Numerical Research of Flow Heat Transfer through Micro Channel of Mems Device

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***Abstract*— Micro-channel has been increasingly applied in MEMS devices and electronics devices due to its higher efficiently heat dissipation rate, more compact size and lower cost. The present work demonstrates that the theoretical analysis of single phase micro channel has been investigated. To predict the behavior of micro-channel, the non-linear thermal hydraulic equations are developed namely mass, momentum and energy conservation, these equations are solved to predict the thermal physical properties and hydrodynamic behavior of the fluid in micro-channel.**

The configuration geometry of the problem has been made in design modular of commercial software ANSYS 15.0 Workbench and meshing of it has been done in ANSYS 15.0 Workbench fluent. Water is used as the working fluid in the micro-channel and the problem has been solved in ANSYS 15.0. To analyze the thermal behavior of micro-channel in force convection for various input power. Numerical simulation is carried out to calculate the wall temperature of the micro-channel, heat transfer coefficient (HTC) values etc. Next more simulation have been performed to investigate the parametric effect on the circular micro channel in terms of different diameter and length, and optimize the geometric parameters and coolant flow rate to maintain the critical temperature of the MEMS device (geometry and thermodynamic performance of micro-channel).

***Keywords*—cfd:-computational fluid dynamics, mems: micro-electrical and mechanical system, dw:- distilled water, mchx:-micro-channel heat exchanger, mchs:- micro-channel heat sink .**

I. INTRODUCTION

1.1GENERAL

The fast development of high density power electronic, with the expanding miniaturization of microelectronic devices and processing speed, thermal problems are more and more influencing overall electronic packaging and capacity of system. Problems relevant to heat dissipation of microelectronic devices have brought need of supplementary research and development. Microelectronic device performance and dependability are known to increase when effective temperatures are kept below 40°C [1].Keeping the temperature conditions in focus, during last two decades research on cooling of electronic devices has increased multi-fold.

Earlier, heat removal from electronic devices was done by using forced air convection. With the expansion in power and speed of electronic devices, the amount of heat to be removed has increased. This requires enhancement in heat transfer coefficient [2]. Owing to superior limits of achievable heat transfer coefficient, the other modes, namely pool boiling and flow boiling utilizing dielectric fluids started to get consideration for microelectronic device cooling. The methodology can be adopted in system integration efficiently.

Because of irrefutable merits like less coolant demands and small dimensions, heat sink becomes a highly efficient cooling device, resulting in micro machining technology being used increasingly. Micro-channel is one of the significant application areas of micro machining. The two study areas of micro-channel with reference to cooling are fluid flow and heat transfer. These two studies can earn extensive applications in both medical and engineering problems. Based on occurrence of boiling in micro-channel, classification of micro-channel is carried out [3].Parameters defining single phase and two phase managing regions are heat flux over the walls of the channel and flow rate of coolant. For constant heat flux condition, the coolant ought to stay in liquid state all through the micro-channel, hence flow leads to single phase. Liquid coolant interior the micro-channel should reach to its boiling point to keep low rate of flow. Flow boiling leads to two phase heat sink.

Abbreviations and Acronyms

ρ_w Water density, Z_m mass added, p static pressure, g gravitational force, $\vec{F}$External body force, $\bar{\bar{\tau}}$Stress Tensor, $\vec{v}$Velocity vector, M Molecular viscosity, I Unit tensor, E Energy, K_{eff} Effective Conductivity, K_t Turbulent Thermal Conductivity, J_j Diffusion Flux Of Species j, H Sensible Enthalpy Y_j Mass Fraction of Species j, φ Heat Flux, p_{in} Pressure Inlet, T_{in} Temperature Inlet, M Mass Flow Rate, D Diameter

- K pa – kilo Pascal ,kg/s –kilo gram per second ,w/m2 – watt per meter square, µm- micrometer

II. MODEL EQUATIONS FOR COMPUTATIONAL FLUID DYNAMICS

In this analysis, the single phase model is used for explaining the problem. This model will compute for the momentum, for continuity and for energy equation which have one transport equation and one for continuity, and then energy equations are resolved to analysis the thermal behavior of the arrangement. This model's theory is appropriated from the ANSYS Fluent 15.0.

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Single Phase Modeling Equations

The single phase model equations are equation of continuity, equation of momentum, and equation of energy (ANSYS Fluent 15.0). The velocity vector is computed by the continuity and momentum equations and temperature distribution is computed by the energy equation at the wall heat transfer coefficient. The equation of mass conservation, continuity equation, may be depicted as:

Mass Conservation Equation

The equation of mass conservation, equation of continuity, may be represented as follows:

$$\frac{\partial \rho_\omega}{\partial t} + \nabla.(\rho_\omega \vec{v}) = Z_m \quad (2.1)$$

Equation (2.1) is the general form of the equation of mass conservation and is authenticated for Incompressible and compressible flows. The causes Z_mis the mass added to the continuous Phase from the scattered second phase (e.g., because of vaporization of liquid droplets) and any user-defined causes.

