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Design of Cooling System for Electronic Devices Using Impinging Jets

Po Ting Lin[1] Ching Jui Chang[2] Huan Huang[3] Bin Zheng[4]

[1]Mechanical and Aerospace Engineering, Rutgers University, Piscataway, NJ, USA
[2]FTR Systems Co. Ltd., Shanghai, China
[3]PolarOnyx, Inc., San Jose, CA, USA
[4]School of Mechatronics Engineering, University of Electronic Science and Technology of China, Chengdu, China

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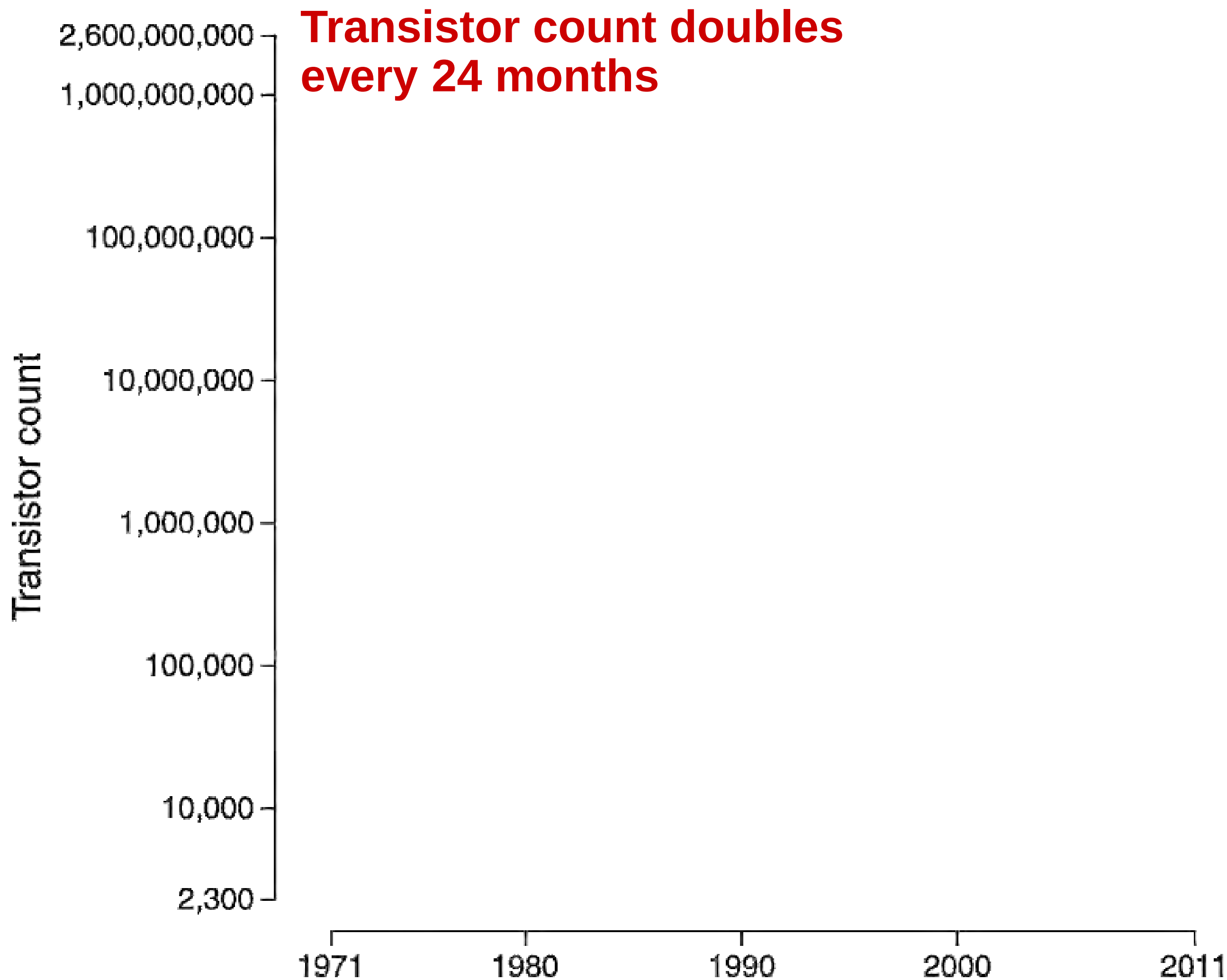
RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

Growth of Integrated Circuits

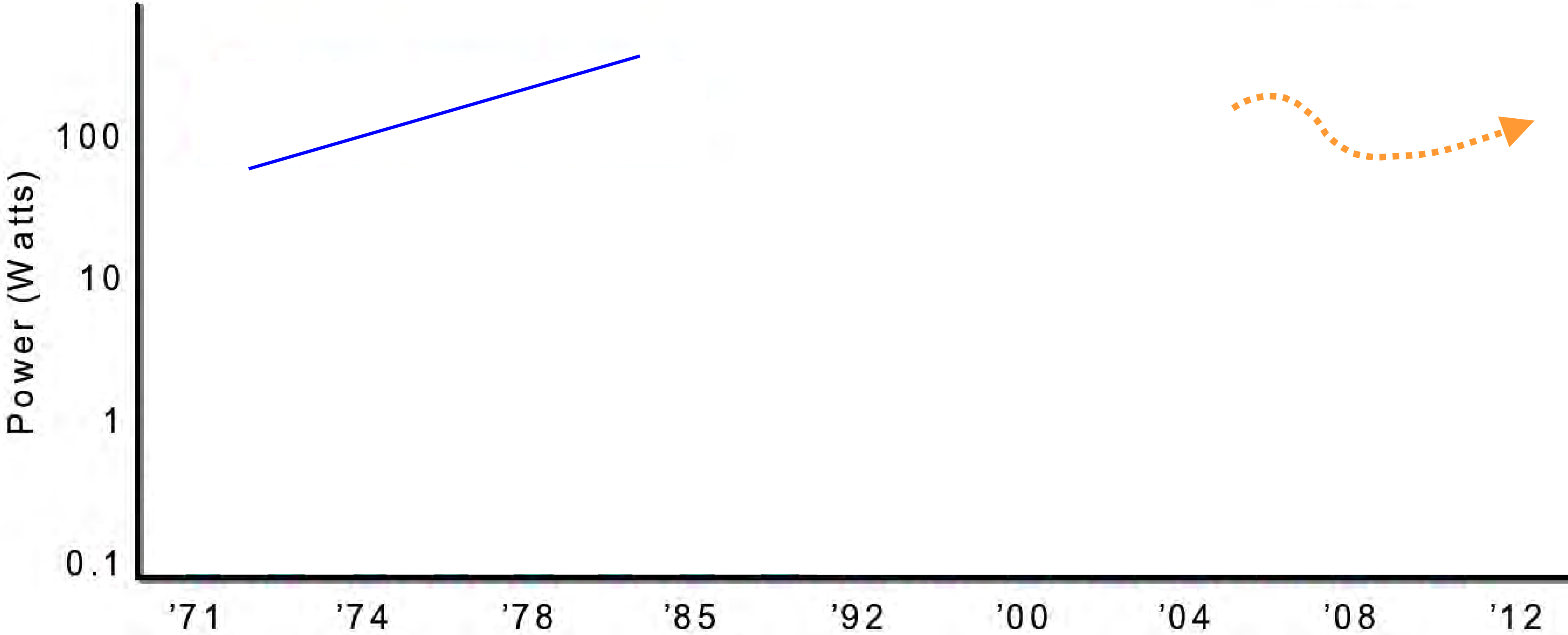
- Moore’s Law: Exponential Rise in Transistor Counts



source: en.wikipedia.org

Growth of Heat Dissipation from ICs

- Morse’s Law
- High heat dissipation from ICs



references:
en.wikipedia.org & intel.com &
Raj Nair, International Symposium on SoC, 2007

