COMSOL CONFERENCE 2018 SHANGHAI

Topology Optimization for Liquid Cooled Heat Sink Design

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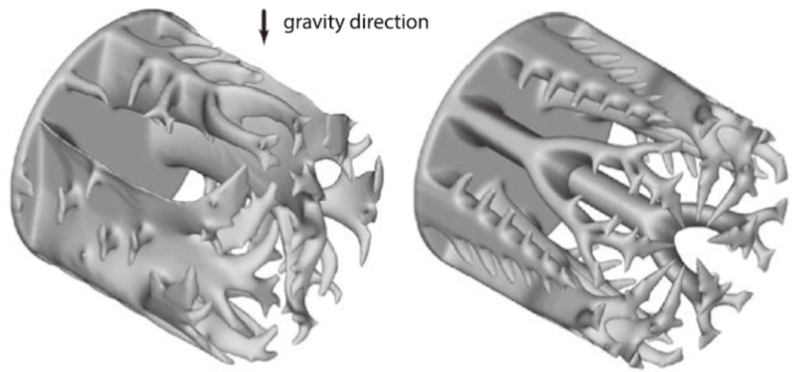
TopOPt for heat sink design

Passive cooling devices (natural convection)



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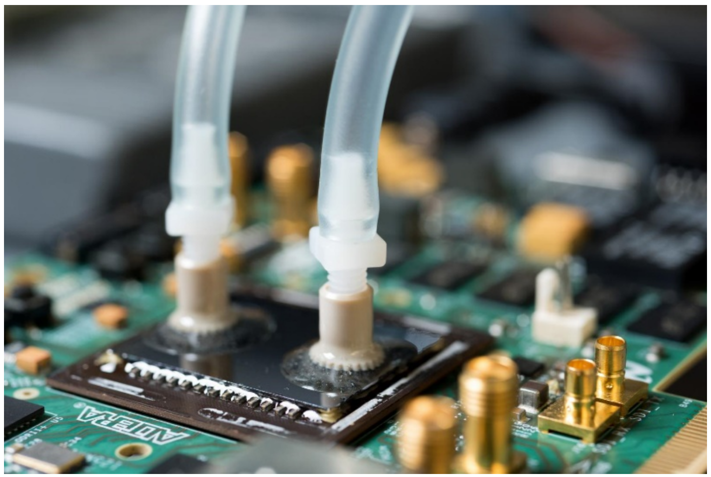
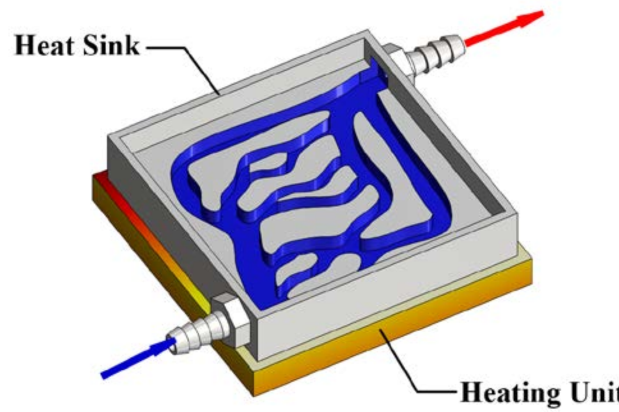
TopOPt for heat sink design

Active cooling devices (forced convection)





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TopOPt for heat sink design

Common in TopOPt for heat sink design:

- Thermo-fluidic problems
- High nonlinear
- Topology (layout) determines the response of structure

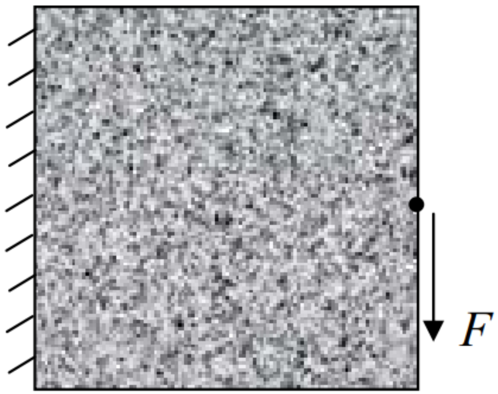
We need to find the OPTIMAL TOPOLOGY (LAYOUT) to enhance the heat transfer rate.

⬇

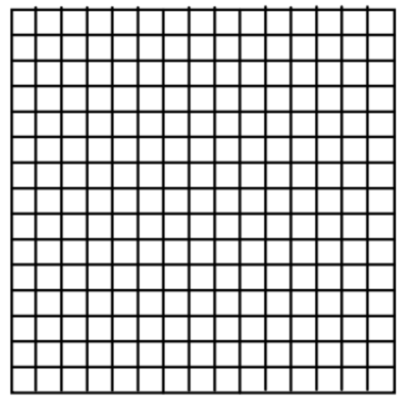
Our project use TOPOLOGY OPTIMIZATION to come up with the optimal cooling channel layout.

