15

Humidification and Dehumidification

Humidification is a unit operation, which involves the transfer of liquid water into water vapour.

Though the definition describes the transfer of liquid into vapour, the reverse process is also possible. The process in which the moisture (humidity) is decreased (transfer of vapour to liquid state) in the air is known as *dehumidification*.

These transfer processes depend on temperature and humidity that are already present in the air. Therefore, it is an equilibrium process. In humidification, the dry air is passed over a liquid, so that liquid evaporates into the gas stream. In case of drying of wet solids, the reduction of the moisture content of the solids is the main aim. The humidification of the air stream also occurs, which is a secondary effect. In dehumidification, liquid vapour from the air is removed by condensation as in the distillation process. Air conditioning and drying also involve humidification and dehumidification operations.

In the normal environmental conditions, the air has a certain humidity. Different seasons, day and night timings also exhibit variations in the humidity and temperature. Such variations influence the characteristics of raw materials, finished products and processing conditions.

The behaviour of solids in the presence of moisture (when these are present in the ambient conditions) is of considerable importance in pharmacy. Based on their reactions, substances are classified as:

(*a*) *Hygroscopic substances* have the natural tendency of absorbing moisture or water. Examples are vegetable drugs such as digitalis leaves and chemicals such as sodium sulphate. Liquids such as glycerin, absolute alcohol and concentrated sulphuric acid are also hygroscopic.

(b) *Deliquescent substances* have the natural tendency to absorb water and liquefy. Examples are calcium chloride, potassium carbonate etc.

(c) *Efflorescent substances* have the natural tendency to loose water. Examples are borax, caffeine, quinidine sulphate etc.

Applications

Preservation of pharmaceuticals : The effect of humidity on the materials is as follows.

(1) The substances absorb moisture and undergo chemical degradation such as hydrolysis and oxidation, when they are exposed to excessive humidity.

(2) Physical stability of drugs and dosage forms can be affected. For example, gelatin capsules absorb moisture and become soft and sticky. Suppositories and creams become liquids.

(3) Low humidity has adverse effects. For example, hard gelatin capsules loose water and become dry and brittle.

Therefore, controlled humidity should be maintained.

Evaluation of dosage forms : Environmental test chambers are designed to carry out stability and shelf life testing of drugs. The test chambers offer reproducible temperature and humidity conditions. Climatic conditioning is also required for herbal research, pesticide research and zoology.

Processing conditions in unit operations : In case of normal drying and freeze drying, experimental conditions are chosen based on humidity consideration.

Maintenance of animals and equipment : According to the Drugs and Cosmetics Act and Rules, in many cases the animal house should be air-conditioned. Sophisticated electronic (analytical) equipment are placed and the work is carried in air-conditioned rooms.

Fabrication of environmental conditioners : The principles have been applied for the construction of equipment such as dehumidifiers, air conditioners and refrigerators. Some manufacturing areas where humidity is controlled are given below.

Compression of tablets : In the granulation section, air conditioning is optional, if necessary the conditions are 45% RH and 22°C. In the tabletting section, the conditions are less than 20% RH and 22°C.

Manufacture of soft gelatin capsules : The temperature is usually in the range of 20° C to 22°C and the humidity is controlled to a maximum of 40% RH in the processing areas and between 20 and 30% RH in the drying areas.

The composition and properties of mixture of air and water vapour are essential to maintain the desired environmental conditions. The thermal properties of such a mixture are also important. The discussion in this chapter is devoted to air-water systems, however, the principles can be applied to liquid gases also.

Definitions

The basic definitions of different terms involved are discussed in order to appreciate the theory, practice, handling of equipment etc.

Humidity (H) : It is also known as *humidity ratio*. It is mathematically expressed under any given set of conditions as:

$$\text{Humidity, } H = \frac{\text{mass of vapour present in the air (kg)}}{\text{mass of dry air (kg)}} \qquad (1)$$

Normally, the amount of vapour is measured in terms of pressure, but not in weight terms. Let the partial pressure of water vapour in the sample of air in question be p_A kilopascals. Then humidity in equation (1) may be expressed as:

$$\text{Humidity, } H = \frac{\text{partial vapour pressure of water in air}}{\text{partial vapour pressure of dry air}} = \frac{p_A}{(1 - p_A)} \qquad (2)$$

Since molecular weights of water and air are 18 and 29, respectively, then humidity at the temperature and pressure can also be written as:

$$H = \frac{M_A p_A}{M_B(1 - p_A)} = \frac{18 p_A}{29\ (1 - p_A)} \qquad (3)$$

where M_A = molecular weight of gas or vapour (water)
M_B = molecular weight of air

Humidity at saturated gas (air) (H_s) : At a given temperature and pressure, if the gas in vapour (air) is in equilibrium with the liquid gas, then that gas is said to be *saturated*. If H_s is the saturated humidity and P_A is the vapour pressure of the liquid, then,

$$H_s = \frac{M_A P_A}{M_B(1 - P_A)} \quad (4)$$

Percent humidity (H_A) : Percentage of humidity may be expressed, at certain temperature and pressure, as:

$$\textit{Percent humidity } (H_A) = \frac{\text{actual humidity (H)}}{\text{saturation humidity } (H_S)} \times 100 \quad (5)$$

At humidities other than 0 and 100 percent, the percent humidity is less than relative humidity.

Relative humidity (H_R) : Relative humidity is expressed as a percentage. It is defined mathematically at a temperature as:

$$\textit{Relative humidity, } H_R = \frac{\text{actual partial pressure of water vapour in the air-water mixture } (p)}{\text{partial pressure of water vapour at saturation } (p_s)} \times 100 \quad (6)$$

Humid volume (V) : It is the volume occupied by a unit mass of dry gas and its associated vapour

Humid heat : It is the heat required to raise unit mass of dry gas and its associated vapour through one unit difference in temperature at constant pressure.

Mathematically it is expressed as:

$$s = C_a + HC_w \quad (7)$$

where s = humid heat, kJ/kg·K
C_a = specific heat capacity of gases, kJ/kg·K
C_w = specific heat capacity of vapour, kJ/kg·K
H = humidity

For air-water system

$$\text{Humid heat} = 1.00 + 1.9 \text{ H kJ/kg·K}$$

Saturated volume : It is humid volume of saturated vapour.

Enthalpy : Enthalpy of air-water vapour is the heat content of 1 kg of dry air and its associated moisture (water vapour) expressed as kilojoules per kg of dry air.

Dew point : It is the temperature to which a mixture of air-water vapour must be cooled (at constant humidity) to become saturated (i.e., to be in equilibrium with liquid at the dew point).

Dry bulb temperature : It is the temperature of moist air when it is measured at rest by any instrument, which is not affected by the moisture content of air or by radiation.

Wet bulb temperature–Theory : Wet bulb temperature is the dynamic equilibrium temperature attained by a water surface when exposed to air under adiabatic conditions.

Consider a case in which the air is unsaturated at a given temperature and humidity. Such a stream of air is passed over a wet surface under adiabatic conditions, i.e., no heat is received from or given to the surroundings during the operation.

The initial temperature of the wet surface is approximately that of the air. A partial pressure difference (driving force) is set up between air and wetted surface. The water tends to evaporate from the surface and increases the humidity of the air. As a result, the temperature of the surface decreases and sensible heat will be transferred from the air to wetted surface. Ultimately a steady state will be reached at which the loss of heat due to the heat of evaporation is exactly balanced by the heat passing from the air into the water as *sensible heat*. Under these conditions, the temperature of water remains constant. This temperature is called wet bulb temperature.

If the initial temperature of the wetted surface is less than wet bulb temperature, it will rise to the wet bulb temperature. Since heat transfer and mass transfer are observed in the above process, their coefficients are important and are effected by many factors. The wet bulb temperature depends upon the temperature and humidity of air.

HUMIDITY CHARTS AND ITS UTILITY

Humidity Charts

For engineering calculations, the properties of mixture of air and water vapour are necessary. *Humidity charts* or *psychometric charts* are helpful for this purpose. Three types of plots are shown in Figure 15-1.

Humidity vs. temperature : In this chart, humidity (expressed as kg of water per kg of dry air) is plotted on *y*-axis and temperature (in °C) is plotted on *x*-axis at atmospheric pressure. The plots are curved and each represents a definite humidity value. The following information may be obtained from the chart.

(a) Any point on the chart represents the temperature and humidity of the sample of air.

(b) The curved line marked 100% gives the humidity of saturated air at various temperatures.

