Lecture six

5-Humidification:

By this process the moisture content of air is increased.

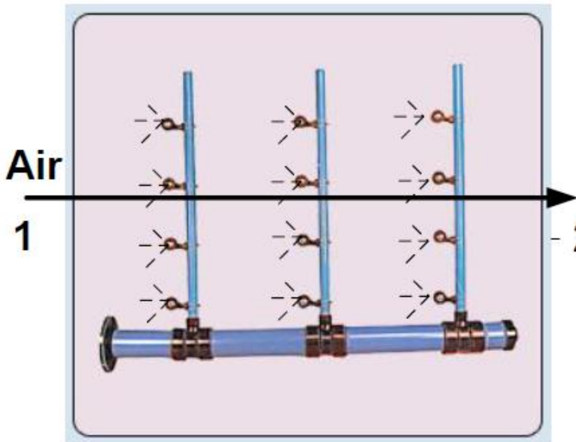
Humidification is used with heating process since in such situations heating is only sensible and the air becomes dry, therefore additional moisture is required.

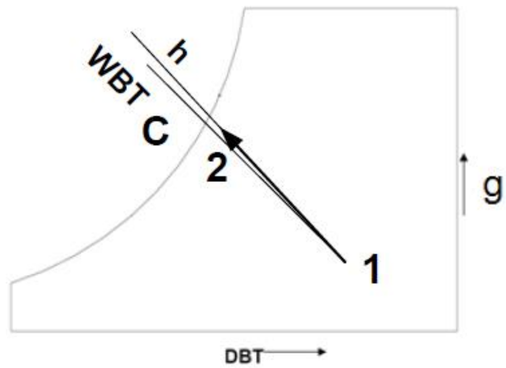
Humidification is done by humidifier either by:

a. By passing moist air stream through a spray chamber containing a very large number of small water droplets.
b. Passage of air over a large, wetted surface.
c. By direct injection of steam or water droplets aerosol size into the room being conditioned.

passing moist air stream through a spray chamber

In this method a device called an air washer is used, in this method it is customary to speak of *humidification efficiency* or the *effectiveness* ***E*** of an air washer than the contact factor or by a by-pass factor. The effectiveness of air washer may be defined as the extent to which the DBT of the entering moist- air stream approaches its initial WBT value, or it can be define as the change of state undergoes by the air.





Although humidification efficiency is often expressed in terms of a process of adiabatic saturation, but this process is a special case.

The effectiveness (***E***)of spray chamber is

$$E=\frac{h_2-h_1}{h_c-h_1}=\frac{W_2-W_1}{w_c-W_1}$$

And the humidity efficiency η is: η =100 *E*

Consider the special case of adiabatic saturation, for this to occur it is necessary that:

a. The spray water is totally re-circulated, no heat exchange being present in the pipeline or in the waste tank.

b. The spray chamber, tank and pipelines are perfectly lugged.

c. The feed water supplied is at the temperature of adiabatic saturation.

Under these conditions it may be assumed that the change of state follows a line of constant enthalpy, and since the lines of enthalpy and WBT are corresponding each other, therefore we can assume that the process follows the line of constant WBT.

Example:

1.5 m^3/s of moist air at 15° C DBT, 10° C WBT and 101.325 kPa enters the spray chamber of an air washer. The humidification efficiency of the washer is 90%, all the spray water is recirculated, the spray chamber and the tank are perfectly lugged, and the feed water at 10°C is supplied to make good the losses due to evaporation: calculated; a- the state of the air leaving the washer b- the rate of flow of makeup water from the mains.

Solution:

Since the process is at constant WBT, the point (c) must lie on saturation curve at 10°C, i.e. Tc=10° C. (W_1 = 5.56 g_w /kg dry air, W_c = 7.6 g_w /kg dry air) from chart.

$E=\frac{DBT_1-DBT_2}{DBT_1-T_c}$ [i.e., the ratio of(**higher value - lower value**) of temperature in the numerator and denominator].