Structural Topology Optimization

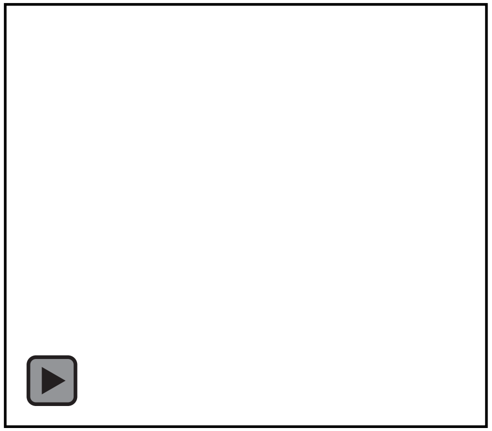
Bendsoe (1989), Zhou and Rozvany (1991), Miejnek (1992)



Design problem



Discretized elements



Optimal topology

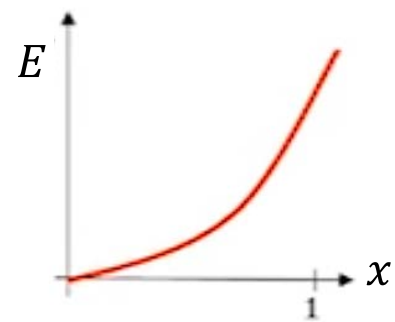
$$Find: X = \{x^1, x^2, \cdots x^N\}^T \quad (x_{\min} \leq x \leq x_{\max} = 1)$$

$$Min: \quad C = F^T U = U^T K U$$

$$s.t.: \quad V = f V_0 = \sum_{e=1}^{N} x^e v^e$$

$$F = KU$$

Interpolation function:



$$E(x_e) = x_e^p E_0$$

$$p > 1$$

Topology optimization

Common in TopOPt:

- Objective function
  - i.e. compliance, flow dissipation, sound pressure
- Design variable
- Constraint
  - i.e. volume fraction

Fluid problems

Navier-Stokes equations

Incompressible Navier-Stokes equation for porous flow

$$\left(\mathbf{u}^* \cdot \nabla^*\right)\mathbf{u}^* = \nabla^*\left[-p^*\mathbf{I} + \frac{1}{\mathrm{Re}}\left(\nabla^*\mathbf{u}^* + \left(\nabla^*\mathbf{u}^*\right)^T\right)\right] - \alpha^*\mathbf{u}^*$$

$$\nabla^* \cdot \mathbf{u}^* = 0$$

Non-fluid (solid) domain

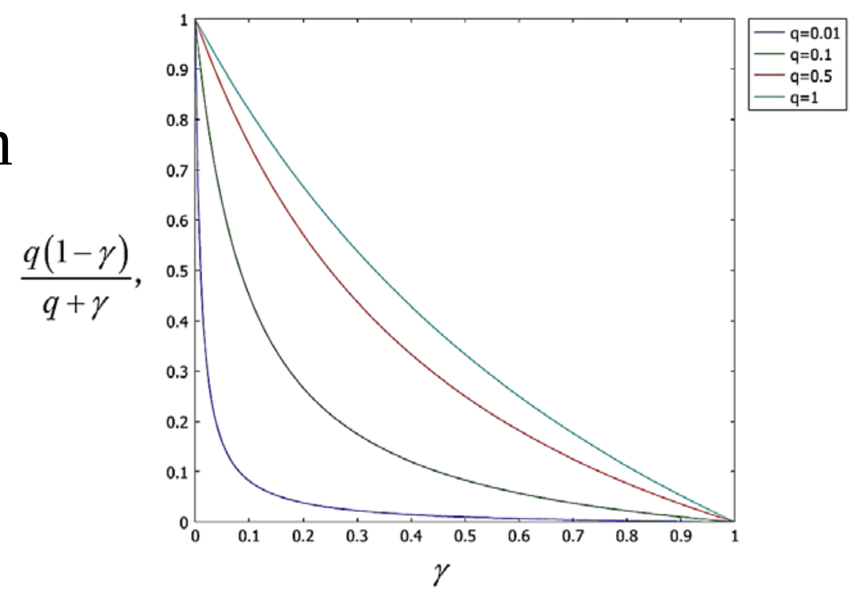
$\gamma=0,\ \alpha\rightarrow\infty,\ F\rightarrow\infty \ \Longrightarrow\ \mathbf{u}=0$

