

Abstract

Double-pipe heat exchangers are widely used in thermal systems due to their simple design, compactness, and ease of maintenance. However, their performance is often limited by weak fluid mixing and thermal boundary layer development. Passive techniques, such as twisted tape inserts, can enhance convective heat transfer without external power input. To address this limitation, the present thesis employs three-dimensional computational fluid dynamics (CFD) simulations to investigate the thermo-hydraulic performance and passive heat transfer enhancement of double-pipe heat exchangers (DPHEs) equipped with various twisted tape-based flow modifiers. The flow and thermal fields are simulated by solving the steady-state, incompressible Reynolds-Averaged NavierStokes (RANS) equations coupled with the energy equation using the finite volume method, while neglecting thermal radiation, gravity, and viscous dissipation effects. Turbulence closure is achieved using the realizable $k - \epsilon$, and SST $k - \omega$ models, selected based on extensive validation against established empirical correlations. The numerical simulations are performed using the commercial CFD solver ANSYS Fluent 2021 R2. Second-order discretization schemes are adopted for the convective and diffusive terms, while the pressure-velocity coupling is handled using the SIMPLE algorithm. Water is considered as the working fluid on both the hot and cold sides. In the present thesis, a counterflow double-pipe heat exchanger configuration is analyzed, wherein hot water flows through the inner tube and cold water flows through the annular region. Realistic inlet boundary conditions are prescribed by imposing mass flow rates and inlet temperatures for both hot and cold streams. Initially, a plain double pipe heat exchanger (P-DPHE) is simulated in both laminar and turbulent flow regimes to establish numerical accuracy. The predicted Nusselt number and friction factor are validated against classical correlations, and further validation is carried out using a conventional twisted tape (TT) insert in order to assess the suitability of turbulence models and mesh resolution. Subsequently, the heat transfer and flow characteristics of DPHEs fitted with passive enhancement devices are systematically investigated. The modified inserts comprise rectangular-cut multichannel twisted tapes, triangular-cut multichannel twisted tapes, and fractal-edge twisted tapes, designed to intensify secondary flows and promote fluid mixing. The influence of geometric parameters such as twist ratio, pitch length, cut depth, cut width, and edge length between successive cuts is examined in detail. The turbulent flow regime is explored over a Reynolds number range of 6000-20000, while

selected cases are also analyzed in the laminar regime ($Re = 600\text{--}2000$) to examine transitional behavior and establish performance trends across regimes. The hydrothermal performance of each configuration is evaluated using the average Nusselt number, friction factor, and thermal performance factor (TPF). The results demonstrate that the introduction of twisted tape inserts significantly alters the internal flow structure by generating strong swirling motion, longitudinal vortices, and enhanced radial mixing. Multi-channel twisted tapes are found to produce multiple interacting swirl cores, which substantially increase the convective heat transfer coefficient compared to both the plain DPHE and the DPHE fitted with conventional twisted tapes. For a fixed Reynolds number, the Nusselt number is observed to increase with the introduction of a splined inner tube, multi-channels, and cut-based modifications, albeit at the expense of an increased pressure drop. However, the rise in friction factor remains within acceptable limits, leading to an overall improvement in thermal performance. Among all studied configurations in this thesis, triangular-cut trilobe ($w=5\text{ mm}$, $d=4.8\text{ mm}$, Case 3) showed the highest Nu at a $TR=2.5$ in both laminar and turbulent flow regimes. It achieved a Nusselt number enhancement of approximately 463.58%–704.74% higher compared to the plain DPHE and 30.98%–31.97% higher compared to the DPHE equipped with a conventional twisted tape in laminar flow regime. Similarly, it achieved a Nusselt number enhancement of approximately 106.55%–187.95% and 55.38%–87.45% higher compared to the P-DPHE and DPHE equipped with a conventional twisted tape, respectively, in the turbulent flow regime. The corresponding thermal performance factor reaches a maximum value of 3.07 and 1.37 in laminar and turbulent flow, respectively, which indicates a favorable trade-off between heat transfer enhancement and pressure penalty. A comparative analysis of different multichannel geometries reveals that both the number of channels and the nature of edge modifications play a critical role in governing the flow physics and thermal performance. Increasing geometric complexity leads to stronger secondary flows and enhanced heat transfer. Overall, the results establish that carefully designed multichannel and cut-based twisted-tape inserts can significantly improve the thermal efficiency of DPHEs operating in the laminar and turbulent regime. The findings of this thesis provide detailed physical insight into the mechanisms responsible for passive heat transfer enhancement in DPHEs and offer valuable design guidelines for selecting optimized twisted tape configurations.

Keywords: Heat transfer enhancement, Thermal performance factor, Multi-channel twisted tapes, Rectangular cut, Triangular cut, Fractal edge twisted tape, CFD.