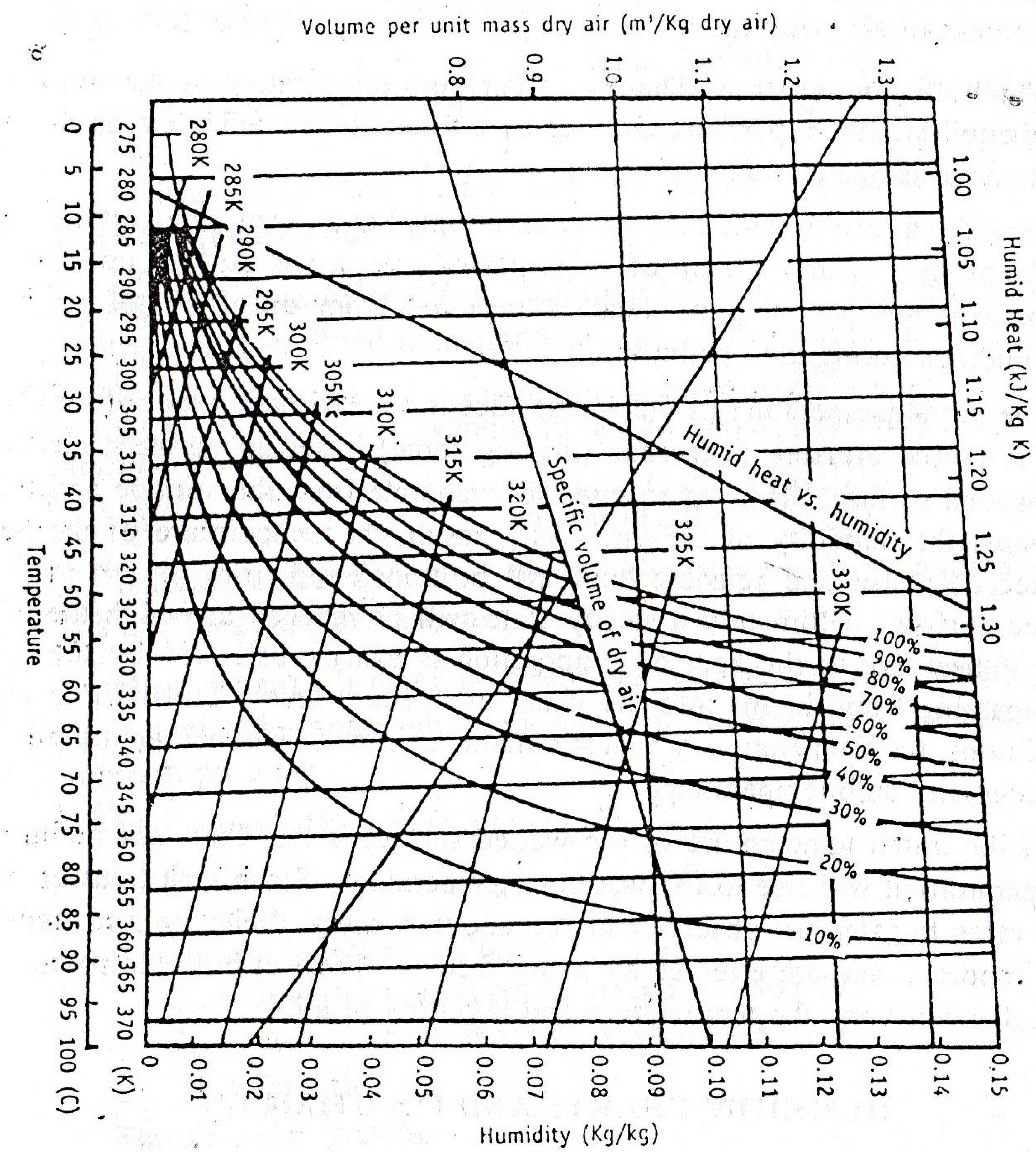


Figure 15-1. Humidity chart, air-water at 1 atmosphere.

(c) To the left of the saturation curve (100% RH), mixtures of air and water vapour can not exist.

(d) Curved lines below the saturated air curve (100% RH) represent various percents of humidity, namely 60%, 40% etc.

Humid heat vs. Humidity : This line is plotted by taking humidity on the right-hand edge (y-axis) and humid heat (kilojoules per kg·Kelvin) along the top of the chart (x-axis). These lines are useful for designing the air conditioners.

Specific volume vs. temperature : The line for specific volume of dry air (and for the saturated volume) is plotted with temperature on x axis and metre cube per kg dry air along the left edge of chart on y axis. The humid volume of a sample of air at a given temperature and humidity can be found by linear interpolation to the humidity-temperature curve.

Adiabatic cooling lines : The groups of lines, which are right side of the saturation curve, are the adiabatic cooling curves. These curves serve two very useful purposes. Firstly, they can be used to determine humidity from the knowledge of wet-bulb and dry-bulb temperatures. Secondly, these curves show the changes in humidity during drying under adiabatic conditions.

Use of Humidity Chart

Humidity chart is a source of data on a definite air-water mixture. A portion of the chart is shown in Figure 15-2. Assume that a given stream of unsaturated air is having a temperature, t_1. It can be represented by point A. By moving vertically downwards, the axis gives the temperature, t_1 which is dry-bulb temperature. Point A is used to illustrate the usefulness of chart. The following types of data can be obtained from the chart.

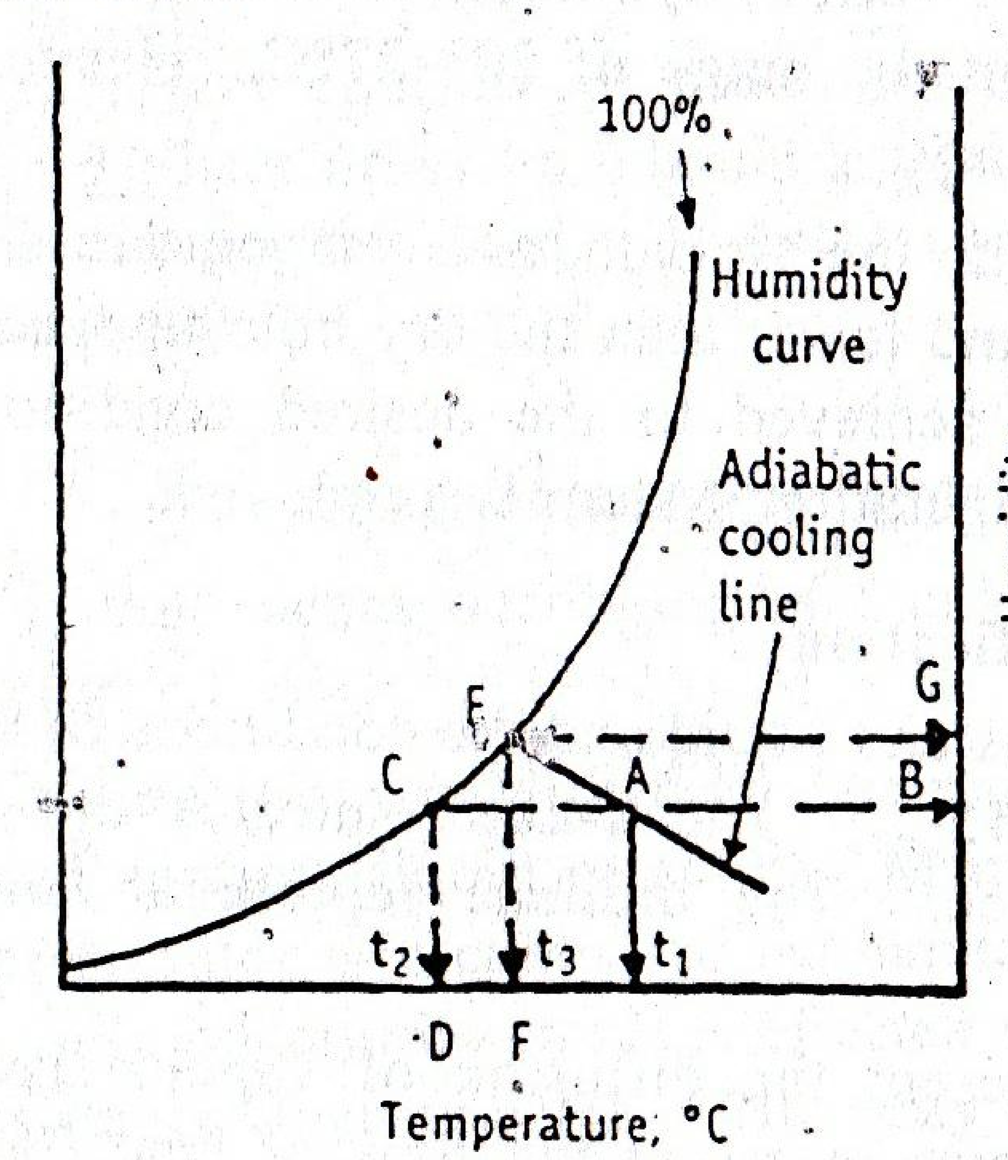


Figure 15-2. Use of humidity chart.

(1) **Humidity :** From point A moving horizontally towards humidity axis gives an intercept point B on axis, which is the humidity of the sample.

(2) **Dew point :** From point A moving horizontally towards left to the 100% line gives an intersection point C. Moving vertically from C downwards to temperature axis gives an intercept point D, which is the dew point temperature, t_2.

(3) **Adiabatic-saturation temperature :** From point A moving along the adiabatic cooling line towards the 100% line gives an intersection point E. Moving vertically from point E downwards to temperature axis gives an intercept point F, which is the adiabatic-saturation temperature t_3.

(4) **Humidity at adiabatic-saturation :** From point E moving horizontally towards humidity axis gives an intersection point G, which is the humidity at adiabatic saturation line.

In a similar manner, humid volume and humid heat can be obtained, by considering the corresponding lines, humid volume and humid heat lines, respectively, as shown in Figure 15-1.

HUMIDIFICAITON

Humidification is the process of increasing the moisture in the air.

Applications

In pharmaceutical industry, if special conditions are not prescribed, the humidity required for various operations is from 20 to 30% RH and the temperature is within the range of 20°–27°C. Hence, dry weather humidification is necessary.

By spraying water into the air path, at a temperature higher than the dew point temperature and lower than the dry bulb temperature, cooling and humidification are achieved to the desired conditions. For this purpose, absorption refrigeration system is employed.

