Proceedings of the 10th World Congress on Mechanical, Chemical, and Material Engineering (MCM'24)
Barcelona, Spain –August 22-24, 2024
Paper No. HTFF 145
DOI: 10.11159/htff24.145

A Numerical Analysis of Thermo-Hydraulic Performance of Pillow-Plate Heat Exchangers with Ellipsoidal Secondary Structures

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Extended Abstract

Mitigating climate change and reducing the dependency on fossil resources necessitates a significant transformation of industrial processes, aiming for enhanced energy efficiency and reduced raw material utilization. Within this context, optimizing heat exchangers as a central element of many industrial plants can make a substantial contribution. Pillow-plate heat exchangers (PPHEs) emerge as a viable alternative to conventional shell-and-tube (STHE) and plate heat exchangers (PHEs).

PPHEs are composed of multiple pillow plates (PPs) assembled into a unified structure. These PPs are formed by two spot-welded steel sheets, seam-welded along the edges, and then treated by hydroforming, resulting in the distinctive, leak-tight pillow-like surface. The inherent waviness of their channels stimulates fluid mixing and facilitates heat transfer. The overall flat structure allows using the PP as a panel, while by assembling multiple PP panels, two channel structure is formed: the inner channel within the PP panel and the outer channel between the adjacent PPs.

Compared to STHEs, PPHEs show superior characteristics, being lighter, more compact, and efficient. However, to achieve efficiency and compactness comparable to PHEs, further optimization of PPHEs is required.

Applying secondary surface structuring can further enhance the overall thermo-hydraulic performance of PPHEs [1, 2], thus increasing their competitiveness against conventional heat exchangers. Such secondary structures can be realized using the method of Electrohydraulic Incremental Forming (EHIF) [3]. In [3], the effect of the dimples as a secondary structure on the fluid dynamics and heat transfer in the inner channel was investigated based on CFD simulations. It was found that the dimpled surface results in an increase of the heat transfer coefficient. A more detailed investigation of the influence of secondary structures on the thermo-hydraulic performance of the PPHEs in the outer channel was carried out in [1, 2]. Piper et al. [1] demonstrated that the dimples reduced the negative impact of the recirculation zones in the outer channel, enhancing heat transfer. Afsahnoudeh et al. [2] showed that more streamlined secondary structures, particularly with an ellipsoidal form, led to higher thermo-hydraulic efficiency, up to about 6%, compared to PPHEs without secondary structures.

This work extends our previous numerical studies, with the focus on the influence of ellipsoidal secondary structures on fluid dynamics and heat transfer in the inner channels of PPHEs. First, the complex geometry of the PPHEs, both with and without secondary structures, is generated using forming simulation with ABAQUS 2020. Afterwards, the flow and heat transfer within PPHEs are simulated using FLUENT 23.2. The simulations are conducted under assumption of single-phase, incompressible, turbulent system with constant physical properties.

The performance of the simulated PPHEs is evaluated based on pressure drop, heat transfer coefficients, and thermo-hydraulic efficiency. Furthermore, for a deeper understanding of the fluid dynamics, the Fanning friction factor and drag coefficient are investigated for various Reynolds numbers.

References

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