International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Simulation of Micro-Channel Based on the Applying Different Boundary Conditions using ANSYS (Fluent)

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ABSTRACT-

The utilisation of the micro-channel cooling approach presents itself as a feasible resolution for addressing the demanding heat dissipation needs of micro-electro-mechanical system (MEMS) devices. The thermal design of these devices is a crucial concern that necessitates maintaining the operating temperature below the permitted threshold. Therefore, the objective of this study is to enhance the thermal efficiency and dependability of these devices by ensuring that the operational temperature remains below the crucial threshold of 85°C. This work employs numerical simulations to examine the impact of varying aspect ratios and heat transport within a micro-channel of rectangular shape. Water was employed as the working fluid in the current investigation. In this study, a 3-D rectangular microchannel is utilised to investigate the effects of four distinct heat fluxes applied to the channel wall. The simulations were conducted utilising the commercially available software ANSYS Fluent 19.2. The study's findings indicate that there is a significant variation in velocity at the micro-channel wall as the aspect ratio increases along its length. The aspect ratio experiences minimal impact. Subsequently, a numerical simulation was conducted to analyse the heat transfer rate through a micro-channel at different aspect ratios.

Key Words: Micro-channel, Heat transfer, Boundary conditions, Heat flux, Aspect ratio

1. Introduction

In the past few decades with advances in technology, the needs for chilling in numerous micro electronic gadgets and other electrical equipment have grown significantly. Electronic and electrically interconnected equipment generates energy that must be moved (dissipated) from the system to another location for different cooling mechanisms to work properly. For the past decade, researchers have focused on micro-channel cooling systems. The amount of study on the effects of thermal elimination in micro channels is quickly rising. A number of investigations have been published with different types of micro channel geometry; however the form of these passageways impacts the coefficient of convective heat transfer (HTC). The main advantage of using a micro channel is that it allows for more heat evacuation in less space. Single-phase and non-viscous flow and convection in micro-channels have been demonstrated to be one of the most effective cooling strategies in a variety of Microelectromechanical system applications. In the past, the most common form of electronic cooling was air cooling.[1][2][3] An exploratory study was conducted on a multi channel heat sink to identify the optimum distance of the fan for the maximum thermal dissipation of the electronic devices.[4] Tariq[5] identified the optimal geometry for the heat removal of the electronic components to maximize cooling effects by the use of air as a coolant.[6] Liao[6] investigated the forced type of convection of the heat exchange in an enclosed duct structure with a pin-fin structure.[7] Bianchini[7] examined the circular cross section of a micromachined heat sink.[8] Finally, Yang[9] examined the effect of a comparative energy efficiency parameter on finned Heat Exhaust Systems. With the continuous miniaturisation of microchips as well as processing quickness, heat concerns are having an increasing impact on total electrical packaging and system performance. Issues with heat dissipation in microelectronic applications have necessitated more study and development. When optimum temperatures stay under 40°C, microelectronic device performance and durability improve [1].Keeping temperature circumstances in mind, research on cooling of electronic equipment has risen multi-fold during the previous two decades.

In the past few decades, researchers have done both experimental and theoretical work on flow boiling heat transfer in microchannels. There has been a lot of recent interest in this field from both academics and the business world. Research on flow boiling heat transfer in microchannels has been reviewed as follows. Various fields of study, including biology, physics, chemistry, electronics, sensing, and others, have found growing usage for micro-fluidic systems as this technology has advanced. Convective transport processes in microchannels and microchannel structures have gained in relevance due to the prevalence of these geometries in micro-fluidic systems. Heat transfer and pressure drop statistics for laminar and turbulent liquid or gas flow in microchannels have been published by a number of studies in recent years. The demand for extremely high heat flux cooling for the latest generation of computer chips has made flow boiling heat transfer in microchannels the most talked-about issue in heat transfer. While progress has been made in our understanding of macroscopic flow and heat transfer, micro channel flow is far different and more difficult. Research into microelectromechanical systems (MEMS), micro-heat exchangers (MHEs), micro-fluidics, and other biological applications (e.g., micro medication delivery) has expanded.

When it came to cooling electronics, air cooling was formerly the gold standard[1-3]. For their experiment on the best fan distance, Sivasankaran et al. [4] used a heat sink with many channels. When using air as a coolant, Tariq et al. [5] found the optimal geometric design for cooling electronic components. The heat exchange through forced convection was studied by Liao et al. [6] in a wedged duct with a pin-fin design. Bianchini et al. [7] studied the conceptual and experimental properties of a micro-channel heat sink arrangement with circular cross-sections. The effect of the relative energy allocation parameter in finned heat exchangers was investigated by Yang et al. [8].

The micro-channel heat sink was first proposed in 1981 by Tuckerman and Pease et al. [9]. Using a rapid heat dissipation thermal sink, the authors studied VLSI circuits. The IC thermal sink design incorporates a mini-channel of silicon and uses water as a coolant. They also noted that reducing the size of a fluid cooling thermal sink to the microscale may help boost the device's efficiency in transferring heat. Lee et al. [10] published the results of an experiment and a numerical analysis, verified the experimental and numerical result with the prior classical correlations, and repotted comparison outcome behaviour of single-phase micro-channels with conventional channels. Different Reynolds numbers (from 300 to 3500) are utilised in the experiment using a copper micro-channel filled with DI water. The computational prediction was generated using traditional methods. The predictions were found to be within a reasonable margin of error of the findings found in the literature (5%). In 2002, Qu et al. [11] examined the heat dissipation and pressure drop of a copper-manufactured thermal sink using DI water as a coolant by experimental and computational means. The micro-channel was used to analyse a collection of rectangular geometries with hydraulic diameters of 231 m. We apply heat energy to the top of the plate and conduct a numerical study to determine how different geometric factors affect the water flow and heat transfer properties. The results show that at a given Reynolds number at the microchannel's top surface, the pressure drop decreases as the heat flow rises. They also looked at non-linear flows including steps, curves, and zigzags. For micro-channels with identical cross-sections, the zigzag design was shown to have the maximum heat transfer coefficient (HTC) [12, 13]. Using NH3 as the working fluid, researchers compared the thermal performance of micro-channels of various geometries, namely circular and square. Heat resistance was found to be 21% lower for circular channels than for square channels, while pumping power was found to be 35% greater for circular channels than for square channels (Mohd et al., 14). The heat was also better evacuated from the channel when it was round instead of square. The influence of geometry on the thermo-hydraulic characteristics of supercritical CO2 was studied by Lei et al., who used three-dimensional numerical models to examine heat dissipation and pressure drop behaviour of supercritical CO2 in mini-channels. Important data and recommendations for the design of compact heat exchangers for supercritical CO2 power system applications are also provided, as are comparisons between the local Nusselt number and friction factor and the empirical correlations employed. Numerical studies show that the heat transfer coefficients for circles and ellipses are the greatest among all geometries studied[15-19]. Ghasemi et al. [20] used experimental analysis to look at the thermal performance and hydraulic parameters. Aluminium is used to construct all four channels, each of which is divided into two smaller channels with circular cross-sections and three different hydraulic diameter settings. The heat resistance of a hydraulic diameter of 4 mm is lower than that of a hydraulic diameter of 6 mm and 8 mm. Laminar flow in micro-channels and forced convection micro-channels with a wedge shape geometry were shown to be related by Kewalramani et al. [21]. For a wedge with 30° and 60° sides and a length-to-width ratio of 0.1 to 10, the poiseuille and Nusselt numbers were determined by experimental investigation and a computer model. The effects of Reynolds number and entry length of channel on the friction factor and on Nusselt number were thoroughly investigated by Su et al. [22], who also studied the elliptical shape of micro-channels and developed an empirical correlation between frication factor and entry length.

