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Ahmad Fawaz, Yuchao Hua, Steven Le Corre, Yilin Fan, Lingai Luo. Convergent-divergent design of fins for simultaneous thermohydraulic improvement assisted by dual-flow topology optimization. 31ième Congrès Français de Thermique (CFT) 2023, May 2023, Reims, France. hal-04121842

HAL Id: hal-04121842

<https://hal.science/hal-04121842>

Submitted on 8 Jun 2023

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Convergent-divergent design of fins for simultaneous thermo-hydraulic improvement assisted by dual-flow topology optimization

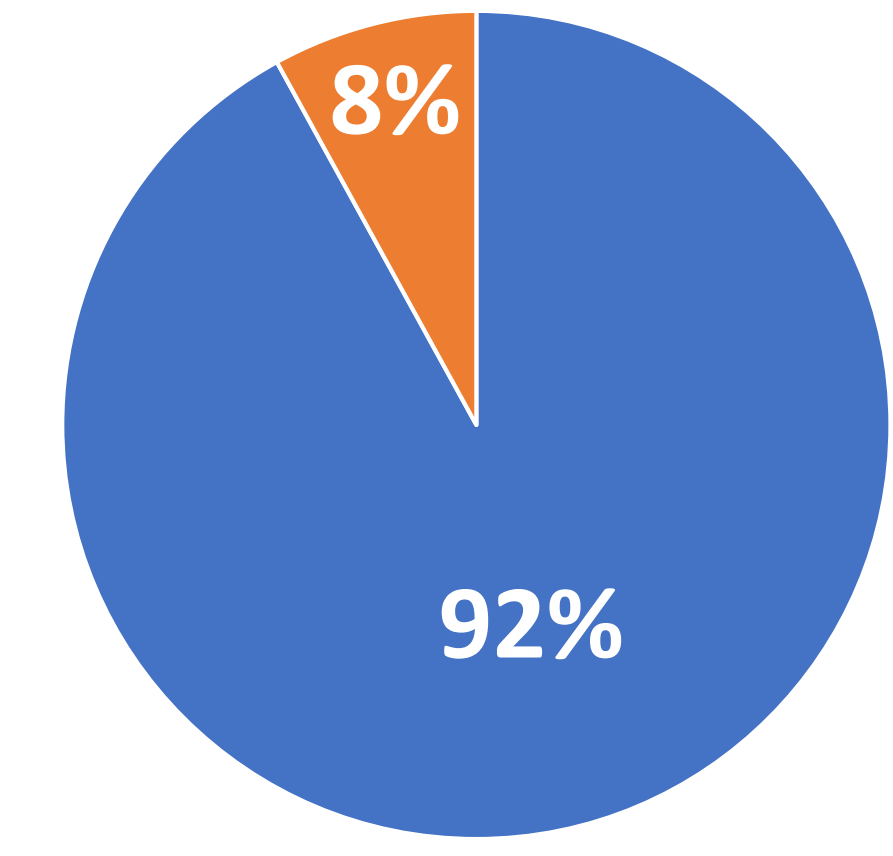


Ahmad FAWAZ⁽¹⁾, Yuchao HUA^(1*), Steven LE CORRE⁽¹⁾, Yilin FAN⁽¹⁾ & Lingai LUO^(1*)

