

Evaluation of hollow fiber-based direct contact and vacuum membrane distillation systems using aspen process simulation

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Table 1 Summary of equations for transport models in MD hollow fiber module

	Lumen side		Shell side	
			DCMD	VMD
EOS	$\rho_1 = \rho_{1,0}$		$\rho_2 = \rho_{2,0}$	$\frac{1}{p_2} \frac{dp_2}{dz} = \frac{1}{\rho_2} \frac{d\rho_2}{dz} + \frac{1}{T_2} \frac{dT_2}{dz}$
Mass	$\frac{d(\rho_1 v_1)}{dz} = \frac{4}{d_1} J_M$		$\frac{d(\rho_2 v_2)}{dz} = -\frac{4Nd_1}{d_2^2} J_M$	$\frac{d(\rho_2 v_2)}{dz} = -\frac{4Nd_1}{d_2^2} J_M$
Momentum	$\Delta p_1 = \frac{f_1(\rho_1 v_1)^2}{2\rho_1} \left(\frac{L}{d_1}\right) \left(\frac{\mu_1}{\mu_{W,1}}\right)^{-0.14}$		$\Delta p_2 = \frac{f_2(\rho_2 v_2)^2}{2\rho_2} \left(\frac{L}{d_{e,2}}\right) \left(\frac{\mu_2}{\mu_{W,2}}\right)^{-0.14}$	$\frac{dp_2}{dz} + v_2^2 \frac{d\rho_2}{dz} + 2\rho_2 v_2 \frac{dv_2}{dz} = 0$
Transport equations				$\rho_2 v_2 \hat{c}_{P,2} \frac{dT_2}{dz} + \left[p_2 - p^\circ + \rho_2 \hat{c}_{P,2} (T_2 - T^\circ) + \frac{3}{2} \rho_2 v_2^2 \right] \frac{dv_2}{dz} + \left[\frac{1}{2} v_2^3 + \hat{c}_{P,2} (T_2 - T^\circ) v_2 \right] \frac{d\rho_2}{dz} + v_2 \frac{dp_2}{dz} = -\frac{4Nd_1}{d_2^2} J_{H,2}$
Energy	$\rho_1 v_1 \hat{c}_{P,1} \frac{dT_1}{dz} + v_1 \frac{dp_1}{dz} = \frac{4}{d_1} J_{H,1}$		$\rho_2 v_2 \hat{c}_{P,2} \frac{dT_2}{dz} + v_2 \frac{dp_2}{dz} = -\frac{4Nd_1}{d_2^2} J_{H,2}$	
Boundary conditions	$T_1 _{z=0} = T_{1,0}, v_1 _{z=0} = v_{1,0}$		$T_2 _{z=L} = T_{2,0}, v_2 _{z=L} = v_{2,0}$	$p_2 _{z=0} = p_{2,0}, v_2 _{z=0} = 0$
Heat flux	$J_{H,1} = h_1(T_1 - T_{W,1})$ $J_{H,1} = J_M \Delta h_V _{T_{W,1}} + \frac{\kappa_m}{\delta} (T_{W,1} - T_{W,2})$		$J_{H,2} = h_2(T_{W,2} - T_2)$ $J_{H,2} = J_M \Delta h_V _{T_{W,2}} + \frac{\kappa_m}{\delta} (T_{W,1} - T_{W,2})$	$J_{H,2} = h_2(T_{W,2} - T_2)$ $J_{H,2} = \frac{\kappa_m}{\delta} (T_{W,1} - T_{W,2})$
Boundary correction equations	Heat transfer coefficient $Nu_1 = 3.66 + \frac{0.19 Gr_1^{0.8}}{1+0.1117 Gr_1^{0.467}} \left(\frac{\mu_1}{\mu_{W,1}}\right)^{0.14} \quad (0.1 \leq Gr_1 \leq 100)$ $Nu_1 = 1.86 + Gr_1^{0.33} \left(\frac{\mu_1}{\mu_{W,1}}\right)^{0.14} \quad (Gr_1 > 100)$			$Nu_2 = 0.16 Re_2^{0.6} Pr_2^{0.33} \left(\frac{\mu_2}{\mu_{W,2}}\right)^{0.14}$

Table 2 Comparison of measured and simulated permeation flux in the VMD hollow fiber module

References	Raw brine concentration (g/L)	Feed-side inlet temperature (°C)	Measured permeation flux (kg m ⁻² h ⁻¹)	Simulated permeation flux (kg m ⁻² h ⁻¹)	Relative error (%)
[1]	50	53	10.1	8.845	12.4
	94.5	52	9.3	10.481	-12.2
	148.6	48	7.9	8.079	2.3
			RMS		10.1
[22]	15	25	0.540	0.466	13.7
	60	25	0.540	0.462	14.4
	120	25	0.432	0.447	-3.5
	0	44	1.620	1.691	-4.4
	0	36	1.080	1.051	2.7
	0	28	0.648	0.600	7.3
	0	23	0.468	0.398	14.9
			RMS		10.0