FT I – Exercicios

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Conteúdo

Questão 7 – 3

Um permutador de calor de invólucro e tubos (com 10 tubos que realizam 8 passagens pelo invólucro) está dimensionado para aquecer $2.5\,\mathrm{kg\,s^{-1}}$ de água de $15\,^{\circ}\mathrm{C}$ a $85\,^{\circ}\mathrm{C}$. O aquecimento é conseguido graças à passagem de um óleo de processo, que se encontra disponível a $160\,^{\circ}\mathrm{C}$. O coeficiente de filme do lado do óleo assume o valor de $400\,\mathrm{W\,m^{-2}\,K^{-1}}$. A água circula pelo interior dos tubos. Os tubos possuem um diâmetro externo de $25\,\mathrm{mm}$ e um diâmetro interno de $23\,\mathrm{mm}$. Sabendo que o óleo sai do permutador de calor a $100\,^{\circ}\mathrm{C}$, calcule:

- Fator de Correlação de θ_m : $y = 0.87$
- Condutividade da parede do tubo: $k_W = 45\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $C_{p,oleo} = 2350\,\mathrm{J\,kg^{-1}\,K^{-1}}$
- $C_{p,agua} = 4181\,\mathrm{J\,kg^{-1}\,K^{-1}}$
- $k_{agua} = 0.643\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $\mu_{agua} = 548 * 10^{-6}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho_{agua} = 1000\,\mathrm{kg\,m^{-1}}$

Q7 – 3 a)

O caudal mássico de óleo necessário para realizar a operação desejada.

$$G_{m,oleo,1} = \frac{Q_{oleo}}{C_{m,p,oleo}\ \Delta T_{oleo}} = \frac{-Q_{agua}}{C_{m,p,oleo}\ \Delta T_{oleo}} =$$
$$= -\frac{G_{m,agua}\, C_{m,p,agua}\ \Delta T_{agua}}{C_{m,p,oleo}\ \Delta T_{oleo}} = -\frac{2.5 * 4181 * (85 - 15)}{2350 * (100 - 160)} \cong 5.19$$

Q7 – 3 b)

O comprimento que deverá ter cada tubo do permutador.

$$L = \frac{A_e}{2\,\pi\,r_e} = \frac{A_i}{2\,\pi\,r_i}; \qquad (\bar{h}_i\,A_i)^{-1} =$$

$$= \frac{y\;\Delta(\Delta T)_{\ln}}{Q_{agua}} = \frac{y\,\left(\frac{\Delta T_1 - \Delta T_0}{\ln\left(\Delta T_1/\,\Delta T_0\right)}\right)}{\left(G_{m,agua}\,C_{p,agua}\;\Delta T_{agua}\right)} =$$

$$= \frac{y(\Delta T_1 - \Delta T_0)}{\left(G_{m,agua}\,C_{p,agua}\;\Delta T_{agua}\right)\,\ln\left(\Delta T_1/\,\Delta T_0\right)} =$$

$$= (h_i\,A_i)^{-1} + (h_e\,A_e)^{-1} + \frac{x_w}{k_w\,A_w} =$$

$$= \begin{pmatrix} \left(\left(\frac{k_{agua}\,0.023}{D_i}\left(\frac{\rho\,D_i\,u}{\mu_{agua}}\right)^{0.8}\left(\frac{C_{p,agua}\,\mu_{agua}}{k}\right)\right)\left(2\,\pi\,(D_i/2)\,L\right)\right)^{-1} & + \\ +\,(h_e\,2\,\pi\,(D_e/2)\,L)^{-1} & + \\ +\frac{(D_e - D_i)/2}{k_w}\,\left(\frac{A_e - A_i}{\ln\left(A_e/A_i\right)}\right)^{-1} & \end{pmatrix} =$$

$$= \begin{pmatrix} \frac{\mu_{agua}^{0.4}}{k_{agua}^{0.6}\,0.023\,\rho_{agua}^{0.8}\,u^{0.8}\,C_{p,agua}^{0.4}\,D_i^{0.8}}\,(\pi\,L)^{-1} & + \\ +\,(h_e\,D_e)^{-1}\,(\pi\,L)^{-1} & + \\ +\frac{(D_e - D_i)/2}{k_w}\,\left(\frac{\ln\left(D_e/D_i\right)}{D_e - D_i}\right)(\pi\,L)^{-1} & \end{pmatrix} =$$

