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# COMPARISON OF HEAT TRANSFER & FLUID FLOW IN THE MICRO-CHANNEL WITH RECTANGULAR AND HEXAGONAL CROSS SECTION

Emami Sajjad[1], Hosein Dibaei Bonab Mohammad[1],Mohammadiun Mohammad[1], Mohammadiun Hamid[1], Sadi Maisam[1]

*[1]Department of Mechanical Engineering, Shahrooad Branch, Islamic Azad University, Shahrooad, Iran*
*e-mail: dibaeibonab.m.h@gmail.com*

ABSTRACT

Due to the shrinking of the industrial equipment, the heat transfer and cooling of these devices are of particular importance. Therefore, this paper studies fluid flow and heat transfer in a micro-channel. In this study three-dimensional laminar numerical simulations, based on the Navier–Stokes equations and energy equation, are obtained for pressure drop and heat transfer in these micro-channel heat sinks under the same conditions. In this article, the first step is to investigate the effect of channel shape and geometry on the heat transfer and pressure drop in micro-channels. In, the second step, the effect of undefined heat flux and distinct input condition is investigated, and third step, the effect of increasing the number of channels is checked to do an ideal form of heat transfer in a micro-channel. According to the results, heat transfer using a hexagonal micro-channel is improved 20% on the rectangular micro-channel (with equal hydraulic diameter).

Keywords: *numerical simulation, rectangular andhexagonal micro-channel, heat transfer, Pressure drop.*

## INTRODUCTION

In very large scale integrated (VLSI) circuits, generation of high heat fluxes dictates a proper thermal management strategy. Otherwise amplified base plate temperature may lead to the collapse of any electronic device. The concept of MCHS was firstly proposed by Tuckerman and Pease. They investigated a heat sink with micro-channels utilizing water as the coolant. Nowadays, micro-channels, as closed circuits channels for fluid flow and heat removal are an essential part of electronic microsystems. The concept of MCHS was firstly proposed by Tuckerman and Pease. They investigated a heat sink with micro-channels utilizing water as the coolant. Nowadays, micro-channels, as closed circuits channels for fluid flow and heat removal are an essential part of electronic microsystems. Micro-channels can be made with several materials such as glass, polyamide, silicon and metals, and therefore have different types in terms of their materials (using various processes such as micro-machining surfaces, volumetric microprocessors, molding, lamination And other conventional machining methods on Micro-channels) as well as their topographic and geometric structure with different cross-sectional shapes of square, rectangular, triangular and trapezoidal shapes, enclosed cylinders, pure coaxial models, non-circular channels and nonlinear channels [2].

Koo and Kleinstreuer, using dimensional analysis and numerical simulation, investigated the effect of this word on the temperature field and the coefficient of friction. Their results showed that the effect of temperature changes on the loss of zinc in the long channels with a small hydraulic diameter, and especially for fluid, is important. This effect increases the temperature of the fluid and thereby reduces the effect of the loss of lazy [3]. Hung In his two papers, transmitted the transmission of the displacements in the micro-channel from the point of view of the second law. He found that although the loss of viscosity not the most important parameter in entropy production, it is very influential. Therefore, he concluded that, based on the results of his papers and other papers, in the analysis of heat transfer in the dimensions of the micro-channel, this sentence should be taken into account [4,5]. Çetinet al. investigated the flow of two-dimensional fluid in a microscope, taking into account the effect of dilution, loss of viscosity and axial conductivity with boundary conditions of constant heat flux. They used analytic methods and Mathematica software to solve the energy equation. The results indicate that the local Nusselt number increases with the increase of the Nadsen and Brinkman numbers. As the Nadsen number increases, the effect of the Brinkman number on the Nusselt number is diminished [6].

Mokrani et al, investigated experimentally the flow of a long rectangular microwave channel. The study of hydrodynamic and thermal results showed that by changing the hydraulic diameter from 1 mm to 100 μm, the experimental data extracted are consistent with the results obtained from the classical relations of large-diameter channels. They concluded that the rules and relations of flow and heat transfer (Navier-Stokes) can be used for Micro channels with a smooth wall and hydraulic diameters larger than 100 μm [7]. Koo and al, by examining experimental papers related to Micro channels, divided them into three categories. The first category emphasizes the instability of flow in small dimensions. The second group considers oscillation variations as the factor of current deviation from its conventional theory, while the third group assumes that there is no deviation and the only factor is the problems in measuring in small dimensions. By studying their results, they considered the third group closer to reality [8]. Rezania and Rosendahl in 2012 examined the effect of a thermoelectric generator on a parallel micro-channel thermal sink. They investigated the effect of the general layout at the entrance on the smooth distribution of Micro channels in a wide range of pressure drop across the thermal sink, and they achieved optimal pumping capacity for their working conditions [9]. Anand used power law fluid as the working fluid and studied the effects of three different slip laws such as non-linear Navier, Hatzikiriakos and asymptotic on heat transfer and entropy generation of pressure driven flow, analytically. For this purpose he considered a rectangular micro-channel under uniform heat flux boundary condition. For a similar slip coefficient, the Nusselt number and average entropy generation rate predicted utilizing different slip laws were not the same. Also he showed that the effect of slip on entropy generation due to heat transfer is significant and has to be considered. Two-dimensional analysis is the shortcoming of this study [10].