Context and Objective

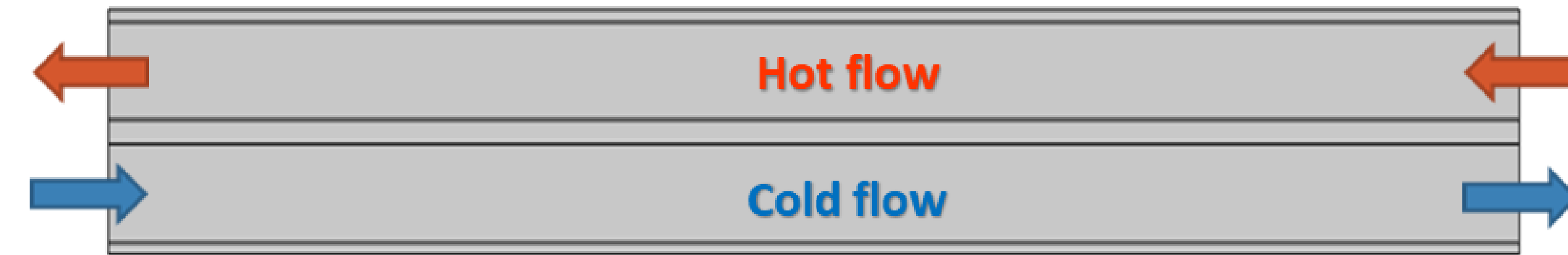
- The critical importance of heat exchangers (HXs) on energy systems has been widely recognized.
- Enhancing their thermal performance will inherently lead to a commensurate elevation in pressure losses.
- Topology optimization (TO) is a mathematical method used to optimize the material distribution of a given design domain for the purpose of boosting the performance under several constraints.
- Among the researchers who conducted the TO, a significant majority of 92% applied the TO technique on single-flow HXs, while a minor proportion of 8% implemented it on dual-flow HXs.

■ Single flow TO ■ Multi-flow TO



[1]

[1]: Fawaz et al. "Topology optimization of heat exchangers: A review." Energy (2022).

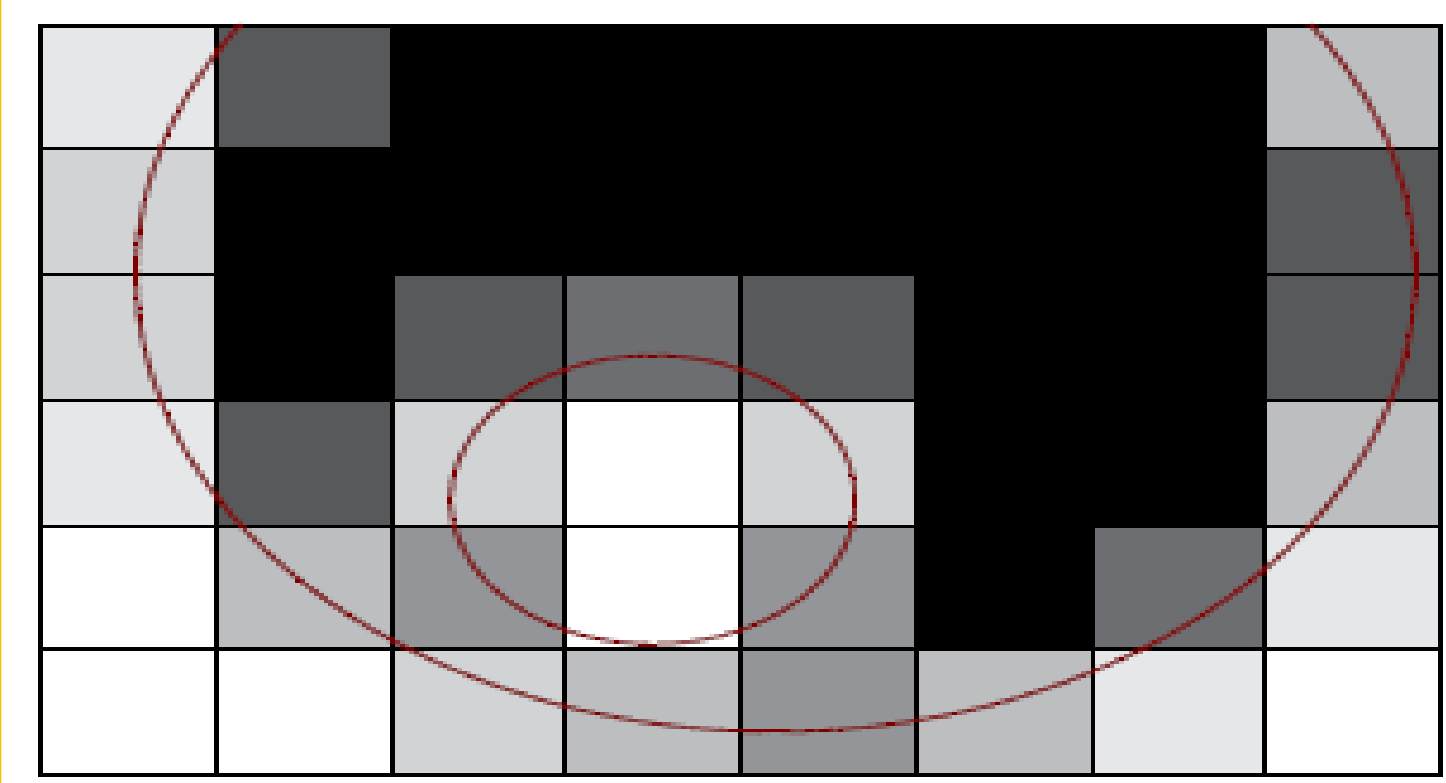
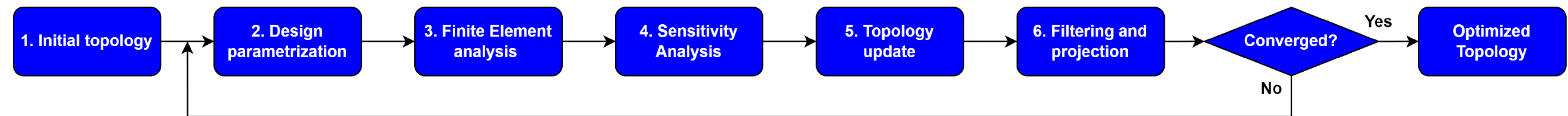


