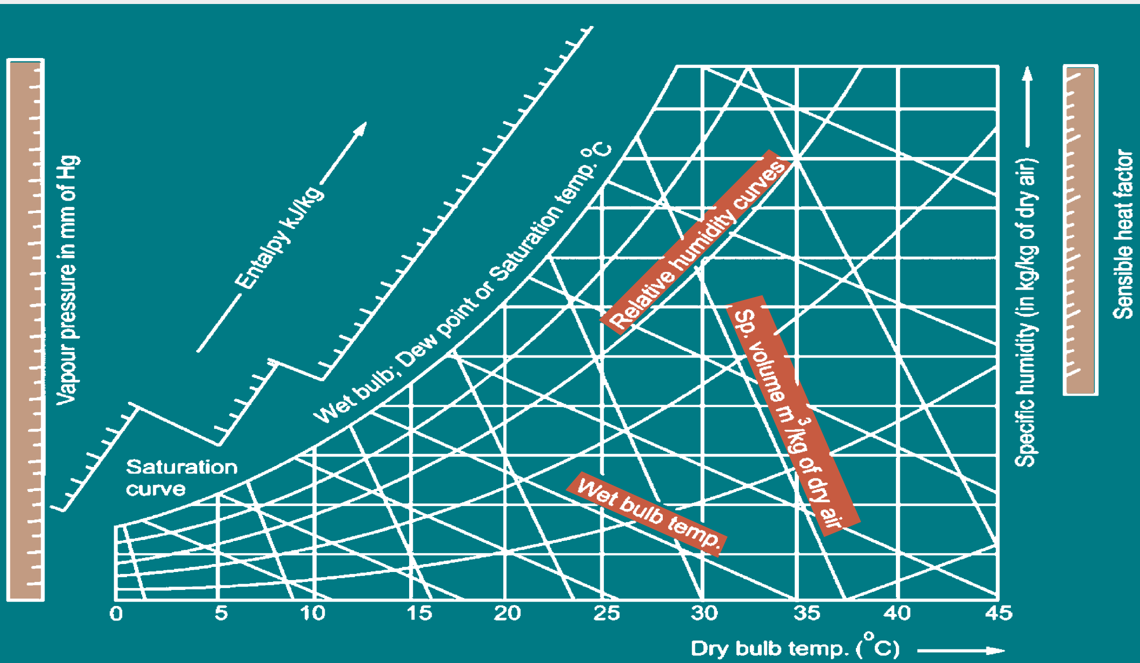
Part 1



Understanding Psychrometrics

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Introduction

All of us breathe air, without which life cannot sustain. However, most of us know very little about the properties of the air-vapor mixture, whose behavior is constantly changing. We generally only know that air contains mainly oxygen and nitrogen gases, along with some other gases and impurities.

To be able to respond to the questions given below speedily and effortlessly, it is necessary to learn the properties of air, also known as applied Psychrometrics.

Questions

1. Is dry air lighter, or is moist air lighter?
2. Which sample of air is lighter? Please list them in descending order: cold and dry, cold and moist, hot and moist, hot and dry.
3. What is the maximum moisture content we can expect in Earth's atmosphere: 1%, 2%, 5%, or 10%?
4. Which air sample has more moisture content: 40°C and 20% R.H., or 5°C and 90% R.H?
5. Can water be cooled to 33°C when the ambient temperature is 40°C to 45°C without the help of refrigeration?
6. Why is the latent heat of water vapor important in air conditioning calculations?
7. True or false: Does the enthalpy of air largely depend on both dry bulb and wet bulb temperature of air, only dry bulb, or only wet bulb?
8. Why is dew point temperature more important than relative humidity?
9. Can humidity of air be decreased by spraying water into the air?
10. What is the difference between cold water and chilled water?
11. Why are all load calculations done with respect to kg of dry air and not total air, when we know that air always contains some moisture?
12. What is the difference between fog, mist, cloud, frost, and haze?

About the Authors

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13. While driving a car, sometimes there is fogging inside the car and sometimes it is outside the car. Can you explain why?
14. In a cooling tower, please indicate temperatures in descending order: make-up water temperature, wet bulb temperature, spray water temperature, tank water temperature.
15. Which air will absorb more moisture: cold and dry, or hot and dry?
16. As the relative humidity decreases, does the difference between dry and wet bulb readings increase, decrease, or remain uniform?
17. Which of the following is represented by curved lines on the psychrometric chart? a) Specific humidity b) Relative humidity c) WBT d) DPT
18. Enthalpy lines and specific volume lines are the same. a) False b) True
19. The dew point temperature is less than the wet bulb temperature for: a) saturated air b) unsaturated air c) both saturated and unsaturated air d) none of the above
20. When we use a bypass factor for cooling load calculations and selection of a cooling coil, does some air really get bypassed in the coil, or is it only an assumption?

