A Thesis on

Heat Transfer Enhancement in Single Micro Channel using Micro Fins

Submitted by

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In partial fulfilment of the requirements for the degree of

Bachelor of Technology

in

Mechanical Engineering

Under the guidance of

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May, 2014

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

CERTIFICATE

This is to certify that the thesis entitled "**HEAT TRANSFER ENHANCEMENT IN SINGLE MICROCHANNEL USING MICRO FINS**" submitted to the National Institute of Technology, Rourkela by **KRISHNA CHANDRA TOPPO**, Roll No. **110ME0340**, and **DEEPAK KUMAR ROUT**, Roll No. **110ME0321** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Mechanical Engineering**, is a bona fide record of research work carried out by him under my supervision and guidance. The thesis, which is based on candidate's own work, has not been submitted elsewhere for any degree/diploma.

Date: 12.05.2014

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ACKNOWLEDGEMENT

We take this opportunity to express our sense of gratitude and indebtedness to **Prof. M.K. Moharana** for helping us a lot to complete the project, without whose sincere and kind effort, this project would not have been success.

We are also thankful to all the staff and faculty members of Mechanical Engineering Department, National Institute of Technology, Rourkela for their consistent encouragement.

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ABSTRACT

A three dimensional numerical simulation of developing laminar and turbulent flow in a micro channel is carried out. Constant wall heat flux is applied at the bottom of the substrate and the remaining surfaces are insulated. Water is used at the working fluid which enters the channel inlet with a slug velocity profile. Micro fins are considered along the channel length at different locations. When fluid flows past any The term "enhanced" has get to be exceptionally vital for the business with advancing time. Due to progressed manufacturing techniques moderately complex geometry can be fabricated very effortlessly. Here, Different Reynolds number will be taken to differentiated between the heat transfer between the laminar and the turbulent stream. A 3-dimensional channel without fin was taken as the reference and after taking a fin in the channel the heat transfer improvement is compared with a simple microchannel. A wide range of materials with diverse thermal conductivity for the substrate as well as for the fin was taken to get distinctive solid by fluid conductivity ratio (k_{sf}) which play an important role in heat transfer process. Thermal performance of microchannel with single and multiple hurdles studied.

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NOMENCLATURE:

A_s	Surface area, mm^2
C_p	Specific heat of fluid, J/kgK
D	Hydraulic diameter, m
h_c	Heat transfer coefficient in convection
k_f	Fluid thermal conductivity, W/mK
k_s	Solid thermal conductivity, W/mK
k_{sf}	Ratio of k_s and k_f
L	Total length of tube, m
Nu	Local Nusselt number (-)
Re	Reynolds number (-)
q_w	Wall heat flux, W/m^2
q”	Heat flux at the solid-fluid interface of the micro tube, W/m^2
T_f	Bulk fluid Temperature, K
T_w	Wall temperature, K
ū	Average velocity at inlet, m/s
Z	Axial coordinate, m

Symbol

μ	Dynamic viscosity, Pa-s
ρ	Density, kg/m^3
ν	Dynamic viscosity, m^2s^{-1}
α	Thermal diffusivity, J/m^3K
δ	Thickness of the tube wall, m
δ_f	Thickness of fluid flow
δ_s	Thickness of wall
δ_{sf}	Ratio of δ_f and δ_s

Chapter 1
INTRODUCTION

INTRODUCTION

1.1 Back ground

For continuous development there is a need of improved technology but sometimes it's not always how we get the result we want. Sometimes with improved technology, there are some defects or demerits or some consequences. Now a days we use lots of machine, instrument, device to make our life easier but there is a main problem in all those equipment or mechanical instrument that we use in our day to day life. That is the thermal effect of all those equipment. Overheating can lead to the failure of equipment or may be harmful. So scientists are trying to find more efficient and affect way to lower the thermal effect of all those equipment's. In Industries the thermal or heating problem is more common than domestics. With the developments of micro-electro mechanical systems (MEMS) engineering, microchannels are very often widely used for heat transfer applications.

Normally fins are used to enhance heat transfer from any heated surface as it increase the surface area from which heat transfer takes place. In recent times, micro size fins of different shapes are being used to enhance heat transfer capability of microchannel systems. Numerous studies have demonstrated that, also the increase of the surface area, the expansion of pin fins in a micro channel permits better stream blending and accordingly, improved heat transfer. Mobile phones, machines, and Mp3 players, are some of the widely used electronic devices. There is a drive to acquire the most proficient and influential yet more compact electrical gadgets, and engineers are attempting to build the threshold that thermal impacts have on the part material. Overheating of these electrical segments is a worry as the temperatures achieve values that debilitate the correct working and their physical respectability [1]. Presently, electrical parts must support a low steady surface temperature to abstain from overheating. The progressions in the electrical gadgets are restricted to the nonattendance of the productive strategies to evacuate the heat that is constantly produced. Little channels have been compelling in uprooting heat through convection from the surface of a microchip. These channels demonstrate as heat exchangers at the nano, micro and mini scales. Forced and natural convection from fluids moving through these channels can scatter high surface temperatures. Nano channels, micro channels, and mini channels have a higher heat transfer surface territory to fluid volume proportion than a conventional channel which upgrades convection. The heat transfer coefficient builds as the hydraulic diameter's size is decreased in the channel empowering a brilliant cooling apparatus. In spite of the fact that it has very good cooling proficiencies, these types of channels encounter a very high weight drop as liquid streams. This can result in issues when attempting to re-circulate the liquid with a pump. As a result of the advancements in electrical gadgets, improving these channels has been an essential part of the research industry

Changes to mini/microchannels to improve thermal performance are continuously analysed by many researchers. Review of literature indicates that increasing surface roughness [2] and/or creating little cavities [3-7] on the channel walls will enhance the heat transfer. The addition of fins or little cavities on the surfaces of the channel creates disturbance inside the channels along the fluid stream and thus improve heat transfer.

It has been observed that triangular and parabolic fins hold less material and are much more productive requiring least weight. Also the efficiency of most fins utilized as a part of practice is over 90 %. Many changes to the micro channel's surface have been explored in upgrading the thermal performance [8].

1.2 Introduction to Heat transfer

Before understanding technique or real heat transfer process, one must understand the difference between the developing/entrance region and fully developed region for internal convective fluid flow through a duct.

When fluid enters a circular tube with uniform velocity profile at the inlet, velocity boundary layer develops on the surface of the tube and its thickness continuously increases along the direction of fluid flow. The area of uniform velocity decreases with the increasing boundary thickness. When the boundary layer merges the velocity profile as well as the temperature profile get to be invariant with regard to the position along the fluid flow and the shape acquires parabolic profile in nature. Figure 1 depicts the formation of fully developed region.

Consider the case of heating the fluid flow through a circular tube. Constant wall heat flux is applied on the outer surface of the circular tube. Thus heat flux move radially towards the centre of the tube by means of conduction through the tube wall. When the heat reach the solid-fluid interface, heat transfer from solid wall to the fluid particle near the wall takes place by conduction. Thus fluid particle near the wall acquire energy and its temperature increase and this particle move forward and transfer energy to its immediate neighbour fluid particle. In this manner fluid particle as it moves through the circular tube acquire energy and continuously increase in temperature takes place. But there will be variation in temperature in the radial direction with maximum near the wall and minimum at the centre of the tube as shown in Fig. 2. The temperature profile will be parabolic in the thermally fully developed region as can be seen in Fig. 2.

