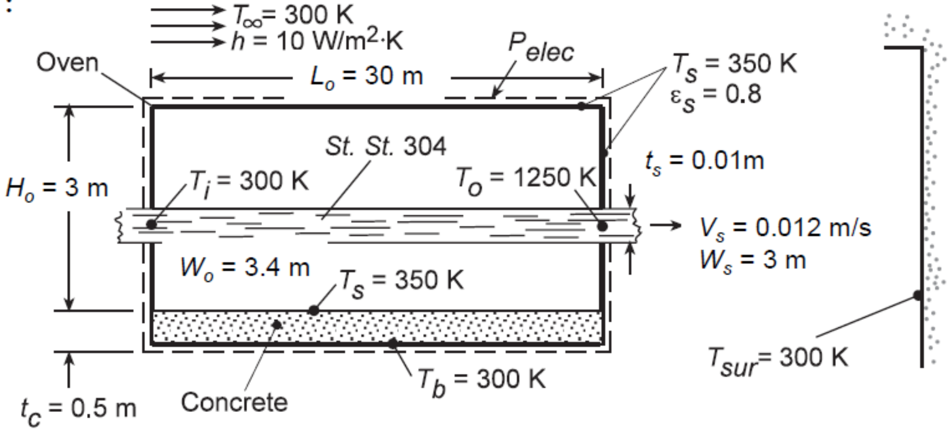
PROBLEM 1.44

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, Stainless 304 $\left(\overline{T} = (T_i + T_o)/2 = 775\,K\right)$: 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. Viewing the oven as an open system, Equation (1.12e) yields

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

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

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

it follows that

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

$$P_{elec} = 7900\,kg/m^3 \times 0.012\,m/s(3\,m \times 0.01\,m)578 J/kg\cdot K(1250 - 300)K$$
$$+(2\times 3m\times 30m + 2\times 3m\times 3.4m + 3.4m\times 30m)[10 W/m^2\cdot K(350-300)K$$
$$+0.8\times 5.67\times 10^{-8} W/m^2\cdot K^4\left(350^4 - 300^4\right)K^4] + 1.4 W/m\cdot K(3.4m\times 30m)(350-300)K/0.5m$$

$$P_{elec} = 1{,}560{,}000 W + 302.4 m^2(500 + 313)W/m^2 + 14{,}280 W$$

$$= (1{,}560{,}000 + 151{,}200 + 94{,}730 + 14{,}280)W = 1822\ kW$$ <

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.