Morgan et al. [5] summarises many methods of micro-machining, including mechanical and electro-discharge techniques, for the removal of material. Micro-machining of both conductive and non-conductive materials are shown, demonstrating the possibilities of mechanical and electro-discharge micro-machining. Ashman et al. [6] looked examined the present production techniques for micro heat exchangers, focusing on those that provide channels with a hydraulic diameter of less than 200 m. Micro-machining, chemical etching, stereo lithography, and LIGA were all discussed. Tolerances, compatibility with other materials, and simplicity of production are discussed as they pertain to many distinct methods. Capacitance and voltage were discovered to be the most influential factors in the production of microchannels using micro Electric Discharge (ED) Machining by Mohammad Yeakub Ali et al. [7]. The MRR is very sensitive to the feed rate, capacitance, and voltage. Studies showed that mass replication of miniaturised functional components may be accomplished at a cheaper cost if micro ED milling and moulding were combined. Harvinder lal et. al. [8] studied and compared three type of micro machining processes namely wire-cut EDM, micro-slotting and micro-milling. The surface finish of fabricated microchannel in case of wire-cut EDM was observed to be of better-quality as compared to micro end mill cutter, followed by those from slotting saw and the time taken to finish the job using wire-cut EDM was highest. The slotting takes least time to finish the job. The micro machining operation using end mill cutter has intermediate surface finish but at lesser time. The cost of operating the wire-cut EDM was highest, followed by end mill cutter and slotting saw.

Micro-slotting, micro-milling, and wire-cut electrical discharge machining (EDM) were the three types of micro-machining procedures that Harvinder lal et al. [8] examined and compared. Wire-cut electrical discharge machining (EDM) took the longest to complete the task, but the resulting microchannel had a higher quality surface finish than those produced by micro end mill cutter or slotting saw. The slotting process is the quickest way to get the task done. The end mill cutter may provide an intermediate surface finish in a shorter amount of time during micro machining. The wire-cut EDM had the greatest operational costs, followed by the end mill cutter and the slotting saw. In their study, Sobierska et al. (2019) conducted experiments to investigate flow boiling phenomena in a vertical rectangular channel. The authors examined many aspects such as pressure drop, heat transmission, and flow patterns. The study involves conducting comparisons between existing correlations for pressure drop and heat transfer coefficient, as well as determining the boundaries that separate different flow patterns. An observed correlation between the heat transfer coefficient and heat flux in two-phase flow indicates an increase, while a reduction is seen with an increase in thermodynamic vapour quality. Three fundamental vapour flow patterns, namely bubbly, slug, and annular flow, may be identified by the use of flow visualisation techniques. Chen et al. (10 conducted an experimental study to investigate the fluid flow and heat transfer properties of methanol in a silicon microchannel heat sink with a (100) orientation. Methanol was used as the working fluid in microchannels with hydraulic diameters ranging from 57 to 267 μm to investigate the frictional characteristics of fluid flow, the bubble nucleation process, and the heat convection capabilities in both phase change and single-phase flow. This work presents an experimental investigation of the relationship between the friction factor and the Reynolds number, focusing on the fluid properties. Research has shown that the impact of friction and viscosity coefficients on fluid behaviour inside microchannels is much more pronounced compared to macro-scale channels.

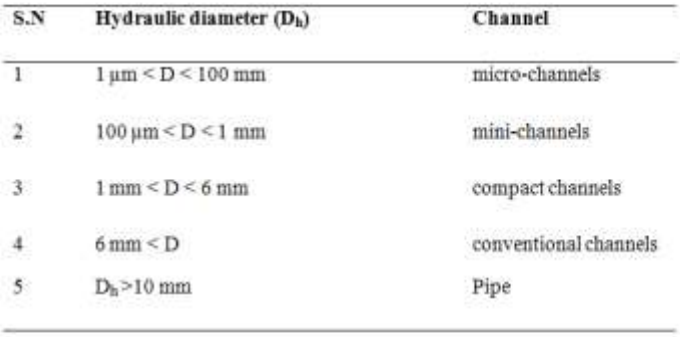
Kandlikar et al. (2010) proposed a straightforward correlation for predicting heat transfer coefficients during saturated flow boiling in both horizontal and vertical tubes. A comprehensive series of 24 experimental trials were conducted to investigate the phenomenon of saturation flow boiling in both vertical and horizontal tube configurations. A correlation is established based on the given data sets using an additive model and a parameter that depends on fluid properties. This correlation reveals a continuous fluctuation of the heat transfer coefficient along an evaporator tube.

Based on the aforementioned examination of prior research, it can be deduced that a broad array of investigations have been undertaken on a global scale, using diverse geometries and fluid mediums inside mini and microchannels. Furthermore, many studies have been undertaken to investigate the phenomenon of heat dissipation in rectangular mini-channels. The current study involves the use of numerical simulations to ascertain the rate of heat dissipation, heat transfer coefficient (HTC), and pressure drop inside a mini-channel. The coolant employed in this investigation is water, and the focus is on optimising the geometry of the mini-channel.