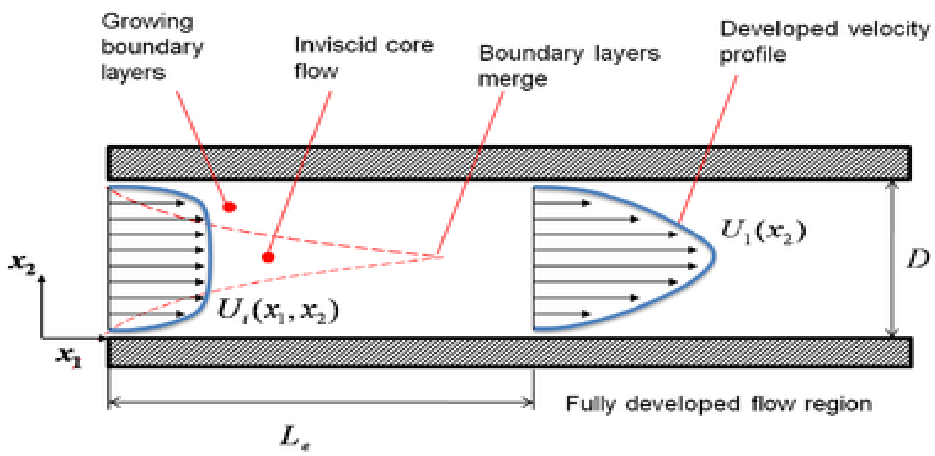

Figure 1: Hydrodynamic entry length in a circular tube

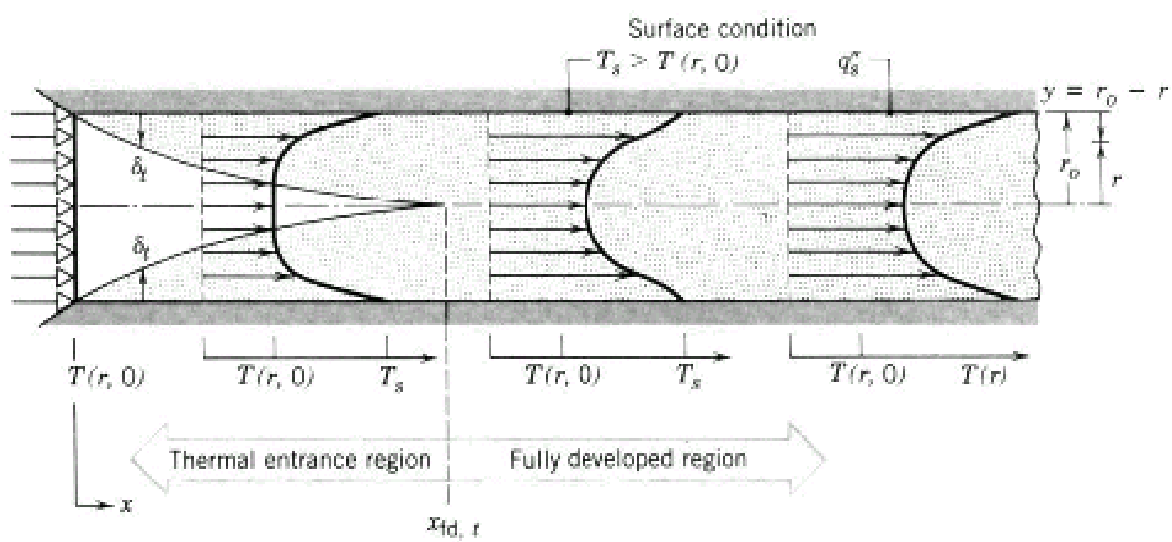

Figure 2: Thermal entry length in a circular tube

The applied heat flux (which is uniformly applied over the outer surface of the duct) is given by:

$$q'' = h\cdot(T_w - T_f)$$

The wall temperature can be calculated form the above equation as:

$$T_w = q''/h + T_f$$

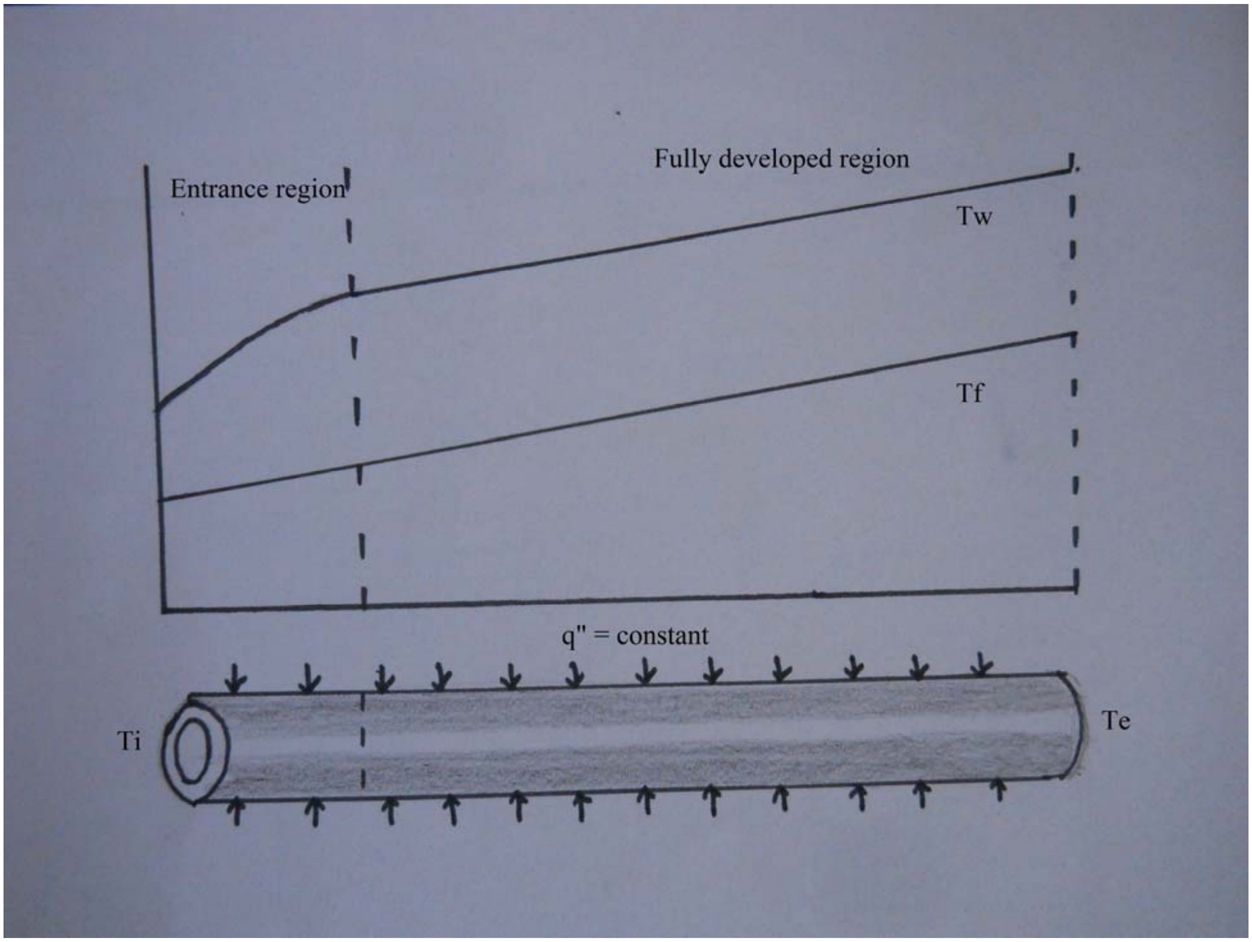

Figure 3: Variation of side wall temperature and bulk fluid temperature subjected constant heat flux

Variation of fluid and side wall temperature in the fluid flow direction of a circular channel is given constant heat flux around the wall [8].

As shown in FIG: wall temperature increases exponentially until it reaches fully developed region and then increases linearly in the direction of flow. It is assumed that all the fluid property remains constant. Constant heat flux is given at the wall of the circular channel. Heat transfer coefficient is kept constant throughout the axial length.

