{2}\rho v^2} \tag{13}$$

And the performance index of counter flow microchannel are calculated as

$$\eta = \frac{\epsilon}{\Delta P} \tag{14}$$

Then the following results are obtained from the above calculations.

3. RESULTS AND DISSCUSION

To check the accurateness of the present model the comparison of temperatures of hot fluid, cold fluid and the separating wall with different values of Reynolds numbers are made between data of Hasan et al. (2014) and the present model as shown in figure 2. [2]

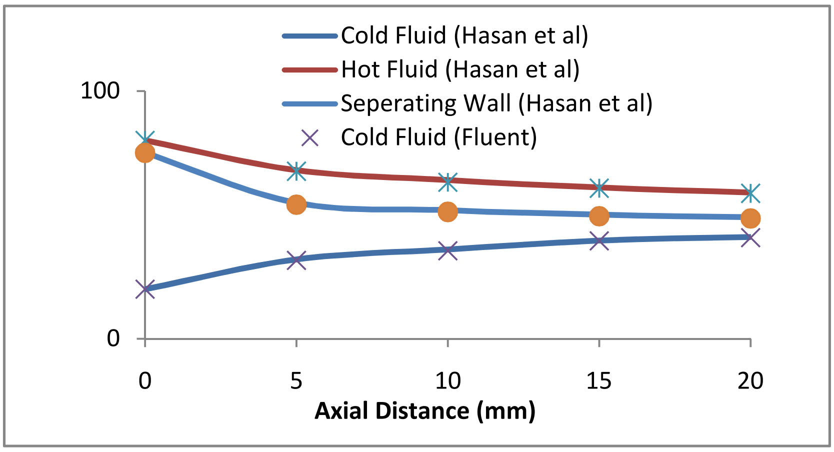

Figure 2 Comparison between temperatures profiles with different values of Reynolds number

The figure 2 shows the good agreement the percentage error is very low. This comparison is accounted for parallel flow channel.

To calculate the effectiveness of a counter flow heat exchanger the inlet temperature of cold fluid is 20˚c and the inlet of temperature of hot fluid is 80˚c are taken. Figure 3 shows the effectiveness of counter flow heat exchanger with different values of Reynolds number. From the figure it can be noted that the effectiveness is decreasing with increase in the value of Reynolds number.

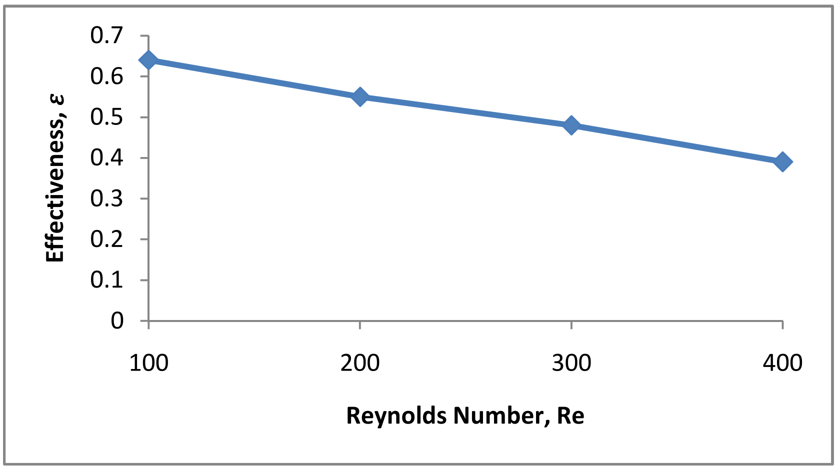

Figure 3 Variation in effectiveness with different values of Reynolds number

Heat transfer rate are calculate for counter flow microchannel heat exchanger. Figure 4 shows the variation in heat transfer rate.

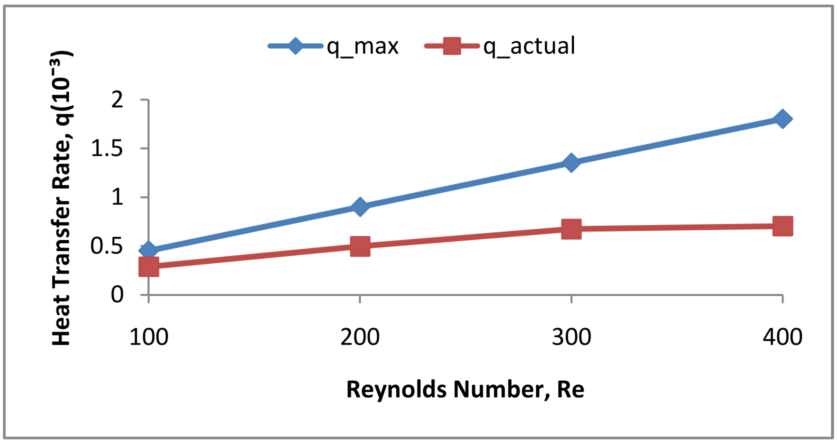

Figure 4 Variation in heat transfer rate with different values of Reynolds number

Form figure 4 it can be concluded that the heat transfer rate is increasing with increase in the values of Reynolds number. The variations of both actual and maximum possible heat transfer are approximating linear. This difference is increasing with increased value Reynolds number. Re = 100 has minimum heat transfer difference and Re = 400 has maximum heat transfer difference.

