COMSOL
CONFERENCE
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NUMERICAL STUDY OF MICROSCALE HEAT SINKS USING DIFFERENT SHAPES & FLUIDS

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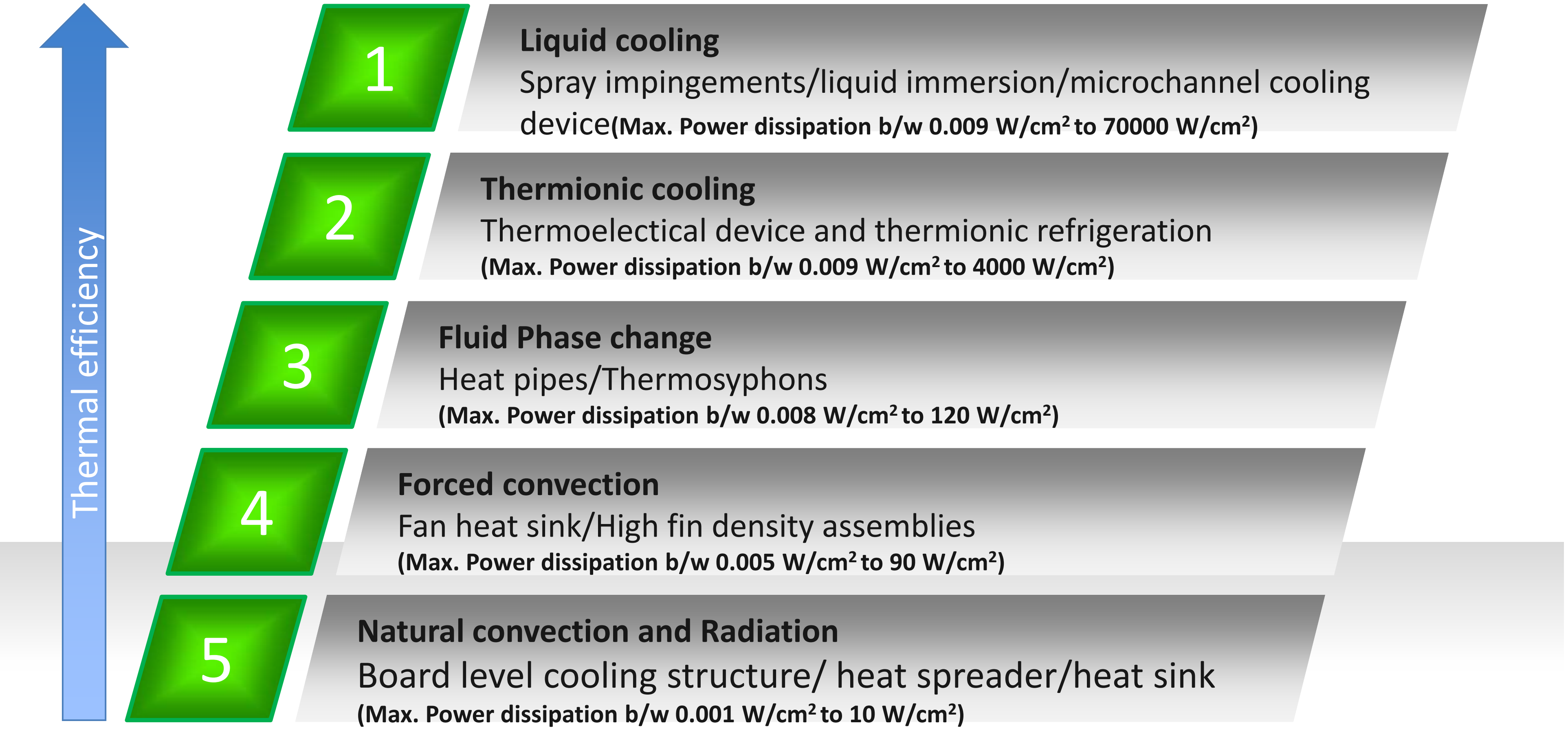
Thermal Solution



1

Liquid cooling

Spray impingements/liquid immersion/microchannel cooling device**(Max. Power dissipation b/w 0.009 W/cm^2 to 70000 W/cm^2)**

2

Thermionic cooling

Thermoelectical device and thermionic refrigeration

(Max. Power dissipation b/w 0.009 W/cm^2 to 4000 W/cm^2)

3

Fluid Phase change

Heat pipes/Thermosyphons

(Max. Power dissipation b/w 0.008 W/cm^2 to 120 W/cm^2)