Mechanism of Humidification

The interaction of gas and liquid and the conditions of humidification are shown in Figure 15-3. The x-axis indicates the perpendicular distance to the interface. The ordinate represents temperature and humidity.

Broken arrows represent the diffusion of vapour through the gas phase. Continuous arrows represent the flow of heat (both latent and sensible) through the gas and liquid phases.

In adiabatic humidification, the air is in contact with the liquid at constant temperature. The humidity at the interface (H_i) must be greater than humidity (H_y) of the gas, so that the air gets humidified. Since water is vaporised, the latent heat is transferred from the liquid to gas. The gas temperature (t_y) must be higher than the interface temperature (t_i) in order that sensible heat may flow to the interface. (Heating or cooling without the addition or subtraction of moisture content is called sensible heating or cooling).

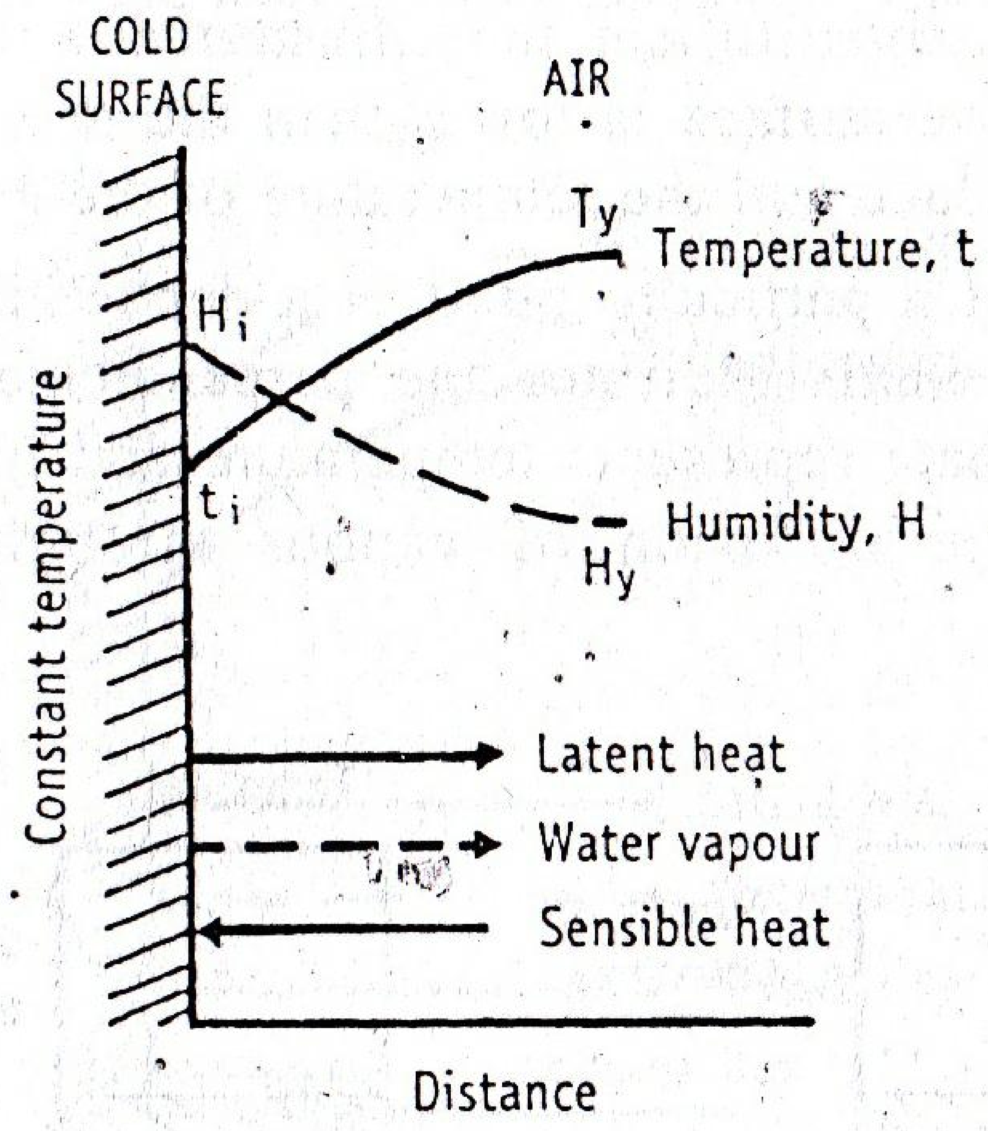


Figure 15-3. Conditions in adiabatic humidifier.

H_i and t_i represent equilibrium conditions of interface (saturation conditions). Latent heat flows from liquid to gas and sensible heat flows from gas to liquid get balanced. Therefore, there is no temperature gradient in the liquid.

DEHUMIDIFICATION

Dehumidification means decreasing of humidity (removal of moisture) from the air.

Dehumidification is accomplished by bringing the moist air in contact with a cold surface (liquid or solid). Many large air conditioner plants incorporate automatic control of the humidity and temperature of the issuing air. Temperature control is effected with the aid of thermocouple or resistance thermometer. Humidity is controlled using a thermocouple recording of the difference between the wet and dry-bulb temperatures.

Applications

Dehumidifiers are used in special heat transfer devices to liquefy vapour by removing their latent heat. Such systems are called *condensers*.

In pharmaceutical industry, many operations are carried at a stated humidity to get optimum results. In many parts of India (e.g., Bengal, Kerala etc.) the air is very humid and it becomes difficult to carry on operation with hygroscopic substances even in air-conditioned room. Hence, dehumidifiers are installed for certain operations.

Mechanism of Dehumidification

The principle of dehumidification is illustrated in the Figure 15-4. If the temperature of the surface is lower than the dew point of the gas, condensation takes place and the temperature of the gas falls.

The conditions at a particular point in a dehumidifier are shown in Figure 15-5. The x-axis indicates the perpendicular distance to the interface. The ordinate represents temperature and humidity. (Broken arrows represent the diffusion of vapour through the gas phase.

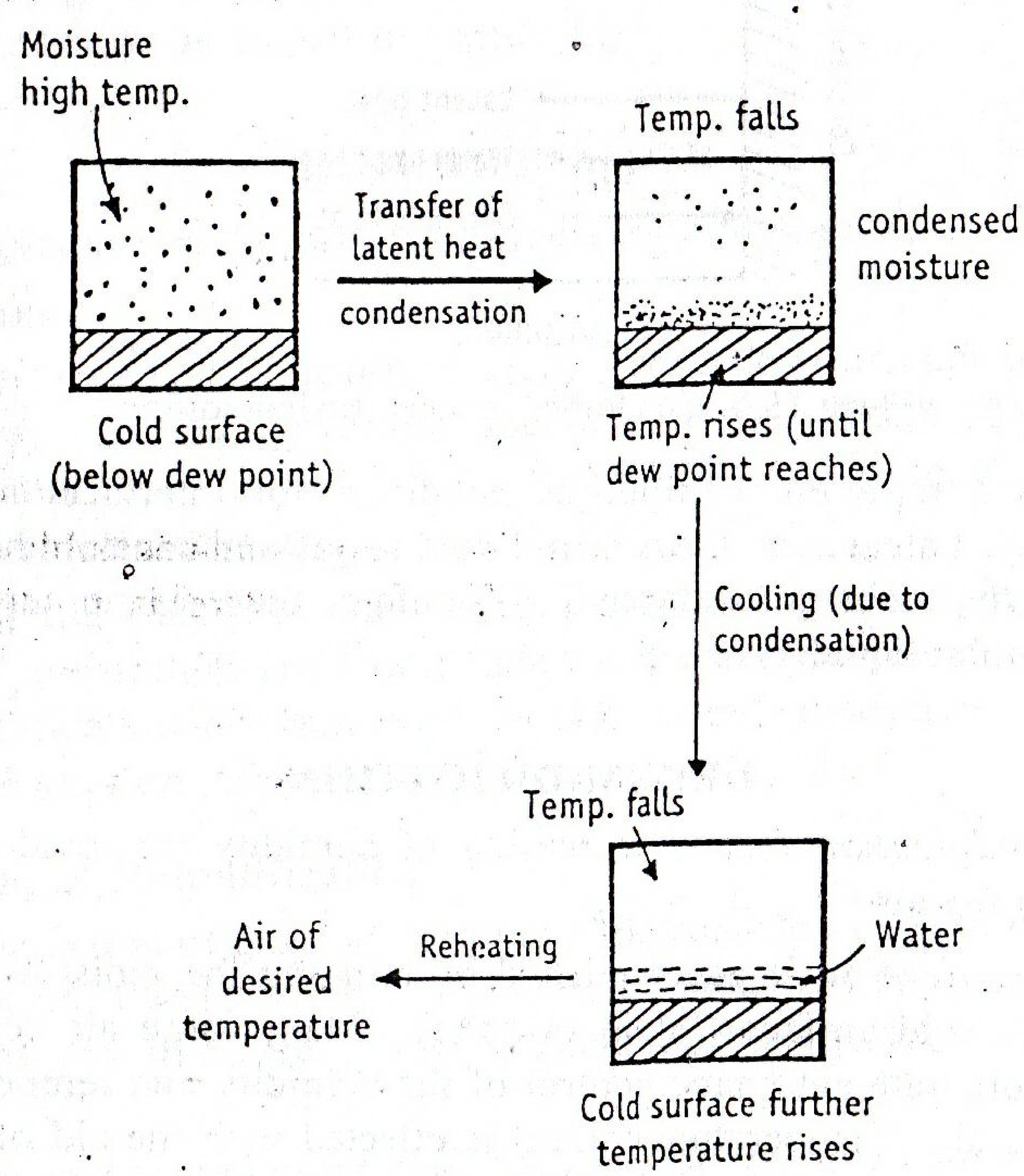


Figure 15-4. Principle of dehumidification process. Temperature and humidity are reduced simultaneously.

