STUDY OF FLUID DYNAMICS AND HEAT TRANSFER IN MEMS STRUCTURES

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Work description

- Here the fluid dynamics and heat transfer through a micro channel of different radius and shape is studied.
- It is very costly and difficulty to manufacture the micro channel(<1000μm) structure and analyze its performance.
- Therefore here the modeling and simulation is done by using COMSOL Multi-physics software.

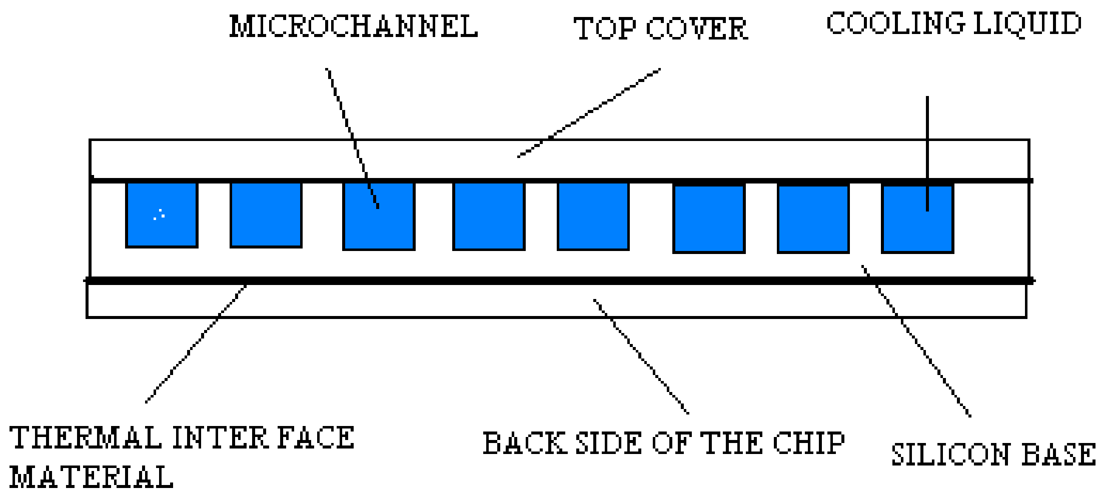
Application

- This micro channel structures can be used in various field:
  - Electronics cooling structures such as on chip micro channel cooler.
  - Micro channel mixers which can be used in biomedical as well as chemical industry.
  - Localized cooling by using micro nozzle.

Electronics cooling structures such as on chip micro channel cooler

- As electronic components get smaller and heat transfer requirements increase, air becomes a less efficient coolant.
- Liquid cooling provides a means in which thermal resistance can be reduced dramatically
- 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.

Electronics cooling structures such as on chip micro channel cooler contd..



Schematic cross section view of square micro channel heat sink on the back side of the IC chip

Objective

- Here micro channels of different shapes are modeled and simulated.
  - Square shaped micro channel
  - Circular shaped micro channel
  - Staggered fin micro channel
- Again in each case the diameter is varied from 200µm up to 1000µm and the fluid flow parameters as well as the heat transfer parameters are studied and compared.

Objective continued..

- The parameters taken into considerations are
  - Pressure variations along the length of the channel
  - Temperature variations along x-axis
  - Reynolds number variation along x-axis

D_h

Results and analysis for square shaped channel

- The pressure drop is given by:

