

$$2) \quad \dot{m}_{\text{Caustic Soda}} = 51500 \frac{\text{kg}}{\text{h}} \quad C_{p \text{ caustic soda}} = 0.88 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}}$$

$$S = 1115 \quad k = 0.849 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}} \cdot \left(\frac{1 \text{ W/m}^\circ\text{C}}{0.5778 \frac{\text{Btu}}{\text{h} \cdot \text{ft} \cdot ^\circ\text{F}}} \right) = 0.604 \frac{\text{W}}{\text{m}^\circ\text{C}}$$

$$T_{c,o} = 120^\circ\text{F} = \frac{5}{9} (120^\circ\text{F} - 32) = 48.8889^\circ\text{C}$$

$$T_{c,i} = 190^\circ\text{F} = \frac{5}{9} (190^\circ\text{F} - 32) = 87.7778^\circ\text{C}$$

$$T_{h,o} = 48.8889^\circ\text{C} = 120^\circ\text{F}$$

$$T_{h,i} = 80^\circ\text{F} = \frac{5}{9} (80^\circ\text{F} - 32) = 26.6667^\circ\text{C}$$

$$Q = \dot{m}_{\text{Caustic Soda}} \cdot C_{p \text{ Caustic Soda}} \cdot (87.7778 - 48.8889)^\circ\text{C}$$

$$= 51500 \frac{\text{kg}}{\text{h}} \cdot 0.88 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}} \cdot \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) \cdot \left(\frac{1 \text{ kJ}}{0.23884 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}}} \right) \cdot (87.7778 - 48.8889)^\circ\text{C} = 2041.81 \frac{\text{kJ}}{\text{s}}$$

$$\dot{m}_{\text{water}} = \frac{2041.81 \frac{\text{kJ}}{\text{s}}}{4.1869 \frac{\text{kJ}}{\text{kg}^\circ\text{C}} \cdot (48.8889 - 26.6667)^\circ\text{C}} = 79001.66 \frac{\text{kg}}{\text{h}}$$

$$\frac{T_{h,o} + T_{h,i}}{2} = T_{h, \text{avg}} = \frac{48.8889 + 26.6667}{2} = 37.7778^\circ\text{C}$$

$$C_p = 1.0 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}} \cdot \left(\frac{1 \text{ kJ}}{0.23884 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}}} \right) = 4.1869 \frac{\text{kJ}}{\text{kg}^\circ\text{C}}$$

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$$\frac{1}{U_p} = \frac{1}{h_o} + \left(\frac{r_o}{r_i} \right) \frac{1}{h_i} + R_p + \frac{r_o}{k} \ln \left(\frac{r_o}{r_i} \right)$$

$$d_o = 2t + d_i = \frac{1.0 \text{ in}}{12} = 0.0833 \text{ ft} \times \left(\frac{0.3048 \text{ m}}{1 \text{ ft}} \right) = 0.02538 \text{ m}$$

$$d_i = \frac{0.834 \text{ in}}{12} = 0.0695 \text{ ft} \times \left(\frac{0.3048 \text{ m}}{1 \text{ ft}} \right) = 0.0211 \text{ m}$$

$$R_p = 0.002 \frac{\text{Btu} \cdot \text{ft}^2}{\text{h}^\circ\text{F}} \times 0.1761 = 3.522 \times 10^{-4} \frac{\text{m}^2 \cdot \text{K}}{\text{W}}$$

Assume

$$h_o = 1000 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

$$h_i = 5000 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

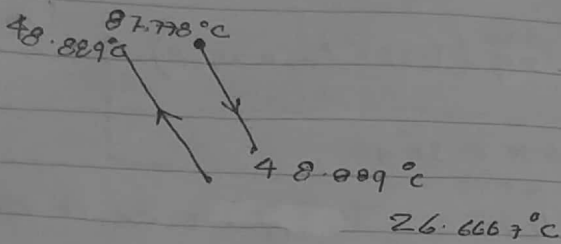
kakac & et. Heat exchanger selection, Rating & thermal design, 3rd edition

