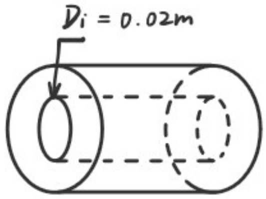
ME 320 Homework 7

I. 11.17 (note: thin wall means the thermal resistance due to this wall can be ignored)

A counterflow, concentric tube heat exchanger is designed to heat water from 20 to 80°C using hot oil, which is supplied to the annulus at 160°C and discharged at 140°C. The thin-walled inner tube has a diameter of $D_i = 20$ mm, and the overall heat transfer coefficient is 500 W/m$^2\cdot$K. The design condition calls for a total heat transfer rate of 3000 W.

(a) What is the length of the heat exchanger?

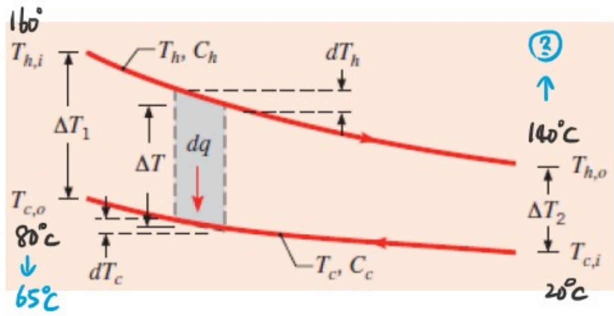
(b) After 3 years of operation, performance is degraded by fouling on the water side of the exchanger, and the water outlet temperature is only 65°C for the same fluid flow rates and inlet temperatures. What are the corresponding values of the heat transfer rate, the outlet temperature of the oil, the overall heat transfer coefficient, and the water-side fouling factor, $R''_{f,c}$?



$U = 500\ W/m^2\cdot K$

$q = 3000\ W$

同心对流热交换器



(a) 使用LMTD算法

$$\Delta T_1 = 160°C - 80°C = 80K$$

$$\Delta T_2 = 140°C - 20°C = 120K$$

$$q = U\,A\,\Delta T_{\ell m} \qquad (11.14)$$

$$\Delta T_{\ell m} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \qquad (11.15)$$

$$\Delta T_{Lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\Delta T_1 - \ln\Delta T_2} = \frac{80-120K}{\ln\left(\frac{80}{120}\right)} = 98.65$$

$$\left.\begin{array}{l} q = U\cdot A\cdot\Delta T_{Lm} \\ A = \pi\cdot D\cdot L \end{array}\right\} \Rightarrow L = \frac{q}{\Delta T_{Lm}\cdot U\cdot\pi\cdot D}$$

$$= \frac{3000\ W}{98.65 \times 500\ W/m^2\cdot K \times \pi \times 0.02m}$$

$$= 0.968\ m$$

(b).

$$q = C_p\cdot m\cdot(T_{c,o} - T_{c,i})$$

$$\frac{q_1}{q_2} = \frac{C_p\cdot m\cdot(80°C - 20°C)}{C_p\cdot m\cdot(65°C - 20°C)} = \frac{60}{45} = \frac{4}{3}$$

$$\therefore q_2 = \frac{3}{4}q_1 = \frac{3}{4}\times 3000\ W = \boxed{2250\ W}$$

$$\frac{q_1}{q_2} = \frac{C_p\cdot m\cdot(160°C - 140°C)}{C_p\cdot m\,(160°C - T_{h,o})} = \frac{4}{3}$$

$$\therefore T_{h,o} = 160°C - \frac{3}{4}(160°C - 140°C) = \boxed{145°C}$$

$$\Delta T_1 = 160°C - 65°C = 95°C$$

$$\Delta T_2 = 145°C - 20°C = 125°C$$

$$\because q_2 = UA(\Delta T_{Lm,2}) \Rightarrow U_2 = \frac{q_2}{A\cdot\Delta T_{Lm,2}}$$

$$\therefore U_2 = \frac{2250W}{\pi\times 0.02m \times 0.968m \times \frac{95°C - 125°C}{\ln\left(\frac{95}{125}\right)}} = \boxed{338.4\ W/m^2\cdot K}$$

$$\left.\begin{array}{l} U_1 = \left(\frac{1}{h_{里}} + \frac{1}{h_{外}}\right)^{-1} \\ U_2 = \left(\frac{1}{h_{里}} + \frac{1}{h_{外}} + R''_{f,c}\right)^{-1} \end{array}\right\} \Rightarrow R''_{f,c} = \frac{1}{U_2} - \frac{1}{U_1}$$