Chapter 2

LITERATURE SURVEY

LITERATURE SURVEY

Wang et al. [9] had done an experimental study of heat transfer in micro channel with pillar / pillars using air as working fluid. Area averaged temperature was measured by a 1×1 mm^2 resistance temperature detector (RTD), and data were collected over the range $100<Re<5600$. The micro channel with a pillar had a heat Transfer coefficient that was twice that of the channel without a pillar. Among the three geometric shapes of pillar studied, triangular pillar performed the best with $17.7<Nu<88.9$. Micro particle image velocimetry was used to measure the velocity field in the micro channel and turbulent kinetic energy (TKE) calculation provided a measure of flow mixing. It was shown that TKE is closely related to the thermal performance and can be used to predict the Nusselt number.

Tullius et al. [1] had dealt with micro fins in micro channel to upgrade microstructure geometry and amplify heat transfer dispersal through convection from a heated surface. Six pin fins shapes – ellipse, square, triangle, circle, diamond and hexagon are used in a staggered array and attached to the bottom heated surface of rectangular minichannel and analysed. Likewise, using a square pin fins, different channel clearance over fins are investigated to optimize the fin height of the fins with respect to that of the channel. Fin width and spacing are researched utilizing a proportion of fin width area to the channel width. Fin material is then varied to research the high temperature dissemination impacts. Triangular fins with bigger fin height, smaller fin width and spacing double the fin width maximizes the number of fins in each row and yields better performance. Correlations describing the Nusselt number and the Darcy friction factor are obtained and compared to previous ones from recent studies. These correlations for a minichannel are essential to maximizing the performance in small scale cooling apparatuses to keep up with future electronic advancements. Tullius et al. [1] considered four parameters - the tip clearance, the geometrical shapes, pin fin to channel height ratio, pin fin width and spacing, and pin fin material. Densely populated triangular pin fins with larger fin height and smaller fin width yield the best performance.

Montelpare and Ricci [10] examined heat transfer from a single heated pin fin with the aid of infrared thermography. They visualized the flow using ink tracers and related the thermal behaviour with the flow field. Among the four shapes (circular, square, triangular, and rhomboidal) tested, triangular r fin had the greatest heat transfer rate because the separation on the vertices of the triangular pin was strong, leading to a rigorous remixing in the wake behind the pin.

Zhong et al. [11] studied the effects on fins by taking different values of thermal conductivity on a micro channel. By increasing thermal conductivity, There is decrease in temperature and little pressure drop.

John et al. [12-13] analysed the effects of different shape of fins and deduce that the shape of fin depends upon the flow rate used in the system.

Reyes et al. [14] observed how fin clearance affect a micro channel and decided that due to fin clearance there is little decrease in thermal performance but it requires little power to supply fluid to the channel.

Vanapalli et al. [15] investigated micro channel with a pillar for pressure drop of gas by different pillar shapes. The pillars having lowest friction factor was investigated using nitrogen gas as the convection medium. Different types of shapes are tested and found out that pillars having sine-section gives lowest friction factor. Pillar structure having low pressure drop but with large wetted area are more effective.

Shafeie et al. [16] examined the density of minichannel with cylindrical fins. In case of laminar flow fins with lower density are the most efficient for measuring heat capacity and pressure drop. But if pressure drop increases, then it out weight the increase of heat removed.

Kosar et al. [17-18] found a relationship between friction factor across a number no low aspect ratio pin fin and also inspected the effects of pin fin aspect ratio, fin spacing, fin configuration and fin shape for different pressure drop. And determined that the current conventional correlations cannot be accurately captured by the micro scale interaction of the fins and fluid

Meis et al. [19] proved that thermal and hydrodynamic features of micro pin fin heat sinks are intensely affected by some factors like the tip clearance, end-wall effect, tip clearance, aspect ratio of the channels, the geometrical shape, the array configuration and the density of the pin fins.

Chapter 3

PROBLEM STATEMENT

3. DETAILS OF NUMERICAL STUDY

3.1 INTRODUCTION TO CFD

Computational fluid dynamics, abbreviated as CFD, is a part of fluid mechanics that uses mainly numerical methods and computerized algorithms to solve and analyse problems that involve the flow of fluids. Computers are being used to do the calculations required to simulate the interaction of fluids with surfaces that are defined by boundary conditions, and initial conditions. The Navier-Stokes equations form the basis of all CFD problems. In case of CFD, the geometry of the problem is first made. Then the volume of the fluid is quantified into discrete and definite cells which may be referred as the mesh. Then the modelling equations are all set up, boundary conditions defined. The simulation is then done iteratively so that the solution converges to a point. CFD may be used for both steady state and transient state analysis.

3.2 DESCRIPTION OF WORK

Here our main focus is to increase the heat transfer in a micro channel using micro fins. The flow in microchannels remains in laminar region due to smaller channel hydraulic diameter and lower flow rate. Conventionally turbulent flow causes higher heat transfer due to mixing of fluid particle along fluid flow. A rectangular channel carved on a solid substrate is considered in the study where constant heat flux is applied at the bottom of the substrate. Rectangular fin/fins are placed at the base of micro channel which increases the surface area as well as disturb the fluid flow, and causing more heat transfer. Before carrying out the numerical study certain assumptions are considered such as heat transfer through the solid liquid interface is assumed to be steady. Even the fluid flow rate is assumed to be constant. The flow is taken as laminar, incompressible and all the thermo physical properties are assumed as constant. The amount of heat loss by radiation and natural convection is neglected.

The numerical study includes increasing extensive use of rectangular micro channel. A three dimensional investigation using the ANSYS - fluent software is done to highlight the effect of conductivity ratio on the local Nusselt number which in effects the heat transfer rate.

It also highlights the difference in the rate of heat convection due to the increased Reynolds number to distinguish between the laminar flow and turbulent flow. First an ANSYS simulation is done to differentiate between the heat transfer enhancement with and without a fin.

At first the geometry of micro channel is generated in ANSYS 13 workbench and properly meshed. After that in set up window type of model is defined like laminar or turbulent, then material and fluid is selected as per requirement, here water liquid is taken as fluid. Heat flux is set 10,000 at the bottom wall, Reynolds number is set to 100 for laminar flow model, energy option is checked, and inlet temperature is set to 300℃. Operation condition is take as atmospheric pressure. Residual is set to 1e-06 for better convergence. Then program is initialized and iterated. The values of wall temperature, bulk mean temperature and heat fluxes are computed and collected at different point.

The experiment is carried out using different types of material using both laminar and turbulent flow. The list of material is given below.

Table 1: Thermo-physical properties of different materials used in the numerical study.

metal	**ρ (kg/m³)**	**Cp (J/kgk)**	**K_s (w/mK)**	**K_f(w/mK)**	**$k_{sf} = k_s/k_f$**
Aluminum	2719	871	202.4	0.61032	331.629
Silicon dioxide	2220	745	1.38	0.61032	21.9557
Nicrome	8400	420	12	0.61032	19.6611
Bronze	8780	355	54	0.61032	88.4781
Bismuth	9780	122	7.86	0.61032	12.87849
Zinc	7140	389	116	0.61032	190.0642
Ss 316	8238	468	13.4	0.61032	21.9557
Constantan	8920	384	23	0.61032	37.68515
Chromium steel	7822	444	37.7	0.61032	61.77087
Sulphur	2070	708	0.206	0.61032	0.337528
Steel	8030	502..48	16.27	0.61032	26.658

Then nusselt number is calculated using the following formula

$$Nu = (q'' \cdot D) / (k \cdot (T_w - T_f))$$

Again the heat transfer effect observed for the same material using different δ_{sf} values

Here $\delta_{sf} = \delta_s / \delta_f$

Two types of δ_{sf} value is taken 0.5 and 1.0

The geometry was created in ANSYS 13 workbench and iterated using proper terms and conditions as mentioned above. After iteration the wall temperatures, mean/fluent temperatures and corresponding heat flux at different points are retrieved and variation of nusselt number along axial length was plotted. The figure of work is given below

