30th Oct 2025

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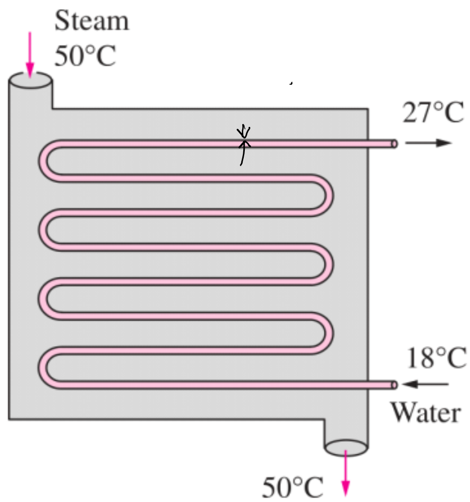
Heat Exchanger

Thermal Resistance & $\rightarrow$ (R)

$$\frac{1}{UA_s} = \boxed{\frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R} = \frac{1}{h_iA_i} + R_{wall} + \frac{1}{h_oA_o}$$

$i \rightarrow$ inner surf $\qquad o \rightarrow$ outer surf.

$$\frac{1}{U} \approx \frac{1}{h_i} + \frac{1}{h_o}$$



Fouling

$$\frac{1}{UA_s} = \frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R = \frac{1}{h_iA_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{R_{f,o}}{A_o} + \frac{1}{h_oA_o}$$

If we assume that HE is fully insulated:

$$\dot{Q} = \dot{m}_c C_{p,c}(T_{c,out} - T_{c,in}) = C_c(T_{c,out} - T_{c,in})$$
$$\dot{Q} = \dot{m}_h C_{p,h}(T_{h,in} - T_{h,out}) = C_h(T_{h,in} - T_{h,out})$$

Problems

(2) equations:

(i)

(ii) $\underbrace{\text{LMTD}}_{\text{If we know all inlet outlet Temp.}}$ or $\underbrace{\epsilon\text{-NTU method}}_{\text{Otherwise}}$

If using LMTD

$$\dot{Q} = UA_s\Delta T_{lmtd} \rightarrow \Delta T_{lm}$$

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

Cross flow $\rightarrow$ $[\Delta T_{lm} = F \times \Delta T_{lm,CF}]$

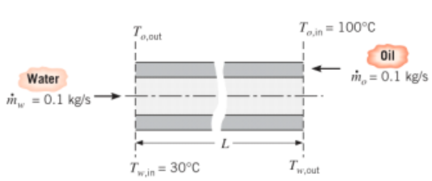
$$\text{Effectiveness of HE } (\epsilon) = \frac{\dot{Q}}{\dot{Q}_{max}}$$

$$\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in})$$

C_{min}: min $[\dot{m}_h C_{p,h} / \dot{m}_c C_{p,c}]$

11.4, 11.18, $\boxed{11.23, 11.35}$

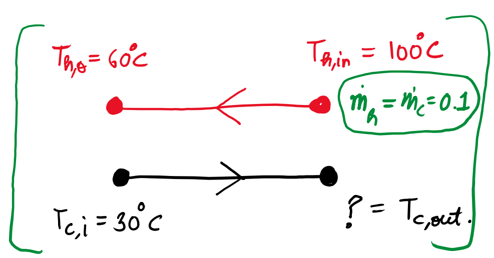
11.23 A concentric tube heat exchanger for cooling lubricating oil is comprised of a thin-walled inner tube of 25-mm diameter carrying water and an outer tube of 45-mm diameter carrying the oil. The exchanger operates in counterflow with an overall heat transfer coefficient of 60 W/m^2 · K and the tabulated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



Properties	Water	Oil
ρ (kg/m^3)	1000	800

(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.



Using overall energy balance equation

$$\dot{q} = \cancel{\dot{m}_h} C_{p,h}(T_{h,in} - T_{h,out}) = \cancel{\dot{m}_c} C_{p,c}(T_{c,out} - T_{c,in})$$

$$1900 \times (100 - 60) = 4200(T_{c,out} - 30°C)$$

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

$$1900 \times (100-60) = 4200\,(T_{c,out} - 30^\circ C)$$

$$\Rightarrow \boxed{T_{c,out} = 48.1^\circ C} \quad \text{--- (1)}$$

$$q = UA\Delta T_{lm,CF} = U(\pi D L)\,\Delta T_{lm,CF} \Rightarrow \boxed{L = \frac{q}{U \times \pi D \times \Delta T_{lm,CF}}} \quad \text{--- (2)}$$

