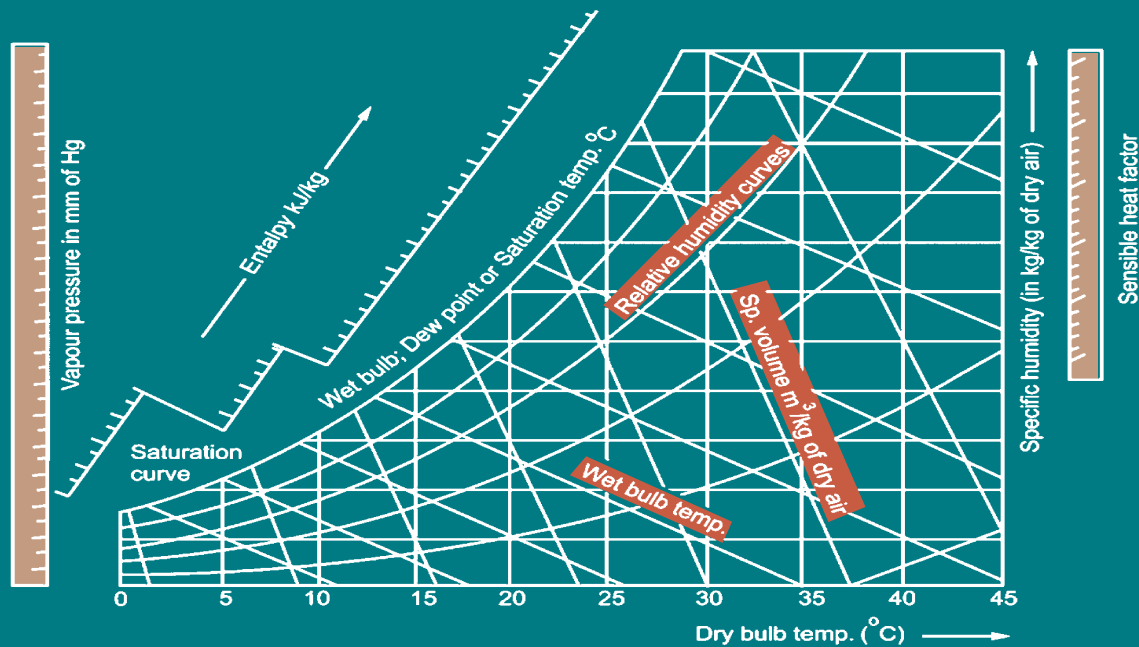


Part 3



Understanding Psychrometrics

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 Supported by **Mukund Ranade**, AC Consultant

Introduction

In Parts I and II, we covered the properties of moist air, the relevant laws, and the formulae for sensible, latent, and total heat calculations. We'll now deal with the properties of air that are typically used and plotted on the psychrometric chart.

Before we begin this part, it is worth noting that psychrometric charts can vary from designer to designer as there is no single standard methodology. The aim of this series is not to create a textbook, but to assist you in easily understanding and plotting various psychrometric processes.

A significant word of caution regarding accuracy is necessary. Psychrometrics does not yield exact arithmetical solutions. In HVAC design, two-digit accuracy is generally acceptable. If designers

About the Authors

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arrive at slightly different numbers, don't be discouraged; being close is being right.

Properties of Air

Let us start with the properties of air indicated on the psychrometric charts.

Ability of Air to Hold Moisture

High temperature air has more ability to hold moisture than low temperature air.

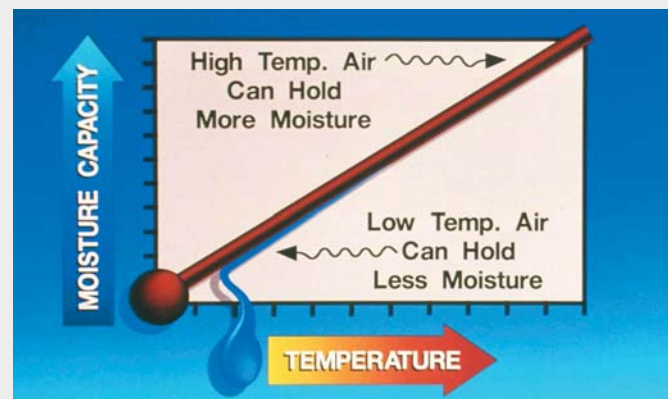


Figure 1: High temperature air can hold more moisture

Saturated and Superheated Air-Vapor Mixtures

In the atmosphere, the air normally carries superheated vapor. When the air is cooled, its ability to hold moisture decreases, and at a certain point the moisture reaches a saturated condition at the same atmospheric pressure. When air and saturated vapor occupy the same volume, the air is frequently called saturated air. Such a statement is in reality incorrect, for actually it is only the water vapor part, which is saturated. Since the term saturated air has been widely accepted in the air conditioning industry, it will be used henceforward with this reservation.