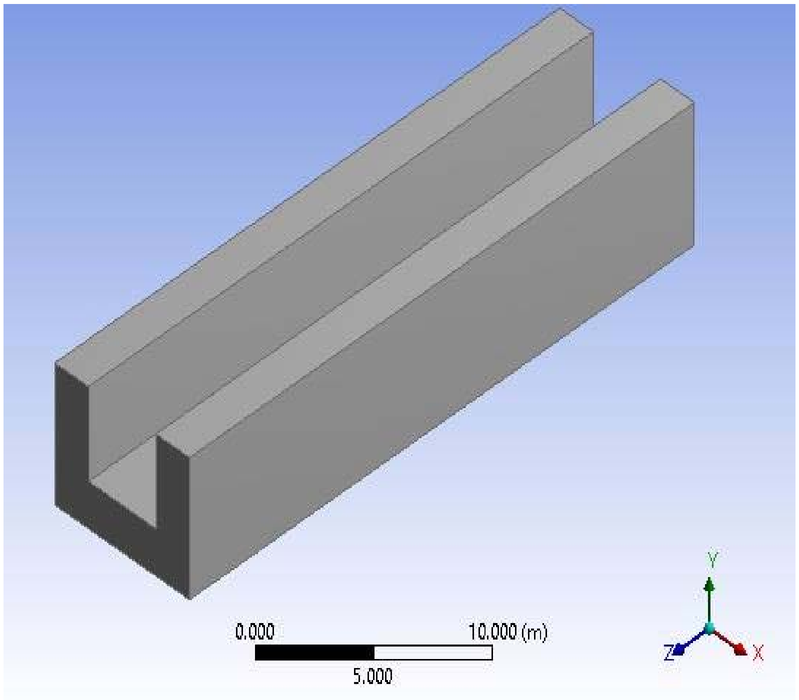

Figure 4: Isometric view of a simple micro channel

In this figure of simple micro channel length is 30 mm and fluid flow area (4×2) mm^2. Thickness of the wall is taken to be 2 mm.

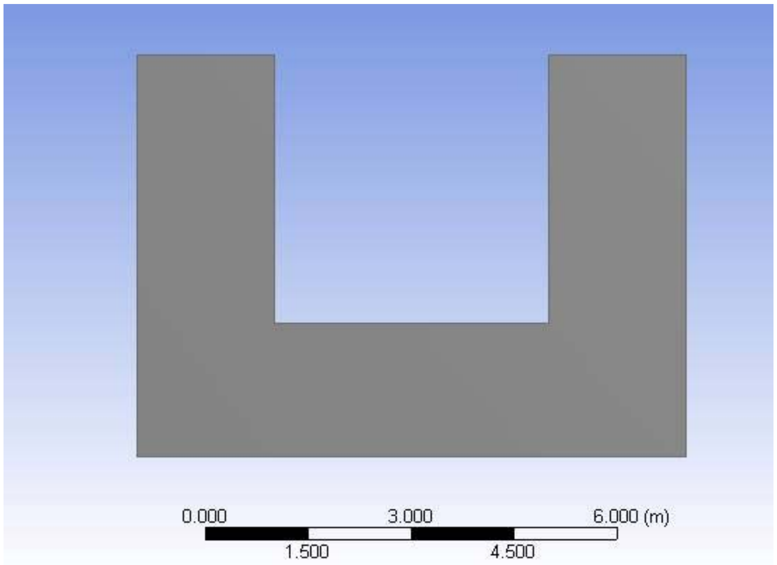

Figure 5: Cross-sectional view of a simple micro channel

Figure show the cross-sectional area of simple micro channel with fluid flow area (4×2) mm^2 and thickness of wall is 2 mm.

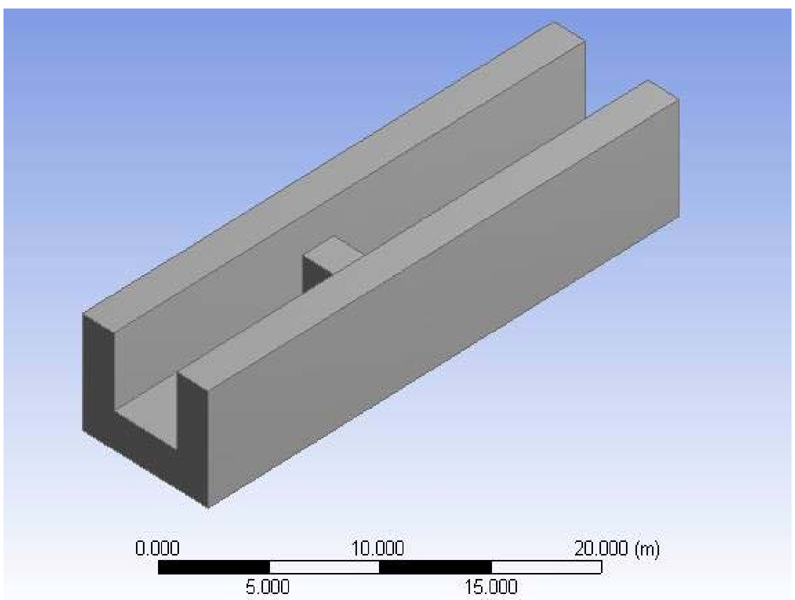

Figure 6: Micro channel with a hurdle

Figure show a micro channel with single hurdle. The dimensions of micro channel is taken same as simple micro channel. The dimensions of hurdle is (4×2×2) mm^3.