Mc Haleand al studied the heat transfer in a trapezoidal micro-channel with different shape ratios and 54.74 and 45 degrees angles were selected as effective plates for the construction of silicon crystalline structures. The average Nusselt number was expressed as a function of dimensionless length and coefficient of form, and the coefficient of friction was also obtained as a function of the coefficient of form, which during their review showed that the shape and trapezoid angles had an effect on the amount of heat transfer [11]. Liu et al. studied the effect of micro-channel geometry on the amount of heat transfer to water. CFD modeling is the most common method for fluid flow and heat transfer issues, which many researchers have used well, and they also used LBM for CFD in addition to CFD, and showed that both methods are in good agreement with laboratory results have. They constructed several structures as shown below [12].

In November 2016, Anbumeenakshi and Thansekhar empirically investigated the shape of the header and input configuration in the inappropriate flow distribution in the micro-channel. Generally, according to their findings, it was found that the distribution of the current in the micro-channel significantly depends on the setting of the input current, the shape of the header and the flow rate [13]. Rezaei et al reviewed the numerical transfer of heat and turbulent flow pressure drop in a triangular micro-channel in 2017, and in this study, in order to increase the heat transfer from the channel walls, the semi-short and semi-connected ribs are inserted into the channel And the effect of the forms and the number of ribs was studied, their results indicated that the ribs affected the flow physics and its influence was completely related to the Reynolds flow and caused the pressure drop by the ribs The effect of the amount of heat transfer was affected [14]. Mr. Dowy Yang et al. in 2017, gave numerical and empirical analysis of the single-phase fluid operation in a micro-channel with different pin configuration and considered that pin shape plays an important role in balancing the pressure drop and the heat transfer rate to achieve the better the cooling performance of the micro-channel [15]. In 2017, Sahar,Wissinket measured the diameter and the ratio of hydraulic dimensions to single-phase flow and heat transfer in a rectangular micro-channel with an input and output. The results showed that the slope of the velocity profile in the channel wall significantly changes with the aspect ratio. It also does not affect the aspect ratio of the heat transfer coefficient, while the dimensionless Nusselt increases with increasing hydraulic diameter and increases the hydraulic diameter by increasing the friction factor al [16].

Moreover, it is from the above literature review, there is very little work done to investigate the effect of geometric parameters on the heat sink performance especially for Micro-channels. Thus, the present work attempts to complete the existing gap by studying the effect of the geometric parameters, the different Reynolds number, and the heat flux is a pressure drop and laminar convective heat transfer in a hexagonal micro-channel. This work intends to obtain the overall information on the fluid flow and heat transfer when a micro-channel heat sink is operated.

## MICRO-CHANNEL HEAT SINK GEOMETRIC CONFIGURATIONS

The issues involved in increasing the transfer of heat from the solid to the fluid include increasing the heat transfer surface, such as the use of fins [17], increasing the conductivity of the cooling fluid [18], optimizing the design of the heat pipe used in terms of channel size [19] and the shape of the micro-channel section [20] and the input and output arrangement [16], etc. In the present work, the effect of channel geometry and number of channel in different Reynolds and heat flux on flow and heat transfer is investigated.

In Figure 1, the geometric shape of the hexagonal micro-channel has been shown to have 25 channels. The fluid enters the entrance to the canals and absorbs the heat from the top of the channels. The outer walls of the micro-channel are insulated and the heat transfer inside the inner walls is done.

W=0.149mm  $D_H$=0.259mm  L=12mm  t=1.5mm

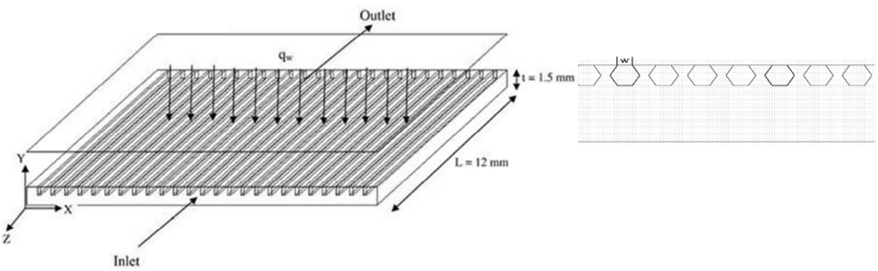


Figure 1. Geometric Micro channels

## MATHEMATICAL FORMULATION

### Boundary conditions

In this paper, the following assumptions and conditions are considered:

1. The flow is calm, incompressible, three dimensional and stable
2. Fixed heat flux is transferred from the upper wall to the micro-channel
3. There is no radiation in the problem and it is neglected due to the loss of laziness
4. The micro-channel is of aluminum, and the fluid base is water, Table 1

Table 1. Properties of metals

| Thermo-physical properties | $H_2O$ | AL |
|---|---|---|
| $\rho(Kg/m^3)$ | 998.2 | 3970 |
| CP(J/Kgk) | 4182 | 765 |
| k(W/mk) | 0.6 | 40 |
| $\mu(Ns/m^2)$ | 0.001003 | |

The boundary conditions of the problem are as follows:

A. The fluid inlet temperature is K 298 in all conditions.
B. The flow velocity at the input level of the channel is constant and is calculated from the following formula

$$u_{in} = \mathrm{Re}\mu \;/\; \rho \; \mathrm{D}_H \tag{1}$$

C) The output pressure is up to the atmosphere.
D) The external walls of the micro-channel are insulated, except for the upper wall where the constant heat flux enters.

## GOVERNING EQUATIONS

The equations governing the problem, as discussed previously in detail in the previous chapter, are summarized briefly in this chapter [21].

Continuity equation:

$$\partial u/_{\partial x} + \partial v/_{\partial y} + \partial w/_{\partial z} = 0 \tag{2}$$

Momentum equation: (3)

$$u\partial u/_{\partial x} + v\partial u/_{\partial x} + w\partial u/_{\partial x} = -\,{}^{dp}/_{dx} + {}^{1}/_{Re}\left(\partial^2 \mathrm{u}/_{\partial x^2} + \partial^2 \mathrm{u}/_{\partial y^2} + \partial^2 \mathrm{u}/_{\partial z^2}\right)$$

$$u\partial v/_{\partial x} + v\partial v/_{\partial x} + w\partial v/_{\partial x} = -\,{}^{dp}/_{dy} + {}^{1}/_{Re}\left(\partial^2 \mathrm{v}/_{\partial x^2} + \partial^2 \mathrm{v}/_{\partial y^2} + \partial^2 \mathrm{v}/_{\partial z^2}\right)$$

$$u\partial w/_{\partial x} + v\partial w/_{\partial x} + w\partial w/_{\partial x} = -\,{}^{dp}/_{dz} + {}^{1}/_{Re}\left(\partial^2 \mathrm{w}/_{\partial x^2} + \partial^2 \mathrm{w}/_{\partial y^2} + \partial^2 \mathrm{w}/_{\partial z^2}\right)$$

Energy Equation:

$$u\partial T/_{\partial x} + v\partial T/_{\partial x} + w\partial T/_{\partial x} = {}^{1}/_{Re \times pr}\left(\partial^2 \mathrm{T}/_{\partial x^2} + \partial^2 \mathrm{T}/_{\partial y^2} + \partial^2 \mathrm{T}/_{\partial z^2}\right) \tag{4}$$

## RESULTS AND DISCUSSION

The following bug shows a sample of meshes made. The mesh types are of a six-faced type. Figure 2 shows schematic and meshing of regular hexagonal micro channel and Figure 3 shows the number of meshes in the grid, which is chosen according to the number of 475000 meshes to be simulated. ($q=500\ w/m^2$, W=0.149 mm, $D_H$=0.259 mm).

