Lecture Note
For
Mass Transfer - II

Course-Diploma
Stream-Chemical Engineering
Semester-5th(2023-24)

Prepared by
Mr. Yayati Kishore Mohanta
Lecturer Chemical Engineering
Uma Charan Patnaik Engineering School, Berhampur

Drying

Drying refers to an operation in which the moisture of a substance (usually solid) is removed by thermal means (i.e., with the help of thermal energy).

Drying usually refers to the removal of relatively small amounts of water from a solid or nearly solid material. It involves the transfer of liquid from a wet solid into an unsaturated gas phase (drying medium).

During drying operation, mass and heat transfer occur simultaneously. Heat is transferred from the the bulk of the gas phase (drying medium) to the solid phase and mass is transferred from the solid phase to the gas phase in the form of liquid and vapour through various resistances. The material (liquid) that is transferred is the solute and transfer takes place as the gas phase is always unsaturated with respect to the solute material.

In drying, relatively small amounts of water or other liquid is removed from a solid or semi-solid material (using thermal energy), whereas in evaporation relatively large amount of water is removed from solutions. Drying involves the removal of water at a temperature below the boiling point, while evaporation involves the removal of water as vapour at its boiling point. Drying involves circulation of a hot air or other gas over a solid material for the removal of water, whereas evaporation involves use of steam heat for the removal of water. To obtain products almost in the dried form is the purpose of drying operation, while to obtain concentrated solutions is the main purpose of evaporation.

As the removal of moisture by thermal means is more costly than mechanical means (e.g., filtration), the moisture content of material must be reduced to the minimum possible level by the latter means before the material is fed to drying equipments.

In most of the drying operations, the heat (required to evaporate water) is provided by hot air or any other gas-drying medium.

Drying is frequently the last operation in manufacturing processes and is usually carried after evaporation, filtration, or crystallisation.

This operation is carried out in food, chemical, agricultural, pharmaceutical and textile industries.

Drying operation is carried out for the reasons given below:

(i) For reducing the transport cost.
(ii) For purifying a crystalline product so that the solvent adhering to the crystals is removed.
(iii) For making a material more suitable for handling and storage. Handling and storage of dry solids is easy.
(iv) To meet the market specifications of solid products set by the customers.
(v) For providing definite properties to materials.
(vi) In some cases for preventing corrosion arising due to the presence of moisture. Dry chlorine gas is not corrosive but traces of moisture make it very corrosive.
(vii) Sometimes it is an essential part of the process (e.g., drying of paper in paper making).

General Definitions:

The moisture content of a wet material may be expressed on the wet or dry basis.

Moisture content, wet basis:

The moisture content of a wet feed material, on wet basis, is defined as the ratio of the weight of the moisture to the weight of the wet feed material. If X is the kg moisture associated with one kg of dry solids, then

Moisture content (wet basis) = $\frac{X}{1+X}$

The weight percent moisture of a wet feed material, on wet basis, is defined as the weight of the moisture expressed as a percentage of the weight of the wet feed material (i.e., wet solid).

Weight % moisture content (wet basis) = $\frac{\text{kg moisture}}{\text{kg wet solid}} \times 100 = \left[\frac{X}{1+X}\right] \times 100$

Moisture content, dry basis:

The moisture of a wet feed material, on dry basis, is defined as the ratio of the weight of the moisture to the weight of the dry solids present in the wet feed material. If the feed material contains X kg moisture and 1 kg of dry solids, then

Moisture content (dry basis) = $\frac{kg\ moisture}{kg\ dry\ solid} = \frac{X}{1} = X$

Percentage moisture content on dry basis = $100X$

Equilibrium moisture content (X*):
It is the moisture content of a substance that is in equilibrium with its vapour in the gas phase under the specified humidity and temperature of the hot gas or air. It represents the limiting moisture content to which a given material can be dried under constant drying conditions.

It is the moisture content of a substance which is in equilibrium with a given partial pressure of the vapour.

Bound Moisture content:
It is the moisture content in a material which exerts a vapour pressure less than that of the pure liquid at the same temperature.

Unbound moisture content:
It is the moisture held by a material in excess of the equilibrium moisture content corresponding to saturation humidity. It is primarily held in the voids of solid.

It is the moisture content in a material which exerts an equilibrium vapour pressure equal to that of the pure liquid at the same temperature.

Free moisture content:
It is the moisture contained by a material in excess of the equilibrium moisture content $(X - X^*)$. At a given temperature and humidity, it is the moisture content of a material that can be removed by drying. It may include bound and unbound moisture.

Critical moisture content:
It is the moisture content of a material at which the constant rate period ends and the falling rate period starts. This moisture content is a function of constant drying rate, material properties and particle size.

Constant rate period:
It is that part of the drying process during which the rate of drying expressed as the moisture evaporated per unit time per unit area of drying surface remains constant.

Falling rate period:
It is that part of the drying process during which the rate of drying varies with time and the instantaneous drying rate expressed as the amount of moisture evaporated per unit time per unit area of drying surface continuously decreases.

Properties of air-water system:
The moisture removed (from a wet solid) during drying operation gets added in the hot gas or air which in turn depends upon the temperature and humidity of the gas or air. Usually, in drying operation the hot air is used as a drying medium, so it is essential to know some of the properties of the air-water vapour system.

Relative humidity (R.H.):
It is a measure of the degree of saturation of air at the dry bulb temperature. It is defined as the ratio of the partial pressure of water vapour in the air water-vapour mixture to the vapour pressure of pure water at the temperature of the mixture, expressed on a percentage basis.

$$\% \, RH = \frac{P_A}{P_A^{\circ}} \times 100$$

where P_A = partial pressure of water vapour in the mixture
P_A° = vapour pressure of pure water

when $P_A = P_A^{\circ}$, air is said to be saturated with water vapour.
The relative humidity is defined as the ratio of the actual water vapour content of air to the water vapour content of the fully saturated air at the same temperature, expressed on a percentage basis.

Humidity (H)/Absolute humidity:
It is the ratio of the mass of water vapour to the mass of dry air present in the air-water vapour mixture under any given set of conditions.

$$H = \frac{kg \ of \ water \ vapour}{kg \ of \ dry \ air} = \frac{18}{29}\left(\frac{P_A}{P-P_A}\right) = 0.62 \ H_m$$

H_m is the molal humidity.

Dry bulb temperature:
The temperature of the air-water vapour mixture recorded by a thermometer whose bulb is kept dry is called dry bulb temperature.

Wet bulb temperature:
The temperature of the air-water vapour recorded by a thermometer whose bulb is kept wet by wrapping a wet cloth in the open air is called wet bulb temperature.

Since the latent heat of vaporisation required for natural evaporation of water from the cloth will be supplied from the bulb, the temperature of the bulb decreases. The evaporation is continued until the air surrounding the bulb becomes saturated. Some of the heat will flow from the surrounding air to the bulb by temperature difference, even then the temperature of bulb will not rise as that heat gets consumed in evaporation of water. At one particular point, the temperature becomes constant and is recorded as wet bulb temperature.

When the air is more unsaturated, then the difference between dry bulb temperature and wet bulb temperature is more and is less for a more humid air. The relative humidity of the air is found out from a psychrometric chart knowing wet bulb and dry bulb temperatures.

Saturation humidity:
It is the humidity of air when it is fully saturated with water vapour. It is denoted by the symbol H_s.

$$H_s = \frac{18}{29}\left(\frac{P_A^{\circ}}{P-P_A^{\circ}}\right)$$