Momentum Conservation Equation

Momentum conservation in an inertial (non-accelerating) remark frame is explained by:

$$\frac{\partial}{\partial t}(\rho_w \vec{v}) + \nabla.(\rho_w \vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho_w \vec{g} + \vec{F} \quad (2.2)$$

Computational Fluid Dynamics Model Equations

Where p is the static pressure, $\bar{\bar{\tau}}$ is the stress tensor (specified below), and $\rho_\omega \vec{g}$ and $\vec{F}$are the gravitational body force and external body forces (e.g., that arise from interaction with the dispersed phase), respectively. $\vec{F}$Additionally include other model vulnerable cause terms such as porous-media and user-defined causes.

The stress $\bar{\bar{\tau}}$ is given by:

$$\bar{\bar{\tau}} = \mu\,[(\nabla\vec{v} + \nabla v^{-t}) - \frac{2}{3}\nabla\vec{v}\, I\,] \quad (2.3)$$

Where μ is the molecular viscosity, I is the unit tensor, and the second term on the right hand side is the effect of volume dilation.

Energy equation

Equation of energy is explained by ANSYS FLUENT in the following form:

$$\frac{\partial}{\partial t}(\rho_w E) + \nabla\left(\vec{v}(\rho_w E + p)\right) = \nabla\left(K_{eff} - \nabla T - \sum_j h_j \vec{J}_j + (\overline{\overline{\tau_{eff}}}.\vec{v})\right) + s_h \quad (2.4)$$

Where K *eff*is the effective conductivity ($K+K_t$ *where* K_t is the turbulent thermal conductivity, described as per as turbulence model being utilized), and j_j is the diffusion flux of species J . The first three terms on the right-hand side of equation depicted as transfer of energy because of conduction, species diffusion, and viscous dissipation, commonly. s_hIncludes the heat of chemical reaction, and any other volumetric heat causes.

In Eq. (2.4)

$$E = h - \frac{p}{\rho} + \frac{v^2}{2}$$

Where sensible enthalpy h is defined for ideal gases as

$$h = \sum_j Y_j h_j$$

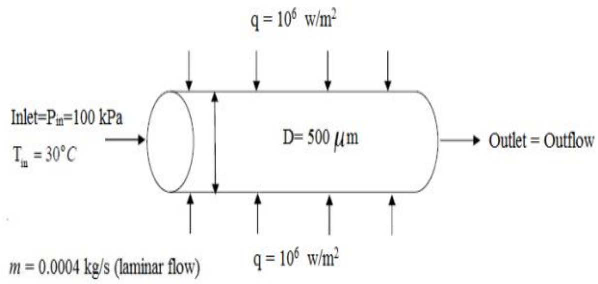
$Y_j$is the mass fraction of species j.

$$h_j = \int_{T_{ref}}^{T} C_{p.j}\, dT$$

$T_{ref}$is used as 298.15 K.

III. RESULT AND DISCUSSION

Schematic Diagram of circular micro channel



3.1 Schematic Diagram

Fig. 3.2 shows that the variation of density of water at laminar state about center line axial length of micro channel is constant due to single phase. There is no change in water density.

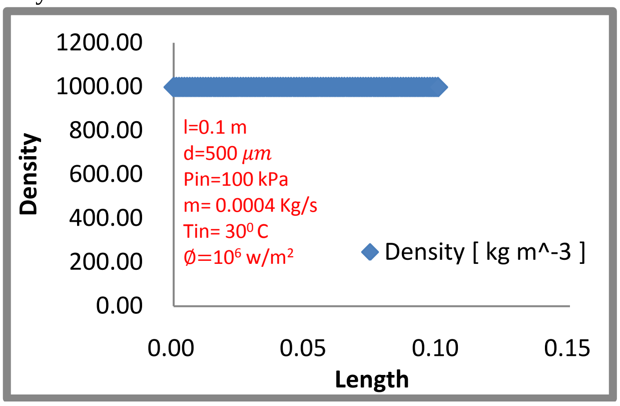


Fig. 3.2 Density profile at center line in circular micro channel

Fig.3.3 represent that the pressure of water is increasing along with the axis of the micro channel. It is showing pressure is increasing up to 30000 pa. The pressure of water liquid is representing at laminar regime of axial length micro channel's center line

