Fundamentals of Refrigeration and Air Conditioning

المرحلة الثانية

محاضرة رقم (2)

خواص الهواء

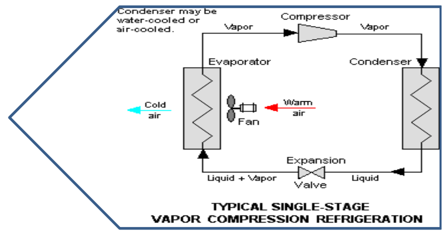
Air Properties

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

Fundamentals of Refrigeration and Air Conditioning

Hassan Rijabo

Lecture 2
Air Properties



AL MUSTAKBAL UNIVERSITY
College of Engineering and Technology
Department of Mechanical Power Engineering

Hassan.Ghanim.Hassan@uomus.edu.ly
hvac.eng.edu
Ref_AC

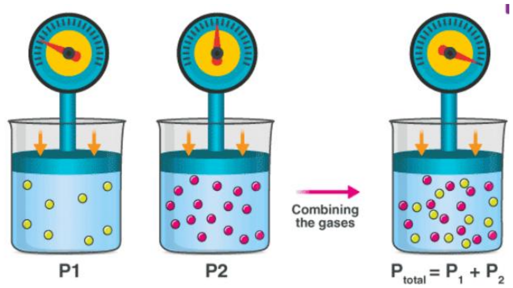
1. DRY AND ATMOSPHERIC AIR

- Air is a mixture of nitrogen, oxygen, and small amounts of some other gases.
- Air in the atmosphere normally contains some water vapor (or *moisture*) and is referred to as **atmospheric air**. By contrast, air that contains no water vapor is called **dry air**. It is often convenient to treat air as a mixture of water vapor and dry air since the composition of dry air remains relatively constant, but the amount of water vapor changes as a result of condensation and evaporation from oceans, lakes, rivers, showers, and even the human body.
- Although the amount of water vapor in the air is small, it plays a major role in human comfort. Therefore, it is an important consideration in air-conditioning applications.

Dalton's Law of Partial Pressure

What is Dalton's Law?

Dalton's law of partial pressures is a gas law which states that the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures exerted by each individual gas in the mixture. For example, the total pressure exerted by a mixture of two gases A and B is equal to the sum of the individual partial pressures exerted by gas A and gas B (as illustrated below).



Dalton's Law of Partial Pressures

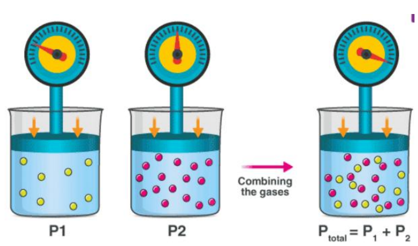
Dalton's Law Formula

Dalton's law of partial pressures can be mathematically expressed as follows:

$$P_{total} = \sum_{i=1}^{n} P_i \quad \text{or} \quad P_{total} = P_1 + P_2 + P_3 + \ldots\ldots\ldots + P_n$$

Where

- P_{total} is the total pressure exerted by the mixture of gases
- P_1, P_2,…, P_n are the partial pressures of the gases 1, 2,…, 'n' in the mixture of 'n' gases



Dalton's Law of Partial Pressures

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

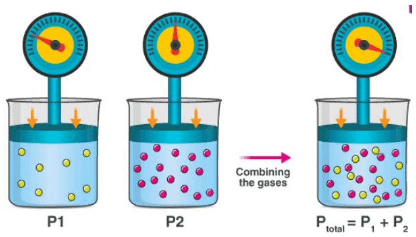
Dalton's Law Formula

Dalton's law of partial pressures can be mathematically expressed as follows:

$$P_{total} = \sum_{i=1}^{n} P_i \qquad \text{or} \qquad P_{total} = P_1 + P_2 + P_3 + \ldots\ldots\ldots + P_n$$

Where

- P_{total} is the total pressure exerted by the mixture of gases
- $P_1, P_2, \ldots, P_n$ are the partial pressures of the gases 1, 2,…, 'n' in the mixture of 'n' gases



Dalton's Law of Partial Pressures

- The temperature of air in air-conditioning applications ranges from about -10 to about 50°C. In this range, dry air can be treated as an ideal gas with a constant ***Cp*** value of **1.005 kJ/kg · K** [0.240 Btu/lbm · R] with negligible error (under 0.2 percent).
- Taking 0°C as the reference temperature, the enthalpy and enthalpy change of dry air can be determined from:

DRY AIR

T, °C	c_p, kJ/kg · °C
−10	1.0038
0	1.0041
10	1.0045
20	1.0049
30	1.0054
40	1.0059
50	1.0065

The c_p of air can be assumed to be constant at 1.005 kJ/kg · °C in the temperature range −10 to 50°C with an error under 0.2 percent.

$$h_{\text{dry air}} = c_p T = (1.005 \text{ kJ/kg} \cdot °\text{C})T \qquad (\text{kJ/kg})$$

and

$$\Delta h_{\text{dry air}} = c_p \Delta T = (1.005 \text{ kJ/kg} \cdot °\text{C})\ \Delta T \qquad (\text{kJ/kg})$$

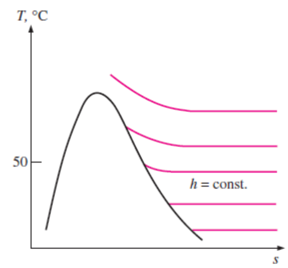
where ***T*** is the air temperature in **°*C*** and **Δ*T*** is the change in temperature

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

The atmospheric air can be treated as an ideal-gas mixture whose pressure is the sum of the partial pressure of dry air *Pa* and that of water vapor *Pv*:

$$P = P_a + P_v \qquad \text{(kPa)}$$

- The partial pressure of water vapor is usually referred to as the **vapor pressure**. It is the pressure water vapor would exert if it existed alone at the temperature and volume of atmospheric air.
- Since water vapor is an ideal gas, the enthalpy of water vapor is a function of temperature only, that is, *h* = *h*(*T*).



At temperatures below 50°C, the h = constant lines coincide with the T = constant lines in the superheated vapor region of water.

The enthalpy of water vapor in air can be taken to be equal to the enthalpy of saturated vapor at the same temperature. That is,.

$$h_v(T, \text{low } P) \cong h_g(T)$$

The enthalpy of water vapor at **0°C** is **2500.9 kJ/kg**. The average ***cp*** value of water vapor in the temperature range -10 to 50°C can be taken to be **1.82 kJ/kg · °C**. Then the enthalpy of water vapor can be determined approximately from

$$h_g(T) \cong 2500.9 + 1.82T \qquad \text{(kJ/kg)} \qquad T \text{ in } °\text{C}$$

or

$$h_g(T) \cong 1060.9 + 0.435T \qquad \text{(Btu/lbm)} \qquad T \text{ in } °\text{F}$$

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

2. SPECIFIC AND RELATIVE HUMIDITY OF AIR

The amount of water vapor in the air can be specified in various ways. Probably the most logical way is to specify directly the mass of water vapor present in a unit mass of dry air. This is called **absolute** or **specific humidity** (also called *humidity ratio*) and is denoted by **ω**:

$$\omega = \frac{m_v}{m_a} \qquad \text{(kg water vapor/kg dry air)}$$

The specific humidity can also be expressed as

$$\omega = \frac{m_v}{m_a} = \frac{P_v V/R_v T}{P_a V/R_a T} = \frac{P_v/R_v}{P_a/R_a} = 0.622\frac{P_v}{P_a}$$

or

$$\omega = \frac{0.622 P_v}{P - P_v} \qquad \text{(kg water vapor/kg dry air)}$$

where ***P*** is the total pressure, Ra = 0.287 kJ/kg.K , Rv = 0.4615 kJ/kg.K

Lecture2. Air Properties

- The specific humidity will increase if add some water vapor to dry air until the air can hold no more moisture. At this point, the air is said to be saturated with moisture, and it is called **saturated air**.
- Any moisture introduced into saturated air will condense.
- The amount of moisture in the air has a definite effect on how comfortable we feel in an environment. However, the comfort level depends more on the amount of moisture the air holds (*mv*) relative to the maximum amount of moisture the air can hold at the same temperature (*mg*). The ratio of these two quantities is called the **relative humidity** **ϕ** .

$$\phi = \frac{m_v}{m_g} = \frac{P_v V/R_v T}{P_g V/R_v T} = \frac{P_v}{P_g}$$

where

$$P_g = P_{\text{sat @ } T}$$

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

we can also express the relative humidity as:

$$\phi = \frac{\omega P}{(0.622 + \omega)P_g} \quad \text{and} \quad \omega = \frac{0.622\phi P_g}{P - \phi P_g}$$

- The relative humidity ranges from ***0*** for dry air to ***1*** for saturated air.
- The amount of moisture air can hold depends on its temperature. Therefore, the relative humidity of air changes with temperature even when its specific humidity remains constant.