Fluid domain

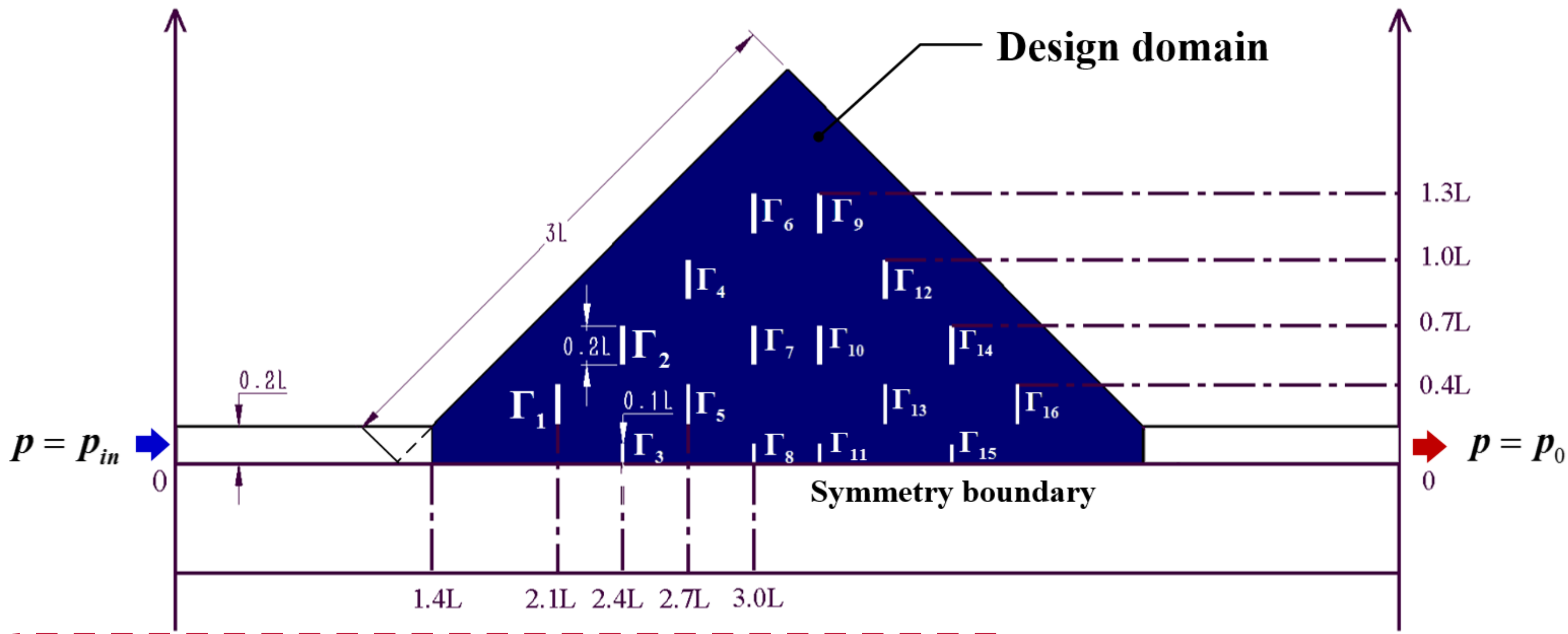
$\gamma=1,\ \alpha\rightarrow 0,\ F\rightarrow 0 \ \Longrightarrow$ NS equation

Interpolation function

$$\alpha^*(x) = \alpha^*_{\max}\frac{q(1-\gamma)}{q+\gamma}$$



2D flow distribution problem



$$\underset{\gamma\in[0,1]}{\text{minimize}} \quad \Phi = \int_{\Omega}\left[\nabla^{*}\mathbf{u}^{*}\cdot\left(\nabla^{*}\mathbf{u}^{*}+\nabla^{*}\mathbf{u}^{*T}\right)+\alpha^{*}\mathbf{u}^{*}\cdot\mathbf{u}^{*}\right]d\Omega,$$

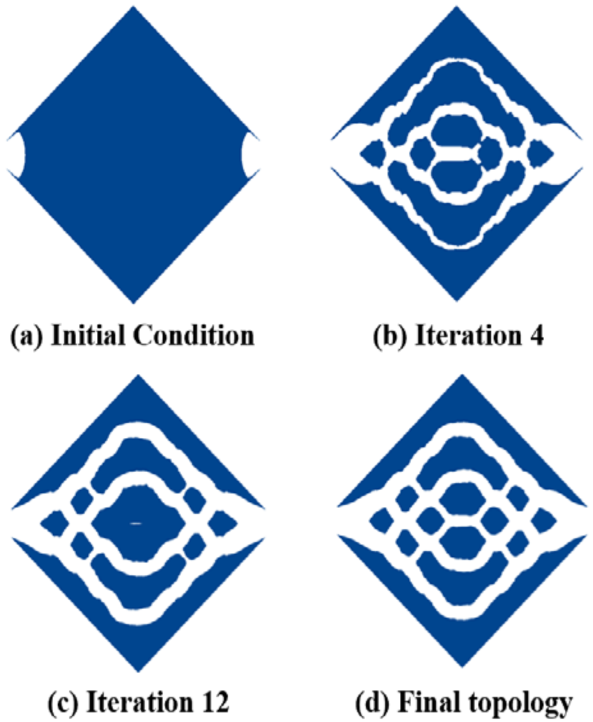
$$s.t. \quad \int_{\Omega}\gamma\, d\Omega \leq V_f\cdot Vol_{\Omega},$$

$$\int_{\Gamma_i}\mathbf{u}^{*}\cdot\mathbf{n}\, d\Gamma_i = FR_i\cdot\dot{V}_{in}, \quad \text{i=1,...,n},$$