Unbroken arrows represent the flow of heat (both latent and sensible) through the gas and liquid phase).

In this case, humidity of air, H_y, is greater than the humidity at interface, H_i and, therefore, water vapour diffuses to the interface. Since vapour is condensed to water, latent heat is transferred to the water. So the temperature of the surface tends to rise and that of the air decreases. It would be expected that the air would cool at constant humidity, until the dew point is reached (Figure 15-4).

Since t_i and H_i represent saturated air, t_y must be greater than t_i. Hence the bulk of the air would be saturated with water vapour at that temperature. The sensible heat is transferred into the water.

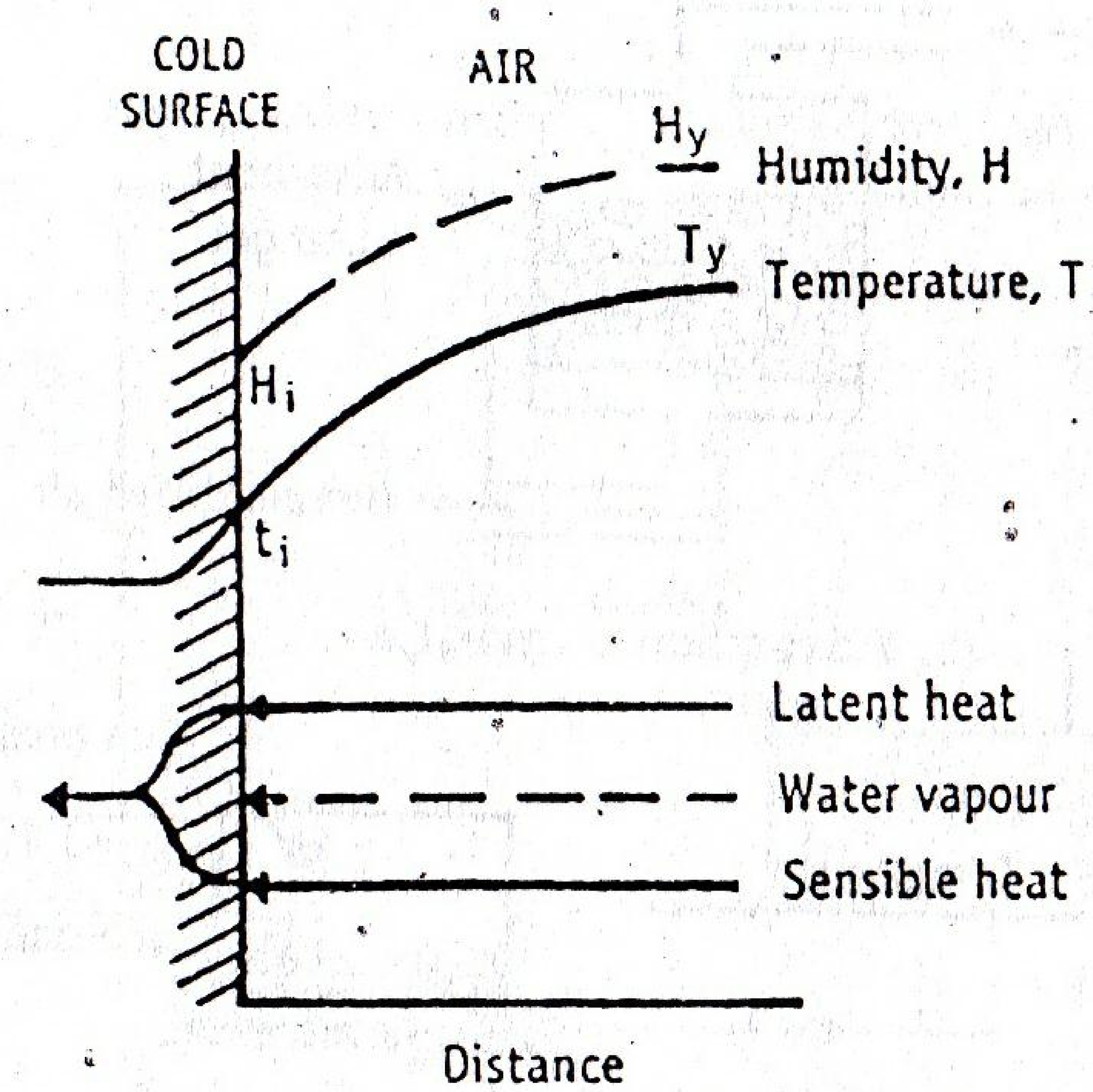


Figure 15-5. Condition of dehumidifier.

The air in contact with the surface is cooled below its dew point. Subsequently, air from a distant place condenses, which requires time to cool. Therefore, effective mixing enhances the dehumidification. Normally, the temperature and humidity are reduced simultaneously throughout the process. After dehumidification, the gas can be reheated to its original dry-bulb temperature.

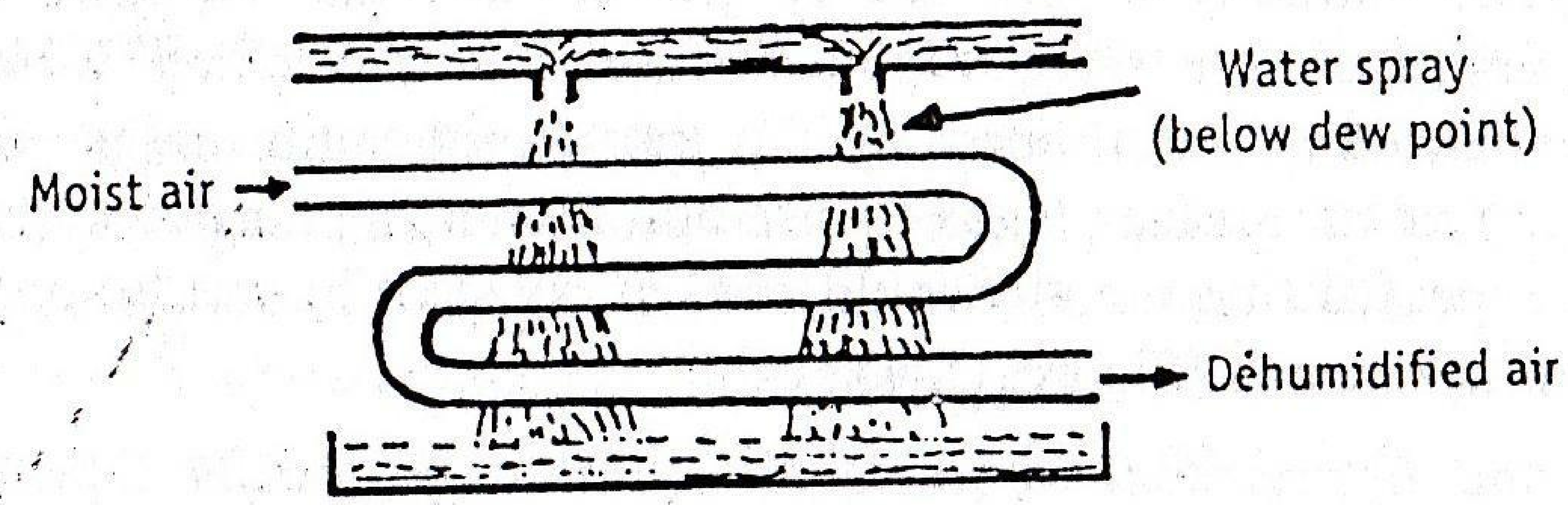
Approaches to Dehumidification

Different approaches to dehumidification are described in Fig. 15-6.

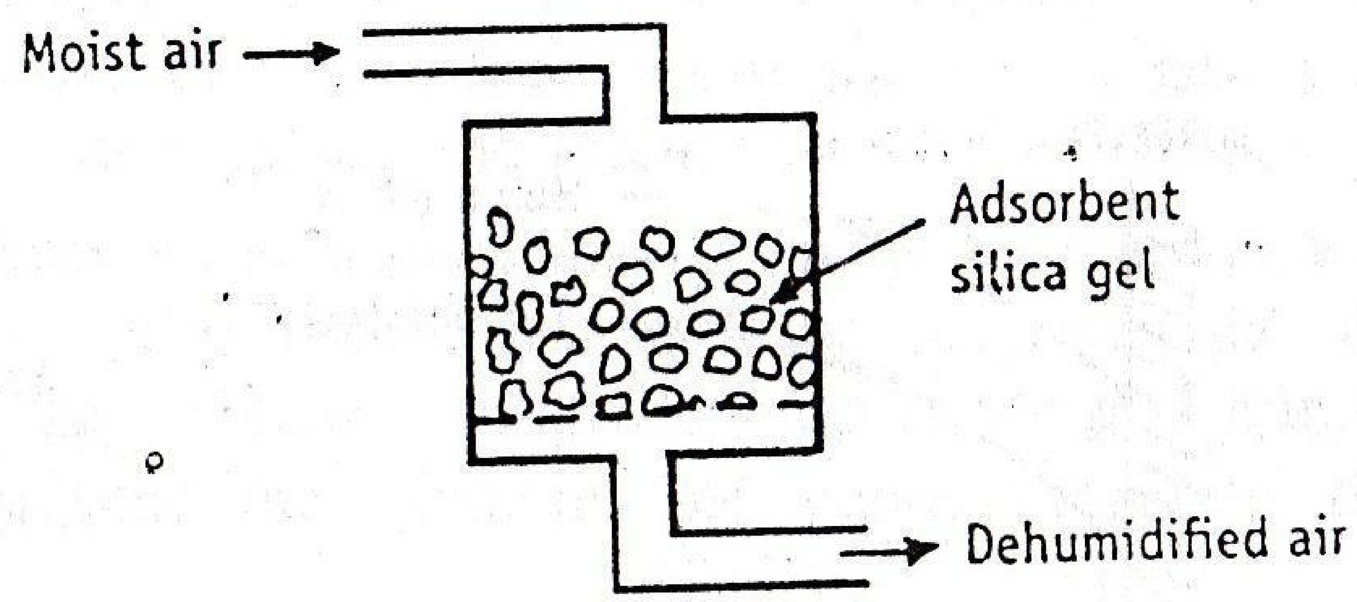
(a) Moist air is brought in contact with a spray of cold water, whose temperature is lower than the dew point of the entering air. (Figure 15-6a)

(b) Humidity can be reduced by compressing the air (Figure 15-6c). During compression, the partial pressure of the vapour increases.