- Atmospheric air is a mixture of dry air and water vapor, and thus the enthalpy of air is expressed in terms of the enthalpies of the dry air and the water vapor.
- In most practical applications, the amount of dry air in the air-water-vapor mixture remains constant, but the amount of water vapor changes. Therefore, the enthalpy of atmospheric air is expressed *per unit mass of dry air* instead of per unit mass of the air–water vapor mixture.
- The total enthalpy (an extensive property) of atmospheric air is the sum of the enthalpies of dry air and the water vapor:

$$H = H_a + H_v = m_a h_a + m_v h_v$$

Dividing by m_a gives

$$h = \frac{H}{m_a} = h_a + \frac{m_v}{m_a} h_v = h_a + \omega h_v$$

or

$$h = h_a + \omega h_g \qquad \text{(kJ/kg dry air)}$$

since $h_v \cong h_g$

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

Al-Mustaqbal University
Department of Mechanical Power Engineering
Class (2nd)
Subject (**Fundamentals of Refrigeration and Air Conditioning**)

Lecturer (Hassan Ghanim Hassan)

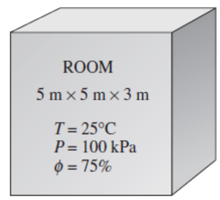
EXAMPLE 1 The Amount of Water Vapor in Room Air

A 5-m x 5-m x 3-m room shown in Fig. contains air at 25°C and 100 kPa at a relative humidity of 75 percent. Determine (*a*) the partial pressure of dry air, (*b*) the specific humidity, (*c*) the enthalpy per unit mass of the dry air, and (*d*) the masses of the dry air and water vapor in the room.

Solution

The constant-pressure specific heat of air at room temperature is *cp* = 1.005 kJ/kg ·

For water at 25°C, we have *Psat* = 3.1698 kPa and *hg* = 2547.2 kJ/kg (Table A-2)



Analysis (*a*) The partial pressure of dry air can be determined from

$$P_a = P - P_v$$

where

$$P_v = \phi P_g = \phi P_{sat\,@\,25°C} = (0.75)\,(3.1698\text{ kPa}) = \mathbf{2.38\text{ kPa}}$$

Thus,

$$P_a = (100 - 2.382)\text{ kPa} = \mathbf{97.62\text{ kPa}}$$

(*b*) The specific humidity of air is determined from

$$\omega = \frac{0.622P_v}{P - P_v} = \frac{(0.622)(2.38\text{ kPa})}{(100 - 2.38)\text{ kPa}} = \mathbf{0.0152\text{ kg }H_2O/\text{kg dry air}}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$h = h_a + \omega h_v = C_pT + \omega h_g$$

$$= (1.005\text{ kJ/kg.°C})(25°C) + (0.0152)(2547.2\text{ kJ/kg})$$

$$= \mathbf{63.8\text{ kJ/kg dry air}}$$

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

(*d*) Both the dry air and the water vapor fill the entire room completely. Therefore, the volume of each gas is equal to the volume of the room:

$$V_a = V_v = V_{room} = (5\text{ m})(5\text{ m})(3\text{ m}) = 75\text{ m}^3$$

The masses of the dry air and the water vapor are determined from the ideal gas relation applied to each gas separately:

$$m_a = \frac{P_a V_a}{R_a T} = \frac{(97.62\text{ kPa})(75\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = \mathbf{85.61\ kg}$$

$$m_v = \frac{P_v V_v}{R_v T} = \frac{(2.38\text{ kPa})(75\text{ m}^3)}{(0.4615\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = \mathbf{1.30\ kg}$$

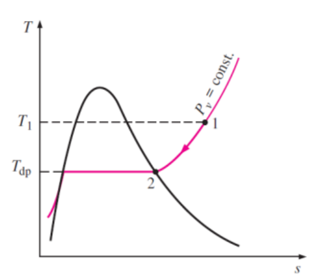
The mass of the water vapor in the air could also be determined from

$$m_v = \omega m_a = (0.0152)(85.61\text{ kg}) = 1.30\text{ kg}$$

3. DEW-POINT TEMPERATURE

- The **dew-point temperature** T_{dp} is defined as *the temperature at which condensation begins when the air is cooled at constant pressure*. In other words, T_{dp} is the saturation temperature of water corresponding to the vapor pressure:

$$T_{dp} = T_{sat\ @\ P_v}$$

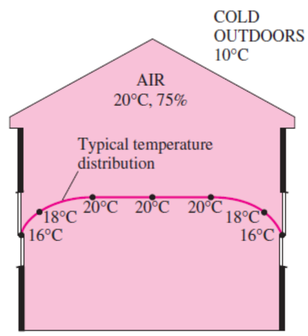


This is also illustrated in Fig. As the air cools at constant pressure, the vapor pressure P_v remains constant. Therefore, the vapor in the air (state 1) undergoes a constant-pressure cooling process until it strikes the saturated vapor line (state 2). The temperature at this point is T_{dp}, and if the temperature drops any further, some vapor condenses out.