4

Forced convection

Fan heat sink/High fin density assemblies

(Max. Power dissipation b/w 0.005 W/cm^2 to 90 W/cm^2)

5

Natural convection and Radiation

Board level cooling structure/ heat spreader/heat sink

(Max. Power dissipation b/w 0.001 W/cm^2 to 10 W/cm^2)

How does Microchannel works

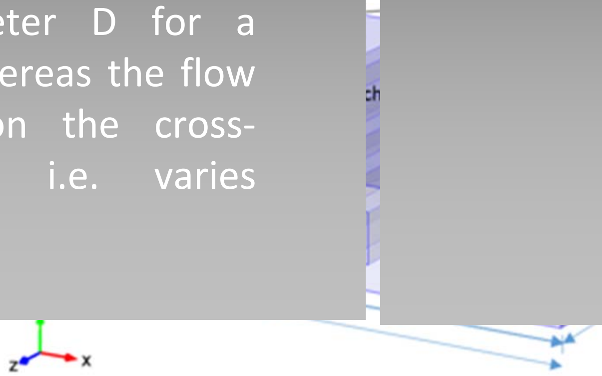
Physical Principle of Microchannel

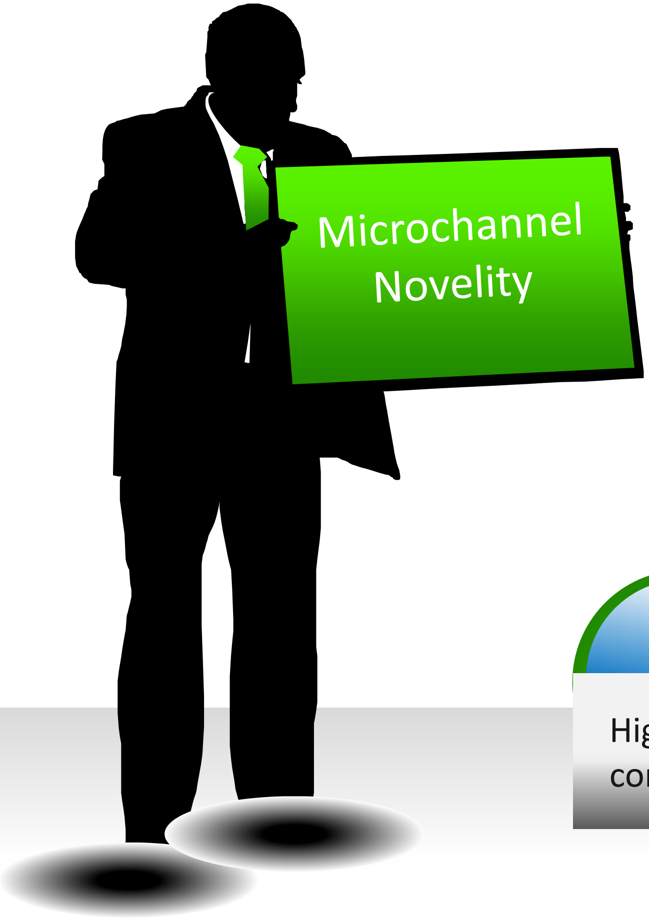
A channel mainly serves the objective to bring a fluid in contact with the channel walls and remove fluid away from the walls as the transport process is accomplished. The rate of the transport process depends on the surface area, which varies with the diameter D for a circular tube, whereas the flow rate depends on the cross-sectional area, i.e. varies linearly with D^2.

Where it can be embeded

Micro channels are most commonly used for indirect liquid cooling of IC’s and may be:

- Machined into the chip itself.
- Machined into a substrate or a heat sink and then attached to a chip or array of chips.





1. High performance cooling with fully integrated, efficient, rugged and compact design.
2. Reduction of overall cost of the system.
3. The cooling system draws least power from the system.