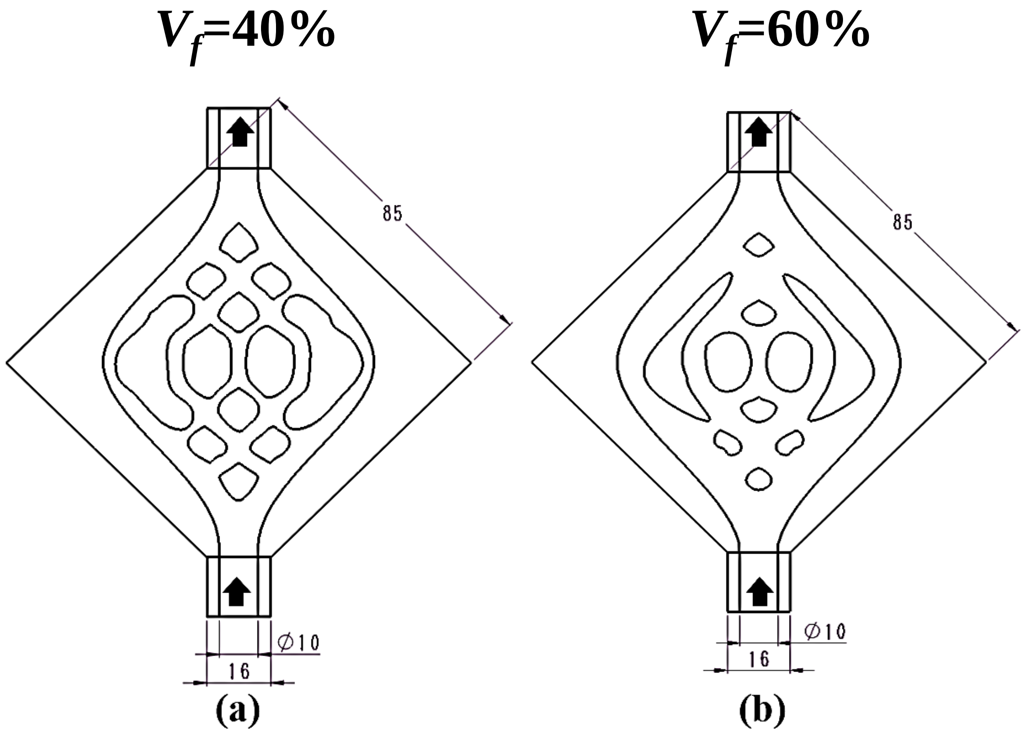
$$\int_{\Gamma_{\text{in}}} p_{in}^{*}\, u^{*}\, d\Gamma = 1,$$

$FR_1 = FR_{16} = 1/2$,
$FR_2 = FR_{14} = 1/3$,
$FR_3 = FR_{15} = 1/6$,
$FR_4 = FR_5 = FR_{12} = FR_{13} = 1/4$,
$FR_6 = FR_7 = FR_9 = FR_{10} = 1/5$,
$FR_8 = FR_{10} = 1/10$

2D flow distribution problem



Iterative process
(V_f=40%)



Optimal channel layout

Thermo-fluidic problems

Navier-Stokes equations

Incompressible Navier-Stokes equation for porous flow

$$\left(\mathbf{u}^* \cdot \nabla^*\right)\mathbf{u}^* = \nabla^*\left[-p^*\mathbf{I} + \frac{1}{\mathrm{Re}}\left(\nabla^*\mathbf{u}^* + \left(\nabla^*\mathbf{u}^*\right)^T\right)\right] - \alpha^*\mathbf{u}^*$$

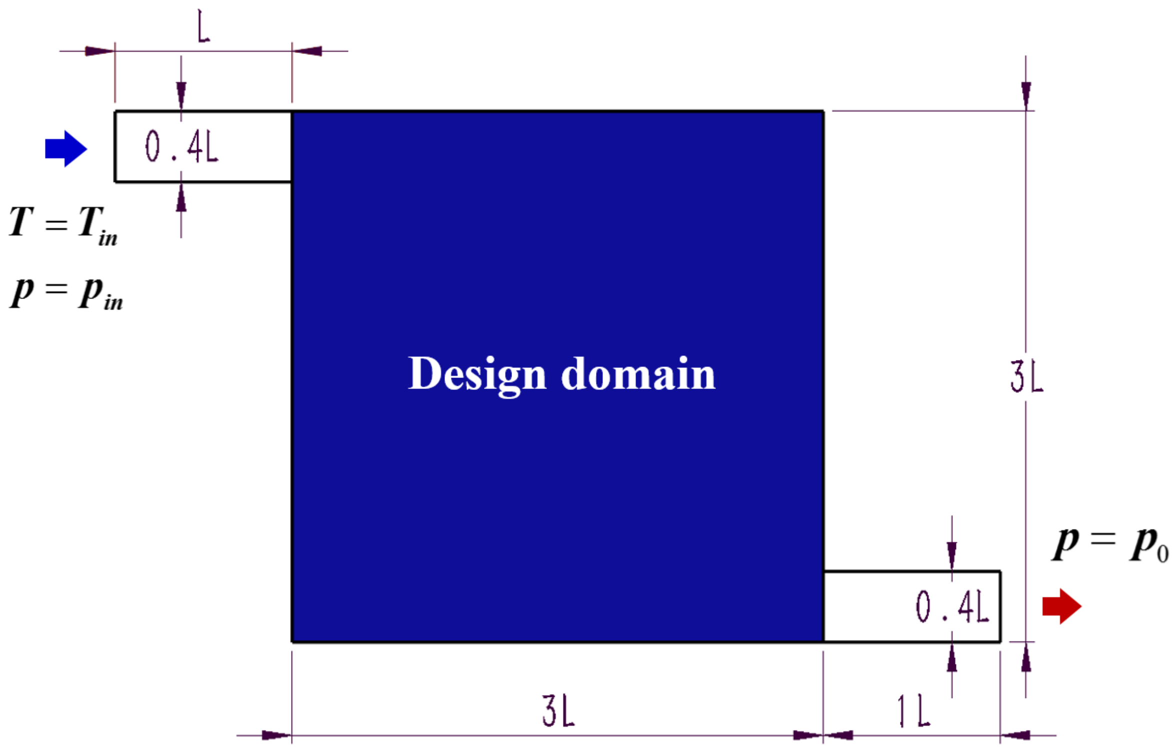
$$\nabla^* \cdot \mathbf{u}^* = 0$$

Energy equation

$$\mathrm{Re}\,\mathrm{Pr}\left(\mathbf{u}^* \cdot \nabla^*\right)T^* = \nabla^{*2}T^*, \qquad \text{(in fluid domains)}$$

