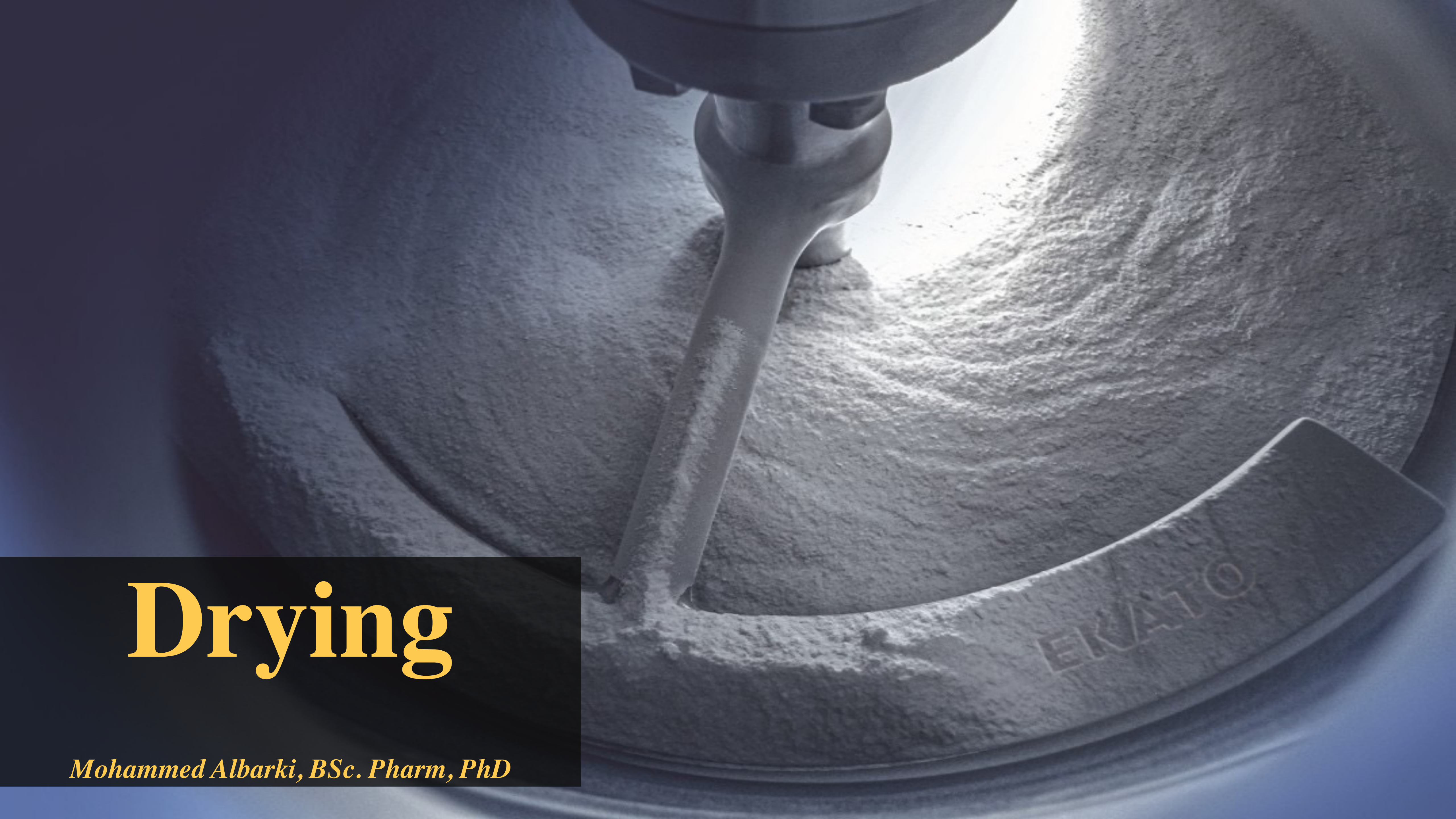

Drying

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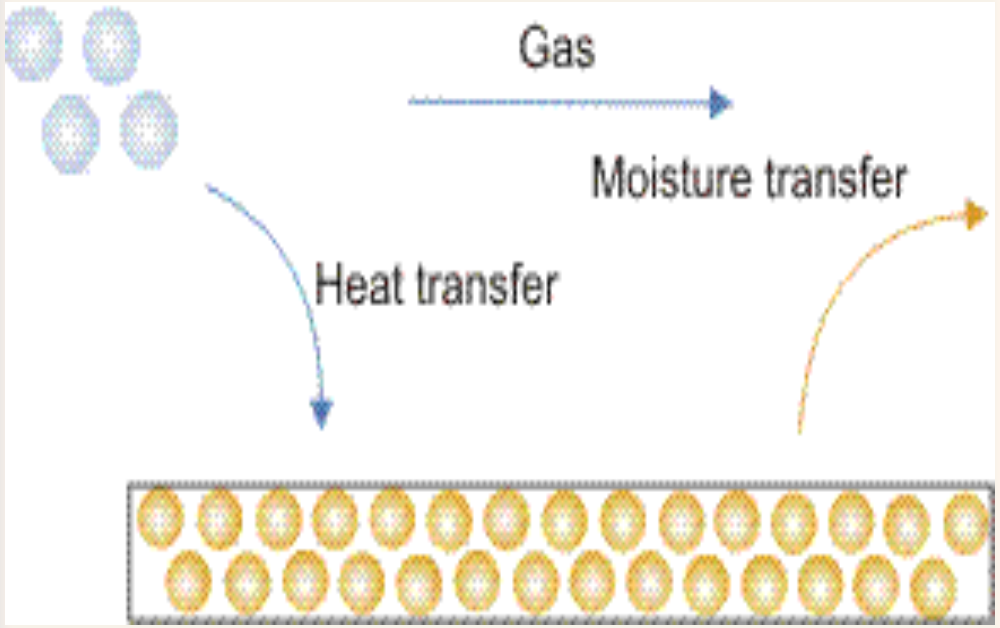
Drying

- Defined as the removal of a small amount of a liquid from a material by the application of **heat.**
  - The liquid is transferred from a **surface** into an unsaturated **vapor phase**.
- **Drying** and **evaporation** are distinguishable merely by the relative quantities of liquid removed from the solid.



Non-Thermal Drying

- There are **non**-thermal methods of drying for example:

