Exercise 10.1

A steel tube ($k = 50 W/mK$) of inner and outer diameters $D_i = 20 mm$ and $D_o = 26 mm$ respectively, is used to transfer heat from hot gases flowing over the tube ($h_h = 200 W/m^2K$) to cold water flowing through the tube ($h_c = 8000 W/m^2K$).

a) What is the cold-side overall heat transfer coefficient U_c?

b) To enhance heat transfer, 16 straight fins of rectangular profile are installed longitudinally along the outer surface of the tube. The fins are equally spaced around the circumference of the tube, each having a thickness of $2 mm$ and a length of $15 mm$. What is the corresponding overall cold-side heat transfer coefficient U_c? Assume adiabatic fin tip.

Reflect on the effect of adding the fins.

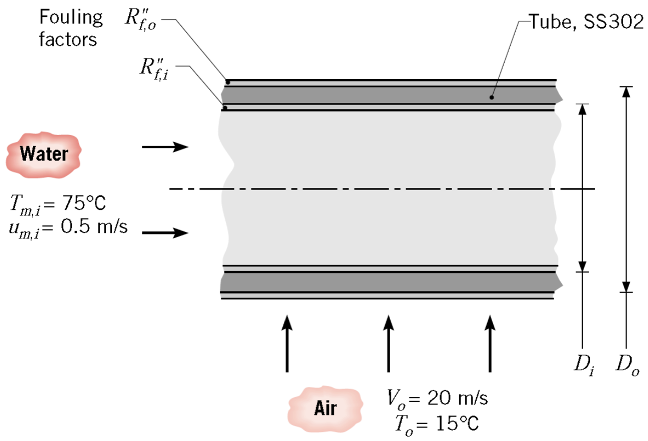
Solutions

a) $U_c = 249 W/m^2K$

b) $U_c = 1138 W/m^2K$

Exercise 10.2

A type-302 stainless steel tube of inner and outer diameters $D_i = 22mm$ and $D_o = 27mm$, respectively, is used in a cross-flow heat exchanger. The fouling factors, R'_f for the inner and outer surfaces are estimated to be 0.0004 and $0.0002 m^2K/W$, respectively.



After depicting the thermal resistance circuit of the considered system:

a) Determine the overall heat transfer coefficient based on the outside area of the tube, U_o. Compare the thermal resistances due to convection, tube-wall conduction and fouling.

Hint: initially assume that the temperature of the outer surface of the tube is $T_{f,o} = 315K$. Verify at the end of the exercise whether this assumption was reasonably accurate. Also, assume that the flow inside the tube is fully developed.

b) Instead of air flowing over the tube, consider a situation for which the cross-flow fluid is water at 15°C with a velocity of $V_o = 1m/s$. For this case assume $T_{f,o} = 292K$ as it is expected that the convection effects will be stronger in water. Determine the overall heat transfer coefficient based on the outside area of the tube U_o. Compare the thermal resistances due to convection, tube-wall conduction and fouling.

Hint: determine first the conditions of flow on the inner and outer sides of the tube and select the appropriate correlations for the convection coefficient.

Solutions

a)

$R_{cv,i}$	$R_{f,i}$	R_w	$R_{f,o}$	$R_{cv,o}$	U_o	R_{tot}
0.00436	0.00578	0.00216	0.00236	0.1134	92.1	0.128

b)

$R_{cv,i}$	$R_{f,i}$	R_w	$R_{f,o}$	$R_{cv,o}$	U_o	R_{tot}
0.00436	0.00579	0.00216	0.00236	0.00240	691	0.0171

Exercise 10.3

A recuperator is a heat exchanger that heats the air used in a combustion process by extracting energy from the products of combustion (the flue gas). Consider using a single-pass cross-flow heat exchanger as a recuperator.

Eighty silicon carbide ceramic tubes ($k = 20W/mK$) of inner and outer diameters equal to $55mm$ and $80mm$ respectively, and of length $L = 1.4m$ are arranged as an aligned tube bank of longitudinal and transverse pitches $S_L = 100mm$ and $S_T = 120mm$, respectively. Cold air is in cross flow over the tube bank with upstream conditions of $V = 1m/s$ and $T_{c,i} = 300K$, while hot-flue gases of inlet temperature $T_{h,i} = 1400K$ pass through the tubes. The tube outer surface is clean while the inner surface is characterized by a fouling factor of $R_f^i = 0.0002m^2K/W$. The air and flue gas flow rates are $\dot{m}_c = 1kg/s$ and $\dot{m}_h = 1.05kg/s$, respectively.

Use the following assumptions:

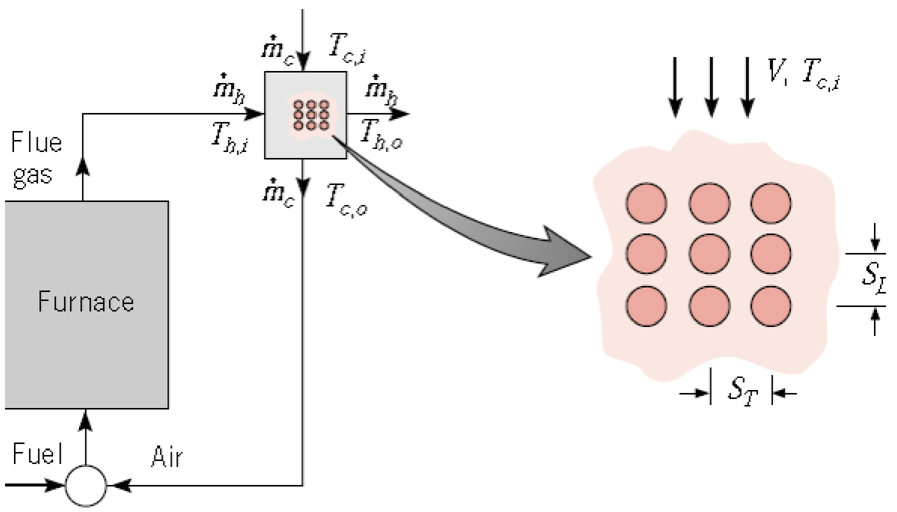
a) evaluate all required air properties at $1atm$ and $300K$

b) assume the flue gas to have the properties of air at $1atm$ and $1400K$

c) assume the tube wall temperature to be at $800K$ for the purpose of treating the effect of variable properties on convection heat transfer.

d) assume fully developed flow inside the tubes

Determine the overall heat transfer coefficient referred to the internal surface.



Solutions

- $h_i = 31.1W/m^2K$, $h_o = 33.6W/m^2K$, $U_i = 18.6W/m^2K$

Exercise 10.4 FOR REVISION

Saturated water at $1atm$ and velocity $2m/s$ flows over a cylindrical heating element of diameter $5mm$.

a) What is the maximum heating rate $[W/m]$ for nucleate boiling?

b) How much is the maximum heat flux $[W/m^2]$ enhanced compared to just pool boiling? (Hint: Assume it can be treated as a large horizontal cylinder).

Solutions

a) $q^{'}_{max} = 68kW/m$

b) $q^{"}_{max} = 1.107MW/m^2$