$$\Delta p = \frac{2fL\rho V^2}{D_h}$$

Where

V: mean flow velocity

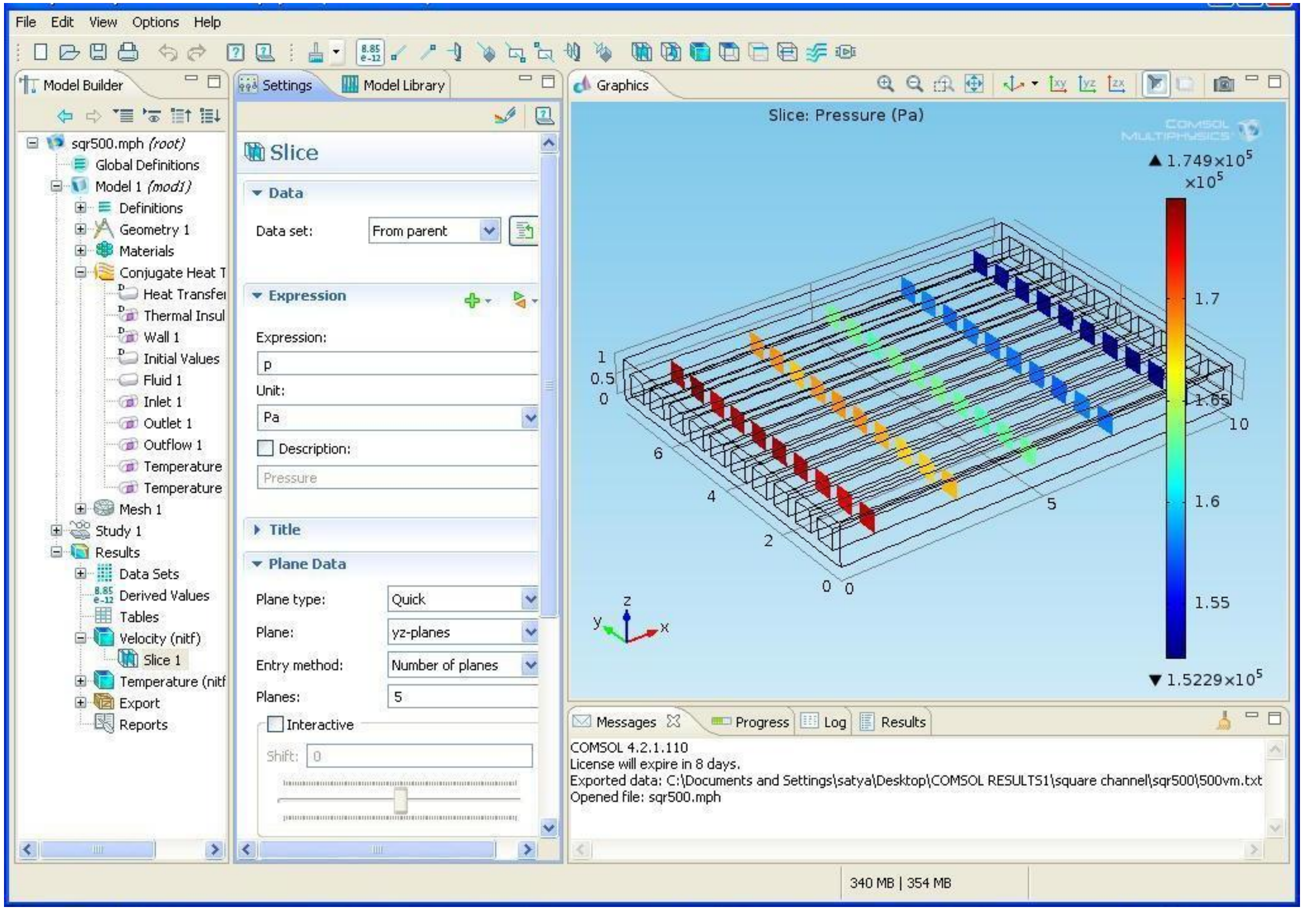
L: flow length

ρ: fluid density

f: friction factor depends upon aspect ratio

Dh: hydraulic diameter

Results and analysis for square shaped channel continued..

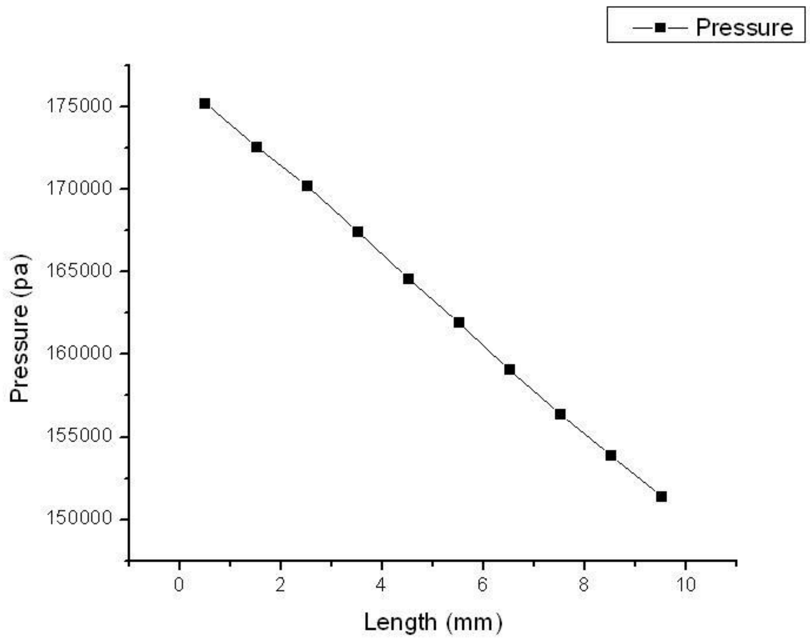


3D plot of Pressure variation in 200µm square channel

Results and analysis for square shaped channel continued..

Length(mm)	Pressure(pa)
0.5	175266.55
1.5	172624.91
2.5	170263.87
3.5	167487.90
4.5	164654.21
5.5	161950.07
6.5	159087.14
7.5	156422.09
8.5	153912.49
9.5	151410.93