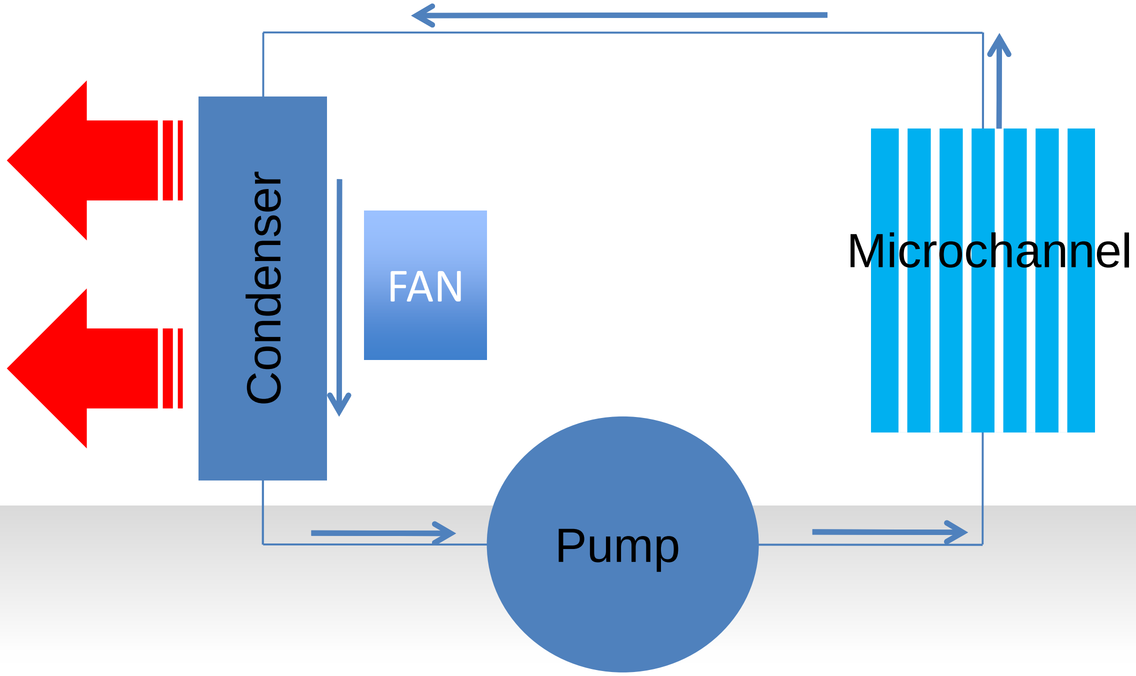
Microchannel Objectives

1. Development of High performance cooling technology for Strategic / Smart Systems in the range of 100-1000 W/cm^2
2. Optimization of Weight, Volume, Cost & Reliability of Strategic/Smart system depending upon heat load.
3. Optimization of different geometrical parameters for High Performance of the system

Schematics of Microchannel Active cooling & characteristics

Characteristics

- High Heat Transfer Coefficient
- High Temp. Gradient
- Lowest pressure loss
- Lesser Moving Parts with high reliability
- Minimal Pumping Power
- Minimal Thermal Resistance
- Better use of Thermal Conductivity & Specific Heat
- Fully Closed
- True Single Phase



Strategies

1. Minimizing impact of local hot spots by improving heat spreading.
2. Increasing the power dissipation capability of the thermal solution.
3. Expanding the thermal envelope of the systems.
4. Developing thermal solutions that meet cost constraints imposed by business consideration.
5. Developing solutions that fit within form factor considerations of the chasis

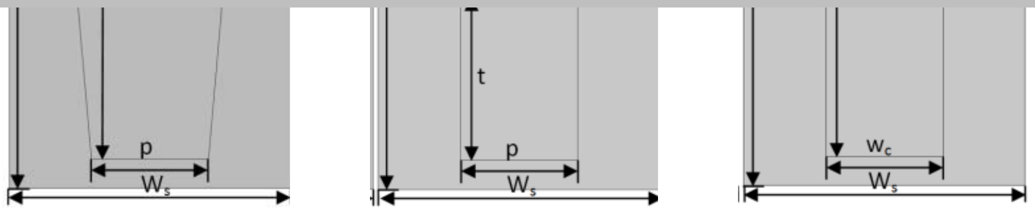
High Performance Cooling

Physical Parameter required

- Flow should be efficient & heat transfer should be maximum.
- Minimum Thermal resistance should be there.
- The Pumping power should be as less as possible & should be near passive systems.

