5-Humidification:

By this process the moisture content of air is increased.

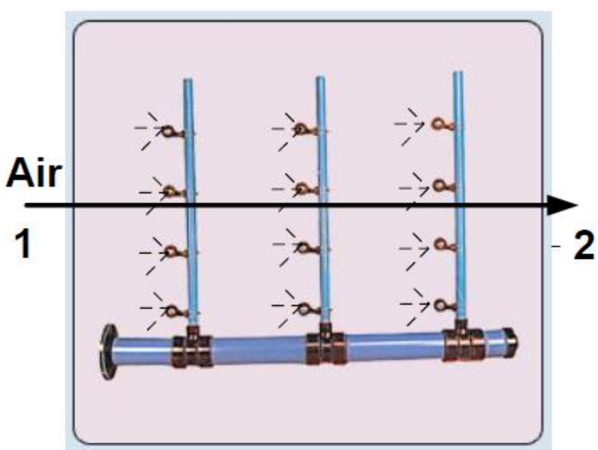
Humidification is used with heating process since in such situations heating is only sensible and the air becomes dry, therefore additional moisture is required.

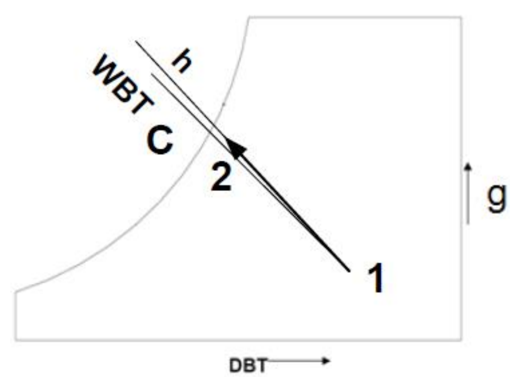
Humidification is done by humidifier either by:

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.

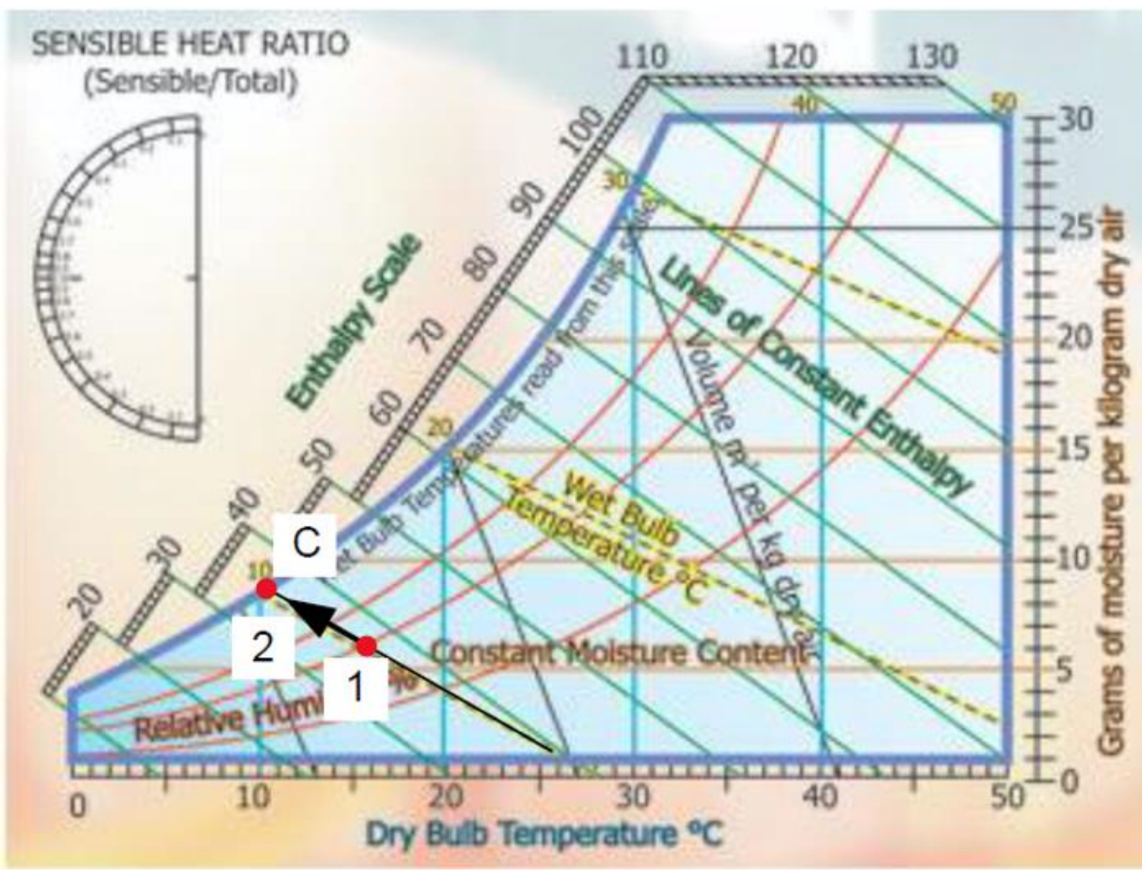
The rate of makeup water = $\dot{m}_a(W_2 - W_1)$

$\upsilon_1 = 0.824 m^3/kg$

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

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

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



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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.