To be able to answer the above questions, we need to learn Psychrometrics. Many designers do not use a psychrometric chart at all, instead relying on complex formulae or computer software for solutions. Consequently, results may differ significantly from designer to designer due to widely varying assumptions.

Some engineers mistakenly believe that using Psychrometrics will result in a more complicated system. Instead, it is more likely to guide one to a simpler solution.

Mastering the psychrometric chart is not a difficult task. However, the number of individuals who design air conditioning systems and select equipment without using psychrometric charts is truly astounding.

Most believe that using the chart requires considerable engineering ability. Actually, solving any air conditioning problem by means of a psychrometric chart is the easiest way. Besides, one gains much more assurance that the solution is correct, as it is easier to visualize and verify.

The use of a psychrometric chart provides a visual description of HVAC system design, which cannot be fully appreciated through the use of formulae or software alone.

The psychrometric chart is invaluable for describing cooling coil performance, cooling towers, humidification equipment, air conditioning processes, heat recovery strategies, and solutions to many other related applications. Devoting time to master the psychrometric chart will undoubtedly be a fruitful exercise.

This effort aims to help the reader understand these fundamentals and their applications in a simplified manner. This will enable them to feel more confident in tackling problems and designing optimized systems.

We will therefore begin by understanding the properties of air. Air is a mixture of many gases, primarily:

78% Nitrogen (N_2)
20.9% Oxygen (O_2)
1% Argon
0.1% other gases by volume.

Their respective molecular weights are:

N_2 : 14×2 = 28
O_2 : 16×2 = 32
H_2O (Water) : 1×2+16 = 18

The molecular weight of air is approximately 28.9645.

Moist Air

In Earth's atmosphere, totally dry air is never present. Air always contains a variable quantity of water vapor, which is the gaseous phase of H_2O.

The highest naturally occurring and recorded quantity of water vapor in the air is 0.035 kg of water vapor per kg of dry air (with a 34°C dew point), a measurement taken in Sharjah, Saudi Arabia. Typically, the dew point temperature at sea level is around 28°C, which is equivalent to 0.025 kg of water vapor per kg of dry air.

The lowest recorded quantity of water vapor in the atmosphere was at Vostok, Antarctica, at a minuscule 0.00000001 kg of water vapor per kg of dry air. Thus, it is evident that air always contains some water vapor. Earth's atmosphere, therefore, in addition to dry air, contains water vapor, which usually exists as superheated steam at a low partial pressure and temperature.

The amount of water vapor in the atmosphere is typically less than 3.5%, but its contribution is significant, because its latent heat of vaporization is approximately 2500 kJ/kg at 21.5°C. This is substantial when compared to the specific heat of dry air, which is 1.006 kJ/kg.K. This means that to remove or condense one kg of water vapor, we require approximately 2500 times more energy.

Superheated Vapor in Atmosphere

Atmospheric air is a mechanical mixture of dry air and water vapor. The amount of water vapor varies from near zero (dry air) to the maximum that air can hold (its saturation point), depending on vapor pressure and temperature.

The saturation vapor pressure at 20°C is 2.33 kPa, at 25°C it is 3.1692 kPa, at 30°C it is 4.2460 kPa, and at 40°C it is 7.3835 kPa. Even at 55°C, it is 15.75 kPa whereas atmospheric pressure is 101.325 kPa.

Therefore, the actual vapor pressure Pv exerted by water vapor is very small relative to the total atmospheric pressure.

This indicates that the actual temperature of the air/vapor mixture is much higher than its saturation vapor temperature (dew point). This is why water vapor normally exists in a superheated and invisible condition within the air. Such air is therefore referred to as unsaturated air.

Superheated means that at a given vapor pressure, the actual temperature of the vapor is higher than its corresponding saturation temperature.

Table 1 gives temperature and corresponding saturation vapor pressure.

Table 1: Temperature and corresponding saturation vapor pressure

Temperature	Saturated Vapor Pressure
100°C	101.325 kPa
55°C	15.75 kPa
40°C	7.3835 kPa
30°C	4.246 kPa.
20°C	2.33 kPa

We shall now compare actual moisture content generally present in design conditions in various major cities and the corresponding dew point temperature v/s actual design temperatures as shown in *Table 2*.

Table 2: Actual moisture content and corresponding dew point temperature v/s actual design temperature

City	Design DB/WB, °C	Humidity Ratio, gm_w/kg_{da}	Dew point Temperature	Vapor Pressure, mm-hg/kPa
Mumbai	32.6/29	24.17	27.96	28.3175/3.7
New Delhi	44.30/24.9	11.87	16.61	14.1833/1.8
Chennai	39.5/27.2	17.83	23	21.0938/2.8
Kolkata	41.2/27	16.75	22	19.8534/2.6

Table 2 shows that the actual dry bulb temperature is mostly higher than the dew point temperature. Hence, the moisture is always present in vapor form, or technically, in a superheated condition.

