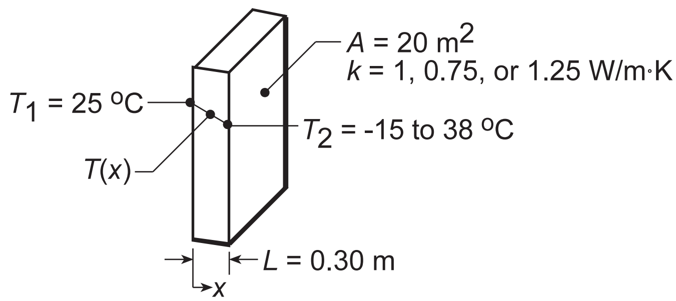
PROBLEM 1.2

KNOWN: Inner surface temperature and thermal conductivity of a concrete wall.

FIND: Heat loss by conduction through the wall as a function of ambient air temperatures ranging from -15 to 38°C.

SCHEMATIC:



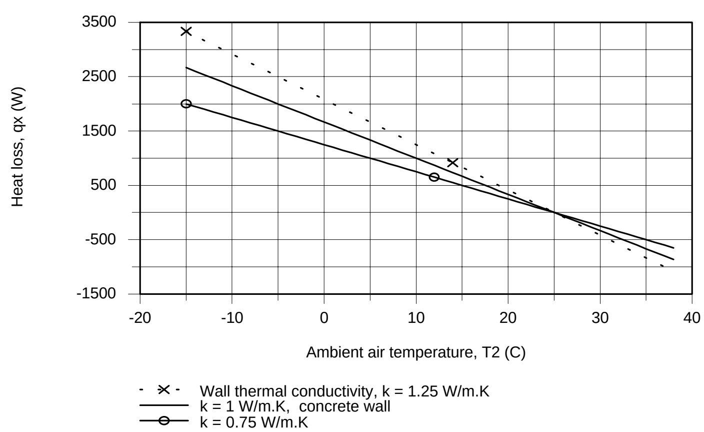
ASSUMPTIONS: (1) One-dimensional conduction in the x-direction, (2) Steady-state conditions, (3) Constant properties, (4) Outside wall temperature is that of the ambient air.

ANALYSIS: From Fourier's law, it is evident that the gradient, $dT/dx = -q''_x/k$, is a constant, and hence the temperature distribution is linear, if q''_x and k are each constant. The heat flux must be constant under one-dimensional, steady-state conditions; and k is approximately constant if it depends only weakly on temperature. The heat flux and heat rate when the outside wall temperature is T_2 = -15°C are

$$q''_x = -k\frac{dT}{dx} = k\frac{T_1 - T_2}{L} = 1\,W/m\cdot K\,\frac{25^\circ C - \left(-15^\circ C\right)}{0.30\,m} = 133.3\,W/m^2 . \qquad (1)$$

$$q_x = q''_x \times A = 133.3\,W/m^2 \times 20\,m^2 = 2667\,W . \qquad (2) <$$

Combining Eqs. (1) and (2), the heat rate q_x can be determined for the range of ambient temperature, -15 ≤ T_2 ≤ 38°C, with different wall thermal conductivities, k.



For the concrete wall, k = 1 W/m·K, the heat loss varies linearily from +2667 W to -867 W and is zero when the inside and ambient temperatures are the same. The magnitude of the heat rate increases with increasing thermal conductivity.

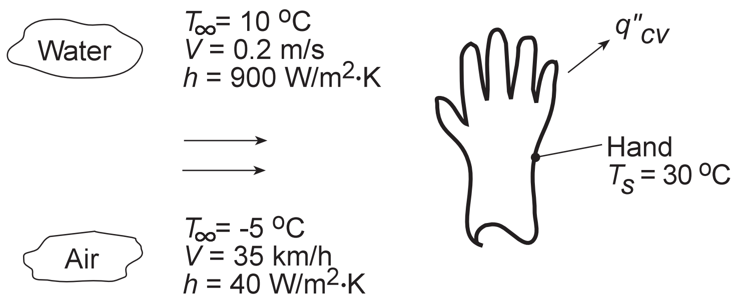
COMMENTS: Without steady-state conditions and constant k, the temperature distribution in a plane wall would not be linear.

PROBLEM 1.13

KNOWN: Hand experiencing convection heat transfer with moving air and water.

FIND: Determine which condition feels colder. Contrast these results with a heat loss of 30 W/m^2 under normal room conditions.