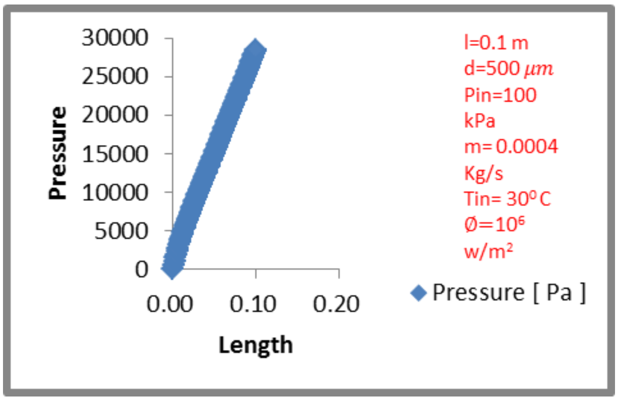


Fig.3.3 Pressure profile at center line in circular micro channel

Fig.3.4 Shows that the variation in water temperature at center line in laminar regime along with axial length of micro channel is gradually increasing from 303 k up to 333k. it is showing the linearly graph.

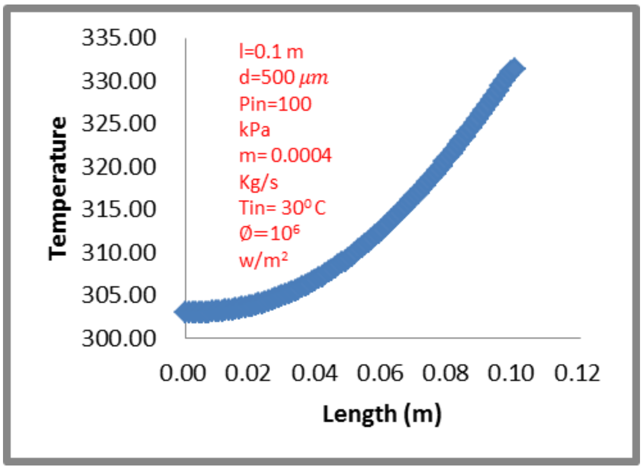


Fig.3.4 Temperature profile at center line in micro channel

Fig.3.5 Shows that enthalpy of water is gradually increasing along the axial length of micro channel .it is increasing from the point 20000 j kg-1 up to 140000.the enthalpy of water is showing of center line at laminar state with the axial length of micro channel.

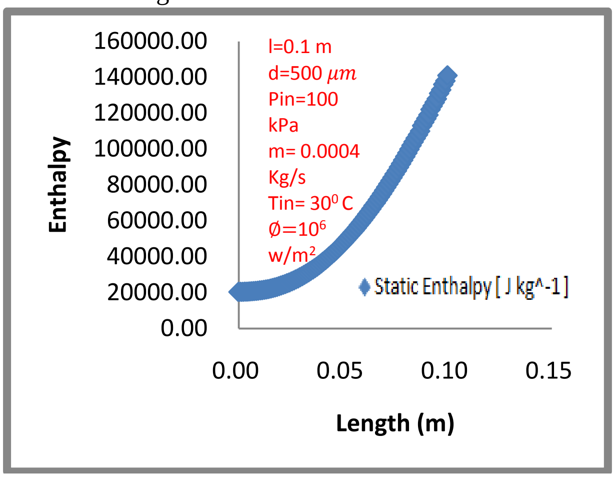


Fig.3.5 Enthalpy profile at center line in circular micro channel

Fig.3.6 Shows that velocity of water in laminar regime at center line in micro channel is increasing from 2.00 ms-1 up to 3.50 ms-1 then it becomes constant so it is showing initially get the fully developed region

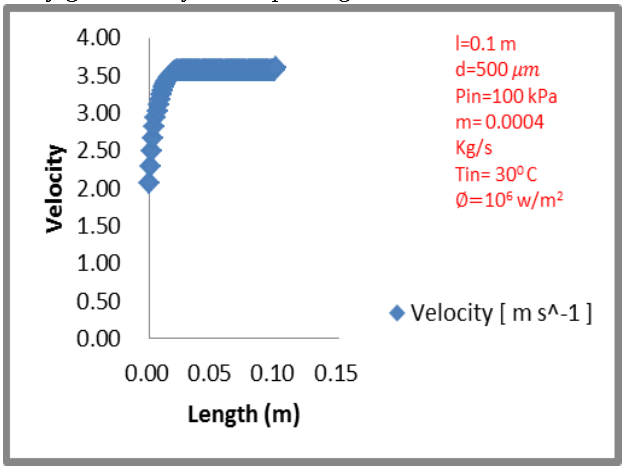


Fig.3.6 Velocity profile at center line in circular micro channel

Fig.3.7 Shows that the Reynolds number of water is gradually increasing at laminar regime of axial length of micro channel's center line. It increase from 140 up to 250 then it becomes constant along with the axial length of micro channel. Reynolds number is representing such as velocity graph because Reynolds number is directly proportional to velocity.