Objective:

Applying the density-based TO on a simplified 2D counter flow plate heat exchanger to increase its thermo-hydraulic performance.

Dual-flow density-based TO Method

Method's principal: The density-based TO is conducted to optimize solid/fluid distribution of the PHE for the purpose of improving its thermo-hydraulic performance. The optimization objective is set the maximizing of the exchanged heat transfer while the pressure drop is diminished by testing different designs acquired under various Reynolds number.



1&2. The design domain is parametrized using densities (or porosities) that represents the ratio between solid and fluid which are initially set to 0.5. Then they are correlated with the thermo-hydraulic properties of solid & fluids.

3. Dimensionless equations for conjugate heat transfer physics

$$\nabla \cdot v = 0$$

$$(v \cdot \nabla)v = -\nabla P + \frac{1}{Re} \cdot \nabla^2 v - \alpha v$$

$$Pr \cdot Re (v \cdot \nabla T) = C_k \nabla \cdot (\nabla T)$$

* Re : Reynolds number, Pr : Prandtl number, C_k : Thermal conductivity ratio

4 & 5. The discrete adjoint analysis is utilized to compute the objective function sensitivities. Then, a gradient-based optimizer (GCMMA) is used to iteratively update the densities distribution.

6. To avoid the checkerboard effect in the acquired topology, the densities are filtered using the Helmholtz filter. The densities are then projected by the hyperbolic tangent projection method for the aim of removing the intermediate densities created by the filter.