Pressure variation for 200μm in square channel



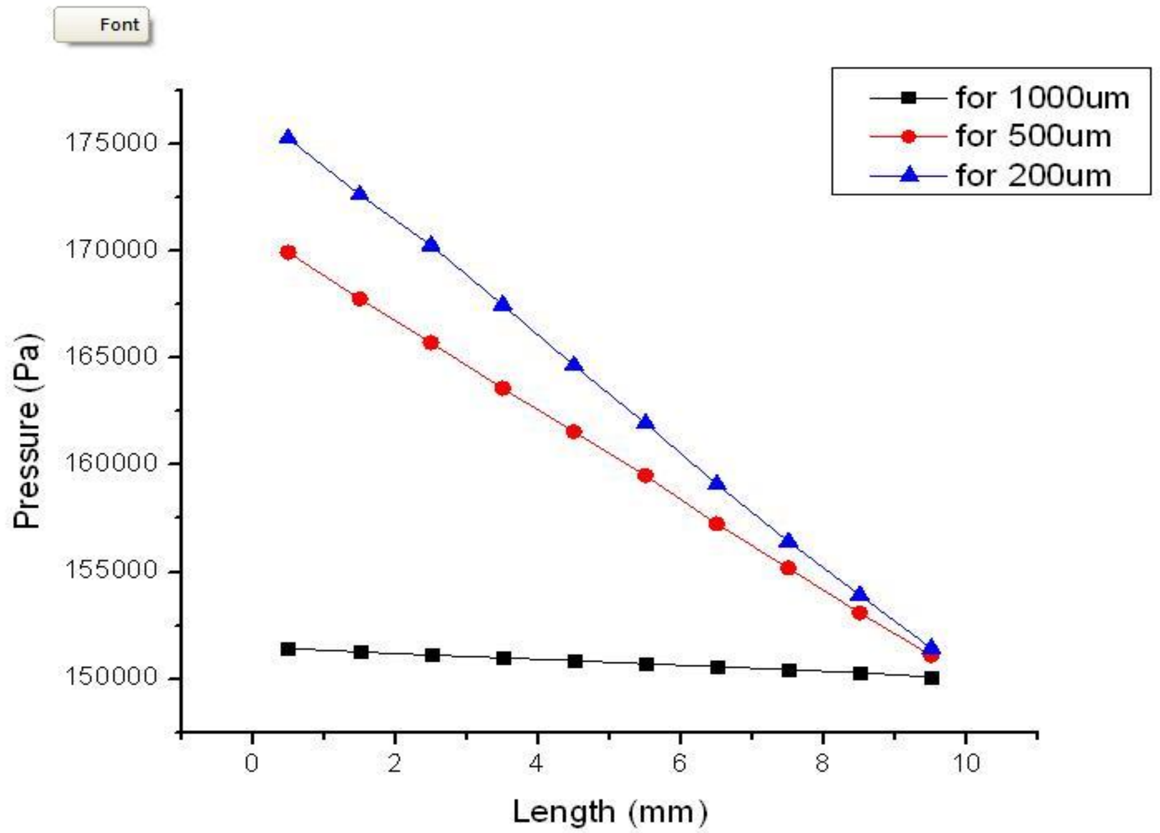
Plot of pressure versus length for 200μm square channel

Results and analysis for square shaped channel continued..

Length(mm)	Pressure(pa) for D_h=1000µm	Pressure(pa) for D_h=500µm	Pressure(pa) for D_h=200µm
0.5	151417.21	169938.9	175266.55
1.5	151255.27	167764.2	172624.91
2.5	151114.38	165713.4	170263.87
3.5	150975.44	163577.4	167487.90
4.5	150836.73	161543.6	164654.21
5.5	150698.04	159495.6	161950.07
6.5	150559.36	157233.2	159087.14
7.5	150420.67	155169.8	156422.09
8.5	150282.25	153079.5	153912.49
9.5	150065.62	151082.9	151410.93

Variation of pressure due to variation of D_h in square channel along the length

Results and analysis for square shaped channel continued..



Variation of pressure due to variation D_h in square channel along the length

Results and analysis for square shaped channel continued..

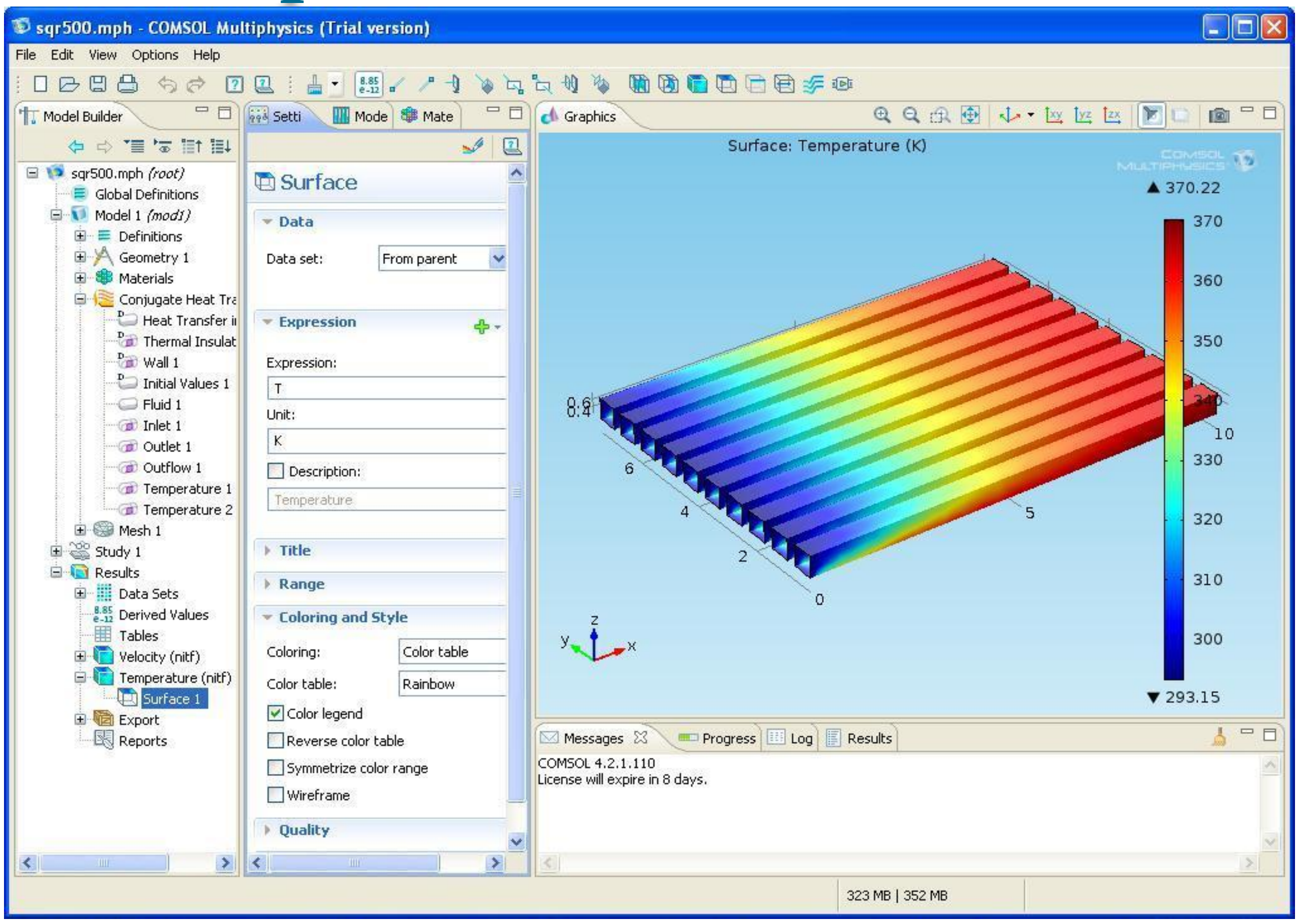
- The heat transfer by convection is described by the Newton's law of cooling:

$$Q = hA\,(T_w - T_\infty)$$

where:

- Q = Heat transfer rate (W)
- h = Heat transfer coefficient (W/m2.K)
- Tw= Wall temperature (K)
- $T\infty$= Free stream fluid temperature (K)

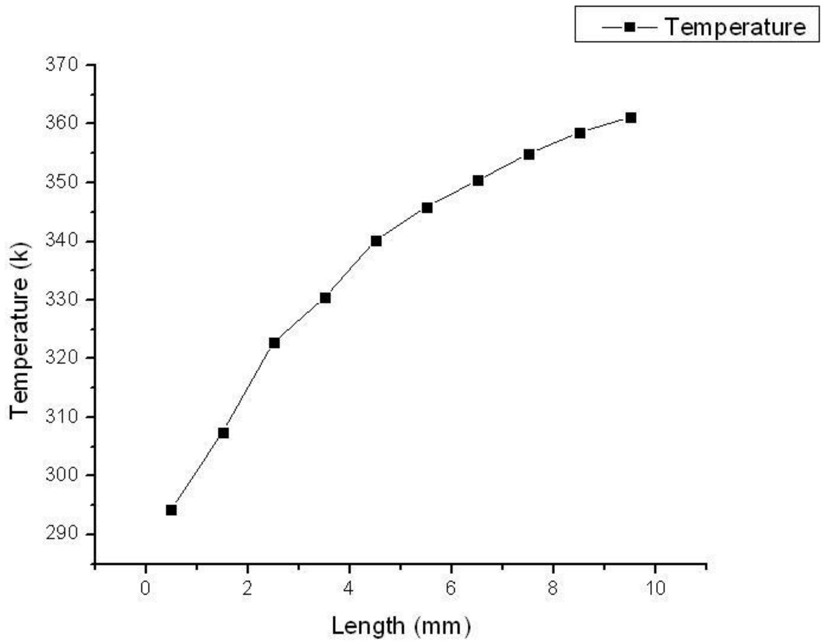
Results and analysis for square shaped channel continued..



3D plot of Temperature variation in 500um square channel

Results and analysis for square shaped channel continued..

Length(mm)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
Temperature(k)	294.3	307.4	322.7	330.4	340.1	345.8	350.3	354.9	358.6	361.1



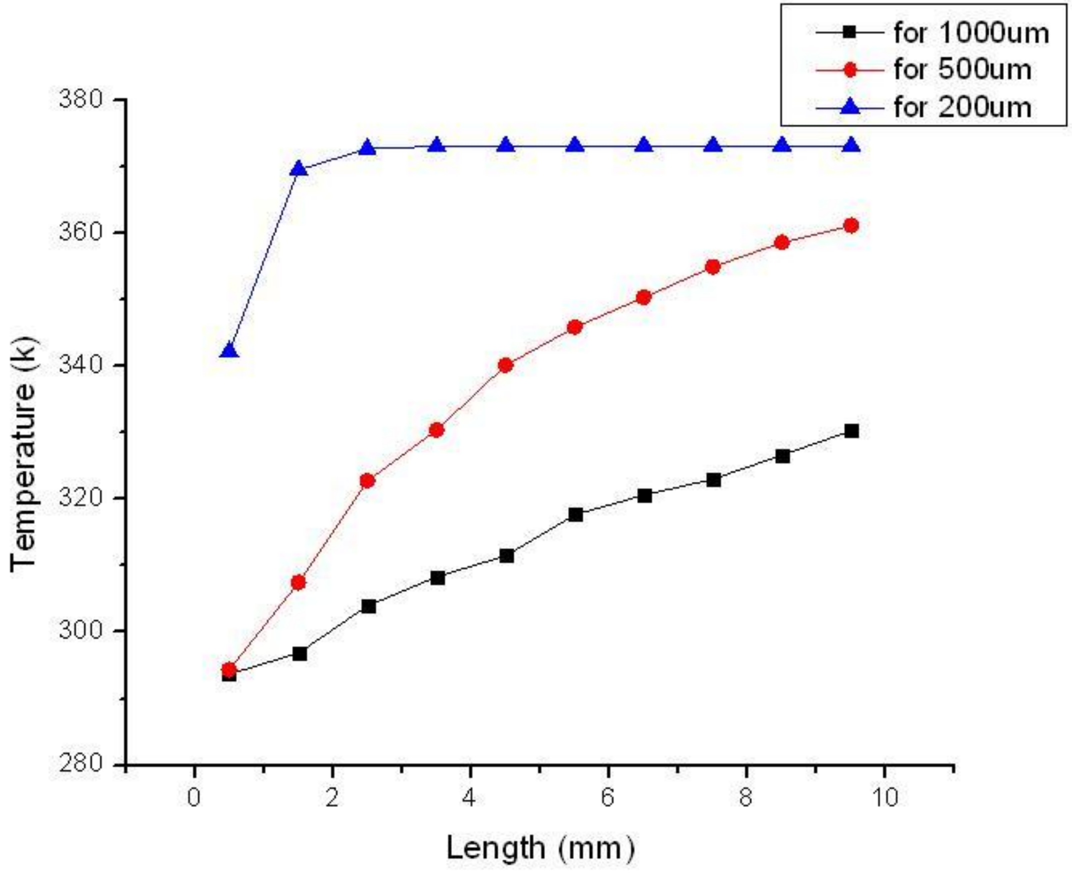
Temperature variation for 500um in square channel

