CC 11:FOOD ENGINEERING

Unit 7—Psychrometrics

By

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In the present module, following topics are covered:

1. **Properties of dry air**
   1.1 Specific Heat of dry air
   1.2 Specific volume of dry air
   1.3 Density
   1.4 Enthalpy of Dry Air
   1.5 Dry Bulb Temperature

2. **Properties of water vapour**
   2.1 Latent Heat
      2.1.1 Latent Heat of Vaporization
      2.1.2 Latent Heat of sublimation
      2.1.3 Latent Heat of fusion
      2.1.4 Latent Heat of condensation
   2.2 Sublimation
   2.3 Evaporation
   2.4 Vapour Pressure

3. **Properties of air vapour mixture**
   3.1 Humdity Ratio
   3.2 Dew Point Teperature
   3.3 Wet Bulb Temperature

3.4 Relative Humidity

3.5 Adiabatic Saturation of Air

4. Psychrometric chart

4.1 Principle

4.2 Psychrometrics-use and application

1. Properties of dry air

1.1 Specific Heat of dry air

The specific heat is the amount of heat per unit mass required to raise thetemperature by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.At 1 atm (101.325 kPa), the specific heat of dry air C_{pa} in a temperature range of -40 to 6O^{O}C varying from 0.997 to 1.022 kJ/(kg K) can be used.

For most calculations, an average value of 1.005 kJ/[kg K] may be used.

1.2 Specific volume of dry air

Ideal gas laws can be used to determine the specific volume of dry air.

Therefore,

$$V'_a = R_a T_a / p_a$$

Where, V'_a is the specific volume of dry air (m^3/kg); T a is the absolutetemperature (K); p_a is partial pressure of dry air (kPa); and R_a is thegas constant ([m^3 Pa]/[kg K]).

1.3 Enthalpy of Dry Air

It is a measurement of energy in a thermodynamic system. It is the thermodynamic quantity equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume.

Enthalpy, the heat content of dry air, is a relative term and requiresselection of a reference point. In psychrometric calculations the referencepressure is selected as the atmospheric pressure and the referencetemperature is 0C. Use of atmospheric pressure as the reference allowsthe use of the following equation to determine the specific enthalpy:

$$H_a=1.005(Ta-T_0)$$

1.4 **Dry Bulb Temperature**

Dry bulb temperature is the temperature indicated by an unmodifiedtemperature sensor. This is in contrast to the wet bulb temperature where the sensor is kept covered with alayer of water.

1.5 Density of air

The density of air is the mass per unit volume of Earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature or humidity. At sea level and at 15 °C air has a density of approximately 1.225 kg/m^3 (0.001225 g/cm^3, 0.0023769 slug/ft^3, 0.0765 lbm/ft^3) according to ISA (International Standard Atmosphere).

2. Properties of water vapour

2.1 Latent Heat

When heat is added or extractedfrom a system the temperature changes.
However, there are certain situations whenthe addition or subtraction of heat from asystem does not result in a temperaturechange. In these situations, the heat that isadded or extracted is being converted intoenergy to cause a phase change from onephysical state to another.The value of latent heat is dependent upon the exact nature of the phase change as well as on the specific properties of the substance. Latent heat is usually expressed in terms of calories per gram.
There are various forms of latent heat,depending on what transformation isoccurring when it is taken up or released.

2.1.1 Latentheat of fusion (Lf):

Refers to the heat lost orgained by the air when liquid water changesto ice or vice versa. Lf=333 Joules per gram(J/g) of water or 80 calories per gram (cal/g) of water.

2.1.2 Latent heat of sublimation (Ls):

Refers to the heat lost or gained by the airwhen ice changes to vapor or vice versa.Ls=2833 Joules per gram (J/g) of water or680 calories per gram (cal/g) of water.

2.1.3 Latent heat of condensation (Lc):

Refers to the heat gained by the air when water vapor changes into a liquid. Lc=2500 Joules per gram (J/g) of water or 600 calories per gram (cal/g) of water.

2.1.4 Latent heat of vaporization (Lv):

Refers tothe heat lost by the air when liquid waterchanges into vapor. This is also commonlyknown as the latent heat of evaporation. Lv=-2500 Joules per gram (J/g) of water or -600calories per gram (cal/g) of water.

2.2 Sublimation

Sublimation is the direct transition from solid state to gaseous state without melting. Sublimation occurs at a definite range of temperatures and pressures, depending onthe substance in question.Heat of sublimation is conducted to thesurface of the ice core through the dried outer layer. Vaporized water diffuses through the pores ofthe dried outer layer before it leaves the solid and goes to the atmosphere in the drying chamber.

