Properties of air-water vapor mixtures

Total pressure : defined by **Gibbs-Dalton Law**

$$\text{Total pressure} = \Sigma \text{ partial pressures}$$

$$P_{total} = P_A + P_B + P_C + \ldots\ldots\ldots\ldots$$

For air-water vapor mixtures the total pressure of moist air (barometric pressure)

$$P_{barometric} = P_{air} + P_{wv}$$

Humidity or **Humidity ratio** or **moisture content** of air : mass of water vapor per unit mass of dry air

$$\mathbf{H} = \frac{\text{mass of water vapor}}{\text{mass of dry air}} = \frac{m_{wv}}{m_a} = \frac{\text{kg } H_2O}{\text{kg dry air}}$$

or

$$\mathbf{H} = \frac{M_{wv}}{M_a}\frac{x_{wv}}{x_a} = \frac{18.01534}{28.9645}\frac{x_{wv}}{x_a} = 0.622\frac{x_{wv}}{x_a}$$

where x is mole fraction and can be expressed in terms of partial pressures.

$$x_a = \frac{n_a}{n_t}$$

from ideal gas law

$$n_a = \frac{P_a V}{R T} \qquad\qquad n_t = \frac{P_t V}{R T}$$

hence,

$$x_a = \frac{P_a}{P_t}$$

For a binary air-water vapor mixture $P_t = P_a + P_{wv}$

$$\mathbf{H} = 0.622 \frac{x_{wv}}{x_a} = 0.622 \frac{P_{wv}}{P_a} = 0.622 \frac{P_{wv}}{P_t - P_{wv}}$$

Saturation Humidity mass of water vapor per unit mass of dry air when air is saturated with the water vapor. Saturated air is the air-water vapor mixture in which the partial pressure of water vapor is equal to the vapor pressure, P_{wvs}, of pure water at the given temperature.

$$\mathbf{H}_s = 0.622 \frac{P_{wvs}}{P_t - P_{wvs}}$$

Percentage Humidity the actual humidity of the air divided by the humidity of saturated air at the same temperature and pressure.

$$\mathbf{H}_p = 100 \frac{H}{H_s}$$

Relative Humidity the ratio of mole fraction of water vapor in a given moist air sample to the mole fraction in an air sample saturated at the same temperature and pressure.

$$\%RH = \mathbf{H}_R = 100 \frac{P_{wv}}{P_{wvs}}$$

It is an estimate of the amount of moisture in air relative to the maximum possible amount. %RH varies with temperature.

<u>Note</u> $\mathbf{H}_R$ is not equal to $\mathbf{H}_p$.

Example problem 1: The air in a room is at 27°C and a total pressure of 101.325 kPa. Air contains water vapor with a partial pressure of 2.76 kPa. Calculate the following.

a) Humidity

b) Saturation humidity and percentage humidity

c) Relative humidity

d) Do you expect a change in humidity if the air is heated to 40°C at the same relative humidity?

Dew point temperature The temperature at which a given mixture of air and water vapor would be saturated is called the dew point temperature or simply the dew point.

Humid heat of an air-water vapor mixture : The amount of heat c_S, in kJ required to raise the temperature of 1 kg of dry air plus the water vapor present by 1K or 1°C.

$$c_S = 1.005 + 1.88\, H \quad (\text{kJ/ kg dry air K})$$

Humid volume of an air-water vapor mixture : The total volume in m^3 of 1 kg of dry air plus the vapor it contains at 101.325 kPa absolute pressure and the given gas temperature

$$V' = \frac{22.4\text{L}}{1\text{ mole of air}} \; \frac{1\text{ mole of air}}{28.97\text{g}} \; \frac{T_{db}+273}{0+273} \; +$$

$$\frac{22.4\text{L}}{1\text{ mole of water}} \; \frac{1\text{ mole of water}}{18.02\text{g}} \; \frac{T_{db}+273}{0+273} \; \mathbf{H} \; \frac{\text{kg water}}{\text{kg air}}$$

$$V' = (0.082\, T_{db} + 22.4)\left(\frac{1}{28.97} + \frac{H}{18.02}\right)\; m^3/\text{kg}$$

Total enthalpy of air-water vapor mixture : The total enthalpy of 1kg of air plus its water vapor

$$H_S(\text{kJ/kg}) = H_a + H_{wv} = c_S\,(T_{db} - T_{ref}) + \mathbf{H}\, \Delta H_{vap}$$

$$\Delta H_{vap} = 2501.4 \text{ kJ/kg at } 0°\text{C}$$

Example problem 2: Calculate the specific volume, humid heat and total enthalpy of air-water vapor mixture at 90°C and at a humidity of 0.01 kg water / kg dry air.