Aside problem can be solved using

- Suitable Height of the channel
- Suitable Width of the channel
- Different cross-section geometry
  - Trapezoidal ,Rectangular & combined geometry
- Aspect Ratio(AR) of the channel
  - AR=height/width of flow channel



Selection of Liquid for cooling and Important parameters

Physical Parameter required

- Low Density.
- Ultra Low Freezing Point
- High Heat Carrying Capacity
- High Thermal Conductivity
- High Boiling Point

Aside problem can be solved using

- Aspect Ratio-AR
- Hydraulic Diameter- D(h)
  D(h)=4Area/Perimeter (flow Section)
- Required Flow rate
- Mean Heat Transfer Coefficient- h
- Nusselt Number – Nu
- Cooling fluid
  - Water
  - Ethylene glycol
  - Custom fluid(high thermal conductivity)

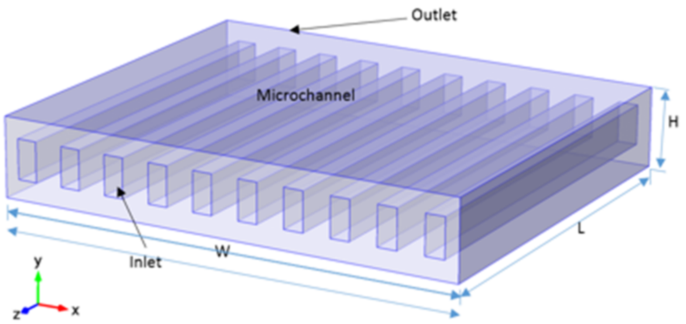
Limitation of Microchannel

1. Since heat transfer in heat sinks relies on the transfer of energy from substrate to coolant via convection, the cooling capability is proportional to the coolant flow rate.
2. As long as an adequate supply of coolant can be maintained, there is no theoretical limit to the heat transfer rate that can be obtained in the heat sink. But space and power are limitations.
3. Pumping requirement & Thermal Resistance are the primary obstacle in real-time application of liquid cooling.
4. The primary metrics in measuring pump performance: flow rate / volume & pressure
5. Other important metrics in their selection are power consumption, input voltage, cost, sound and reliability.
6. Poor thermal conductivity of the water reduces the effectiveness of the heat transfer.
7. Mechanically moving pumps that may be unreliable, occupy large spaces, and Contribute to vibration or noise

Computational Domain

Microchannel

- Length of channel L=10mm
- Width of channel W=20mm
- Height of the channel H=2mm
- Number of the channel n=10
- Aspect ratio AR=2,2.5, 3,3.5
- Cross-section
  - Rectangular
  - Trapezoidal & Mixed



Assumptions & physical condition

- Steady state flow.
- Incompressible fluid.
- Laminar flow.
- Constant properties of both fluids and solid.
- Effects of viscous dissipation are negligible.

- Constant temperature at inlet .
- Constant heat flux at the bottom.
- Pressure at outlet is assumed to be zero.
- Thermal insulation on side walls of heat sink, top & area surrounding inlet and outlet.

Computational Domain

Numerical solution

- Heat transfer

$$\rho C_p u.\nabla T = \nabla.(k\nabla T) + Q$$

- Thermal Insulation

$$-\ n.(k\nabla T) = 0$$

- Walls: u=0, Boundary condition: No Slip
- Fluid Continuity, momentum and energy equation.

$$\nabla.(\rho u) = 0$$

$$\rho(u.\nabla)u = .[-pI + \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla.u)I] + F$$

$$\rho C_p u.\nabla T = \nabla.(k\nabla T) + Q$$

- Initial value: u=0,P=0 & T_0 =293.15K
- Inlet: u=0.01m/s to .1m/s 10 values equally incremented
- Boundary condition: Pressure, no viscous stress, T_0=293.15K
- Outlet: P=P_0,P_0=0,
- Boundary condition: Pressure, no viscous stress
- Heat flux applied at the bottom of microchannel q”=100W/cm^2 $n.(k\nabla T) = q_0, q_0 = 100\text{Wcm}^{-2} = q''$

