Enhanced Finned Tube Heat Exchanger Design through Topology Optimization

Zeng Shi
Sun Chuan
Lee Poh Seng

Department of Mechanical Engineering

NUS
National University of Singapore

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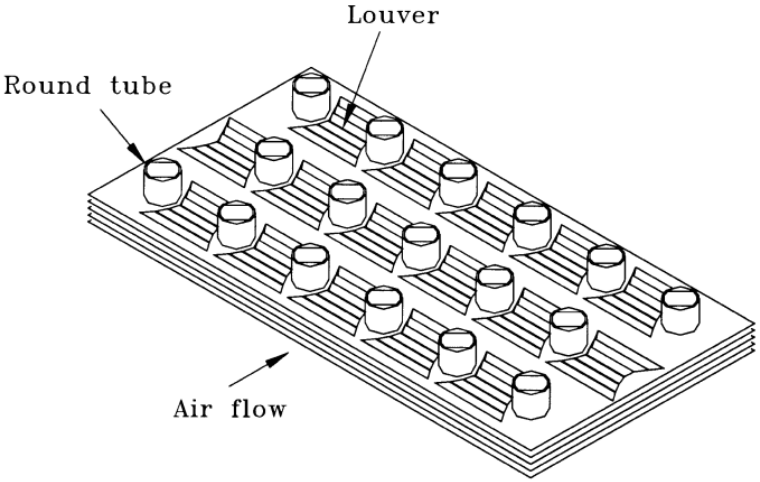
1. Introduction

1.1 Finned tube heat exchangers

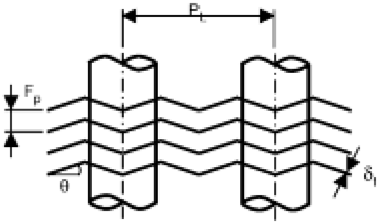


A typical louver fin geometry with round tube configuration [1]

Applications:
Air conditioning, refrigeration…

In-tube fluid: water, oil, refrigerant…
Cross-tube fluid: air

Thermal resistance: $\frac{R_{air}}{R_{liquid}} = 5\sim10$



Wavy fin [2]

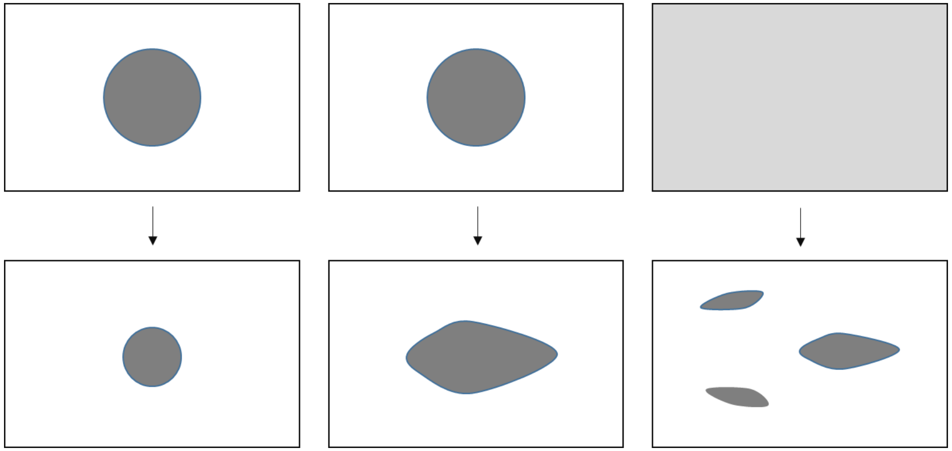
Vortex generator [3]

[1] C. C. Wang, C. J. Lee, C. T. Chang and S. P. Lin (1998); [2] T. Kuvannarat, C. C. Wang and S. Wongwises (2006)
[3] C. C. Wang, K. Y. Chen, J. S. Liaw and C. Y. Tseng (2015)