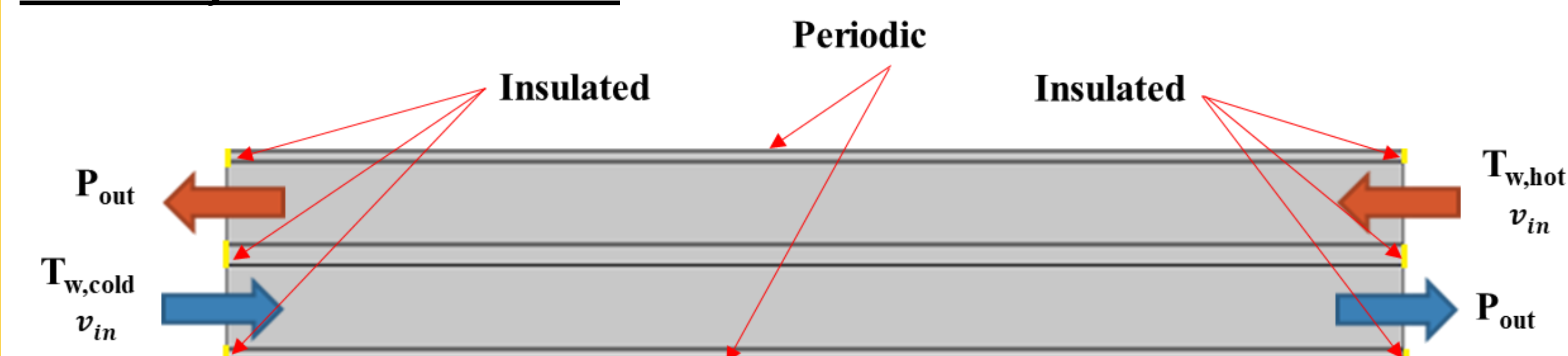
Helmholtz filter: $\gamma_f = R^2 \nabla^2 \gamma_f + \gamma$

Hyperbolic tangent projection: $\gamma_p = \frac{\tanh(\beta(\gamma_f - \gamma_\beta)) + \tanh(\beta\gamma_\beta)}{\tanh(\beta(1 - \gamma_\beta)) + \tanh(\beta\gamma_\beta)}$

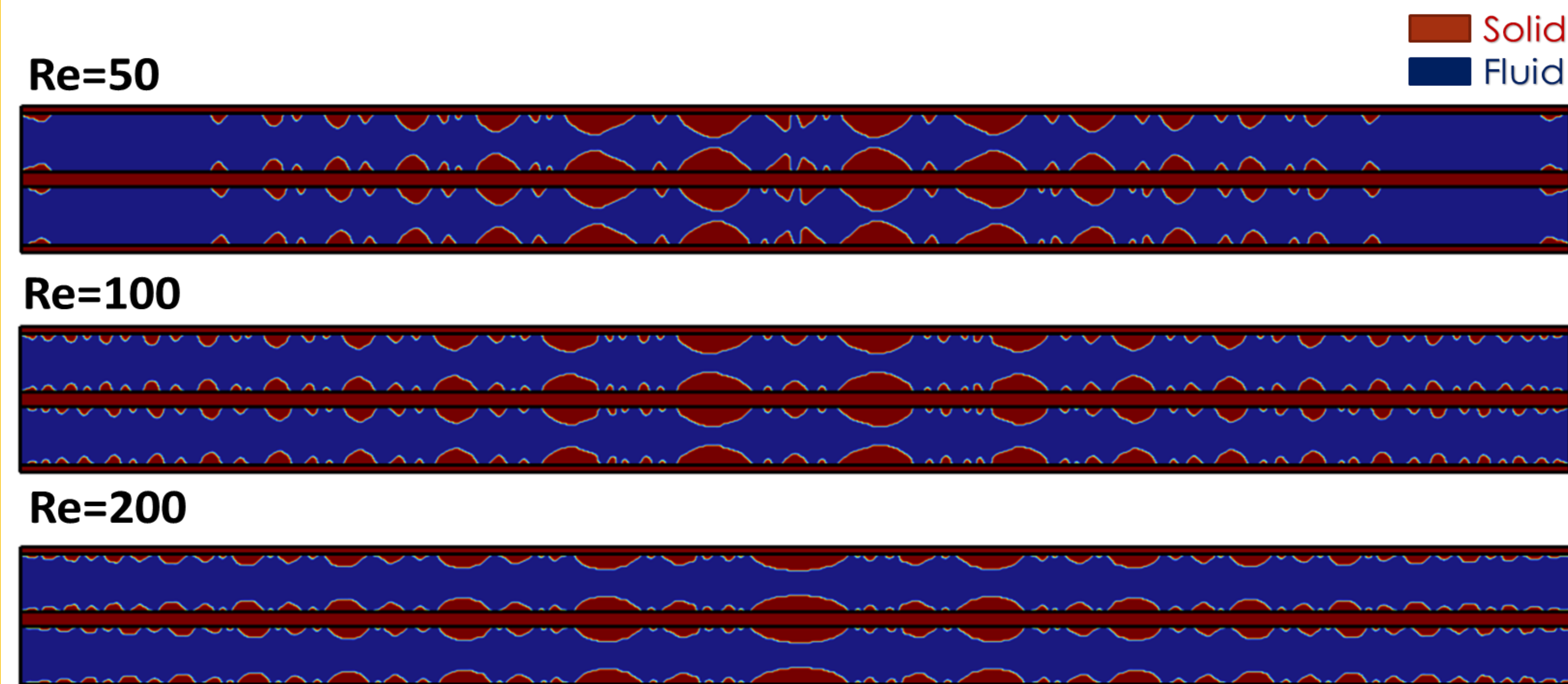
* γ : Design variables, R : Filter radius, β : Projection slope, γ_β : Projection point