$$0 = \nabla^{*2}T^* + Q^*, \qquad \text{(in solid domains)}$$

2D heat exchange problem

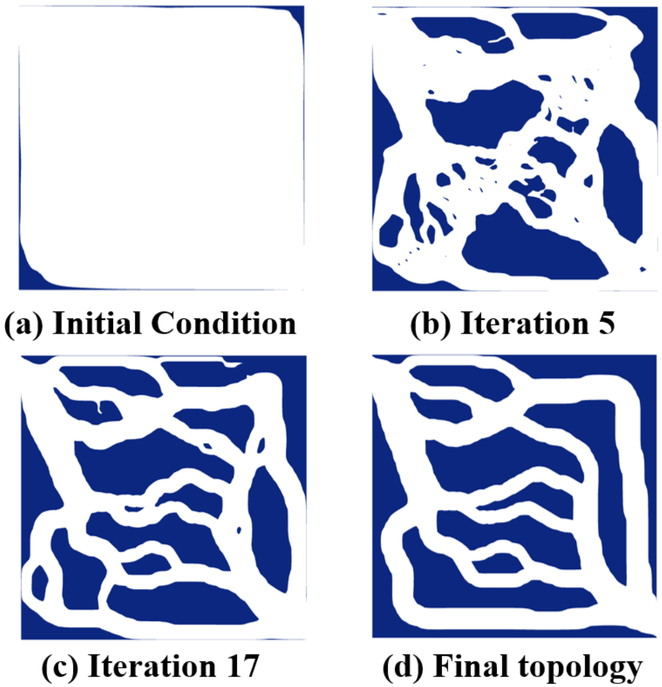


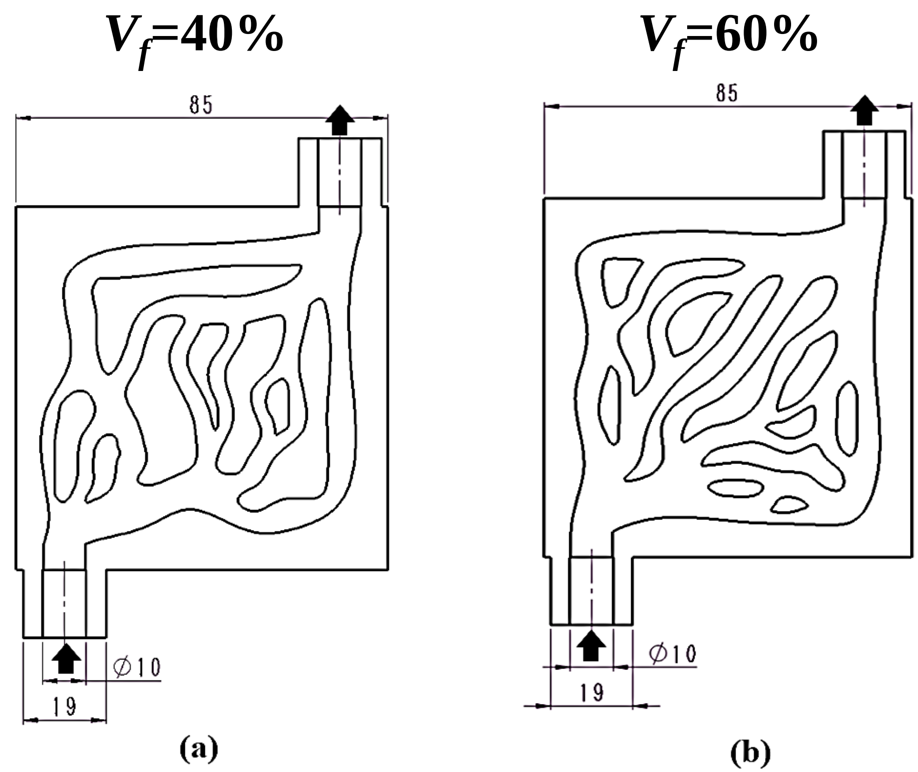
$$\underset{\gamma \in [0,1]}{\text{maximize}} \quad \Phi = \int_\Omega (1-\gamma) h^* (1-T^*)\, d\Omega,$$