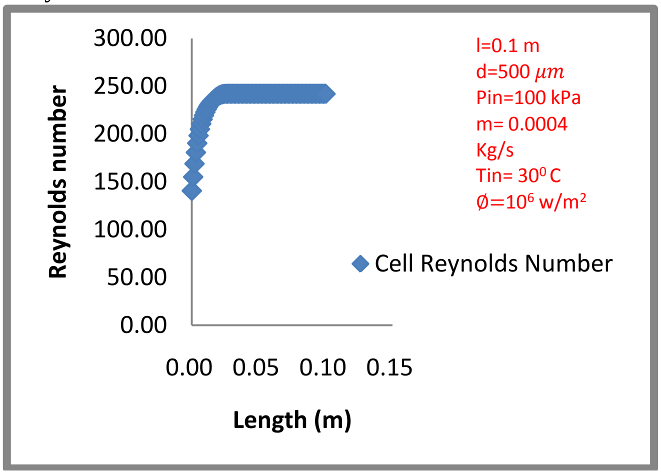


Fig.3.7 Reynolds number profile at center line in circular micro channel

Analyzed the parametric study about thermal behavior of water liquid, when the heat flux at wall of different diameter of circular micro channel is 106 w/m2.

EFFECT OF DIFFERENT DIAMETER AT CIRCULAR MICRO CHANNEL

Fig.3.8 That represent that the pressure of water is increasing along with the axis of the micro channel with different diameter of micro channel. The pressure of water liquid is representing at laminar regime of axial length micro channel's center line with different diameter such as : 500 micro diameter is increasing from 0.00 up to 28515 pa then 400 micro diameter is increasing from 0.00 up 69571 pa then 600 micro diameter is increasing from 0.00 up to 14658 pa. Figure is showing that the higher increasing in 400 micro diameter then 500 micro diameter then 600 micro diameter.

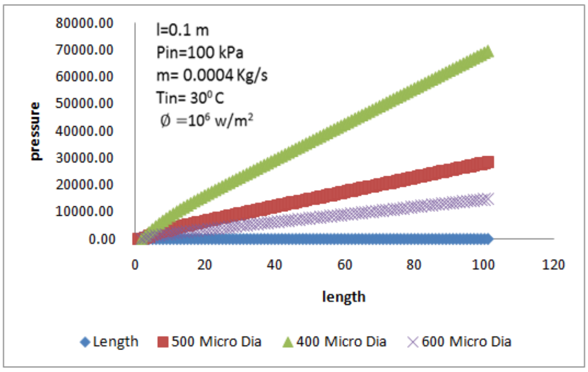


Fig.3.8 Pressure profile at center line in circular micro channel with different diameter

Fig.3.9 Shows that the Reynolds number of water is gradually increasing at laminar regime of axial length of micro channel's center line. With the different diameter of micro channel is showing 500 micro diameter Reynolds number is 241. Then 400 micro diameter Reynolds number is 302 and then 600 micro diameter Reynolds number is 122. Here represent that greater increasing of Reynolds number is : 400 micro diameter then 500 micro diameter,600 micro diameter.

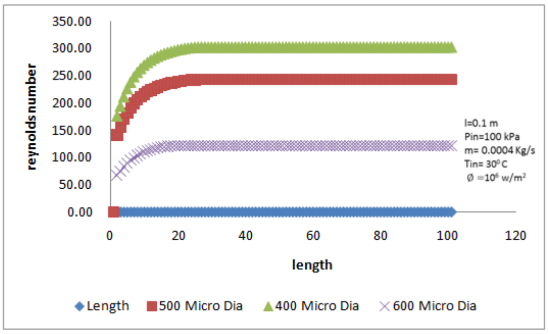


Fig.3.9 Reynolds number profile at center line in circular micro channel with different diameter

Fig.3.10 Shows that the variation in water temperature at center line in laminar regime along with axial length of micro channel .it is showing higher increasing in different diameter of micro channel such as 500 micro diameter is 331k, then 400 micro diameter is 325k , then 600 micro diameter is 320.So higher temperature of water in 500 micro diameter then 400 micro diameter then 600 micro diameter of circular micro channel.

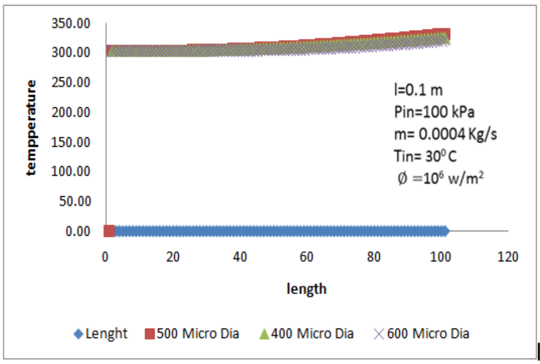


Fig.3.10 Temperature profile at center line in circular micro channel with different diameter

Fig.3.11 that velocity of water in laminar regime at center line in micro channel higher increasing in that 400 micro diameter 6 ms-1 then 500 micro diameter 3.6 ms-1 then 600 micro diameter 2.62 ms-1 then it becomes constant so it is showing initially get the fully developed region. Here represent the higher velocity in 400 micro diameter then 500 micro diameter then 600 micro diameter.