$0.9=\frac{15-DBT_2}{15-10}$, DBT_2=10.5°C → $WBT_2 = WBT_1$ =10°C

$E=\frac{W_2-W_1}{W_c-W_1}$ $0.9=\frac{W_2-5.56}{7.6-5.56}$ → W_2=7.396 gram water/kg dry air.

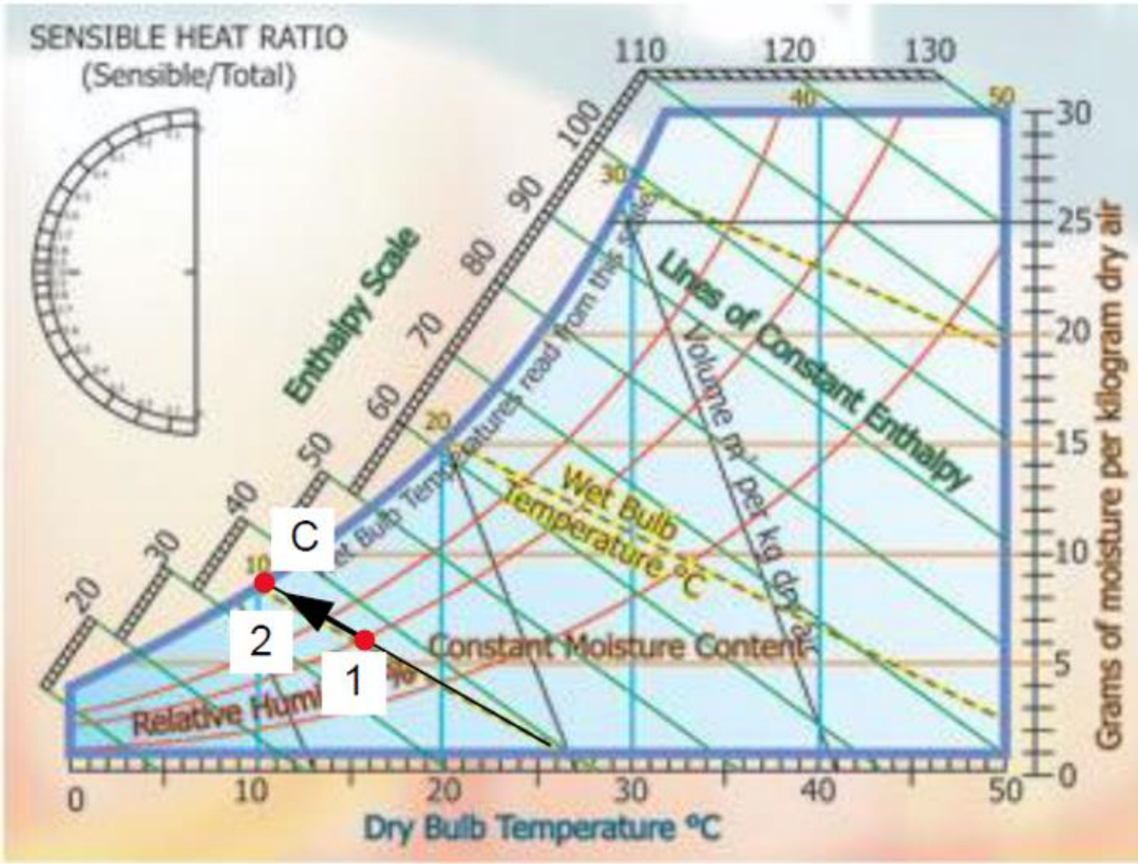
The rate of makeup water = $\dot{m}_a(W_2-W_1)$

$\upsilon_1=0.824 m^3/kg$

$\dot{m}_a=\frac{V}{\upsilon}=\frac{1.5}{0.824}=1.82 kg/sec$

$\dot{m}_w=1.82(7.396-5.56)=3.342$ gram water/sec.