2.1 Classifications of Micro-channel

Micro-channels are channels characterized by a hydraulic diameter that is smaller than 1 mm. The classification of micro-channels is based on their hydraulic diameter, as indicated in Table 1 below. Additionally, Table 1 provides relevant data and information related to this diagram. The categorizations of micro-channels.

Table: 1 Classifications of micro-channel (MCHN)2.2 Overview of the Geometric Computational Approach



S.N	Hydraulic diameter (D_h)	Channel
1	1 µm < D < 100 mm	micro-channels
2	100 µm < D < 1 mm	mini-channels
3	1 mm < D < 6 mm	compact channels
4	6 mm < D	conventional channels
5	D_h>10 mm	Pipe

The micro-channel model seen in Figure 1 is a rectangular form that has been constructed using SolidWorks software. The dimensions of the cross section of the micro-channel exhibit variation. The micro-channel has a length of 10 mm, a width of 150 micrometres, and a height that varies between 150 mm and 1500 micrometres. In 2018, an experimental investigation conducted by C. J. Ho et al. [15] using comparable geometric methods. Figure 2 displays the cross-sectional view of each micro channel, together with the boundary heat flow. The top surface of the micro-channel is coated with identical materials in order to prevent the escape of coolant from the channel. The dimensions of geometry in this study were determined using the hydraulic diameter and aspect ratio as the basis. The hydraulic diameter and aspect ratios of all the geometries varied.

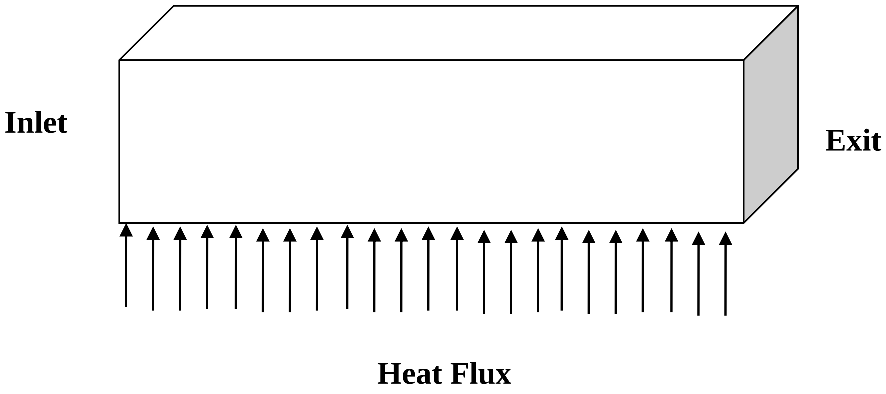
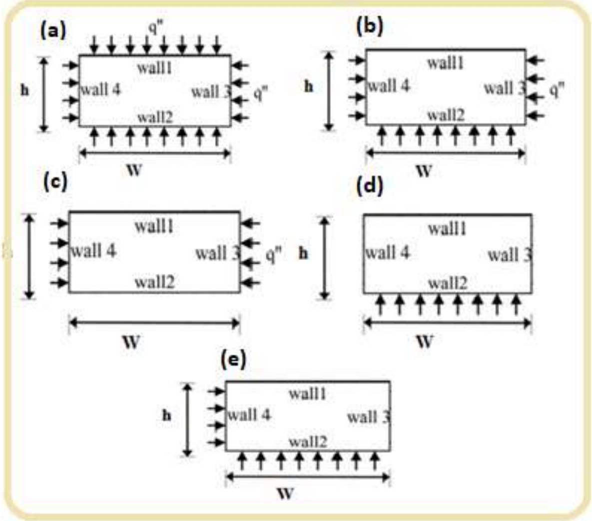


Figure 1: Micro channel in rectangular shape showing heat flux in perpendicular from the flow.

Figure 2: Micro-channel with uniform heat flux (HF) wall boundary conditions (WBC) (a) 4-WBC (b) 3-WBC (c) 2-opposite WBC (d) 1-WBC and (e) 2-adjecent WBC



2.3 A Model Derived From Mathematics

Following the description presented above, the governing differential equations that were used in order to make a prediction about the behaviour of the micro channel are as follows [23-25]:

Equations for the conservation of mass (3.1):

$$\frac{\partial}{\partial x}(\rho u_i) = 0 \qquad (3.1)$$

Momentum conservation equations (3.2):

$$\frac{\partial}{\partial x}(\rho u_i u_j) + \frac{\partial p}{\partial x} - \frac{\partial}{\partial x}\left[(\mu + \mu_t)\frac{\partial \mu_j}{\partial x_i}\right] - \frac{\partial}{\partial x}\left[(\mu + \mu_t)\frac{\partial \mu_i}{\partial x_j}\right] = 0 \qquad (3.2)$$

Energy conservation equations (3):

$$\frac{\partial}{\partial x}(\rho u_i T) - \frac{\partial}{\partial x}\left[\left(\frac{\gamma}{c_p} + \frac{\mu_t}{\sigma_T}\right)\frac{\partial T}{\partial x_i}\right] = 0 \qquad (3.3)$$

Heat dissipation rate can be determined by using the equation (3.4)

$$Q = \dot{m}\, c_p\, (\Delta T)_f \qquad (3.4)$$

The average convective HTC is determined by using the empirical relation (3.5).

$$h = \frac{Q}{A\,\Delta T} \qquad (3.5)$$

Nusselt number and Reynolds number are determine by using the equation (3.6) and (3.7)

$$Nu = \frac{hD_h}{K} \qquad (3.6)$$

$$Re = \frac{\rho u D_h}{\mu} \qquad (3.7)$$

Where, D_h is a hydraulic diameter. D_h is mentioned in equation (3.8) and ratio of width and height can be depicted from equation (3.9)

$$D_h = \frac{4\,A_{cr}}{P} \qquad (3.8)$$

and aspect ratio

(AR_{mc}) = width(w)/height(h) (9)

The multiple boundary variables that were utilized for the modeling process included No slip circumstances, inlet velocity at inlet is fixed (Ui = 0.16 m/s, 0.35 m/s, 0.7 m/s), and Velocity is zero in the frame. Other conditions included No slip conditions, inlet velocity at inlet is fixed (Ui = 0.35 m/s, 0.7 m/s), and No slip conditions. The heat flux is applied in several portions, including the bottom of the microchannel, the top and bottom surfaces, the top-bottom and left side, and all of the sides of the microchannel. The temperature of the fluid at its point of entry is always the same (Tin = 300 K). The outlet pressure is deciding what it will be at the end of the channel.