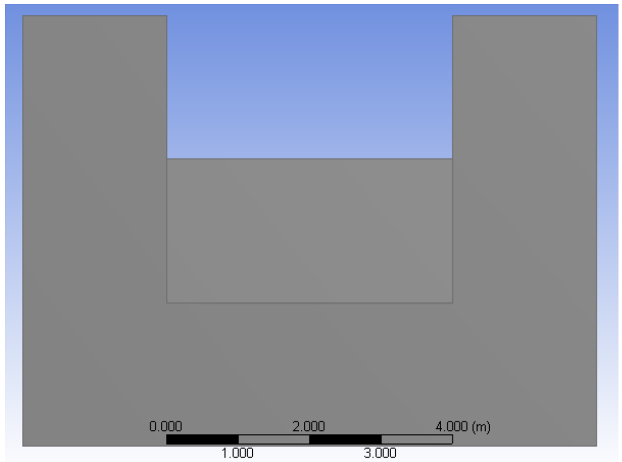

Figure 7: Cross-sectional view of micro channel using hurdle/hurdles

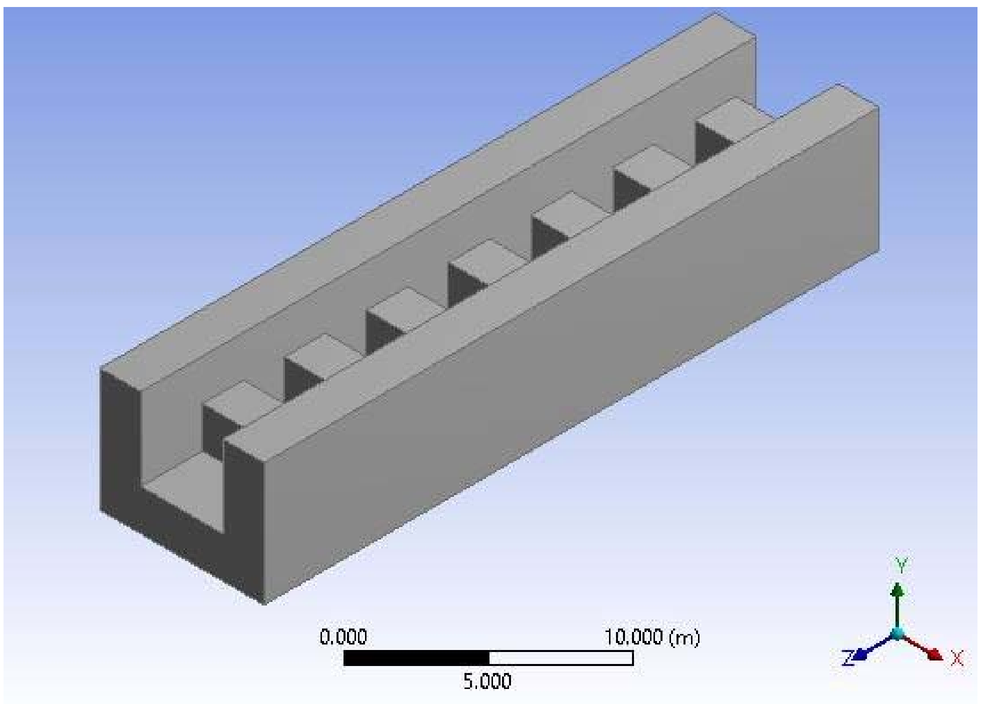

Figure 8: Micro channel with multiple hurdles

Figure shows a micro channel using multiple hurdle. The micro channel and hurdle dimensions are same as above. The hurdles are placed at 1.8 mm apart from each other. Hurdles are placed at point 1.9-2.1, 3.9-4.1, 5.9-6.1…27.9-28.1.

Chapter 4

RESULTS & DISCUSSION

RESULTS AND DISCUSSION

First, a square microchannel (0.4 mm × 0.4 mm) without any hurdle/micro fin is considered. The axial variation of wall temperature and bulk fluid temperature is plotted for aluminum (k = 202.4 W/m·K) as well as steel (k = 16.27 W/m·K) taking as substrate materials using laminar flow model as shown in Fig. 9.

In Fig. 9 it can be observed that the bulk fluid temperature is varying almost linearly between the inlet and outlet. Secondly, the difference between wall temperature and bulk fluid temperature becomes constant in the fully developed region for both steel and aluminium. This is as per conventional theory of constant heat flux boundary condition. The slope of the wall temperature for aluminium slightly decreased near the outlet. This indicates presence of axial back conduction in the aluminium solid substrate. This is because of higher k_{sf} in case of aluminium compared to steel substrate.

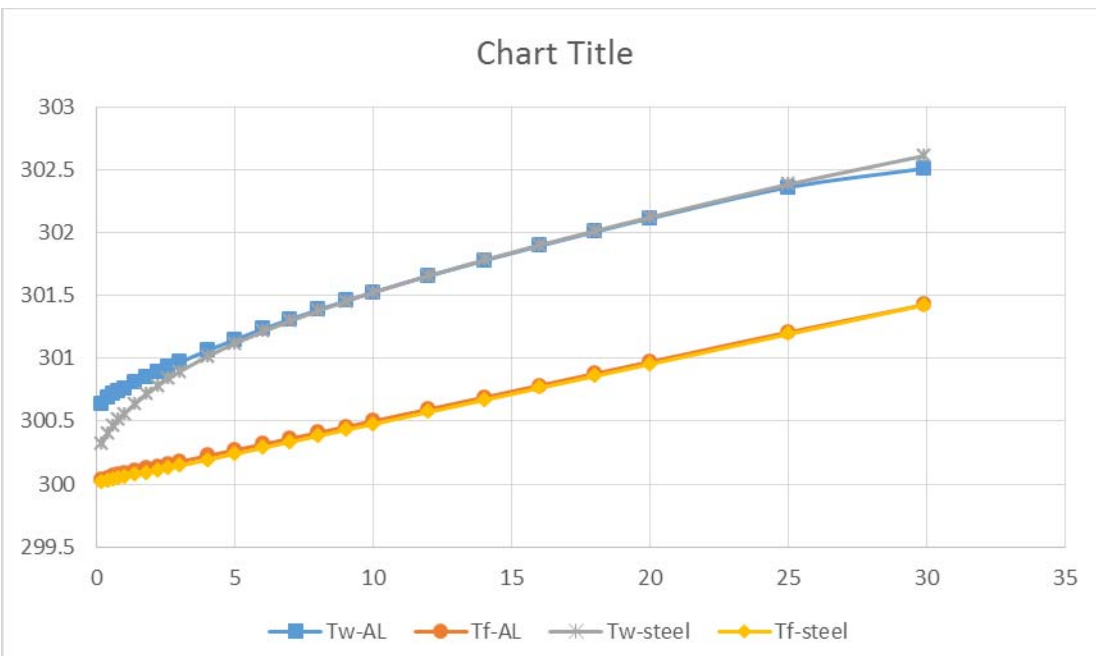

Figure 9: Axial variation of bulk fluid and wall temperature.

The local Nusselt number can be derived using the following expression

$Nu = (q''\cdot D_h) / (k \cdot (T_w - T_f))$

where T_w is the peripheral averaged local wall temperature, T_f is the average bulk fluid temperature, k is the solid substrate conductivity, D_h is the hydraulic diameter of the rectangular microchannel, and q" is the heat flux applied at the bottom of the substrate. The axial variation local Nusselt number corresponding to Fig.9 for bot steel and aluminium is shown in figure 10. The value of local Nu is almost same for both materials except near the inlet where the local Nu is slightly higher for steel compared to aluminium. This is due to lower k_{sf} and less axial wall conduction.

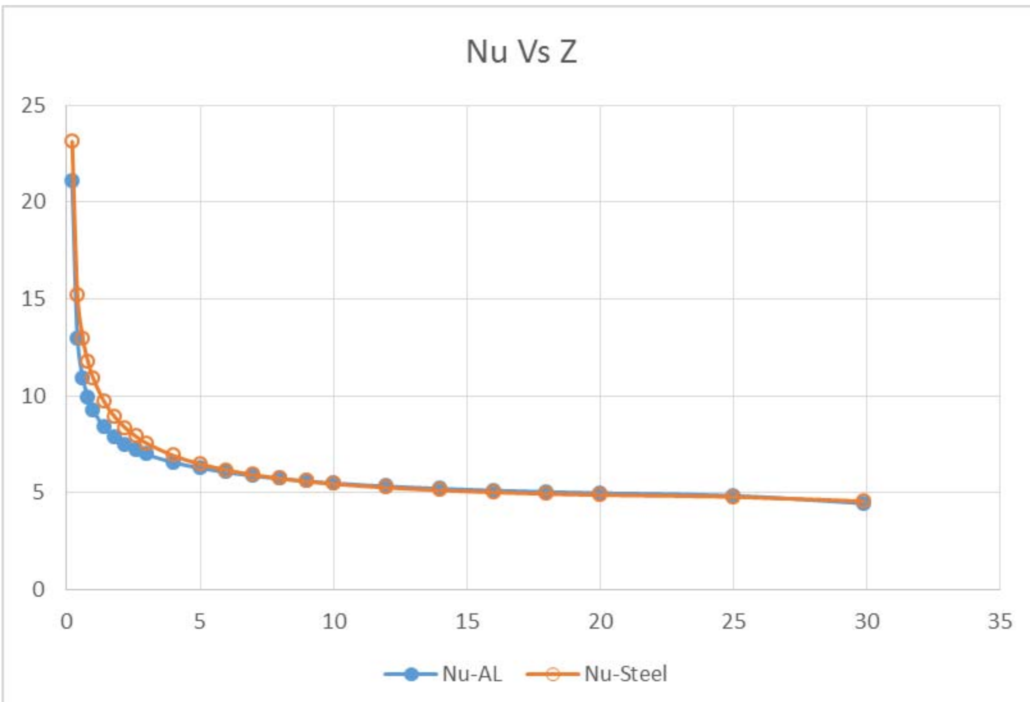

Figure 10: Local Nu along the axial length for a micro channel without fin.