$$U = 612.88 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

$$\frac{1}{U_c} = \frac{1}{h_o} + \left(\frac{r_o}{r_i} \right) \frac{1}{h_i} + \frac{r_o}{k} \ln \left(\frac{r_o}{r_i} \right)$$

$$U_c = 781.7756 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

$$\Delta T_{lm} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln \left[\frac{(T_{h,i} - T_{c,o})}{(T_{h,o} - T_{c,i})} \right]}$$



$$= 12^\circ\text{C}$$

$$F = 0.9$$

$$A_p = \frac{Q}{U_p F \Delta T_{lm}} = \frac{308.4722 \text{ m}^2 \cdot 2041.81 \text{ kJ} \times 10^3}{5 \cdot 1 \text{ kJ}} = 612.88 \text{ W} \cdot \text{m}^2/\text{K} \cdot 0.9 \times 12^\circ\text{C}$$

$$A_c = \frac{Q}{U_c F \Delta T_{lm}} = 241.922 \text{ m}^2$$

$$\frac{A_p}{A_c} = 1.275$$

$$A_o = \pi d_o N_t L$$

$$N_t = CTP \left(\frac{\pi D_s^2}{4 A_1} \right)$$

1-tube Pass

$$CTP = 0.93$$

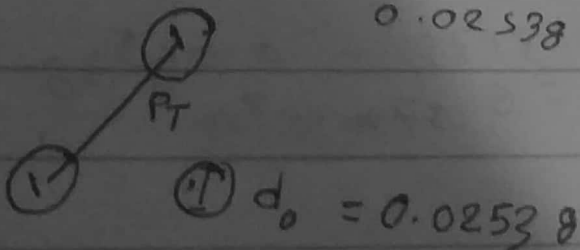
= Tube Count Calculation

$$A_1 = (CL) P_T^2 = 0.87 \times 0.03175^2 = 8.7701 \times 10^{-4} \text{ m}^2$$

Cost

$$CL = 0.87 \text{ for } 30^\circ\text{C} \text{ to } 60^\circ\text{C}$$

$$P_R = \frac{P}{\frac{1}{d}} = \frac{1.25 \times \frac{1}{12} \times 0.3048 \text{ m}}{0.02538} = 1.25$$

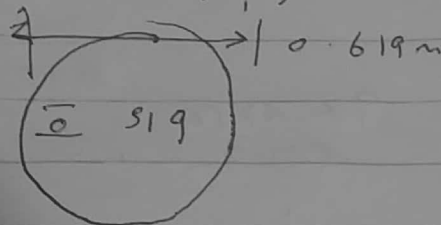


$$D_s = 0.637 \sqrt{\frac{eL}{CTP}} \left[\frac{A_o (PR)^2 d_o}{L} \right]^{1/2}$$

$$= 0.637 \sqrt{\frac{0.87}{0.93}} \left[\frac{308.472 (1.25)^2 (0.02538)}{16 \times 0.3048} \right]^{1/2}$$

$$= \frac{0.975}{m} = 3.914 \approx 0.9906m$$

$$N_T = CTP \left(\frac{\pi D_s^2}{4A_i} \right) = 793 \approx 766$$



$$0.02538m \rightarrow 0.0211m$$

$$D_e = \frac{4 \left(\frac{P_T^2}{4} - \pi d_o^2 / 4 \right)}{\pi d_o / 2} = \frac{0.184m}{0.02519m}$$

Bundle cross flow area clearance

$$A_s = \frac{D_s C_B}{P_T} \quad \text{Battin & Posing}$$

transverse pitch

$$C = P_T - d_o = 0.03175 - 0.02538$$

$$= 6.37 \times 10^{-3}m$$

The selected shell & tube HE for this purpose has the following geometrical parameters

$$\text{Shell internal diameter} = D_j = 25 \text{ in} = 0.9906 \text{ m}$$

$$\# \text{ of tubes} = 766$$

$$\text{Tube diameter } (d_o) = 25.38 \text{ mm} \quad \text{ID } (d_i) = 21.1 \text{ mm}$$