Computational Domain

Derived parameters using comsol solution

$$\text{Heat Flux}: q = \frac{Q}{A_b}$$

$$\text{Reynolds Number}: Re = \frac{\rho u l}{\mu}$$

$$\text{Nusselt Number}: Nu = \frac{hl}{k}$$

$$\text{Heat Transfer Coefficient}: h = \frac{Q}{A_w (T_w - T_f)}$$

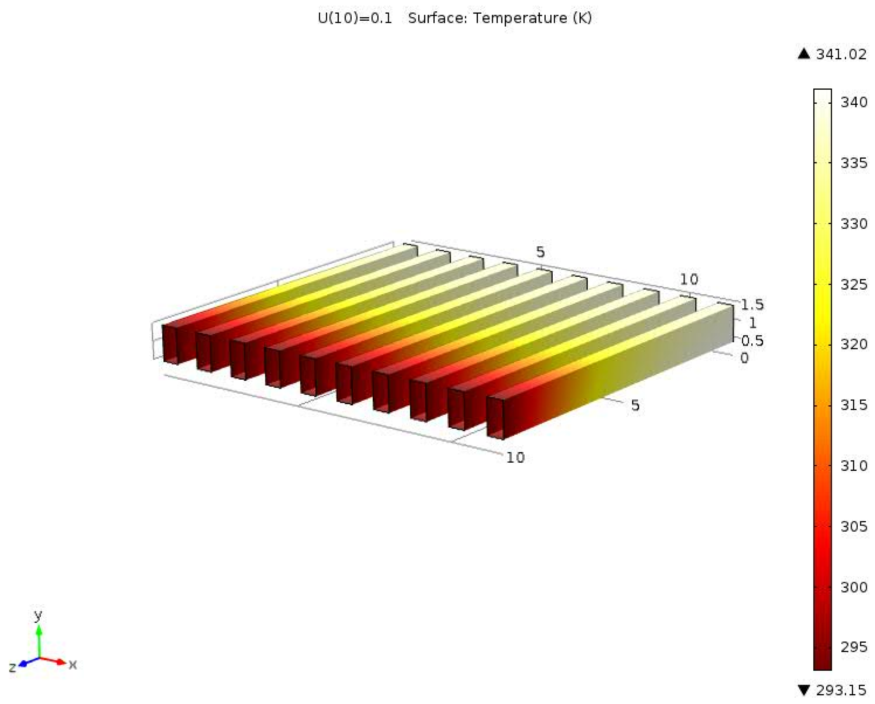
$$\text{Friction Factor}: f = \frac{\Delta P}{2 \rho u^2} \cdot \frac{l}{L}$$

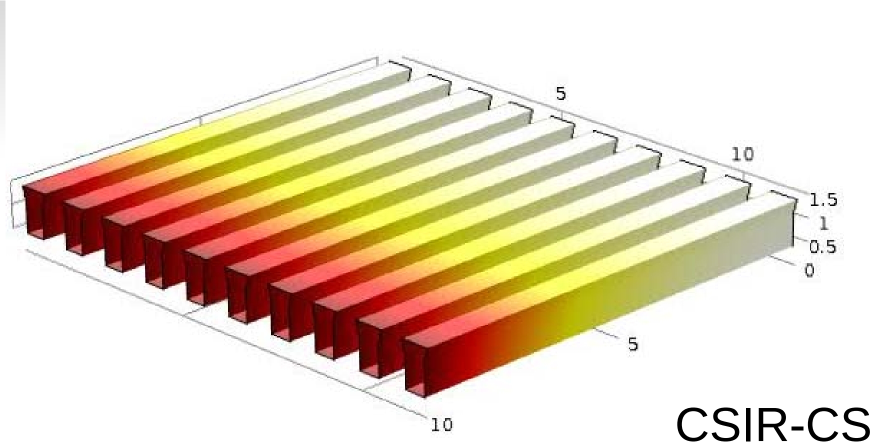
$$\text{Pumping power} = V \Delta P = u A_c \Delta P$$

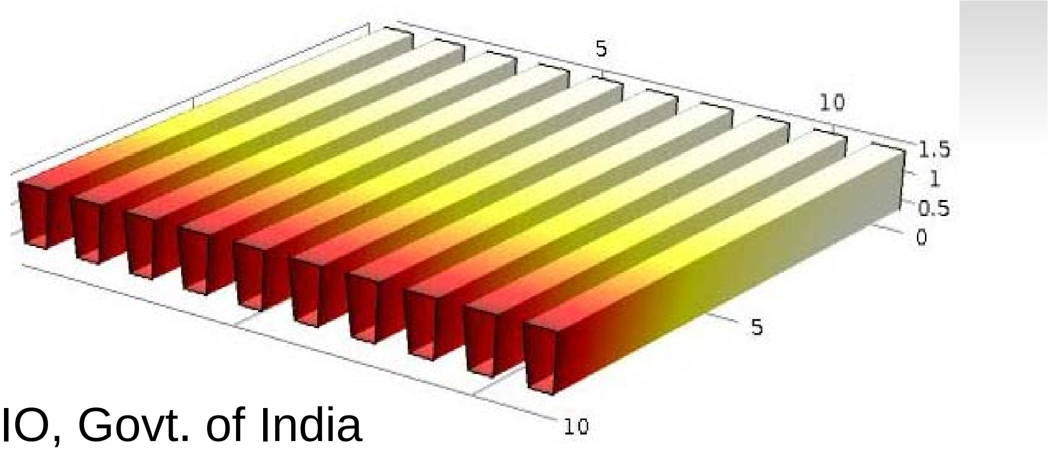
Results

Temperature variation

Temperature of the walls of the fluid increases along the length of the microchannel showing larger cooling effect at the inlet, and this is comman in all the cases but temperature variation is different.