SCHEMATIC:



ASSUMPTIONS: (1) Temperature is uniform over the hand's surface, (2) Convection coefficient is uniform over the hand, and (3) Negligible radiation exchange between hand and surroundings in the case of air flow.

ANALYSIS: The hand will feel colder for the condition which results in the larger heat loss. The heat loss can be determined from Newton's law of cooling, Eq. 1.3a, written as

$$q'' = h\left(T_s - T_\infty\right)$$

For the air stream:

$$q''_{air} = 40\,\mathrm{W/m^2 \cdot K}\left[30 - (-5)\right]\mathrm{K} = 1,400\,\mathrm{W/m^2}$$ <

For the water stream:

$$q''_{water} = 900\,\mathrm{W/m^2 \cdot K}\left(30 - 10\right)\mathrm{K} = 18,000\,\mathrm{W/m^2}$$ <

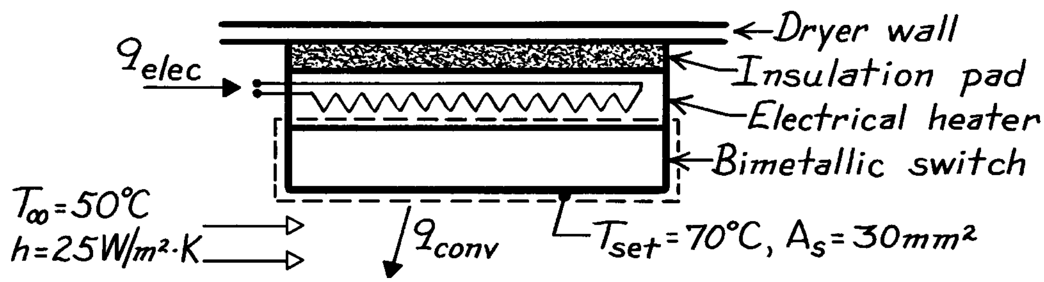
COMMENTS: The heat loss for the hand in the water stream is an order of magnitude larger than when in the air stream for the given temperature and convection coefficient conditions. In contrast, the heat loss in a normal room environment is only 30 W/m^2 which is a factor of 400 times less than the loss in the air stream. In the room environment, the hand would feel comfortable; in the air and water streams, as you probably know from experience, the hand would feel uncomfortably cold since the heat loss is excessively high.

PROBLEM 1.21

KNOWN: Upper temperature set point, T_{set}, of a bimetallic switch and convection heat transfer coefficient between clothes dryer air and exposed surface of switch.

FIND: Electrical power for heater to maintain T_{set} when air temperature is $T_\infty = 50°C$.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Electrical heater is perfectly insulated from dryer wall, (3) Heater and switch are isothermal at T_{set}, (4) Negligible heat transfer from sides of heater or switch, (5) Switch surface, A_s, loses heat only by convection.

ANALYSIS: Define a control volume around the bimetallic switch which experiences heat input from the heater and convection heat transfer to the dryer air. That is,

$$\dot{E}_{in} - \dot{E}_{out} = 0$$
$$q_{elec} - hA_s\left(T_{set} - T_\infty\right) = 0.$$

The electrical power required is,

$$q_{elec} = hA_s\left(T_{set} - T_\infty\right)$$

$$q_{elec} = 25 \text{ W/m}^2 \cdot \text{K} \times 30 \times 10^{-6} \text{ m}^2 \left(70 - 50\right)\text{K} = 15 \text{ mW}.$$ <

COMMENTS: (1) This type of controller can achieve variable operating air temperatures with a single set-point, inexpensive, bimetallic-thermostatic switch by adjusting power levels to the heater.