Air Cooling

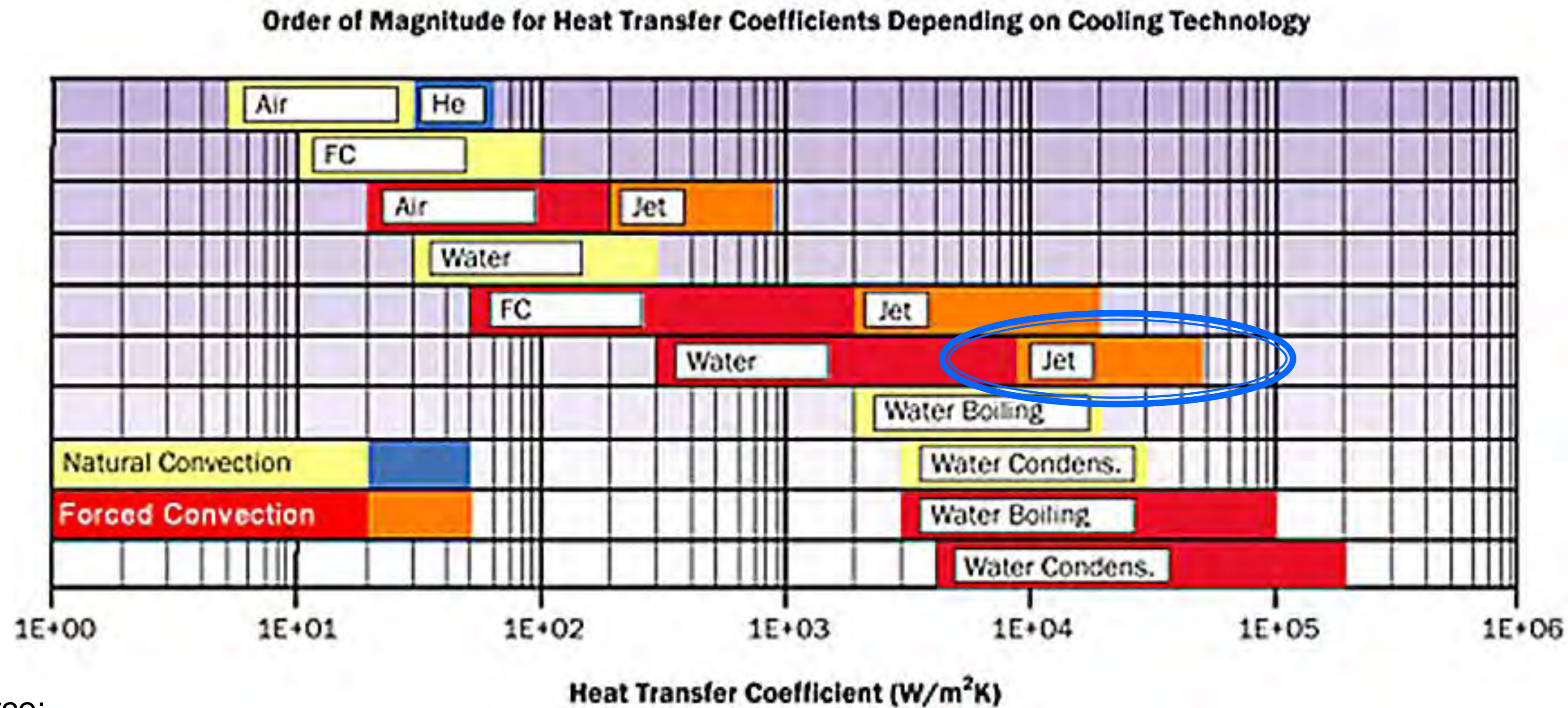
- Large surface area for convection
- Forced convection for higher heat transfer coefficient

- Cons of air cooling
  - Size of the fins and fans
  - Noise from the fan
  - Built-up dust
  - Manufacturing

source: frostytech.com

Why Liquid Cooling?

- Compact system size
- Quiet: <25dB
- Low maintenance
- Easy fabrication



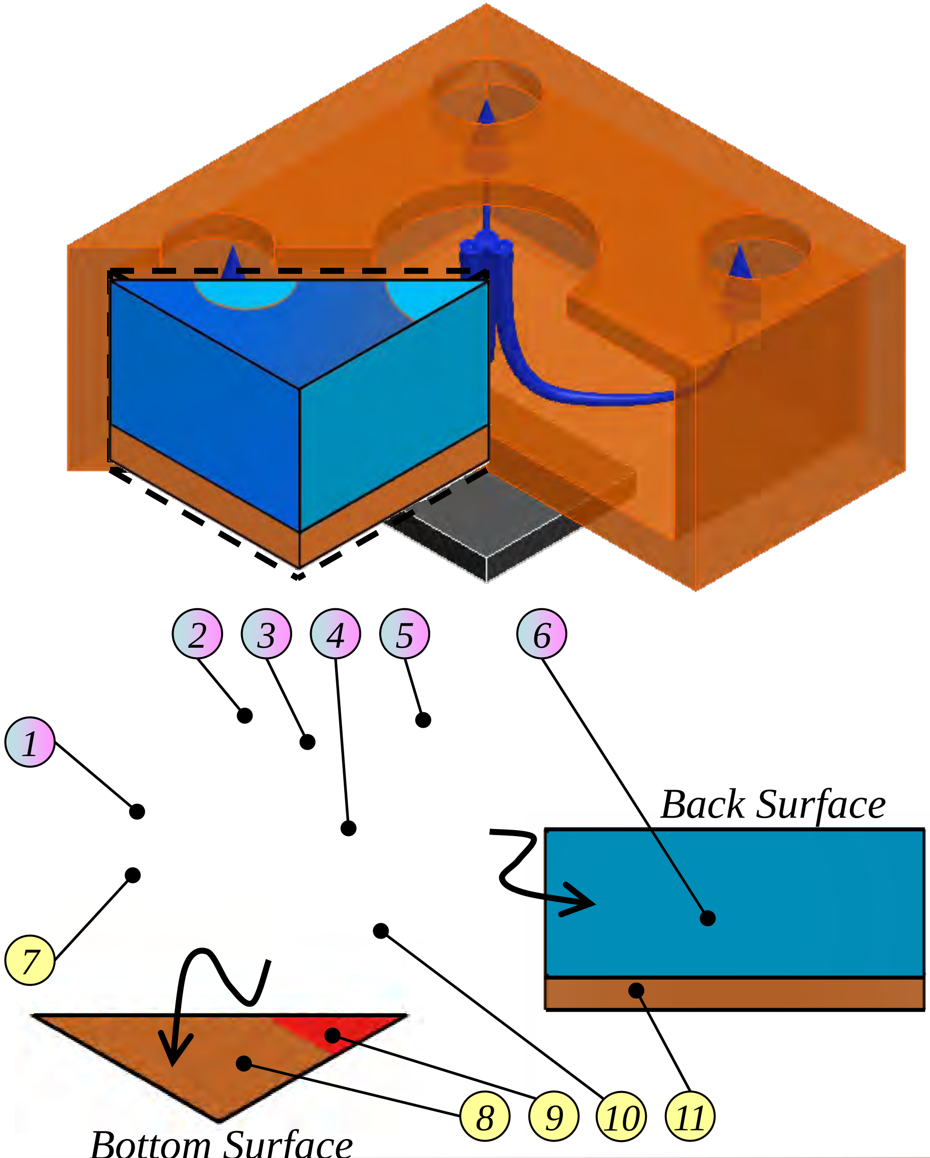
source:
electronics-cooling.com

Design Objectives

"A Better Design for PC cooling"

- Better thermal conductivity
  - Conducting material enclosing the fluid
- Better thermal agent
  - Electronic safe and thermal efficient
- Better geometry design
  - Central impinging jet
  - Micro impinging jets
  - Uniform-cross-section central impinging jet