Results

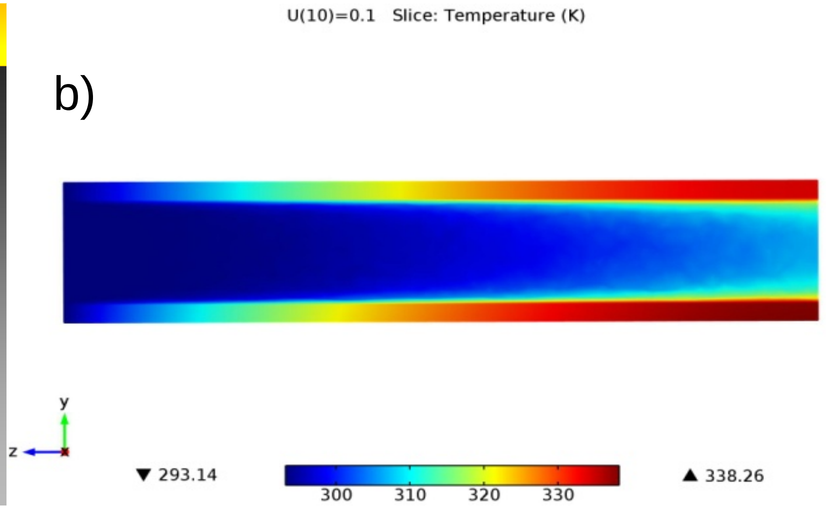
Temperature variation

a) Micro channel showing the variation of temperature in different channel and substrate.

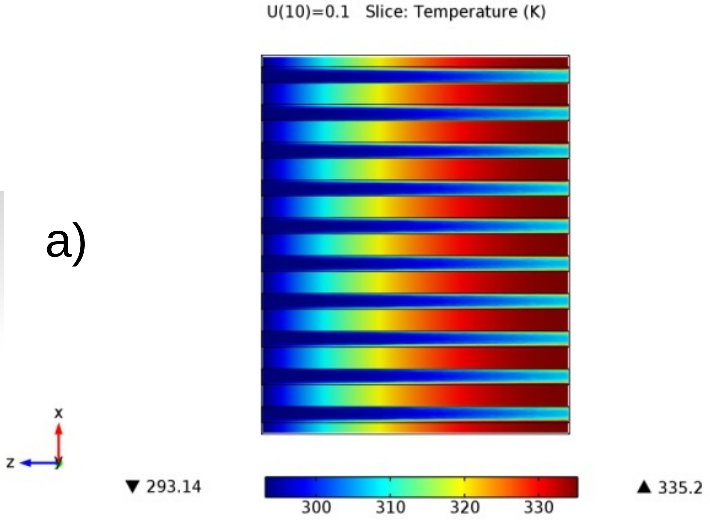
b) Thermal boundary layer formation inside the channel for AR 2.5,water

c) Velocity boundary layer formation& velocity profile inside the channel for AR 2.5,water .

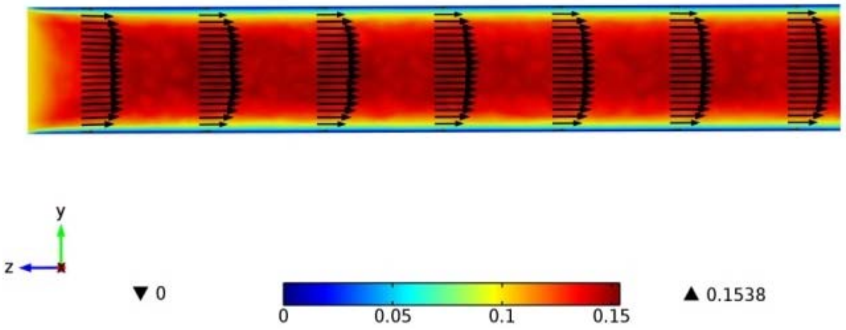
b)


U(10)=0.1 Slice: Temperature (K)

a)