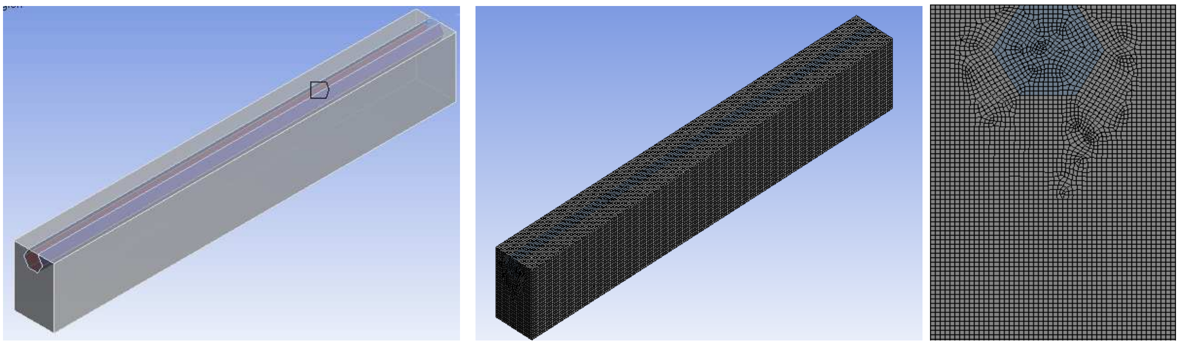

Figure 2. Schematic and meshing of geometric model

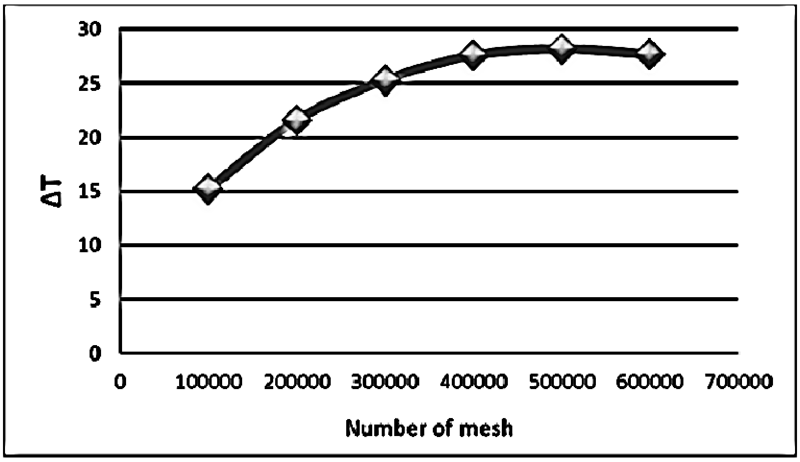


Figure 3. Independence of results from the grid

## NUMERICAL ANALYSIS OF THE PROBLEM

The numerical simulations are performed using FVM. Reynolds number is kept constant for all cases in order to confirm laminar flow through hexagonal micro-channels. Pressure-based solver is used for simulation to achieve steady state analysis. The semi-implicit method for pressure-linked equations (SIMPLE) algorithm is used for introducing pressure into the continuity equation. The energy equation activated during the analysis to predict heat transfer effects in Micro channels and check the effect of entrance type on heat transfer. The flow momentum and energy equations are solved with second-order upwind scheme.

## VALIDATING RESULTS

According to the selected paper, Gunnasegaran et, the simulated micro-channel was simulated and the results of rectangular micro-channel were compared with the results of the paper al [22]. The following figures 4 and 5 show the comparison between numerical results in rectangular and hexagonal micro-channel ($D_H$=0.259mm). The conditions are as follows: ($D_H$=0.259 mm, q=500 w/m$^2$)

Given the figure 4 and 5, it is seen that there is an acceptable agreement between the numerical results of the current work and the results of the reference article, so further studies are done.

Figure 4 shows that the fluid could have more heat in the hexagonal micro-channel than the micro-channel heating source, and the heating increased and the shape 5 shows that the pressure drop in the hexagonal cross section was increased Therefore, for further examination, the values of heat transfer and pressure drop are investigated.

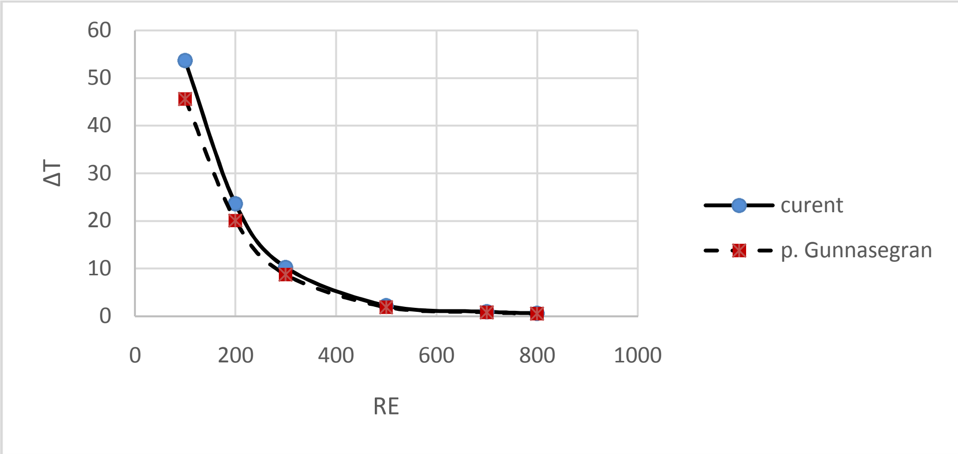


Figure 4. Validation chart for Fluid temperature rise versus Reynolds number [22]