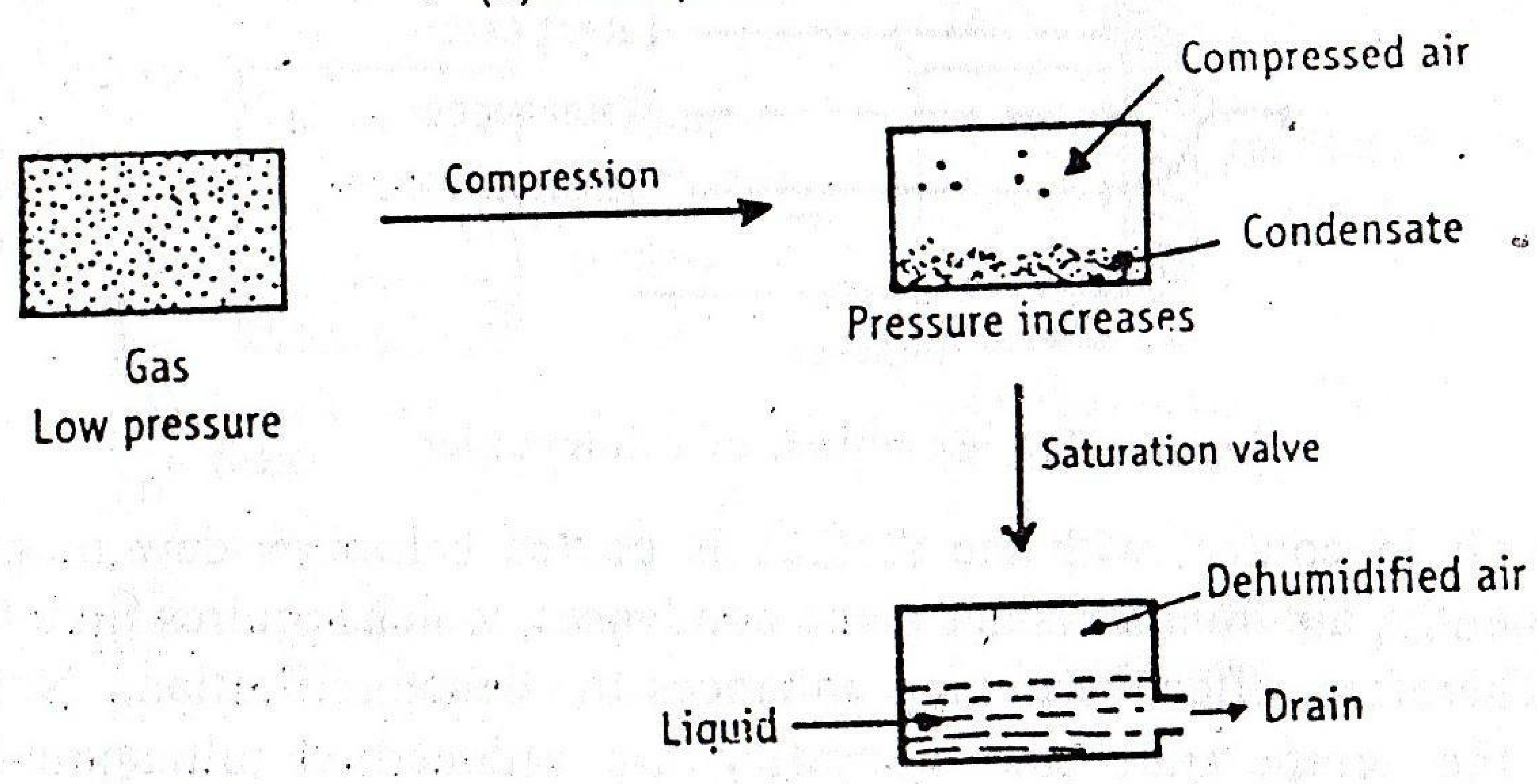
As soon as it reaches the saturation value, condensation takes place. The water gets liquefied and drained off.



(a) Spraying of water on moist air.



(b) Adsorption of moist air.



(c) Compression of moist air.

Figure 15-6. Approaches for achieving dehumidification.

(c) Moist air is passed over a solid adsorbent surface or through a liquid adsorbent spray (Figure 15-6b). Dehumidification occurs due to the lowering of water vapour pressure. The adsorbents used are silica gel or activated alumina. The liquid adsorbents are solutions of inorganic salts (brine, lithium chloride) or organic compounds such as ethylene glycol. Reactivation of adsorbents

is necessary. It is done intermittently or continuously. Silica gel has to be regenerated as soon as or even before it adsorbs 40% of its weight of water.

REFRIGERATION

Mechanical refrigeration is a process of lowering the temperature of a substance less than that of its surroundings.

The simplest form of refrigeration observed in daily life is the use of ice. Ice absorbs heat from the surroundings and melt. During this process the surrounding area becomes cool due to the loss of heat. The capacity of refrigeration is expressed in tonne.

A *tonne of refrigeration* is defined as the rate of heat removal from the surroundings equivalent to the heat required for melting 1 tonne of ice in one day.

If the latent heat of fusion of ice is taken as 336 kilojoules per kg, one tonne is equivalent to heat removal at a rate of 14,000 kilojoules per hour.

Applications

Refrigeration is used extensively in air conditioning plants in the areas for comfort and processing areas. It is used in several other areas as given below.

(1) Removal of heat from chemical reactions.

(2) Preservation of thermolabile substances. For example, insulin, ACTH, pituitary hormones and vaccines are stored in refrigerator. It is extremely important to store all blood products such as whole human blood at as low a temperature as possible above freezing point.

(3) Liquefy processing gas.

(4) Separation of vapour by distillation.

(5) Purification of products.

(6) Preferential freeze-out of one component from a liquid mixture.

Refrigerants

Refrigerant is a liquid which readily absorbs heat when evaporated at a low temperature and pressure and gives out heat on condensing at a higher temperature and pressure. Refrigerants may be primary or secondary.

Primary refrigerants are those liquids that change from a liquid to a gas after absorbing heat.

A number of refrigerants are available, which permits the selection for a specific application. Examples of primary refrigerants and their chemical constitution are given below.

Numerical designation	*Chemical name*
R11	Trichlorofluoromethane (Cl_3FC)
R12 (Freon 12)	Dichlorodifluoromethane (Cl_2F_2C)
R13	Chlorotrifluoromethane (ClF_3C)
R21	Dichlorofluoromethane (Cl_2FCH)
R22 (Freon 22)	Chlorodifluoromethane (ClF_2CH)
R113	Dichlorotetrafluoroethane
R1150	Ethylene
R1270	Propylene
	Ammonia

Secondary refrigerants are those liquids, which act only as heat carriers. Examples are brine, air and water.

The choice of a suitable refrigerant depends upon many factors, although a few are mentioned below.

(1) The latent heat of vaporisation should be large so that the desired cooling effect is produced.

(2) At normal temperature and pressure, refrigerant must be in vapour phase and on compression and cooling it should be liquefied easily.

(3) The pressure required to liquefy the vapour of the refrigerant in the condenser section must be so as to maintain it usually at room temperature.

(4) The vapour pressure of refrigerant liquid in the evaporator section must be maintained at about −15°C greater than the atmospheric pressure.

(5) The specific volume of the refrigerant vapour should not be large.

Principle

The refrigeration cycle is also known as vapour compression cycle. This is illustrated using single-stage vapour compression.

The basic construction of refrigeration cycles is shown in Figure 15-7. The cycle operates at two pressures, high and low, to enable the process to produce a continuous cooling effect. The sequence of events in the refrigeration cycle is explained by taking basic components in order.

(a) *Receiver or condenser* : The liquid refrigerant is kept in a container namely condenser. The refrigerant is under pressure and the vapour and liquid phases are in equilibrium.

(b) *Expansion valve* : It is a device, which controls the rate of flow of refrigerant into the evaporator, converting the refrigerant from high pressure to low pressure. The refrigerant enters a low-pressure zone.