Why moisture is not visible in the atmosphere

Since the pressure exerted by water vapor (P_v) is small, the saturation temperature (or dew point) corresponding to this pressure is less than the atmospheric temperature (or dry-bulb temperature). Therefore, the water vapor in the air normally exists in the superheated state, and the air is said to be unsaturated.

Let us consider an example: The dry-bulb temperature of air is 40°C and the wet-bulb temperature is 24°C . At these conditions, the dew-point temperature is 17°C . Since the dry-bulb temperature is greater than the dew-point or saturation temperature, the moisture exists in superheated form, and hence it is invisible.

Which Air Weighs More – Dry Air or Moist Air?

The barometric level rises on a clear, 'good day,' which means the atmospheric pressure exerted on the mercury surface is greater. This increased pressure indicates the air column weighs more, specifically that dry air is denser (weighs more per m^3). Conversely, as the atmosphere becomes cloudy with moisture and the chance of rain increases, the barometric pressure decreases. This lower pressure indicates that moist air is less dense (weighs less per m^3) than dry air.



Figure 2: Dry air weighs more than wet air

Dry air weighs more than moist air because it is primarily composed of the heavier molecules nitrogen (N_2) and oxygen (O_2).

Dry air mainly consists of nitrogen (molecular weight: 28g/mol) and oxygen (molecular weight: 32g/mol). Moist air contains lighter water vapor (18g/mol) molecules that displace some of the heavier nitrogen and oxygen.

Since water vapor is significantly lighter than both nitrogen and oxygen, introducing it into dry air reduces the overall average

molecular weight of the mixture. Consequently, a lower average molecular weight results in lower density (mass per unit volume). Therefore, a given volume of moist air will have a lower mass than the same volume of dry air.

Measuring Dry Bulb Temperature

Since air is a mixture of dry air and water vapor, it follows that dry bulb temperature is the temperature of not only dry air component but also the temperature of water vapor component. Hence, it is the temperature of moist air in equilibrium.

The dry-bulb temperature usually referred to as air temperature. It is the temperature of air as registered by the ordinary thermometer whose bulb is dry and is freely exposed to atmosphere as also not subjected to radiation or condensation/evaporation of moisture.

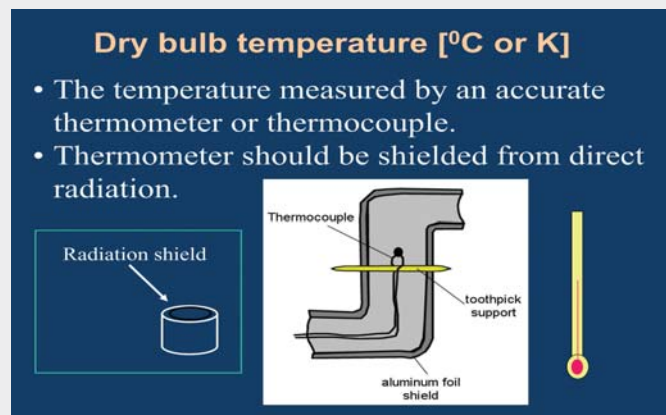


Figure 3: Dry-bulb temperature

The dry-bulb temperature (T_{db}) is the temperature of the air as measured by a standard thermometer whose sensing bulb is dry and shielded from radiation and moisture effects (condensation or evaporation).