$$s.t. \quad \int_\Omega \gamma \, d\Omega \le V_f \cdot Vol_\Omega,$$

$$\int_{\Gamma_{\text{in}}} p_{in}^* \, u^* \, d\Gamma = 1.$$

2D heat exchange problem



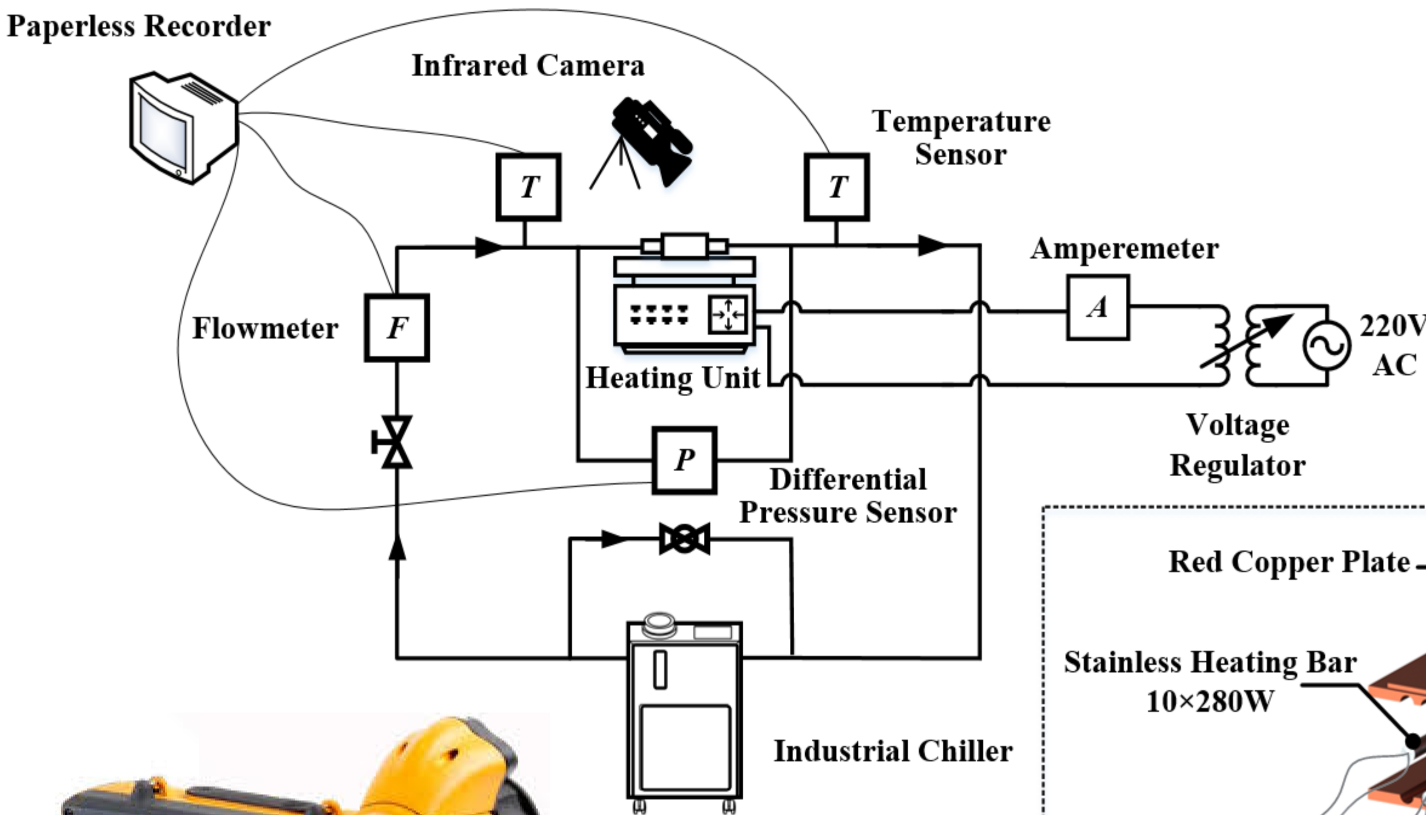


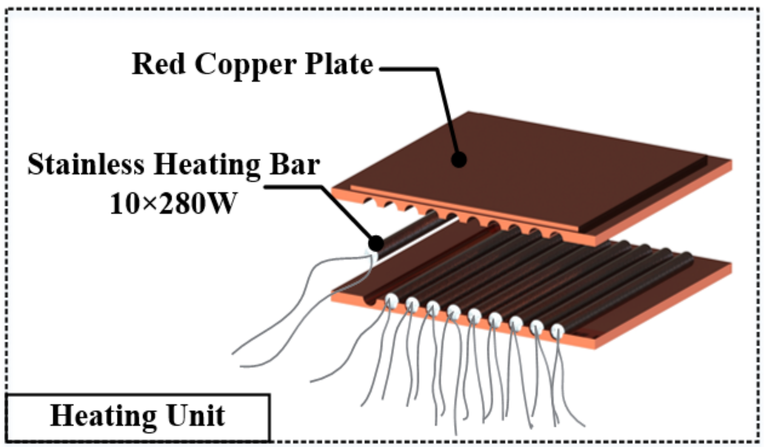
Iterative process (V_f=40%)