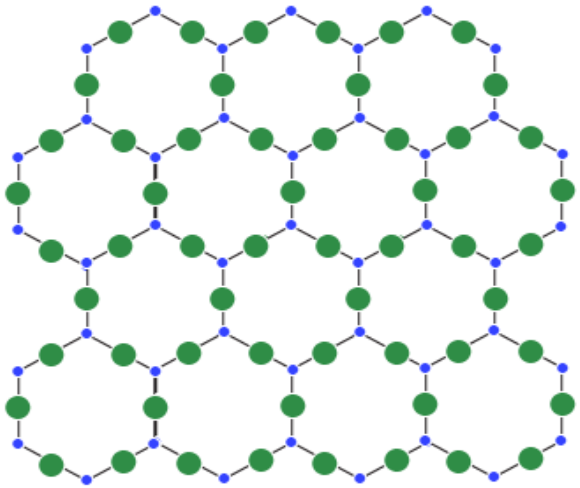
1. **Expression** of the solid to remove liquid (the squeezing of wetted sponge).
2. **The extraction** of liquid from a solid by use of a solvent
3. **Adsorption** of water from a solvent by the use of desiccants (anhydrous calcium chloride)
4. **Absorption** of moisture from gases by passage through a sulfuric acid column
5. **Desiccation** of moisture from a solid by placing it in a sealed container with moisture-removing material (silica gel)

Purpose of Drying (Uses)