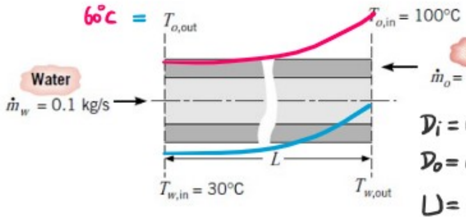
$$\boxed{= 9.55\times 10^{-4}\ m^2\cdot K/W}$$

II. 11.21 (Use both the LTMD and NTU-E methods)

A concentric tube heat exchanger for cooling lubricating oil is comprised of a thin-walled inner tube of 25-mm diameter carrying water and an outer tube of 45-mm diameter carrying the oil. The exchanger operates in counterflow with an overall heat transfer coefficient of 60 W/m$^2\cdot$K and the tabulated average properties.

(a) If the outlet temperature of the oil is 60°C, determine the total heat transfer and the outlet temperature of the water.

(b) Determine the length required for the heat exchanger.



$D_i = 0.025\,m$

$D_o = 0.045\,m$

$U = 60\,W/m^2\cdot K$

Properties	Water	Oil
ρ (kg/m^3)	1000	800
c_p (J/kg · K)	4200	1900
ν (m^2/s)	7×10^{-7}	1×10^{-5}
k (W/m · K)	0.64	0.134
Pr	4.7	140

LMTD

$$q = U A \Delta T_{lm} \quad (11.14)$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} \quad (11.15)$$

$$q_{油} = \dot{m}_{油} \cdot c_{p油} \cdot |T_{油进} - T_{油出}|$$
$$= 0.1\,kg/s \times 1900\,J/kg\cdot K \times (100°C - 60°C)$$
$$= 7600\,W$$

$$q_{水} = \dot{m}_{水} \cdot c_{p水} \,|T_{水进} - T_{水出}|$$
$$= 0.1\,kg/s \times 4200\,J/kg\cdot K \times (T_{水出} - 30°C)$$

$$q_{水} = q_{油} \Rightarrow T_{水出} = 30°C + \frac{7600\,W}{0.1\,kg/s \times 4200\,J/kg\cdot K} = \boxed{48.1°C}$$

$$\Delta T_1 = 60°C - 30°C = 30\,K$$

$$\Delta T_2 = 100°C - 48.1°C = 51.9\,K$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{30 - 51.9\,K}{\ln\left(\frac{30}{51.9}\right)} = 39.95\,K$$

$$\left\{\begin{array}{l} q = U\cdot A\cdot \Delta T_{lm} \\ q = q_{水} \end{array}\right. \Rightarrow L = \frac{q_{水}}{U\cdot\pi\cdot D_i\, T_{lm}} = \frac{7600\,W}{60\,W/m^2\cdot K \cdot \pi \cdot 0.025\,m \times 39.95\,K} = \boxed{40.37\,m}$$

NTU

$$\Delta T_{max} = 100°C - 30°C = 70°C$$

$$C_{min} = C_{oil} = 1900\,J/kg\cdot K \times 0.1\,kg/s$$

$$q_{max} = C_{min} \times \Delta T = 13300\,W$$

$$q = q_{油} = \dot{m}_{油} \cdot c_{p油} \cdot |T_{油进} - T_{油出}|$$
$$= 0.1\,kg/s \times 1900\,J/kg\cdot K \times (100°C - 60°C)$$
$$= 7600\,W$$

$$\varepsilon = \frac{q}{q_{max}} = \frac{7600}{13300} = 0.5714$$

$$C_r = \frac{C_{min}}{C_{max}} = \frac{C_{油}}{C_{水}} = \frac{1900}{4200} = 0.4524$$

$$\left.\begin{array}{l} NTU = f(\varepsilon, C_r) = 1 \\ NTU = \frac{U\cdot A}{C_{min}} = \frac{U\cdot\pi\cdot D_i\cdot L}{C_{min}} \end{array}\right\} \Rightarrow \boxed{L = 40.3\,m}$$