Results and analysis for square shaped channel continued..

Length(mm)	Temperature(k) for D_h=1000μm	Temperature(k) for D_h=500μm	Temperature(k) for D_h=200μm
0.5	293.72	294.34	342.25
1.5	296.86	307.47	369.54
2.5	303.97	322.76	372.73
3.5	308.37	330.41	373.10
4.5	311.53	340.16	373.14
5.5	317.72	345.89	373.14
6.5	320.64	350.38	373.14
7.5	323.04	354.97	373.14
8.5	326.69	358.61	373.14
9.5	330.33	361.19	373.14

Variation of temperature due to variation D_h in square channel along the length

Results and analysis for square shaped channel continued..



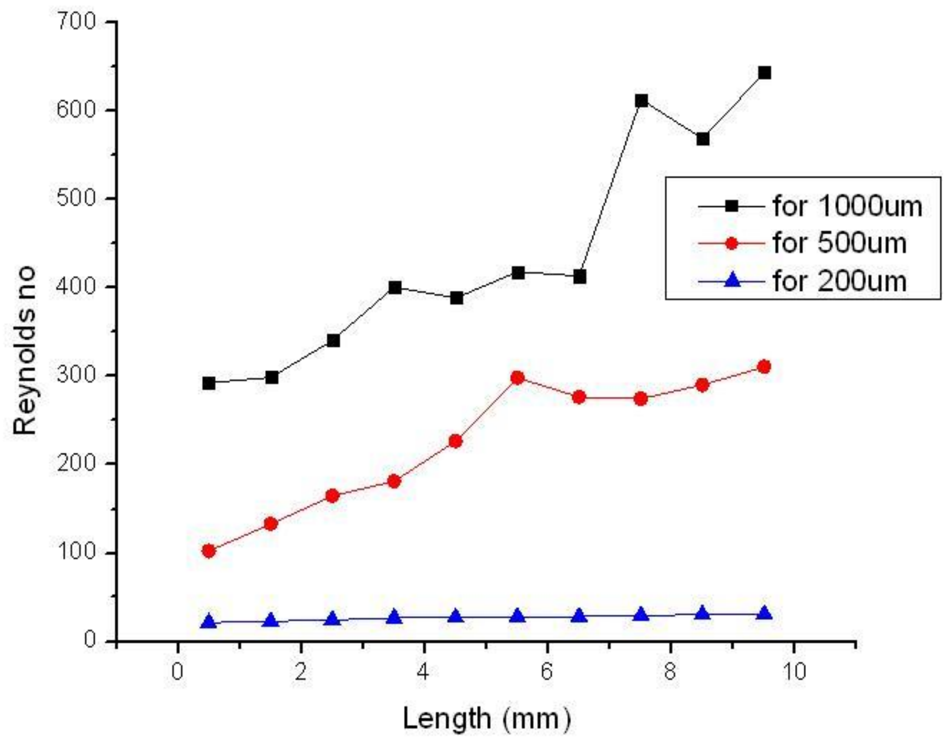
Variation of temperature due to variation D_h in square channel along the length

Results and analysis for square shaped channel continued..

Length(mm)	Reynolds number for D_h=1000µm	Reynolds number for D_h=500µm	Reynolds number for D_h=200µm
0.5	292.590912	102.5356	21.3565
1.5	298.912604	133.1602	22.9564
2.5	340.482822	165.0039	24.5986
3.5	400.873792	181.1991	26.5984
4.5	388.47101	226.8120	27.3459
5.5	418.123818	298.4926	28.0036
6.5	413.431331	276.6334	28.3698
7.5	613.085691	274.5871	29.3659
8.5	568.693593	290.2206	30.699
9.5	643.552921	310.6532	31.1213

Variation of Reynolds no. due to variation D_h in square channel along the length

Results and analysis for square shaped channel continued..



