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T. Lohaus, N. Herkenhoff, R. Shankar, M. Wessling

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Feed flow patterns of combined Rayleigh-Bénard convection and membrane permeation

T. Lohaus[a], N. Herkenhoff[a], R. Shankar[a], M. Wessling[a,b,*]

[a] *RWTH Aachen University, Chemical Process Engineering, Turmstrasse 46, D-52064 Aachen, Germany*
[b] *DWI-Leibniz-Institute for Interactive Materials, RWTH Aachen University, Forckenbeckstrasse 50, D-52074 Aachen, Germany*

Abstract

In micro- and nano-scale filtration processes, concentration polarization and fouling phenomena degrade the overall performance of porous membranes. To reduce these phenomena we aim to induce hydrodynamic instabilities near the membrane surface, which promote local turbulence in the vicinity of the membrane-solution interface. In this work, we utilize thermal instabilities related to buoyancy-driven Rayleigh-Bénard convection by heating a novel electrically conductive membrane. The heated membrane induces a local temperature gradient and thus a convective flow perpendicular to the membrane. We investigate the evolution of the mixed convection flow patterns arising from combining Rayleigh-Bénard convection with pressure-driven membrane permeation. The flow patterns are analyzed experimentally by particle image velocimetry and computed with CFD simulations. We study the contribution of the individual convection modes on the resulting mixed convection using the Richardson (Ri) number. By inducing natural convection on the steady flow pattern from dead-end permeation, a large convective vortex forms with significant shear velocities near the membrane surface. These shear velocities increase with increasing impact of natural convection. The resulting shear flows show good potential in enhancing the mixing of the bulk and to enable convective mass transport of accumulated solutes away from the membrane and thus reduce concentration polarization and membrane fouling.

Keywords: Mixed convection, Rayleigh-Bénard convection, hydrodynamic instabilities, membrane permeation

1. Introduction

Concentration polarization and fouling phenomena degrade the overall performance of porous membranes through decreasing the magnitude and quality of the permeate stream. Influencing the fluid mechanics in membrane filtration can greatly improve the performance of the membrane [1]. A general strategy utilized to reduce concentration polarization and fouling is to manipulate the feed, for example by increasing the volumetric feed flow rate [2, 3], using turbulence promoters [4, 5], and through pulsatile flows [6–8]. These techniques result in aggravated mixing of the solution which in turn reduces the apparent thickness of the concentration boundary layer. An alternative technique is to

*manuscripts.cvt@avt.rwth-aachen.de
Email address: manuscripts.cvt@avt.rwth-aachen.de (M. Wessling)