Saturation

It is a state of neutral equilibrium between moist air and its condensed water phase. Water vapor and dry air share the same volume in the atmosphere.

Saturation with respect to water vapor means that the volume contains the maximum possible number of water vapor molecules. Such air is referred to as air saturated with water vapor, and it is invisible. If further water vapor is added to this air, the water vapor droplets may remain in suspension, making the air misty or foggy. These drops are condensed vapor particles and occur only beyond saturation.

Fog, Mist, Dew, Cloud, Haze

When air cools to its dew point temperature and below, the excess moisture becomes visible, forming fog, mist, clouds, dew, frost, and ice. We will now differentiate these phenomena in an easy-to-understand manner, listed in descending order of apparent density/visibility characteristics where applicable:

Fog

This is the thickest, with water droplet sizes ranging from 1 to 10 microns and visibility less than 200 meters.

Mist

Water droplets are typically 50 to 100 microns, and visibility ranges from 1 to 2 kilometers.

Dew

Consists of water droplets generally larger than 10 microns, with clear visibility.

Cloud

At ground level, a "cloud" is referred to as fog or mist, depending on visibility. At sea or for aircraft landing and takeoff, fog is specifically defined as visibility of 1000 meters or less. When a cloud descends to ground, lake, or mountain level, a temperature reversal occurs, where colder air is at the bottom and warmer air is above.

Haze

This phenomenon has nothing to do with moisture. Haze is a condition where the air's lower layer, closest to the surface, contains a high concentration of solid, dry particles that remain suspended for an extended duration.

When warm air passes gently over a colder sea or land surface, the air in contact with the colder surface also cools. If the air is cooled below its dew point, it releases moisture, and the water droplets settle on the land surface. This is **dew**.

Some of these water droplets settle on dust particles, pollutants, and salt present in the air. These water droplets remain suspended in the air as they are very small and light. These suspended water droplets form **mist**.

Fog

Fog

Fog occurs when air is saturated, it is cloud at the ground level-size –1 to 10 micron

Figure 1: Fog

Water droplets range in size from 1 to 10 microns, and visibility is less than 1 km. Normally, over land, forecasters use the word "fog" when visibility is 200 meters or less. This is because a car driver may be fairly comfortable if they can see over 200 meters, while the same is not true for an aircraft pilot landing at Heathrow or the skipper of a boat in mid-Channel, who require visibility of 1 to 2 km.

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Mist

Mist

Size of water droplets is more than 50 micron up to 100 microns, and the visibility is about 1 km to 2 km.

Figure 2: Mist

The size of water droplets is 50 to 100 microns, and visibility is 1 to 2 km. Mist refers to visibility between 1000 and 2000 meters. Fog and mist are both created by water droplets, differing only in their overall locations and density. Fog is a cloud that reaches ground level, even if that 'ground' is a hill or mountaintop. Mist forms wherever water droplets are suspended in the air by temperature inversion.

Dew

Dew

Figure 3: Dew

Dew consists of droplets typically larger than 10 microns, and visibility remains clear. Dew is water in the form of droplets that appears on thin, exposed objects in the morning or evening. As the exposed surface cools by radiating its heat, atmospheric moisture condenses at a rate greater than that at which it can evaporate, resulting in the formation of water droplets. When temperatures are low enough, dew takes the form of ice, which is called frost.

Cloud

Cloud at ground level

Figure 4: Cloud

At ground level, a cloud is called fog or mist, depending on visibility. At sea or for aircraft landing and takeoff purposes, fog is defined as visibility of 1,000 meters or less. When a cloud descends to ground, lake, or mountain level, a temperature inversion takes place. In this phenomenon, the low-temperature air is at the bottom, and the warm air is on top.

Clouds can form at many different altitudes. They can be as high as 12 miles above sea level or as low as the ground. Fog is a type of cloud that touches the ground.

Ideal Gas

The term ideal gas refers to a hypothetical gas composed of molecules that follow a few rules: Ideal gas molecules do not attract or repel each other. The only interaction between ideal gas molecules is an elastic collision upon impact with each other or an elastic collision with the walls of the container.

Dry air behaves as an ideal gas, and moist air also behaves as an ideal gas up to a pressure of 3 bar, obeying perfect gas laws with sufficient accuracy for engineering calculations.

Moist air is a mixture of dry air plus water vapor, and its moisture content is continuously variable; hence, the mixture is not an ideal gas.

Dry air is a pure substance, and similarly, water vapor is a pure substance. However, moist air is not a pure substance since condensation or evaporation of moisture occurs in any process. Thus, moist air has two parts: dry air, which is a fixed part, and moisture, which is a variable part.

In air conditioning practice, all calculations are therefore based on the dry air part, since the water vapor part is continuously variable, whereas the dry air component is comparatively constant.

Conclusion

Having learned about the behavior of air, in Part 2 of this series we will tackle some basic foundational laws that govern air properties and help us prepare a psychrometric chart.