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

EXAMPLE 2 Fogging of the Windows in a House

In cold weather, condensation frequently occurs on the inner surfaces of the windows due to the lower air temperatures near the window surface. Consider a house, shown in Figure, that contains air at 20°C and 75 percent relative humidity. At what window temperature will the moisture in the air start condensing on the inner surfaces of the windows?



Solution

The saturation pressure of water at 20°C is P_{sat} 2.3392 kPa . (TABLE A-2).

$$T_{dp} = T_{sat\ @\ P_v}$$

$$P_v = \phi P_{g\ @\ 20°C} = (0.75)(2.3392\ \text{kPa}) = 1.754\ \text{kPa}$$

From Table A-2

$$T_{dp} = T_{sat\ @\ 1.754\ \text{kPa}} = 15.4\ °C$$

Discussion Note that the inner surface of the window should be maintained above 15.4°C if condensation on the window surfaces is to be avoided.

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

Al-Mustaqbal University
Department of Mechanical Power Engineering
Class (2nd)
Subject (**Fundamentals of Refrigeration and Air Conditioning**)

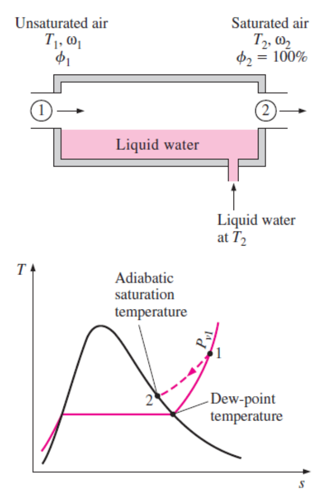
Lecturer (Hassan Ghanim Hassan)
2nd term – Lect. (**Air Properties**)

2-4 ADIABATIC SATURATION AND WET-BULB TEMPERATURES

- Relative humidity and specific humidity are frequently used in engineering and atmospheric sciences, and it is desirable to relate them to easily measurable quantities such as temperature and pressure.

- One way of determining the relative humidity is to determine the dew-point temperature of air. Knowing the dew-point temperature, we can determine the vapor pressure *Pv* and thus the relative humidity.

- Another way of determining the absolute or relative humidity is related to an ***adiabatic saturation process***, shown schematically and on a *T-s* diagram in Fig. The system consists of a long insulated channel that contains a pool of water.
- A steady stream of unsaturated air that has a specific humidity of ω_1 (unknown) and a temperature of T_1 is passed through this channel.
- As the air flows over the water, some water evaporates and mixes with the airstream.
- The moisture content of air increases during this process, and its temperature decreases, since part of the latent heat of vaporization of the water that evaporates comes from the air.
- If the channel is long enough, the airstream exits as saturated air (φ 100 percent) at temperature T_2, which is called the **adiabatic saturation temperature.**



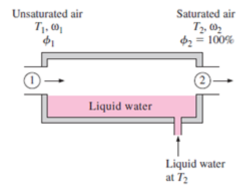
Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

The process involves no heat or work interactions, and the kinetic and potential energy changes can be neglected. Then the conservation of mass and conservation of energy relations for this two inlet, one-exit steady-flow system reduces to the following:

Mass balance:

$\dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a$ (The mass flow rate of dry air remains constant)

$\dot{m}_{w_1} + \dot{m}_f = \dot{m}_{w_2}$ (The mass flow rate of vapor in the air increases by an amount equal to the rate of evaporation $\dot{m}_f$)



or

$$\dot{m}_a\omega_1 + \dot{m}_f = \dot{m}_a\omega_2$$

Thus,

$$\dot{m}_f = \dot{m}_a(\omega_2 - \omega_1)$$

Energy balance:

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}} \qquad (\text{since } \dot{Q} = 0 \text{ and } \dot{W} = 0)$$