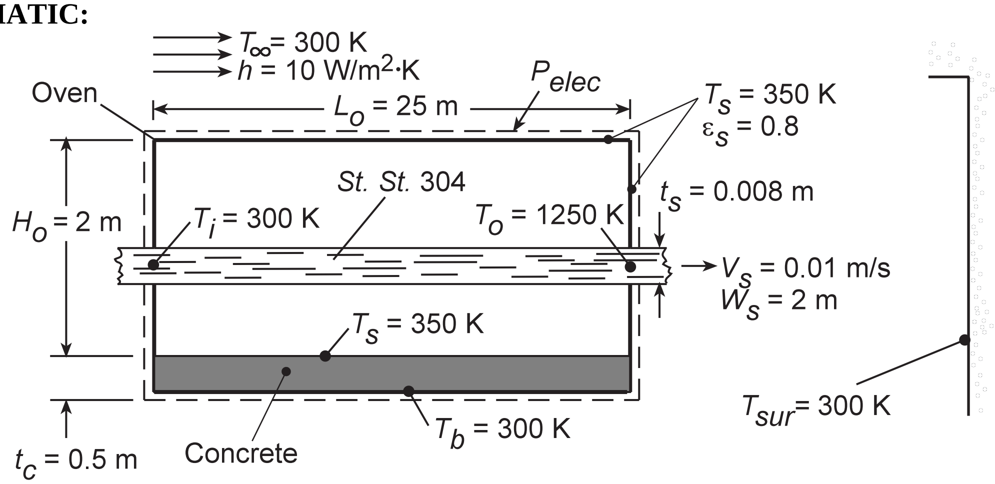
(2) Will the heater power requirement increase or decrease if the insulation pad is other than perfect?

PROBLEM 1.40

KNOWN: Speed, width, thickness and initial and final temperatures of 304 stainless steel in an annealing process. Dimensions of annealing oven and temperature, emissivity and convection coefficient of surfaces exposed to ambient air and large surroundings of equivalent temperatures. Thickness of pad on which oven rests and pad surface temperatures.

FIND: Oven operating power.

SCHEMATIC:



ASSUMPTIONS: (1) steady-state, (2) Constant properties, (3) Negligible changes in kinetic and potential energy.

PROPERTIES: Table A.1, St.St.304 $\left(\bar{T} = \left(T_i + T_o\right)/2 = 775\,K\right)$: ρ = 7900 kg/m^3, c_p = 578 J/kg·K; Table A.3, Concrete, T = 300 K: k_c = 1.4 W/m·K.

ANALYSIS: The rate of energy addition to the oven must balance the rate of energy transfer to the steel sheet and the rate of heat loss from the oven. With $\dot{E}_{in} - \dot{E}_{out} -$ = 0, it follows that

$$P_{elec} + \dot{m}\left(u_i - u_o\right) - q = 0$$

where heat is transferred from the oven. With $\dot{m} = \rho V_s\left(W_s t_s\right)$, $\left(u_i - u_o\right) = c_p\left(T_i - T_o\right)$, and

$$q = \left(2H_oL_o + 2H_oW_o + W_oL_o\right)\times\left[h\left(T_s - T_\infty\right) + \varepsilon_s\sigma\left(T_s^4 - T_{sur}^4\right)\right] + k_c\left(W_oL_o\right)\left(T_s - T_b\right)/t_c,$$

it follows that

$$P_{elec} = \rho V_s\left(W_s t_s\right)c_p\left(T_o - T_i\right) + \left(2H_oL_o + 2H_oW_o + W_oL_o\right)\times$$
$$\left[h\left(T_s - T_o\right) + \varepsilon_s\sigma\left(T_s^4 - T_{sur}^4\right)\right] + k_c\left(W_oL_o\right)\left(T_s - T_b\right)/t_c$$

$$P_{elec} = 7900\,kg/m^3 \times 0.01\,m/s\left(2\,m \times 0.008\,m\right)578\,J/kg\cdot K\left(1250 - 300\right)K$$
$$+\left(2\times 2m\times 25m + 2\times 2m\times 2.4m + 2.4m\times 25m\right)[10\,W/m^2\cdot K\left(350 - 300\right)K$$
$$+0.8\times 5.67\times 10^{-8}\,W/m^2\cdot K^4\left(350^4 - 300^4\right)K^4] + 1.4\,W/m\cdot K\left(2.4m\times 25m\right)\left(350 - 300\right)K/0.5m$$

Continued.….

PROBLEM 1.40 (Cont.)

$$P_{elec} = 694,000\,\text{W} + 169.6\,\text{m}^2\left(500 + 313\right)\text{W/m}^2 + 8400\,\text{W}$$

$$= \left(694,000 + 84,800 + 53,100 + 8400\right)\text{W} = 840\,\text{kW}$$

<

COMMENTS: Of the total energy input, 83% is transferred to the steel while approximately 10%, 6% and 1% are lost by convection, radiation and conduction from the oven. The convection and radiation losses can both be reduced by adding insulation to the side and top surfaces, which would reduce the corresponding value of T_s.