$\dot{m}_w=3.342*10^{-3}*3600=12.0312 kg_w/hr$



For adiabatic humidification we had:

$h_2=h_1+(w_2-w_1)h_{fg}$.

Since humidification may be accomplished with steam or water let (h_{fg})be (h_3) to indicate enthalpy of water, water vapour or even ice.

$\therefore$ for humidification $h_2=h_1+(w_2-w_1)h_3$

Also, mass balance can be written for the process as:

$m_2=m_1+m_w$ (total mass balance).where (m_w) is the mass of water or steam injected. Alternatively, since the mass of dry air is constant.

$w_2=w_1+m_w$

where w_1 & w_2 are specific humidities & m_w is mass in kg water or steam/kg of dry air.

e.g: moist air at 21°C d.b. & 15°C w.b. and standard atmospheric pressure is humidified by water spray. If for each kg of dry air passing through the duct (0.002kg) of water at 100°C is injected and totally evaporated. Calculate for the air leaving the spray chamber.

a. the moisture content. b. enthalpy. & c. dry bulb temperature.

Solution:

: $P_1 = P_{sw} - P_B.A.(t_d - t_w)$

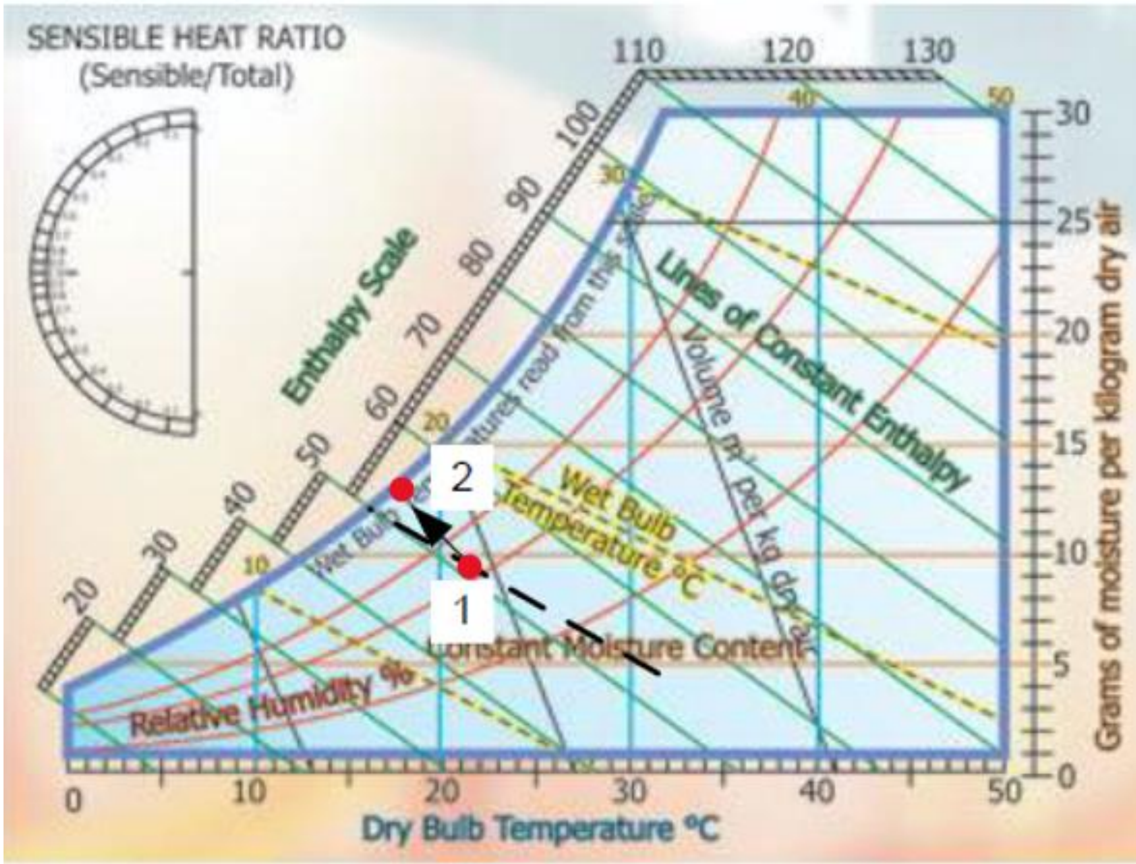
$= 1.7051 - 101.325 * 6.66 * 10^{-4}(21-15) = 1.3kP_a$