2.3 Evaporation

Liquids can also change to gases attemperatures below their boiling points. Vaporization of a liquid below its boilingpoint is called evaporation, which occurs atany temperature when the surface of a liquidis exposed in an unconfined space. When,however, the surface is exposed in aconfined space and the liquid is in excess ofthat needed to saturate the space with vapor,an equilibrium is quickly reached betweenthe number of molecules of the substancegoing off from the surface and thosereturning to it. A change in temperatureupsets this equilibrium; a rise intemperature, for example, increases theactivity of the molecules at the surface andconsequently increases the rate at whichthey fly off. When the temperature ismaintained at the new point for a short time,a new equilibrium is soon established.

2.4 Vapor Pressure

All liquids and solids have atendency to evaporate to a gaseous form,and all gases have a tendency to condenseback into their original form (either liquid orsolid). At any given temperature, for aparticular substance, there is a pressure atwhich the gas of that substance is indynamic equilibrium with its liquid or solidforms. This is the vapor pressure of thatsubstance at that temperature. The vaporpressure of a liquid is the pressure exertedby its vapor when the liquid and vapor are indynamic equilibrium.Vapor pressures differ for different substances at any given temperature, buteach substance has a specific vapor pressurefor each given temperature. At its boilingpoint the vapor pressure of a liquid is equalto atmospheric pressure. For example, thevapor pressure of water, measured in termsof the height of mercury in a barometer, is4.58 mm at 0°C

The equilibrium vapor pressure is anindication of a liquid's evaporation rate. Itrelates to the tendency of molecules andatoms to escape from a liquid or a solid. Asubstance with a high vapor pressure atnormal temperatures is often referred to asvolatile.

3. Properties of air vapour mixture

3.1 Humidity Ratio

The ratio of mass of water vapor to mass of air in a mixture is referred to as the specific humidity or the humidity ratio with the symbol ω (no this is not the humidity the goofy weathermen are reporting). The advantage in dealing with the specific humidity is that if the amount of water vapor in the air remains unchanged, the specific humidity remains constant. The specific humidity is expressed in grams of moisture (water vapor) per kilogram of dry air. Alternatively it is given as lbsv /lbsa or grains of water vapor per pound of dry air where 7000 grains is onepound mass.

3.2 Relative Humidity (RH)

There are two distinct ways of expressing humidity relative to saturation conditions. Relative humidityis variously called percentage relative humidity or simply %RH. Moisture-saturated air is air in equilibrium with pure liquid water at a given temperature.

The RH is a ratio. It does not define the water content of the air unless the temperature is given. The reason RH is so much used in conservation is that most organic materials have an equilibrium water content that is mainly determined by the RH and is only slightly influenced by temperature.

Consequently, the partial vapor pressure of water vapor in moisture-saturatedair is equal to the vapor pressure of liquid water at the same temperature:

$$(p_w)_{sat.}= p_0$$

The saturation humidity H s is the maximum quantity of water vapor that air cancontain at a given temperature, without phase separation.

The relative humidity (φ or RH) is the ratio (as percentage) of the partial pressureof water vapor in air, to the vapor pressure of liquid water at the same temperature.

$$RH= p_w/p_0 \ x\ 100$$

'Percent 'saturation' (S), often confounded with relative humidity, is:

$$S= H/H_s x\ 100$$

The saturation and constant percent saturation lines are indicated on the psychrometricchart.

3.3 Wet Bulb Temperature

The lowest temperature attained by evaporating water from a saturated wick covering the bulb of a thermometer at the point of observation.The wet bulb temperature of air is also measured by the ordinary thermometer, but the only difference is that the bulb of the thermometer is covered by the wet cloth. Temperature of the ordinary air measured by the thermometer when it is covered by wet cloth or wick is called as the wet bulb temperature, commonly referred to as WBT. When the air comes in contact with the wet cloth it absorbs some moisture and gives up some heat, sue to which the temperature of the air reduces. This reduced temperature measured by the thermometer is called as the wet bulb temperature.Wetbulb temperature can never be higher than dry-bulb temperature. From the definition point of view, it is defined as the temperature at which water vapour evaporating into the air can bring down the air in saturation adiabatically at that temperature. It is a measure of the evaporating capacity of the air. Its unit is °F or °C or ~~kelvin~~ Kelvin (K).