$$\text{Tube material } k = 60 \frac{\text{W}}{\text{m}^2 \text{K}}$$

$$B = 0.6 \times 0.9906 = 0.59436 \text{ m} \quad \text{Baffle cut } 25\%$$

$$P_T = 0.03175 \text{ m}$$

$$N_p = 1$$

The Properties of the shell side fluid can be taken at

$$T_b = \frac{87.7778 + 48.8889}{2} = 68.33335^\circ\text{C}$$

$$\rho = \frac{1001.154}{978.88 \times 1.115} = 1076.548 \frac{\text{kg}}{\text{m}^3}$$

$$C_p = 3.7606 \frac{\text{kJ}}{\text{kg}^\circ\text{C}}$$

$$\mu = 0.76 \text{ cP} \times 2.42 = 1.8392 \frac{\text{lb}_m}{\text{ft hr}} \times \frac{1 \text{ kg/m.s}}{2419.2 \frac{\text{lb}_m}{\text{ft hr}}} = 7.602 \times 10^{-4} \frac{\text{kg}}{\text{m.s}}$$

$$k = 0.604 \frac{\text{W}}{\text{m}^\circ\text{C}}$$

$$Pr = \frac{C_p \mu}{k} = \frac{7.602 \times 10^{-4} \frac{\text{kg}}{\text{m.s}} \times 3.7606 \frac{\text{kJ}}{\text{kg}^\circ\text{C}}}{0.604 \frac{\text{W}}{\text{m}^\circ\text{C}}} = 4.733$$

Properties of the tube side at 37.778 °C

$$\rho = 1001.154 \text{ kg/m}^3$$

$$c_p = 4.1869 \frac{\text{kJ}}{\text{kg}^\circ\text{C}}$$

$$\mu = 0.702 \times 10^{-4} = 1.7416 \text{ / ft hr}$$

$$= 7.12 \times 10^{-4} \frac{\text{kg}}{\text{m s}}$$

$$k = 0.3628 \times \left(\frac{1 \text{ W/m}^\circ\text{C}}{0.5778 \frac{\text{Btu}}{\text{hr}^\circ\text{F}}} \right)$$

$$= 0.6279 \frac{\text{W}}{\text{m}^\circ\text{C}}$$

$$Pr = 4.79$$

The specifications are

$$\text{Maximum tube length } L_{\text{max}} = 4.8768$$

$$\text{Max pressure drop on the shell side, } \Delta P_s = 10 \text{ psi}$$

$$\frac{h_o D_o}{k} = 0.36 \left(\frac{D_o G_s}{\mu} \right)^{0.55} \left(\frac{c_p \mu}{k} \right)^{1/3} \left(\frac{\mu_b}{\mu} \right)^{0.14}$$

$$\text{For } 2 \times 10^5 < Re_s = \frac{G_s D_o}{\mu} < 1 \times 10^6$$

For the triangular Pitch layout

$$D_e = 0.0184 \text{ m}$$

$$C = 0.00637 \text{ m}$$

$$\frac{A_s}{P_T} = \frac{D_s C_B}{P_T} = \frac{0.9906 \times 0.00637}{0.05175} = 0.1181$$

$$G_s = \frac{m'}{A_s} = 51300 \text{ kg/hr} \left(\frac{1 \text{ hr}}{3600 \text{ s}} \right) = 120.660 \frac{\text{kg}}{\text{s m}^2}$$

$$Re_s = \frac{G_s D_e}{\mu} = \frac{120.660 \frac{\text{kg}}{\text{s m}^2} \times 0.0184 \text{ m}}{0.1181 \frac{\text{kg}}{\text{m s}}} = 184.47$$

$$T_w = \frac{1}{2} \left(\frac{T_{c1} + T_{c2}}{2} + \frac{T_{h1} + T_{h2}}{2} \right)$$

$$= \frac{1}{2} \left(\frac{26.667 + 48.889}{2} + \frac{87.889 + 48.889}{2} \right)$$

$$= 53.055^\circ \text{C}$$

$$\mu_w = 1.15 \text{ cP} \times 2.42 \times \frac{1}{2919.2} = 1.1578 \times 10^{-3} \frac{\text{kg}}{\text{m s}}$$

