

# PSYCHROMETRY

(The study of gas mixtures including a condensable gas.)

In this case we will be looking exclusively at steam & air but the principles apply generally

## Revision of First Year Work

*Gibbs Dalton Law:*

In a mixture of gases a property of any constituent is that which would be measured if that constituent alone occupied the volume of the mixture. It follows that a property of the mixture is the sum of the corresponding properties of the constituents.

$$\text{i.e. } H_{mix} = m_A h_A + m_B h_B + m_C h_C + \text{etc}$$

$$p_{mix} = p_A + p_B + p_C + \text{etc}$$

$p_A, p_B$  are the **partial pressures** of the constituents A, B etc.

*Avogadro's Law:*

Equal volumes of any gas at the same temperature and pressure have the same number of gas molecules.

This led us to the Universal gas Equation:

$$pV = n\bar{R}T$$

where  $n$  = number of molecules (in kmols) and

$R$  = Universal gas constant

*Molar Mass (or Relative Molecular Mass)*

The mass in kg of a fixed number of molecules of a substance (relative to carbon 12)

$$n(\text{kmol}) = \frac{m(\text{kg})}{M(\text{kg/kmol})}$$

e.g. Molar mass of  $N_2$  is 28 kg/kmol

In the following we will consider dry air as a homogeneous gas with properties derived from its constituents.

Air means **dry air!** (See *Haywood* Table 2)

In considering air/steam mixtures we begin with a definition:

In a given volume of mixture the ratio of the mass of steam to mass of dry air is known as the **moisture content** or **absolute humidity**. ( $w$ )

$$W = \frac{m_s}{m_{air}}$$

We shall determine the properties of the mixture for different values of  $w$ .

Note that the **temperature** of each constituent in a mixture must be the same!

From G-D the total **pressure** of the mixture (that which we can measure using a pressure gauge or manometer) is the sum of the partial pressures of the constituents.

$$P_{mix} = P_{air} + P_s$$

For ambient atmospheric air,  $P_{mix} = P_{barometric}$  ;

For pressure in a condenser,  $P_{mix} = P_{condenser}$ .

## Enthalpy of an air/steam mixture.

From G-D:

$$H_{mix} = m_a h_a + m_s h_s$$

$$= m_a (h_a + w h_s)$$

or  $\frac{H_{mix}}{m_a} = \boxed{h_{mix} = h_a + w h_s}$

Note that the specific enthalpy of the mixture is expressed per kilogram of **dry air**. All of the properties of air/steam mixtures are expressed this way.

We take as our datum temperature: 0°C

If the temperature of the mixture is t°C then :

$$h_a = c_p t$$

In order to find  $h_s$  we need to use steam tables, but before we can do that we need to find the steam (partial) pressure.

From the Universal gas equation:-

$$p_s V_{mix} = n_s \bar{R} T$$

$$\& p_{mix} V_{mix} = n_{mix} \bar{R} T$$

$$\backslash \quad p_s = \frac{n_s}{n_{mix}} p_{mix} = \frac{n_s}{n_s + n_{air}} p_{mix} \quad (i)$$

but  $w = \frac{m_s}{m_{air}} = \frac{n_s M_s}{n_{air} M_{air}} \quad (ii)$

From (i) & (ii):

$$\boxed{p_s = \frac{1}{1 + \frac{18}{29w}} p_{mix}}$$

Example: air at 25°C and 1.47% moisture content.  
( $w = 0.0147$ )

$$p_s = \frac{1}{1 + \frac{18}{29 \cdot 0.0147}} 101.325 = 2.340 \text{ kPa}$$

From steam tables the specific enthalpy of steam @ 2.340 kPa and 25°C is 2547.7 kJ/kg.  $h_s \approx h_g + 1.9(t - t_{sat}) \text{ kJ/kg}$

