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ADDING WATER VAPOUR TO HUMID AIR

Statement

Ambient air at 25 ºC, 93 kPa and 50%RH is forced to flow at a rate of 0.1 kg/s inside a duct, and a saturated (at 93 kPa) water-vapour flow-rate of 0.001 kg/s is added in a mixing chamber.

a) Evaluate the dew and wet-bulb temperatures of the incoming air.

b) Conditions after mixing.

A una corriente de 0,1 kg/s de aire atmosférico en condiciones 25 ºC, 93 kPa y 50% de humedad relativa se le añade un flujo de vapor saturado a 93 kPa de 0,001 kg/s. Se pide:

a) Temperaturas de rocío y de bulbo húmedo de la atmósfera.

b) Condiciones tras el mezclado.

Solution

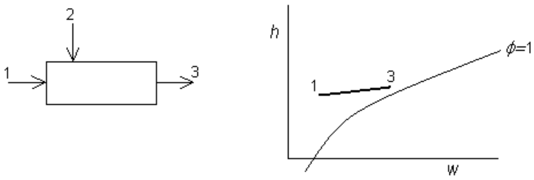

Fig. 1. Sketch of the process.

a) Evaluate the dew and wet-bulb temperatures of the incoming air.

For the dew point temperature, $p^*(T_{\text{dew}})=\phi\, p^*(T)$, using Antoine equation, one gets an explicit form:

$$\ln\frac{p^*(T_{\text{dew}})}{p_0}=\ln\phi+\ln\frac{p^*(T)}{p_0}\quad\rightarrow\quad A-\frac{B}{\dfrac{T_{\text{dew}}}{T_0}+C}=\ln\phi+A-\frac{B}{\dfrac{T}{T_0}+C}$$

$$\rightarrow\quad \frac{T_{\text{dew}}}{T_0}=\frac{1}{\dfrac{1}{\dfrac{T}{T_0}+C}-\dfrac{\ln\phi}{B}}-C=\frac{1}{\dfrac{1}{\dfrac{298\text{ K}}{1\text{ K}}+(-39)}-\dfrac{\ln 0.5}{3985}}-(-39)\quad\rightarrow\quad T_{\text{dew}}=13.8\text{ ºC}$$

but for the wet-bulb temperatures we have an implicit equation:

$$c_{pa}(T_1-T_0)+\frac{M_{va}}{\dfrac{p}{\phi_1\, p^*(T_1)}-1}h_{LV_0}=c_{pa}(T_{wet}-T_0)+\frac{M_{va}}{\dfrac{p}{p^*(T_{wet})}-1}h_{LV_0}$$

$$(1000\text{ J/(kg}\cdot\text{K))}\left(298\text{ K}-273\text{ K}\right)+\frac{0.622}{\dfrac{93\text{ kPa}}{0.5\cdot(3.17\text{ kPa})}-1}\left(2.5\text{ MJ/kg}\right)=$$

$$=(1000\text{ J/(kg}\cdot\text{K))}\left(T_{wet}-273\text{ K}\right)+\frac{0.622}{\dfrac{93\text{ kPa}}{p^*(T_{wet})}-1}\left(2.5\text{ MJ/kg}\right)$$

which must be solved by iterations (a good start is the actual temperature), or simply by linear-root-finding between the residuals at the actual temperature and at the dew-point temperature), yielding T_{wet}=17.4 ºC. Warning: mind that the iterative procedure can diverge if improperly followed (e.g. it diverges if the linear term in T_{wet} is solved for, a value is given to T_{wet} in the other term, and the resulting T_{wet} iterated.

b) Conditions after mixing.
If we assume that the exit is still unsaturated humid air, the equations are:

mass balance for dry air: $\dot{m}_{a1} = \dot{m}_{a3}$
mass balance for water: $\dot{m}_{a1} w_1 + \dot{m}_2 = \dot{m}_{a3} w_3$
energy balance: $\dot{m}_{a1} h_1 + \dot{m}_2 h_2 = \dot{m}_{a3} h_3$

that reduce to one equation with one unknown, T_3:

$$c_{pa}\left(T_1 - T_0\right) + w_1 h_{LV0} + \frac{\dot{m}_2}{\dot{m}} h_2 = c_{pa}\left(T_3 - T_0\right) + \left(w_1 + \frac{\dot{m}_2}{\dot{m}}\right) h_{LV0}$$

the other variables, absolute humidity, air enthalpy, and vapour enthalpy, at the entrance, being known:

$$w_1 = \frac{0.622}{\dfrac{93\text{ kPa}}{0.5\cdot(3.17\text{ kPa})} - 1} = 0.011$$

$h_1 = c_{pa}(T_1 - T_0) + w_1 h_{LV0}$=1000·(298-273)+0.011·2.5·10^6=52.5 kJ/kg

$h_2 = c_L(T_b - T_0) + h_{LVb} + c_{pv}(T_2 - T_b)$=4200·(373-273)+2.26·$10^6$+2000·(371-373)=2670 kJ/kg

$$\frac{\dot{m}_2}{\dot{m}} = \frac{0.001}{0.1} = 0.01$$

and so on, yielding as result T_3=299 K (26 ºC). Now we compute the relative humidity for these values (p,T,w) and we find ϕ_3=0.88.

Comments. Notice that the assumption of unsaturated exit must be checked by computing the relative humidity and checking that ϕ<1. If more water vapour were added, the exit could be super-saturated (see Ex. 8.4: Adding water vapour to humid air).

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