1. Introduction

1.2 Optimization method

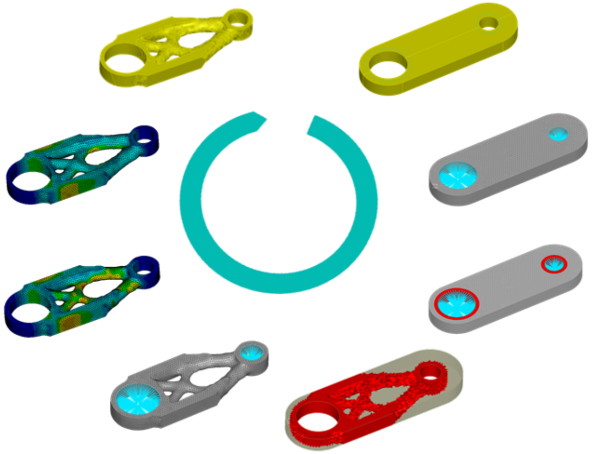
Optimization Methods



(a)Size (b)Shape (c)Topology

Finned tube design

Topology optimization in mechanical structures[1]



A mature and widely used technique

Topology optimization in fluids

- Treat design domain as porous media
- Solid – 0 porosity; Fluid – infinite porosity
- Optimize porosity distribution

[1] http://info.simuleon.com

1. Introduction

1.3 Topology optimization of fluid flow

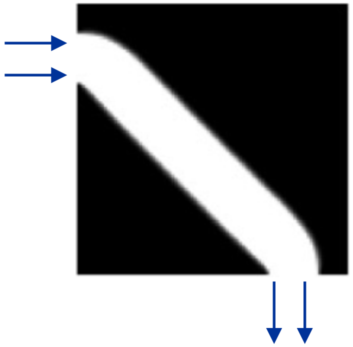
Pioneering work

(1)Thomas Borrvall and Joakim Petersson(2003)

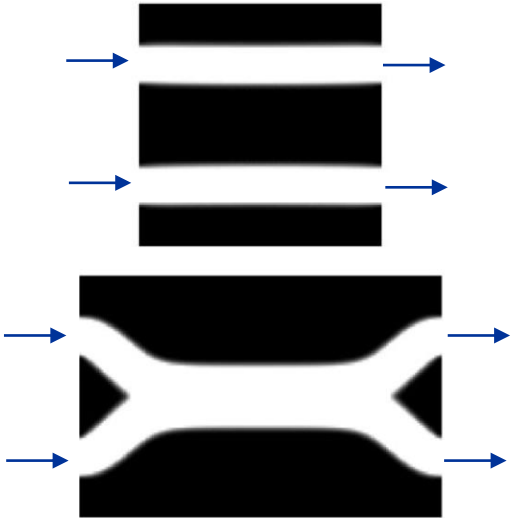
Stokes flow(Convection term is neglected)

1) Diffuser

2) Pipe bend



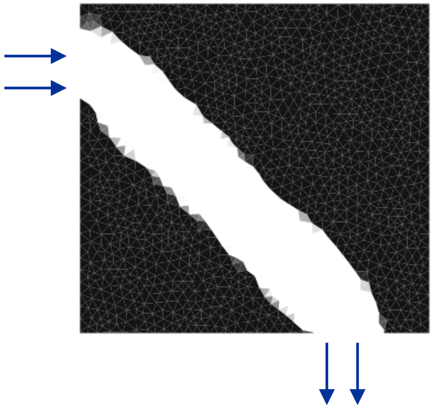
3) Double pipe



(2) Gersborg-Hansen et al.(2005)

Laminar viscous flow

Pipe bend

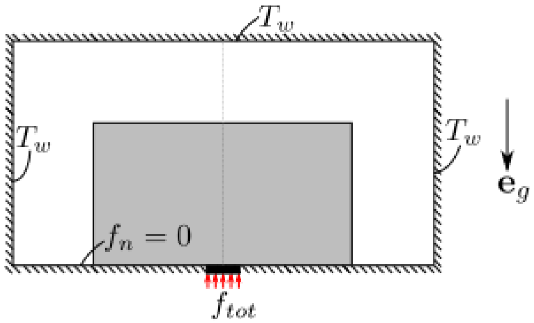


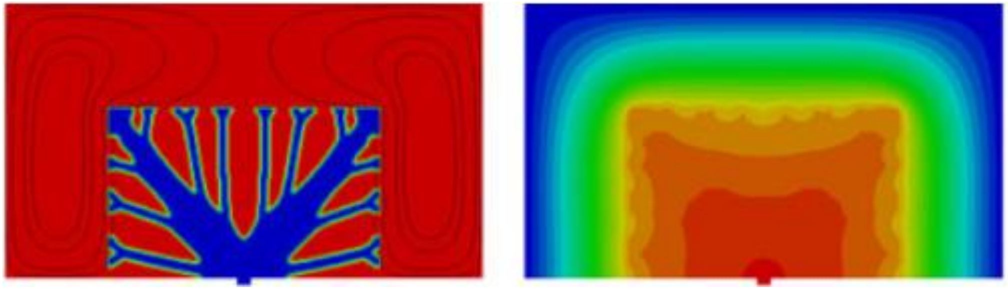
1. Introduction

1.4 Topology optimization of fluid flow and heat tranfer

1) Joe Alexandersen et al.(2014)

