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

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2014

Guan, G., Yang, X., Wang, R., Field, R., & Fane, A. G. (2014). Evaluation of hollow fiber-based direct contact and vacuum membrane distillation systems using aspen process simulation. Journal of Membrane Science, 464, 127-139.

https://hdl.handle.net/10356/79612

https://doi.org/10.1016/j.memsci.2014.03.054

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

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

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