Psychrometric Wet Bulb Temperature

The wet-bulb temperature is the temperature measured by a thermometer whose bulb is covered with wetted cotton or wrapped in wet muslin, with the reading stabilized in an air stream. To achieve stabilized conditions quickly, the thermometer

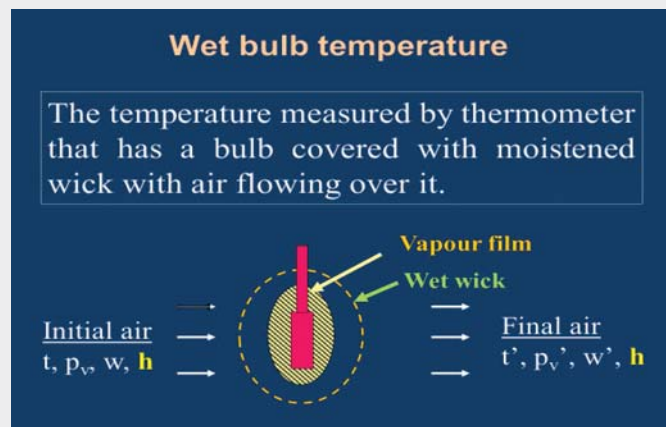


Figure 4: Wet bulb temperature

is moved through the air at a velocity of 3 to 5 m/s. Due to evaporative cooling, the temperature measured with a wet-bulb thermometer is lower than the dry-bulb temperature, except when the air is saturated.

Sling Psychrometer

A device called the sling psychrometer is used for convenience and provides reasonably accurate results. It consists of two thermometers mounted in a frame and attached to a handle by means of a swivel. One thermometer is exposed to the air (the dry bulb), and the second (the wet bulb) has a cotton wick wrapped around its mercury bulb, which is kept wetted. The wet-bulb thermometer is made longer to ensure that when the sling psychrometer is rotated, moisture does not affect the dry-bulb thermometer.

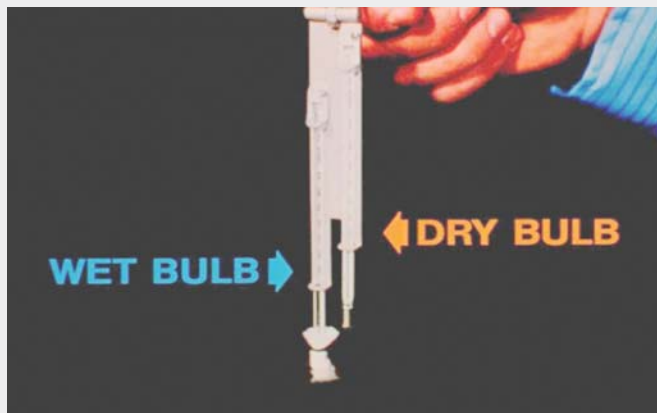


Figure 5: Sling psychrometer

The psychrometric wet-bulb temperature is not, strictly speaking, a thermodynamic property. It is a measurement of what water can do to air when brought into intimate contact and is not the same as the true thermodynamic wet-bulb temperature (or adiabatic saturation temperature).

For any other gas or mixture, these two temperatures would be different. However, for the air-water mixture, they happen to be nearly the same, which often causes confusion, leading to the belief that the psychrometric wet-bulb temperature and the thermodynamic wet-bulb temperature are identical. Nevertheless, for all practical purposes, the measured wet-bulb temperature is taken to be equal to the adiabatic saturation temperature.

The wet-bulb temperature is predominantly used for rating cooling towers, evaporative condensers, evaporative air coolers, air washers, and evaporative humidifiers, as well as for calculating the capacity of cooling coils.

The wet-bulb temperature is always lower than the dry-bulb temperature except when the air is at 100% relative humidity (i.e., at the saturation line), in which case they are identical.

Thermodynamic or Adiabatic Wet Bulb Temperature

It is the saturation temperature to which moist air can be adiabatically (without gain or loss of heat) cooled by evaporation of water at the same (saturation) temperature into moist air.

It means we pass the air through a series of water sprays that use the same water over and over again except for the small amount that may evaporate. This device is called a saturator. As the air goes through the water spray, the temperature of the air drops, because heat is absorbed to evaporate the atomized water. If the sprays are well designed, the air temperature drops down to almost water temperature and this temperature is known as wet bulb temperature.

Realistically, the adiabatic saturator is a theoretical instrument because it must be properly insulated, be very long, & have intimate contact between air and water.

