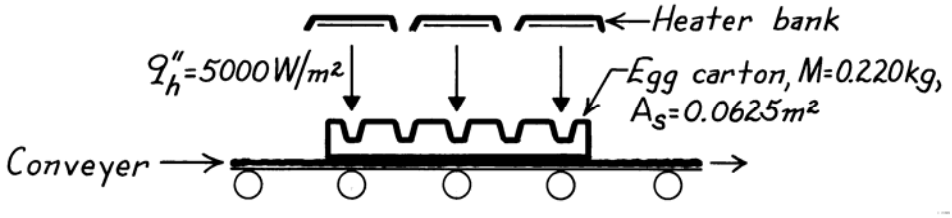
PROBLEM 1.68

KNOWN: Hot formed paper egg carton of prescribed mass, surface area, and water content exposed to infrared heater providing known radiant flux.

FIND: Whether water content can be reduced by 10% of the total mass during the 18s period carton is on conveyor.

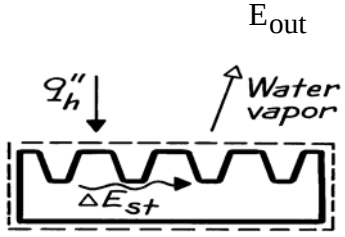
SCHEMATIC:



ASSUMPTIONS: (1) All the radiant flux from the heater bank causes evaporation of water, (2) Negligible heat loss from carton by convection and radiation, (3) Negligible mass loss occurs from bottom side.

PROPERTIES: Water (given): $h_{fg} = 2400$ kJ/kg.

ANALYSIS: Define a control surface about the carton, and write conservation of mass and energy for an interval of time, Δt,



$$\Delta m_{st} = -\dot{m}_{out}\Delta t \qquad \Delta E_{st} = \left(\dot{E}_{in} - \dot{E}_{out}\right)\Delta t \qquad (1a,b)$$

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

$$\Delta E_{st} = \Delta m_{st} h_f \qquad \dot{E}_{out}\Delta t = \dot{m}_{out} h_g \Delta t \qquad (2a,b)$$

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

$$\dot{m}_{out} h_{fg}\Delta t = \dot{E}_{in}\Delta t = q''_h A_s \Delta t$$

where q''_h is the absorbed radiant heat flux from the heater. Hence,

$$\Delta m = \dot{m}_{out}\Delta t = q''_h A_s \Delta t / h_{fg} = 5000\ \text{W/m}^2 \times 0.0625\ \text{m}^2 \times 18\ \text{s} / 2400\ \text{kJ/kg} = 0.00234\ \text{kg}$$

The chief engineer's requirement was to remove 10% of the water content, or

$$\Delta M_{req} = M \times 0.10 = 0.220\ \text{kg} \times 0.10 = 0.022\ \text{kg}$$

which is nearly an order of magnitude larger than the evaporative loss. Considering heat losses by convection and radiation, the actual water removal from the carton will be less than ΔM. Hence, the purchase should not be recommended, since the desired water removal cannot be achieved. <