$$h = 1.010 \cdot 25 + 0.0147 \cdot 2547.7 = 62.7 \text{ kJ/kgda}$$

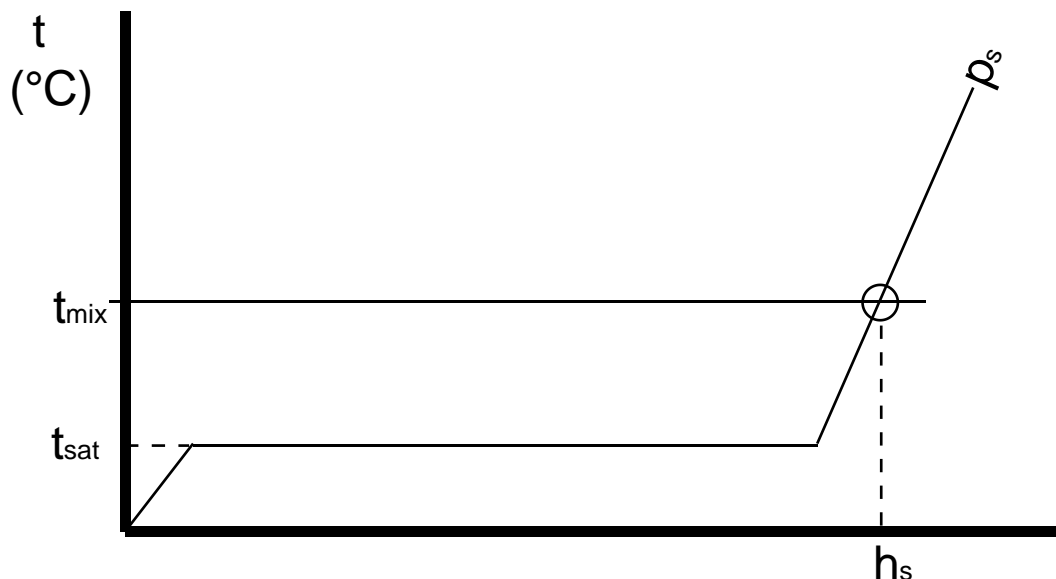
Other mixture properties are found in a similar way, e.g.

**specific volume :**  $v = v_{air} + W v_s$

**sp. int. energy :**  $u = u_{air} + W u_s$

Using the above methods it is possible to obtain the mixture properties. However, two matters remain unresolved:-

- \* we have assumed the steam is superheated - what happens when it becomes saturated?
- \* how do we determine  $w$ ?



## The Psychrometric chart

The saturation temperature of the steam determines a lower limit down to which the steam remains steam. **At** the saturation temperature the steam is saturated steam with properties obtainable from the steam saturation tables (g).

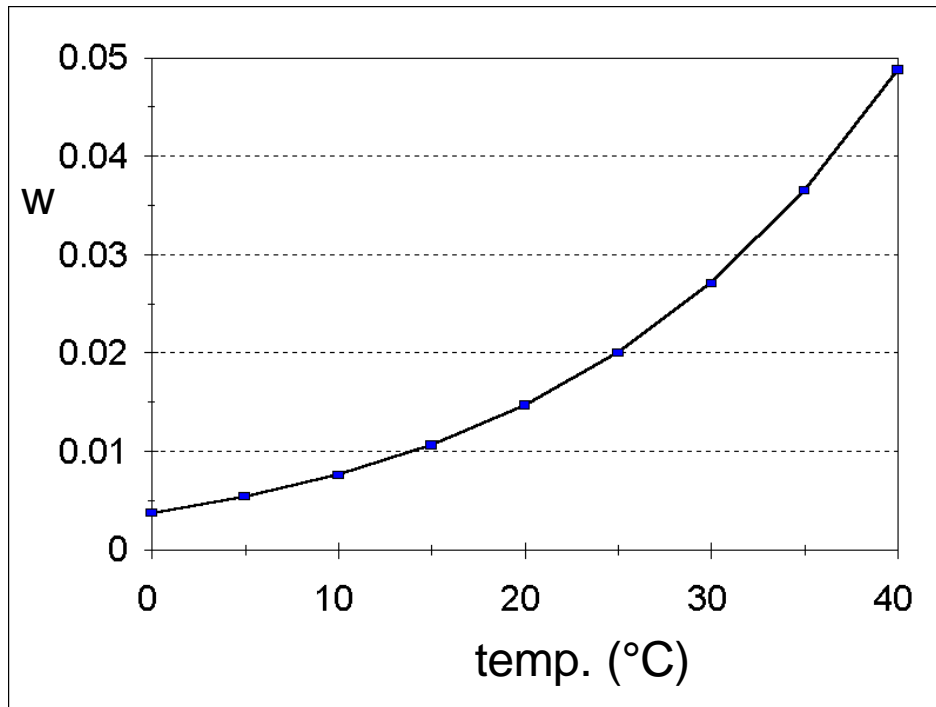
If we cool the mixture to a temperature below the saturation temperature some of the steam precipitates (condenses) to liquid water and hence is no longer part of the air/steam mixture. The remaining steam is still saturated but at the lower temperature.