Adiabatic Saturator

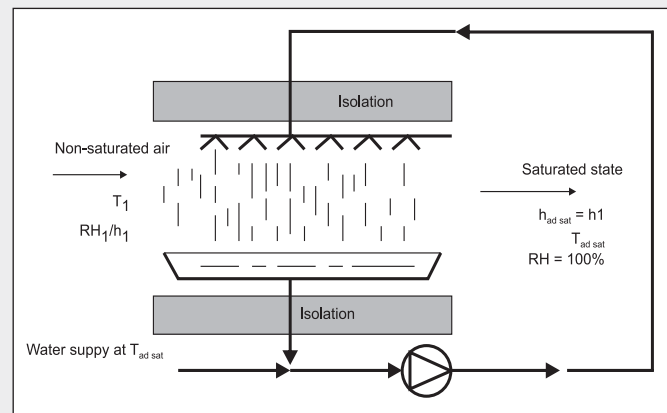


Figure 6: Adiabatic saturator

Since (w^*-w) is very small and h_{fw} is also small $(w^*-w) \times h_{fw}$ can be neglected

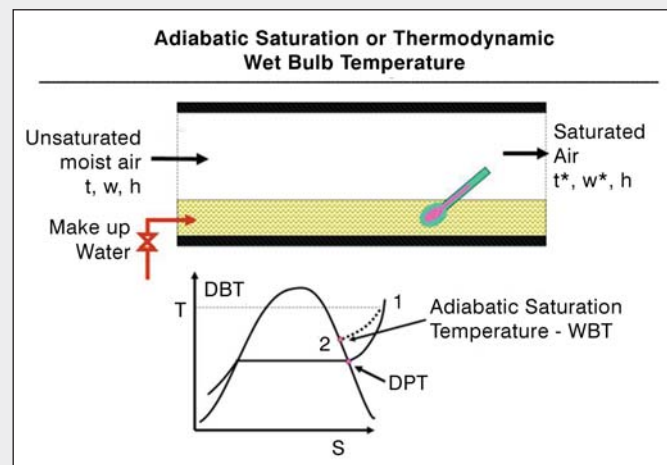


Figure 7: Thermodynamic wet bulb temperature

Therefore $h_1=h_2=h_s$; hence, enthalpy remains constant for any dry bulb temperature for a given wet bulb temperature.

Wet-Bulb Depression

The difference between the dry-bulb and wet-bulb temperatures is known as wet-bulb depression. A higher wet-bulb depression indicates drier air and greater potential for evaporative cooling.

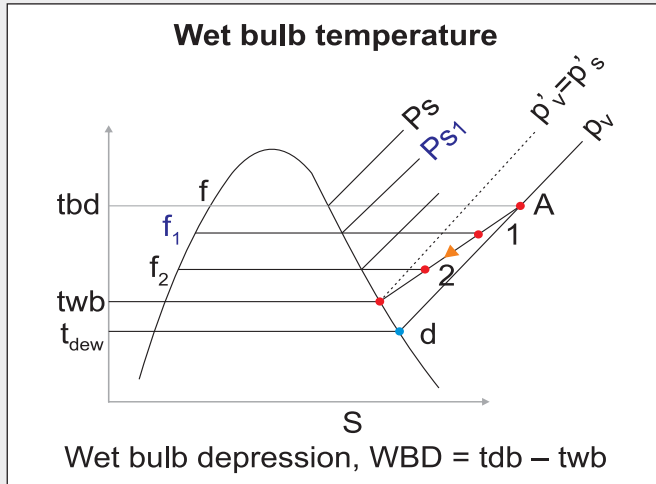


Figure 8: Wet-bulb depression

Humidity Ratio (ω)

Humidity ratio (also known as specific humidity) is kilograms of water vapor per kilogram of dry air (kg/kg). This unit represents the mass of water vapor present in a given mass of dry air.

While the SI unit is kg/kg, you might also encounter it expressed as grams of water vapor per kilogram of dry air (g/kg).

Formula

$\omega = m_v / m_{da}$ where m_v is the mass of water vapor and m_{da} is the mass of dry air.

ASHRAE differentiates between humidity ratio and specific humidity stating that what we normally refer to as specific humidity is in reality a humidity ratio.

Specific Humidity

Humidity ratio is with respect to dry air while specific humidity is with respect to moist air.

Formula

In some contexts, specific humidity is defined as $m_v / (m_v + m_{da})$, where m_v is the mass of water vapor and m_{da} is the mass of dry air.