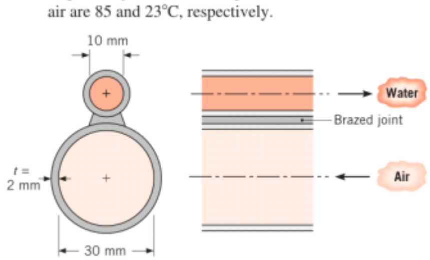
$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{(60-30) - (100-48.1)}{\ln\left[\frac{(60-30)}{(100-48.1)}\right]} \Rightarrow \boxed{40^\circ C = \Delta T_{lm,CF}} \quad \text{--- (3)}$$

$$q = 1900 \times (100-60) = \boxed{7600\,W = q} \quad \text{--- (4)}$$

Using (1) through (4)

$$L = \frac{7600}{60 \times \pi \times 0.025 \times 40} = \boxed{40.3\,m}$$

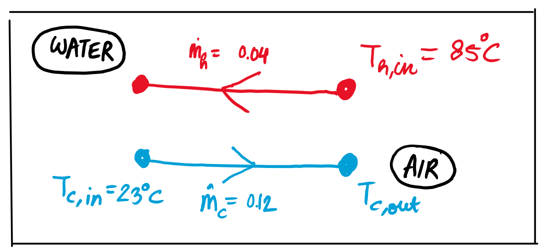
11.35 A counterflow, twin-tube heat exchanger is made by brazing two circular nickel tubes, each 40 m long, together as shown below. Hot water flows through the smaller tube of 10-mm diameter and air at atmospheric pressure flows through the larger tube of 30-mm diameter. Both tubes have a wall thickness of 2 mm. The thermal contact conductance per unit length of the brazed joint is 100 W/m·K. The mass flow rates of the water and air are 0.04 and 0.12 kg/s, respectively. The inlet temperatures of the water and air are 85 and 23°C, respectively.



Employ the ε–NTU method to determine the outlet temperature of the air. *Hint:* Account for the effects of circumferential conduction in the walls of the tubes by treating them as extended surfaces.

PROPERTIES: *Table A-6*, Water ($\bar{T}_h$ = 335 K): $c_h = c_{p,h}$ = 4186 J/kg·K, $\mu = 453 \times 10^{-6}$ N·s/m^2, k = 0.656 W/m·K, Pr = 2.88; *Table A-4*, Air (300 K): $c_c = c_{p,c}$ = 1007 J/kg·K, $\mu = 184.6 \times 10^{-7}$ N·s/m^2, k = 0.0263 W/m·K, Pr = 0.707; *Table A-1*, Nickel ($\bar{T}$ = (23 + 85)°C/2 = 327 K): k = 88 W/m·K.

$\boxed{\epsilon\text{-NTU}}$



$$\epsilon = \frac{1 - \exp[-NTU(1-C_r)]}{1 - C_r \exp[-NTU(1-C_r)]} \qquad NTU = UA/C_{min} \qquad C_r = C_{min}/C_{max}$$

$$\epsilon = \frac{C_c(T_{c,o} - T_{c,i})}{C_{min}(T_{h,i} - T_{c,i})}$$

$$Re_w = \frac{\rho v D}{\mu} = \frac{4\dot{m}_h}{\pi D \mu} = \left[\frac{4 \times 0.04}{\pi \times 0.01 \times 453 \times 10^{-6}}\right] = 11243 \rightarrow \text{Turbulent.}$$

$$Nu = \frac{h_o D}{k} = 0.023\,Re^{0.8}\,Pr^{0.3} = 0.023 \times (11243)^{0.8} \times (2.88)^{0.3} = 54.99.$$

$$h_o = \frac{54.99 \times 0.656}{0.01} \qquad \boxed{h_o = 3607\ W/m^2K}$$

$$Re_a = \frac{\rho v D}{\mu} = \frac{4\dot{m}_c}{\pi D \mu} = \left[\frac{4 \times 0.12}{\pi \times 0.03 \times 184.6E{-7}}\right] = 275890 \rightarrow \text{Turbulent}$$

$$h_i = \frac{450.9 \times 0.0263}{0.03} \qquad \boxed{h_i = 395.3\ W/m^2K}$$

$Nu = \frac{h_i D}{...}$ ... $^{0.8}$ ... $^{0.3}$ 450.9

$$\mathrm{Re}_d = \frac{\rho V D}{\mu} = \frac{4\dot m}{\pi D \mu} = \left[\frac{4 \times \ldots}{\pi \times 0.03 \times 184.6E-7}\right] = 275890 \rightarrow \text{turbulent}$$

$$Nu = \frac{h_i D}{k} = 0.023\,Re^{0.8}\,Pr^{0.3} = 0.023 \times (275890)^{0.8} \times (0.707)^{0.3} = 450.9$$

$$\boxed{h_i = 395.3\ W/m^2 {}^\circ C}$$

0.03

$$\frac{1}{UA} = \frac{1}{(\eta_o hA)_h} + \frac{1}{K_t' L} + \frac{1}{(\eta_o hA)_c}$$

$\{\eta_o \;\&\; K_t'\} \rightarrow$ not a simplified HE

Simplified form of this problem

$$\frac{1}{UA} = \frac{1}{(hA)_h} + \frac{1}{KL} + \frac{1}{(hA)_c}$$

$\Rightarrow$ From this, we can get the value of [UA] ✓✓

[get UA → get NTU → get C_R → get ϵ → get $T_{c,o}$]