Multi-Physics and Boundary Conditions



FLUIDIC

- (1)(3) No slip
- (4)(6) Slip
- (2) Outflow
- (5) Inflow: constant 10 L/hr

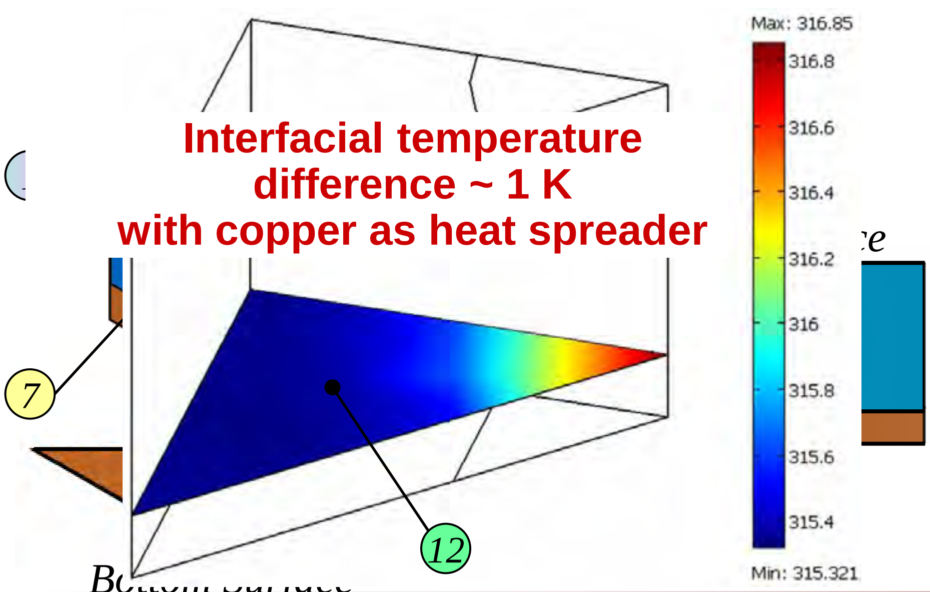
CONVECTION

- (1)(3)(4)(6) Insulation
- (2) Convective flux
- (5) Constant 300 K

CONDUCTION

- (7)(8)(10)(11) Insulation
- (9) Constant heat flux: 25 W/cm^2

Multi-Physics and Boundary Conditions



Interfacial temperature difference ~ 1 K with copper as heat spreader

FLUIDIC

- (12) (1) (3) No slip
- (4) (6) Slip
- (2) Outflow
- (5) Inflow: constant 10 L/hr

CONVECTION

- (1) (3) (4) (6) Insulation
- (2) Convective flux
- (5) Constant 300 K
- (12) Constant 350 K @ interface

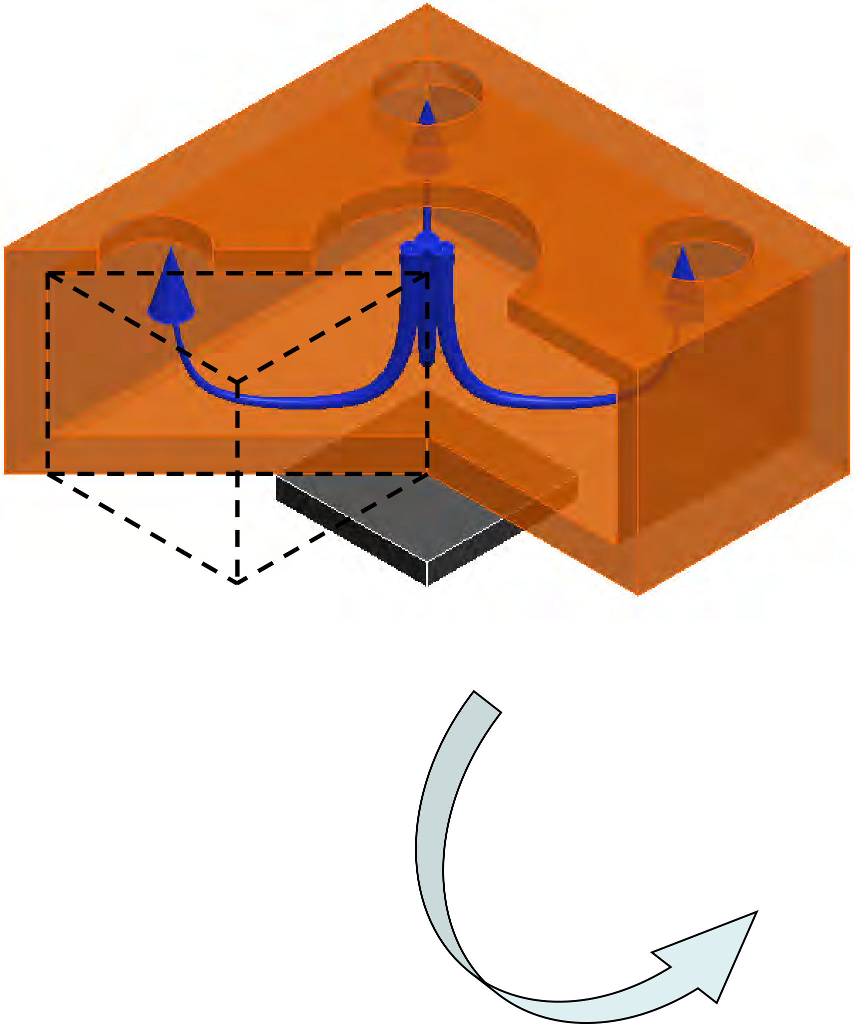
CONDUCTION

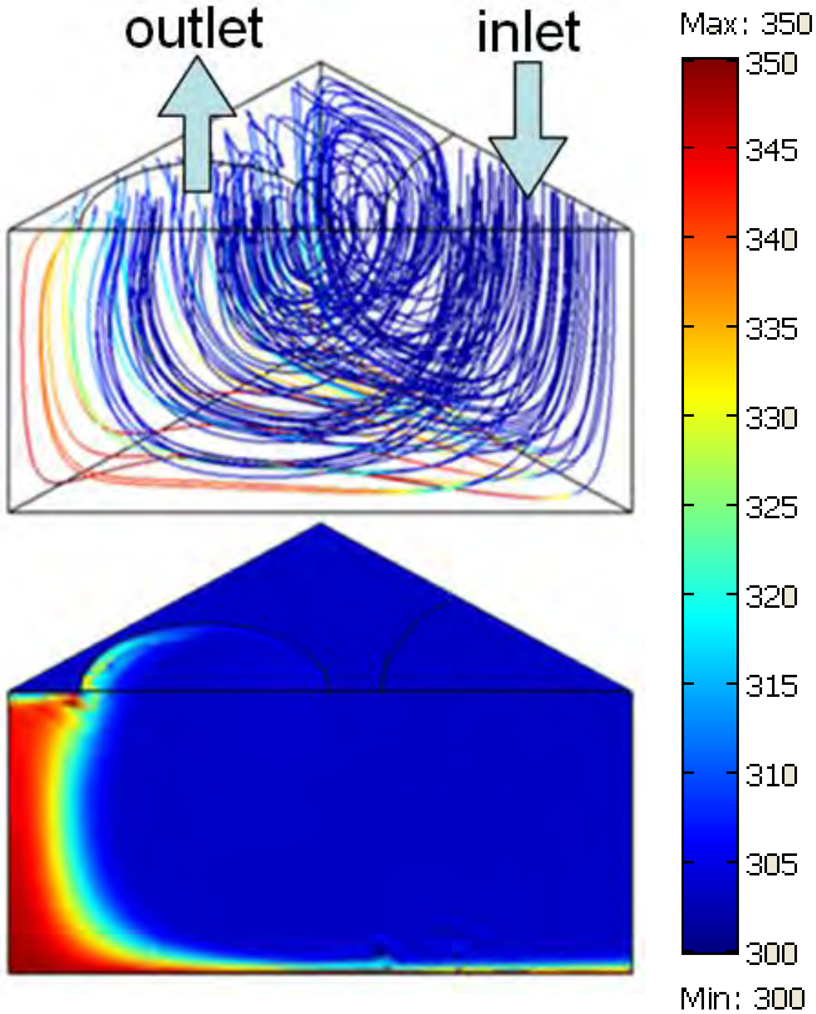
- (7) (8) (10) (11) Insulation
- (9) Constant heat flux: 25 W/cm^2