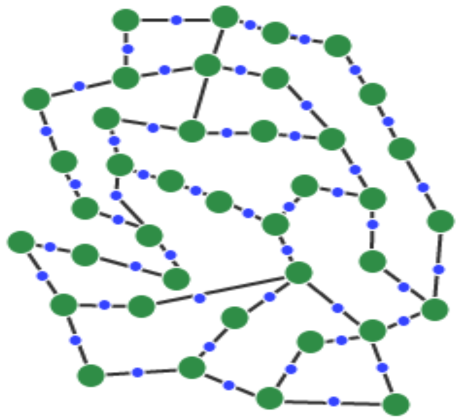
1. In the **preparation of granules** in tablets and capsules.
2. Used in the **processing of materials** e.g. the preparation of dried aluminum hydroxide, **spray drying** of lactose, and the preparation of powdered extracts.
3. Used to **reduce bulk and weight of drying material**, thereby lowering the cost of transportation and storage.
4. **Removing the moisture to facilitate milling (comminution)** by making the dried substance far more friable.
5. Aids in the **preservation** of animal and vegetable drugs by minimizing mold and bacterial growth.
6. Dried products are **more stable** such as effervescent salts, aspirin, hygroscopic powders, ascorbic acid, and penicillin; through reducing the chemical reactivity.

Classification of Solids Based on Drying Behavior

- Solids to be dried may be classified based on their drying behavior into:
- **Granular or crystalline solids** in which the water is held in open surface pores and interstitial spaces between particles that are **easily accessible** to the surface.
- **Amorphous solids** in which the moisture is an integral part of the molecular structure and entrapped in fine capillaries and pores, accordingly it is **more difficult** to dry than crystalline solids.



Crystalline Solids



Amorphous Solids

- The moisture in a solid can be expressed on a wet-weight or dry-weight basis.
- **Loss on drying (LOD):** is an expression of moisture content of a **wet-weight basis** which is calculated as:

$$\%LOD = \frac{weight\ of\ water\ in\ sample}{Total\ Weight\ of\ wet\ sample} x\ 100$$

- This is determined using moisture balance which has a heat source for rapid heating and a scale calibrated in percent LOD.
- The weighted wet sample allowed to dry and obtain %LOD.

Drying of Solids

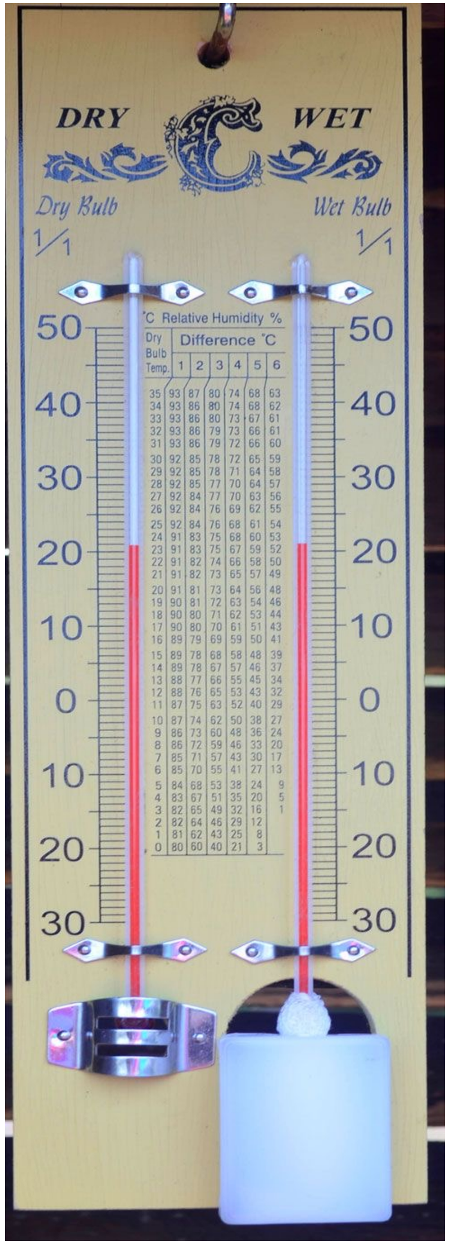
- **Moistrure Content**
- On a **dry-weight basis**, the water is expressed as a percentage of the weight of the dry solid.
- Moisture in a wet solid is calculated on a dry-weight basis. This value is referred to as moisture content (MC)

$$\%MC = \frac{\textbf{weight of water in sample}}{\textbf{Weight of dry sample}} \, x\, 100$$

