Air-Conditioning & Refrigeration

BSc

Lecture 3

Course weekly Outline &

Ch.1 (Introduction to Air conditioning & Refrigeration)

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1. Dew point temperature (t_{dp})

This is defined as the temperature of saturated air which has the same vapor pressure as the moist air under condensation. It may also be stated as a mixture is cooled at constant pressure, the temperature at which condensation first begins is the dew point.

Example:

Find the dew point temperature for air at 20°C DBT and 15°C WBT and atmospheric pressure is 95 kPa.

Solution:

From Table 1 at $t_w = 15^oC$, $P_{wss} = 1.705$ kPa

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

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

From Table 1, we find the saturation temperature that corresponds to P_s

$t_{sat} = t_{dp} = 11.84^oC$

2. Specific volume (v)

This is defined as the volume of one kg of moist air, it can calculated by three ways:

1. Used of dry air mass and partial pressure
2. Used of vapor mass and partial pressure
3. Used of mass of mixture and its total pressure.

Example:

Calculate the specific volume (v) of air at 35°C DBT and 25°C WBT at a barometric (atmospheric) pressure of 95 kPa.

Solution:

$P_a V_a = m_a R_a T_a \rightarrow v_a = R_a T_a / P_a$

But; $P_a = P_{at} - P_s$

$P_{wss} = 3.169$ kPa at t = 25°C from table 1

$P_s = 3.169 - 95 \times 6.66 \times 10^{-4} (35 - 25) = 2.5363$ kPa

Then $P_a = 95 - 2.5363 = 92.46$ kPa

$v_a = (0.287)(35 + 273)/(92.46) = 0.956$ m³/kg

Or by other way;

$g = 0.622 (P_s)/(P_{at} - P_s) = 0.622(2.5363)/(95 - 2.5363) = 0.01706$ $kg/kg_{d.a}$

So for 1 kg of dry air there is 0.01706 kg of steam ; $m_s = 0.01706$ kg

$v_s = (0.01706)(0.461)(35 + 273)/(2.5363) = 0.956$ m³/kg.

$v_s = v_a = v = 0.956$ m³/kg

3. Enthalpy (h)

If a heat exchange occurs at constant pressure, as well as a change in internal energy taking place, work may be done.

This leads to a definition of enthalpy, H:

$$H = U + PV$$

The equation is strictly true for a pure gas of mass m, pressure p, and volume V.

However it may be applied without appreciable error to the mixtures of gases associated with air conditioning. The enthalpy, h, used in psychrometry is the specific enthalpy of moist air, expressed in kJ/kg

dry air, defined by the equation:

$h = h_a + g\, h_s$ .... (1)

where ;

h_a is the enthalpy of dry air, h_s is the enthalpy of water vapor, both expressed in kJ/kg and g is the moisture content.

An approximate equation for the enthalpy of dry air over the range 0°C to 60°C is, however $h_a = 1.007\, t_d - 0.026$ .... (2)

and for lower temperatures, down to – 10°C, the approximate equation is

$h_a = 1.005\, t_d$ ....(3)

For purposes of approximate calculation, we may assume that, in the range 0°C to 60°C, the vapor is generated from liquid water at 0°C and that the specific heat of superheated steam is a constant. The following equation can then be used for the enthalpy of water vapor:

$h_s = 2501 + 1.84\, t_d$ ....(4)

Equations (2.17) and (2.19) can now be combined, as typified by equation (2.16), to give an approximate expression for the enthalpy of humid air at a barometric pressure of 101.325 kPa:

$h = (1.007\, t_d - 0.026) + g(2501 + 1.84\, t_d)$ ....(5)

Example: Calculate the enthalpy (h) of air at 35°C DBT and moisture content = 0.01805 kg/kg$_{d.a}$ at an atmospheric pressure of 95 kPa.

Solution:

$h = (1.007x\ 35 - 0.026) + 0.01805\ (\ 2501 + 1.84\ x\ 35) = 76.4$ kJ/kg$_{d.a}$

Example: Compute the enthalpy of saturated air at 15°C and standard atmospheric pressure.