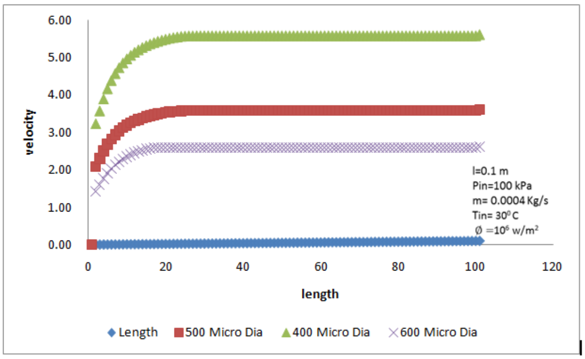


Fig.3.11 Velocity profile at center line in circular micro channel with different diameter

Analyzed the parametric study about thermal behavior of water liquid, when the heat flux at wall of different length of circular micro channel is 106 w/m2.

EFFECT OF DIFFERENT LENGTH AT CIRCULAR MICRO CHANNEL

Fig. 3.12 That represent that the pressure of water is increasing along with the axis of the micro channel with different length of micro channel. The pressure of water liquid is representing at laminar regime of axial length micro channel's center line with different diameter such as : 0.1 m length is increasing from 0.00 up to 28515 pa then 0.2 m length is increasing from 0.00 up 55642 pa then 0.3 m length is increasing from 0.00 up to 80895 pa. Figure is showing that the higher increasing in 0.3 m length then 0.2 m length then 0.1m.

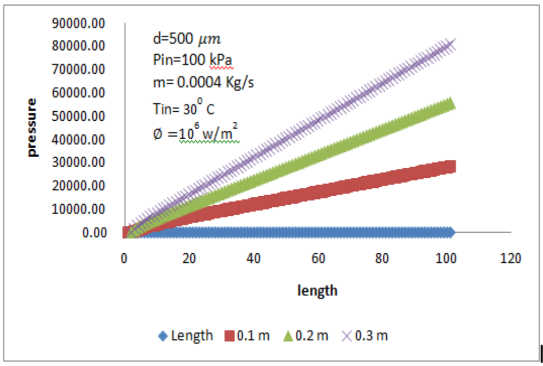


Fig. 3.12 Pressure profile at center line in circular micro channel with different length

Fig.3.13 shows that the Reynolds number of water is gradually increasing at laminar regime of axial length of micro channel's center line. With the different length of micro channel is showing 0.1 m length Reynolds number is 241. then 0.2 m length Reynolds number is 240.80 and then 0.3 m length Reynolds number is 276. here represent that higher increasing in Reynolds number is : 0.3 m length then 0.1 m length then 0.2 m length.

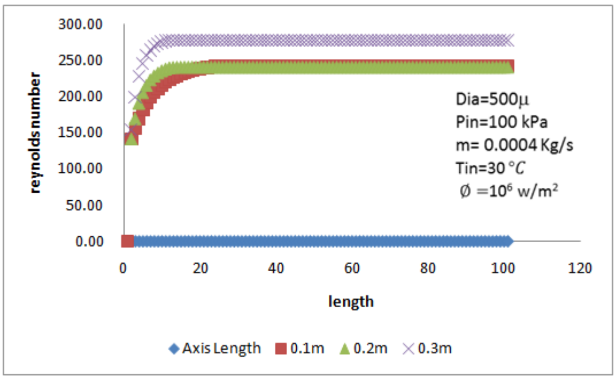


Fig.3.13 Reynolds number profile at center line in circular micro channel with different length

Fig.3.14 Shows that the variation in water temperature at center line in laminar regime along with axial length of micro channel .it is showing increment of temperature in different length of micro channel such as 0.3 m length is 480k, then 0.2 m length is 403k , then 0.1 m is 331 k. so higher increasing of water temperature in 0.3 m then 0.2 m then 0.1 m length of circular micro channel.

