Numerical Study Of Effective Thermal Conductivity Of Periodic Complex Structures To Be Used In HIDiC

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Abstract

In this numerical investigation, the effective thermal conductivities (ETC) of periodic complex structures are evaluated. These structures are to be used as packing in Heat-Integrated Distillation Columns (HIDiC). Only high-porosity (>85%) complex structures are considered for distillation column in order to allow counter-current liquid-gas circulations with low-pressure drop. HIDiC are designed as co-axial columns where heat is transferred horizontally through an internal wall from internal zone (rectification) to external zone (stripping) to allow energy saving. Thermal performance of the complex structure (packing) soldered with the internal wall is a determinant factor of heat transfer efficiency in HIDiC. The heat transfer is carried out by convection and conduction between the liquid film on the structure and the structure itself. As a first assessment of the heat transfer efficiency, only heat conduction in the solid is considered for this study.
The steady-state heat transfer by conduction in the solid-structure and the stagnant fluid (air) is modeled using COMSOL Multiphysics®, a finite-element method based software. The energy equations of heat transfer module are solved in order to determine the ETC. The computational domain is parallelepiped, which contains the complex structure. Hot and cold temperatures are imposed in two opposite boundaries and thermal insulation boundary condition is applied to the remaining exterior boundaries. The volume integral of the heat flux (Qn) in the direction normal to the hot and cold boundaries is calculated. Then, ETC for this direction is calculated using Fick's law, $ETCn = Qn /((Thot-Tcold)*L)$, with L as the distance between the two temperature boundaries.
The studied structures are a kelvin-cell foam structure and tetra-spline (TS) structures. The study is carried out in three steps. First, a mesh sensitivity study is carried out in order to achieve mesh-independent results. Then, given that TS geometry consists in the replication of an elementary pattern, a domain-size sensitivity study is performed. Finally, ETC is calculated for different parameters of TS structure such as thread's diameter and length and tetrahedrons' angles. According to the literature, ETC is sensitive to the solid intrinsic conductivity and structure's geometry and orientation. For a given geometry and material, a correlation of the ETC could be estimated in function of the intrinsic thermal conductivities of the solid material and the stagnant fluid and the structure porosity. In this study, a correlation is proposed for the TS geometry in order to be able to maximize the ETC while respecting the hydrodynamics constraints of the HIDiC, which were assessed experimentally in another study.

Figures used in the abstract

Figure 1 : Detailed geometry of tetra-spline's elementary pattern, l1 & l2 are threads' lengths, dw is thread diameter, θ1 & θ2 are tetrahedron angles

Figure 2 : Computational domain for heat transfer by conduction in the x direction TS geometry, in red & blue are the hot & cold temperatures' boundaries resp.

Figure 3 : Block of tetra-spline packing with the internal wall separating the internal cylindrical zone (rectification) and external annular zone (stripping)