3.4 Adiabatic Saturation of Air

If the gas is passed over the liquid surface at such a rate that equilibrium can be established, the gas becomes saturated and both phases attain the same temperature. However, in an adiabatic (i.e. thermally insulated) system the sensible heat of the gas will fall by an amount equal to the latent heat of the liquid being evaporated. The equilibrium temperature of the liquid is now known as the adiabatic saturation temperature T_s. whereas, in deriving the wet bulb equation the rates of heat and mass transfer were equated, in an adiabatic system it is appropriate to write an energy balance. Hence, per unit mass of material

3.5 The Dew Point

The water vapour content of air is often quoted as dew point. This is the temperature to which the air must be cooled before dew condenses from it. At this temperature the actual water vapour content of the air is equal to the saturation water vapour pressure. The dew point is usually calculated from the RH. First one calculates p_s, the saturation vapour pressure at the ambient temperature. The actual water vapour pressure, p_a, is:

$$p_a = p_s * RH\,\%/100$$

Water vapors present in the air can be considered steam at low pressure.The water vapor in the air will be saturated when air is at a temperatureequal to the saturation temperature corresponding to thepartial pressure exerted by the water vapor. This temperature of airis called the dew-point temperature. The dew-point temperature canbe obtained from the steam table; for example, if the partial pressureof water vapor is 2.064 kPa, then the dew-point temperature can bedirectly obtained as the corresponding saturation temperature, 18^oC.

4. The Psychrometric Chart

Psychrometry is concerned with the behaviour of humid air and the prediction of its properties. Psychrometry is most commonly applied to air at atmospheric pressure. In this case, the pressure is not a ‘variable’. It follows that the state of homogeneous moist air at atmospheric pressure can be unequivocally defined by two variables: temperature and moisture content (humidity). More strictly it covers the behaviour of any vapour (not just water vapour) when mixed with a gas (not just air).

4.1 Principle

A psychrometric chart can be used to follow changes in the condition of moist air during processingoperations such as drying or humidification which involve mixtures of air and vaporised water.The chart is a way of representing graphically the adiabatic cooling (or wet bulb) line. Essentially,therefore it is a plot of absolute humidity (vertical axis) against dry bulb temperature (horizontalaxis) with a series of curves representing particular values of percentage saturation superimposed.On some charts relative humidity is used in place of percentage saturation. The wet bulb temperaturescale is shown along the saturated humidity curve.

The dry bulb temperature and amount of water vapor in a moist air mixture can be graphically shown on a psychrometric chart. Such a chart is very useful to visualize the changes undergone by a mixture of air and water vapor as the air is conditioned. The chart is also useful in determining the amount of energy required for a specific conditioning of the air. It is strongly suggested that you become familiar with the chart.

The various quantities that can be determined from a psychrometric chart are as follows:

Humidity (absolute humidity) (H): the mass ratio of water to dry air in the mixture.

Relative humidity (% RH): the ratio of partial pressure of water in the air to the vapor pressure of water, expressed in a percentage.

Dry bulb temperature (T_{db}): actual air temperature measured using a dry temperature sensing element.

Wet bulb temperature (T_{wb}): air temperature measured using a wet sensing element that allows cooling by evaporation of water.

Dew point (T_{dp}): temperature to which a given air-water mixture needs to be cooled to start condensation of water. At the dew point, the air is saturated with water vapor. The dew point is also that temperature where the vapor pressure of water equals the partial pressure of water in the air.

A psychrometric chart has its axes temperature on the abscissa and humidity on the ordinate. Two parameters are necessary to establish a point on the chart that represents the condition of air. These parameters could be any two from relative humidity, dry bulb temperature, wet bulb temperature, and dew point or absolute humidity. Dew point and absolute humidity are not independent, knowing one establishes the other.

Figure 1 shows the psychrometric chart for sea level in SI units. Similar charts are available for selected altitudes and in English units. The right hand vertical scale gives the humidity ratio or specific humidity of the mixture. Note that in most situations encountered in buildings practice the mass of water vapor is much less than the mass of air in the mixture. Typical values of ω are 0 to 20 grams of water vapor per kilogram of air. Thus, the mass of water vapor is only at most one to two percent of the mass of air.

The horizontal axis is the dry bulb temperature. There are parallel slanted straight lines starting from the upper left which are lines of constant mixture enthalpy per mass of dry air. To keep the enthalpy lines straight and parallel, it turns out that line of constant dry bulb temperature deviate somewhat from vertical.

The chart also shows other information. Curves of constant relative humidity, φ, are shown as are lines of constant wet bulb temperature. Thus, if the dry bulb temperature and relative humidity are known, the state of the mixture can be located on the chart and the corresponding value of the mixture enthalpy and humidity ratio read from the chart.

The left hand border represents saturation conditions of the mixture, 100% relative humidity.

