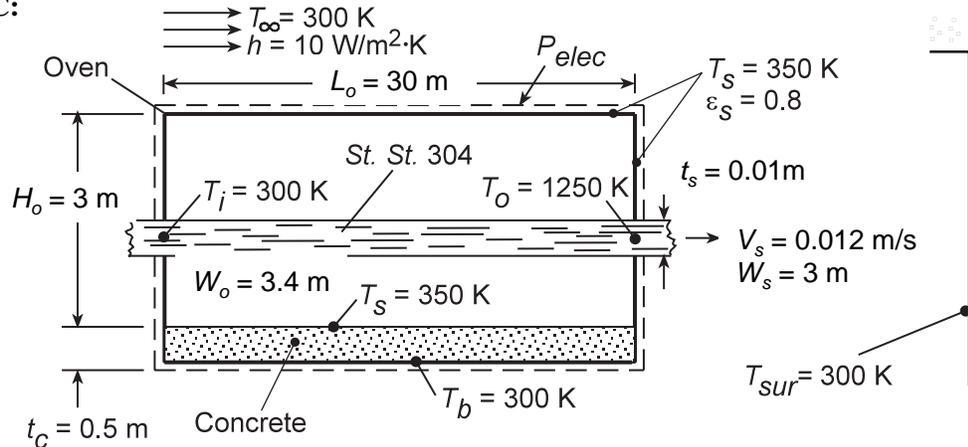


## PROBLEM 1.53

**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 ( $\bar{T} = (T_i + T_o)/2 = 775 \text{ K}$ ):  $\rho = 7900 \text{ kg/m}^3$ ,  $c_p = 578 \text{ J/kg}\cdot\text{K}$ ;  
Table A.3, Concrete,  $T = 300 \text{ K}$ :  $k_c = 1.4 \text{ W/m}\cdot\text{K}$ .

**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. Viewing the oven as an open system, Equation (1.12e) yields

$$P_{\text{elec}} - q = \dot{m}c_p(T_o - T_i)$$

where  $q$  is the heat transferred from the oven. With  $\dot{m} = \rho V_s (W_s t_s)$  and

$$q = (2H_o L_o + 2H_o W_o + W_o L_o) \times \left[ h(T_s - T_\infty) + \epsilon_s \sigma (T_s^4 - T_{\text{sur}}^4) \right] + k_c (W_o L_o) (T_s - T_b) / t_c,$$

it follows that

$$\begin{aligned} P_{\text{elec}} &= \rho V_s (W_s t_s) c_p (T_o - T_i) + (2H_o L_o + 2H_o W_o + W_o L_o) \times \\ &\quad \left[ h(T_s - T_\infty) + \epsilon_s \sigma (T_s^4 - T_{\text{sur}}^4) \right] + k_c (W_o L_o) (T_s - T_b) / t_c \\ P_{\text{elec}} &= 7900 \text{ kg/m}^3 \times 0.012 \text{ m/s} (3 \text{ m} \times 0.01 \text{ m}) 578 \text{ J/kg} \cdot \text{K} (1250 - 300) \text{ K} \\ &\quad + (2 \times 3 \text{ m} \times 30 \text{ m} + 2 \times 3 \text{ m} \times 3.4 \text{ m} + 3.4 \text{ m} \times 30 \text{ m}) [10 \text{ W/m}^2 \cdot \text{K} (350 - 300) \text{ K} \\ &\quad + 0.8 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 (350^4 - 300^4) \text{ K}^4] + 1.4 \text{ W/m} \cdot \text{K} (3.4 \text{ m} \times 30 \text{ m}) (350 - 300) \text{ K} / 0.5 \text{ m} \\ P_{\text{elec}} &= 1,560,000 \text{ W} + 302.4 \text{ m}^2 (500 + 313) \text{ W/m}^2 + 14,280 \text{ W} \\ &= (1,560,000 + 151,200 + 94,730 + 14,280) \text{ W} = 1822 \text{ kW} \end{aligned}$$

**COMMENTS:** Of the total energy input, 86% is transferred to the steel while approximately 10%, 5% 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  $T_s$ .