$$Re = \frac{\rho v L}{\mu}$$

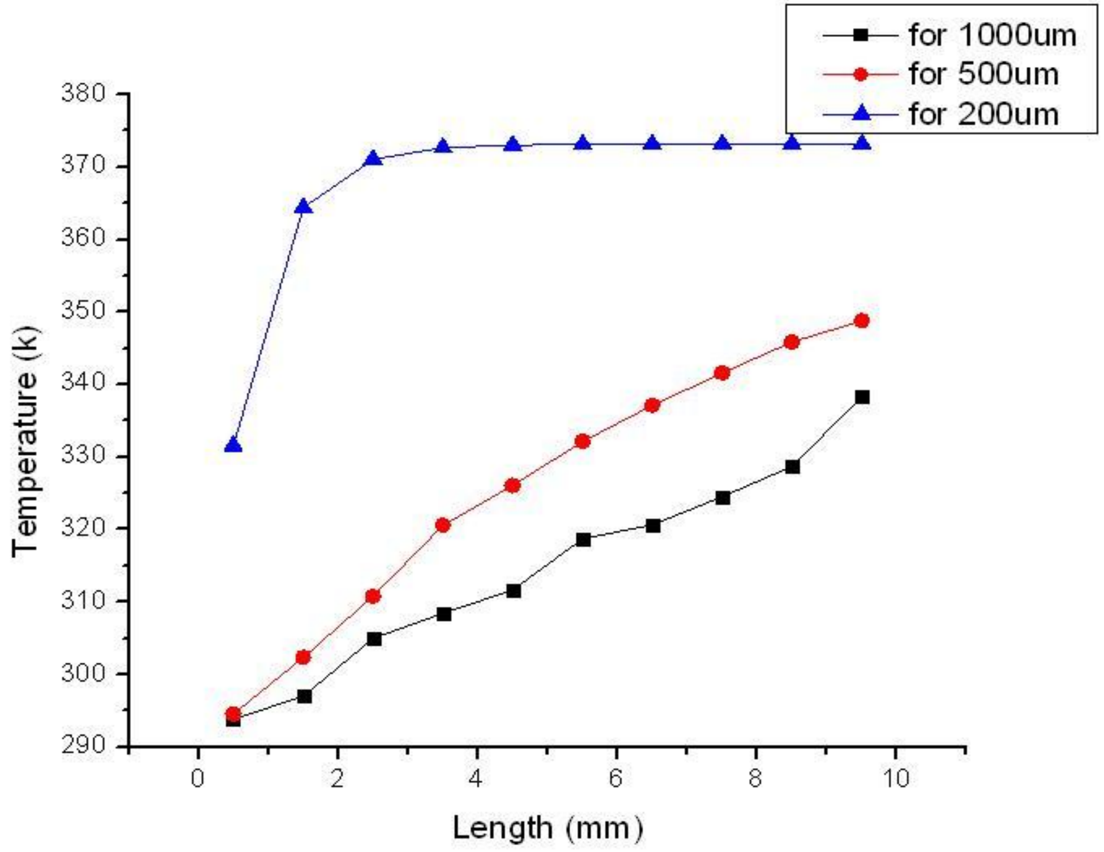
Variation of Reynolds no. due to variation D_h in square channel along the length

Results and analysis for circular shaped channel continued..

Length(mm)	Temperature(k) for D_h=1000µm	Temperature(k) for D_h=500µm	Temperature(k) for D_h=200µm
0.5	293.82	294.51	331.54
1.5	296.97	302.35	364.41
2.5	304.95	310.74	371.07
3.5	308.42	320.57	372.67
4.5	311.63	326.03	373.04
5.5	318.73	332.13	373.12
6.5	320.64	337.10	373.14
7.5	324.54	341.61	373.14
8.5	328.69	345.85	373.14
9.5	338.32	348.78	373.15

Variation of temperature due to variation D_h in circular channel along the length

Results and analysis for circular shaped channel continued..



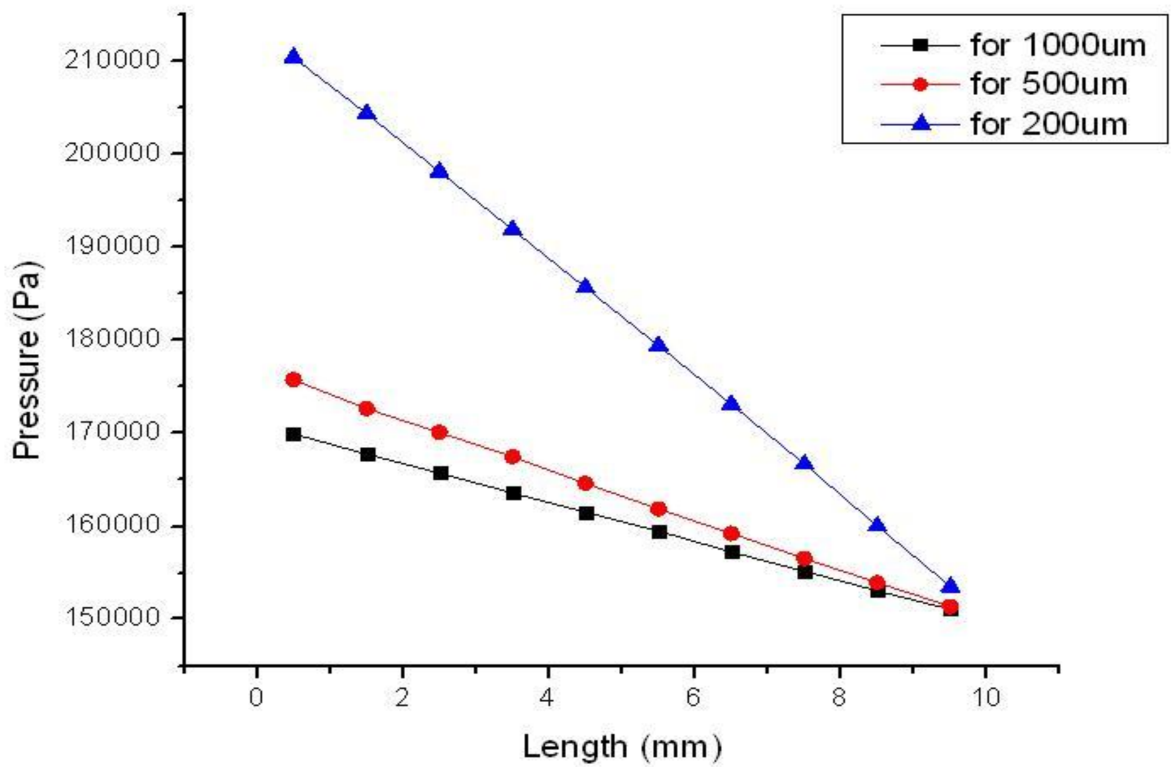
Variation of temperature due to variation D_h in circular channel along the length