∴ 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:

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

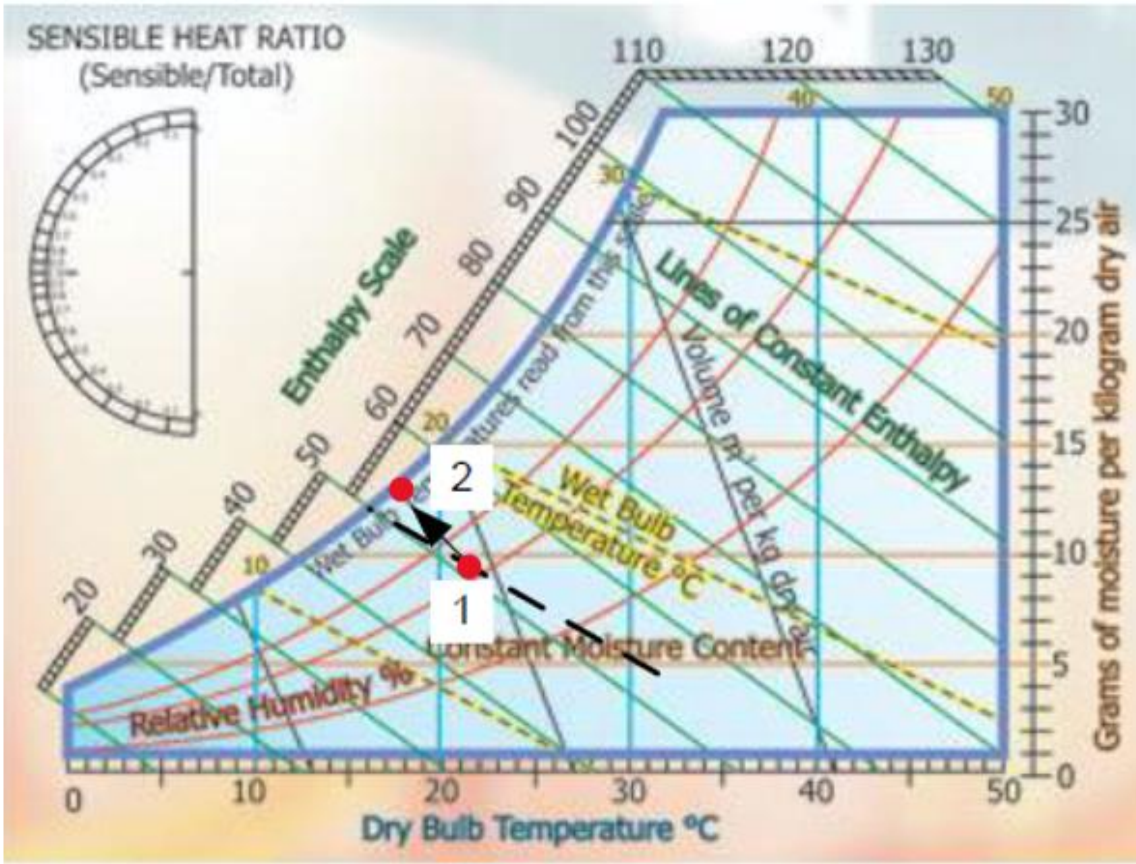
$=1.7051-101.325*6.66*10^{-4}(21-15)=1.3kP_a$

$W_1=0.622\frac{P_1}{P_B-P_1}=0.622*\frac{1.3}{101.325-1.3}=0.008084$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=419.04kJ/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:

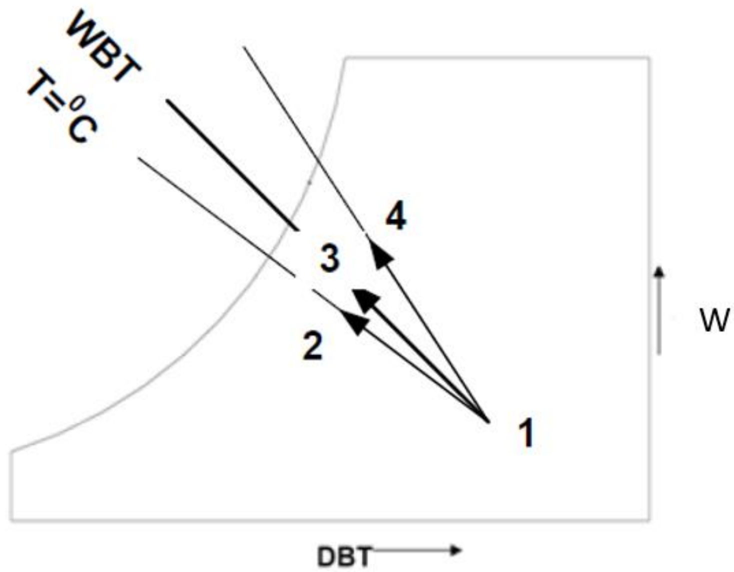
a. If water is at t=0°C, [$h_f|_{0°c}=0$].

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

$\therefore h_2=h_1$, 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.

Water injection.

The simplest case to consider and one that provides the moist insight into change of state of the air stream subjected to humidification by the injection of water is where ***all the injected water is evaporated***. The following figure shows what happens when total evaporation occur, air enters a spray chamber, all injected water being evaporated, no falling to the bottom of the chamber to run to waste or to be circulated. The feed water temperature is important to release that since total evaporation has occurred. State 2, 3 and 4 must be lie nearer to the saturation curve, but just how nearer will depend on the amount of water injected. Two equations, a heat balance and mass balance, provide the answer required:

$h_1+h_w=h_2$

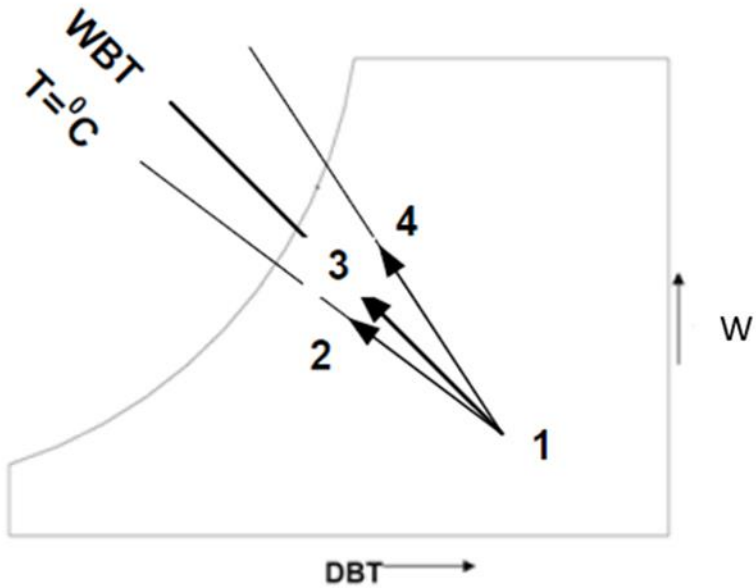
$m_{a1}+m_w=m_2$

$W_2=m_a+m_w$ the associated kg of dry air be ignored.

m_w: the amount of feed water in kgw/kga flowing through the spray chamber.

Applying the heat balance:

$h_1+h_w=h_2=(1.007DBT_2 -0.026) + W_2(2501 +1.84DBT_2)$



humidification by water injection

Humidification by steam injection

Steam injection may be dealt with by consideration at a mass and energy balance.

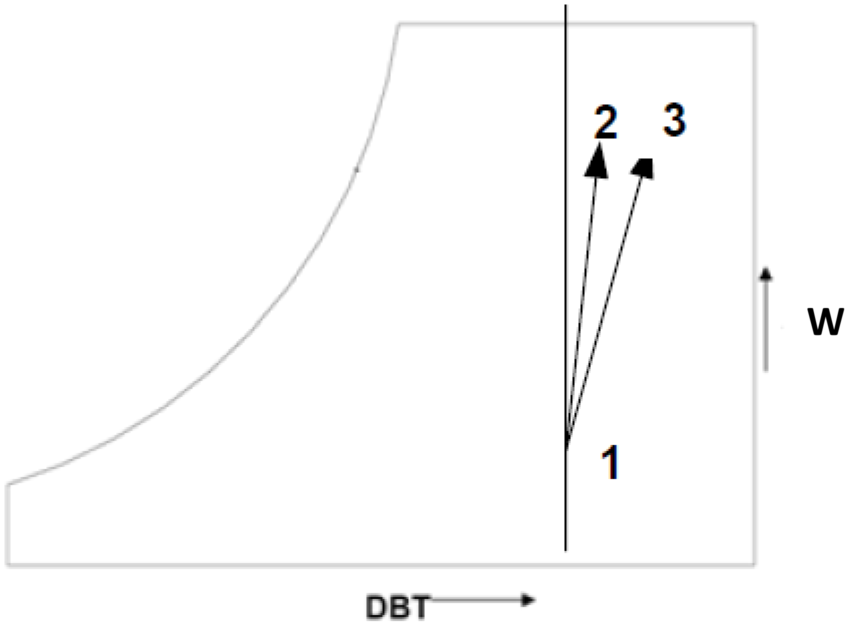
$W_2 = W_1 + m_s$

m_s: mass of steam injected in kg into one kg/s of dry air stream.