$$= \begin{pmatrix} \frac{\mu_{agua}^{0.4}}{k_{agua}^{0.6}\,0.023\,\rho_{agua}^{0.8}\,C_{p,agua}^{0.4}\,D_i^{0.8}}\left(\frac{G_{m,agua}}{n_{tubos}\,\rho_{agua}\,(\pi\,(D_i/2)^2)}\right)^{-0.8} & + \\ +\,(h_e\,D_e)^{-1} & + \\ +\frac{\ln\left(D_e/D_i\right)}{(2\,k_w)} & \end{pmatrix}(\pi\,L)^{-1} =$$

$$= \begin{pmatrix} \frac{\mu_{agua}^{0.4}\,n_{tubos}^{0.8}\,\pi^{0.8}\,D_i^{0.8}}{k_{agua}^{0.6}\,0.023\,C_{p,agua}^{0.4}\,G_{m,agua}^{0.8}\,2^{1.6}} & + \\ +\,(h_e\,D_e)^{-1} & + \\ +\frac{\ln\left(D_e/D_i\right)}{(2\,k_w)} & \end{pmatrix}(\pi\,L)^{-1} \implies$$

$$\implies L = \begin{pmatrix} \dfrac{\mu_{agua}^{0.4}\, n_{tubos}^{0.8}\, \pi^{0.8}\, D_i^{0.8}}{k_{agua}^{0.6}\, 0.023\, C_{p,agua}^{0.4}\, G_{m,agua}^{0.8}\, 2^{1.6}} & + \\ +\,(h_e\, D_e)^{-1} & + \\ +\dfrac{\ln\left(D_e/D_i\right)}{(2\,k_w)} & \end{pmatrix} *$$

$$* \frac{\left(G_{m,agua}\, C_{p,agua}\ \Delta T_{agua}\right) \ln\left(\Delta T_1/\,\Delta T_0\right)}{\pi\, y(\Delta T_1 - \Delta T_0)} =$$

$$= \begin{pmatrix} \dfrac{(548 * 10^{-6})^{0.4} * 10^{0.8} * \pi^{0.8} * (23 * 10^{-3})^{0.8}}{(0.643)^{0.6} * 0.023 * 4181^{0.4} * (2.5)^{0.8} * 2^{1.6}} & + \\ +\,(400 * 25 * 10^{-3})^{-1} & + \\ +\dfrac{\ln\left(25/23\right)}{(2 * 45)} & \end{pmatrix} *$$

$$* \frac{2.5 * 4181 * (85 - 15) * \ln\left(\frac{100-15}{160-85}\right)}{\pi * 0.87 * ((100 - 15) - (160 - 85))} \cong 379.15$$

Q7 – 3 c)

A área total necessária.

$$A_w = \frac{A_e - A_i}{\ln(A_e/A_i)} = \pi\, L \frac{D_e - D_i}{\ln(D_e/D_i)} \cong \pi\, 379.15 \frac{(25 - 23) * 10^{-3}}{\ln(25/23)} \cong 28.57$$

Questão 7 – 4

Condensa-se benzeno à temperatura de 353 K no exterior dos tubos dum permutador de calor do tipo caixa/tubos, com tubos verticais de diâmetros interior 22 mm e exterior 25 mm, fazendo passar água pelo interior dos tubos a um caudal de 0.03 $\mathrm{m^3/s}$. Qual será o comprimento total de tubo necessário, sabendo que a água entra a 290 K e sai a 300 K, e que o coeficiente de transferência de calor do lado da água é 850 $\mathrm{W\,m^{-2}\,K^{-1}}$?

- Condutividade térmica do material da parede do tubo: $k_w = 45\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $C_{p,agua} = 4181\,\mathrm{J\,kg^{-1}\,K^{-1}}$
- $\rho_{agua} = 1000\,\mathrm{kg\,m^{-3}}$
- $\mu_{ben} = 0.35 * 10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho_{ben} = 880\,\mathrm{kg\,m^{-3}}$
- $k_{ben} = 0.15\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $\lambda_{ben} = 394\,\mathrm{kJ\,kg^{-1}}$

$$L = \frac{A_e}{\pi\, D_e} = \frac{A_i}{\pi\, D_i}; \quad (\bar{h}\, A)^{-1} = \frac{\Delta(\Delta T)_{\ln}}{Q_{agua}} = \frac{\left(\frac{\Delta T_1 - \Delta T_0}{\ln(\Delta T_1/\Delta T_0)}\right)}{(G_{m,agua}\, C_{p,agua}\, \Delta T_{agua})} =$$