Optimal channel layout

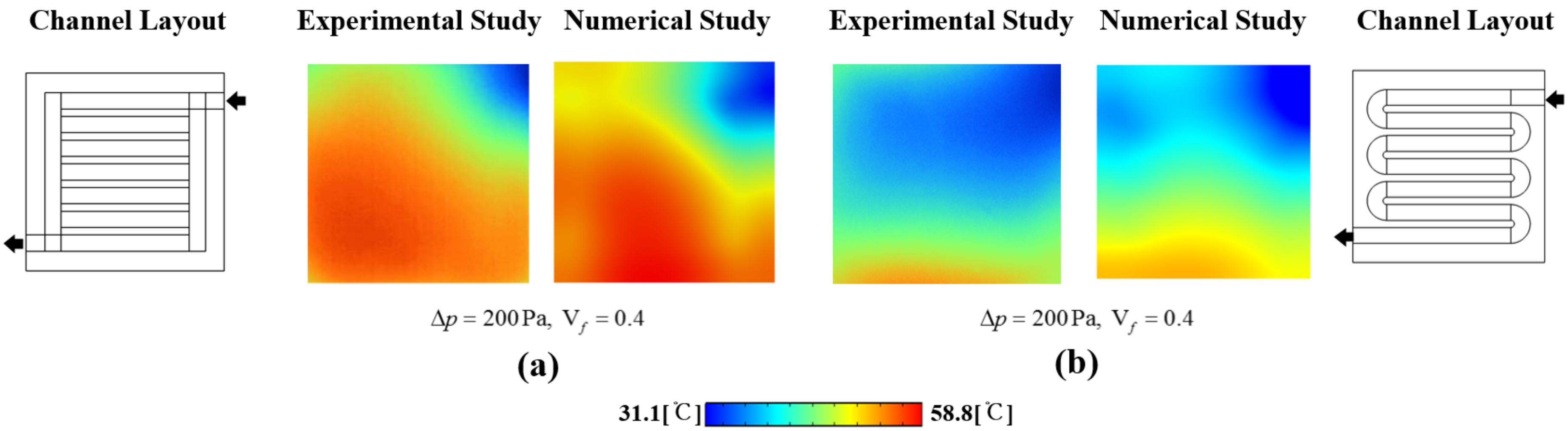
Flow and Thermal Performance

Experimental Verification

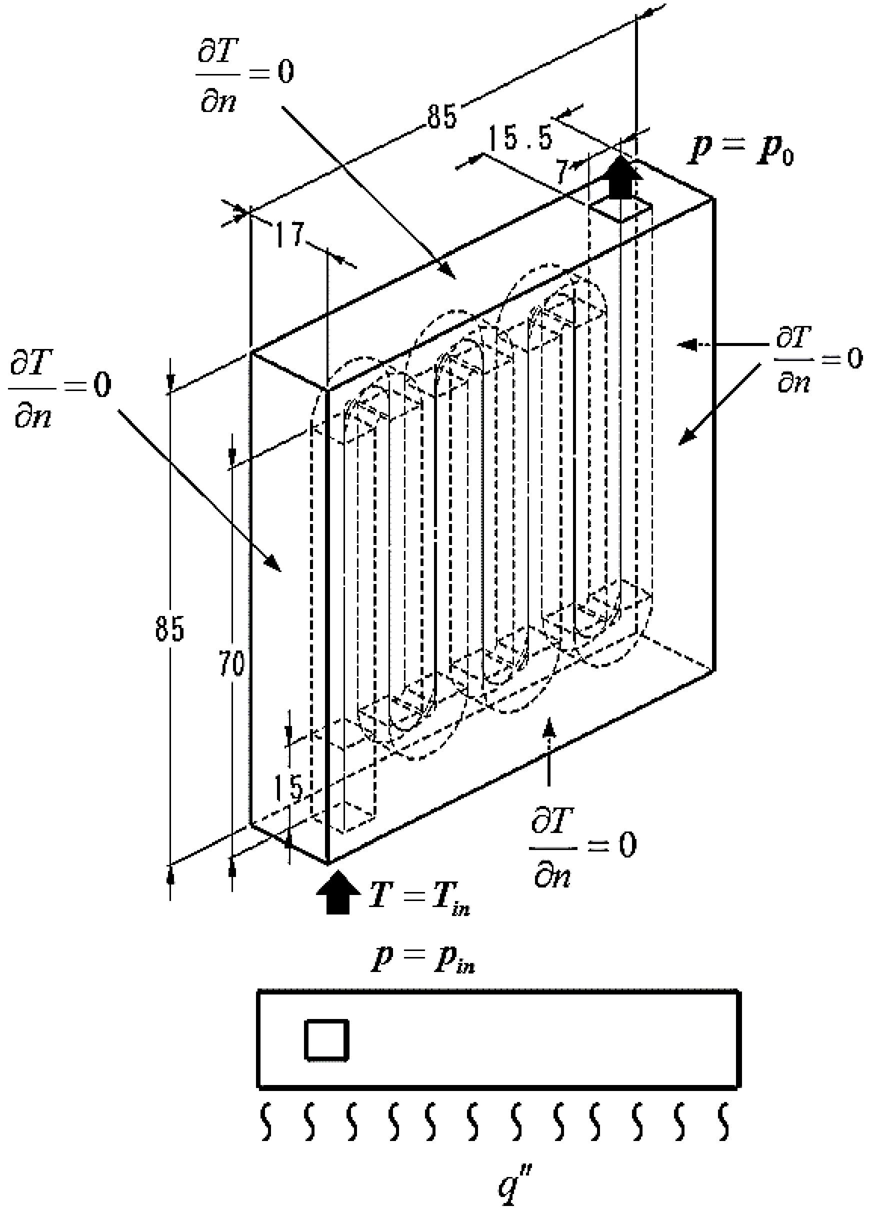




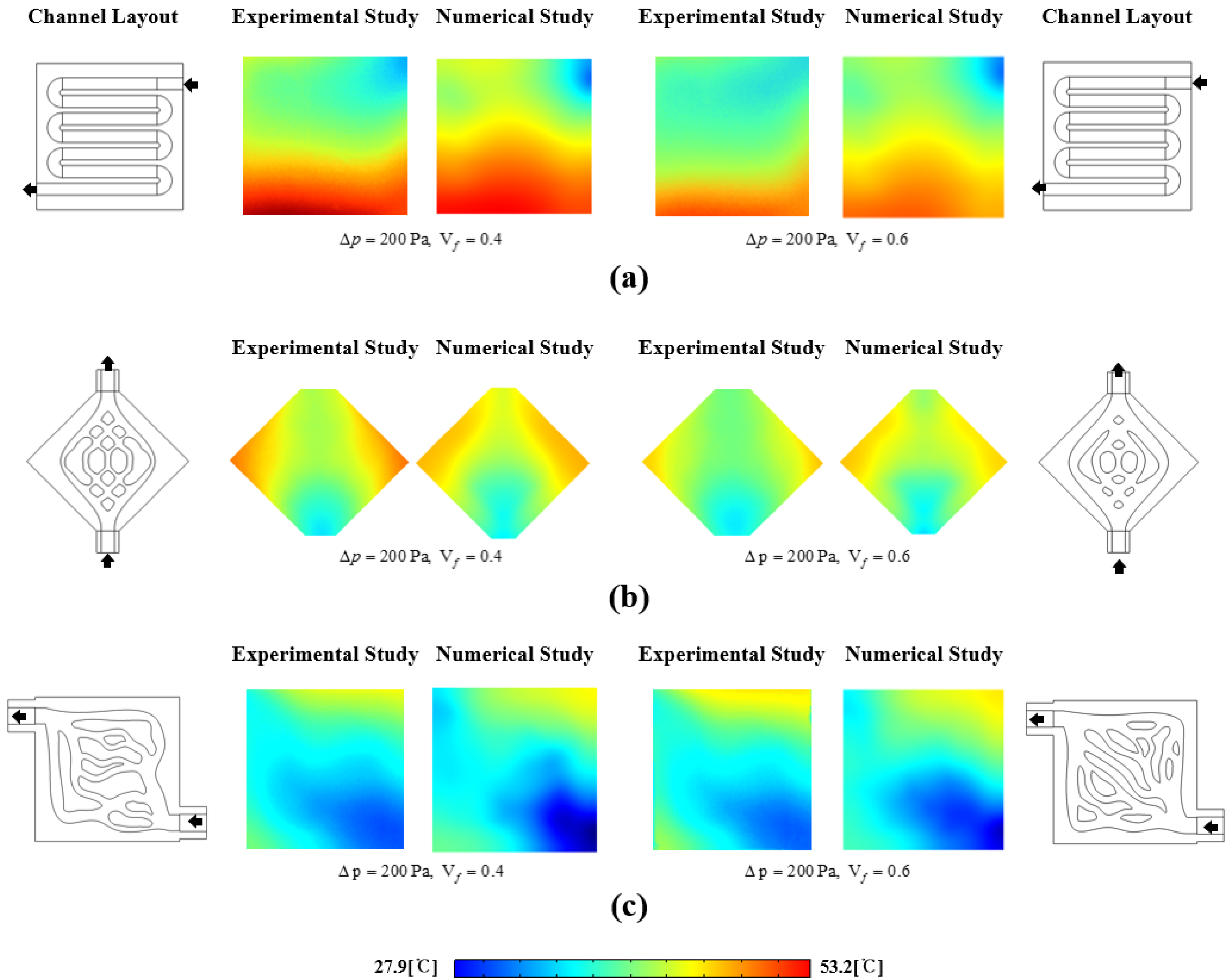
Reference case



Reference case



Temp. distrib. (Exper. VS Numerical)

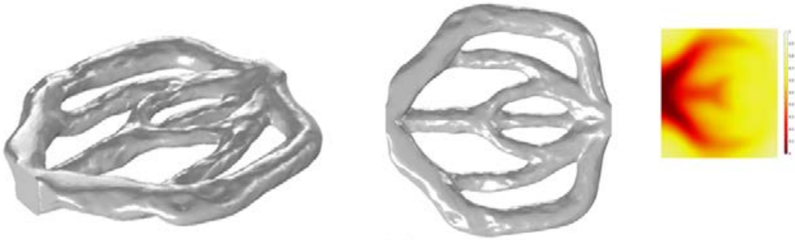


Conclusions

- Presented industrial application of TO in fluids, thermo-fluidic problems
- We are at the verge of being able to send TO results to manufacturing

Future works…

- 3D channels with 3DP technology
- TO considering turbulent flow



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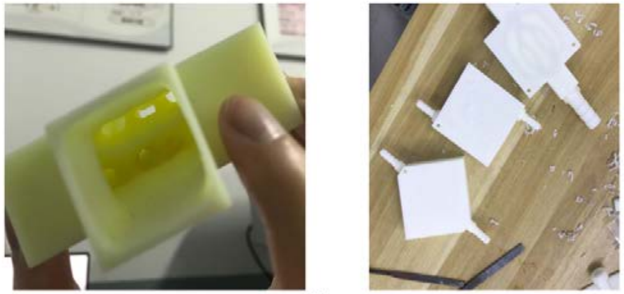

(b)

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Thanks for your attention!

Q&A

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