$h_2 = h_1 + m_s h_s$

The change of state takes place almost along a line of constant DBT between limits defined by smallest and largest enthalpies of injected steam, provided the steam is in dry saturated condition. The following figure shows the possibility of steam injection.

The lowest possible enthalpy is for dry saturated steam at 100° C, the other extreme is provided by the steam which has maximum enthalpy at 2804.2 kJ/kg, which is exist at 30 bar and 233.9° C.



Example 1:

Dry saturated steam at 100° C is injected at a rate of 0.01 kg/s into a moist airstream moving at a rate of 1 kg of dry air per second and initially at a state of 28° C DBT, 12° C WBT and 101.325 kPa. barometric pressure. Calculate the leaving state of moist airstream.

Solution:

from the psychrometric chart h1=33.2 kJ/kg W_1=2.1 gw/kga

hg=2676.1 kJ/kg from table at (100°C and 101.325 kPa).

W_2=2.1gw/kg d.a+(10gw/s /1kg d.a/s)=12.1gw/kga =0.0121kgw/kg d.a.

h2=33.2+0.0121x2676.1=65.58kJ/kg

65.58=(1.007 DBT2-0.026) + 0.0121(2501+1.84DBT2)

DBT2=34.34° C

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Example 2:

Dry saturated steam with maximum enthalpy is injected at a rate of 0.01 kgw/s into a moist air stream moving at a rate of 1 kg of dry air per second and initially at a state of 28° C DBT, 12° C WBT and 101.325 kPa barometric pressure. Calculate the leaving state of moist airstream.

Solution:

From the psychometric chart h1=33.2 kJ/kg W_1=2.1g/kga, the maximum enthalpy of steam is 2804.2 kJ/kg at 30 bar and 233.9° C saturated.

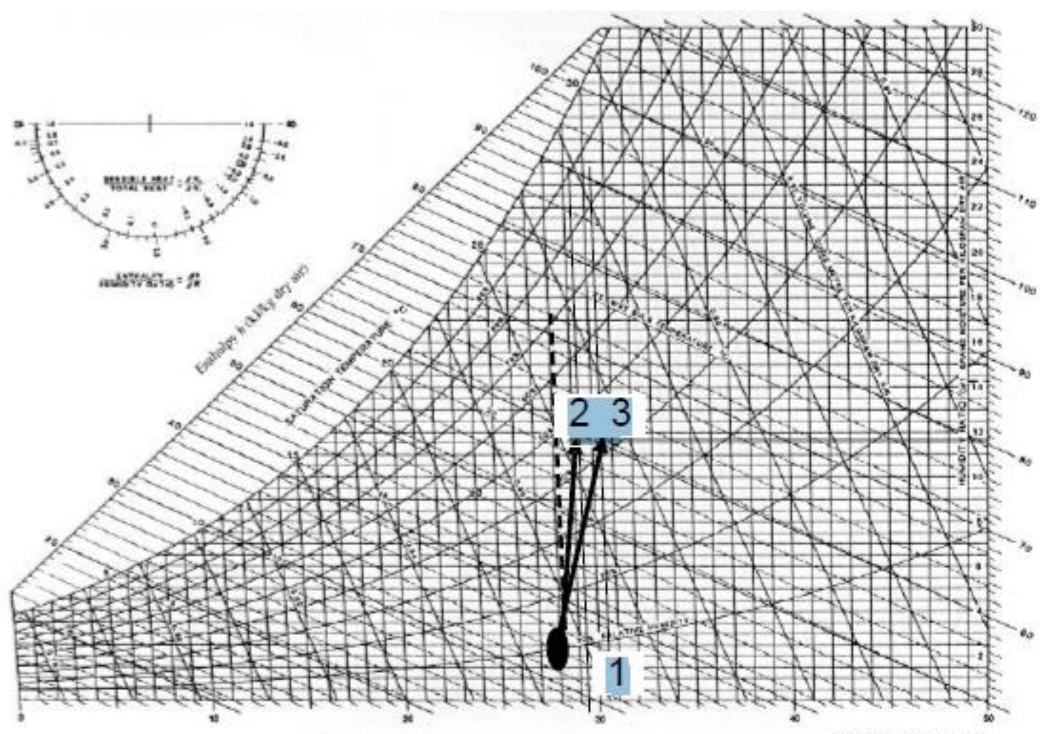
$W_3 = W_1 + 0.01kgw/s /1kg/s =0.0021+0.01=0.0121kgw/kg$ d.a

$h_3 = h_1 + W_3 * h_g$

h3=33.2+0.0121x2804.2=67.13kJ/kg

67.13=(1.007DBT3-0.026)+0.0121(2501+1.84DBT3) DBT3=35.84°C.