Geometry Design I: Central Jet

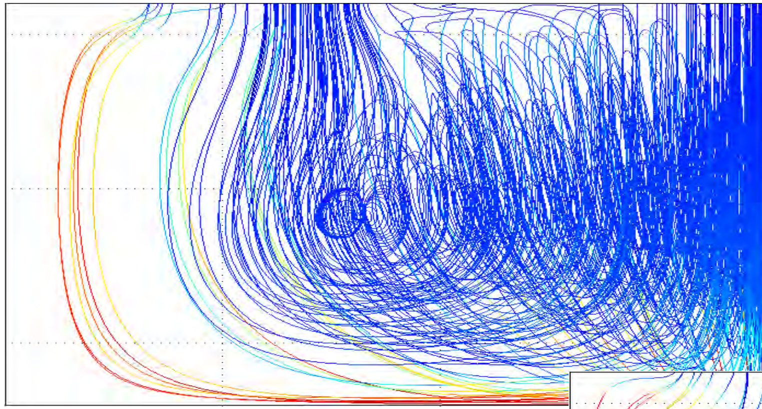
- In the design, different kinds of inlets/outlets sizes have been selected to find the optimal sizes for the heat convection in the defined symmetric volume.
  - same total volume flow rate (10 liter per hour)
  - same total inflow and outflow area
  - three pairs of inflow and outflow radius have been selected for comparison

