CHE318 L27

Final topic: Humidification operation
& Cooling tower

Definition: gas phase (drier air)
$\uparrow N_A$
liquid water

What's different about hum. tower ?
when mass transfer occur between $L \rightleftarrows G$
heat is also transferred !
(evaporation of water $\downarrow$ cools down)

Some definitions with water as A

① Humidity **H** (kg of water in 1kg dry air)

$$H = \frac{m_A C_A}{m_B C_B} = \frac{m_A P_A}{m_B P_B} = \frac{m_A P_A}{m_B (P_T - P_B)}$$

(rare to use concentration)

$$= \frac{18.02}{28.97} \frac{P_A}{P_T - P_A}$$

② Percent humidity

$$H_P = 100 \times \frac{H}{H_S}$$

③ Relative humidity

$$H_R = 100 \times \frac{P_A}{P_{vap}}$$

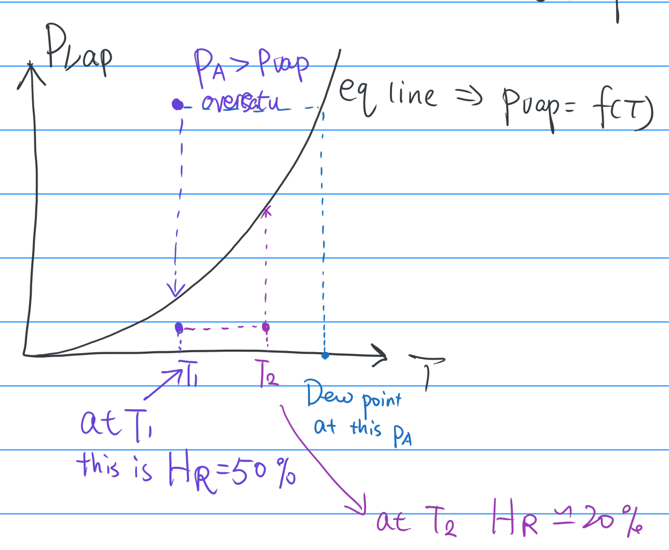
(this is the actual humidity % on your home thermostat)

Saturation humidity ?

at each temperature saturation P_{vap}

$$H_S = \frac{18.02}{28.97} \frac{P_{vap}}{P_T - P_{vap}}$$

④ Dew point. (which T does vapour/ water Saturate at current pressure ?)



⑤ Humidity heat

C_S amount of heat in Joule needed to raise 1 °C of 1kg(dry air) + vapour

$C_S = C_B + H C_A$ ⇒ s.h. water vapour (per kg per K)

$\left[\frac{J}{kg\ K}\right]$ ⇓ specific heat dry air (per kg per K)

In Joule/(kg dry air · K)

$C_S = 1.005 + 1.88 H$ (water vapour more heat cap.)

Total heat needed

$Q = w_B \cdot C_S \cdot \Delta T$

⑥ Humid volume (V_H)

volume (in m^3) of dry air + H_2O vapour (dry air: 1 kg)

$pV = nRT$

solve n for air + H_2O mixture (1 kg)

$$\begin{cases} n \text{ for air} = \dfrac{1\,kg}{M_B} \\ n \text{ for water} = \dfrac{1\,kg \cdot H \text{ (absolute)}}{M_A} \end{cases}$$

$pV = (n_B + n_A) R T$

$V = \left(\frac{n_B + n_A}{P}\right) R T$

$R = 8314 \quad P = 101325$

$= \left(\frac{1}{M_B} + \frac{H}{M_A}\right) \frac{R}{P} T = \left(\frac{1}{M_B} + \frac{H}{M_A}\right) \frac{22.414}{273} T$

M_B for air = 28.97 ≃ 29

M_A for water = 18.02 ≃ 18

Question: humidifier design

A living room of 60 m^2 at 22°C has eq. humidity of 20%, how much water is required to humidify the whole room to a final humidity of 45%? Assume height of ceiling is 3 m.