It can be seen from examples 1 and 2 for the range of states considered, the change in DBT is not very great, so, we can conclude that, the change of state following **steam injection is up a line of constant Dry Bulb Temperature.**



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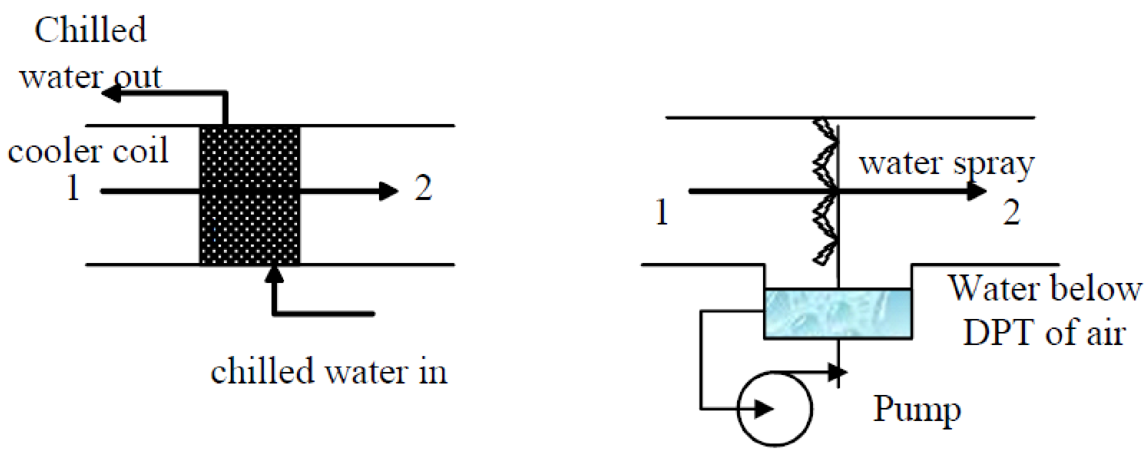
1- Dehumidification:

Removal of excess moisture from air, usually associated with air cooling applications.

Four ways to dehumidify:

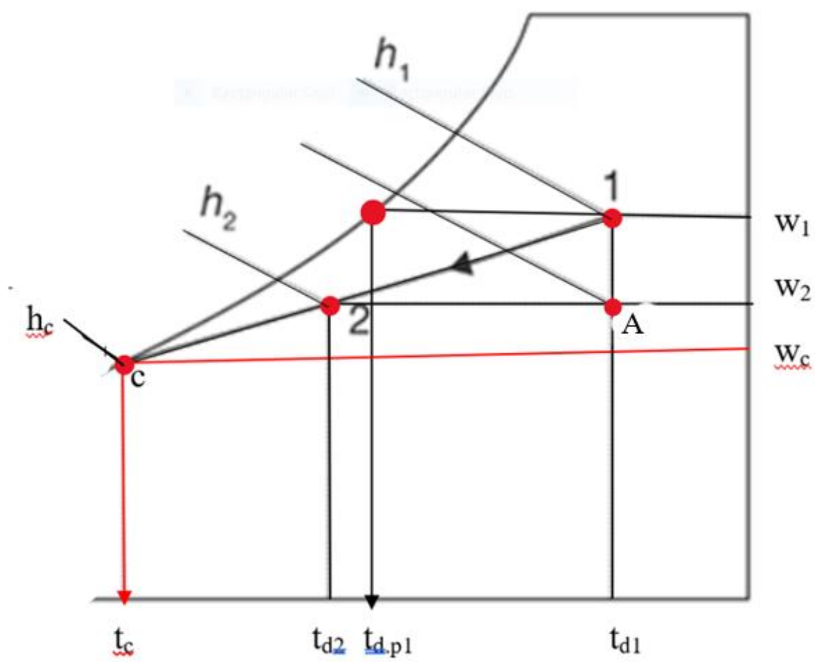
1. Cooling the air to a temperature below the dew point temperature.
2. Adsorption into a solid without phase change.
3. Absorption into solid or liquid usually with chemical change.
4. Compression followed by cooling to a temperature below the dew point.

