Air-Conditioning & Refrigeration

BSc

Lecture 2

Course weekly Outline &

Ch.1 (Introduction to Air conditioning & Refrigeration)

P. Dr. Maki Haj Zaidan

Tikrit university\ engineering college\ mechanical dept.

2.1 Introduction and definitions

2.1.1 Review of basic principles

Air conditioning : Is the science and practice of controlling the indoor climate in term of temperature , air motion , humidity , air purity and noise.

Refrigeration :Is the process of removing the undesirable heat from a given body to maintain it at a desired lower temperature.

Moist air : Working substance in air conditioning is the moist air which is a mixture of two gases. One of these is dry air which itself is a mixture of a number of gases and the other is water vapor which may exist in a saturated or super heated state. Both are treated as perfect gases since both exist in the atmosphere at low pressures. In addition Gibbs-Dalton laws for non reactive mixture of gases can be applied to the dry air part only to obtain its properties as a single pure substance.

2.2 VAPOR PRESSURE (P_s)

The vapor pressure or steam pressure (P_v or P_s) can be calculated from the empirical formula:

$P_s = P_{wss} - P_{at.} A. (t_d - t_w)$ or $P_v = P_{wss} - P_B. A. (t_d - t_w)$..................(1)

Where:

A is constant = $A = 6.66 \times 10^{-4}$ if $t_w \geq 0 °C^{-1}$

$A = 5.94 \times 10^{-4}$ if $t_w < 0 °C^{-1}$

$P_B = P_{at}$ = Barometric or Atmospheric pressure at kPa

$t_d = DBT$ = Dry Bulb Temperature °C

$t_w = WBT$ = Wet Bulb Temperature °C

P_{wss} = Saturated pressure of vapor at wet bulb temperature (t_w) from (table 1) kPa

Example:

Calculate the water vapor pressure in wet air under 20°C dry bulb and 15°C wet bulb temperature and P_B = 950 mbar?

Solution:

$P_s = P_{wss} - P_{at} A (t_d - t_w)$

From steam table 1 at t_w = 15°C

P_{wss} = 1.705 kPa

$P_s = 1.705 - 95 \times 6.66 \times 10^{-4} (20 - 15)$ = 1.388 kPa

2.3 Relative Humidity RH (Φ)

Relative humidity is the ratio of the water vapor pressure P_s , to the vapor pressure of saturated air at the same temperature (t_d) and P_{Dss} expressed as a percentage.

Relative humidity by partial pressure:

$\Phi = P_s \, / \, P_{Dss} \, 100\%$ ……………………………………(2)

where

Φ = Relative humidity (%)

P_s = Vapor pressure (Pa)

P_{Dss} = Saturation vapor pressure at the actual dry bulb temperature (t_d) Pa

Example:

Air at 24°C and 40% RH, and P_{at}= 92 kPa. Find the vapor density (ρ_s) and vapor pressure (P_s).

Solution:

From Table 1 at t_d =24°C, υ = 45.883 m³/kg

$\rho_{ss} = 1/\upsilon = 1/45.883 = 0.02179$ kg/m³

$\Phi = [\rho_s / \rho_{ss}]_{t,\,p} \rightarrow \rho_s = \Phi . \rho_{ss} = 0.4 \times 0.02179$ = 0.008716 kg/m³

$P_s = \rho_s R T$ = 0.008716 x 461x (24+273) = 1193.4 Pa

Or by other way;

$\Phi = [P_s / P_{dss}]_{t,\,p}$, from Table 1 at t= t_d =24°C → P_{dss}= 2985 Pa

P_s= 0.4 x 2985= 1194 Pa

Moisture content (w) or (g)

Sometimes called the specific humidity or humidity ratio, it is the ratio of the mass of water vapor (m_v) or (m_s) to the mass of the dry air (m_a) in the mixture:

$w = m_v / m_a$ or $g = m_s / m_a$ ....(3)

To find the values of (m_s) and (m_a) using equation (2.3)

$m_s = P_s V_s / R_s T_s$, $m_a = P_a V_a / R_a T_a$

but m_s / m_a and $V_s = V_a$, $T_s = T_a$

$g = (P_s/R_s)/ (P_a/R_a) = (P_s/P_a). (R_a/R_s) = (P_s/P_a). (287/461)$

$= 0.622 P_s / P_a = 0.622 P_s / (P_{at} - P_s)$ … ....(4)

$g = 0.622 P_s / P_a = 0.622 P_s / (P_{at} - P_s)$

or $w = 0.622 P_v / P_a = 0.622 P_v / (P_B - P_v)$

Example:

Air at 20°C dry bulb and 15°C wet bulb and the barometric pressure is 95 kPa. Calculate the moisture content of the air and the density of the vapor.