Geometry Design I: Central Jet

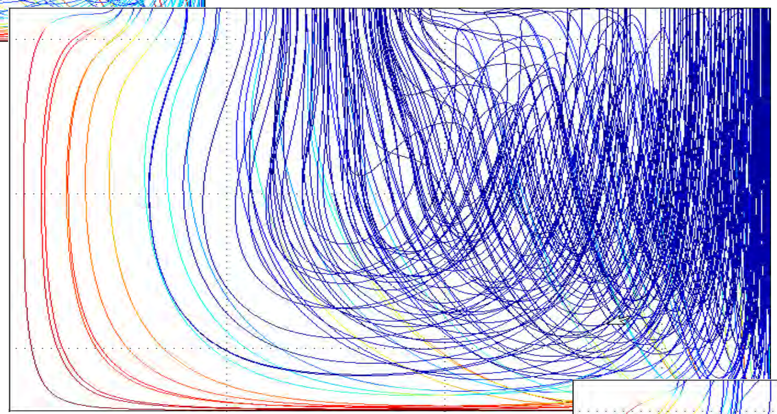




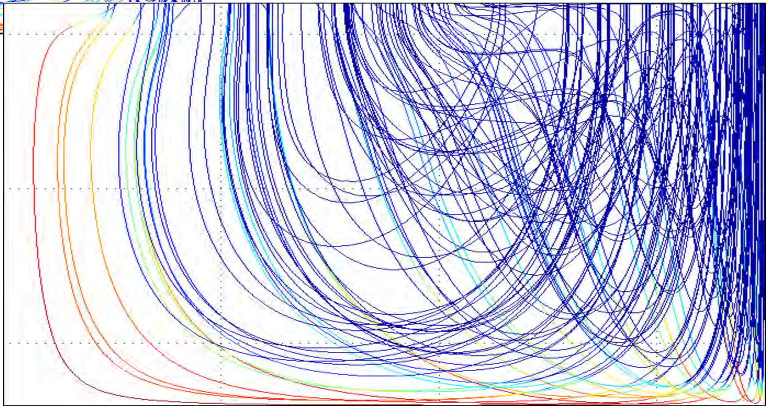
Geometry Design I: Central Jet



Inlet Radius: 6 mm



8 mm



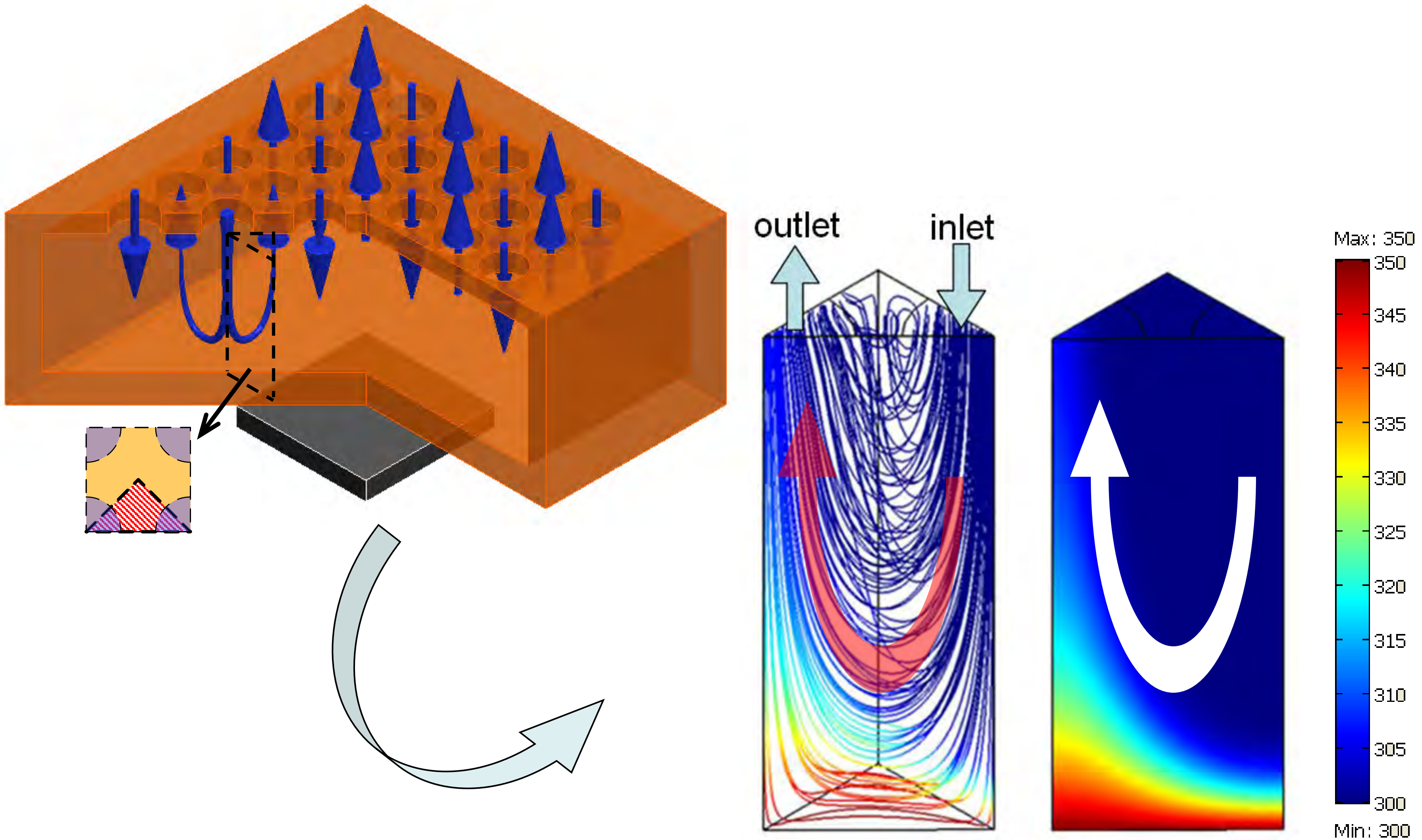
10mm

Geometry Design I: Central Jet

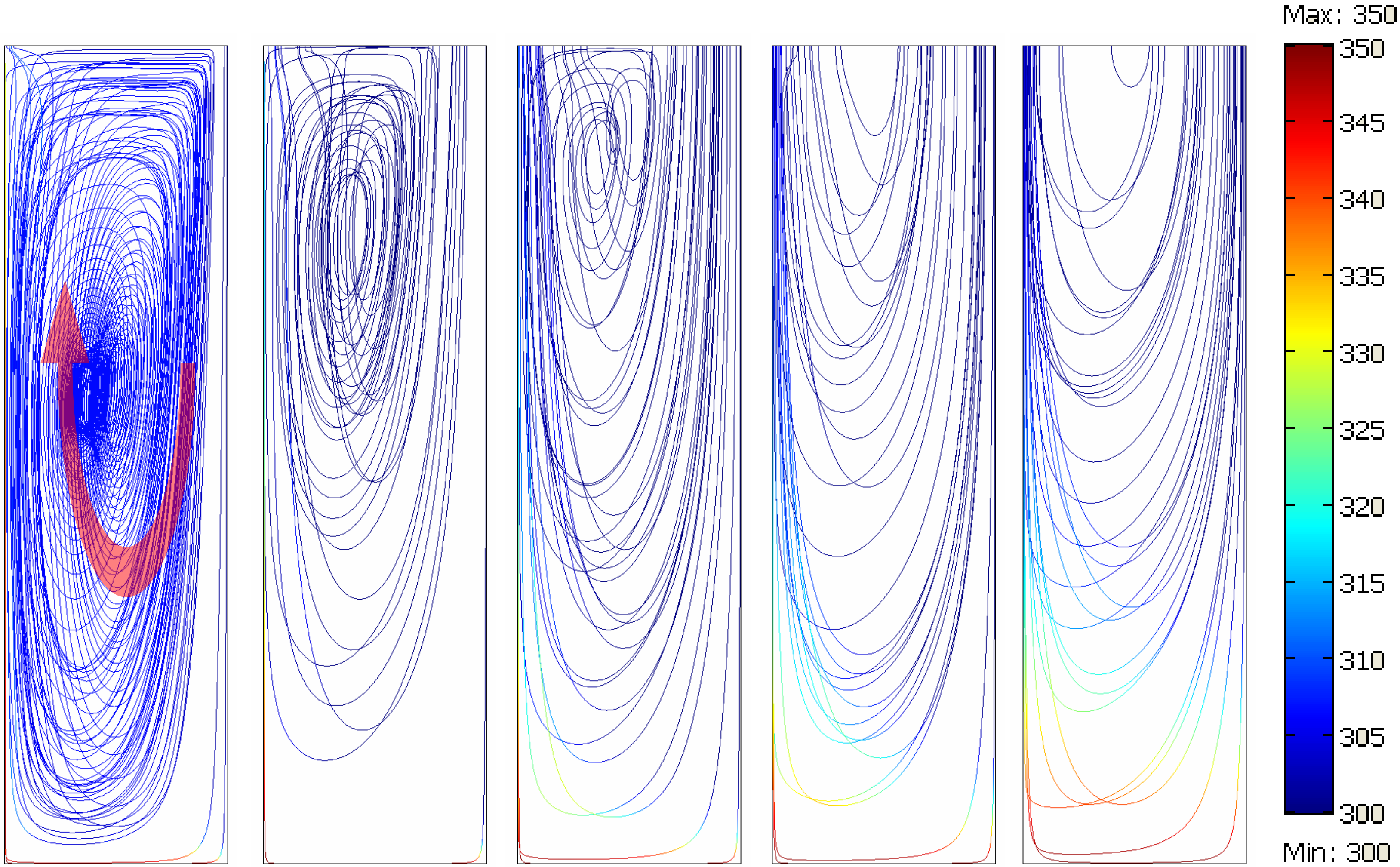
- Heat transfer efficiency (e) = the ratio of the total heat flux at the fluid-solid interface and the total exhausted power of the pump.

$r_{in}(mm)$	$V_{in}\ (mm/s)$	$\int q'' dA_b\ (w)$	$\Delta p \cdot A_{in}\ (N)$	$e = \frac{\int q'' dA_{base}}{\Delta p \cdot A_{in} \cdot V_{in}}$
6	24.56	10.746	3.2912E-6	1.3294E+05
8	13.82	9.473	1.7395E-6	3.9405E+05
10	8.84	7.848	1.5817E-6	5.6128E+05