ASHRAE Fundamentals Chapter 6.2 gives the formula as $kg_{wv} / kg (d_a + w_v)$ the correct definition of specific humidity is mass of water vapor to total mass of air ($m_w / m_w + m_{da}$).

Thus, both terms refer to the amount of moisture in the air, but the humidity ratio focuses on the dry air component while specific humidity considers the total moist air mass. For practical purposes, the difference is often negligible, especially in typical atmospheric conditions. However, at high temperatures and humidities, the distinction can become more noticeable.

Absolute Humidity

Absolute humidity is a measure of the actual amount of water vapor present in the air, regardless of temperature. It is expressed as the mass of water vapor per unit volume of air, typically in grams per cubic meter (g/m^3), according to physics and meteorology resources. Similarly, absolute humidity is the ratio of mass of water vapor to total air volume of the sample: $Mw/v (kg_{wv}/m^3)$.

Unlike relative humidity, absolute humidity does not change with temperature. It reflects the actual amount of water vapor present.

Example

If you have 7 grams of water vapor in 2 cubic meters of air, the absolute humidity is $3.5 g/m^3$.

Significance

While scientifically accurate, it is less commonly used in everyday language compared to relative humidity. *Specific (correctly speaking: humidity ratio) Humidity Scale.*

'Y' axis represents specific humidity i.e. amount of water vapor mixed with each kilogram of dry air. This scale is read in grams of water vapor per kilogram of dry air at standard atmosphere or g/kg of dry air.

Dew Point Temperature

It is the temperature at which water vapor in the air just starts to condense, when air is cooled.

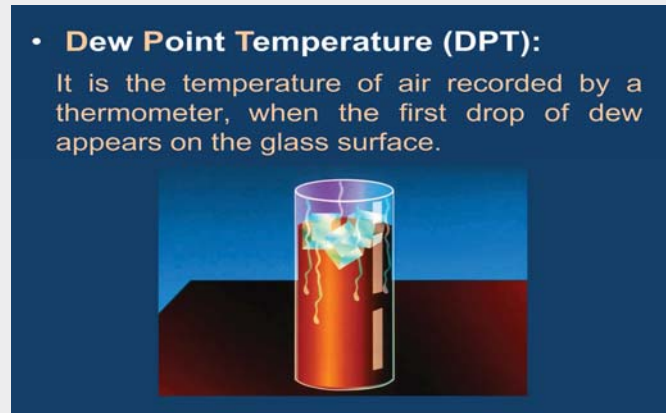


Figure 9: Dew point temperature

Carrier Training Module Definition

Dew point temperature is the temperature at which the vapor phase of a substance will be saturated without change in pressure, i.e., the saturation temperature corresponding to the actual vapor pressure. Dew point temperature of vapor and saturation temperature of vapor are synonymous. Since the temperature of saturated vapor is

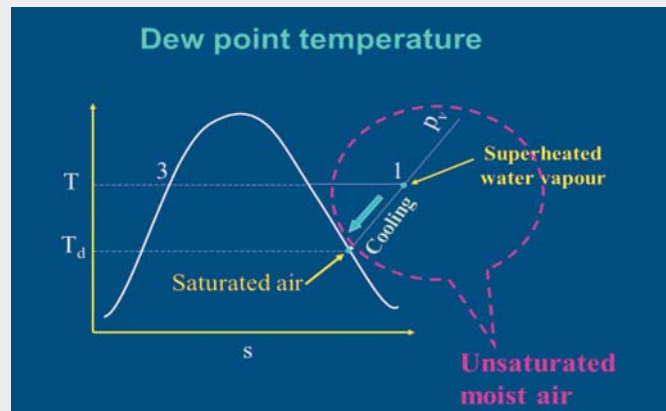


Figure 10: Saturation line

dependent only on the absolute pressure, the dew point temperature is simply the saturation temperature corresponding to the partial pressure of the vapor in air-vapor mixture.

Technically, the temperature at which frost forms is called frost-point temperature. In this text however, they will both be called dew-point temperature.

Dew Point and Saturation Line

When the air is cooled, at first, only temperature is reduced, no water vapor is removed until the air reaches its point of maximum humidity. Any further cooling will cause some water vapor to condense as the ability of air to retain moisture decreases as the temperature is reduced. The temperature at which the moisture content or relative humidity has reached 100% is called the dew point. A line, which connects these points and other 100% saturation points is called saturation line, which is the same as 100% relative humidity line. The dew point temperature of air depends upon the amount of water vapor present and is found on the chart by moving horizontally over to the saturation curve and reading temperature there.