Results and Discussion

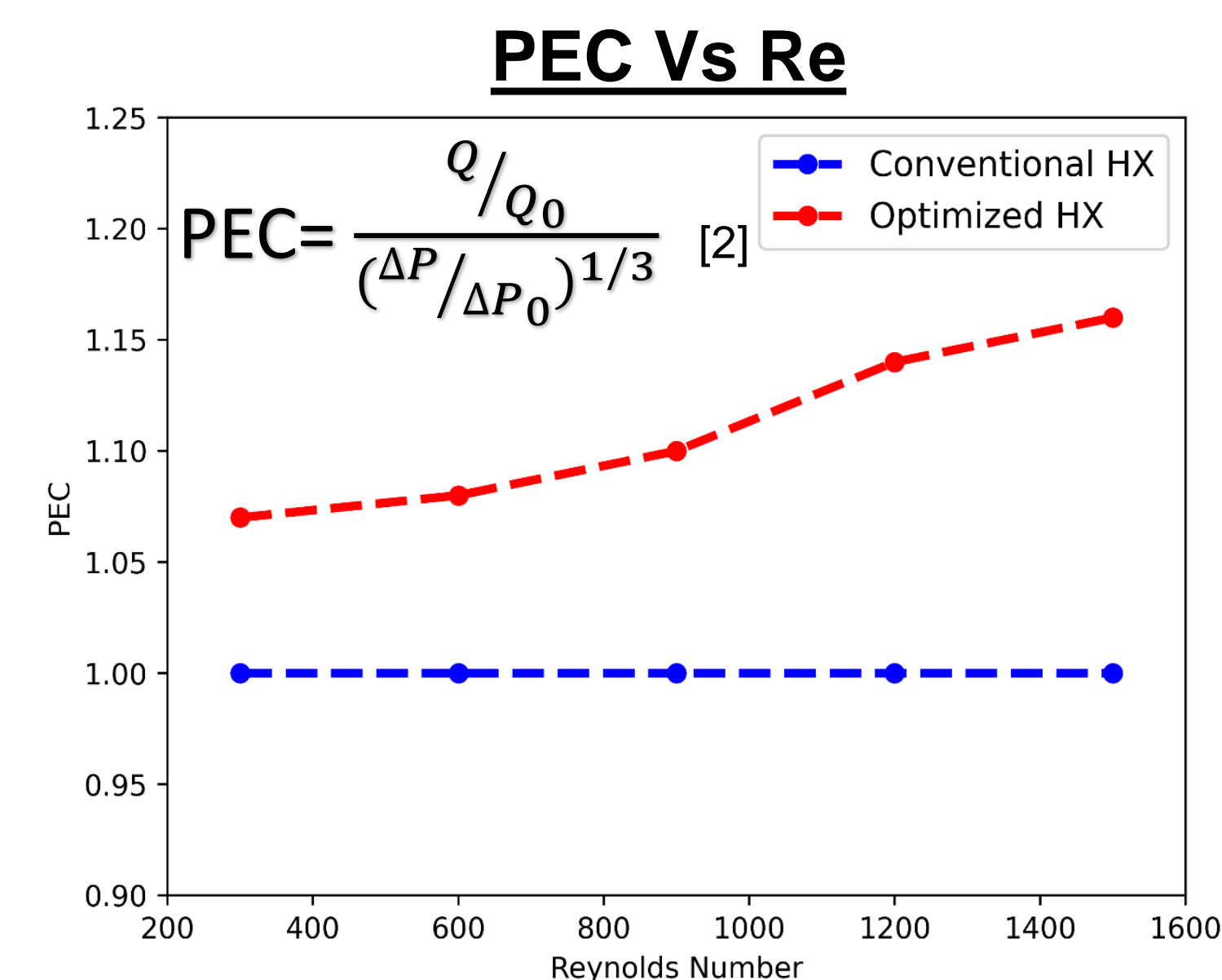
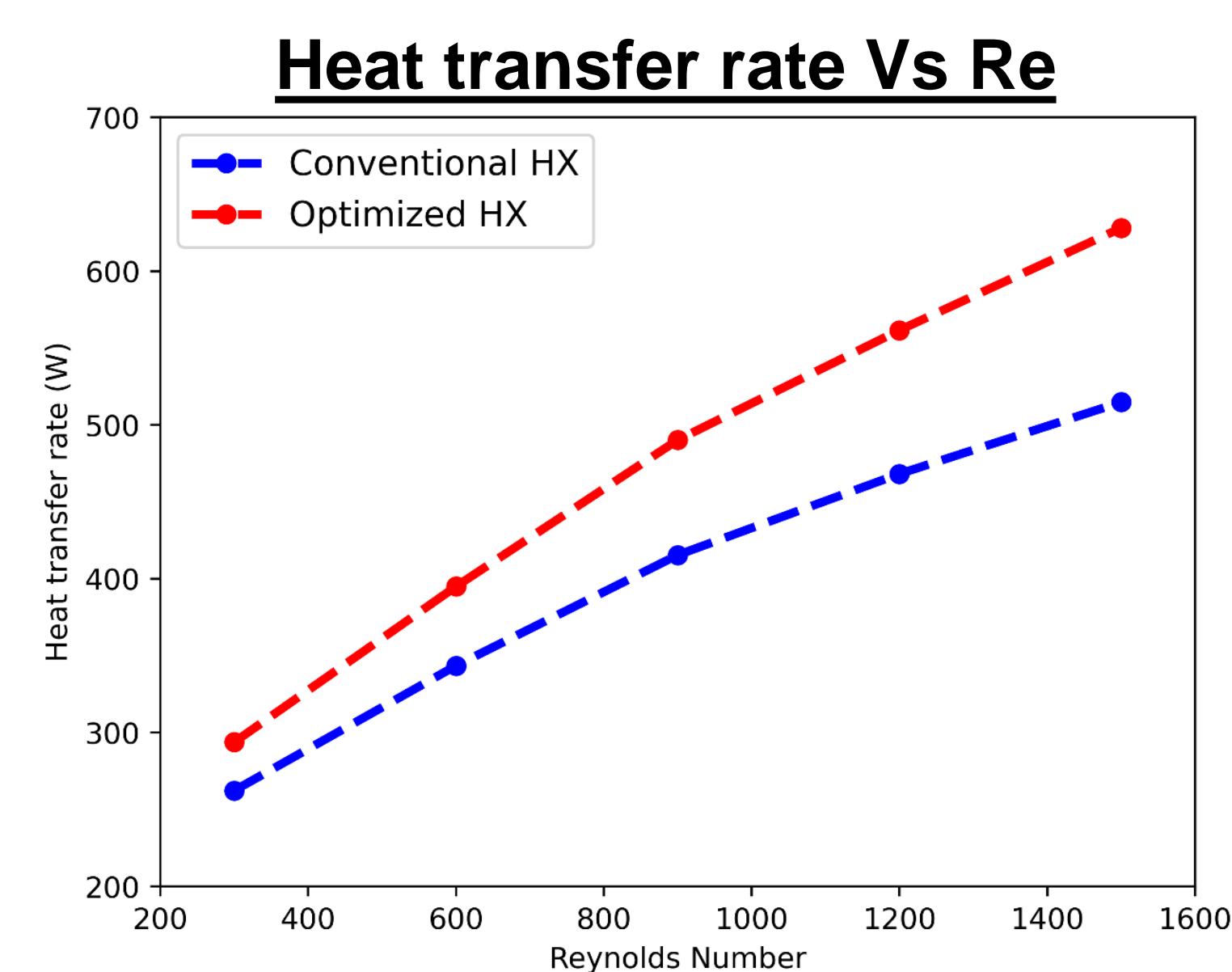
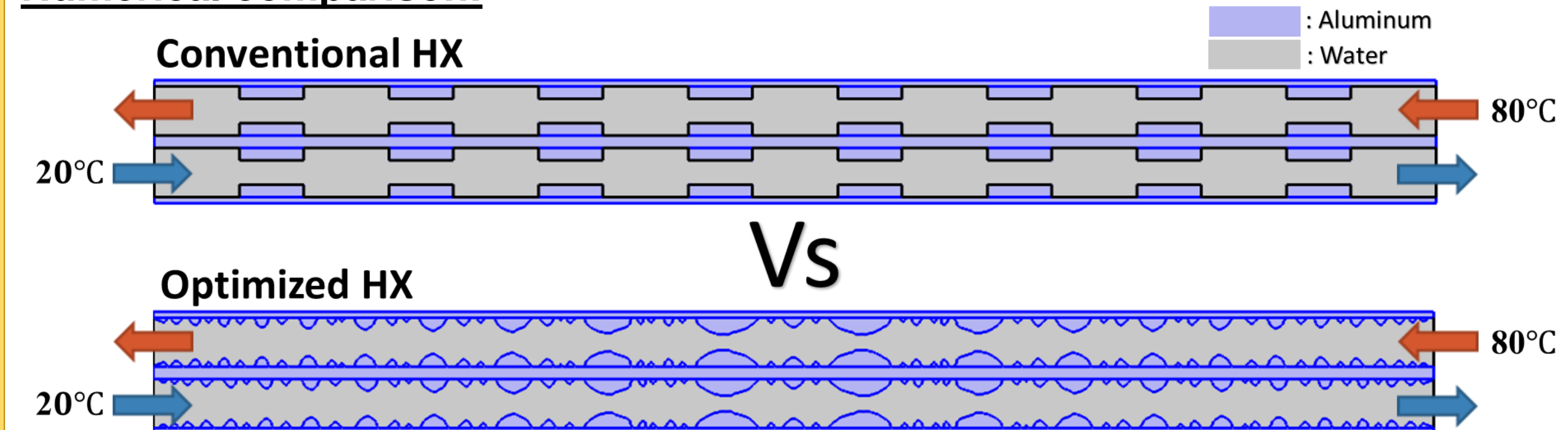
Boundary Conditions in TO:



Influence of the Reynolds number:



Numerical comparison:



[2]: Webb et al., "Application of rough surfaces to heat exchanger design, IJHMT, 1972.

Conclusion and Perspective

- A density-based TO is applied on a bi-flow HX to optimize its thermo-hydraulic performance.
- The heat transfer rate of the optimized HX is magnified compared to the conventional one with an intensification rate up to 22 %.
- The PEC (Performance evaluation criteria) is used as a criteria to compare the thermo-hydraulic performance. The results show the superiority of the optimized HX with an enhancement up to 16%.

On-going work:

- Experimental validation of the numerical results by testing different HXs and prove the advantage of the proposed design over the conventional one.
- Perform size optimization on the Convergent-divergent distribution to test the effect essential parameters on the thermo-hydraulic performance of the HX.
- Integration of the machine learning techniques with the TO algorithm to increase its efficiency.

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This work is financially supported by Région Pays de la Loire within the NEX2Talents program TOP-OPTIM project (998UMR6607 EOTP NEXINTERTALENTHUA).

