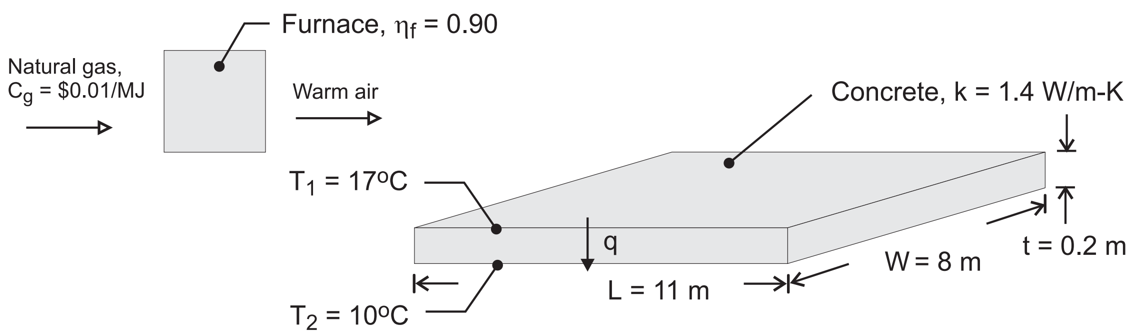
PROBLEM 2

KNOWN: Dimensions, thermal conductivity and surface temperatures of a concrete slab. Efficiency of gas furnace and cost of natural gas.

FIND: Daily cost of heat loss.

SCHEMATIC:



ASSUMPTIONS: (1) Steady state, (2) One-dimensional conduction, (3) Constant properties.

ANALYSIS: The rate of heat loss by conduction through the slab is

$$q = k\,(LW)\frac{T_1 - T_2}{t} = 1.4\,\text{W/m}\cdot\text{K}\,(11\,\text{m} \times 8\,\text{m})\frac{7^\circ\text{C}}{0.20\,\text{m}} = 4312\ \text{W} \qquad <$$

The daily cost of natural gas that must be combusted to compensate for the heat loss is

$$C_d = \frac{q\,C_g}{\eta_f}(\Delta t) = \frac{4312\,\text{W} \times \$0.01/\text{MJ}}{0.9 \times 10^6\,\text{J/MJ}}(24\,\text{h/d} \times 3600\,\text{s/h}) = \$4.14/\text{d} \qquad <$$

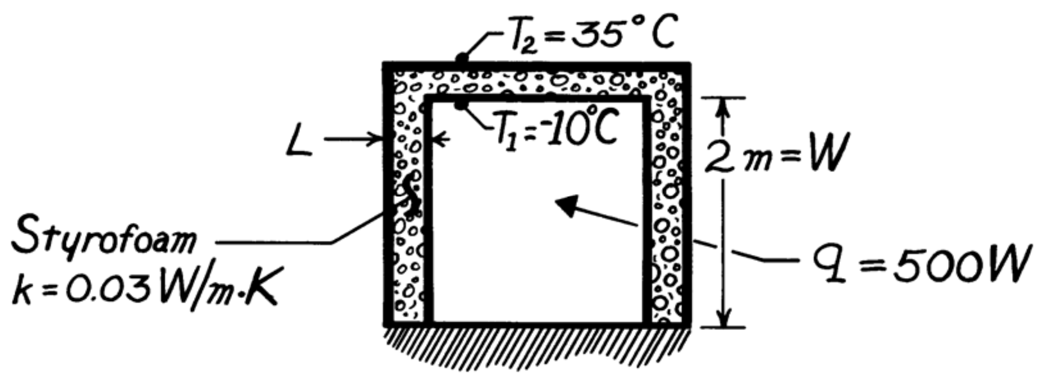
COMMENTS: The loss could be reduced by installing a floor covering with a layer of insulation between it and the concrete.

PROBLEM 3

KNOWN: Dimensions of freezer compartment. Inner and outer surface temperatures.

FIND: Thickness of styrofoam insulation needed to maintain heat load below prescribed value.

SCHEMATIC:



ASSUMPTIONS: (1) Perfectly insulated bottom, (2) One-dimensional conduction through 5 walls of area A = $4m^2$, (3) Steady-state conditions, (4) Constant properties.