- Dimensionless form of governing equation



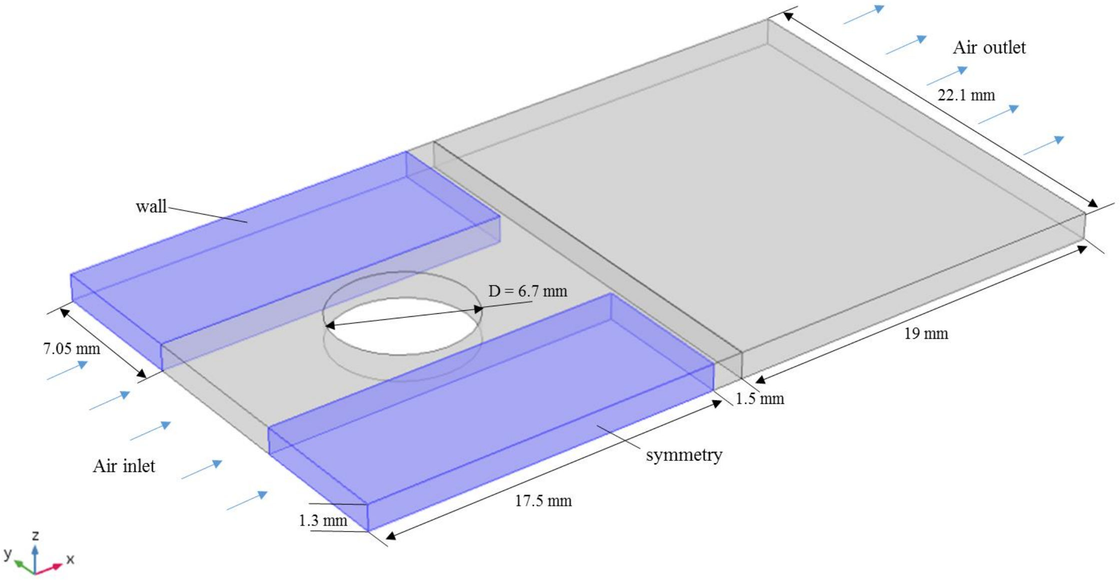


2) Joe Alexandersen et al.(2016)

- 3D large scale
- Computed on a cluster

2.1 Problem Definition

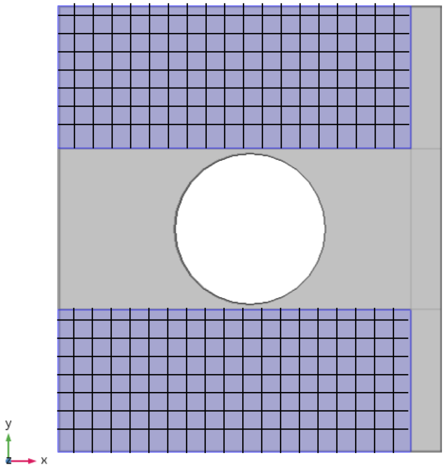
Increased heat transfer areas ⟶ enhance heat transfer performance



Target 1: Introduce new fins into air flow path

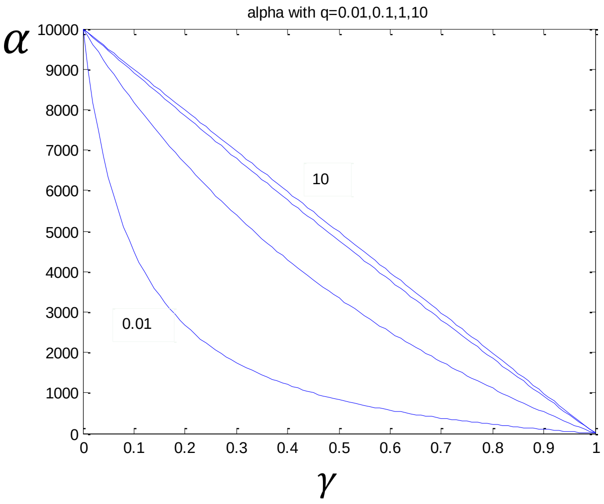
Target 2: minimum pressure drop penalty

2.2 Theory of Topology Optimization



- Design domain is discretized
- Each element is assigned a design variable

$$\gamma = \begin{cases} 1, fluid\ domain \\ (0,1), porous\ media \\ 0, solid\ domain \end{cases}$$



