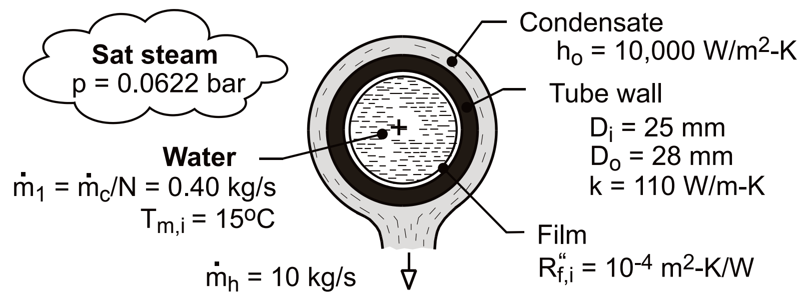
PROBLEM 07

KNOWN: Number, inner and outer diameters, and thermal conductivity of condenser tubes. Convection coefficient at outer surface. Overall flow rate, inlet temperature and properties of water flow through the tubes. Flow rate and pressure of condensing steam. Fouling factor for inner surface.

FIND: (a) Overall coefficient based on outer surface area, U_o, without fouling, (b) Overall coefficient with fouling, (c) Temperature of water leaving the condenser.

SCHEMATIC:



ASSUMPTIONS: (1) Water is incompressible with negligible viscous dissipation, (2) Fully-developed flow in tubes, (3) Negligible effect of fouling on D_i.

PROPERTIES: Water (Given): c_p = 4180 J/kg·K, $\mu = 9.6 \times 10^{-4}$ N·s/m^2, k = 0.60 W/m·K, Pr = 6.6. *Table A-6*, Water, saturated vapor (p = 0.0622 bars): T_{sat} = 310 K, $h_{fg} = 2.414 \times 10^6$ J/kg.

ANALYSIS: (a) Without fouling, Eq. 11.5 yields

$$\frac{1}{U_o} = \frac{1}{h_i}\left(\frac{D_o}{D_i}\right) + \frac{D_o \ln(Do/Di)}{2k_t} + \frac{1}{h_o}$$

With $Re_{D_i} = 4\dot{m}_1/\pi D_i \mu = 1.60\,kg/s/\left(\pi \times 0.025m \times 9.6 \times 10^{-4}\,N \cdot s/m^2\right) = 21,220,$ flow in the tubes is turbulent, and from Eq. 8.60

$$h_i = \left(\frac{k}{D_i}\right)0.023\,Re_{D_i}^{4/5}\,Pr^{0.4} = \left(\frac{0.60\,W/m\cdot K}{0.025m}\right)0.023(21,200)^{4/5}(6.6)^{0.4} = 3400\,W/m^2\cdot K$$

$$U_o = \left[\frac{1}{3400}\left(\frac{28}{25}\right) + \frac{0.028\ln(28/25)}{2\times 110} + \frac{1}{10,000}\right]^{-1} W/m^2\cdot K =$$

$$\left(3.29\times 10^{-4} + 1.44\times 10^{-5} + 10^{-4}\right)^{-1} W/m^2\cdot K = 2255\,W/m^2\cdot K \qquad <$$

(b) With fouling, Eq. 11.5 yields

$$U_o = \left[4.43\times 10^{-4} + (Do/Di)R''_{f,i}\right]^{-1} = \left(5.55\times 10^{-4}\right)^{-1} = 1800\,W/m^2\cdot K \qquad <$$

(c) The rate at which energy is extracted from the steam equals the rate of heat transfer to the water, $\dot{m}_h\,h_{fg} = \dot{m}_c\,c_p\left(T_{m,o} - T_{m,i}\right)$, in which case

$$T_{m,o} = T_{m,i} + \frac{\dot{m}_h\,h_{fg}}{\dot{m}_c\,c_p} = 15°C + \frac{10\,kg/s \times 2.414\times 10^6\,J/kg}{400\,kg/s \times 4180\,J/kg\cdot K} = 29.4°C \qquad <$$

COMMENTS: (1) The largest contribution to the thermal resistance is due to convection at the interior of the tube. To increase U_o, hi could be increased by increasing $\dot{m}_1$, either by increasing $\dot{m}_c$ or decreasing N. (2) Note that $T_{m,o}$ = 302.4 K < T_{sat} = 310 K, as must be the case.