Exercise 6.1

A bank of tubes uses an aligned arrangement of $10mm$ diameter tubed with $S_T = S_L = 20mm$. There are 10 rows of tubes with 50 tubes in each row. Consider an application for which cold water flows through the tubes, maintaining the outer surface temperature at $27°C$, while flue gases at $427°C$ and a velocity of $5m/s$ are in cross flow over the tubes. The properties of the flue gas may be approximated as those of atmospheric air with temperature of $427°C$. What is the total rate of heat transfer per unit length of the tubes in the bank?

Note: For air use $\nu = 68.1 \cdot 10^{-6} m^2/s$ $k = 0.0524 W/mK$, $\rho = 0.498 kg/m^3$, $Pr = 0.695$ $c_p = 1075 J/kgK$.

Exercise 6.2

Ethylene glycol flows at $0.01 kg/s$ through a $3mm$ diameter, thin-walled tube. The tube is submerged in a well-stirred water bath maintained at $25°C$. If the fluid enters the tube at $85°C$ what heat transfer rate and tube length are required for the fluid to leave at $35°C$?

Use the following properties of ethylene glycol at $T_m = (85 + 35)/2 = 60°C = 333K$:

- $c_p = 2562 J/kgK$
- $\mu = 0.522 \cdot 10^{-2} Ns/m^2$
- $k = 0.260 W/mK$
- $Pr = 51.3$

Exercise 6.3

The evaporator section of a heat pump is installed in a large tank of water, which is used as a heat source during the winter. As energy is extracted from the water, it begins to freeze, creating an ice/water bath at $0°C$, which may be used for air conditioning during the summer. Consider summer cooling conditions for which air is passed through an array of copper tubes, each of inside diameter $D = 50mm$, submerged in the bath.

a) If air enters each tube at a mean temperature of $T_{m,i} = 24°C$ and a flow rate of $\dot{m} = 0.01kg/s$ what tube length L is needed to provide an exit temperature of $T_{m,o} = 14°C$? Assume fully developed flow inside the tube.

b) With 10 tubes passing through a tank of total volume $V = 10m^3$, which initially contains 80% ice by volume, how long would it take to completely melt the ice?

The density and latent heat of fusion of ice are $\rho_{ice} = 920kg/m^3$ and $f_{l,ice} = 3.34 \cdot 10^5 J/kg$, respectively.

Determine the properties of air from Table $A4$ (at the end of this document) at the appropriate temperature.

Exercise 6.4

Water at $290K$ and $0.2kg/s$ flows through a Teflon tube ($k = 0.35W/mK$) of inner and outer radii equal to $10mm$ and $13mm$ respectively. A thin electrical heating tape wrapped around the outer surface of the tube delivers a uniform surface heat flux of $2000W/m^2$, while a convection coefficient of $25W/m^2K$ is maintained on the outer surface of the tape by ambient air at $300K$. What is the outer surface temperature of the Teflon tube? What is the fraction of the power dissipated by the tape, which is transferred to the water?

Determine the properties of water from Table $A6$ at the appropriate temperature.

Hint 1: start by drawing the equivalent thermal circuit for this problem. The heater can be assumed to have negligible thickness (no associated thermal resistance). It only contributes with the input heat flux.

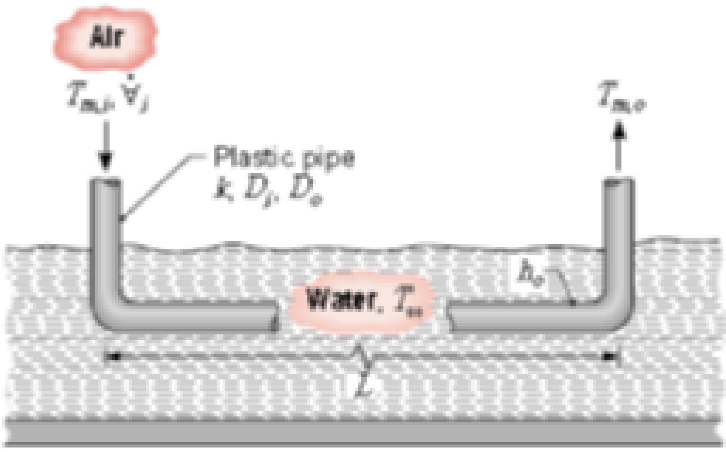
Hint 2: you can use the inlet temperature of water to estimate its physical properties

Exercise 6.5 FOR REVISION

To cool a summer home without using a vapor-compression refrigeration cycle, air is routed through a plastic pipe ($k = 0.15W/mK$, $D_i = 0.15m$, $D_o = 0.17m$) that is submerged in an adjoining body of water. The water temperature is nominally at $T_\infty = 17C$ and a convection coefficient of $h_o = 1500W/m^2K$ is maintained at the outer surface of the pipe. If air from the home enters the pipe at a temperature of $T_{m,i} = 29C$ and a volumetric flow rate of $V_i = 0.025m^3/s$, What pipe length L is needed to provide a discharge temperature of $T_{m,o} = 21°C$?

Additional Question: Now that you know the flow conditions and the length of the pipe, can you calculate the fan power required to move the air through this length of pipe if its inner surface is smooth? From your previous courses you should remember how the pumping power depends on the pressure drop and the volumetric flow rate as well as how the pressure drop is related to the friction factor.

Determine the properties of air from Table $A4$ at the appropriate temperature.



Exercise 6.6 FOR REVISION

Water at $300K$ and a flow rate of $5kg/s$ enters a black, thin-walled tube, which passes through a large furnace whose walls and air are at a temperature of $700K$. The diameter and length of the tube are $0.25m$ and $8m$, respectively. Convection coefficients associated with water flow through the tube and air flow over the tube are $300W/m^2K$ and $50W/m^2K$, respectively.

a) Write an expression for the linearized radiation coefficient corresponding to radiation exchange between the outer surface of the pipe and the furnace walls. Explain how to calculate this coefficient if the surface temperature of the tube is represented by the arithmetic mean of its inlet and outlet values.

Determine the properties of water from Table $A6$ (at the end of this document) using $T_m = (T_{m,i} + T_{m,o})/2 = 331K$.