- Modified N-S equation

$$\rho(\boldsymbol{u}\cdot\nabla\boldsymbol{u}) = -\nabla P + \mu\nabla^2\boldsymbol{u} - \boxed{\alpha\boldsymbol{u}}$$

Friction force

- Inverse permeability interpolation[1]

$$\alpha(\mathbf{r}) = \alpha_{min} + (\alpha_{max} - \alpha_{min})\frac{q[1-\gamma(\mathbf{r})]}{q+\gamma(\mathbf{r})}$$

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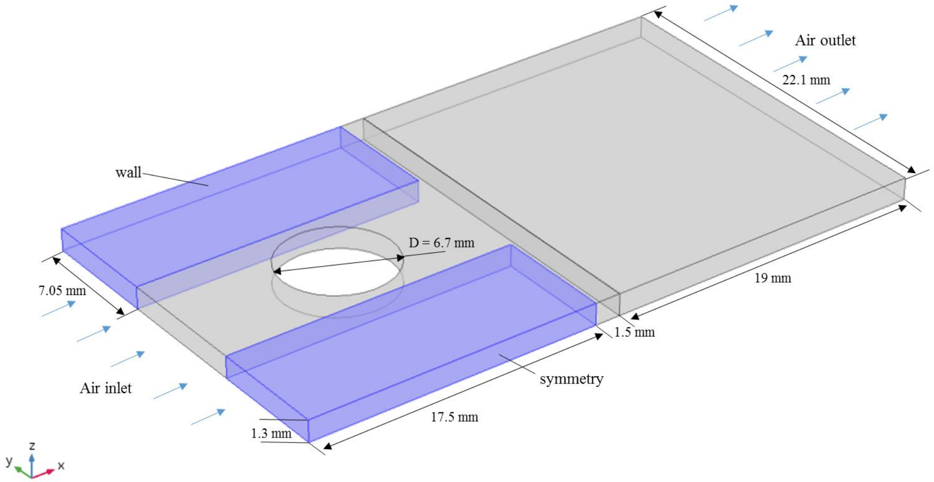
[1] Xiaoping Qian & ErcanM.Dede. (2016);

2.3 Implementation of Topology Optimization

Initiation

- Boundary conditions

Velocity inlet: 2m/s
Pressure outlet: 0 Pa



- Optimization

1) Objective: min pressure drop

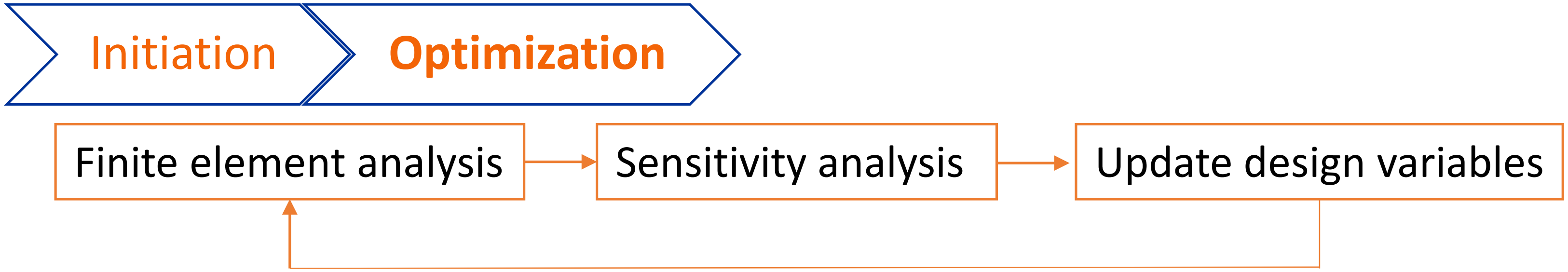
$$f = \Delta P$$

2) Volume constraint:

$$\int_{\Omega} \gamma(\mathbf{r}) d\Omega \leq \bar{V}$$

Maximum volume occupied by fluid domain
(Minimum volume occupied by new fins)