Solution:

From steam table 1 at t_w= 15°C

P_{wss} = 1.705 kPa

$P_s = P_{wss} - P_{at} . A. (t_d - t_w)$

P_s = 1.705 – 95 x 6.66 x 10^{-4}(20 – 15) = 1.389 kPa

$g = 0.622 (P_s)/(P_{at} - P_s)$ = 0.622 (1.389)/ (95 – 1.389) = 0.00923 kg/ $kg_{dry\ air}$

Density of the vapor, $P_s = \rho_s.R_s.T \rightarrow \rho_s$= (1389)/(461)(20+273) = 0.01028 kg/m^3

Degree of saturation (μ) :

Is the ratio of the moisture content (g) to the moisture content of a saturated mixture (g_{ss}) at the same temperature and pressure.

$$\mu = [\, g / g_{ss}]_{t,\, p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$g = m_s / m_a = (P_s / (P_{at} - P_s))\,.(R_a / R_s)$$

$$g_{ss} = (P_{ss} / (P_{at} - P_{ss}))\,.(R_a / R_s)$$

$$\mu = (P_s / (P_{at} - P_s))\,.((P_{at} - P_{ss}) / P_{ss})\,.(R_a / R_s)(R_s / R_a)$$

$$= (P_s / P_{ss}).(P_{at} - P_{ss}) / (P_{at} - P_s)$$

Divided the right hand side by P_{at} / P_{at}

$$= (P_s / P_{ss}).\, (1 - P_{ss} / P_{at}) / (1 - P_s / P_{at})$$

Multiply right hand side by P_{ss} / P_{ss} and note that $\Phi = P_s / P_{ss} \times 100\%$

$$= \Phi[\, (1 - P_{ss} / P_{at}) / (1 - \Phi.\, P_{ss} / P_{at})] \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Example:

Moist air at 40°C DBT, 30°C WBT and 101 kPa barometric pressure, calculate for the air:

a) Relative humidity (Φ)

b) Moisture content (g)

c) Degree of saturation (μ)

Solution:

$P_s = P_{wss} - P_{at}.\ A.\ (t_d - t_w)$, *from Table 1*

$P_{wss} = 4.246$ kPa at 30°C, $P_{dss} = 7.384$ kPa at 40°C

$P_s = 4.246 - 101 \times 6.66 \times 10^{-4}\ (40 - 30) = 3.57$ kPa

a) $\Phi = P_s / P_{dss} \times 100\% = (3.57)/(7.384) \times 100\% = 48.4\%$

b) $g = 0.622\ Ps/\ (P_{at} - P_s) = 0.622(\ 3.57)/(101 - 3.57) = 0.0228\ kg/kg_{d.a}$

c) $\mu = [\ g/g_{ss}]_{t,\ p}$

$g_{ss} = 0.622(7.384)/(101 - 7.384) = 0.049\ kg/kg_{d.a}$

$\mu = 0.0228/0.049 = 0.465 = 46.5\%$

Or:

$\mu = \Phi[\ (1 - P_{ss}/P_{at})/(1 - \Phi.\ P_{ss}/P_{at})] = (0.484)[1 - (7.384/101\ )]/[1 - 0.484\ (7.384/101)]$

$= 46.5\%$

Home Work:

1. Moist air at 42^{o}C DBT, 26^{o}C WBT and 100 kPa barometric pressure.

Calculate:

(a) vapor pressure

(b) relative humidity

(c) moisture content

(d) degree of saturation

2. The atmospheric condition of air are 25^{o}C dry bulb temperature and moisture content of 0.01 $kg/kg_{d.a}$.

Find:

(a) partial pressure of vapor

(b) relative humidity

(c) degree of saturation

[Ans. 0.016 bar, 50.6% , ?]