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Effects of membrane structure and operational variables on membrane distillation performance

Vasiliki Karanikola*[1], Andrea F. Corral[1], Hua Jiang[1], A. Eduardo Sáez[1], Wendell P. Ela[1] & Robert G. Arnold[1]

[1]Department of Chemical and Environmental Engineering, The University of Arizona, 1133 E. James E. Rogers Way, Harshbarger 108, Tucson, AZ 85721

Email: vkaranik@email.arizona.edu Phone: (520) 626-9323

Abstract

A bench-scale, sweeping gas, flat-sheet Membrane Distillation (MD) unit was used to assess the importance of membrane architecture and operational variables to distillate production rate. Sweeping gas membrane distillation (SGMD) was simulated for various membrane characteristics (material, pore size, porosity and thickness), spacer dimensions and operating conditions (influent brine temperature, sweep gas flow rate and brine flow rate) based on coupled mass and energy balances. Model calibration was carried out using four membranes that differed in terms of material selection, effective pore size, thickness and porosity. Membrane tortuosity was the lone fitting parameter. Distillate fluxes and temperature profiles from experiments matched simulations over a wide range of operating conditions. Limitations to distillate production were then investigated via simulations, noting implications for MD design and operation. Under the majority of conditions investigated, membrane resistance to mass transport provided the primary limitation to water purification rate. The nominal or effective membrane pore size and the lumped parameter $\varepsilon/\delta\tau$ (porosity divided by the product of membrane tortuosity and thickness) were primary determinants of membrane resistance to mass transport. Resistance to Knudsen diffusion dominated membrane resistance at pore diameters < 0.3 µm. At larger pore sizes, a combination of resistances to intra-pore molecular diffusion and convection across the gas-phase boundary layer determined mass transport resistance. Findings are restricted to the module design flow regimes considered in the modeling effort. Nevertheless, the value of performance simulation to membrane distillation design and operation is well illustrated.

Key Words: Sweeping Gas Membrane Distillation; Desalination; Flat Sheet Membrane; Heat and Mass Transfer