ANALYSIS: Using Fourier's law, Eq. 1.2, the heat rate is

$$q = q'' \cdot A = k \frac{\Delta T}{L} A_{total}$$

Solving for L and recognizing that $A_{total} = 5 \times W^2$, find

$$L = \frac{5 \, k \, \Delta T \, W^2}{q}$$

$$L = \frac{5 \times 0.03 \text{ W/m} \cdot \text{K} \left[35 - (-10)\right]^{\circ}\text{C} \left(4\text{m}^2\right)}{500 \text{ W}}$$

$$L = 0.054\text{m} = 54\text{mm}.$$ <

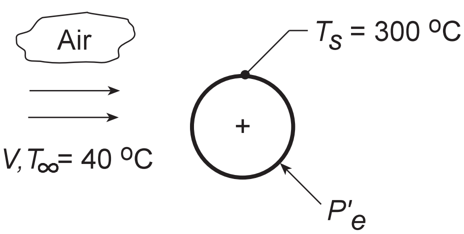
COMMENTS: The corners will cause local departures from one-dimensional conduction and a slightly larger heat loss.

PROBLEM 4

KNOWN: Power required to maintain the surface temperature of a long, 25-mm diameter cylinder with an imbedded electrical heater for different air velocities.

FIND: (a) Determine the convection coefficient for each of the air velocity conditions and display the results graphically, and (b) Assuming that the convection coefficient depends upon air velocity as $h = CV^n$, determine the parameters C and n.

SCHEMATIC:



V(m/s)	1	2	4	8	12
P'_e (W/m)	450	658	983	1507	1963
h ($W/m^2 \cdot K$)	22.0	32.2	48.1	73.8	96.1

ASSUMPTIONS: (1) Temperature is uniform over the cylinder surface, (2) Negligible radiation exchange between the cylinder surface and the surroundings, (3) Steady-state conditions.

ANALYSIS: (a) From an overall energy balance on the cylinder, the power dissipated by the electrical heater is transferred by convection to the air stream. Using Newton's law of cooling on a per unit length basis,

$$P'_e = h(\pi D)(T_s - T_\infty)$$

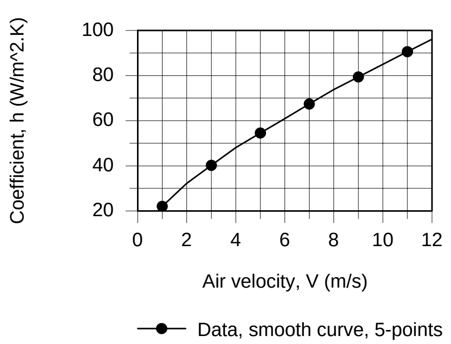
where P'_e is the electrical power dissipated per unit length of the cylinder. For the V = 1 m/s condition, using the data from the table above, find

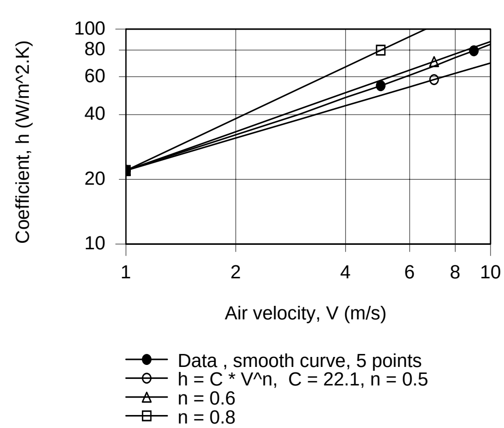
$$h = 450\,W/m \Big/ \pi \times 0.025\,m(300 - 40)^\circ C = 22.0\,W/m^2 \cdot K \qquad <$$

Repeating the calculations, find the convection coefficients for the remaining conditions which are tabulated above and plotted below. Note that h is not linear with respect to the air velocity.

(b) To determine the (C,n) parameters, we plotted h vs. V on log-log coordinates. Choosing C = 22.12 $W/m^2 \cdot K(s/m)^n$, assuring a match at V = 1, we can readily find the exponent n from the slope of the h vs. V curve. From the trials with n = 0.8, 0.6 and 0.5, we recognize that n = 0.6 is a reasonable choice.