We can determine limiting values of  $w$  for given temperatures by re-arranging the equation on p.3 and using  $p_{\text{sat}}$  values from the steam tables.

$$w = \frac{18}{29} \frac{p_{\text{mix}}}{p_s} - 1$$

Use SSL value for  $p_{\text{mix}} = 101.325 \text{ kPa}$

$t_{\text{sat}}$	$p_{\text{sat}}$	$w$
0	0.611	0.0038
5	0.874	0.0054
10	1.227	0.0076
15	1.707	0.0106
20	2.34	0.0147
25	3.17	0.0200
30	4.24	0.0271
35	5.63	0.0365
40	7.38	0.0488



The above graph plots the **maximum** amount of steam per kg of air which can exist as a gas mixture at any given temperature.

When the mixture is at this condition it is described as 100% saturated. Clearly, at any given temperature, air can be mixed with a lower proportion of steam than the maximum. Conditions below the 100% saturated condition can be shown simply by proportioning the ordinate at 10%, 25% etc. giving the **percentage saturation** of the air/steam mixture at any condition.

$$\text{percentage saturation } (\gamma) = \frac{W}{W_{\max}}$$

Since the above chart defines the mixture conditions it is also possible to superimpose other property values. In particular,  $h$  &  $v$ . The resulting chart is known as the **psychrometric chart**.

Note: In older texts the term **relative humidity** is used.  
 Relative humidity (f) is defined as:-

$$f = \frac{p_s}{p_{s(sat)}}$$

$$y = \frac{W}{W_{sat}} = \frac{\frac{p_{mix}}{p_s} - 1}{\frac{p_{s(sat)}}{p_s} - 1}$$

If  $p_{mix} = 101.325$  &  $p_s$  @ 0.7 to 7 kPa,  $\frac{p_{mix}}{p_s} \gg 1$

$$\backslash \quad \frac{W}{W_{sat}} \gg \frac{p_s}{p_{s(sat)}}$$

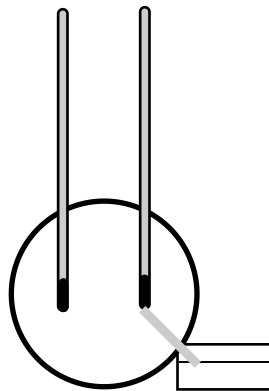
For most practical purposes (at atmospheric pressure) *percentage saturation* and *relative humidity* can be regarded as interchangeable.

## ***Determination of moisture content***

Moisture content or percentage saturation is found using a wet & dry bulb thermometer (***psychrometer***)

In its simplest form a psychrometer consists of two thermometers one of which has its bulb wetted (usually by a wick with one end immersed in water).

The air whose '%sat' we wish to measure is caused to flow over both (wet & dry) bulbs of the psychrometer.