U(10)=0.1 Slice: Temperature (K)

c)



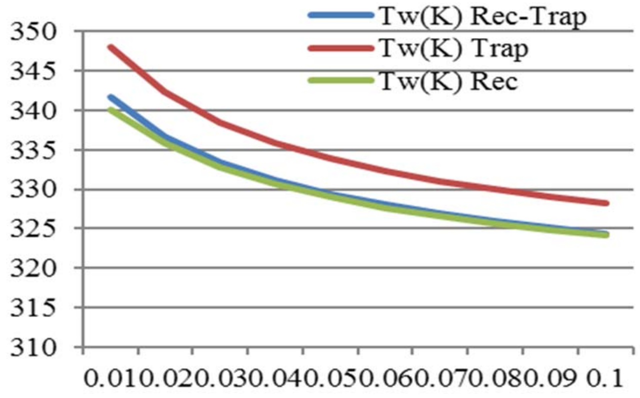
Results

Temperature variation

Graphs shown aside shows the variation of Maximum temperature of microchannel walls for different shapes, different inlet velocities varing from 0.01m/s to .1m/s.

a) AR=2
b) AR=3
c) AR=3.5
Rec: Rectangular geometry
Trap: Trapezoidal geometry
Rec-Trap: Mixed geometry of above two

a)



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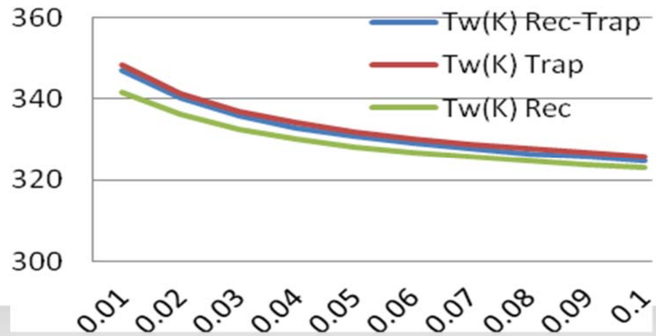
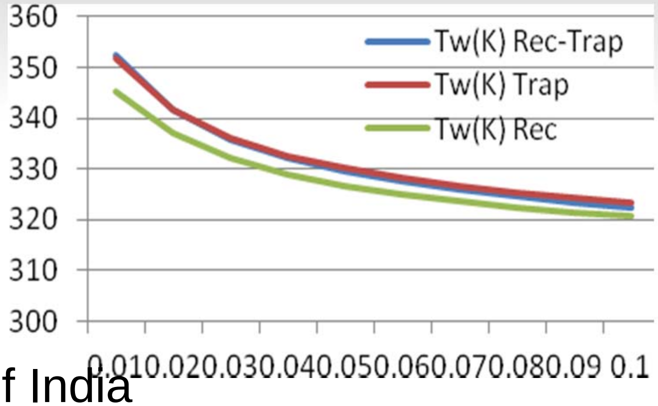


c)



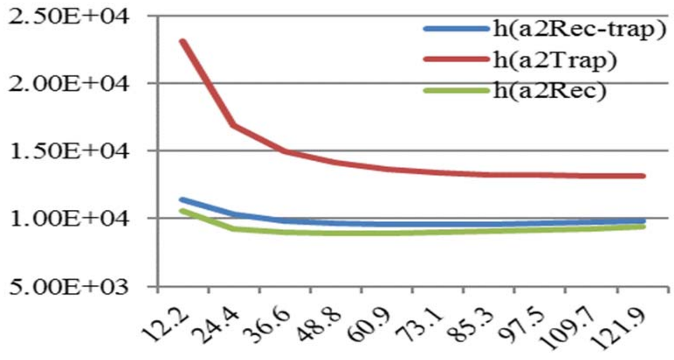
Results

Heat transfer coefficient

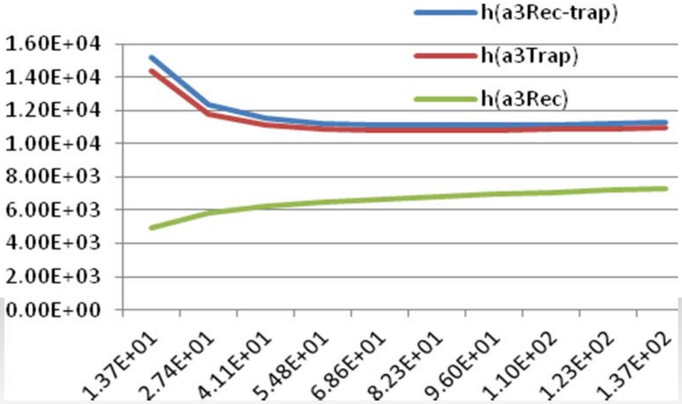
Graphs shown aside shows the variation heat transfer coefficient of microchannel for different shapes, different inlet velocities varing from 0.01m/s to .1m/s (Reynold Number).