$$W_1 = 0.622 \frac{P_1}{P_B - P_1} = 0.622 * \frac{1.3}{101.325 - 1.3} = 0.008084 \text{kg/kg dry air}$$

$h_1 = (1.007\ t - 0.026) + w_1\ (2501 + 1.84\ t)$

$= (1.007*21 - 0.026) + 0.008084(2501 + 1.84*21) = 41.5$kJ/kg dry air.

a. $W_2 = w_1 + m_w = 0.008084 + 0.002 = 0.010084$kg/kg dry air
b. $h_2 = h_1 + (w_2 - w_1)h_3$
   $h_3 = 419.04$kJ/kg for water at 100°C from table.
   $h_2 = 41.5 + (0.010084 - 0.008084) * 419.04 = 42.33$kJ/kg dry air.
c. $h_2 = (1.007\ t_2 - 0.026) + w_2\ (2501 + 1.84\ t_2)$
d. $42.33 = (1.007\ t_2 - 0.026) + 0.010084 * (2501 + 1.84\ t_2)$
   $t_2 = 16.7$°C.



Notes: Three possibilities exist for humidification with water injection:

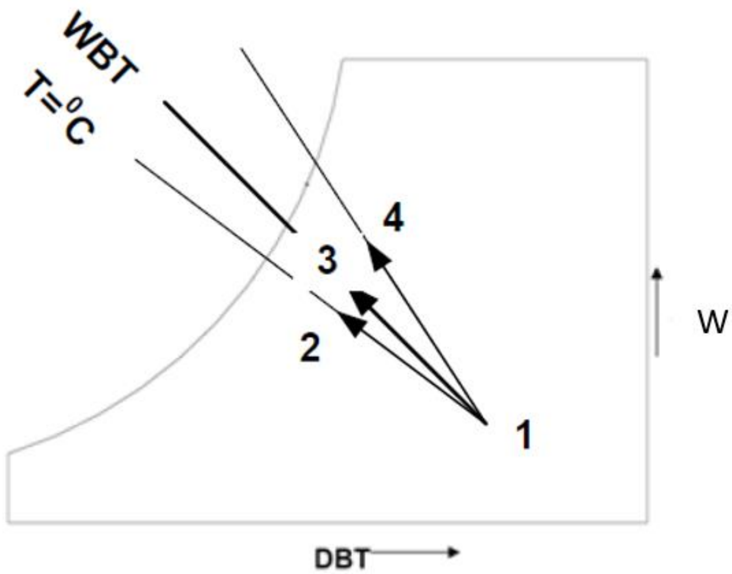
a. If water is at t=0°C, $[h_f|_{0°c}=0]$.

   $h_2=h_1+(w_2-w_1)*h_f$

   $\therefore h_2=h_1$, and the process follows a constant enthalpy line.

b. If the water temperature = air wet bulb temperature, the process follows a constant wet bulb temperature line.

c. If as in the example above the water temperature=100°C, the process follows line (t_w=100°C).



Note: for steam injection, dry bulb temperature is normally constant or very slightly increases. (minimum steam temperature is 100°C), and unless the steam is highly superheated the process can usually be considered a constant dry bulb temperature process. Enthalpy always increases.