   The first method is most common to air conditioning (A/C). It is the required matter for this section. It is accomplished by passing moist air over a cooling coil or through an air washer whose spray water is chilled as shown in the figure below.



Cooling to a temperature below the dew point

The figure below shows a sketch of psychrometric chart what happens when moist air is cooled and dehumidified. Since dehumidification is the aim, some of spray water or same part of cooler coil, must be at a temperature less than dew point temperature of the air entering equipment.



- The air is initially at t_{d1}, w_1, h_1 & dew point temperature $t_{d.p1}$. for dehumidification, coil surface or washer temperature must be less than dew point temperature say (t_c).

t_c – is generally called the Apparatus dew point temperature [(adp) temp.]. This term is use for both coils and washer, but in the case of coil alone, tc is the mean coil surface temperature.

- If state (2) is the outlet condition, the (adp) is obtained by extending process (1---2) to intersect the saturation curve line.

State (2) is the outlet condition and is usually not on the saturation line since the equipment is never 100% efficient.

- This process cools & dehumidifies the air, the temperature drops from [t_{d1} to t_{d2}], moisture content decreases from [w_1 to w_2], enthalpy decreases from [h_1 to h_2].
- The efficiency of a cooling & dehumidifying coil is measured by the [CONTACT] or [BY PASS FACTOR] (B.F].

Bypass factor [B.F]:is a measure of the percentage of air that does not come in contact with the coil surface.

Contact factor = 1-B.F

From the chart. B.F=$\frac{h_2-h_c}{h_1-h_c}=\frac{w_2-w_c}{w_1-w_c}$

It is generally defined in terms of d.b. temperature. B.F=$\frac{t_2-t_c}{t_1-t_c}$ or

(1-B.F)= $\frac{t_1-t_2}{t_1-t_c}$

The process is achieved at both sensible (process A-2) and latent heat (process 1-A) rejection, as follows:

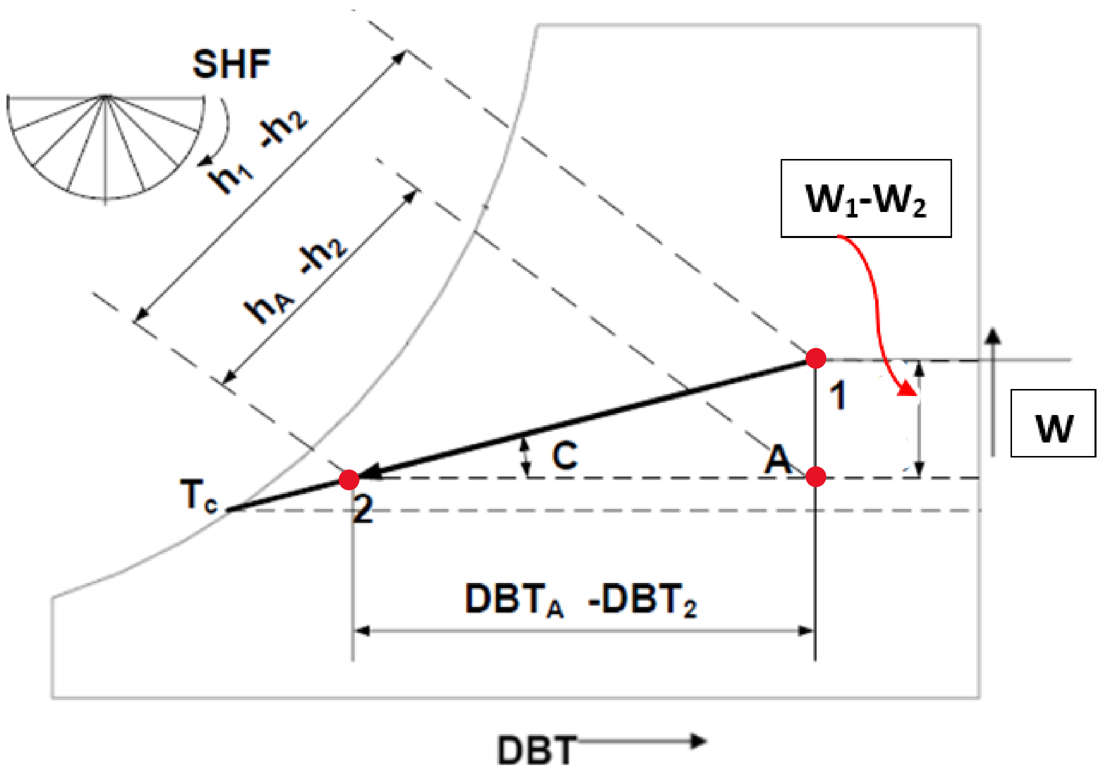
$Q_{s(A-2)}=\dot{m}_a(h_A-h_2)=\dot{m}_a C_{pa}(DBT_A-DBT_2)$