The ANSYS 19.0 Fluent commercial software was used throughout this investigation as it was carried out. It was presumed that the quantity of heat dissipated by each micro-channel was comparable to one another. As a result, one of the micro-channels is put to use in the simulation in order to provide a prediction about the behaviour of heat transfer, as can be seen in figure 3.2. Copper components are used throughout the building process of the micro-channel. Within the context of the simulation, the water serves the purpose of a cooling. After the numerical model has been constructed in Solid Works, it is exported to the workbench for further analysis.

The microchannel was assumed to have a three-dimensional geometry, the fluid flow and heat transfer were assumed to be independent of time, the fluid was assumed to be non-viscous and incompressible, the channel was placed horizontally, so the gravity effect was not taken into account, there was no volumetric heat generation in the channel, the thermal properties did not change with respect to flow, the fully developed, no slip condition, and single phase fluid flow were taken into consideration in the simulations, and some other assumptions were also made

2.4 Parameters of the boundary:

In order to deal with the issue that is outlined below, the constraints on the boundaries were put in place as follows:

Characteristics that is not slippy. There is no change in the inflow velocity at the inlet (Ui = 0.16 m/s, 0.35 m/s, or 0.7 m/s).Within the structure, there is no motion at all.The heat sink is being subjected to a heat flux at its foundation (y = 0, -k T/x= q").Insulation may be found on both of the side walls. There is never an increase or decrease in the temperature of the fluid at the entrance (Tin = 300 K).The outlet pressure is deciding what it will be at the end of the channel.

The commercial programme ANSYS 15.0 Fluent is used in the process of carrying out the numerical simulation. It was presumed that the quantity of heat dissipated by each mini-channel was comparable to one another. Therefore, one of the mini-channels is chosen to be employed in the simulation in order to make a prediction about the behaviour of heat transfer and pressure drop inside the mini channel, as shown in figure 3.2. Copper components are used throughout the building process of the micro-channel channel. Within the context of the simulation, the water serves the purpose of a cooling. After the numerical model has been constructed in Solid Works, it is exported to the workbench for further analysis.

Before beginning the numerical simulation, which is described in more detail below, several presumptions were made. The geometry of the MCHN was constructed in three dimensions. The flow of fluid and the transmission of heat are thought to be unaffected by the passage of time, non-viscous and incompressible fluids. Because of the channel's horizontal orientation, the influence of gravity has been disregarded. There is no creation of heat due to volumetric changes in the channel. There was no discernible shift in the thermal characteristics as a function of flow. During simulation, we took into account the fully developed state with no slip condition and single phase fluid flow.

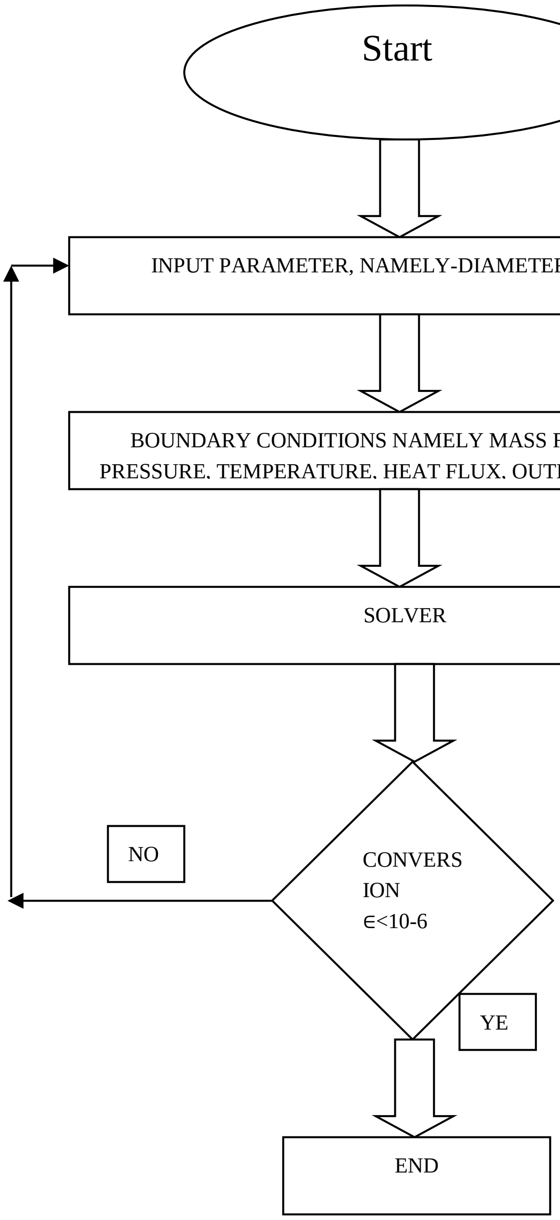


Figure: Flow chart of the methodology

3.5 Independent examination of the mesh

An independent mesh analysis was carried out in order to confirm that the result obtained was not in any way influenced by the total number of nodes. In order to validate the node independence of the solution, many alternative situations were investigated. An in-depth investigation of the mesh was carried out so that the influence of the mesh on the results could be determined. When the CAD model was imported into the workbench, the mesh was automatically produced and added to the model. The micro-channel's mesh is seen in figure 3.4 of the same document. Within ANSYS, the GDEs are discretized via the use of the control volume approach. In order to overcome the issue, the boundary constraints were implemented after the mesh was first generated. In addition to the simple technique, the pressure-based solution was chosen to be implemented, and a second-order spatial and upwind scheme were chosen to be used. The heat flux that was applied at the bottom section of the mini-channel was thirty thousand watts per square metre. The illustration illustrates how the meshing of the heat sink is constructed. It can be seen in figure 5 that the pressure drop does not vary when the number of grid/node values are increased. The value of pressure drop has not changed as a result of an increase in the node number from 45000 to 47000, and the data makes a straight line, which demonstrates that a rise in the node number does not effect the pressure drop.