Humidity sensor $\Rightarrow$ $H_R = \frac{P}{P_{vap}}$

$\Delta p = (H_{R1} - H_{R0}) \cdot P_{vap}$ $\qquad$ $PV = nRT = \frac{m_A}{M_A} RT$

$$\Delta m_A = \frac{\Delta P V M_A}{RT} = \frac{(H_{R1} - H_{R0}) \cdot P_{vap} \cdot V \cdot M_A}{RT}$$

P_{vap} 22°C $= 2.64$ kPa

$$= \frac{(0.45 - 0.20) \cdot 2.64 \times 10^3 \times (60 \times 3) \times 18.02}{8314 \times (273.15 + 22)}$$

$= 0.87$ kg (870 mL)

This is a lower-bound estimation. In reality you need humidifier to have water tank >> 870 mL

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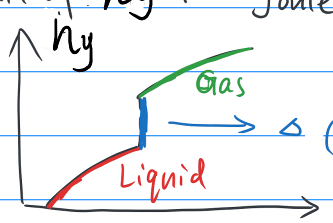
(7) Enthalpy (of mixed water vapour – air)

Enthaply h_y : definition $\frac{\partial h_y}{\partial T} = C_s$ (specific heat)

(text book uses H_y, but I'd like to distinguish between enthalpy & humidity)

Unit of h_y ? Joule / Calories



Δ (Gas − Liquid) $\Rightarrow$ latent heat

Latent heat is a measurement of entropy difference (a big topic)

For out application

$$y = C_s(T - T_0) + H\lambda_0$$

C_s → Specific heat; $(T - T_0)$ → Temp diff; H → abs. humidity; λ_0 → latent heat

You can see in continuous range $\left(\frac{\partial h_y}{\partial T} = C_s\right)$

latent heat is associated with if increase humidity

$H\uparrow \quad h_y \uparrow$

$\Rightarrow$ T uses Celsius

Air/H_2O mixture: $h_y = (1.005 + 1.88\,H)\,T + 2501.4\,H$ at 0°C

$\frac{\partial h_y}{\partial H} = 1.88T + 2501.4$ when temp ↑ more heat is required to humidify

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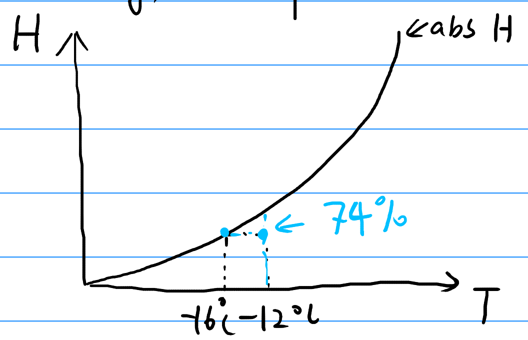
Myth busting time!

1. My weather app shows outside is −12°C & 74% humidity, dew point −16°C. what does that mean?



2. In this scenario (−12°C, 74%), cold air comes in my house and humidity inside house immediated drops. why?

$P_{vap}(T = -12°C) = 0.24$ kPa

$P_{vap}(T = 22°C) = 2.64$ kPa

} 10 times difference!

74% RH at −12°C = $p = 0.24 \times 0.74 = 0.178$ kPa

$H_R(22°C) = \frac{0.178}{2.64} = 6.7\%$!

In other words, { Cold air ⟶ appear dry in high T; hot air ⟶ appear humid in low T

3. Why does "humid hot" feel worse than "dry hot"?
(E.g. compare 35°C in rainforest vs 35°C in desert)
R.H = 95% R.H. = 25%

Link to evaporation of human body. Can evaporation be effective in this scenario?

$P_{vap} \simeq 5.6$ kPa $H = \frac{18.02}{28.97} \frac{P_A}{P_T - P_A}$

R.H. = 95% => H = 0.0345
R.H. = 25% => H = 0.00872

$h_y(95\%)$ = 37.45 + 87.30 = 123.74 kJ/kg
$h_y(25\%)$ = 57.56 kJ/kg = 35.75 + 21.81

↑ gas specific heat ↑ latent heat

(1) humid air's enthalpy (thermal energy) is much more than dry air
(2) when $T_{air} \simeq T_{skin}$ only driving force is R.H. difference.
N_A from skin is smaller is hot & humid air!