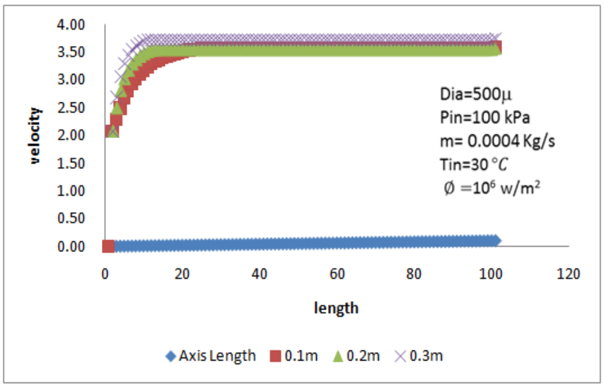


Fig.3.14 Temperature profile at center line in circular micro channel with different length

Fig.3.14 That velocity of water in laminar regime at center line in micro channel is greater increasing in 0. 3 m length is 3.74 ms-1 then 0.1m length 3.60 ms-1 then 0.2 m length 3.58 ms-1 then it becomes constant so it is showing initially get the fully developed region .

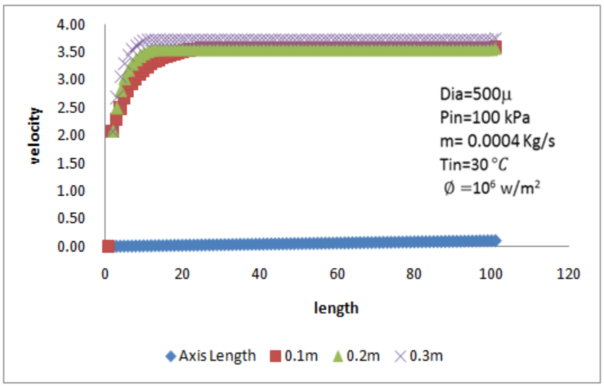


Fig.3.14 Velocity profile at center line in circular micro channel with different length

Analyzed thermal behavior of water liquid, when the heat flux at wall of circular micro channel is 2X106 w/m2

Effect of heat flux is 2x106 used at wall of circular micro channel

Fig.3.15 Represent that the pressure of water is increasing along with the axis of the micro channel. It is showing pressure is increasing up to 30000 pa. The pressure of water liquid is representing at laminar regime of axial length micro channel's center line.

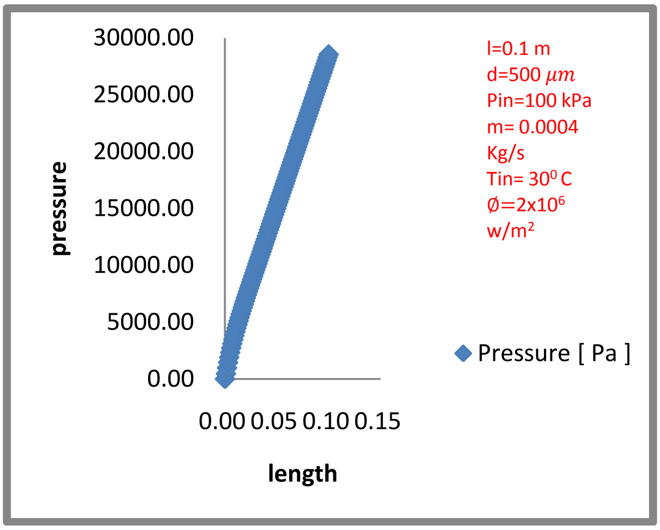


Fig.3.15 Pressure profile at center line in circular micro channel

Fig.3.16 Shows that the Reynolds number of water is gradually increasing at laminar regime of axial length of micro channel's center line. It increase from 140 up to 250 then it becomes constant along with the axial length of micro channel.

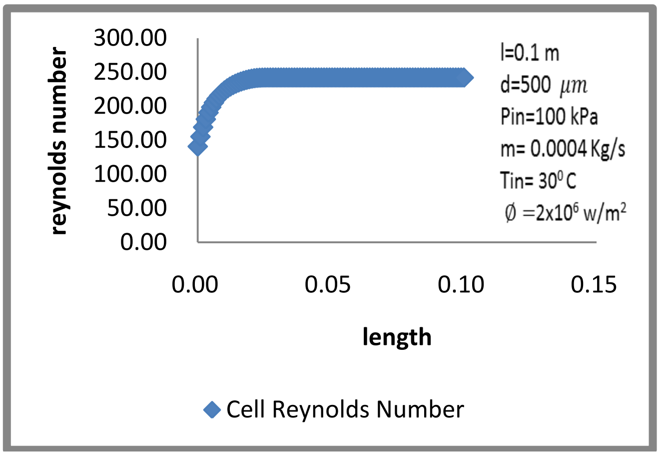


Fig.3.16 Reynolds number profile at center line in circular micro channel

Fig 3.17 Shows that the variation in water temperature at center line in laminar regime along with axial length of micro channel is gradually increasing from 303 k up to 359k it is showing 560c temperature.