- If exactly 5 g of moist solid is brought to a constant dry weight of 3 g →
- MC=[(5-3)/3]*100= 66.7%
- LOD=[(5-3)/5]100=40%

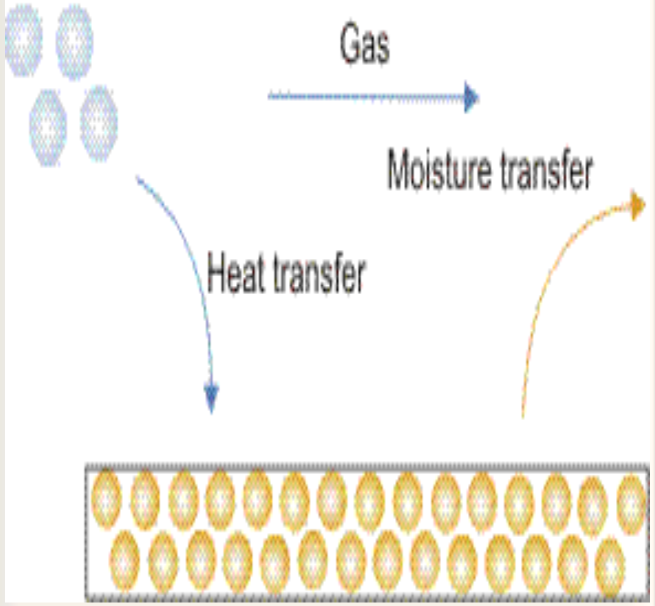
Psychrometry

- **Psychrometry** determines the vapor concentration and **carrying capacity** of the gas (air).
  - **Vapor-carrying capacity** of the air, nitrogen, or other gas stream passing over the drying material.
  - The carrying capacity **determines** the rate and the extent of drying material (the lowest moisture content).
- **Wet-bulb temperature** is measured by a thermometer (the bulb is covered by a wick saturated with water).
- **Dry-bulb temperature** (actual air temperature) is measured by an ordinary thermometer.



Theory of Drying

- Drying involves **heat and mass transfer** operations.
- **Heat must be** transferred into the material to be dried to supply the latent heat required for the vaporization of the moisture.
- **Mass transfer**: It is involved in:
  1. The diffusion of water through the material to the evaporating **surface**, ➔
  2. The subsequent evaporation of the water **from the surface**,
  3. And the diffusion of the resultant vapor into the passing air stream.



Theory of Drying

- The drying process can be understood more easily if attention is focused on the film of liquid at the surface of the material being dried.
- The rate of evaporation of this film is related to the rate of heat transfer by the equation :
- ***Heat Transfer:***

$$dW/d\theta = q/\lambda \quad \text{equation 1}$$

- Where ($dW/d\theta$) is the **rate** of **evaporation.**
- (**q**) is the overall **rate of heat transfer.**
- And (λ) is the latent heat of vaporization.

- **The driving force** for **heat** transfer. it is a **temperature differential**

A *British thermal unit* (Btu) is a measure of the heat content of fuels or energy sources. It is the quantity of heat required to raise the temperature of one pound of liquid water by 1 degree Fahrenheit at the temperature that water has its greatest density (approximately 39 degrees Fahrenheit).

One British thermal unit (Btu) is approximately equal to the energy released by burning a match.

Mass Transfer

- The rate of **diffusion** of moisture into the air stream is expressed by rate equations similar to those for heat transfer in the previous slide.
- The driving force for **mass** transfer is a **humidity differential**. The equation is:

$$dW/d\theta = k' A(Hs - Hg) \qquad \text{equation2}$$

- Where $dW/d\theta$ is the rate of diffusion expressed as pounds of water per hour;
- **k':** the coefficient of mass transfer ;
- **A** is the area of the evaporating surface in square feet;
- **Hs**: the absolute **humidity** at the evaporating surface;
- **Hg:** the absolute **humidity** of the passing air stream.
- ➔ (**Hs-Hg**) is the humidity differential
- **Note:** The coefficient of mass transfer is not constant but varies with the **velocity** of the air stream passing over the evaporating surface.