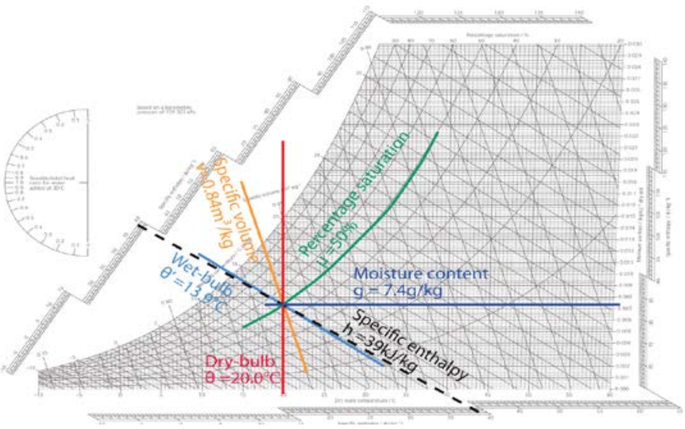
4.2 Psychrometrics– Uses and applications

Psychrometry is a study of the behavior of mixtures of air and water. A graph of humidity as a functionof temperature at varying degrees of saturation forms the main body of a psychrometric chart. Forprocesses that involve loss or gain of moisture by air at room temperature, the psychrometric chart isvery useful for determining changes in temperature and humidity.

Another main feature of a psychrometric chart is the wet bulb temperature. When a thermometeris fitted with a wet sock at the bulb and placed in a stream of air, evaporation of water from the sockcools the bulb to a temperature lower than what would register if the bulb is dry. The difference isknown as the wet bulb depression and is a function of the relative humidity of the air. The more humidair allows less vaporization, thus resulting in a lower wet bulb depression.

Conclusion

In the present module, concept of psychrometry was emphasized which is important in the transportation and storage of food commodity as it is used for determination of physical and thermodynamic properties of gas-vapor mixtures and its principle, uses and applications can be used in tailoring the features in design of storage structures. Latent heat is also an important factor which could be used in case of handling during the transportation and storage of food materials.



~~**Objectives**~~

~~At the end of this module, the student should be able to answer the following questions to meet the objectives of the module.~~

~~1. What is psychrometry?~~

~~2. What is latent heat?~~

~~3. How to determine the different features by using psychometric chart?~~

~~4. What is the difference between dry and wet bulb temperature?~~

~~5. What are the properties of dry air?~~

~~**E-content/FAQs/Problems**~~

~~I. A sample of air has a dry bulb temperature of 35°C and a wet bulb temperature of 30°C. Using a psychrometric chart, determine the absolute humidity, percentage saturation, dew point and specific volume of the air. The point representing the sample is located at the~~

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Solution:

H = 0.026 kg kg−1

Percentage saturation = 68%

Dew point = 28.5◦C

Specific volume = 0.908 m3 kg−1

II. Air, originally at 40◦C and 10% saturation, is cooled adiabatically by contacting it with water, which is at the wet bulb temperature of the gas. What is the lowest temperature to which the air may be cooled and how much water is vaporised per kilogram of dry air in reaching this temperature?

Solution:

The lowest temperature to which the air may be cooled is the wet bulb temperature of the air, that is, 19◦C. At this point the air is saturated and the mass of water vaporised per kg of dry air is equal to the difference in humidity which equals (0.0138−0.0049) kg kg−1 or 0.0089 kg water per kg of dry air.

III. Air at 30°C and 10% relative humidity enters an evaporative cooler where moisture is evaporated until the temperature reaches 21°C. What is the relative humidity of the air as it leaves?

Solution:

The initial conditions (at t1 = 30°C and φ 1 = 10%) are (using Figure 9.01):

t_{wb} = 13.3°C

h1 = 37 kJ/kg dry air

w1 = 2.6 g/kg dry air

This method of moisture addition is a constant wet-bulb process. By following a constant wet-bulb line to t2 = 21°C, we find:

φ_2 = 41%

IV. Steam is added to air at 30°C and 10% relative humidity until the temperature reaches 38°C and the humidity ratio (W) is 18 g water/kg dry air. How much water is added to one kilogram of air?

Solution:

This process does not follow a constant property line. Instead, we define state point one (Example 9.1) and state point two from the given information. Thus, state point two has the following properties:

t_2 = 38°C (given)

W_2 = 18 g/kg dry air (given)

φ_2 = 43%

t_{wb} = 26.9°C

t_{dp} = 23.2°C

h_2 = 84.5 kJ/kg dry air

The moisture added is

$W_2 - W_1 = 18 - 2.6 = 15.4$g/kg dry air

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(3) L.R. Wilhelm, D.A. Suter, G.H. Brusewitz: **Food & Process Engineering Technology textbook,** ISBN: 1-892769-43-3, February 2005.