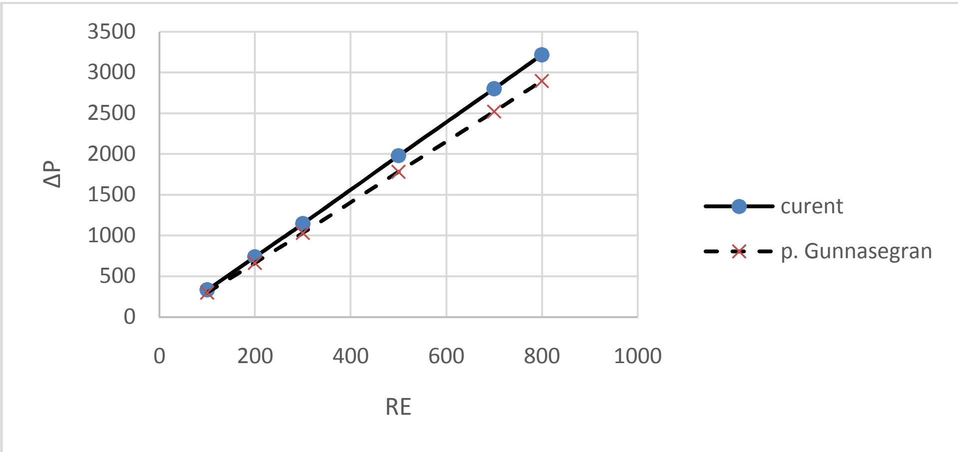


Figure 5. Validation diagram for Pressure drop variations versus Reynolds number [22]

## GEOMETRIC ANALYSIS OF MICRO-CHANNEL

For the geometric analysis of the micro-channel, the following parameters should be considered. In this study, according to the above results, the hexagonal cross section was selected to continue the investigation andin different conditions input and heat flux results are checked.

## EFFECT OF DIFFERENT REYNOLDS NUMBER (RE)

In this paper, the effects of the input velocity on heat transfer and pressure drop are shown by examining different Reynolds numbers. The fixed values in this review are below.

In Figure 6, the values of pressure drop in different Reynolds numbers are shown.

Since the only parameter is the velocity variable, so increasing the number of Reynolds means speeding up. As the Reynolds number increases, increasing the velocity (we see the increase in the pressure drop), since, according to the Hagen-Powell equation, we have a $\Delta P \sim V$ for the flow. The linearity of this graph is the accuracy of the calculations.

In the sequel, we study the effect of the Reynolds number on the heat transfer coefficient. Figure 7 shows the values of the heat transfer coefficient and Reynolds number.