Results and analysis for circular shaped channel continued..

Length(mm)	Pressure(pa) for D_h=1000μm	Pressure(pa) for D_h=500μm	Pressure(pa) for D_h=200μm
0.5	1.699389e5	1.757682e5	2.103963e5
1.5	1.677642e5	1.726745e5	2.043559e5
2.5	1.657134e5	1.700978e5	1.981418e5
3.5	1.635774e5	1.675109e5	1.91913e5
4.5	1.615436e5	1.646111e5	1.856679e5
5.5	1.594956e5	1.618545e5	1.794262e5
6.5	1.572332e5	1.592296e5	1.731243e5
7.5	1.551698e5	1.565561e5	1.666797e5
8.5	1.530795e5	1.539557e5	1.600415e5
9.5	1.510829e5	1.513827e5	1.535287e5

Variation of pressure due to variation of D_h in circular channel along the length

Results and analysis for circular shaped channel continued..



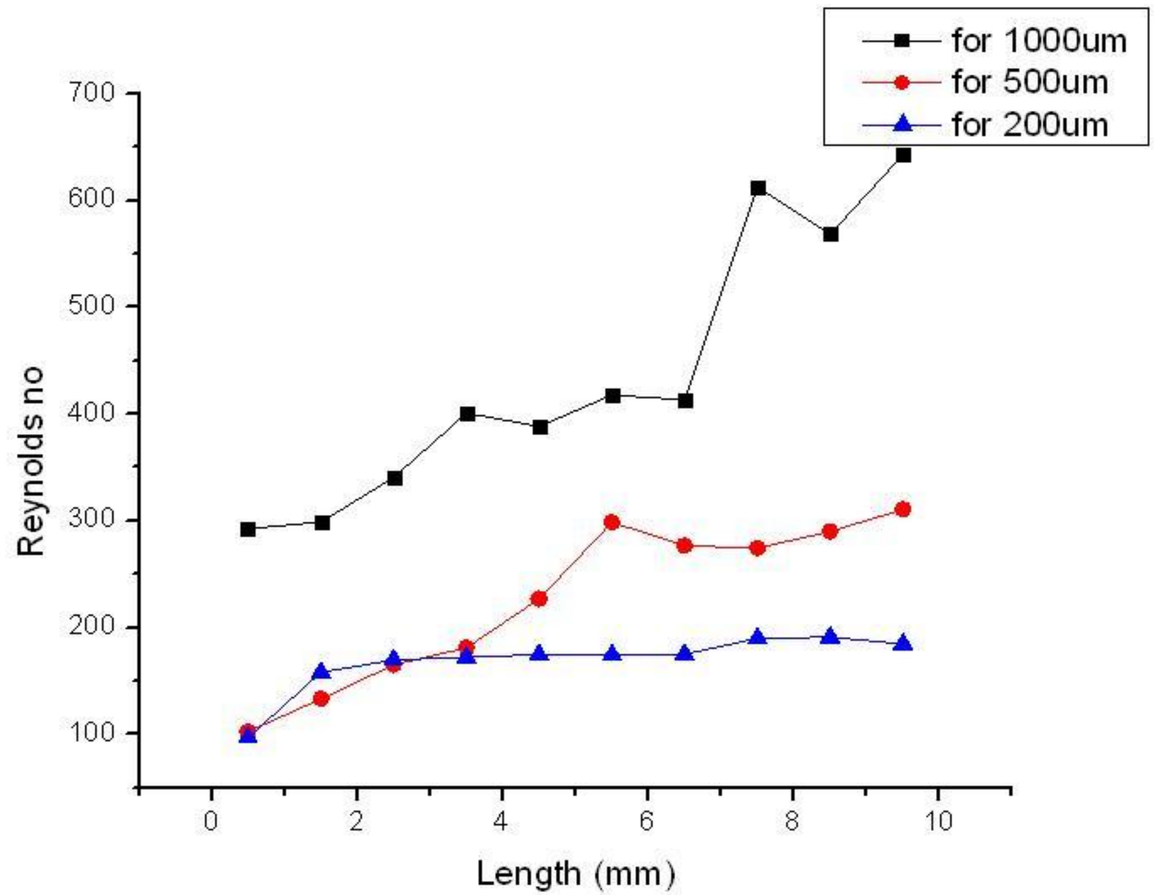
Variation of pressure due to variation D_h in circular channel along the length

Results and analysis for circular shaped channel continued..