$$= (h_i\, A_i)^{-1} + (h_{ben}\, A_e)^{-1} + \frac{x_w}{k_w\, A_w} =$$

$$= \left(\begin{array}{l} (h_i\,(\pi\, D_i\, L))^{-1} \\ + \left(\left(1.47 \left(\frac{k_{ben}^3\, \rho_{ben}^2\, g}{4\, M_{ben}\, \mu_{ben}} \right)^{1/3} \right) (\pi\, D_e\, L) \right)^{-1} \\ + \frac{(D_e - D_i)/2}{k_w} \left(\frac{\ln(A_e/A_i)}{A_e - A_i} \right) \end{array} \right) =$$

$$= \left(\begin{array}{l} (h_i\, D_i)^{-1}\,(\pi\, L)^{-1} \\ + \frac{4^{1/3}\, \mu_{ben}^{1/3}}{1.47\, k_{ben}^{3*1/3}\, \rho_{ben}^{2*1/3}\, g^{1/3}\, D_e} \left(\frac{G_{ben}}{A_e/L} \right)^{1/3} (\pi\, L)^{-1} \\ + \frac{(D_e - D_i)/2}{k_w} \left(\frac{\ln(A_e/A_i)}{A_e - A_i} \right) \end{array} \right) =$$

$$= \left(\begin{array}{l} (h_i\, D_i)^{-1} \\ + \dfrac{4^{1/3}\, \mu_{ben}^{1/3}}{1.47\, k_{ben}\, \rho_{ben}^{2/3}\, g^{1/3}\, D_e} \left(\dfrac{(Q_{ben}\, C_{p,ben}^{-1}\, \rho_{ben}^{-1})\, L}{(\pi\, D_e\, L)} \right)^{1/3} \\ + \dfrac{\ln(D_e/D_i)}{2\, k_w} \end{array} + \right) (\pi\, L)^{-1} =$$

$$= \left(\begin{array}{l} (h_i\, D_i)^{-1} \\ + \dfrac{4^{1/3}\, \mu_{ben}^{1/3}}{1.47\, k_{ben}\, \rho_{ben}\, g^{1/3}\, D_e^{4/3}\, \pi^{1/3}\, C_{p,ben}^{1/3}} (-Q_{agua})^{1/3} \\ + \dfrac{\ln(D_e/D_i)}{2\, k_w} \end{array} + \right) (\pi\, L)^{-1} =$$

$$= \left(\begin{array}{l} (h_i\, D_i)^{-1} \\ + \dfrac{4^{1/3}\, \mu_{ben}^{1/3}\, (-G_{m,agua}\, \rho_{agua}\ \Delta T_{agua})^{1/3}}{1.47\, k_{ben}\, \rho_{ben}\, g^{1/3}\, D_e^{4/3}\, \pi^{1/3}\, C_{p,ben}^{1/3}} \\ + \dfrac{\ln(D_e/D_i)}{2\, k_w} \end{array} + \right) (\pi\, L)^{-1} \implies$$

$$\implies L =$$

$$= \left(\begin{array}{l} (h_i\, D_i)^{-1} \\ + \dfrac{4^{1/3}\, \mu_{ben}^{1/3}\, (-G_{m,agua}\, \rho_{agua}\ \Delta T_{agua})^{1/3}}{1.47\, k_{ben}\, \rho_{ben}\, g^{1/3}\, D_e^{4/3}\, \pi^{1/3}\, C_{p,ben}^{1/3}} \\ + \dfrac{\ln(D_e/D_i)}{2\, k_w} \end{array} + \right) *$$

$$* \left(\frac{G_{m,agua}\, C_{p,agua}\ \Delta T_{agua}}{\pi(\Delta T_1 - \Delta T_0)}\ \ln \frac{\Delta T_1}{\Delta T_0} \right) =$$

$$= \left(\begin{array}{l} (850 * 22 * 10^{-3})^{-1} \\ + \dfrac{4^{1/3} * (0.35 * 10^{-3})^{1/3} * (-0.03 * 880 * (300 - 290))^{1/3}}{1.47 * 0.15 * 880 * g^{1/3} * D_e^{4/3} * \pi^{1/3} * C_{p,ben}^{1/3}} \\ + \dfrac{\ln(D_e/D_i)}{2\, k_w} \end{array} + \right) *$$

$$* \left(\frac{G_{m,agua}\, C_{p,agua}\ \Delta T_{agua}}{\pi(\Delta T_1 - \Delta T_0)}\ \ln \frac{\Delta T_1}{\Delta T_0} \right)$$