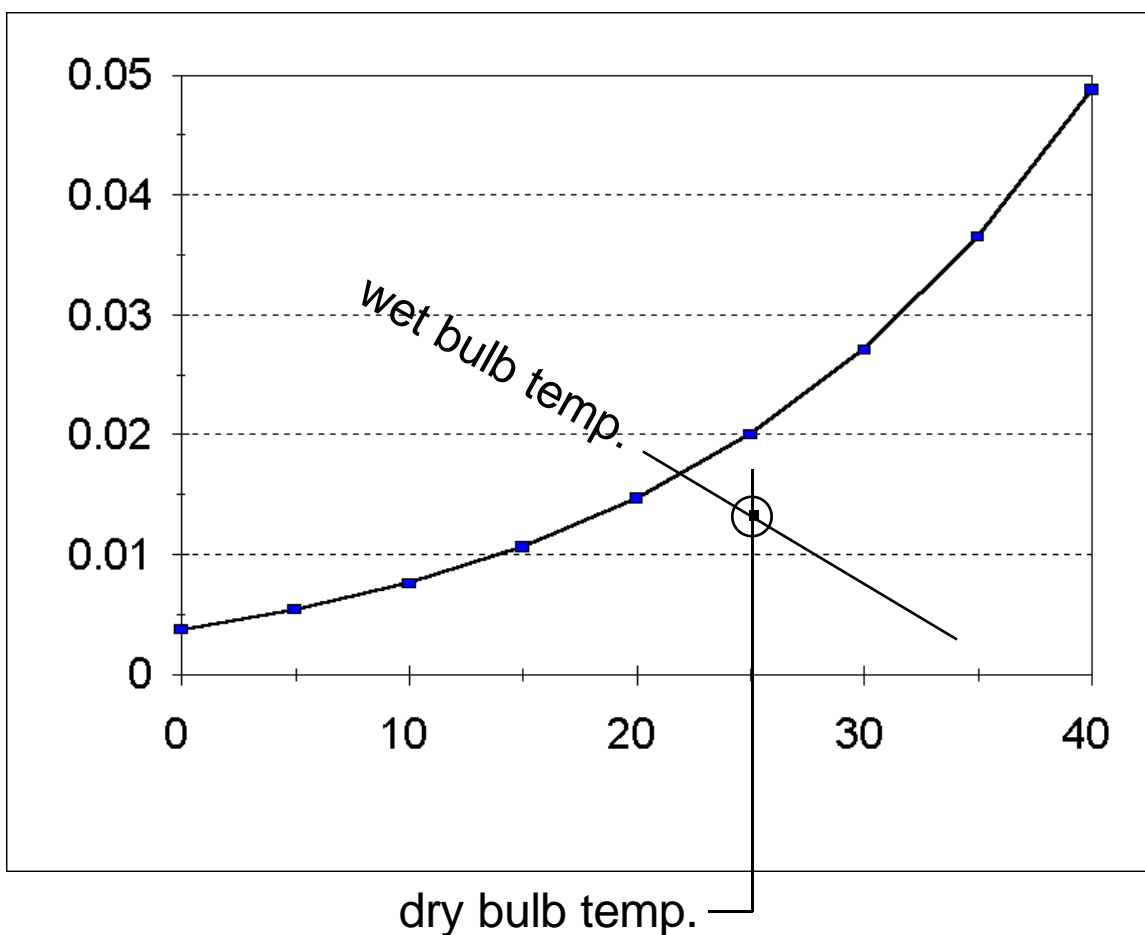


The dry bulb will register the ordinary air temperature. The wet bulb behaviour depends upon the extent to which the air/steam mixture is saturated, i.e. its % saturation.

- ~ if the mixture is 100% saturated no evaporation of the water wetting the wet bulb can occur - it will therefore register the same temperature as the dry bulb.
- ~ if the mixture is 0% saturated (i.e. dry) it will cause maximum evaporation from the wet bulb. The enthalpy of evaporation will be drawn from the remaining water depressing its temperature. An equilibrium situation will occur when the heat and mass transfer rates stabilise.
- ~if the mixture is between 0 & 100%, the wet bulb will register an intermediate depression.

The wet bulb temperature (or more accurately the wet bulb depression) is a function of the percentage saturation of the air/steam mixture.

It is therefore possible to plot lines of **constant wet bulb temperature** on a psychrometric chart, and use these, in conjunction with the psychrometer readings, to determine the condition of the air.



The process of evaporation of liquid water into an airstream is very close to adiabatic, hence the lines of constant wet bulb temperature are very close to the constant enthalpy lines. To avoid confusion, the enthalpy scale is confined to the edges of the chart.