$Q_{l(1-A)}=\dot{m}_a(h_1-h_A)=\dot{m}_a h_{fg}(W_1-W_2)$, as $W_A=W_2$

By separating the total heat transfer rate from the cooling coil into sensible and latent heat tr ansfer rates, a useful parameter called Sensible Heat Factor (SHF) is defined. SHF is defined as the ratio of sensible to total heat transfer rate (as previously mentioned):

SHR=$\frac{Q_s}{Q_s+Q_l}=\frac{Q_s}{Q_T}$

From the above equation, one can deduce that a SHF of 1.0 corresponds to no latent heat transfer and a SHF of 0 corresponds to no sensible heat transfer. A SHF of 0.75 to 0.80 is quite common in air conditioning systems in a normal dry climate. A lower value of SHF, say 0.6, implies a high latent heat load such as that occurs in a humid climate.



The Sensible Heat Factor (SHF)

From the figure above, the slope of the process line 1-2 is given by:

$$\tan (c) = \frac{Q_l}{Q_s} = \frac{\dot{m}_a h_{fg}.(W_1 - W_2)}{\dot{m}_a.c_{pa}.(DBT_A - DBT_2)} = \frac{\dot{m}_a.\ 2501\ (W_1 - W_2)}{\dot{m}_a 1.007 (DBT_A - DBT_2)}$$

$$\tan (c) = \frac{Q_l}{Q_s} = 2483.614\ \frac{(W_1 - W_2)}{(DBT_A - DBT_2)}$$

Thus, we can see that the slope of the cooling and de-humidification line is purely a function of the sensible heat factor, SHF. Hence, we can draw the cooling and dehumidification line on psychrometric chart if the initial state and the SHF are known. In some standard psychrometric charts, a protractor with different values of SHF is provided. The process line is drawn through the initial state point and in parallel to the given SHF line from the protractor as shown in Figure above.

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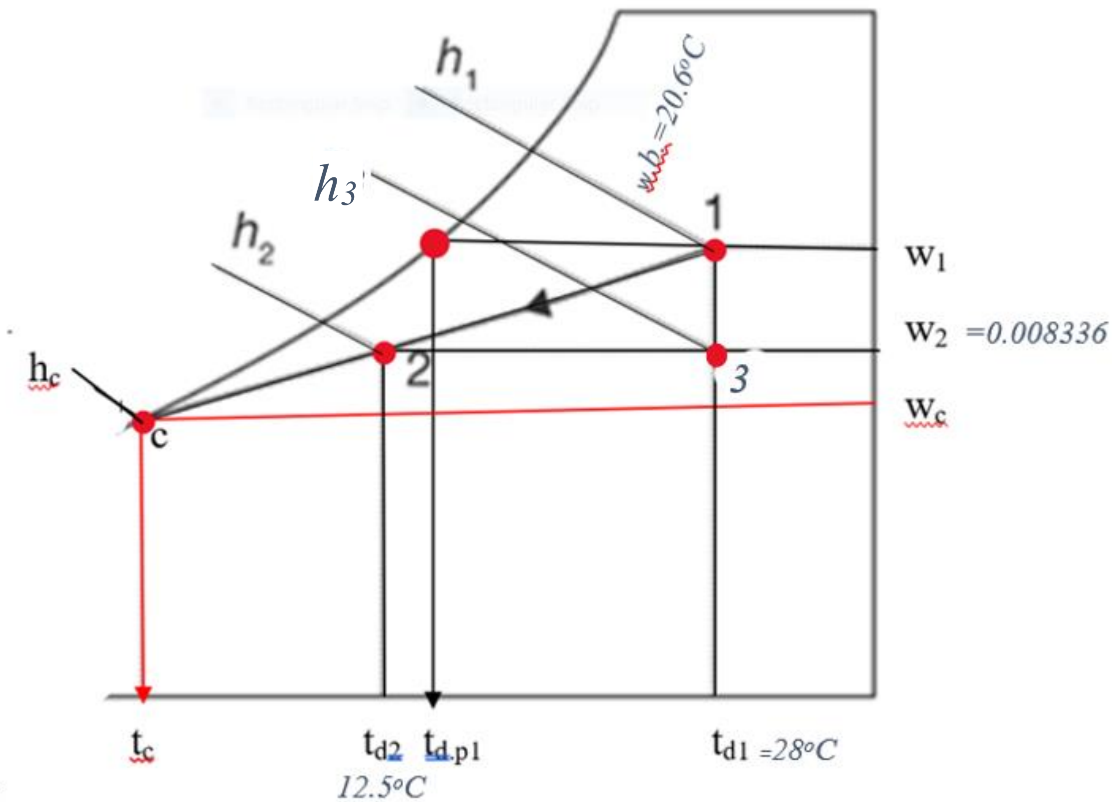
e.g: 1.5m^3 of air at 28°C d.b. & 20.6°C w.b. and standard atmospheric pressure flows across a cooling coil and leaves the coil at 12.5°C d.b. and 0.008336kg/kg dry air moisture content. determine: a) adp. b)B.F c) the cooling load.