Next, a hurdle or microfin is considered along the channel length at a distance of 14 mm from the channel inlet as shown in Fig. 5. The thickness of the hurdle is 0.2 mm and height of 0.2 mm. thus the hurdle position is between z = 14 mm to 14.2 mm. First a laminar model is used and the axial variation of Nusselt number is predicted. It is likely that presence of the hurdle will induce mixing and turbulence as fluid flows past this hurdle. In such a situation laminar model may not be able to predict correctly. Therefore again turbulent model is used for simulation and the local Nusselt number is predicted. A comparison of the local Nusselt number predicted using both laminar and turbulent model for steel (k = 16.27 W/mk) as the substrate material is presented in Fig. 11.

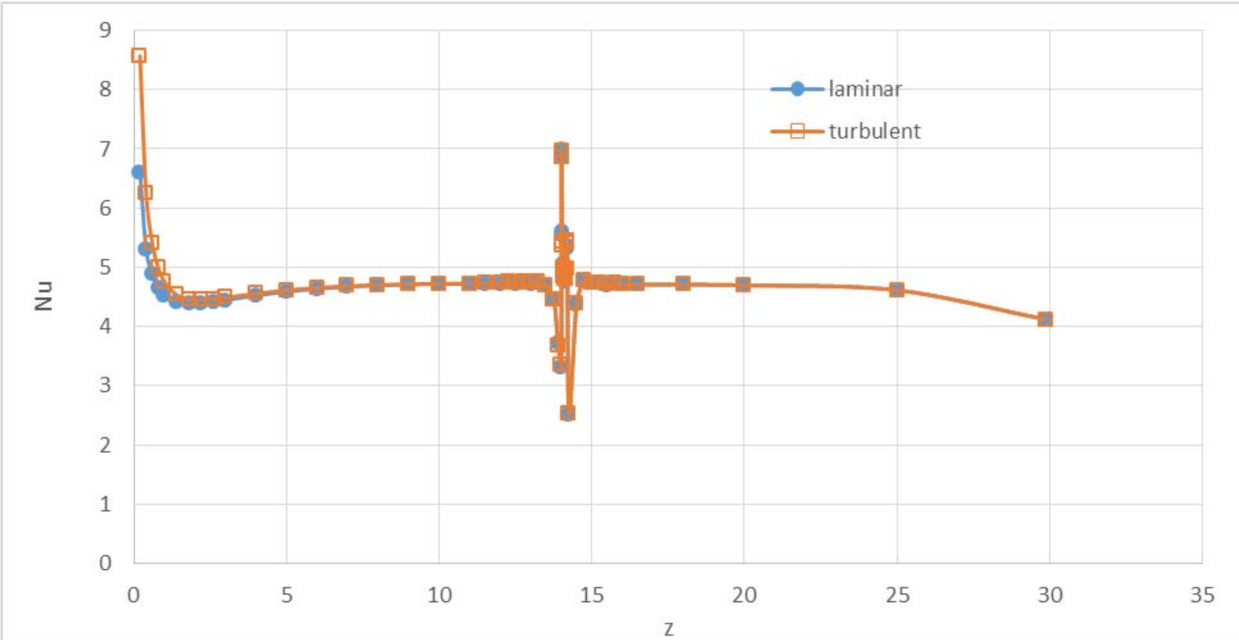

Figure 11: Local Nusselt number predicted using both laminar flow model and turbulent flow model when an obstacle is present across the channel with substrate made from steel.

As fluid flows past the obstacle, some kind of turbulence is created for Z = 14-15, thus the local Nu value deviates from the ideal value presented in Fig. 10. It can be observed that the predictions from both laminar and turbulent model are in perfect agreement with each other. The zoom view of the zone near the hurdle is shown in Fig. 12. It is to note that the hurdle lies in the zone z = 14 to 14.2. The local Nusselt number first increases and then decreases slightly but the local Nu values in this zone remain higher than the zone away from the hurdle. At z = 1.2 again local Nu value decreases as fluid leaves the hurdle.

Next, multiple hurdles are considered along the length of the channel. The spacing between two consecutive hurdles is decided based on the flow disturbance length observed in Fig 11-12. It can be observed in Fig. 13 that a repetitive pattern of what was observed in Fig. 11-12 is found. The zoom view of local Nu near two consecutive hurdles are shown in Fig. 14.