Geometry Design II: Micro Jets

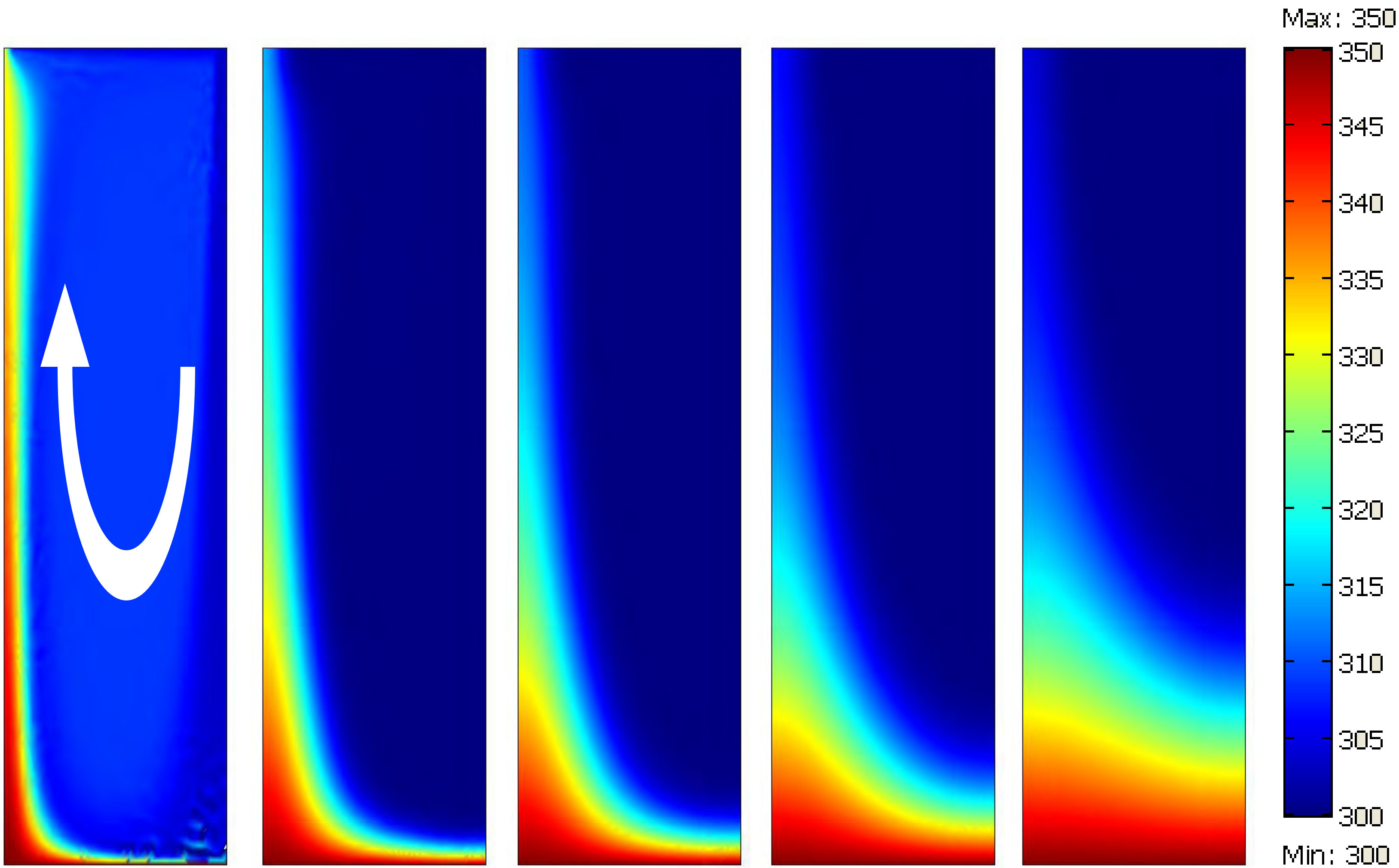


Geometry Design II: Micro Jets



Radius = 0.2 1 1.5 2 2.3 mm

Geometry Design II: Micro Jets



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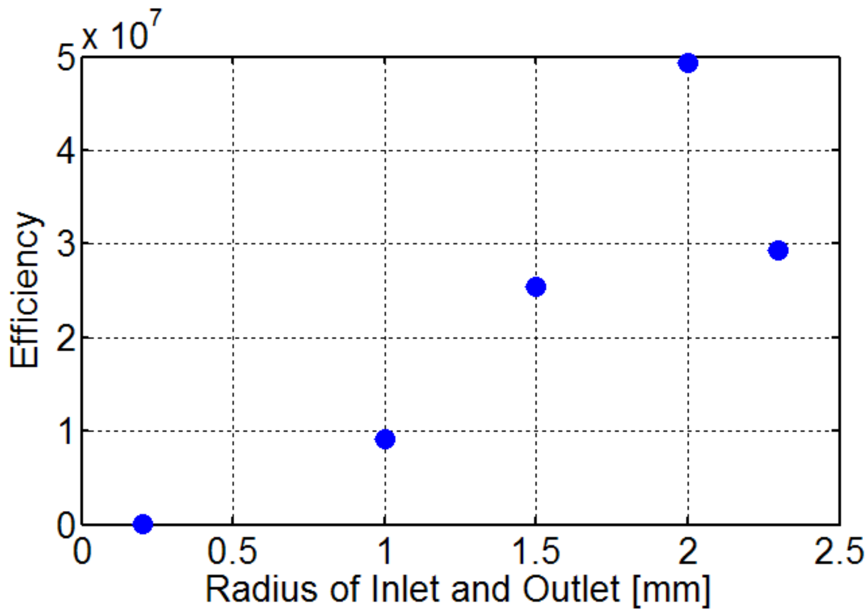
Geometry Design II: Micro Jets

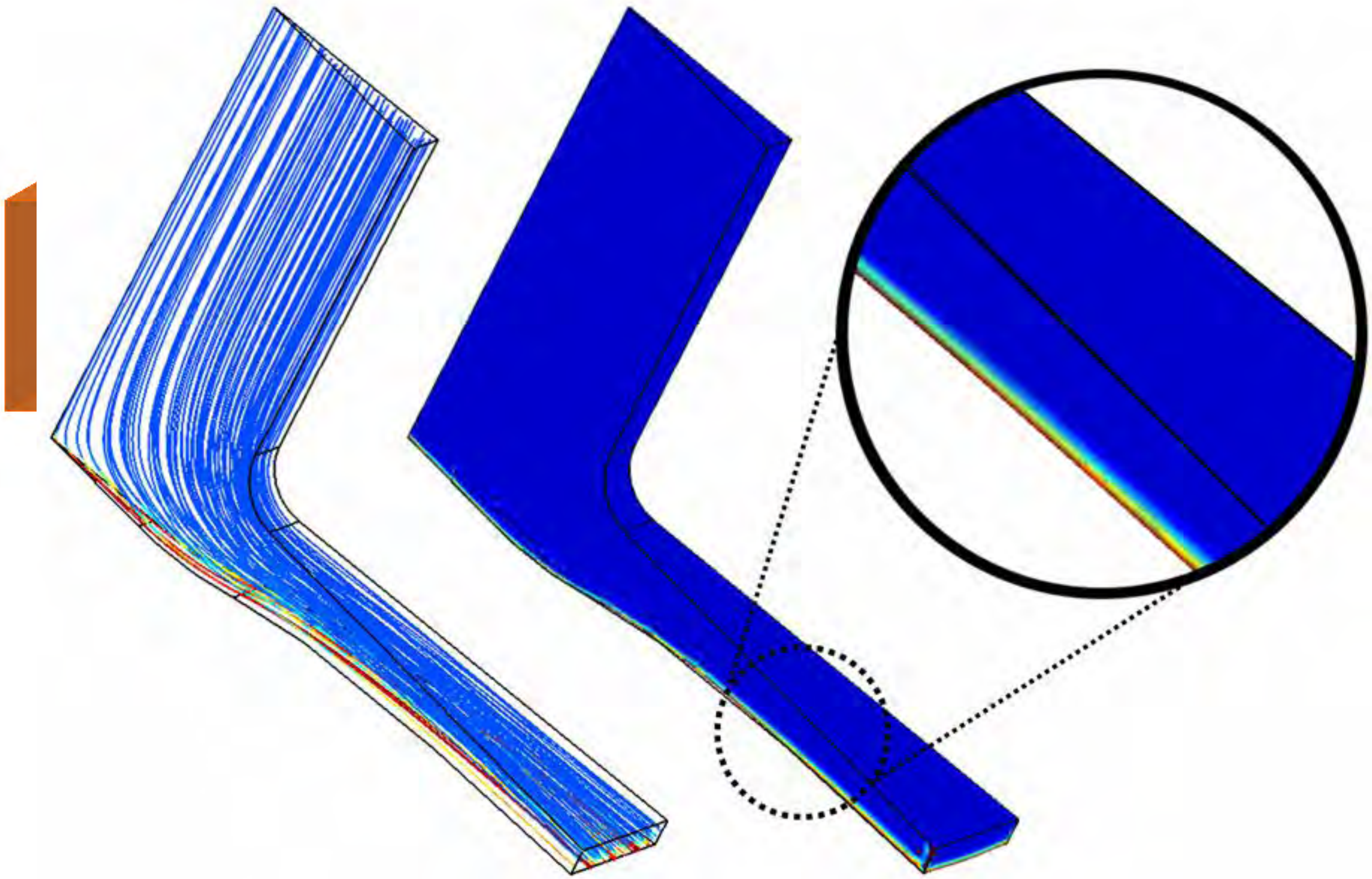


r_{in} (mm)	V_{in} (m/s)	$\int q'' dA_b$ (w)	$\Delta p \cdot A_{in}$ (N)	e
0.2	1.2280E+00	1.1650E+00	1.3971E-05	6.7906E+04
1	4.9122E-02	2.7591E-01	6.1672E-07	9.1076E+06
1.5	2.1832E-02	1.5501E-01	2.7885E-07	2.5462E+07
2	1.2280E-02	7.8645E-02	1.2995E-07	4.9284E+07
2.3	9.2860E-03	4.1599E-02	1.5296E-07	2.9286E+07