The total pressure drop in the counter flow microchannel heat exchanger is calculated along the axial direction of the channel as shown in figure 5

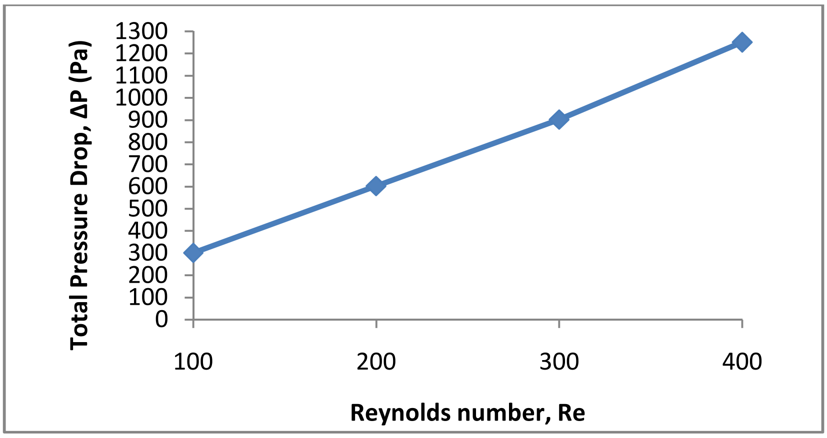

Figure 5 Variations in total pressure drop with different values of Reynolds number

This variation is taken for hot channel of Counter flow with Re 100, 200, 300, and 400. From the figure it can be illustrated that at Reynolds 400 the maximum amount of pressure drop occur at Reynolds 100 the minimum pressure drop accounted.

The friction factor is calculated which occurs due to the surface roughness, velocity with different Reynolds number. The figure 6 shows the variation in friction factor with varying Reynolds number.

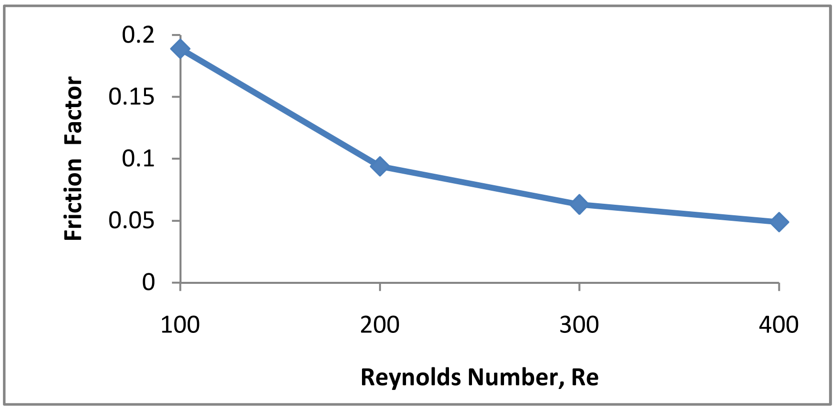

Figure 6 Variation in friction factor with different Reynolds number

From figure 6 it can be noted that friction factor is reducing with amplified values of Reynolds number. Minimum friction factor are obtained at Reynolds 400 and the small Reynolds number100 is maximum friction factor is noted.

Figure 7 shows the hydraulic and thermal performance of the counter flow microchannel heat exchanger.

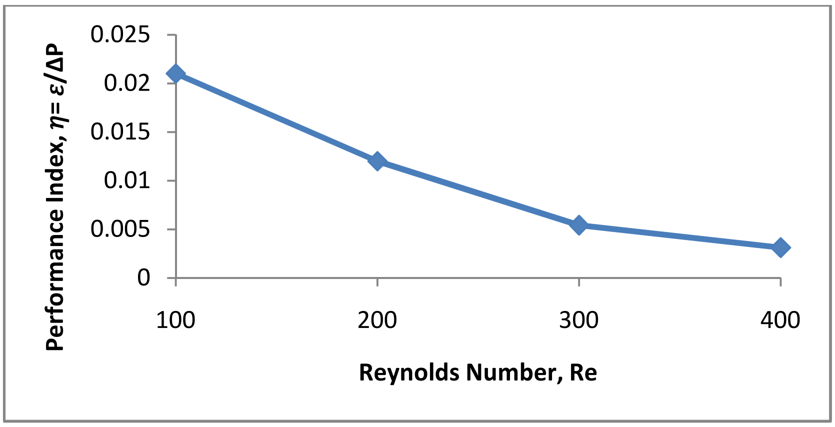

Figure 7 Variation in performance index with varying Reynolds number

From figure it can be understood that the performance index is decreasing with increased value of Reynolds number. Re = 100 has maximum performance index and Re = 400 has minimum. This occurs due to the cumulative value of pressure drop and falling value of effectiveness with increased value of Reynolds number.

4. CONCLUSION

The counter flow microchannel heat exchanger is investigated numerically with No-slip flow heat transfer. Thermal and hydrodynamic performance of microchannel is investigated with different parameters. The microchannel heat exchanger with aluminium material has found better effectiveness. Effectiveness is decreasing with increased value of Reynolds number due to the higher inlet velocity. Pressure drop increases with increased value of Reynolds number for counter flow channel. Heat transfer rate also increases with increased value of Reynolds number in the microchannel heat exchanger and the performance index drops with increased value of Reynolds number. Performance index signifies the overall performance of microchannel heat exchanger unit.

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