2.3 Implementation of Topology Optimization



Initiation

Optimization

Finite element analysis

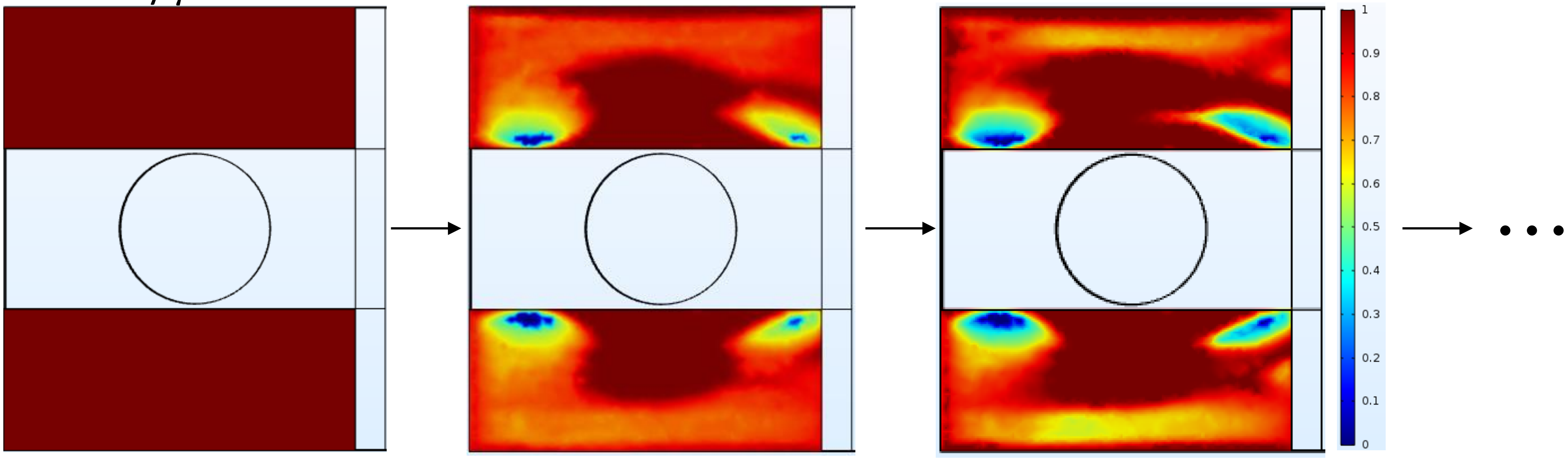
Sensitivity analysis

Update design variables

COMSOL 5.2a
Spf + optimization

$\frac{df}{d\gamma}$ → globally convergent version of Method of Moving Asymptotes (GCMMA)[1,2]

Initially $\gamma = 1$



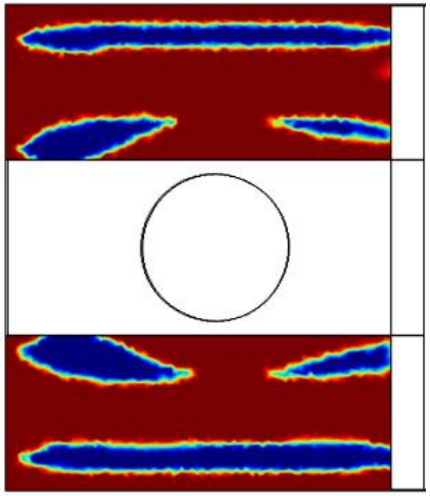
[1]Krister Svanberg. (1987); [2] Krister Svanberg. Comsol User’s Manual(2013)