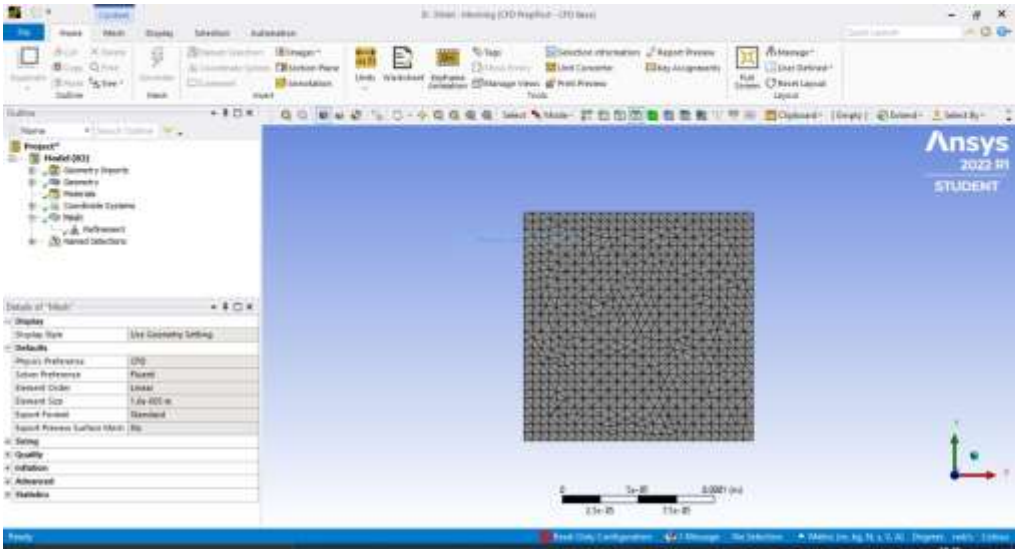


Figure 3.4: Mesh of rectangular shape mini channel

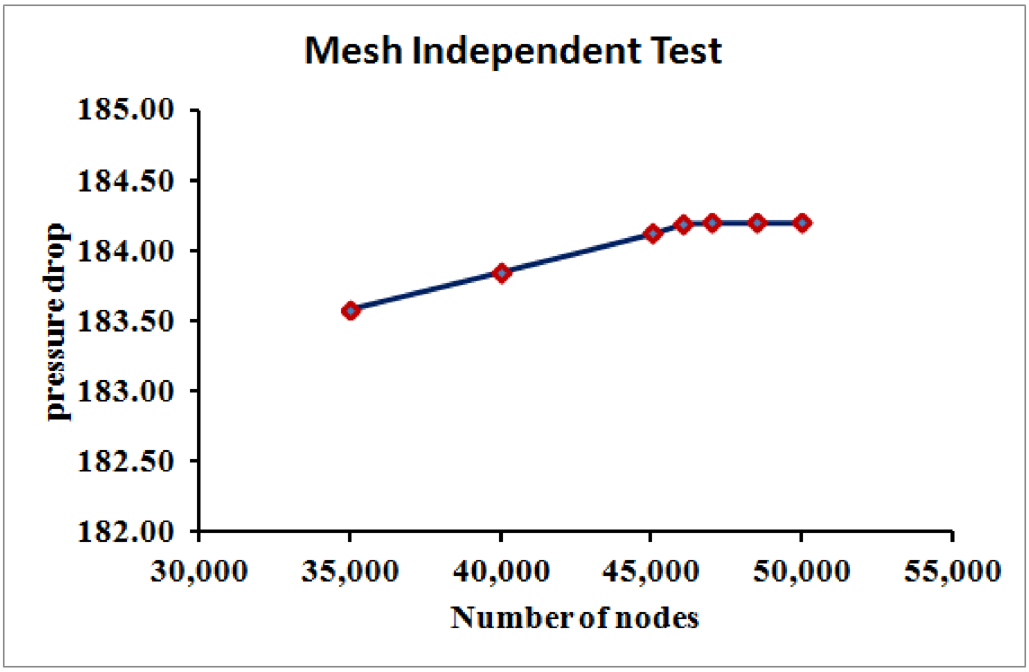


Figure 3.5: Node sensitivity test pressure drop vs. node for rectangular shape mini channel

3. Results and Discussion

The Nusselt number for each of the numerous entry circumstances and each of each of the five wall thermal flux boundary circumstances for each of the various component ratios that fall within the range of 0.1 to 1 has been determined via the numerous calculations which were performed. carried out. For the sake of these tests, the fully developed state was chosen. This simulation is being used to forecast the effect that the intake will have on the thermally expanding inlet zone that exists in microchannels.

4.1 Temperature shifts at the microchannel's point of entry

The temperature changes in a totally created area are shown in Figures 3a and 3b. The width of this zone is 300 micrometres, and the height is 150 micrometres. In order to arrive at an exact estimate of the heat transfer coefficient, several temperature readings are obtained alongside the trend, and then an average wall temperature is calculated. According to the conclusions of the computational analysis, the temperature of the average side face is assessed by taking the temperature at various nodes along the length of each heated wall in the microchannel. This helps to ensure that the temperature readings are accurate. First, the temperatures at several points along the heated walls are calculated in order to obtain the average temperature of the side edge. For the purpose of simplifying the calculations, five nodes on the heated wall are selected, each of which is capable of predicting the average wall temperature with the highest level of precision. The relationship of breadth and height to temperature is shown in figures 3a and 3b. This relationship may be illustrated. It first demonstrates an inverse connection with temperature, but after reaching a particular dimension, it modifies its behaviour such that it demonstrates stability, and subsequently it demonstrates a rising relationship with temperature.