Length(mm)	Reynolds number for D_h=1000μm	Reynolds number for D_h=500μm	Reynolds number for D_h=200μm
0.5	292.59	144.71	97.01
1.5	298.91	135.83	157.97
2.5	340.48	188.47	169.60
3.5	400.87	245.27	172.36
4.5	388.47	222.35	174.75
5.5	418.12	222.17	174.17
6.5	413.43	327.65	175.16
7.5	613.08	281.99	190.11
8.5	568.69	291.31	191.16
9.5	643.55	299.45	184.71

Variation of Reynolds no. due to variation D_h in circular channel

Results and analysis for circular shaped channel continued..

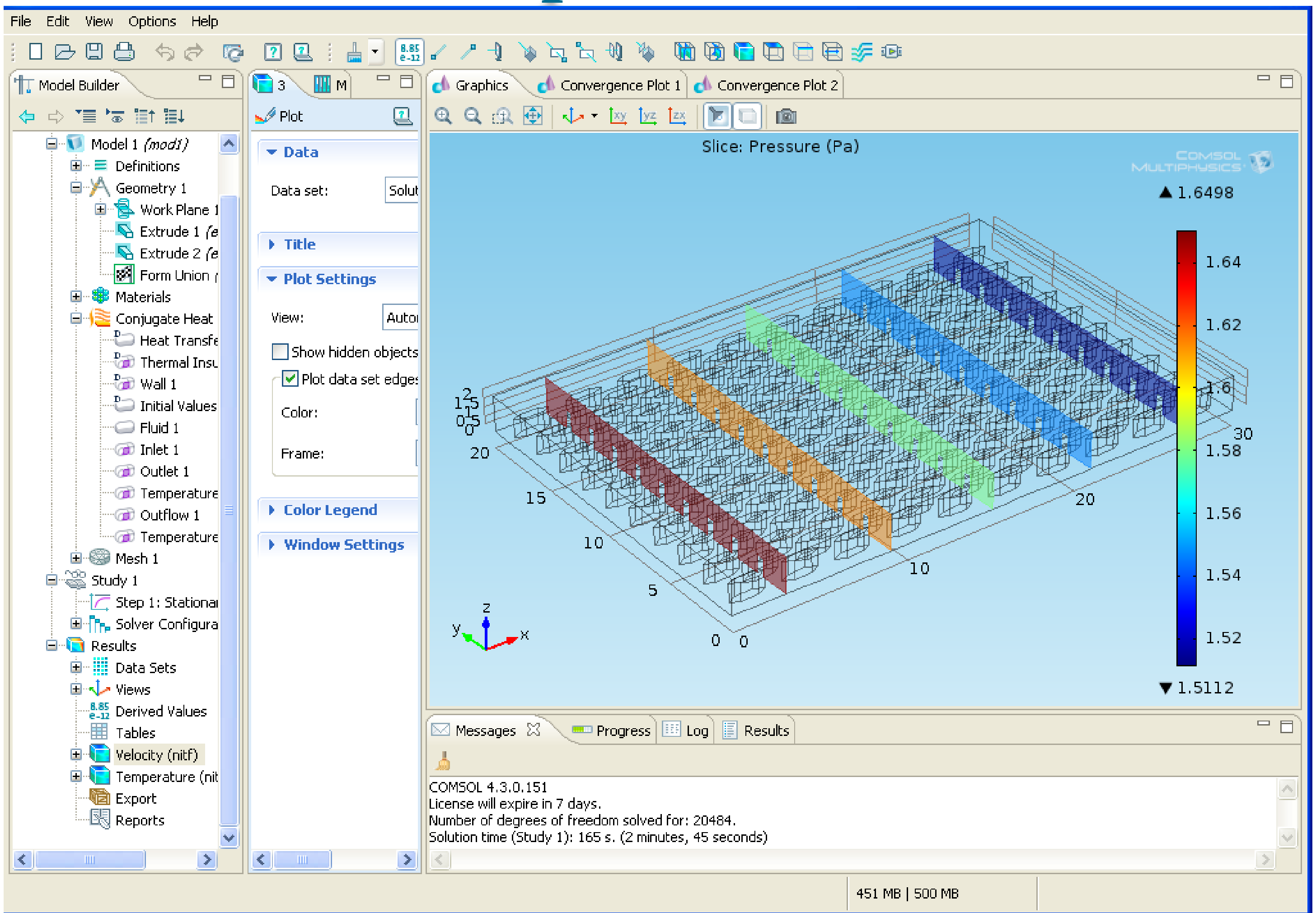


Variation of Reynolds no. due to variation D_h in circular channel

Analysis for circular and square s shaped channel

- From the above analysis the major issues are:
  - Pressure drop
  - Mechanical stress limitation on IC chip material
  - Pumping power
- The issue high pressure drop can be solved by using staggered fin shaped channel ie, continuous channels are broken into small channels.

Results and analysis for staggered fin shaped structure



Conclusion

- From the above results it is concluded that:
  - In staggered fin structure the pressure drop is minimum and heat transfer rate is maximum. Hence this can be effectively used for on-chip micro-channel cooling structures.

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Thank you