2.3 Implementation of Topology Optimization

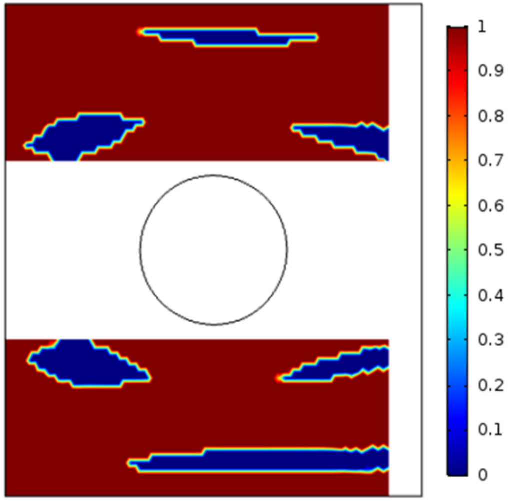
Initiation

Optimization

25% fin areas



15% fin areas

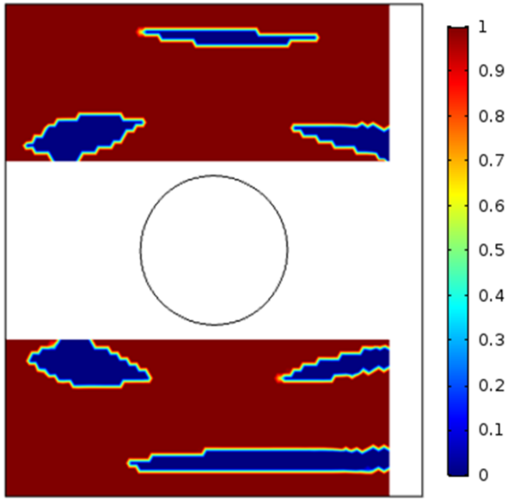


2.3 Implementation of Topology Optimization

Initiation

Optimization

Post processing



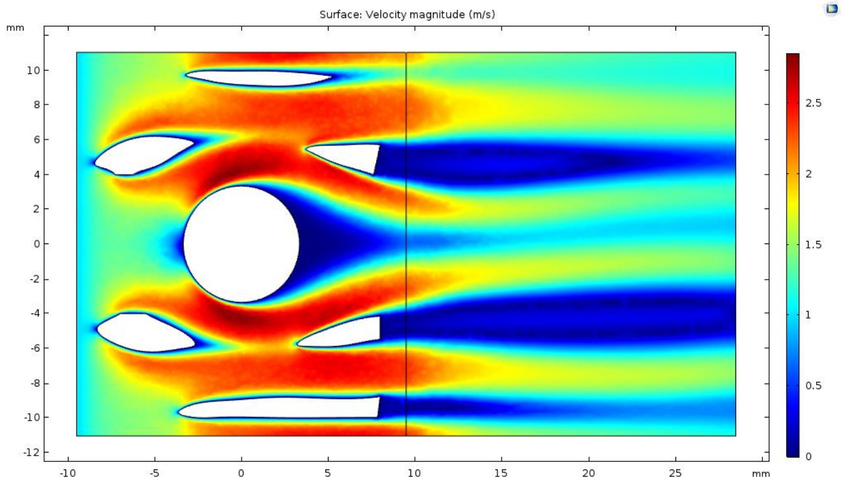
$$\gamma = 0.5$$

Extract the structure with certain gamma contour

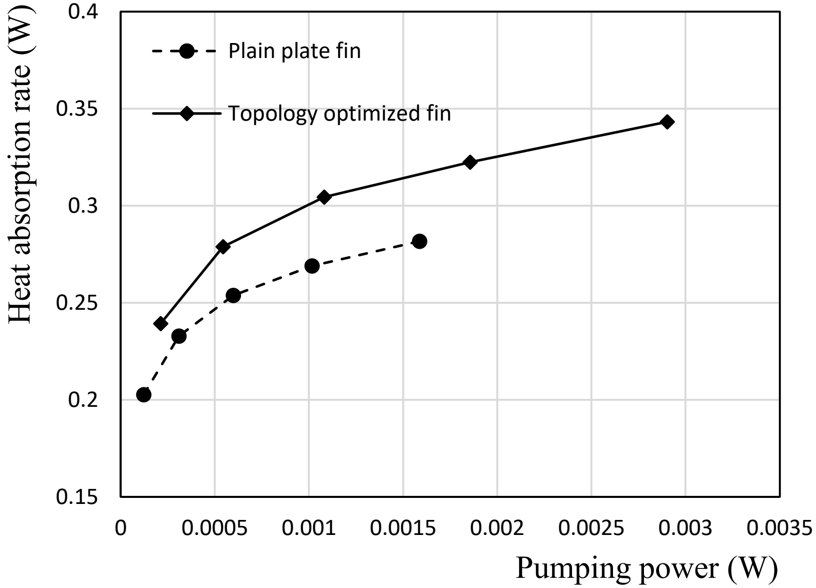
3.1 Results Validation

A comparison with plain plate fin

3D CFD analysis:
Inlet velocity: 1m/s – 3m/s
Inlet air temperature: 307.47 K
Tube wall temperature: 318.57 K



Velocity profile of the optimized structure of 15% volume constraint at inlet velocity 1 m/s



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Q&A

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Thanks!