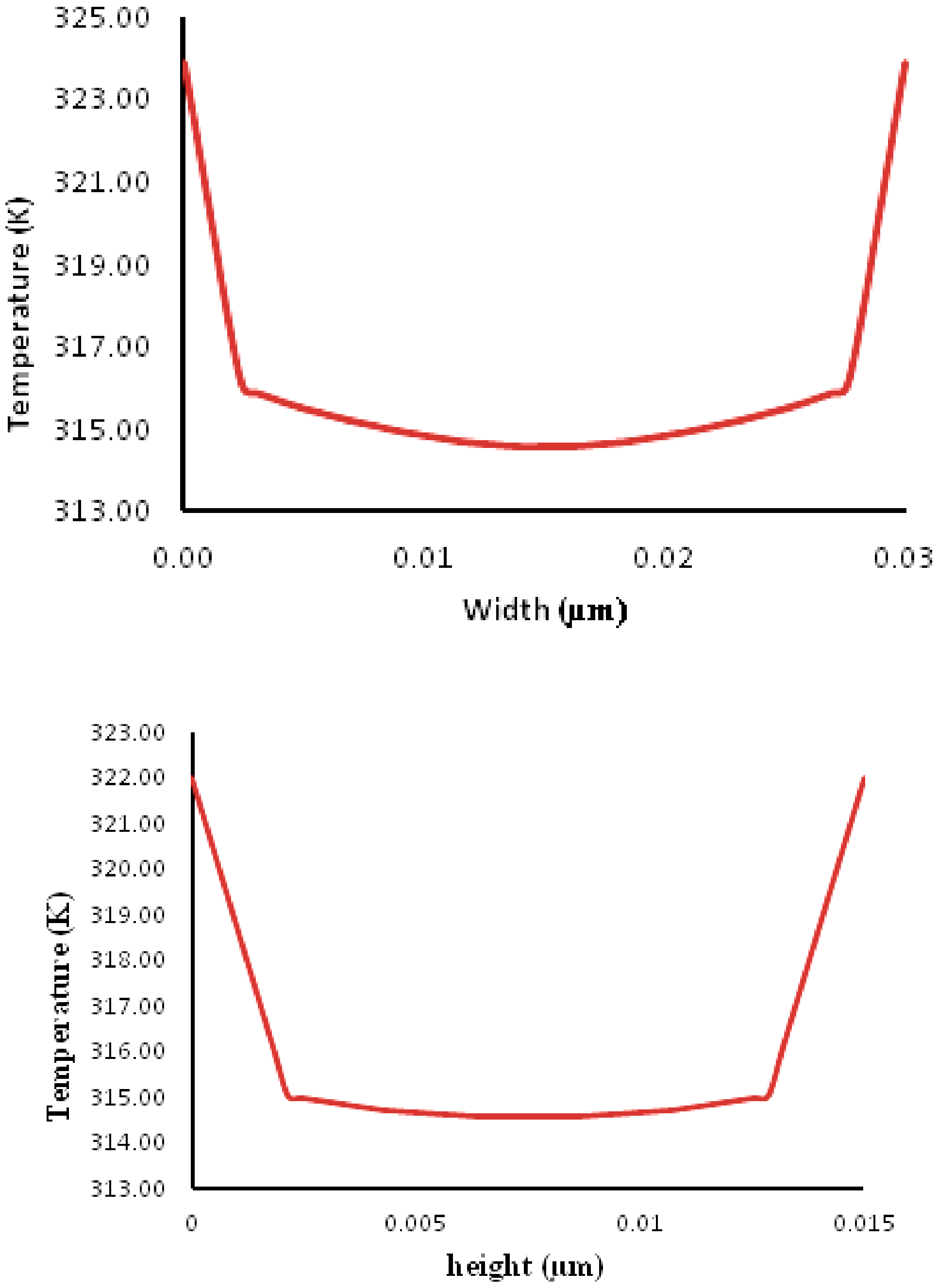


Figure 4.1. Variation of temperature at entrance in micro channel (a) width (b) height

4.2 The impact of the introduction of a micro-channel on the Nusselt (Nu) number

The figures shown in Figures 4a and 4b depict the variations in Nu along the axial direction of the micro-channel, specifically focusing on the impact of inlet headers on Nu. The analysis is conducted by examining the fluctuations in Nu with respect to homogenous power flow on FBWC and TBWC. The impact of inlet headers is focused along the axial dimension of micro-channels. The results for two different aspect ratios, namely 0.1 and 0.5, are shown for both cases with and without an abrupt intake. The entrance type does not significantly impact the Nusselt number in the inlet zone of thermally rising flow, as seen by the presented figures.

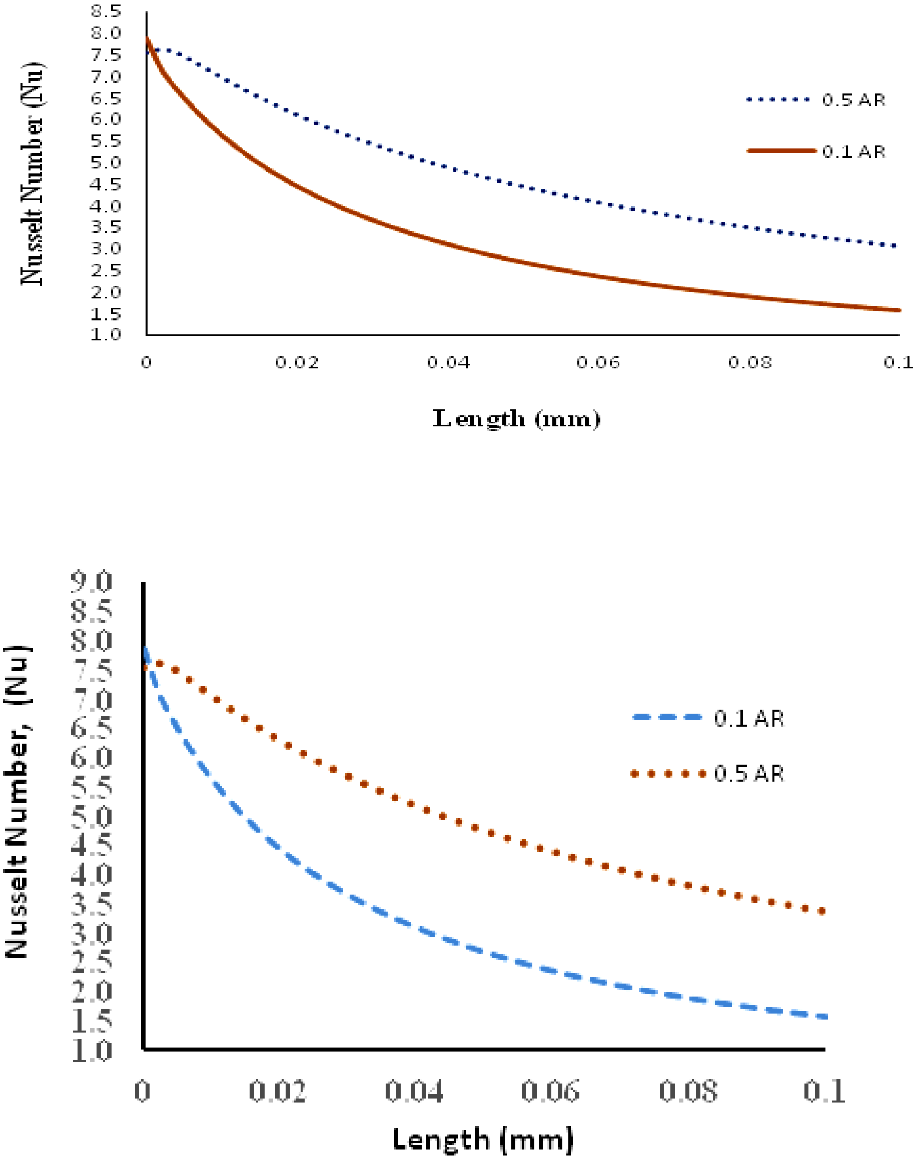


Figure. 4.2 Change in Nusselt number with rest to length of micro-channel (a) 4-WBC and (b) 3-WBC