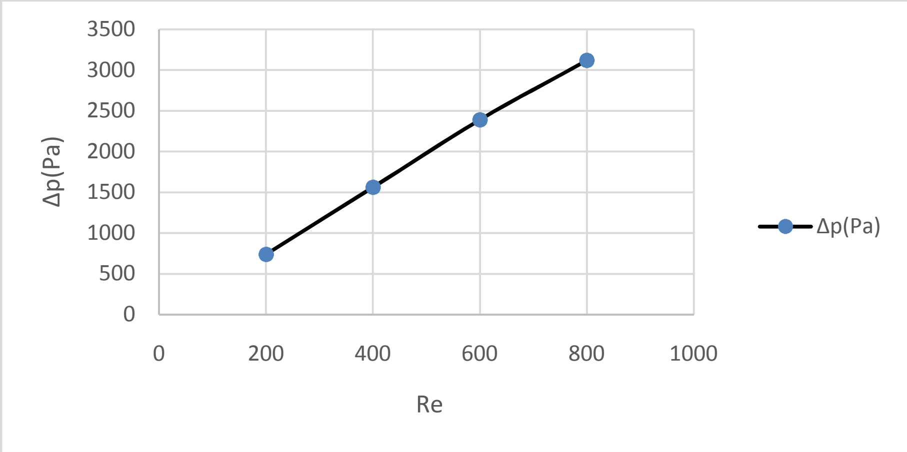


Figure 6. Pressure drop forversus Reynolds number

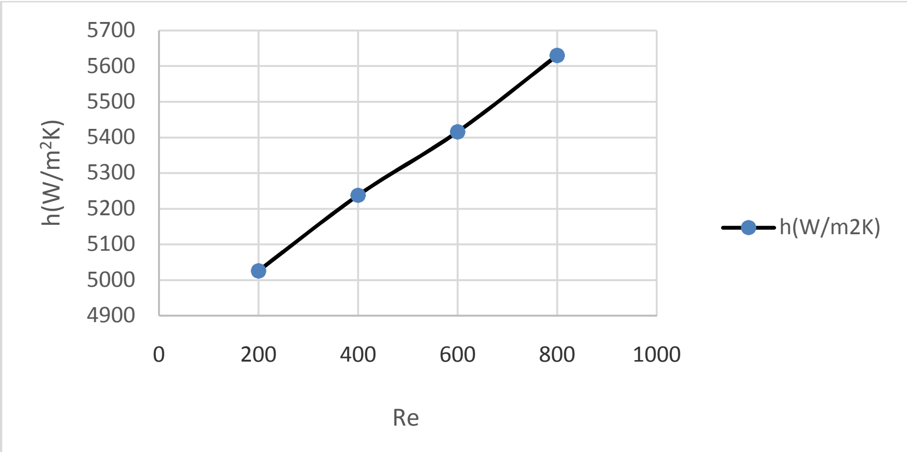


Figure 7. Heat transfer coefficient for versus Reynolds number

As can be seen, with the increase of Reynolds number, increasing the flow rate, the heat transfer coefficient increases. We know that the thickness of the boundary layer has an inverse relation with the Reynolds number. As the Reynolds number increases, the length of the entrance area of the duct or the current developing region increases. We also know that in the developing current region, the displacement coefficient is larger than the current region. Therefore, the average displacement coefficient of the entire duct increases with increasing Reynolds number. According to the above diagrams, the choice of the Reynolds number 400 seems reasonable due to the relatively low pressure drop and the appropriate heat transfer coefficient.

EFFECT OF DIFFERENT HEAT FLUX (q)

Here we examine the effects of thermal fluctuations on pressure drop and displacement coefficients. The following values are considered in constant calculations: ( Re=400, $D_H$=0.259mm, q=500kW/$m^2$). The pressure drop values are visible in Figure 8 in terms of heat flux.

As it is observed, the higher the heat flux, the lower the pressure drop. Whit Increasing the heat flux due to the constant flow of heat into the surface means increasing the heat transfer to the channel wall and the fluid inside the canal. As a result, the fluid temperature rises and the temperature increases, causing a loss of viscosity. With reduced viscosity, friction and drop in pressure are reduced.

In the following, we consider the effect of heat flux on the heat transfer coefficient. Figure 9 shows the effects of heat flux on the heat transfer coefficient.

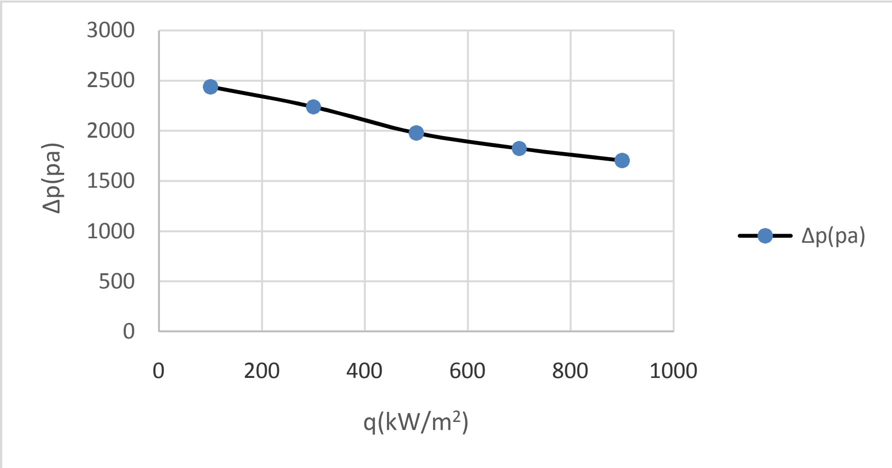


Figure 8. The amount of pressure drop in different amounts of heat flux

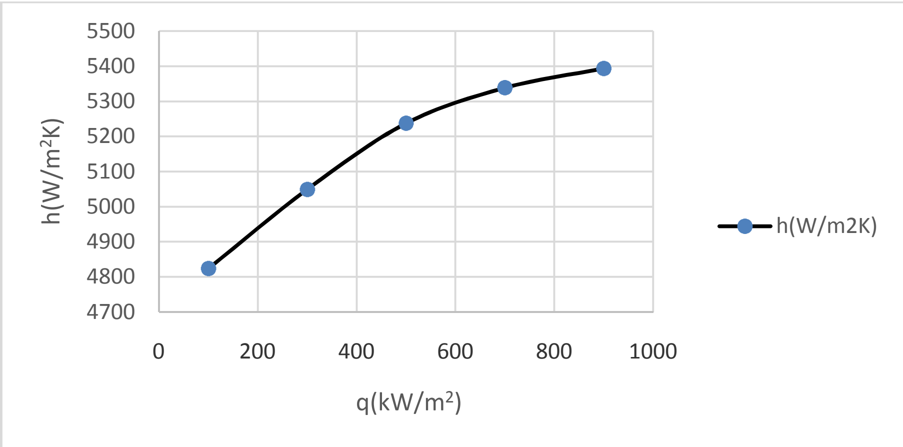


Figure 9. Heat transfer coefficient for different heat flux

Whit the higher the heat flux the heat transfer coefficient be increased. But the slope of this increase gradually slows down. Increasing the displacement factor is due to two reasons. First, increasing the heat transfer to the fluid inside the channel increases the temperature of this fluid, and this increase in temperature for water increases the amount of water conduction coefficient. Given the constant values of the hydraulic diameter and Nusselt number and according to the formula ($Nu= h.D_H/k$), the increase in the conduction coefficient should increase the displacement coefficient. Secondly, with increasing water temperature, the viscosity coefficient decreases.