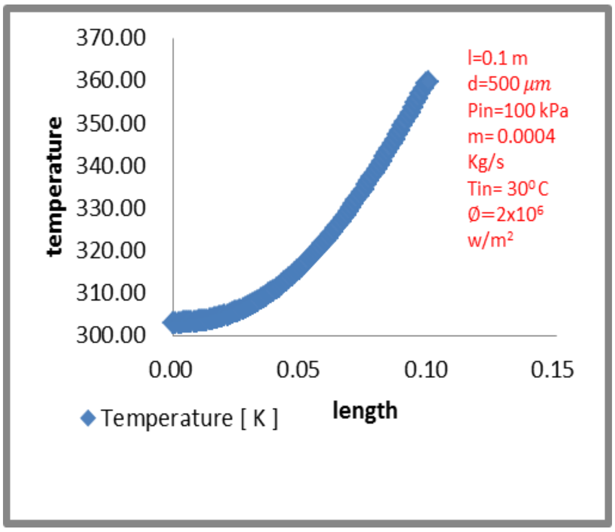


Fig 3.17 Temperature profile at center line in micro channel

Fig.3.18 Shows that velocity of water in laminar regime at center line in micro channel is increasing from 2.00 ms-1 up to 3.50 ms-1 then it becomes constant so it is showing initially get the fully developed region .

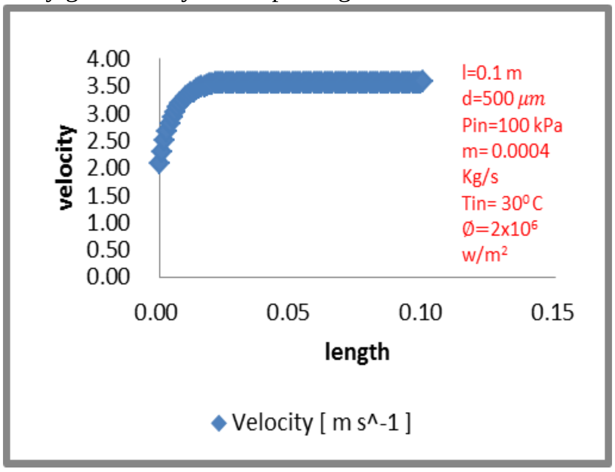


Fig.3.18 Velocity profile at center line in circular micro channel

Analyzed thermal behavior of water liquid, when the heat flux at wall of circular micro channel is 3X106 w/m2

Effect of heat flux is 3x106 used at wall of circular micro channel

Fig.3.19 Represent that the pressure of water is increasing along with the axis of the micro channel. It is showing pressure is increasing up to 30000 pa. The pressure of water liquid is representing at laminar regime of axial length micro channel's center line.

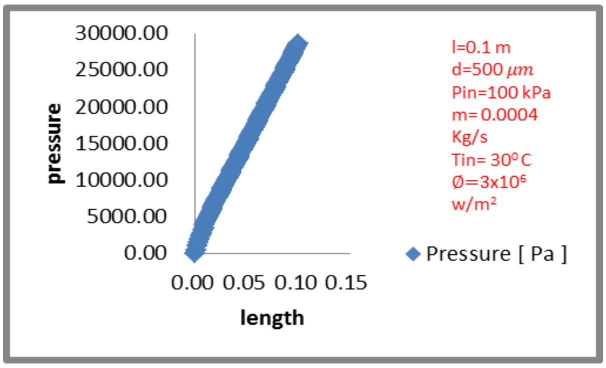


Fig.3.19 Pressure profile at center line in circular micro channel

Fig.3.20 Shows that the Reynolds number of water is gradually increasing at laminar regime of axial length of micro channel's center line. It increase from 140 up to 250 then it becomes constant along with the axial length of micro channel.

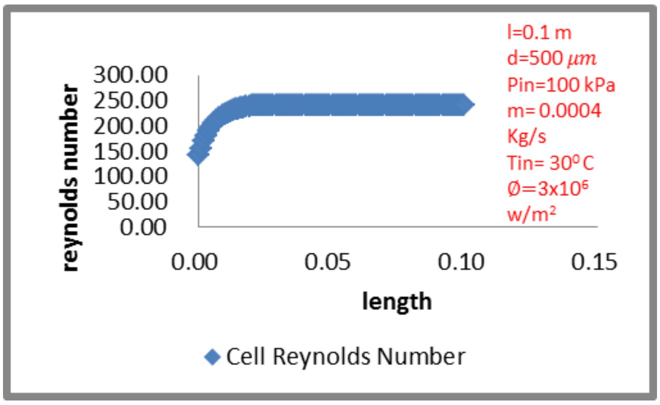


Fig.3.20 Reynolds number profile at center line in circular micro channel

Fig.3.21 Shows that the variation in water temperature at center line in laminar regime along with axial length of micro channel is gradually increasing from 303 k up to 388k it show the linearly and it show 850c temperature.