Different micro-channels experience temperature gradients throughout their lengths

Figures 4.3, 4.4, 4.5, and 4.6 demonstrate the temperature profile over the length of the axis of a rectangular micro-channel with different aspect ratios and boundary circumstances on the walls. Since the thermal flow is delivered consistently over the tiny channel's surface, the temperature rises linearly with relation to channel length. The water coolant is constantly drawing heat from the wall and releasing it outside. Since the temperature differential between the intake and exit is greatest at the lowest aspect ratio, it can be seen in the figure that the rectangular micro-channel has the most heat dissipation.

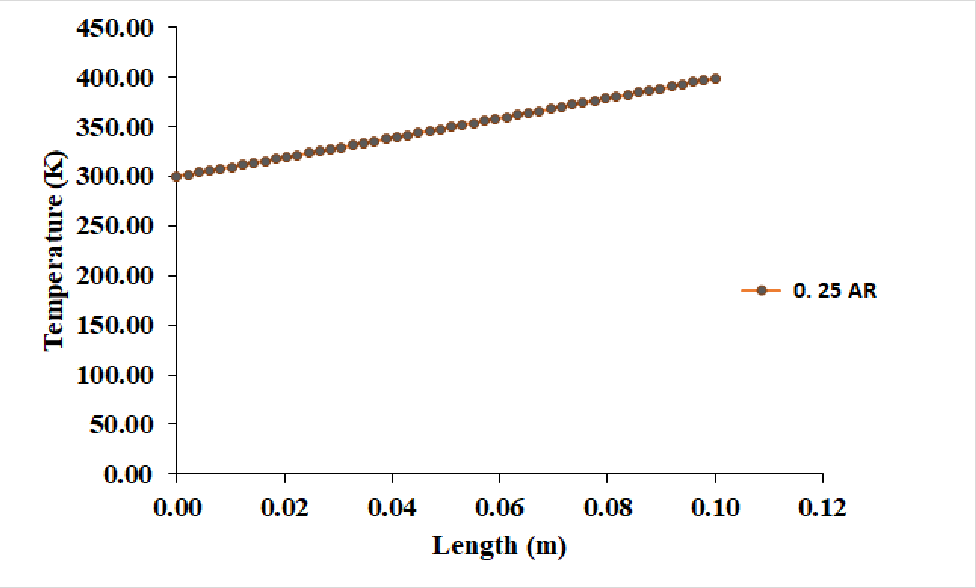


Figure 4.3: Temperature variation along the length of the rectangular micro- channel at 0.1 AR.

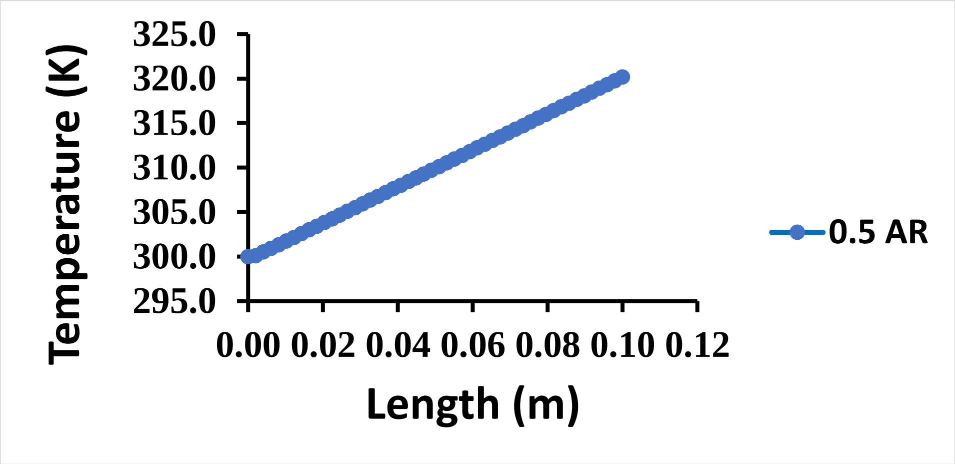


Figure 4.4: Temperature variation along the length of the rectangular micro- channel at 0.5 AR

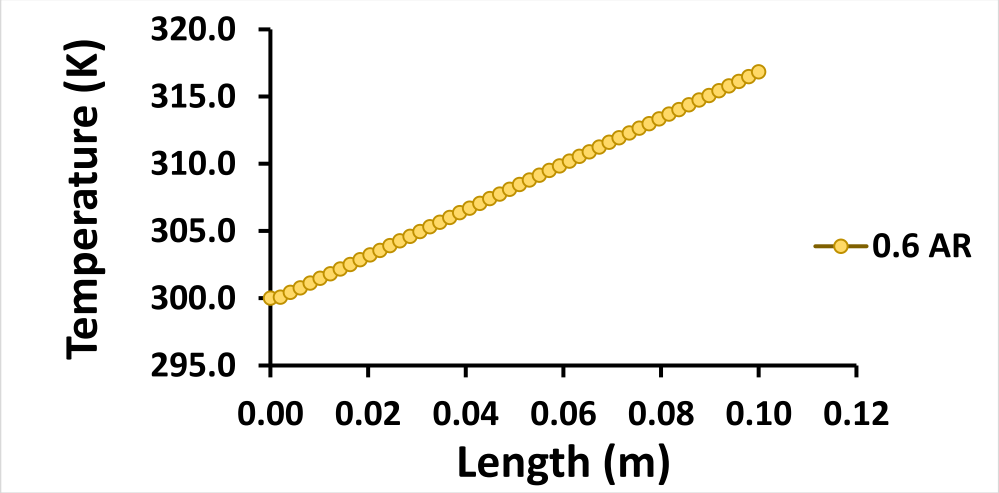


Figure 4.5: Temperature variation along the length of the rectangular micro- channel at 0.6 AR

