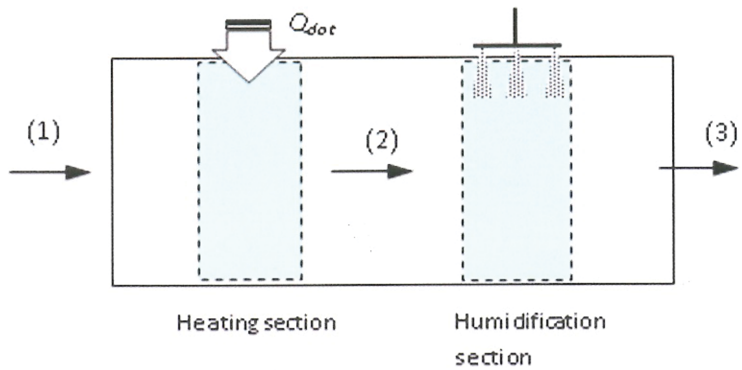
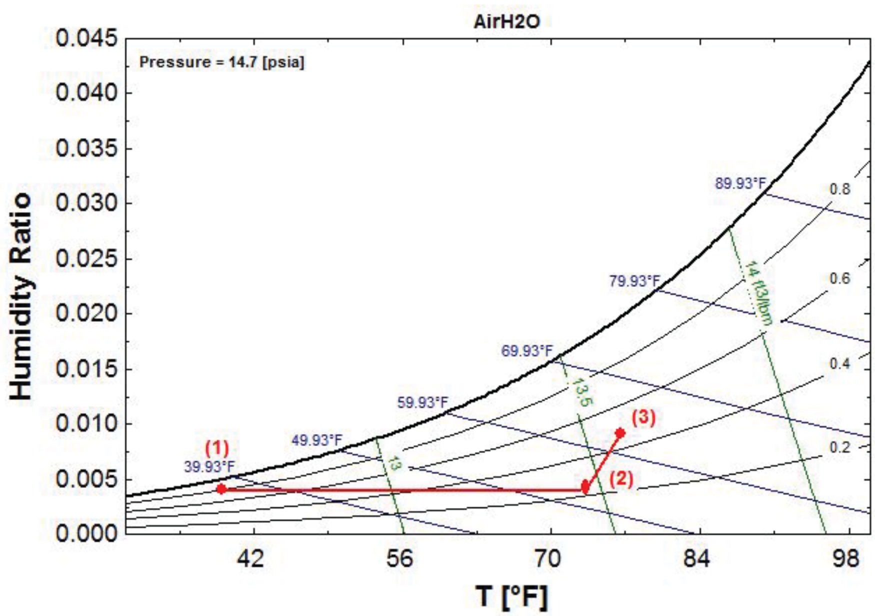
Example

A steady-flow heating and humidification process is used to provide moist air at a dry bulb temperature of 77°F with a relative humidity ϕ = 45%. Outdoor air at T_{DB} = 40°F and ϕ = 90% enters the heating section at a rate of 21000 ft³/min where the temperature is increased to 75°F. The air then enters the humidifier section so that the desired exit conditions are achieved. The entire device operates at a constant total pressure of 1 bar.

(a) Draw the two-step process on a psychrometric diagram.
(b) Determine the mass flow rate of dry air through the device.
(c) Determine the heat transfer rate to the heating section.
(d) Determine the mass flow rate of steam in the humidifying section.
(e) Determine the temperature of the steam if it has a pressure of 1.01325 bar.



(a)



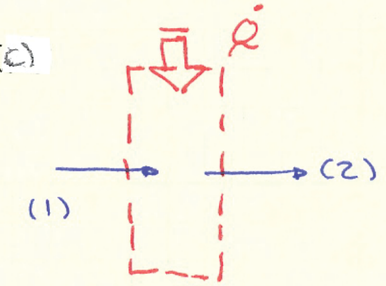
(b) $\dot{m}_a = \dfrac{\dot{V}}{v_{a1}}$ $\qquad v_{a1} = \dfrac{R_a T_1}{P_a} = \dfrac{R_a T_1}{P - P_v} = \dfrac{R_a T_1}{P - \phi P_g(T_1)}$

$= \ldots = 12.69 \text{ ft}^3/\text{lbm}$

(OR USE PSYCH CHART ON EES)

$\dot{m}_a = \ldots = \dfrac{2100 \text{ ft}^3/\text{min}}{12.69 \text{ ft}^3/\text{lbm}} = \boxed{165.5 \text{ lbm/min}}$

(c)



Con of Energy:

$$\frac{dE}{dt}^{\nearrow 0} = \dot{Q}_{IN} - \dot{W}^{\nearrow 0} + \dot{m}_a h_1 - \dot{m}_a h_2$$

$$\dot{Q}_{IN} = \dot{m}_a (h_2 - h_1)$$

$h_1 = h(T_1 = 40°F, \phi_1 = 90\%) = 14.65$ Btu/lbm

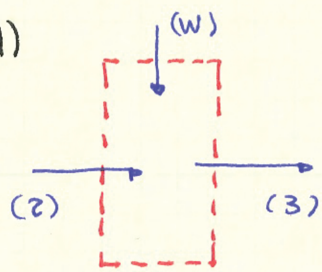
$h_2 = h(T_2 = 75°F, \omega_2 = \omega_1) =$

$= h(T_2 = 75°F \ \omega_2 = 0.00467) = 23.13$ Btu/lbm

[NOTE: $\omega_1 = \omega_1(T_1 = 40°F, \phi_1 = 90\%) = 0.00467$]

$\dot{Q}_{IN} = \ldots =$ **14.03 Btu/min**

(d)



Con of mass:

AIR: $0 = \dot{m}_{a2} - \dot{m}_{a3} \qquad \dot{m}_{a2} = \dot{m}_{a3} = \dot{m}_a$

WATER:

$$0 = \dot{m}_a \omega_2 + \dot{m}_w - \dot{m}_a \omega_3$$

$\dot{m}_w = \dot{m}_a (\omega_3 - \omega_2) \qquad \omega_3 = \omega(T_3 = 77°F, \phi_3 = 45\%)$

$= 165.5 \frac{lbm}{min} (0.008881 - 0.00467) \qquad = 0.008881$

= **0.697 lbm/min**

(e) Cons of energy: SAME SYS. AS IN (d)

$$\frac{d}{dt}(E_{sys})^{\nearrow 0} = \dot{Q}^{\nearrow 0} - \dot{W}^{\nearrow 0} + \dot{m}_a h_2 + \dot{m}_w h_{STEAM} - \dot{m}_a h_3$$

$$h_{STEAM} = \frac{\dot{m}_a}{\dot{m}_w}(h_3 - h_2) = \ldots =$$

$h_3 = h(T_3 = 77°F, \phi_3 = 0.45) = 28.23$ Btu/lbm

$\therefore\ h_{STEAM} = 1211.2\ \frac{Btu}{lbm}$ ← lbm WATER, NOT DRY AIR!

WHY?

FROM STEAM TABLES

$T_{STEAM} = T\left(h_{STEAM} = 1211.2\ \frac{B}{lbm},\ P = 101.325\ kPa\right)$

$= \boxed{339\ °F}$