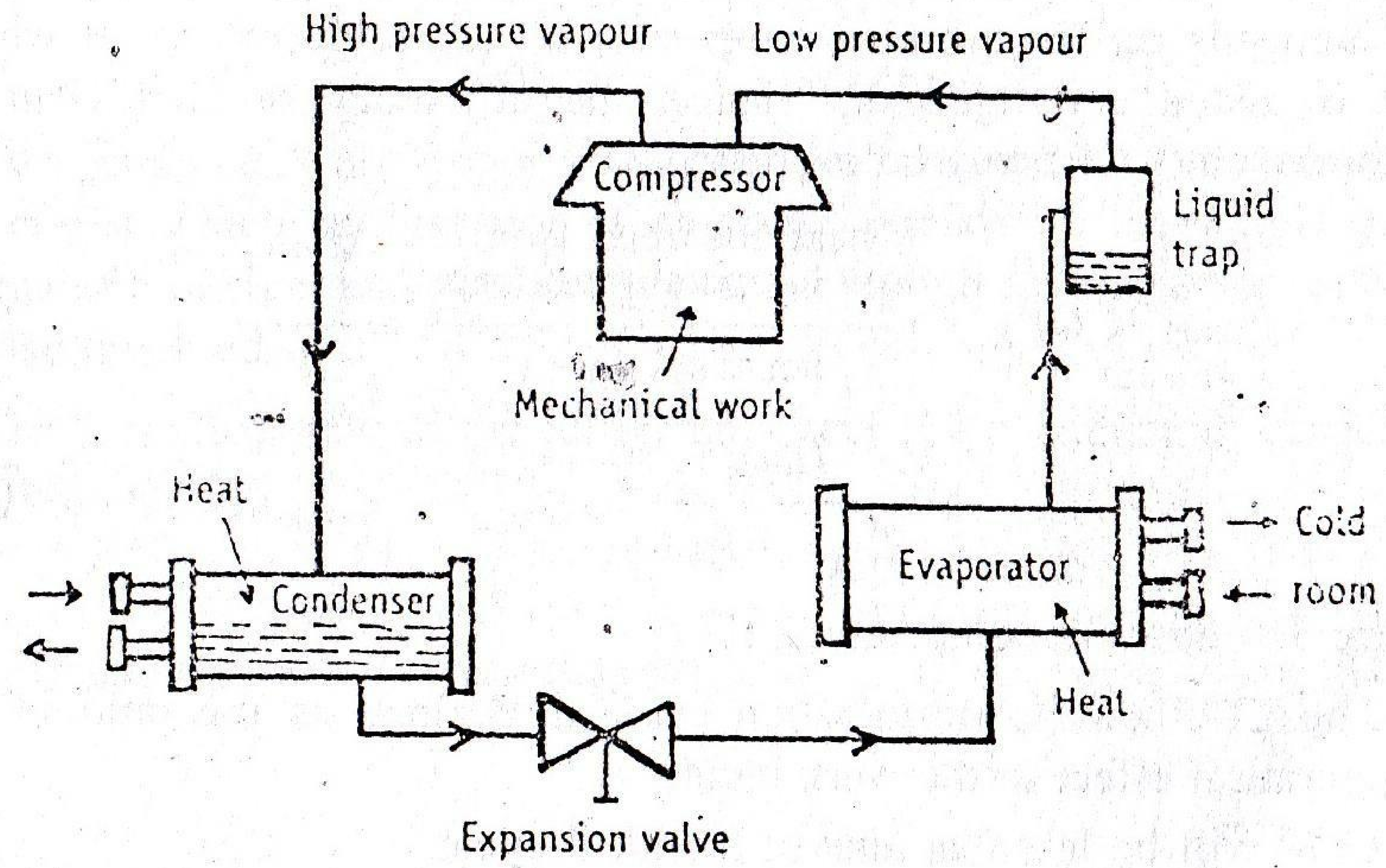


Figure 15-7. Basic construction of refrigeration cycle.

(c) *Evaporator* : Subsequently, a mixture of vapour and liquid enters the evaporator, which consists of coils. Here the refrigerant evaporates by absorbing heat from the space. The molecules move apart by breaking intermolecular forces. The energy (heat) required for this process is taken from the surrounding environment, i.e., space, which is to be cooled. In this step, liquid vaporises completely, though some liquid still remains.

(d) *Liquid trap* : A liquid trap is used to remove liquid, which is then returned to receiver (condenser).

(e) *Compressor* : The saturated vapour is allowed to pass through the compressor. During compression, heat of compression is added to vapour and the pressure raises. The compression is adiabatic and on the discharge side it produces a supersaturated gas. The valve should be opened very slowly. A part of the liquid vaporises to give a stream of high velocity.

(f) *Condenser* : The supersaturated vapour flows to the condenser where the gas is liquefied. These condensers can be air-cooled or water-cooled.

Thus, one cycle is completed as shown in Figure 15-7 and the process continues.

Theory

An ideal refrigeration cycle is a reversal of Carnot cycle as per the second law of thermodynamics. Similar to Carnot cycle, refrigeration also depends on the working temperatures, i.e., temperatures at which heat is added and rejected. Hence, the efficiency or coefficient of performance (COP) may be expressed as:

$$COP_R = \frac{\text{heat absorbed from low temperature source}}{\text{net work input}} = \frac{Q_{low}}{W} \quad (18)$$

$$= \frac{T_{high}}{T_{high} - T_{low}} \quad (19)$$

where T = absolute temperature, K.

The COP of the refrigeration cycle is defined as the ratio of the refrigeration effect to the work input.

COP will be less than that of the ideal cycle.

As mentioned in the working of a refrigerator, the refrigeration process can be understood from the pressure-enthalpy (heat content) charts. During this process, the refrigerant undergoes a change in enthalpy. Essentially the refrigeration process consists of evaporation and compression.

(i) As the liquid evaporates, it takes heat from the environment (the interior of refrigerator or substance placed in it) so that environment gets cooled. The *net refrigerant effect* (RE) accomplished in the evaporator may be written as:

$$\textit{Net refrigerating effect, } Q_{low} = h_g - h_f \quad (20)$$

where h_g = enthalpy of gas (vapour) leaving the evaporator, kJ/kg
h_f = enthalpy of liquid leaving the condenser, kJ/kg

The refrigerant effect is defined as the amount of heat removed from the surroundings per unit mass flow of refrigerant.

(ii) Work is being done on the refrigerant vapour to compress it. Heat of compression is expressed as:

$$\textit{Heat of compression, } W = h_d - h_g \quad (21)$$

where h_d = enthalpy of the discharge, kJ/kg
h_g = enthalpy of inlet compressor, kJ/kg

The work of compression is determined by multiplying the heat of compression by the mass of flow.

Combining equations (20) and (21), COP can be written as:

$$COP = \frac{\text{refrigerating effect}}{\text{work input for compression}} \quad (22)$$

Two parameters are important for the performance of a refrigerator. The rate at which refrigeration is obtained depends on the weight and volume of a refrigerant circulated per tonne, though several other factors are also involved.

The mass flow rate of the refrigerant circulated per tonne of capacity is determined by:

$$\textit{Refrigerant mass flow rate, } (\text{kg/h}) = \frac{\text{Rate of removal of heat (kJ/h)}}{\text{Refrigerant effect (kJ/kg)}} \quad (23)$$

$$= \frac{14000 \text{ kJ/h}}{Q_{low}}$$

The theoretical volume of vapour to be handled per tonne may be expressed as:

$$\textit{Theoretical volume of vapour } (\text{m}^3/\text{h}) = \text{mass flow rate} \times v_g \quad (24)$$

where v_g = specific volume of the suction vapour entering the compressor, m^3/kg.

In order to achieve low temperature effect, it is necessary to have a high compression ratio. A single stage refrigeration cycle cannot yield low temperature effect. To avoid high compression ratio, it is necessary to have several stages of compression. It is necessary for low temperature applications.

A refrigeration system that consists of more than one stage of compression is defined as *multistage refrigeration system*.

Temperatures from -101.1 to $-78°C$ can be obtained by using refrigeration system containing multistage systems.

AIR CONDITIONING

Air conditioning is the process of treating air so as to control its temperature, humidity, cleanliness and distribution simultaneously to meet the requirements of the conditioned space.

In the production area, a desired environment, i.e., humidity and temperature, is maintained. Therefore, air conditioning facilities are essential. Today many offices and pharmaceutical plants are equipped with air conditioners.

Applications

Promoting the human comfort : Human body feels comfort when the heat produced by metabolism of human body is balanced by the sum of the heat dissipated to the surroundings and the heat stored in human body. Air purity is of utmost importance. For example, increase in carbon dioxide adds discomfort. The efficiency and health of workers should be maintained at safe tolerance limits.

Maintenance of proper conditions for the manufacture, processing and preserving of material and equipment : The following areas are identified.

Compression of tablets : In the granulation section, the air conditioning is optional, if necessary the conditions are 45% RH and 22°C. In the tabletting section, the conditions are less than 20% RH and 22°C. In the production of effervescent products, dry syrups, controlling humidity is a vital factor. The relative humidity should not exceed 10 to 15% and temperature is at 22°C.

Manufacture of soft gelatin capsules : The temperature is usually in the range of 20°C to 22°C and the humidity is controlled to a maximum of 40% in the operating areas and between 20 and 30% in the drying areas.

Manufacture of sterile products : In case of parenterals and ophthalmic products, the environmental conditions are much more stringent in filling and sealing rooms. Therefore, the standards of clean air quality are of greater importance. In the production of all biological products (Schedule C & C_1) air conditioning is essential.

Environmental test chambers : These are designed to carry out stability and shelf life testing of drugs. They offer reproducible temperature and humidity conditions. Climatic conditioning is also required for herbal research, pesticide research and zoology.