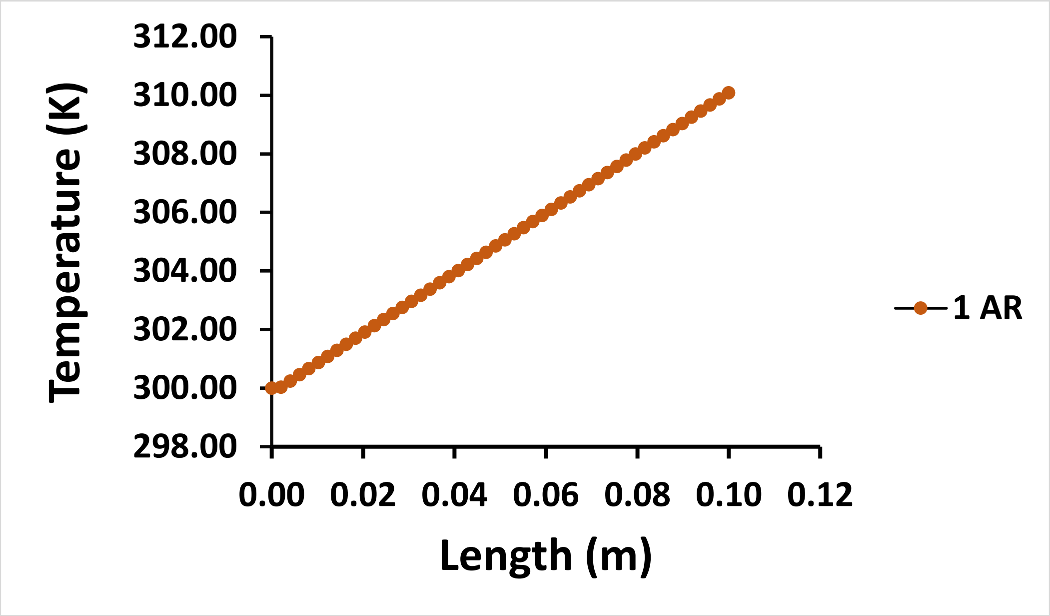


Figure 4.6: Temperature variation along the length of the rectangular micro- channel at 1 AR

4.3 Effects of boundary conditions of temperature at constant aspect ratio

The variation of temperature with respect to aspect ratio at different heat flux apply at different wall such as one wall heat flux boundary condition, two adjacent wall boundary condition, two opposite wall boundary conditions, three wall boundary condition and four wall boundary condition are shown in figure 4.7 keeping other aspect ratio constant. It was found that the temperature is significantly decreased with increase in boundary condition in between 1 to 4 WBC's. At 4 WBC's, the temperature along the length is found least, whereas, in other case the temperature is almost same and linearly increased along the length of the micro-channel. It can be also seen that the temperature difference is decreased with an increase in the heat flux boundary conditions. It can be observed that the minimum temperature difference is found at four boundary flux conditions and maximum temperature difference is found at first wall boundary conditions.

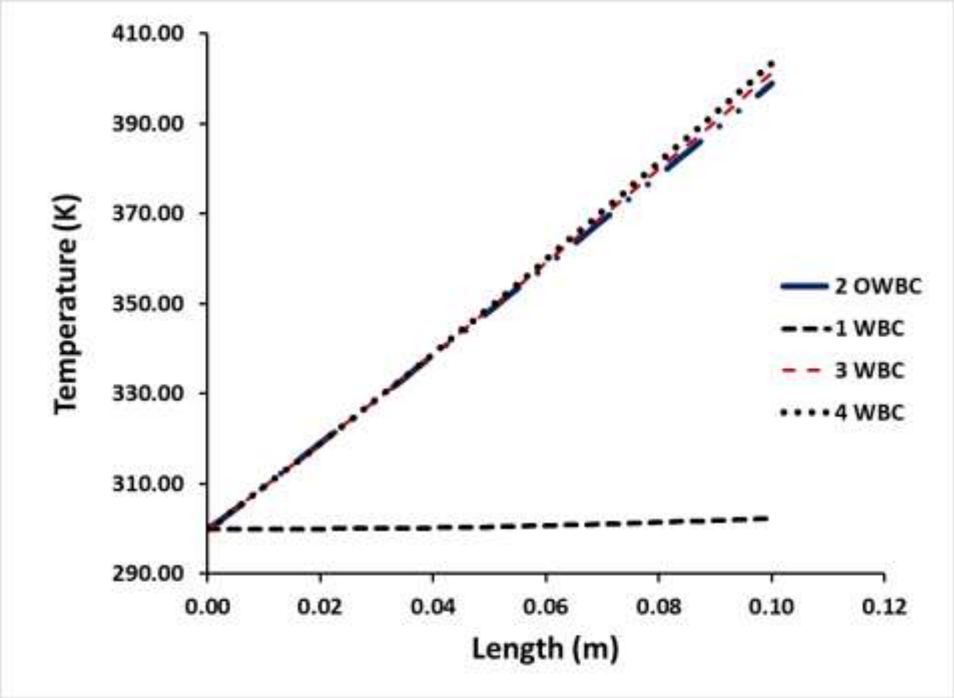


Figure 4.7. Nusselt number with respect to aspect ratio for different BCs.

5. Conclusions

The behaviour of a rectangular micro-channel using water as the working fluid has been simulated in ANSYS workbench employing a number of different scenarios. In the current studies, uniform wall heat flow boundary conditions, including 1–4 wall heating boundary circumstances, were used in the computer simulations. The loss of heat in the expanding thermal intake zone is studied as a function of inlet type. The findings imply that the kind of entry has no impact on the Nusselt values for all the cases considered. A large database of information is gathered for a wide range of ARs for micro-channels, from 0.1 to 1. both scenarios considered include applying a steady heat flux from both sides of the channel. When the aspect ratio decreases, the Nusselt number increases; when it's maximal, the Nusselt number increment is constant regardless of the aspect ratio. There are four wall boundary conditions where heat transmission is at its lowest, and one wall boundary condition where it is at its highest.

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