Theory of Drying

- After an **initial period of adjustment**, the rate of evaporation is equal to the rate of diffusion of vapor (or rate of heat transfer = rate of mass transfer),
- And the rate of heat transfer [equation (1)] can be equated with the rate of mass transfer [equation (2)], or:

$$dW/d\theta = q/\lambda = k' A(Hs-Hg)$$

- The overall rate of heat transfer, **q** includes all methods of heat transfer which are **convection**, **radiation,** and **conduction**
- → From these equations, we can conclude that: The rate of drying may be accelerated by increasing any of the individual terms in the equation →

- **The general principles for efficient drying are: Next Slide**

The General Principles for Efficient Drying

1. The rate of **convective** heat transfer (q_c) can be increased by:
   - Increasing the **air flow rate**
   - Raising the **inlet air temperature**.
2. The rate of **radiation** heat transfer. (q_r).
3. The rate of **conduction** heat transfer (q_k) can be increased by:
   - Reducing the thickness of the material to be dried (**large surface area**)
   - By allowing it to **come in close contact** with a raised temperature surface.
4. Increasing the **air velocity also speeds** up the rate of drying by increasing the coefficient of mass transfer (k)(sufficient turbulence to minimize boundary layer thickness) by:

5. Dehumidifying the inlet air, thus increasing the humidity differential (**Hs-Hg**) also speeds up the rate of drying(low relative humidity)

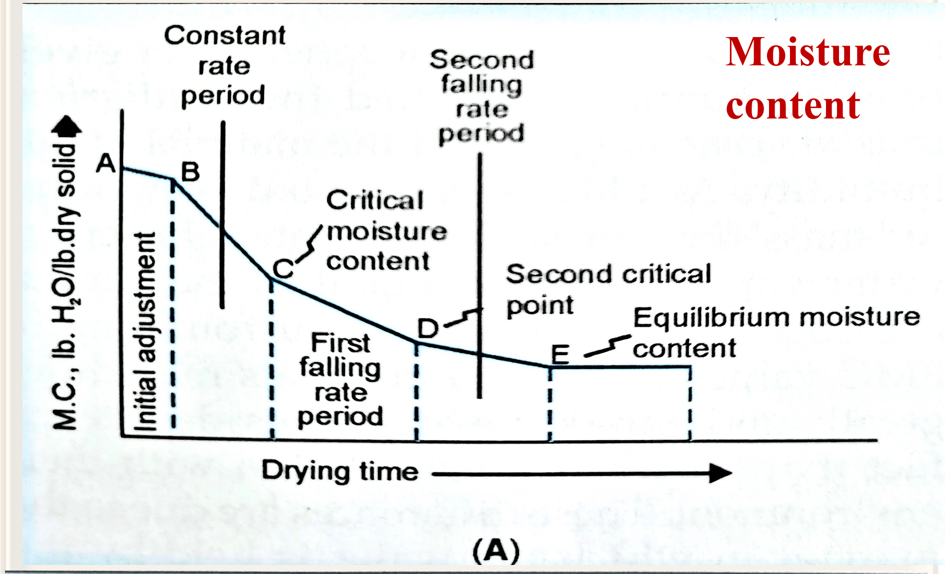
The behavior of Solids during Drying/Rate of Drying