Geometry Design III: Uniform-Cross-Section Central Jet

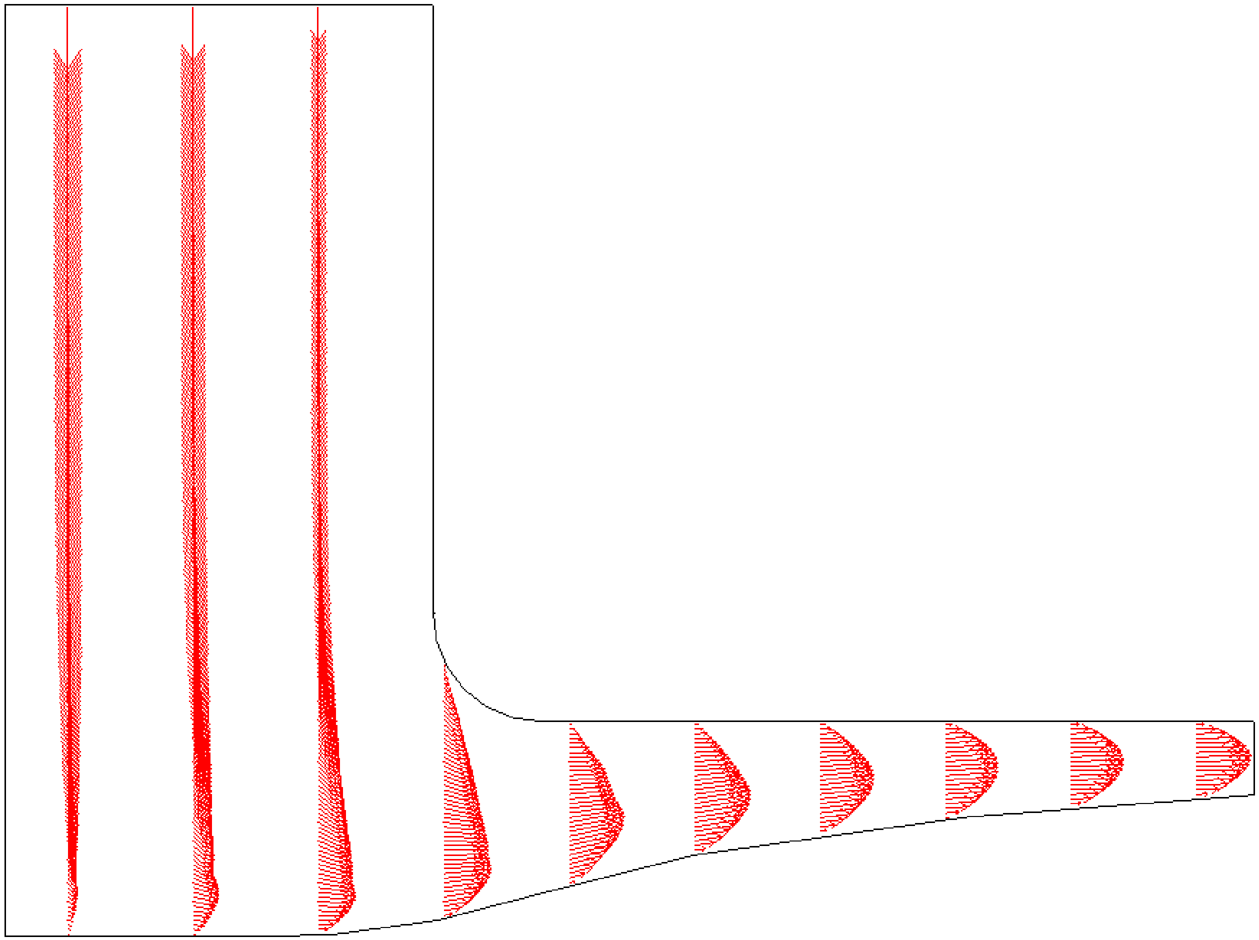
- Design Considerations
  - Minimize vortexes under the same flow rate
  - Increase the heat exchange surface area
  - Decrease thickness of thermal boundary layer
  - Maximized the heat removal ability
  - Reduce the manufacturing cost with simple design

Geometry Design III: Uniform-Cross-Section Central Jet



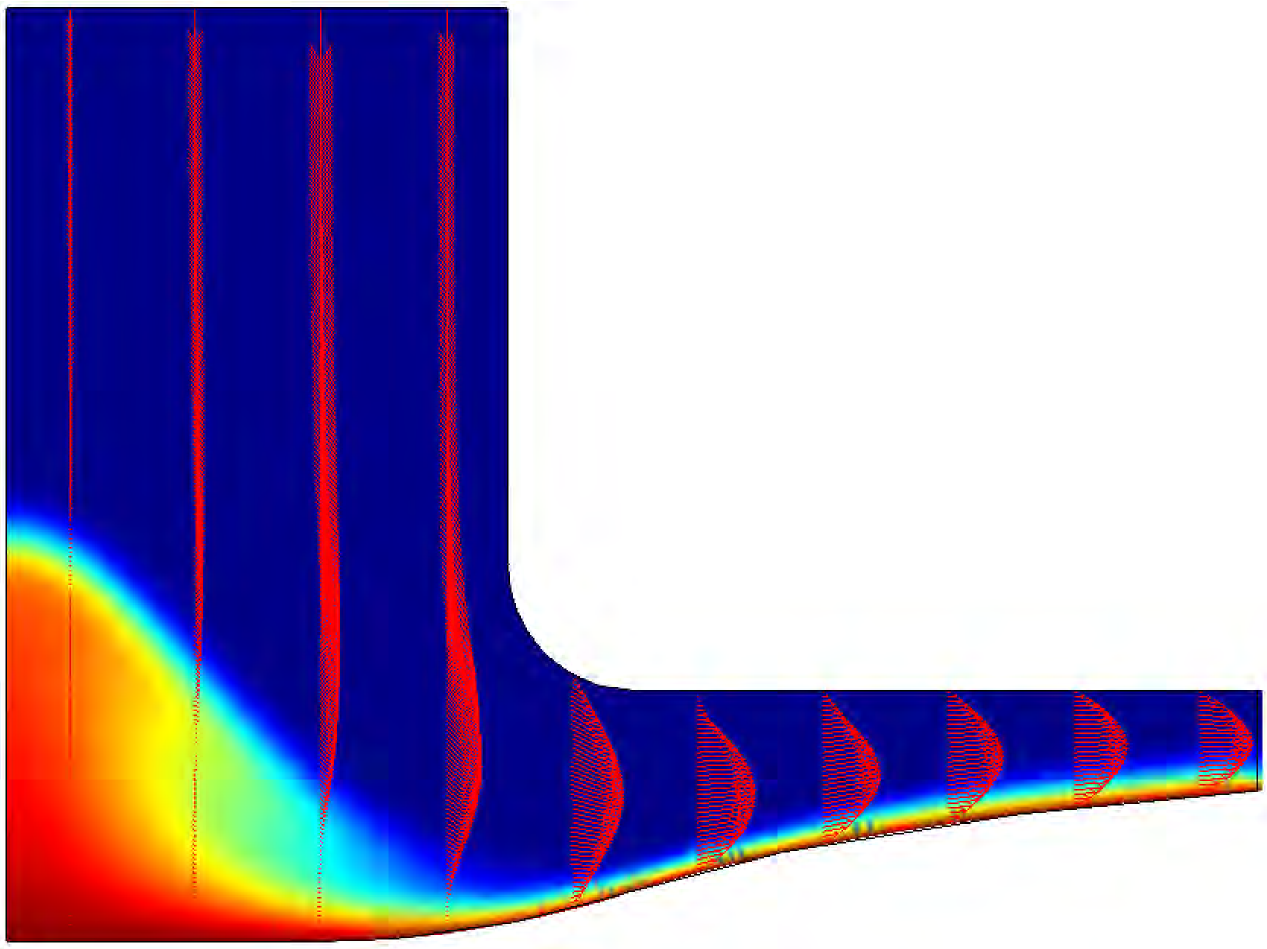
Geometry Design III: Uniform-Cross-Section Central Jet