Measuring Dew-point Temperature

A dew-point hygrometer utilizes a temperature-controlled, highly polished observable surface. In the instrument's simplest form, crushed ice is slowly added to a liquid in a thin-walled silver container. An accurate mercury bulb thermometer is used to constantly stir the liquid in the cup. When the first sign of condensation (dew) is observed on the outside of the cup, the temperature of the liquid in the cup is read as the dew-point temperature. This method requires that the temperature of the outside surface of the silver cup and the temperature of the liquid in the cup be essentially the same. In actual practice, the temperature of the liquid in the cup will be slightly lower than the outside surface temperature of the cup.

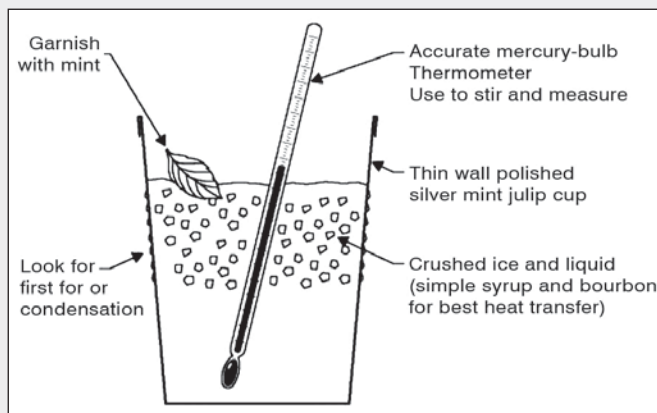


Figure 11: Dew-point hygrometer

The use of these values is made to take decisions as to what should be the maximum relative humidity inside the premises without moisture condensation on windows during winter, or whether the duct running inside the air-conditioned space needs insulation.

- In the absence of rain, the dew-point temperature is generally constant within $\pm 1^\circ\text{C}$ throughout the day and can be roughly approximated as 1°C less than the same dry bulb temperature at 5 am.
- Humidity ratio approximately doubles for each 10°C rise in dew point temperature.
- As we vary the temperature of a given sample of air at constant barometric pressure the quantities that remain constant are humidity ratio, dew point temperature, and the partial pressure of water vapor. The direct measure of dew point temperature would therefore seem to be the most logical way of determining the moisture content of the air. This is of course true up to the point when dry bulb temperature is not reduced below the dew point temperature.

At saturation dry-bulb, wet-bulb, and dew-point temperatures are same.

Degree of Saturation (μ)

It is the ratio of actual mass of water vapor in a unit mass of dry air to the mass of water vapor in the same mass and pressure of dry air when it is saturated at the same temperature and pressure or it is the ratio of the humidity ratio at a defined state-point to the humidity ratio at saturation at the same dry-bulb temperature. This term is now very rarely used.

$$\mu = \frac{\text{kg of moisture actually contained per kg of dry air}}{\text{kg of moisture required to saturate 1 kg of dry air at same dry-bulb temperature.}}$$

$$= 0.622P_v / (P_b - P_v) \div 0.622P_s / (P_b - P_s)$$

$$= p_v(p_b - p_s) / p_s(p_b - p_v)$$

$$\mu = P_v(1 - P_s/P_b) / P_s(1 - P_v/P_b)$$

If water vapor is added in controlled volume at T_1 , P_v will go on increasing until it reaches P_s . After this, pressure cannot increase further at the same temperature T_1 . This state indicated by point 2 is called air saturated with moisture.