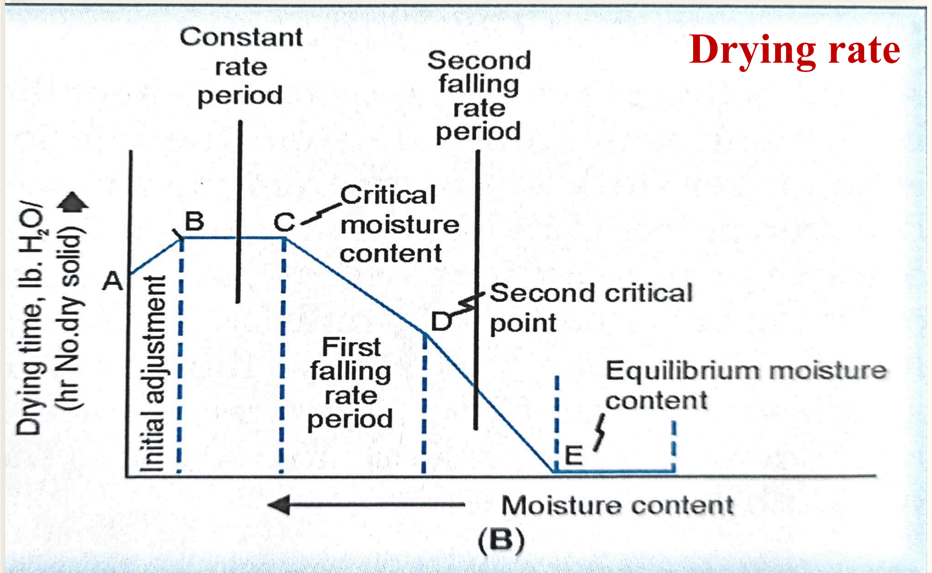
- How would we know if 8 or 12 hr are required to dry a batch weight of the material in a certain dryer?
- How can one determine the size of a particular type of dryer required for drying a substance from one moisture level to the **desired moisture content**?
- The study of drying rate is crucial to understanding the solid behavior during drying.
- The **rate of drying** could be determined by suspending the wet sample on a scale in a drying cabinet and measuring the weight of the dry sample as a function of time.
- The data from the drying rate is plotted as:

1. Drying rate vs moisture content
2. Moisture content vs drying time

The behavior of Solids during Drying

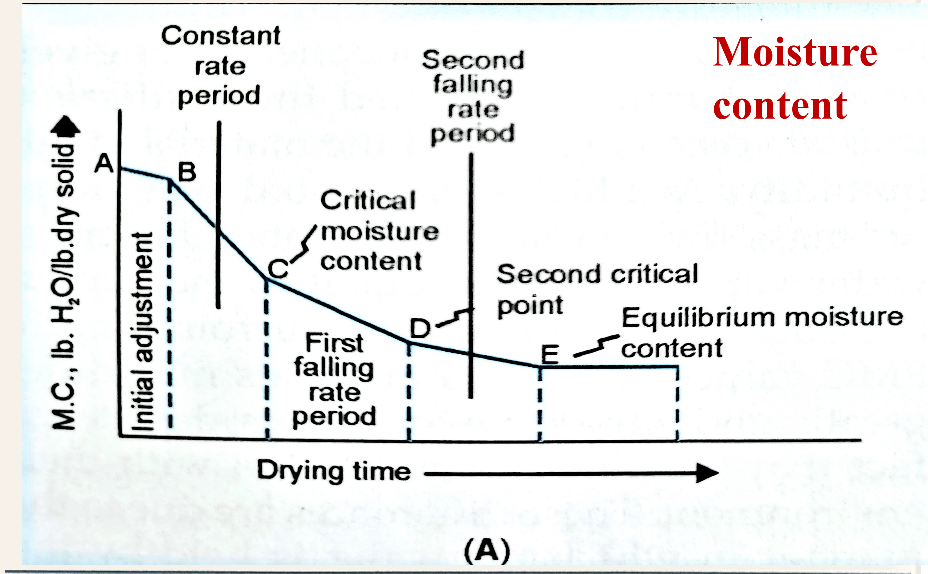
- **A-B segment (initial adjustment)**
- The product starts to **absorb** heat and increase in temperature.
- At the same time: moisture begins to evaporate and this tends to cool the drying solid (lowers surface temperature). ➔
- Heating rate = Cooling rate till drying temperature stabilizes.
- **At B** The temperature is stabilized **as** long as there is a film of moisture remaining at the surface of the solid.
- **B-C segment**: moisture evaporates from the surface and is replaced by water diffusing from the interior at a rate equal to the rate of evaporation, → (**evaporation rate =diffusion rate**).
    - This is a **constant rate period**.