Solution:

Because the air is saturated, $g = g_s$ & $P_s = P_{ss}$ & $t = t_d = t_w$

$g_s = 0.622(P_{ss})/(P_{at} - P_{ss})$ from Table 1 at t=15°C, $P_{ss} = 1705$ Pa

$g_s = 0.622(1705)/(101325 - 1705) = 0.01065$ kg/kg$_{d.a}$

$h = (1.007\, t_d - 0.026) + g(2501 + 1.84\, t_d)$

$= (1.007x\ 15 - 0.026) + 0.01065\ (\ 2501 + 1.84\ x\ 15) = 42$ kJ/kg$_{d.a}$

EXAMPLE:

In a check on an air-conditioning system, a room was maintained at 22°C DBT and 53% RH, by air supply at 1.6 m³/s with 10°C DBT and 9°C WBT. The barometric pressure was 920 mbar. Find:

a) sensible heat gain. b) latent heat gain c) total heat gain

Solution:

From Table 1 at $t_w = 9^oC$, $P_{wss} = 1.15$ kPa

$P_s = 1.15 - 92 \times 6.66 \times 10^{-4}(10 - 9) = 1.0887$ kPa

$P_a = 92 - 1.0887 = 90.91$ kPa

$\dot{m}_a = (P_a V_a)/(R_a T_a) = (90.91 \times 1.6)/(0.287 \times 295) = 1.718$ kg/s

$h_{a1} = 1.007 \times 22 - 0.026 = 22.128$ kJ/kg

$h_{a2} = 1.007 \times 10 - 0.026 = 10.044$ kJ/kg

$Q_s = \dot{m}_a(h_{a1} - h_{a2}) = 1.718(22.128 - 10.044) = 20.7$ kW

Also, from Table 1 at $t_d = 22^oC$, $P_{dss} = 2.645$ kPa

$\Phi = P_s / P_{dss} \rightarrow P_s = 0.53 \times 2.645 = 1.4$ kPa

$g_1 = 0.622(1.4)/(92 - 1.4) = 0.00961$ $kg/kg_{d.a}$

$g_2 = 0.622(1.0887)/(92 - 1.0887) = 0.00745$ $kg/kg_{d.a}$

$h_{s1} = 2501 + 1.84 \times 22 = 2541.48$ kJ/kg

$h_{s2} = 2501 + 1.84 \times 10 = 2519.4$ kJ/kg

$Q_L = \dot{m}_a(g_1 . h_{s1} - g_2 . h_{s2}) = 1.718(0.00961 \times 2541.48 - 0.00745 \times 2519.4) = 9.714$ kW

$Q_{Tot} = Q_s + Q_L = 20.7 + 9.714 = 30.414$ kW

Home Work: For exercise 1 to 4 compare the calculated results with results gain from the Free Online Interactive Psychrometric Chart

http://www.flycarpet.net/en/PsyOnline

1. The atmospheric condition of air are 25°C dry bulb temperature and moisture content of 0.01 kg/kg dry air. Find: (a) partial pressure of vapor (b) relative humidity (c) dew point temperature. [Ans. 0.016 bar, 50.6%, 14.1°C]

2. A sling psychrometer reads 40°C dry bulb temperature and 28°C wet bulb temperature. Calculate the following: (a) moisture content (b) relative humidity (c) vapor density in air (d) dew point temperature (e) enthalpy of mixture per kg of dry air.
[Ans. 0.019 kg/kg of dry air, 40.7%, 0.0208 kg/m^3, 24°C, 88.38 kJ/kg$_{\text{dry air}}$]

3. A sample of moist air has a dry bulb temperature of 25°C and a relative humidity of 50%. The barometric pressure is 740 mm of Hg. Calculate:
(a) partial pressure of water vapor and dry air (b) dew point temperature
(c) specific humidity (moisture content) (d) enthalpy of air
[Ans. 0.01583 bar, 14°C, 0.0101 kg/kg$_{\text{dry air}}$, 50.81 kJ/kg$_{\text{dry air}}$]

4. The atmospheric conditions of air are 35°C dry bulb temperature, 60% relative humidity and 1.01325 bar pressure. If 0.005 kg of moisture per kg of dry air is removed, the temperature becomes 25°C. Determine the final relative humidity and dew point temperature. [Ans. 88.6%, 23°C]

Home Work:

For exercise 1 to 3 compare the calculated results with results gain from the Free Online Interactive Psychrometric Chart

http://www.flycarpet.net/en/PsyOnline

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) Specific Enthalpy
e) specific volume f) dew point temperature g) degree of saturation

2. A sling psychrometer reads $40^{o}C$ dry bulb temperature and $28^{o}C$ wet bulb temperature.
Calculate the following:
(a) moisture content (b) relative humidity (c) vapor density in air
(d) dew point temperature (e) enthalpy of mixture per kg of dry air.
[Ans. 0.019 $kg/kg_{d.a}$, 40.7%, 0.0208 kg/m^3, $24^{o}C$, 88.38 kJ/kg]

3. A sample of moist air has a dry bulb temperature of $25^{o}C$ and a relative humidity of 50%. The barometric pressure is 740 mm of Hg.
Calculate:
(a) partial pressure of water vapor and dry air (b) dew point temperature
(c) specific humidity (moisture content) (d) enthalpy of air
[Ans. 0.01583 bar, $14^{o}C$, 0.0101 $kg/kg_{d.a}$, 50.81 kJ/kg]