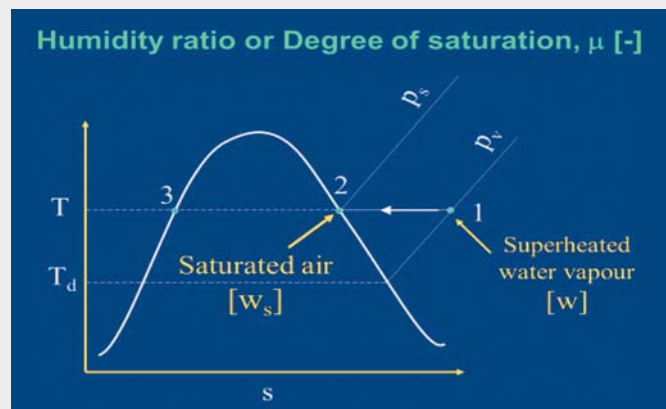


Figure 12: Degree of saturation

Relative Humidity (ϕ)

This is a widely used terminology. In simple terms, it is the capacity of air to hold moisture. For example, if the water bucket is half full, it can hold another 50% more water. And then the relative



Figure 13: Relative humidity

humidity is 50%. If the bucket is 20% full, it can hold another 80% more water. It means relative humidity is 20%.

It is the ratio of actual mass of water vapor in a given volume of moist air to the mass of water vapor in the same volume of saturated air at the same temperature and pressure.

Relative humidity can also be defined as the ratio of actual water vapor pressure of air to the saturated water vapor pressure of the air at the same dry bulb temperature.

For unsaturated vapor:

$$P_w * V_w = m_w * R * T$$

- **Relative Humidity:**
(Actual moisture present in the given volume of air)
(Moisture at Saturation in the same volume)
at same DBT & pressure
Relative humidity is expressed in terms of percent and is a dimensionless figure

Figure 14: Relative humidity definition

For saturated vapor:

$$P_{ws} * V_{ws} = m_{ws} * R * T$$

By definition, volume and temperature are constant.

$$\text{Hence } m_w / m_{ws} = P_w / P_{ws}$$

$$P_w / P_s = m_w / m_s = \phi, \text{ When } P_w = P_s \text{ Relative Humidity is 100\%}$$

Relative Humidity Lines

These lines for partly saturated air look very much like saturation lines and indicate the degree of saturation. These lines are drawn in increments of 10%. Relative humidity is defined as the amount of moisture in the air compared to the maximum amount

- **Relative Humidity (p_v / p_s):**
(Actual Partial pressure of water vapour)
(Partial pressure of water vapour at Saturation)
at same DBT

Figure 15: Relative humidity formula

of moisture that could be present at the same temperature. It is the ratio of actual water vapor pressure of the air to the saturated water vapor pressure of the air at the same temperature.

Humidity ratio
(It signifies quality of air) means
-how much moisture is present in the air
AND
Relative humidity
(Signifies Human Comfort)-means
ability of air to absorb additional moisture

Figure 16: Humidity ratio and relative humidity

Relative humidity can be a misleading indicator of the mass of water vapor in a given volume or space of air. The maximum mass of water vapor approximately doubles for each 10°C rise in temperature. Therefore, volume saturated with water vapor at a warmer temperature contains significantly more water vapor than an equal volume saturated with water vapor at colder temperature. This leads to confusion to a layman because winter RH is often more than summer RH, yet it is a common perception that higher humidity is a problem in the summer and low humidity is a problem in the winter.

Dew point temperature is therefore a more intuitive description of the water vapor component in air. The relative humidity varies throughout the day from high in the early morning to low in the afternoon while the dew point temperature tends to be nearly constant throughout the 24-hour period unless rain occurs.

Humidity Ratio = $m_{wv} / m_{da} = kg_{wv} / kg_{da} = 0.622 P_v / (p_b - P_v)$
Specific Humidity = $m_w / m_w + m_{da} = kg_{wv} / kg_{(da+dww)}$
Absolute Humidity = $m_w / v = kg_{wv} / m^3$
Relative humidity = $m_v / m_s = P_v / P_s$
Degree of Saturation, μ = $m_{wv} / m_{wvs} = P_v (p_b - P_s) / P_s (p_b - P_v)$

Figure 17: Formulae for humidity-related terms

Also, the dew point temperature is always uniform throughout the room. On the other hand, relative humidity varies throughout the room depending upon temperatures at different locations or the heat generating sources at various locations in the room. The relative humidity may be 50% in the center of a room but may be even 90% at the carpet level or higher and at roof level it could be as low as 20 to 30%. Hence stating relative humidity alone without mentioning the corresponding dry bulb temperature is meaningless.

Conclusion

In this part, we have covered information essential for the construction and understanding of psychrometric chart. In the next part, we shall deal with plotting of psychrometric chart and various properties mentioned in this chapter superimposed on the chart. ❖