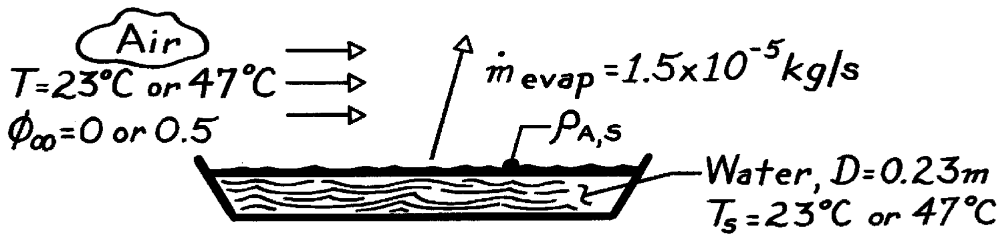
PROBLEM 6.43

KNOWN: Evaporation rate from pan of water of prescribed diameter. Water temperature. Air temperature and relative humidity.

FIND: (a) Convection mass transfer coefficient, (b) Evaporation rate for increased relative humidity, (c) Evaporation rate for increased temperature.

SCHEMATIC:



ASSUMPTIONS: (1) Water vapor is saturated at liquid interface and may be approximated as a perfect gas.

PROPERTIES: *Table A-6*, Saturated water vapor (T_s = 296K): $\rho_{A,sat} = v_g^{-1} = (49.4\ m^3/kg)^{-1} =$ 0.0202 kg/m^3; (T_s = 320 K): $\rho_{A,sat} = v_g^{-1} = \left(13.98\ m^3/kg\right)^{-1} = 0.0715\ kg/m^3$.

ANALYSIS: (a) Since evaporation is a convection mass transfer process, the rate equation has the form $\dot{m}_{evap} = \overline{h}_m A\left(\rho_{A,s} - \rho_{A,\infty}\right)$ and the mass transfer coefficient is

$$\overline{h}_m = \frac{\dot{m}_{evap}}{\left(\pi D^2/4\right)\left(\rho_{A,s} - \rho_{A,\infty}\right)} = \frac{1.5\times10^{-5}\ kg/s}{(\pi/4)(0.23\ m)^2\ 0.0202\ kg/m^3} = 0.0179\ m/s \quad <$$

with $T_s = T_\infty = 23°C$ and $\phi_\infty = 0$.

(b) If the relative humidity of the ambient air is increased to 50%, the ratio of the evaporation rates is

$$\frac{\dot{m}_{evap}(\phi_\infty = 0.5)}{\dot{m}_{evap}(\phi_\infty = 0)} = \frac{\overline{h}_m A\left[\rho_{A,sat}(T_s) - \phi_\infty \rho_{A,sat}(T_\infty)\right]}{\overline{h}_m A\ \rho_{A,sat}(T_s)} = 1 - \phi_\infty \frac{\rho_{A,sat}(T_\infty)}{\rho_{A,sat}(T_s)}.$$

Hence, $\dot{m}_{evap}(\phi_\infty = 0.5) = 1.5\times10^{-5}\ kg/s\left[1 - 0.5\dfrac{0.0202\ kg/m^3}{0.0202\ kg/m^3}\right] = 0.75\times10^{-5}\ kg/s.$ <

(c) If the temperature of the ambient air is increased from 23°C to 47°C, with $\phi_\infty = 0$ for both cases, the ratio of the evaporation rates is

$$\frac{\dot{m}_{evap}\left(T_s = T_\infty = 47°C\right)}{\dot{m}_{evap}\left(T_s = T_\infty = 23°C\right)} = \frac{\overline{h}_m A \rho_{A,sat}\left(47°C\right)}{\overline{h}_m A \rho_{A,sat}\left(23°C\right)} = \frac{\rho_{A,sat}\left(47°C\right)}{\rho_{A,sat}\left(23°C\right)}.$$

Hence, $\dot{m}_{evap}\left(T_s = T_\infty = 47°C\right) = 1.5\times10^{-5}\ kg/s \dfrac{0.0715\ kg/m^3}{0.0202\ kg/m^3} = 5.31\times10^{-5}\ kg/s.$ <

COMMENTS: Note the highly nonlinear dependence of the evaporation rate on the water temperature. For a 24°C rise in $T_s, \dot{m}_{evap}$ increases by 350%.