Hence, C = 22.12 and n = 0.6. $\qquad <$





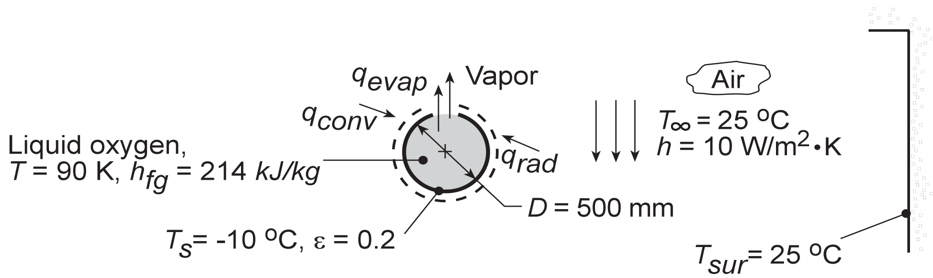
COMMENTS: Radiation may not be negligible, depending on surface emissivity.

PROBLEM 5

KNOWN: Boiling point and latent heat of liquid oxygen. Diameter and emissivity of container. Free convection coefficient and temperature of surrounding air and walls.

FIND: Mass evaporation rate.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Temperature of container outer surface equals boiling point of oxygen.

ANALYSIS: (a) Applying mass and energy balances to a control surface about the container, it follows that, at any instant,

$$\frac{dm_{st}}{dt} = -\dot{m}_{out} = -\dot{m}_{evap} \qquad \frac{dE_{st}}{dt} = \dot{E}_{in} - \dot{E}_{out} = q_{conv} + q_{rad} - q_{evap}. \tag{1a,b}$$

With h_f as the enthalpy of liquid oxygen and h_g as the enthalpy of oxygen vapor, we have

$$E_{st} = m_{st} h_f \qquad q_{evap} = \dot{m}_{out} h_g \tag{2a,b}$$

Combining Equations (1a) and (2a,b), Equation (1b) becomes (with $h_{fg} = h_g - h_f$)

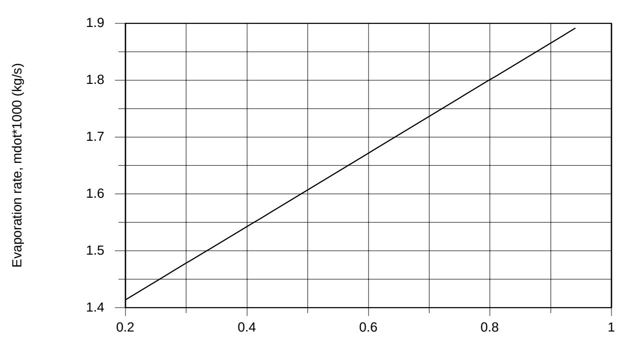
$$\dot{m}_{out} h_{fg} = q_{conv} + q_{rad}$$

$$\dot{m}_{evap} = \left(q_{conv} + q_{rad}\right)/h_{fg} = \left[h\left(T_\infty - T_s\right) + \varepsilon\sigma\left(T_{sur}^4 - T_s^4\right)\right]\pi D^2 / h_{fg} \tag{3}$$

$$\dot{m}_{evap} = \frac{\left[10\,W/m^2 \cdot K\left(298 - 263\right)K + 0.2 \times 5.67 \times 10^{-8}\,W/m^2 \cdot K^4\left(298^4 - 263^4\right)K^4\right]\pi\left(0.5\,m\right)^2}{214\,kJ/kg}$$

$$\dot{m}_{evap} = \left(350 + 35.2\right)W/m^2\left(0.785\ m^2\right)/214\,kJ/kg = 1.41 \times 10^{-3}\ kg/s.$$ <

(b) Using Equation (3), the mass rate of vapor production can be determined for the range of emissivity 0.2 to 0.94. The effect of increasing emissivity is to increase the heat rate into the container and, hence, increase the vapor production rate.



COMMENTS: To reduce the loss of oxygen due to vapor production, insulation should be applied to the outer surface of the container, in order to reduce q_{conv} and q_{rad}. Note from the calculations in part (a), that heat transfer by convection is greater than by radiation exchange.