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Quiz

1. Ideal gas laws can be used to determine the specific volume of______.
A. Wet bulb temperature
B. Dry air
C. Light
2. RH stands for ________
A. Relative humidity
B. Relative heat
C. Ratio humidity
3. Unit of latent heat of fusion is
A. Watt
B. Joule/g
C. Calorie
4. At sea level and at 15 °C air has a density of approximately.
A. 1.225 kg/m^3-
B. 2.5578 kg/m^2
C. 1.522kg/m^3

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5. At 1 atm (101.325 kPa), the specific heat of dry air C_{pa} in a temperature range of -40 to 6O^{0}C varying from __________ can be used.

A. 0.997 to 1.022 kJ/(kg K)

B. 2.5794 KJ/(kgK)

C. 4.1456 KJ/(kgK)

6. The mass ratio of water to dry air in the mixture is called.

A. Humidity

B. Dew point

C. Dry bulb temperature

D. Wet bulb temperature

7. The vapor pressure of a liquid is the pressure exerted by its vapor when the liquid and vapor are in _______equilibrium

A. Static

B. Dynamic

C. Steady

D. Rotating

8. Latent heat of evaporation of water is equal to

A. 2100 J/g

B. 8000 J/g

C. 2500 J/g

D. 1100 J/g

9. Ls is the latent heat of _____

A. Latent heat of sensible heat

B. Latent heat of sublimation

C. Latent of sun

D. Latent heat of summer

10. Equilibrium temperature of the liquid is known as:

A. Dry bulb temperature

B. Equilibrium temperature

C. Adiabatic saturation temperature

D. Saturation temperature

11. ISA stands for ___________

A. Indian Standard Atmosphere

B. International Saturated Atmosphere

C. Indian Saturated Atmosphere

D. International Standard Atmosphere

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12. The specific humidity is expressed in ______

A. Grams of moisture (water vapor) per kilogram of dry air.

B. Kg of moisture (water vapor) per kilogram of dry air.

C. Grams of moisture (water vapor) per grams of dry air.

D. Grams of moisture (water vapor) per grams of dry air.

13. Latent heat of fusion of water is _______

A. 81 calories per gram (cal/g) of water.

B. 90 calories per gram (cal/g) of water.

C. 80 calories per gram (cal/g) of water.

D. 60 calories per gram (cal/g) of water.

14. Actual air temperature measured using a dry temperature sensing element.

A. Dry temperature

B. Dry bulb temperature

C. Wet bulb temperature

D. Absolute temperature

15. Temperature of the ordinary air measured by the thermometer when it is covered by wet cloth or wick is called as:

A. Dry bulb temperature

B. Wet bulb temperature

C. Wick bulb temperature

D. Sensible temperature

Assignment

1. Describe the psychrometry chart with features and applications?
2. What is the difference between web bulb temperature & dry bulb temperature?
3. What are the parameters which can be determined from psycrometric chart? Describe any two in detail?
4. Write a note on dew point?
5. What is the difference between humidity ratio and relative humidity?
6. What is the principle of psychrometry?
7. What are the uses and applications of psychrometrics?
8. Write a note on latent heat?

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Glossary

- **Enthalpy:** is a measurement of energy in a thermodynamic system. It is the thermodynamic quantity equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume
- **Specific heat:** The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat.
- **Psychrometry:** Psychrometry or hygrometry are terms used to describe the field of engineering concerned with the determination of physical and thermodynamic properties of gas-vapor mixtures.
- **Water vapour:** Water vapor, water vapour or aqueous vapor, is the gaseous phase of water. It is one state of water within the hydrosphere. Water vapor can be produced from the evaporation or boiling of liquid water or from the sublimation of ice.
- **Specific volume**: Specific volume is a property of materials, defined as the number of cubic meters occupied by one kilogram of a particular substance. The standard unit is the meter cubed per kilogram (m^3/kg or $m^3 \cdot kg^{-1}$).
- **Humidity**: Humidity is the amount of water vapor in the air. Water vapor is the gaseous state of water and is invisible.
- **Temperature**: A temperature is an objective comparative measure of hot or cold. It is measured by a thermometer, which may work through the bulk behavior of a thermometric material, detection of thermal radiation, or particle kinetic energy.
- **Saturation**: when atmospheric humidity reaches 100% and the air is saturated with moisture

Density: The density, or the volumetric mass density, of a substance is its mass per unit volume.

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