Department of Chemical Engineering Thapar Institute of Engineering & Technology, Patiala

Course: Material and Energy Balances UCH301

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Saturation, Partial Saturation Humidity, Relative Humidity

Saturation or Humidity, & Partial Saturation

- The term saturation refers to any gas-vapor system.
- The term humidity specifically refers to air-water vapor system.
- When partial pressure of a component in the gas phase is equal to its vapor pressure at the given temperature the gas is said to be saturated.

  (for air water system the air is set to be saturated air)
- When the partial pressure of a component in the gas phase is less than its vapor pressure the gas is said to be partially saturated.

  (for air water system the air is set to be partially saturated)

Absolute and Molal Saturation

- ✔ Absolute saturation (Absolute humidity):

  = kg of vapor/kg dry gas

  $$=\mathbf{n_A M_A / n_b M_B = p_A M_A / p_b M_B}$$

  Where, n is number of moles and M is molecular wieght

  Subscript *A is used for vapor and B for dry gas*

(Above expression is for absolute humidity in case the vapor is water and gas is air)

- ✔ Molal saturation (Molal humidity):

  =moles of vapor/mole of dry gas

  $$= \mathbf{n_A / n_{dry\ gas}}$$

  $= p_A/(P-p_A)$ (from ideal gas law, which states mol%=pr%)

Relative and Percentage Saturation

- Relative saturation (Relative humidity):

  It can be defined as the ratio of moles of vapor in dry gas to the moles of vapor in dry gas at saturation condition

  $$RS = p_A/p_A^*(T)$$

  [Relative humidity (RH) data is reported in daily weather data]

- Percentage saturation (Percentage humidity):

  It is defined as the ratio of molal humidity at actual condition to the molal humidity at complete saturation.

  $$=100*[p_A/(P- p_A)]_{actual}/[P_A^{*}/(P- p_A^{*})]_{saturation}$$

Estimation of vapor pressure

✔ For solving the problems related to humidity/saturaion/bubble point/dew point calculations we need the vapor pressure of pure components at a given temperature

- *Clausius-Clapeyron equation:*

$$\ln p^* = -\frac{\Delta H_v}{RT} + B$$

- This equation states that a plot of ln P* vs 1/T will give a sraight line, with slope as $-\frac{\Delta H_v}{R}$, and B as intercept
- Where ΔH_v is latent heat of vaporization, B is constant

Duhring Plot

- This plot is used to estimate the molal heat of vaporization of a liquid, at any temperature, by comparing the $\Delta\hat{H}_v$ of the liquid with the $\Delta\hat{H}_v$ of a reference liquid (such as water).
- PLOT: The temperature of the liquid is plotted against the temperature of reference liquid at equal vapor pressure.
- For example, if the temperature of liquid A (isobutyric acid) and the reference substance are determined at 760, 400, and 200 mm Hg pressure, then the plot of the temperature of A and water will be approximately a straight line over wide range of temperature, and its slope would be

$$(\Delta\hat{H}_{vA}/\Delta\hat{H}_{vH2O})(T_{H2O}/T_A)^2$$

Estimation of vapor pressure

A relatively simple empirical equation that correlates vapor pressure-temperature data extremely well is the ***Antoine equation*** *(Ref.:Richard M. Felder)***:**

$$\log_{10} p^* = A - \frac{B}{T + C}$$

where T in ^0C and p in mm Hg

(A,B,C are constants, values for these can be found in standard text books)

Another form of Antoine equation *(Ref.:David M. Himmelblau):*

$$\ln p^* = A - \frac{B}{T + C}$$

where T in K and p in mm Hg

(Values of A,B,C for this equation will be different due to change of units)

PROBLEM

- Helium contains 12% ethyl acetate vapor by volume. Calculate (a) relative saturation and (b) percent saturation of the mixture at a temperature of 30 ^{0}C and a pressure of 98 kPa.

Data: P^*_{EtAc} at 30 ^{0}C = 15.9 kPa

Solution

- Partial pressure of ethyl acetate:

(Since pr% = mol% for ideal gases)

$$p_{EtAc} = P \times y_{EtAc} = P(n_{EtAc}/n_{total}) = P(V_{EtAc}/V_{total})$$

$$= (98)(0.12) = 11.76 \text{ kPa}$$

Partial pressure of helium:

$$p_{He} = P - p_{EtAc} = 98 - 11.76 = 86.24 \text{ kPa}$$

(a) %relative saturation =

$$(p_{EtAc}/P^*_{EtAc})(100)$$

$$= (11.76/15.9)*100 = 74\%$$

(b) Percent saturation

$$=100*[11.76/(98-11.76)]/\ [15.9/(98-15.9)]$$

$$=70.4\%$$

PROBLEM

- Humid air at 75 ^{0}C, 1.1 bar, and 30% RH is fed into a process at a rate of 1000 m^3/h. Determine

(1) the molar flow rates of water, dry air, and oxygen entering the process

(2) the molal humidity, and percentage humidity of the air.

$P^*_{H2O}(75\ ^{0}C) = 289$ mm Hg

SOLUTION

$\%RH = 100[\, p_{H2O}/P^*_{H2O}(75\ ^0C)]$

$P^*_{H2O}(75\ ^0C) = 289$ mm Hg

$0.3 = p_{H2O}/289$

therefore, $p_{H2O} = (0.3)(289) = 86.7$ mm Hg

$P = 1.1$ bar $= (1.1*10^5/101325)(760)$

$= 825$ mm Hg

$y_{H2O} = 86.7/825 = 0.105$ mol H_2O/mol

Molar flow rate of humid air from ideal gas law

$n_{\text{humid air}} = PV/RT$ [V= vol. flow rate]

$= (825/760)(1000)/\{0.082*348\}$

$= 38$ kmol/h

Molar flow rate of water = n_{H2O} = 0.105*38

=4 kmol/h

Molar flow rate of DA =n_{DA} = (1-0.105)*38

=34 kmol/h

Molar flow rate of O_2 = n_{O2} = (0.21)*34

=7.14 kmol/h

Molal humidity = p_{H2O}/p_{DA} = 86.7/(825-86.7)

= 0.117 molH_2O/molDA

Absolute humidity = 0.117*18/29

= 0.0726 kg H_2O/kg DA

Percentage humidity

= 100*{86.7/(825-86.7)}/ {289/(825-289)}

= 21.7%

Answers

(1)

molar flow rate of water = 4 kmol/h

molar flow rate of dry air = 34 kmol/h

molar flow rate of oxygen = 7.14 kmol/h

(2)

molal humidity = 0.117 mol H_2O/Mol DA

percentage humidity = 21.7 %

Problem

- The atmosphere in the afternoon during a humid period is at 90 ^{0}F and 80%RH (barometer reading=738mm Hg); while at night it is at 68 ^{0}F (barometer reading= 745 mm Hg). Calculate the percentage of water vapor condensed as dew.

Data: $p^*(90\ ^0F) = 36.1$ mm Hg

$p^*(68\ ^0F) = 17.5$ mm Hg

Solution

p_{H2O}(in day air) = 36.1*0.8

= 28.9 mm Hg

(corresponds to 83 ^{0}F Dew Point)

p_{air} (day time) = 738-28.9 = 709.1 mm Hg

Day time molal humidity

= 28.9/(709.1)

= 0.0407 molH_2O/molDA

Air will become saturated at the night conditions

p_{air} (night time) = 745-17.5 = 727.5 mm Hg

Night time molal humidity =17.5/727.5 molH_2O/molDA

= 0.024 molH_2O/molDA

% Moisture condensed=[(0.0407-0.024)/0.0407]*100

= 41%