a) AR=2
b) AR=3
Rec: Rectangular geometry
Trap: Trapezoidal geometry
Rec-Trap: Mixed geometry of above two

a)



b)



Conclusions

1 As the aspect ratio is increasing, the heat capacity of the fluid is also increasing but with increase in the Aspect Ratio there is a fabrication challenge. A trade off is to be maintained between the both.

2 In comparison to both rectangular, trapezoidal section and combined section, the trapezoidal section shows high performance.

3 The heat transfer coefficient of trapezoidal section is higher. But at the same time with increase in aspect ratio there is a lot of variation.

4 It can be deduced that for effective cooling by micro-channels, cross-section and flow rate plays an important role and has to be analyzed carefully.

REFERENCES

[1] **D. B. Tuckerman and R. F. W. Pease**, “High- performance heat sinking for VLSI”, Electron Device Letters, IEEE, vol. 2, May 1981, pp.126-129.

[2] **R.J.Phillips**, “Forced Convection, Liquid Cooled, Micro channel Heat Sinks”, M.S. Thesis, Massachusetts Institute of Technology, Cambridge MA, 1987.

[3] **G.L. Morini**, “Single-phase convective heat transfer in micro channels: a review of experimental results”, Int. J. Thermal Sci. 43 (2004) 631–651.

[4] **S.J. Kim, J.M. Hyun**, “A porous medium approach for the thermal analysis of heat transfer devices”, in: D.B. Ingham, I. Pop (Eds.), Transport Phenomena in Porous Media III, Elsevier, New York, 2005 .

[5] **A. Husain, K.Y. Kim**, “Multiobjective optimization of a micro channel heat sink using evolutionary algorithm”, J. Heat Transfer 130 (2008) 114505

[6] **D.K. Kim, S.J. Kim**, “Closed-form correlation for thermal optimization of micro channels”, Int. J. Heat Mass Transfer 50 (2007) 5318–5322.

[7] **M. A. Kunquan and J. Liu (2007)**. Liquid metal cooling in thermal management of computer chips, Frontiers of Energy and Power Engineering in China 1, p. 384-402.

[8] **A. Miner and U. Ghoshal, 2004**. “Cooling of high-power-density micro devices using liquid metal coolants”, Applied Physics Letters 85 p. 506-508.

REFERENCES

[9] **V. Natrajan, K. Christensen**, “Non-intrusive measurements of convective heat transfer in smooth- and rough-wall microchannels: laminar flow”, Experiments in Fluids, 49(5) (2010) 1021-1037.

[10] **P.-S. Lee, S.V. Garimella**, “Thermally developing flow and heat transfer in rectangular microchannels of different aspect ratios”, International Journal of Heat and Mass Transfer, 49(17-18) (2006) 3060-3067.

[11] **T.-Y. Lin, S.G. Kandlikar**, “A Theoretical Model for Axial Heat Conduction Effects during Single-Phase Flow in Microchannels”, Journal of Heat Transfer, 134(2) (2012) 020902(1-6).

[12] **L. Chai, G. Xia, M. Zhou, and J. Li**, "Numerical simulation of fluid flow and heat transfer in a microchannel heat sink with offset fan-shaped reentrant cavities in sidewall," International Communications in Heat and Mass Transfer, vol. 38, May 2011, pp. 577-584, doi:10.1016/j.icheatmasstransfer.2010.12.037.

[13] **B.X. Wang, X.F. Peng**, “Experimental investigation on liquid forced-convection heat transfer through microchannels”, International Journal of Heat and Mass Transfer, 37, Supplement 1(0) (1994) 73-82.

[14] **J.-Y. Jung, H.-S. Oh, H.-Y. Kwak**, “Forced convective heat transfer of nanofluids in microchannels”, International Journal of Heat and Mass Transfer, 52(1-2) (2009) 466-472.

[15] **P J Ross** “Taguchi techniques for quality engineering”: McGraw-Hill: New York, 1996.

[16] Comsol user guide.

THANK YOU !!!