Pervaporation Membrane Module Design with Simulation

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Abstract

Chemical industry continuously strives to improve its energy efficiency, and pervaporation presents an interesting alternative to many conventional liquid separation processes. Pervaporation is the selective evaporation of one of the components of a liquid mixture using a membrane. In pervaporation, a heated liquid mixture is fed into a membrane module. The permeating species evaporate across the membrane and are condensed to create a partial vacuum and thereby maintain a driving force for permeation. Hybrid silica (HybSi©) membranes for pervaporation have been developed at ECN and are commercially available from Pervatech. In the EMPRESS project, Philips Ceramics and Pervatech have jointly developed new 4-tube membrane assembly to reduce the costs of the membrane system. The present contribution focuses on the pervaporation module design strategy based on the 4-tube membrane assembly.

The membranes consist of porous ceramic support tubes with a thin selective layer on the inside or feed side (lumen). Four membrane tubes are connected as a bundle in a ceramic header: the 4-tube membrane assembly. In two modules designs, either 7 or 19 of these bundles are included in a steel housing, cf. Fig. 1 and 2, for a membrane surface area of 0.74 m2 or 2.0 m2, modules PVM-120-7-P and PVM-120-19-P, respectively. At the permeate/vacuum side, friction might induce an increase in pressure (and hence a decrease in driving force) especially at higher fluxes. The permeate side is modelled as Single-Phase Fluid Flow in COMSOL Multiphysics® in order to evaluate the pressure distribution in the module. The entire geometry is partitioned by work planes that are place along the axes of symmetry. The remaining geometry is meshed in 250,000 elements and the problem is solved with the stationary solver.

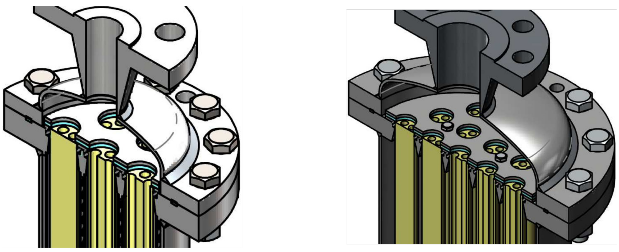
The PVM-120-7-P module has been modelled by assuming 7 membrane bundles in the pervaporation module. The predicted velocity and pressure distributions corresponding to the assumed permeate flux of 20 kg m-2 h-1 are shown in Fig. 3. The highest velocities, and consequently the highest pressure drop on the permeate side, are predicted near the outlet connection of the module. The velocity calculated near the outlet of the module is the highest at a local maximum of 27 m s-1 and has an average of 17 m s-1. Accordingly, the calculated pressure drop is small, only about 0.1 mbar. The same approach has been applied to the PVM-120-19-P module. Using a flux of 20 kg m-2 h-1 and a membrane area of 2.0 m2 the module pervaporates a total of 40 kg hr-1 of water. The predicted velocity and pressure distributions are shown in Fig. 4. Compared to the PVM-120-7-P module, the velocity and pressure drop are slightly higher. The highest velocity of 32 m s-1 exists at the

outlet of the module and the pressure drop over the permeate side is estimated at 0.2 mbar. Thus, the flow conditions at the permeate side for either module do not contribute significantly to the mass transfer resistance for pervaporation.

Figures used in the abstract

PVM-120-7-P module PVM-120-19-P module
Figure 1. Pervatech pervaporation modules

Figure 1



PVM-120-7-P module PVM-120-19-P module
Figure 2. Pervatech pervaporation modules, detail of the header

Figure 2

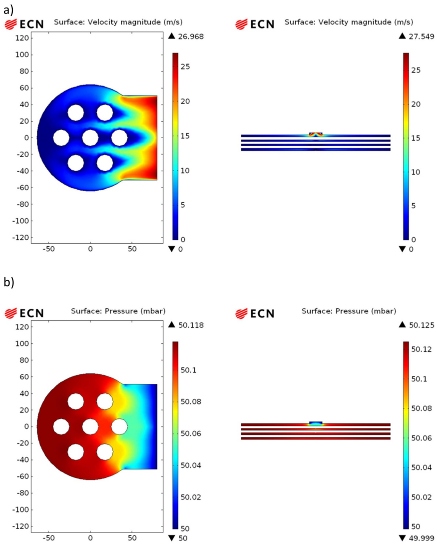


Figure 3. Calculated permeate side flows PVM-120-7-P module, a) velocity, b) pressure

Figure 3

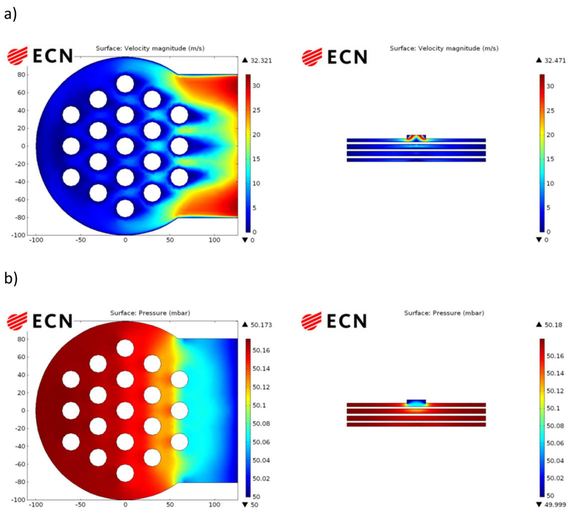


Figure 4. Calculated permeate side flows PVM-120-19-P module, a) velocity, b) pressure

Figure 4