Solution:



a) On the chart locate points (1 & 2) and extend the line until it intersects the saturation line, read:

   adp $=t_c=10.25$°C.

b) B.F$=\frac{t_2-t_c}{t_1-t_c}=\frac{12.5-10.25}{28-10.25}=0.126$

   Contact factor=1-0.126=0.874=$\eta_{cooling\ coil}$.

c) Cooling load $=\dot{m}(h_1-h_2)$

   From chart: h_1=59.1kJ/kg.----- h_2=33.6kJ/kg.

$\dot{m} = \frac{V}{\upsilon}$,v =1.5m³/sec. (given), υ_1=0.87m³/kg (from chart).

$\therefore$ cooling load=$\frac{1.5}{0.87}(59.1 - 33.6) = 43.965$kJ/sec (kW).

Also: cooling load=sensible heat + latent heat

$$=\dot{m}(h_3 - h_2) + \dot{m}(h_1 - h_3)$$

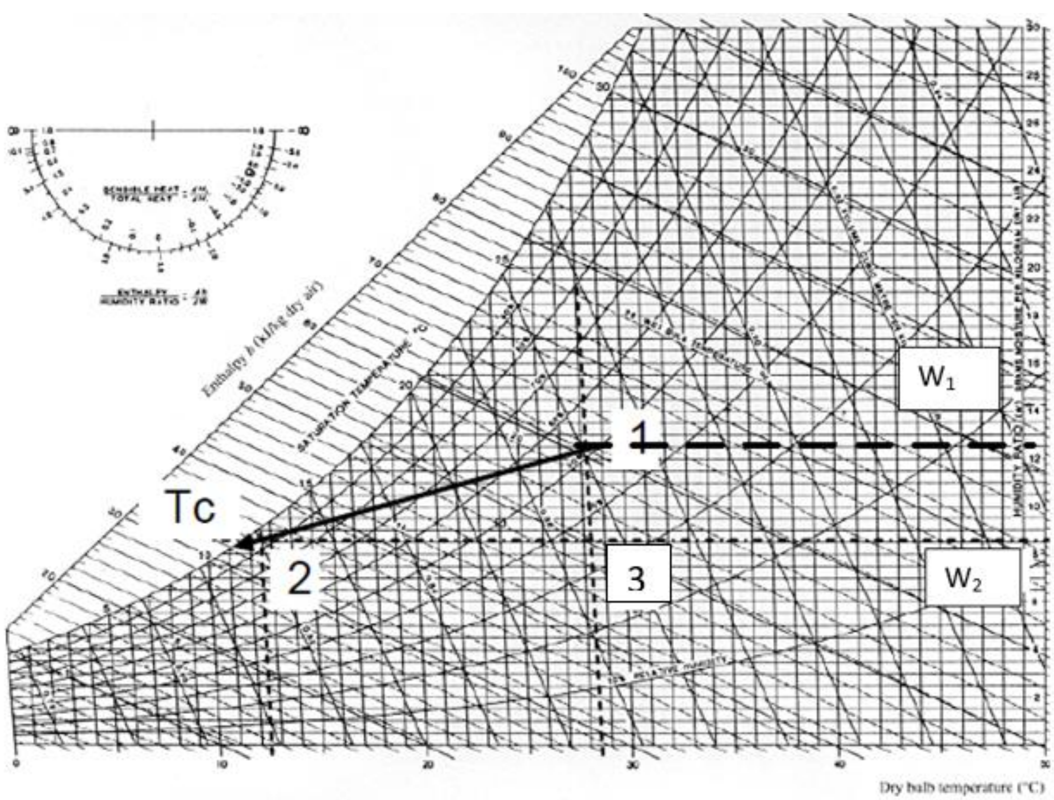
$$= \dot{m}(h_1 - h_2)$$

Or, read h_3 from chart at intersection of vertical line from point (1) and horizontal line from point (2). [h_3=48.7kJ/kg].

Sensible load = $\frac{1.5}{0.87}(48.7 - 33.6) = 26.034$kJ/sec. (kw).

latent load = $(43.965 - 26.034) = 17.93$kJ/sec. (kw).

Or, latent load = $\frac{1.5}{0.87}(59.1 - 48.7) = 17.931$kJ/sec. (kw).



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