**Generating maximal mass transfer in highly curved helical hollow fiber membranes: a CFD study.**

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**Highlights**

* CFD investigation of mass transfer in hollow fiber membranes of helical geometry
* The mass transfer efficiency is positively correlated to the helix curvature
* Mass transfer in highly curved helixes is up to 10 times higher than in straight tubes

**1. Introduction**

Membrane separation is widely used for the separation of homogeneous liquid or gaseous mixtures, and is one of the most promising intensification technologies for gas-liquid absorption processes. The design and operation of membrane modules have been the focus of many scientific researches aiming to improve the separation efficiency.

The mass transfer in membrane modules can be intensified by using helical pipe geometries instead of classic straight membranes. Indeed, the hydrodynamics in helical geometries is characterized by the occurrence of secondary flows, called Dean vortices, which considerably increase the mass transfer efficiency.

The present study addresses mass transfer in highly curved helical pipes, i.e. helical geometries with small helical radius and pitch. Figure 1 presents the limits of the so-called forbidden region in the ($R\_{H}^{\*}$ , p\*) space, where $R\_{H}^{\*}$ and $p^{\*}$ are the reduced helix radius and pitch respectively, both nondimensionalized by the pipe diameter, $d$. The forbidden region corresponds to the zone where it is not possible to design helical shapes. Its frontier, which equation has been determined by Przybył et al. [1], corresponds to closely packed helices, i.e. helices which pitch cannot be further decreased because the consecutive turns of the helix would intersect/overlap one with/on another. Some helix designs are shown in Figure 1. They illustrate the fact that the helical pipe geometry tends toward that of a straight at three asymptotic limits: (i) when the dimensionless pitch *p\** tends to infinity; (ii) when the dimensionless helix radius $R\_{H}^{\*}$ tends to infinity; (iii) when the dimensionless helix radius $R\_{H}^{\*}$ tends to zero.

Figure 1: Limits of the forbidden region in the ($R\_{H}^{\*}$ , p\*) space (adapted from Przybył et.al [1]) and some representative helices.

**2. Methods**

In this paper, CFD (Computational Fluid Dynamics) is used to investigate the mass transfer efficiency in helical membranes. Simulations were conducted for various helix designs ($1.25\leq p^{\*}\leq 15$ and $0.05\leq R\_{H}^{\*}\leq 10$). The computational mesh consisted of hexahedral cells only, with a boundary layer mesh in the near-wall zone for more accurate calculation of the steep gradients in that area. The commercial CFD code FLUENT 16.0 was used to simulate the mass transfer within the helical membranes. A Newtonian fluid was considered, and the flow, treated as laminar and incompressible, was described using the steady Navier-Stokes and continuity equations. The mass transfer equation was solved assuming a dilute medium and a uniform concentration at the walls.

**3. Results and discussion**

For each simulation performed, $Sh\_{H}^{\infty }$, the asymptotic Sherwood number (i.e. in the region where the concentration profile gets fully developed) was calculated. Figure 2 shows the contour plot of $Sh\_{H}^{\infty }$/$Sh\_{S}^{\infty }$ for a Reynolds number of 400 and different Schmidt number values. $Sh\_{S}^{\infty }$ denotes the asymptotic Sherwood number in straight pipes which equals 3.65 under a uniform wall concentration boundary condition.

The contour plots in Figure 2 were obtained using a triangulation-based cubic interpolation of the CFD results. The geometric parameters for which simulations were performed are represented by black dots: at these points, the values of $Sh\_{H}^{\infty }$/$Sh\_{S}^{\infty }$ that are displayed on the contour plots are exactly the same than those provided by CFD. Although the interpolated data exhibit some irregularities that are inherent to interpolation, these contour plots provide valuable information: (1) There is a positive correlation between $Sh\_{H}^{\infty }$ and the pipe curvature. Indeed, highly curved helices involve the highest Sherwood numbers, which is explained by the fact that they engender the most intense Dean-type recirculations. (2) For each dimensionless pitch,$ p^{\*}$, there exists a dimensionless helical radius,$ R\_{H}^{\*}$, at which the Sherwood number is maximal. The ratio $Sh\_{H}^{\infty }$/$Sh\_{S}^{\infty }$ tends to one when $R\_{H}^{\*}$ tends to zero or infinity, since the helical geometry approaches that of a straight pipe. (3) The mass transfer efficiency is extremely sensitive to the pitch value in the case of high curved helixes. For an infinite pitch, $Sh\_{H}^{\infty }/Sh\_{S}^{\infty }$ tends to one since the helical geometry tends to a straight pipe. (4) The mass transfer enhancement is the highest in the case of highly curved helixes and increases when the Schmidt number is increased.





Figure 2: Contour plots of $Sh\_{H}^{\infty }$ to $Sh\_{S}^{\infty }$ ratio at different Schmidt numbers and a Reynolds number of 400. The data is interpolated from CFD results marked with black dots.

**References**

[1] Przybył, S., & Pierański, P. (2001). Helical close packings of ideal ropes. The European Physical Journal E, 4(4), 445-449.