Thus, the Reynolds number is increased and the thickness of the boundary layer decreases in the entrance area. Therefore, the length of the input area increases and the average displacement coefficient increases. Since the slope of the variation of the conductivity and viscosity coefficients decreases with increasing temperature, the slope of the displacement coefficient changes should also be reduced.

## REVIEW THE CHANNEL SET

In the previous sections, the results of the single-channel calculation were obtained. In this section, the calculations are performed for the microchannel assembly in order to check the effect of the adjacent channels on the results obtained. Here the water is used. The number of channels (N) in the study set is 25, which is in line with the source [22]. In addition, according to the studies carried out in this study, the highest heat transfer coefficient is related to Channel No. 14. The Figure 10 shows the effect of Reynolds number on the pressure drop.

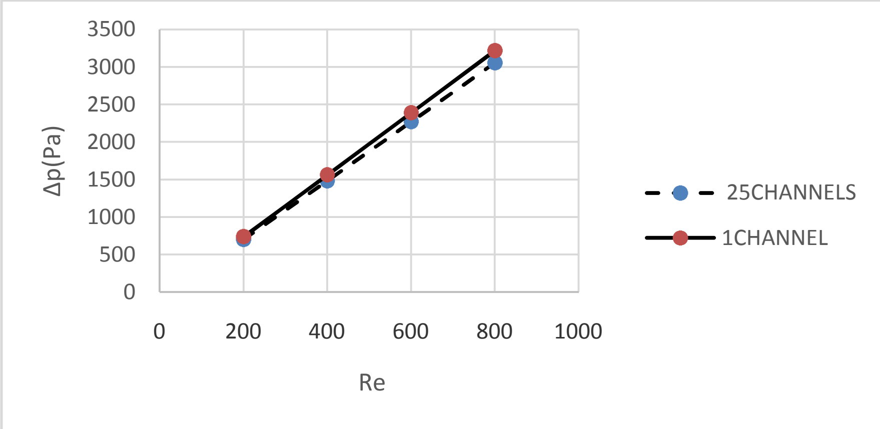


Figure 10. Pressure drop for versus Reynolds number

The variation of the displacement coefficient with the Reynolds number for Channel 14 from the channel set and single channel mode is shown in Figure 11.

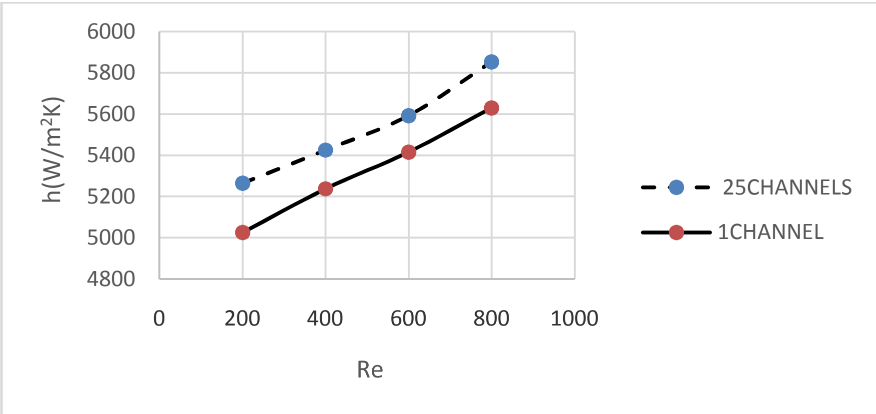


Figure 11. Heat transfer coefficient for versus Reynolds number

As can be seen, there is a significant difference between the two modes. The 25-channel mode is expected to have the same conditions for single channels as the one-channel conditions. But there is an important difference between these two modes, which causes the difference between the results of these two modes.

## CONCLUSION

In this thesis, a single-channel hexagonal channel with the numerical three-dimensional method and taking into account two parameters of heat transfer coefficient and pressure drop, in different Reynolds numbers (Re) And the heat flux (q). Meanwhile, we carry out all these steps with pure water. In the end, the converter is considered to be 25 channels, and the Reynolds number and heat flux are compared with single-channel mode. According to the given description, the following results are obtained:

1. As the velocity increases, the Reynolds numbers increase and thereby increase the pressure drop and increase the heat transfer, but the results indicate that the heat transfer rate in the hexagonal micro-channel is most rectangular.
2. Hydraulic diameter is the main factor for determining the drop of pressure. As the hydraulic diameter increases, the pressure drop decreases.
3. With increasing heat flux in the micro-channel, the amount of heat transfer is increased and the pressure drop decreases, and this value is better in the 25-channel micro-channel mode.
4. By increasing the number of channels, the heat transfer is improved and the pressure drop is reduced.
5. As the study shows that the heat transfer rate is higher than the pressure drop in the hexagonal

cross-section, it can be concluded that the hexagonal cross-section is better than the rectangular cross-section for the selected micro-channel.