$$\frac{h_o Pe}{k} = 0.36 \times \frac{0.55 \left(3.7606 \times 10^3 \frac{\text{J}}{\text{kg}^\circ \text{C}} + 7.602 \times 10^{-4} \frac{\text{kg}}{\text{m s}} \right)^{1/4}}{2920.47 \frac{\text{kg}}{\text{m s}} \times 0.604 \frac{\text{W}}{\text{m K}}}$$

$$\times \left(\frac{7.602 \times 10^{-4}}{6.04 \times 1.1578 \times 10^{-3}} \right)^{0.14}$$

$$= 45.939$$

$$h_o = \frac{156.95 \times 0.604}{0.0184} = 5081.00 \frac{\text{W}}{\text{m}^2 \text{K}}$$

For the tube-side heat transfer coefficient

$$A_{tp} = \frac{\pi d_i^2 N_t}{4} = \frac{\pi (0.0211)^2}{4} = 0.1339 \text{ m}^2$$

$$U_m = \frac{m}{\rho A_{tp}} = \frac{79001.66 \text{ kg/hr}}{1001.154 \frac{\text{kg}}{\text{m}^3} \times 0.1339 \text{ m}^2} \times \left(\frac{1 \text{ hr}}{3600 \text{ s}} \right) = 0.1637 \frac{\text{m}}{\text{s}}$$

$$Re = \frac{1001.154 \frac{\text{kg}}{\text{m}^3} \times 0.1637 \frac{\text{m}}{\text{s}} \times 0.0211 \text{ m}}{0.021} = 7.192 \times 10^{-4} \frac{\text{kg}}{\text{m} \cdot \text{s}} = 4808.1979$$

Since $Re > 10,000$ the flow is turbulent

$$Nu_b = (f/2) (Re_b - 1000) Pr_b / (1 + 12.7 (f/2)^{1/2} (Pr_b^{1/4} - 1))$$

$$f = (1.58 \ln Re - 3.28)^{-2}$$

$$= (1.58 \ln (4808.1979) - 3.28)^{-2}$$

$$= 0.00977$$

$$f/2 = 0.004886$$

$$Nu_b = 33.8$$

$$h_i = \frac{33.8 \times 0.6279}{0.0211} = 1006.710$$

To calculate

$$U_p = 494.63 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$U_c = 527.14 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$R_p = U_c - U_p / U_c U_p \times \frac{1}{0.1761} = 1.990 \times 10^{-3}$$

Shell-side Pressure drop

$$\Delta P_s = \frac{f G_s^2 (N_b + 1) D_s}{2 \rho D_e \phi_s}$$

$$f = e^{(0.576 - 0.19 \ln R_s)}$$

$$= e^{0.576 - 0.19 \ln (2920.47)} = 0.3905$$

$$\phi_s = \left(\frac{\mu_b}{\mu_w} \right)^{0.14} = \left(\frac{7.602 \times 10^{-4}}{1.1578 \times 10^{-3}} \right)^{0.14} = 0.9428$$

$$N_b = \frac{L}{B} - 1 = \frac{16 \times 0.3048}{0.9906 \times 0.6} - 1 = 7$$

$$\Delta P_s = \frac{(0.3905) (120.660)^2 (7+1) (0.9906)}{2 \times 1116.286 \times 0.0184 \times 0.9428}$$

$$= 1163.30 \text{ Pa}$$

$$= 0.168722 \text{ PSI}$$

$$\dot{Q} = 2041.81 \text{ kW}$$

$$A_o P = \frac{\dot{Q}}{U_o P \Delta T_m}$$

$$\Delta T_m = 12^\circ \text{C}$$

$$F = 0.92$$

$$F \Delta T_m = 11.04^\circ \text{C}$$

$$A_o = 415.956 = \pi d_o L N_t$$

$$\frac{A_o}{\pi d_o N_t} = L = \frac{415.956}{\pi \times 0.02538 \times 766} = 6.81 \text{ m}$$

$6.81 \text{ m} < 4.87$ the length of the HE is not acceptable

$$\Delta P_E = \left(\frac{\Delta P L N_p}{d_i} + 4 N_p \right) \frac{\rho U_m^2}{2}$$

$$= 41438.09 \text{ Pa} \approx 6.01 \text{ Psi}$$