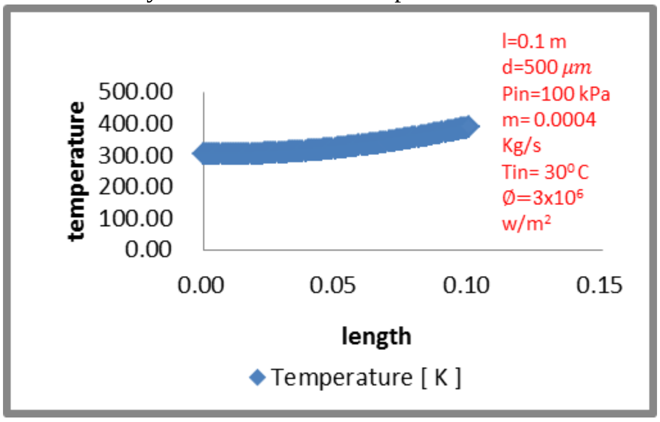


Fig.3.21 Temperature profile at center line in micro channel

Fig.3.22 Shows that velocity of water in laminar regime at center line in micro channel is increasing from 2.00 ms-1 up to 3.50 ms-1 then it becomes constant so it is showing initially get the fully developed region .

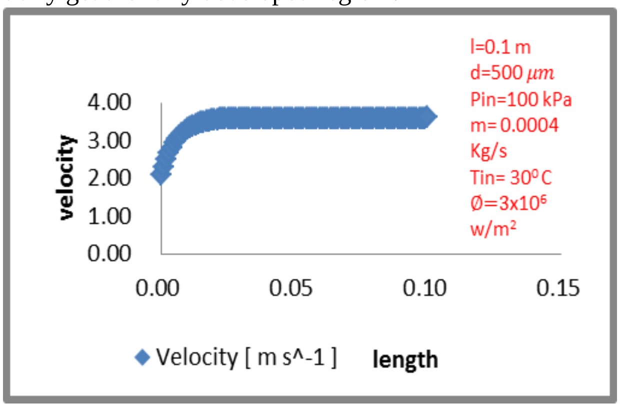


Fig.3.22 Velocity profile at center line in circular micro channel

5.2. Conclusion from simulation through Ansys 15.0

Now discuss about simulation performed on ansys15.0 of circular micro camel. First discuss about the thermal behavior of water liquid when the heat flux 106w/m2 used wall of circular micro channel

- Density variation does not change along the axis length of micro channel.
- Pressure is increase with the axis length of micro channel.
- Temperature is linearly increase along with axis length of micro channel.
- Velocity and Reynolds number is initially increased along with axis length of micro channel then it's becomes constant

Now we discuss about parametric study of circular micro camel, the effect of different diameter are-

- Pressure is highest in 400 □ m then 500 □ m then 600 □ m diameter of circular micro channel
- Temperature is highest in 500 □ m then 400 □ m then 600 □ m diameter of circular micro channel
- Reynolds number is highest in 400 □ m then 500 □ m then 600 □ m diameter of circular micro channel
- Velocity is highest in 400 □ m then 500 □ m then 600 □ m diameter of circular micro channel

Now we discuss about parametric study of circular micro camel, the effect of different length are-

- Pressure is highest in 0.3 m then 0.2 m then 0.1 m length of circular micro channel
- Temperature is highest in 0.3 m then 0.2 m then 0.1 m length of circular micro channel
- Reynolds number is highest in 0.3 m then 0.1 m then 0.2 m length of circular micro channel
- Velocity is highest in 0.3 m then 0.1 m then 0.2 m length of circular micro channel

Now we discuss about the thermal behavior of water liquid when the heat flux 2x106w/m2 and 3x106w/m2 used wall of circular micro channel

- Pressure is increase with the axis length of micro channel.
- Temperature is linearly increase along with axis length of micro channel. When used heat flux 2x106w/m2 the temperature is 359 k and heat flux 3x106w/m2 the temperature is 388 k
- Velocity and Reynolds number is initially increased along with axis length of micro channel then it's becomes constant

5.3. Future Scope:

- We can extend this work in two phase analysis.
- Optimized the length and diameter according to heat dissipation rate
- Develop empirical relationship between power and mass flow rate to maintain the device temperature below critical temperature.
- We can develop tool to predict the behavior of micro channel in various commercial software like MATLAB, FORTRAN and python etc.
- We can observe the exact value of heat transfer coefficient (HTC) in laminar as well as turbulent flow by experimentally and numerical.
- These are the few works till now unresolved.

VI. ACKNOWLEDGMENT

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