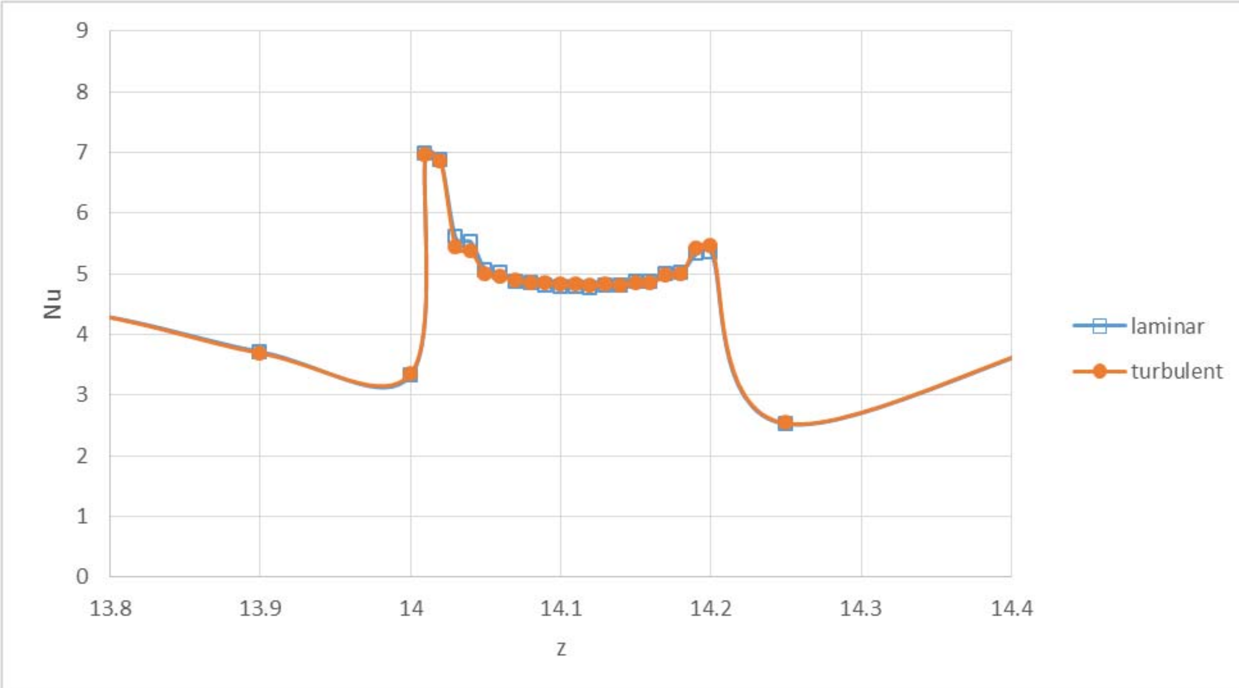

Figure 12 : Zoom view of local Nu presented in Fig. 11

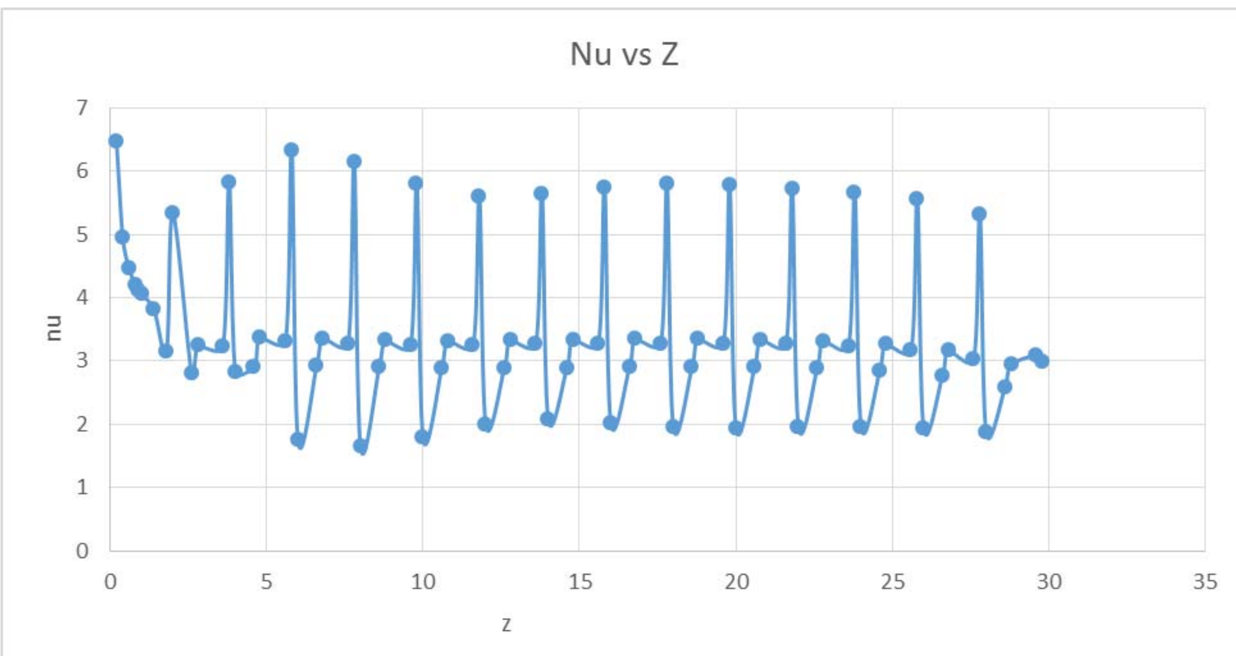

Figure 13: Variation of local Nusselt number for series of multiple hurdles (using laminar flow model).

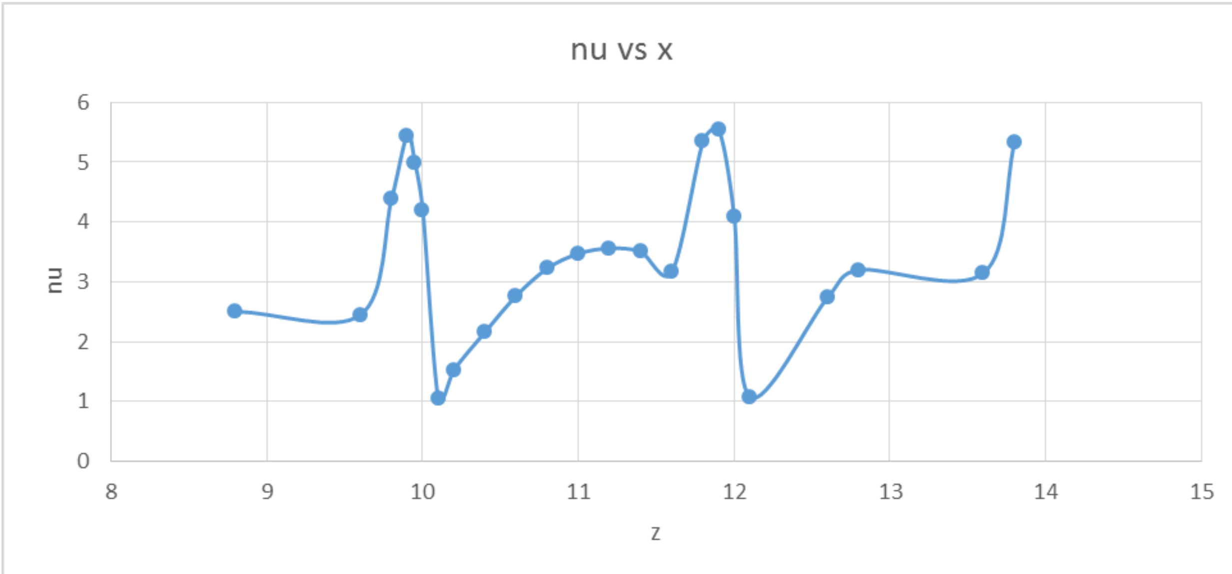

Figure 14: Nusselt number variation in two consecutive hurdles.

The two hurdles in Fig. 14 are present in the zone Z = 9.9-10.1, and Z = 11.9-12.1. As can be seen, a peak in local Nusselt number reaches and then then again decreases to a minimum and after wards increase towards next peak near the next hurdle.

From Fig. 14, the Nusselt number is significantly more around the hurdles, may be due to larger surface area which increases heat transfer. Secondly turbulence also assists in increasing heat transfer.

Next effect of substrate material on heat transfer is studied by considering different substrate material i.e. different values of k_{sf}. The local Nu for different k_{sf} having one hurdle is shown in Fig. 15. Here in Fig. 15 the thickness of wall (δ_s) below the channel to the height of channel (δ_f) ratio is taken as δ_{sf} = 0.5. And the flow model used is laminar flow model. Here it can be seen that the local Nu for sulphur is lowest at any axial location z including near the hurdle also. It also indicates that k_{sf} plays some role ib the heat transfer process. It is to note that sulphur have lowest k_{sf} among other materials considered in the numerical study. Similar graph is plotted for δ_{sf} = 1.0 in Fig. 16. In Fig. 16 it can be observed that the results are independent from k_{sf}. This means at higher substrate thickness, conductivity of substrate does not play any role in heat transfer process whereas at lower substrate thickness, k_{sf} play prominent role in heat transfer process.

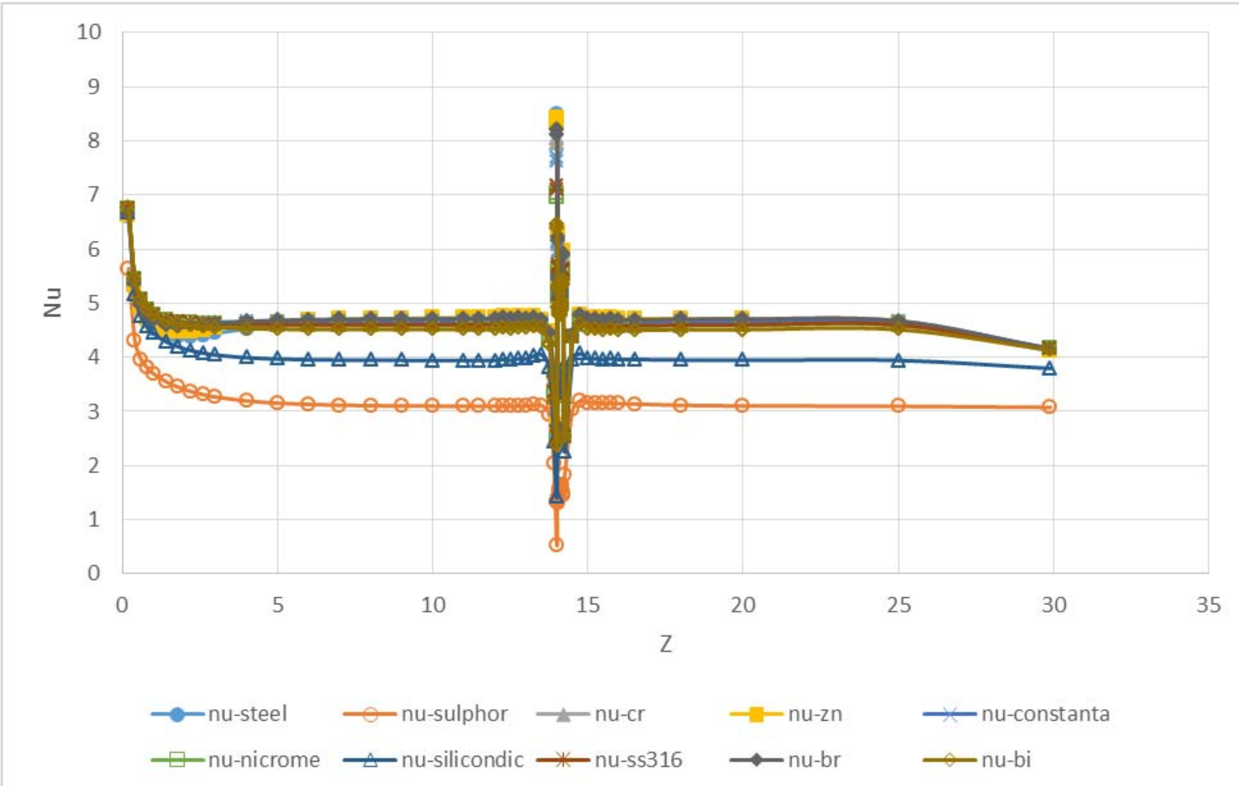

Figure 15: Local Nusselt number for different material for $\delta_{sf} = 0.5$ using laminar model.