- Result: Flow streamlines



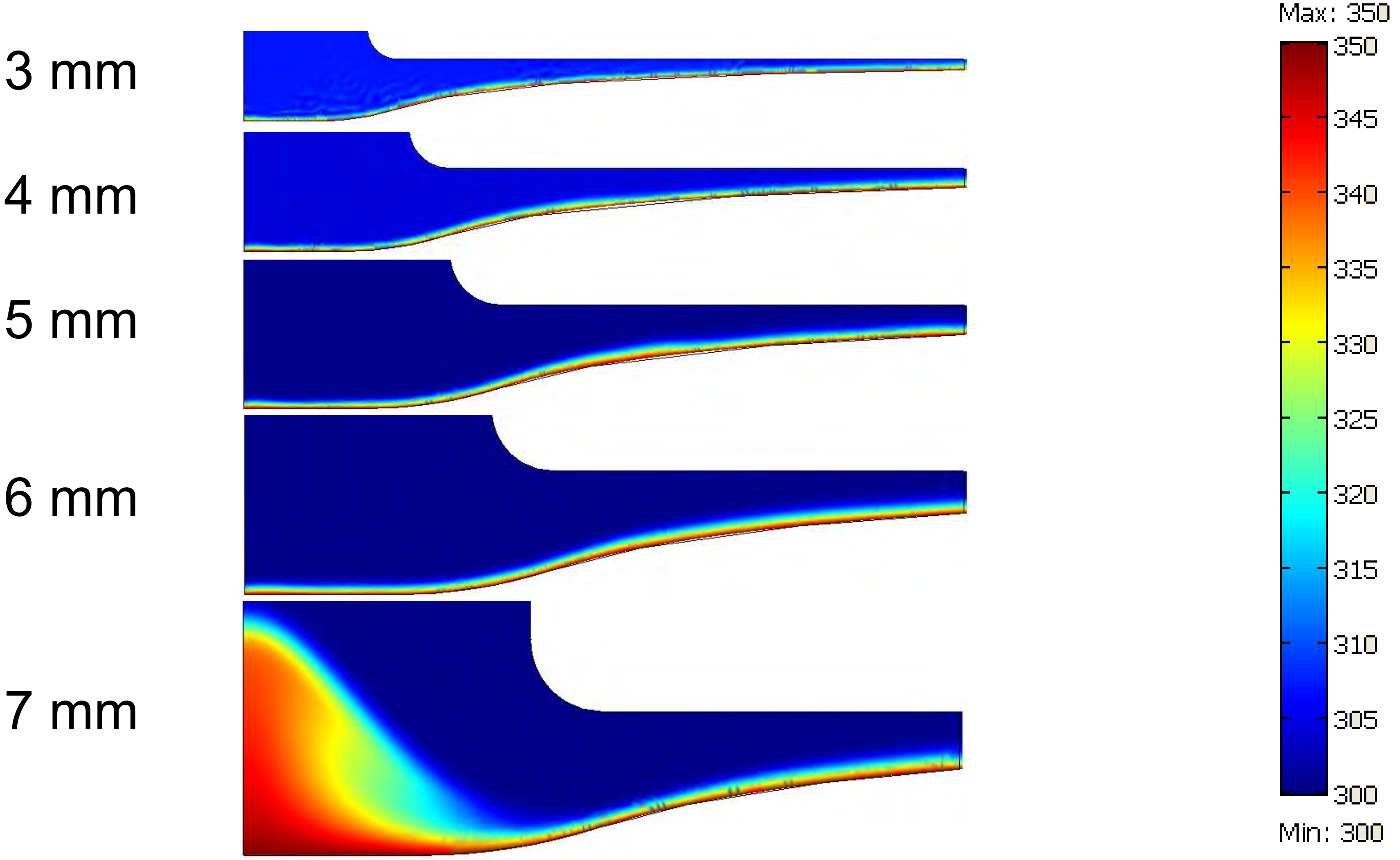
Geometry Design III: Uniform-Cross-Section Central Jet

- Result: Flow streamlines



Geometry Design III: Uniform-Cross-Section Central Jet

Radius =

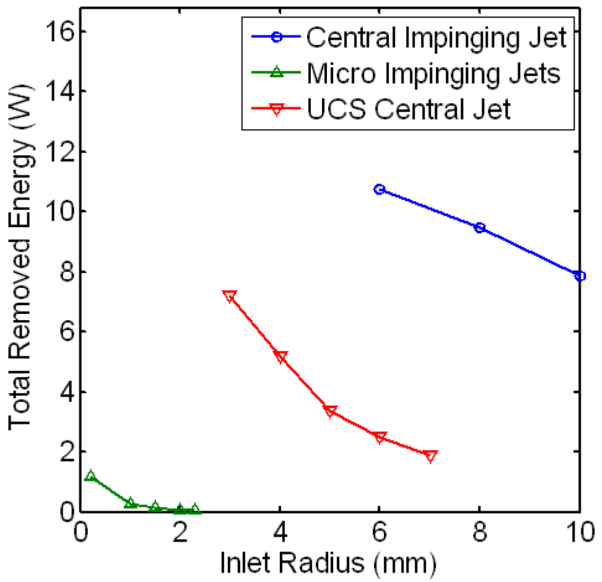


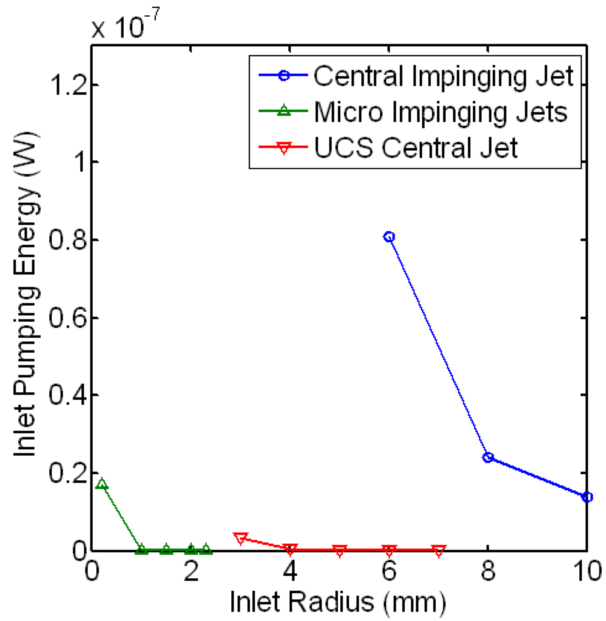
Geometry Design III: Uniform-Cross-Section Central Jet

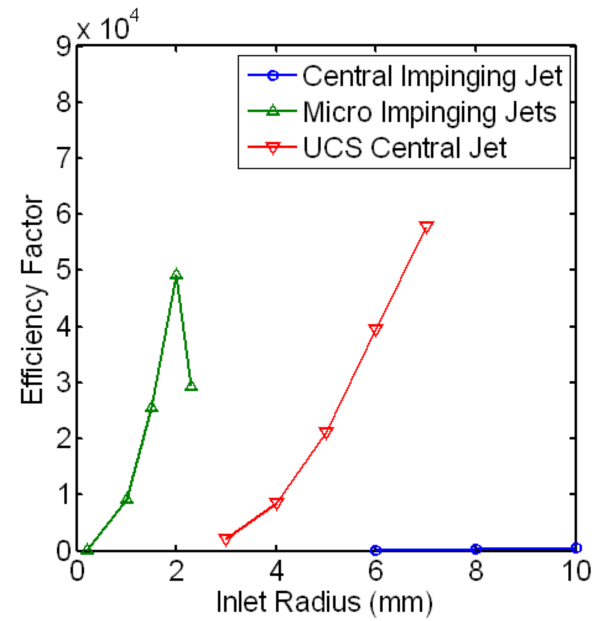
- Result:

r_{in} (mm)	V_{in} (m/s)	$\int q'' dA_b$ (w)	$\Delta p \cdot A_{in}$ (N)	e
3	9.2294E-2	7.2154	3.5688E-5	2.1906E+6
4	5.5290E-2	5.1856	1.0943E-5	8.5703E+6
5	3.5386E-2	3.3678	4.5190E-6	2.1061E+7
6	2.4573E-2	2.4907	2.5705E-6	3.9431E+7
7	1.8054E-2	1.8866	1.8099E-6	5.7735E+7

Comparisons







Conclusion

- Liquid cooling devices using impinging jets
  - Thin hydrodynamic and thermal boundary layers
  - Good improvement of heat transfer efficiency
- Three different geometry designs

  Central impinging jet
  - Removes a large amount of heat but requires higher pumping power.
  - Has lowest thermal efficiency.

  Micro impinging jets
  - Consumes a small amount of pumping power and has higher thermal efficiency than first design.
  - Has an efficiency gap at R = 2 mm.

  Uniform-cross-section central impinging jet
  - Consumes the smallest amount of pumping power and removes the heat efficiently.
  - Has the highest thermal efficiency.