Maintenance of animals and equipment : According to the Drugs and Cosmetics Act and Rules, the animal houses should be air-conditioned. Sophisticated electronic (analytical) equipment are stored and the work is carried out in air conditioned rooms.

Approaches for Achieving Air Conditioning

Normally the air is allowed to reach complete saturation by providing appropriate conditions. Then humidity is fixed. In commercial equipment, the conditions are somewhat indeterminate and the exit humidity is not quite saturated. Therefore the exit humidity is fixed by varying water temperature according to the characteristics of the specific piece of equipment at hand. This can be achieved by re-heating to the desired temperature.

Consider the following example. When air is entering the equipment, let the initial dry bulb temperature of the air be t_1 and humidity be H_1. It is represented by point A. Let the desired dry-bulb temperature be t_2 and humidity be H_2 at the exit point air (point B). The exit air attains the desired conditions in any one of the following methods.

(A) The sequence of steps is shown in Figure 15-8. The air is first allowed to attain the desired humidity by treating with water using humidity chart. It is represented by point C (wet bulb temperature, t_3).

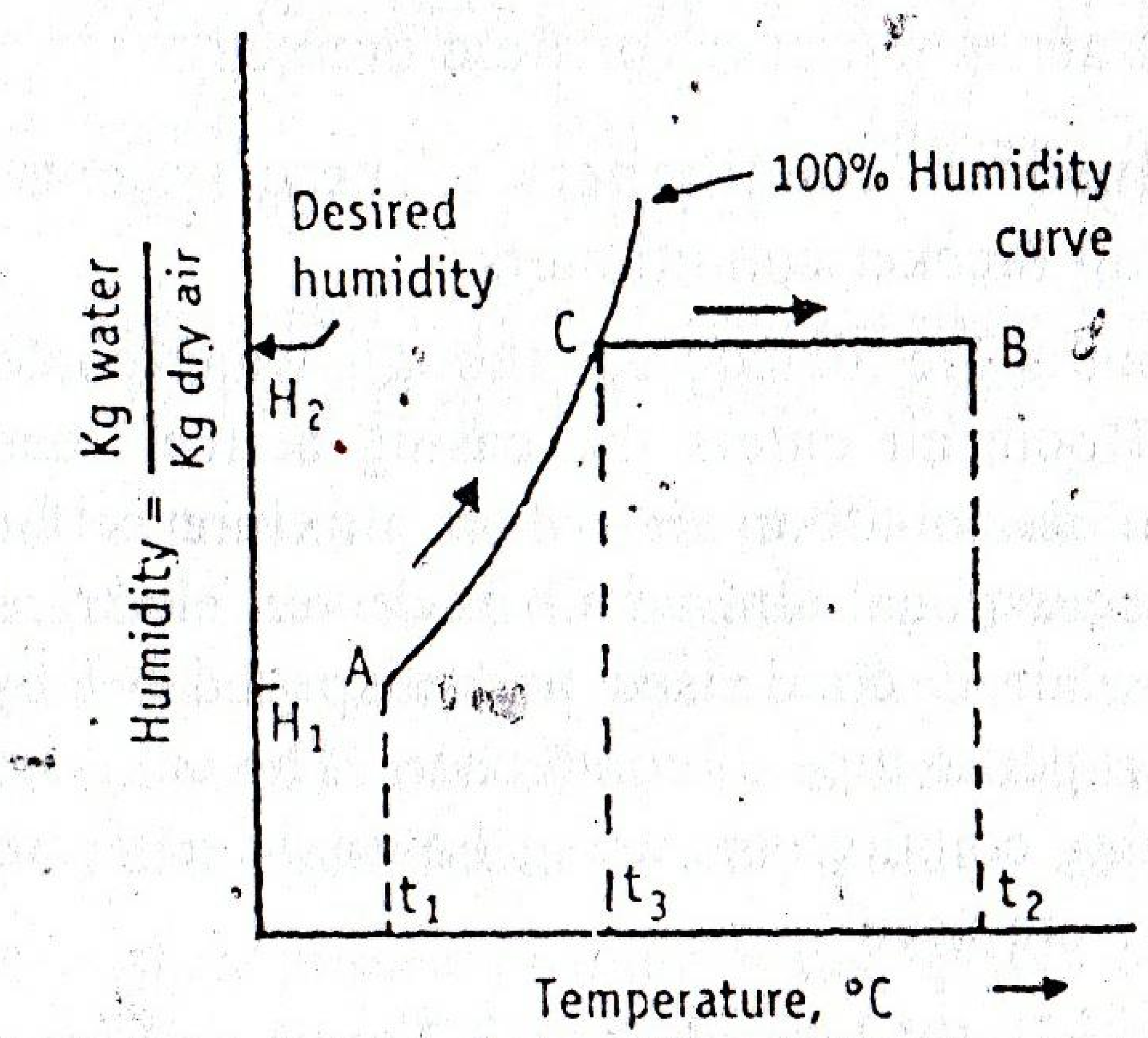


Figure 15-8. Changes in air temperature and humidity for air conditioning process (Approach A), using 100% humidity line of the psychometric chart.

Then it is heated to attain the desired temperature of t_2 at the same humidity. This path of air is represented by ACB in Figure 15-8.

(B) The sequence of steps is shown in Figure 15-9. In the second approach, air is preheated to a temperature, t_4. Subsequently, the air is cooled along the adiabatic cooling line, until it reaches the desired humidity. It is then reheated so as to reach the desired temperature of t_2. This corresponds to path ADCB in Figure 15-9.

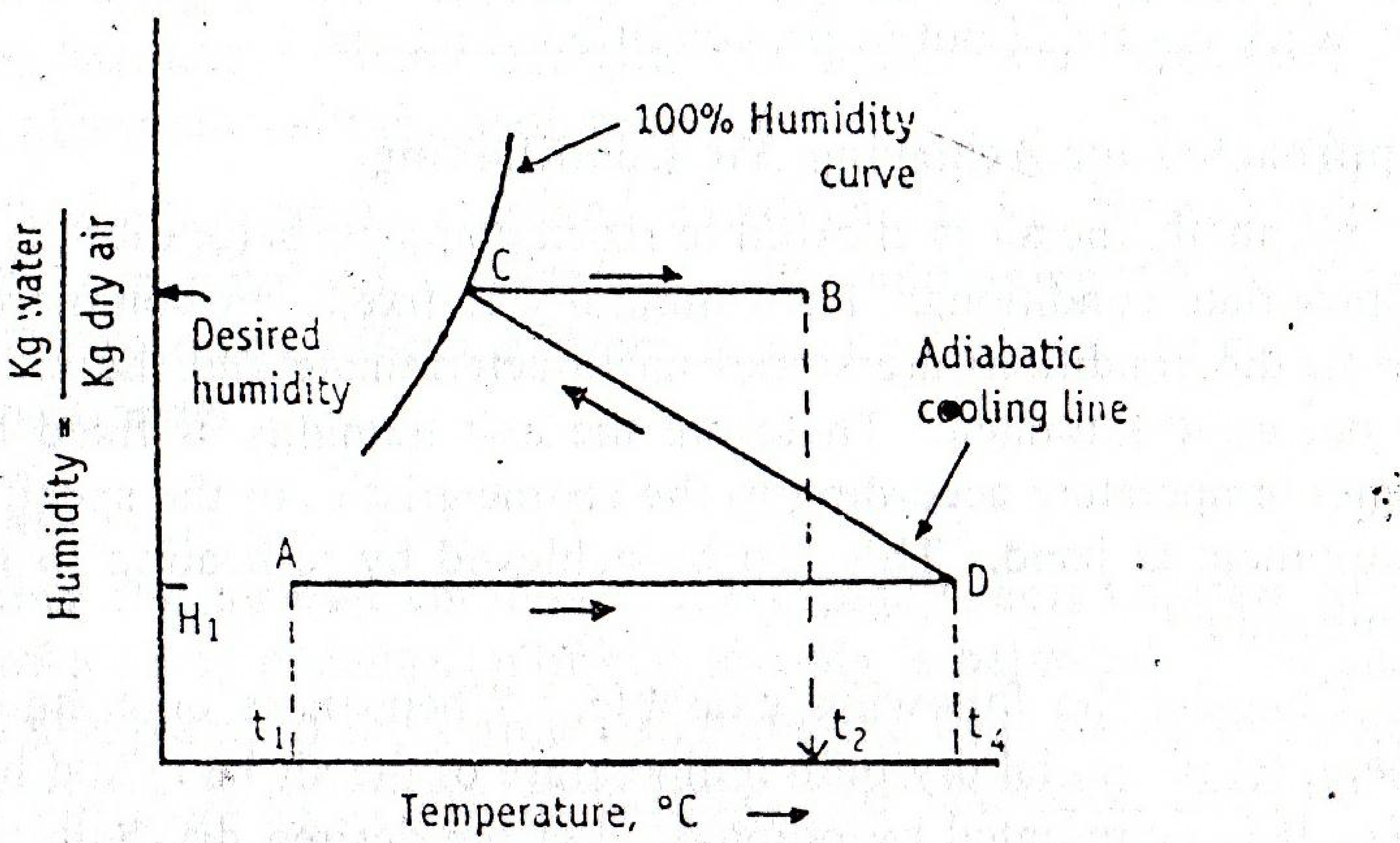


Figure 15-9. Changes in air temperature and humidity for air conditioning process (Approach B), based on adiabatic cooling line.