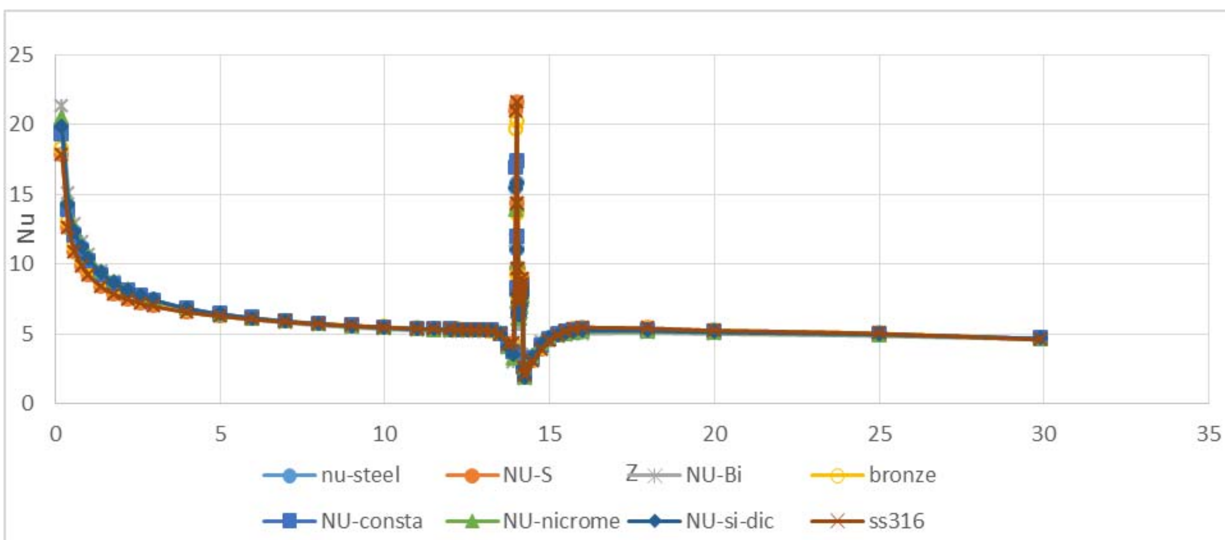

Figure 16: Local Nusselt number variation for different material using laminar model for $\delta_{sf} = 1.0$

Figure 17 shows comparison of local Nu for δ_{sf} = 0.5 and 1.0 for three different k_{sf} values zoomed near the position of single hurdle between Z = 14 and 14.2. Here it can be seen that for higher value of δ_{sf}, i.e δ_{sf} = 1.0, the local Nu is higher compared to lower value of δ_{sf}, i.e. δ_{sf} = 0.5 in the zone of hurdle.

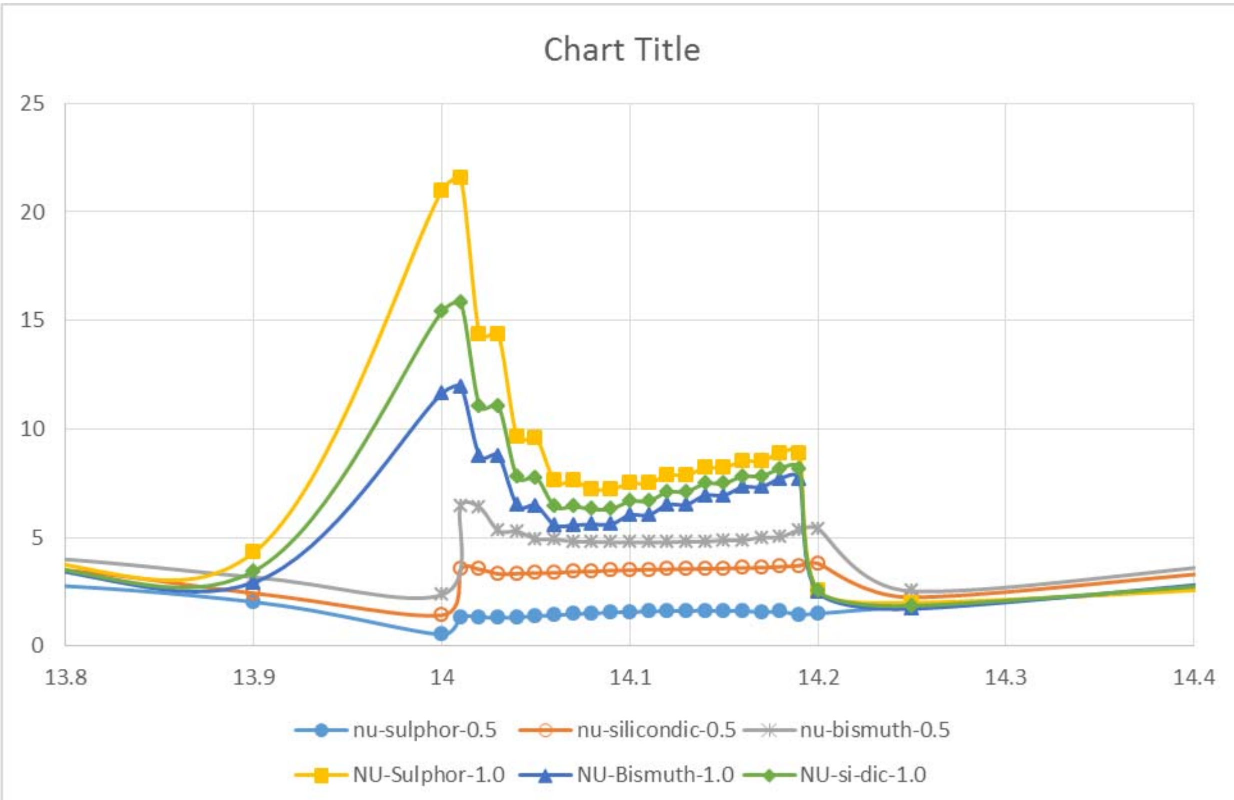

Figure 17: Comparison of 0.5δ_{sf} and 1.0 δ_{sf} of three different material around hurdle (laminar flow)

Chapter 5
CONCLUSION

CONCLUSION:

Heat transfer enhancement in a micro channel is analysed using fins. A number of different materials are used to study the effect of heat transfer. First heat transfer rate in a simple micro channel for laminar flow model is studied and after heat transfer rate using single fin and multiple fins is analysed using laminar flow model with different substrate thickness. Secondly, multiple fins in a single micro channel are also analysed.

The followings are concluded

- Heat transfer increases up to a peak value around fin and then decreases to normal level.
- Laminar model is found to be predicting at par with turbulent model. So for further analysis only laminar model used
- For lower substrate thickness, thermal conductivity found to play some role in heat transfer process with lowest Nu for lowest k_{sf}.
- For higher substrate thickness, effect of k_{sf} found to be negligible.
- Finally, thicker substrate found to give more heat transfer near micro-fin/hurdle compared to thinner substrate.

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