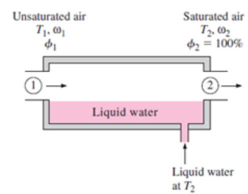
$$\dot{m}_a h_1 + \dot{m}_f h_{f_2} = \dot{m}_a h_2$$

or

$$\dot{m}_a h_1 + \dot{m}_a(\omega_2 - \omega_1)h_{f_2} = \dot{m}_a h_2$$

Dividing by $\dot{m}_a$ gives

$$h_1 + (\omega_2 - \omega_1)h_{f_2} = h_2$$



or

$$(c_p T_1 + \omega_1 h_{g_1}) + (\omega_2 - \omega_1)h_{f_2} = (c_p T_2 + \omega_2 h_{g_2})$$

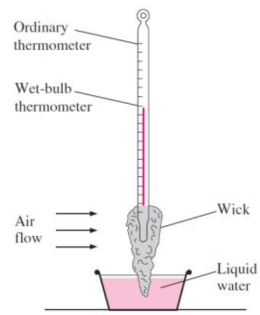
which yields

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}} \qquad \text{where} \qquad \omega_2 = \frac{0.622P_{g_2}}{P_2 - P_{g_2}}$$

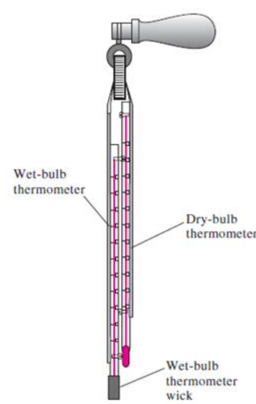
Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

- The adiabatic saturation process discussed before provides a means of determining the absolute or relative humidity of air, but it requires a long channel or a spray mechanism to achieve saturation conditions at the exit.

- Amore practical approach is to use a thermometer whose bulb is covered with a cotton wick saturated with water and to blow air over the wick, as shown in Fig. The temperature measured in this manner is called the ***wet-bulb temperature*** T_{wb}, and it is commonly used in air-conditioning applications.



- The wet-bulb temperature can also be measured by placing the wet-wicked thermometer in a holder attached to a handle and rotating the holder rapidly, that is, by moving the thermometer instead of the air. A device that works on this principle is called a ***sling psychrometer*** and is shown in Fig.
- Usually a dry-bulb thermometer is also mounted on the frame of this device so that both the wet- and dry-bulb temperatures can be read simultaneously.
- Today, hand-held electronic humidity measurement devices based on the capacitance change in a thin polymer film as it absorbs water vapor are capable of sensing and digitally displaying the relative humidity within 1 percent accuracy in a matter of seconds.



Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

EXAMPLE 3 The Specific and Relative Humidity of Air

The dry- and the wet-bulb temperatures of atmospheric air at 1 atm (101.325 kPa) pressure are measured with a sling psychrometer and determined to be 25 and 15°C, respectively. Determine (*a*) the specific humidity, (*b*) the relative humidity, and (*c*) the enthalpy of the air.

Solution

(*a*) The specific humidity ω_1 is determined from :

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}}$$

where T_2 is the wet-bulb temperature and $P_{g2@15°C}$=1.7057kPa (Table A-2) and ω_2 is

$$\omega_2 = \frac{0.622 P_{g_2}}{P_2 - P_{g_2}} = \frac{(0.622)(1.7057\text{ kPa})}{(101.325 - 1.7057)\text{ kPa}}$$

$= \mathbf{0.01065}$ kgH_2O/kg dry air

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}}$$

We take the properties h_{fg2} , h_{g1} and h_{f2} from Table A-2

Thus,

$$\omega_1 = \frac{(1.005\text{ kJ/kg}\cdot°\text{C})[(15 - 25)°\text{C}] + (0.01065)(2465.4\text{ kJ/kg})}{(2546.5 - 62.982)\text{ kJ/kg}}$$

$$= \mathbf{0.00653\ kg\ H_2O/kg\ dry\ air}$$

(*b*) The relative humidity ϕ_1 is determined from

$$\phi_1 = \frac{\omega_1 P_2}{(0.622 + \omega_1)P_{g_1}} = \frac{(0.00653)(101.325\text{ kPa})}{(0.622 + 0.00653)(3.1698\text{ kPa})} = \mathbf{0.332\ or\ 33.2\%}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$h_1 = h_{a_1} + \omega_1 h_{v_1} \cong c_p T_1 + \omega_1 h_{g_1}$$

$$= (1.005\text{ kJ/kg}\cdot°\text{C})(25°\text{C}) + (0.00653)(2546.5\text{ kJ/kg})$$

$$= \mathbf{41.8\ kJ/kg\ dry\ air}$$

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)