Types of Equipment

Modern air conditioning equipment generally fall into two classes.

1. Self contained air conditioner (unitary or packaged)
2. Central air conditioner (or field erected).

1. Self contained air conditioners : These systems include window mounted or wall bracket conditioners.

Most of these units are air cooled, though water-cooled types have also been made. Room air enters the casing at the front panel. It is mixed with part of the outdoor air. This mixture is forced over the cooling coils by a centrifugal fan, which is driven electrically. Some of the moisture in the air is condensed and disposed off by means of a single ring of the propeller type of condenser. The units are hermetically sealed. Reciprocating compressors using nontoxic refrigerant and driven by capacitor motors are used.

2. Central air conditioning system : These systems may serve one or several areas with conditioned air being supplied through duct network.

Air cleaning is usually provided using filters, which can be cleaned for reuse or disposable. Cooling is achieved using either water or by direct expansion in refrigerated coils or air washers. Steam or hot water coils are used for heating. Humidification systems may be provided by surface type water nozzles, steam humidifiers or sprayed coils.

Equipment : Air conditioning involves specialised applications of basic thermodynamics, hydrodynamics and fluid flow principles.

Principle : In this type of air conditioner, approach (B) is used. The air is heated to a higher temperature, followed by cooling along an adiabatic cooling line to reach the desired humidity. It is then reheated to the desired temperature at constant humidity. Thus the path ADCB is followed.

Construction : The construction of the equipment is shown in Figure 15-10.

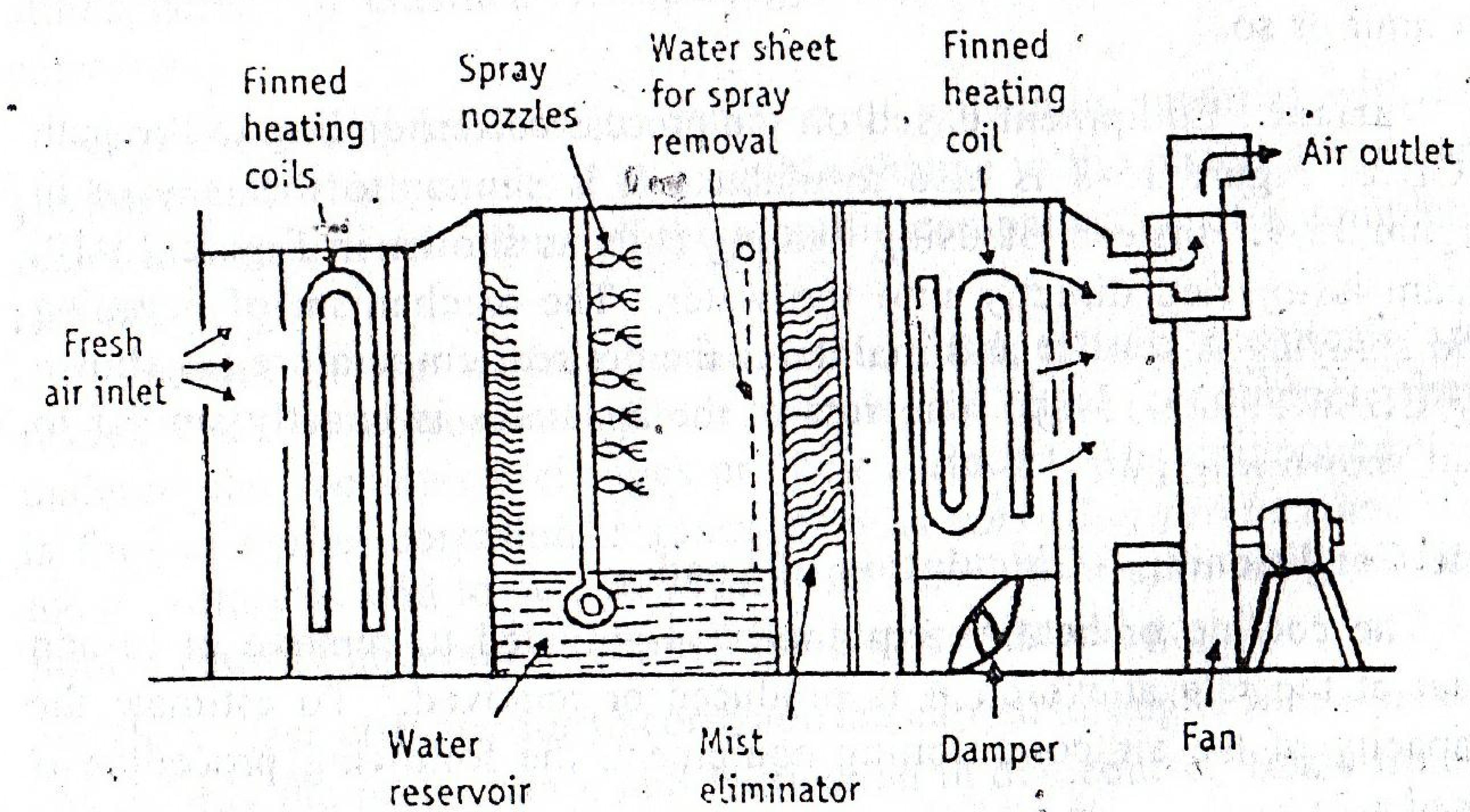


Figure 15-10. Typical, central-stationed air conditioning unit and control systems.

Working : The principle employed in this equipment is approach B. Outdoor air and room air is drawn into the equipment using a fan. Air quality is maintained by allowing the air to pass through the filters in order to remove suspended particles. Air is then allowed to pass through finned coils and heated (as indicated from point A to D in Figure 15-9).

The hot air is then passed through water sprays and is adiabatically cooled and humidified (line DC in Figure 15-9). The pump draws water from the reservoir below and sprays on the air stream. The pump also delivers water to give a curtain of water to eliminate most of the entrained sprays. The air then enters the eliminator baffles where the last entrained water is removed. In the pump discharge, there may be a heater or a provision for steam injection to adjust the water temperature.

A second set of coils performs the final re-heating (line CB in Figure 15-9). The final temperature may be regulated by controlling the steam in the second set of coils or by controlling a bypass damper as shown in Figure 15-9. A fan draws the air through the apparatus and discharges it to the point of use. From this point, the air is sent to the required areas through ducts.

Temperature is regulated by thermostatically controlled heating or cooling units or by a combination of heating-cooling units.

Circulation takes place naturally within area, but it is necessary to use mechanical means to re-circulate air (to replenish air periodically with fresh air) or by ventilation, which circulates fresh air only once in an hour or so.

Variant : Equipment based on the process corresponding to the path ACB of Figure 15-8 is also available. It is similar to that shown in Figure 15-9. Instead of using heating coils as shown in Figure 15-10, steam is injected directly into the water. The mechanism of pumping and spraying is similar and maintains the desired temperature (as shown by CB in Figure 15-8). The rest of the apparatus is exactly similar to that shown in Figure 15-10.

Air Conditioning—Calculation of Load

The cooling or heating equipment is provided to remove or to add heat at the rate at which it is produced or removed. To estimate the capacity of the air conditioning equipment, the following procedure is used.

Step 1. The temperature conditions (outdoor and indoor temperature) are designed for winter and summer outdoor temperatures.

Step 2. Space cooling load is calculated.

(a) Direction and magnitude of wind velocity.

(b) Outside humidity and temperature.

(c) The nature of construction materials.

(d) Orientation of openings, windows and doors.

(e) Period of occupancy and the number of persons in the room and their activities.

Hence, air conditioning is provided under assumed conditions keeping variables fixed. Allowances have to be made for changes in the assumed conditions.

Glossary of Symbols

C_a = Specific heat capacity of gases, kJ/kg.
C_w = Specific heat capacity of vapour, kJ/kg.
COP = Coefficient of performance.
H = Humidity, kg/kg.
H_A = Per cent humidity.
H_R = Relative humidity.
H_s = Humidity at saturated gas (Air).
h = Hour
h_d = Enthalpy of discharge leaving compressor, kJ/kg.
h_g = Enthalpy of gas leaving evaporator, kJ/kg.
h_f = Enthalpy of liquid leaving the condenser, kJ/kg.
M_A = Molecular weight of gas or vapour.
M_B = Molecular weight of air.
P_A = Vapour pressure of liquid, kPa.
P_B = Vapour pressure of the air, kPa.
p_A = Partial pressure of water in air, kPa.
Q = Heat absorbed from low temperature source (net refrigerating effect), kJ/kg.
T = Absolute temperature, K.
V = Humid volume, m^3/kg.
v_g = Specific volume, m^3/kg.
s = Humid heat, kJ/kg·K.
w = Weight of moisture, kg.
W = Heat of compression (net work input), kJ/kg.

QUESTION BANK

Each question carries 2 marks

1. What are humidity charts? Write their uses in pharmacy.
2. Draw a humidity chart and give its significance.
3. Define the terms, humidity and dew point.
4. Write the utility of humidity charts.
5. Differentiate between humidity and relative humidity.
6. What are the applications of dehumidification/humidification?
7. Explain the principle of dehumidification
8. Explain the principle of humidification.
9. Differentiate dry bulb temperature and wet bulb temperatures.
10. What are the applications of air conditioning?

Each question carries 5 marks

1. Describe the important features of humidity charts.
2. Describe the working of a refrigerator.
3. What do the term dehumidification means? Write a note on the applications of dehumidification.
4. With a neat diagram explain principle and working of an air conditioner.