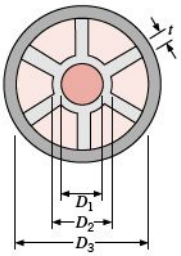
region to pressurized water flowing through the inner tube of the annulus. The inner tube has inner and outer diameters of 24 and 30 mm and is connected by eight struts to an insulated outer tube of 60-mm diameter. Each strut is 3 mm thick and is integrally fabricated with the inner tube from carbon steel ($k = 50$ W/m · K).

Consider conditions for which water at 300 K flows through the inner tube at 0.161 kg/s while flue gases at 800 K flow through the annulus, maintaining a convection coefficient of 100 W/m^2 · K on both the struts and the outer surface of the inner tube. What is the rate of heat transfer per unit length of tube from gas to the water?

11.6 A novel design for a condenser consists of a tube of thermal conductivity 200 W/m · K with longitudinal fins snugly fitted into a larger tube. Condensing refrigerant at 45°C flows axially through the inner tube, while water at a flow rate of 0.012 kg/s passes through the six channels around the inner tube. The pertinent diameters are $D_1 = 10$ mm, $D_2 = 14$ mm, and $D_3 = 50$ mm, while the fin thickness is $t = 2$ mm. Assume that the convection coefficient associated with the condensing refrigerant is extremely large.



Determine the heat removal rate per unit tube length in a section of the tube for which the water is at 15°C.

11.7 The condenser of a steam power plant contains $N = 1000$ brass tubes ($k_t = 110$ W/m · K), each of inner and outer diameters, $D_i = 25$ mm and $D_o = 28$ mm, respectively. Steam condensation on the outer surfaces of the tubes is characterized by a convection coefficient of $h_o = 10{,}000$ W/m^2 · K.

(a) If cooling water from a large lake is pumped through the condenser tubes at $\dot{m}_c = 400$ kg/s, what is the overall heat transfer coefficient U_o based on the outer surface area of a tube? Properties of the water may be approximated as $\mu = 9.60 \times 10^{-4}$ N · s/m^2, $k = 0.60$ W/m · K, and Pr = 6.6.

(b) If, after extended operation, fouling provides a resistance of $R''_{f,i} = 10^{-4}$ m^2 · K/W, at the inner surface, what is the value of U_o?

(c) If water is extracted from the lake at 15°C and 10 kg/s of steam at 0.0622 bars are to be condensed, what is the corresponding temperature of the water leaving the condenser? The specific heat of the water is 4180 J/kg · K.

11.8 Thin-walled aluminum tubes of diameter $D = 10$ mm are used in the condenser of an air conditioner. Under normal operating conditions, a convection coefficient of $h_i = 5000$ W/m^2 · K is associated with condensation on the inner surface of the tubes, while a coefficient of $h_o = 100$ W/m^2 · K is maintained by airflow over the tubes.

(a) What is the overall heat transfer coefficient if the tubes are unfinned?

(b) What is the overall heat transfer coefficient based on the inner surface, U_i, if aluminum annular fins of thickness $t = 1.5$ mm, outer diameter $D_o = 20$ mm, and pitch $S = 3.5$ mm are added to the outer surface? Base your calculations on a 1-m-long section of tube. Subject to the requirements that $t \geq 1$ mm and $(S - t) \geq 1.5$ mm, explore the effect of variations in t and S on U_i. What combination of t and S would yield the best heat transfer performance?

11.9 A finned-tube, cross-flow heat exchanger is to use the exhaust of a gas turbine to heat pressurized water. Laboratory measurements are performed on a prototype version of the exchanger, which has a surface area of 10 m^2, to determine the overall heat transfer coefficient as a function of operating conditions. Measurements made under particular conditions, for which $\dot{m}_h = 2$ kg/s, $T_{h,i} = 325$°C, $\dot{m}_c = 0.5$ kg/s, and $T_{c,i} = 25$°C, reveal a water outlet temperature of $T_{c,o} = 150$°C. What is the overall heat transfer coefficient of the exchanger?

11.10 Water at a rate of 45,500 kg/h is heated from 80 to 150°C in a heat exchanger having two shell passes and eight tube passes with a total surface area of 925 m^2. Hot exhaust gases having approximately the same thermophysical properties as air enter at 350°C and exit at 175°C. Determine the overall heat transfer coefficient.

11.11 A novel heat exchanger concept consists of a large number of extruded polypropylene sheets ($k = 0.17$ W/m · K), each having a fin-like geometry, that are subsequently stacked and melted together to form the heat exchanger core. Besides being inexpensive, the heat exchanger can be easily recycled at the end of its life. Carbon dioxide at a mean temperature of 10°C and pressure of 2 atm flows in the cool channels at a