6. According to numerical results, the micro-channel with a hexagonal cross section is better than the rectangular section, and also the values Re= 400, q=500 (w/m$^2$) and N=25 for the micro-channel is selected.

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REFERENCES


[1] Tuckerman, D.B., Pease, R. (1981). High-performance heat sinking for VLSI. Electron Device Letters, IEEE, 2(5): p. 126-129.

[2] Coblyn, M. et al. (2016). Effect of PEO coating on bubble behavior within a polycarbonate microchannel array: A model for hemodialysis. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 104(5): p. 941-948.

[3] Koo, J., Kleinstreuer, C. (2004). Viscous dissipation effects in microtubes and microchannels. International Journal of Heat and Mass Transfer, 47(14-16): p. 3159-3169.

[4] Hung, Y.M. (2008). Viscous dissipation effect on entropy generation for non-Newtonian fluids in microchannels. International Communications in Heat and Mass Transfer, 35(9): p. 1125-1129.

[5] Hung, Y.M. (2009). A comparative study of viscous dissipation effect on entropy generation in single-phase liquid flow in microchannels. International Journal of Thermal Sciences, 48(5): p. 1026-1035.

[6] Çetin, B., Yazicioǧlu, A.G., Kakaç, S. (2009). Slip-flow heat transfer in microtubes with axial conduction and viscous dissipation–An extended Graetz problem. International Journal of Thermal Sciences, 48(9): p. 1673-1678.

[7] Mokrani, O. et al. (2009). Fluid flow and convective heat transfer in flat microchannels. International Journal of Heat and Mass Transfer, 52(5-6): p. 1337-1352.

[8] Koo, J., Kleinstreuer, C. (2003). Liquid flow in microchannels: experimental observations and computational analyses of microfluidics effects. Journal of Micromechanics and Microengineering, 13(5): p. 568.

[9] Rezania, A., Rosendahl, L. (2012). Thermal effect of a thermoelectric generator on parallel microchannel heat sink. Energy, 37(1): p. 220-227.

[10] Anand, V. (2014). Slip law effects on heat transfer and entropy generation of pressure driven flow of a power law fluid in a microchannel under uniform heat flux boundary condition. Energy, 76: p. 716-732.

[11] McHale, J.P., Garimella, S.V. (2010). Heat transfer in trapezoidal microchannels of various aspect ratios. International Journal of Heat and Mass Transfer, 53(1-3): p. 365-375.

[12] Liu, Y. et al., (2011). A numerical study on heat transfer performance of microchannels with different surface microstructures. Applied Thermal Engineering, 31(5): p. 921-931.

[13] Anbumeenakshi, C., Thansekhar, M. (2016). Experimental investigation of header shape and inlet configuration on flow maldistribution in microchannel. Experimental Thermal and Fluid Science, 75: p. 156-161.

[14] Rezaei, O. et al. (2017). The numerical investigation of heat transfer and pressure drop of turbulent flow in a triangular microchannel. Physica E: Low-dimensional Systems and Nanostructures, 93: p. 179-189.

[15] Yang, D. et al. (2017). Numerical and experimental analysis of cooling performance of single-phase array microchannel heat sinks with different pin-fin configurations. Applied Thermal Engineering, 112: p. 1547-1556.

[16] Sahar, A.M. et al. (2017). Effect of hydraulic diameter and aspect ratio on single phase flow and heat transfer in a rectangular microchannel. Applied Thermal Engineering, 115: p. 793-814.

[17] Vanapalli, S. et al. (2007). Pressure drop of laminar gas flows in a microchannel containing various pillar matrices. Journal of micromechanics and microengineering, 17(7): p. 1381.

[18] Aghaei, A. et al. (2015). Numerical investigation of turbulent forced-convective heat transfer of Al2O3–water nanofluid with variable properties in tube. Ain Shams Engineering Journal, 6(2): p. 577-585.

[19] Li, J., Peterson, G. (2006). Geometric optimization of a micro heat sink with liquid flow. IEEE Transactions on Components and Packaging Technologies, 29(1): p. 145-154.

[20] Nonino, C., Del Giudice, S., Savino, S. (2010). Temperature-dependent viscosity and viscous dissipation effects in microchannel flows with uniform wall heat flux. Heat Transfer Engineering, 31(8): p. 682-691.

[21] Maxwell, J. A Treatise on Electricity and Magnetism 1st edn, Vol. 2, 391. 1873, Oxford Clarendon, USA.

[22] Gunnasegaran, P. et al. (2010). The effect of geometrical parameters on heat transfer characteristics of microchannels heat sink with different shapes. International Communications in Heat and Mass Transfer, 37(8): p. 1078-1086.