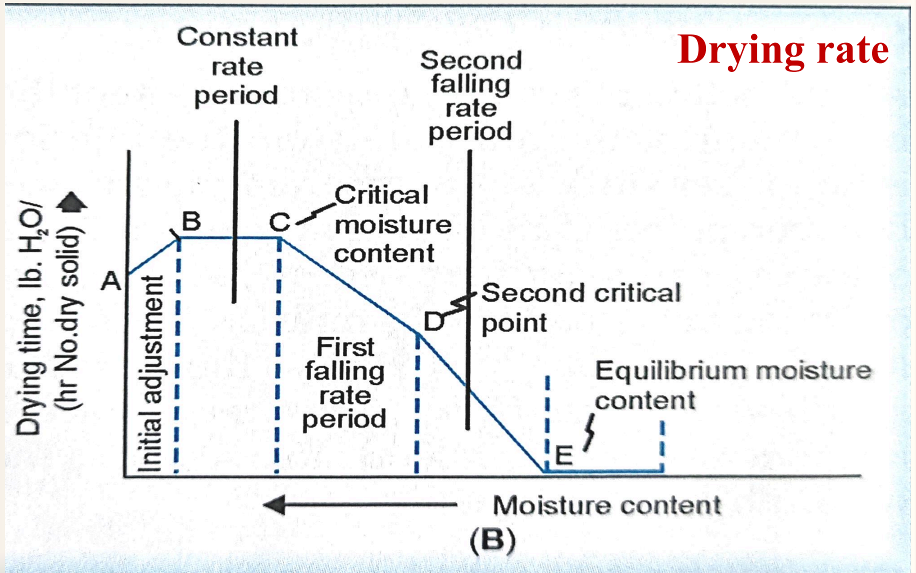




The behavior of Solids during Drying

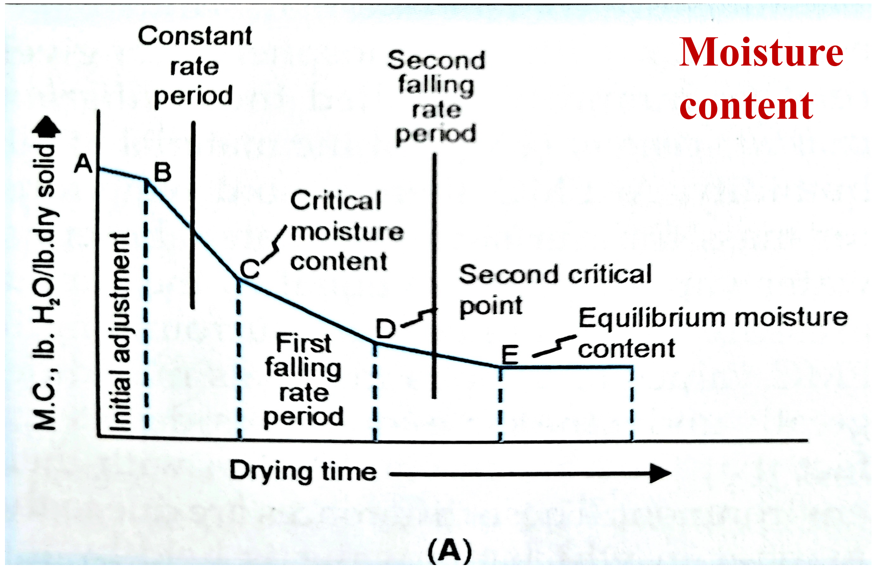
- **At point C**: water replacement will decline and dry spots start to appear on the surface. ➔ (drying rate falls off)
  - This is the **first critical moisture content point**.
- **C-D segment**: This is called the **first falling rate period** or a period of unsaturated surface drying
  - The first **decrease** in drying **rate** and dry spots continue to grow.
- **At D**: the surface film is **completely** evaporated. This is the **second critical point.**
  - The drying rate **depends on** the diffusion rate of moisture to the surface of the solid

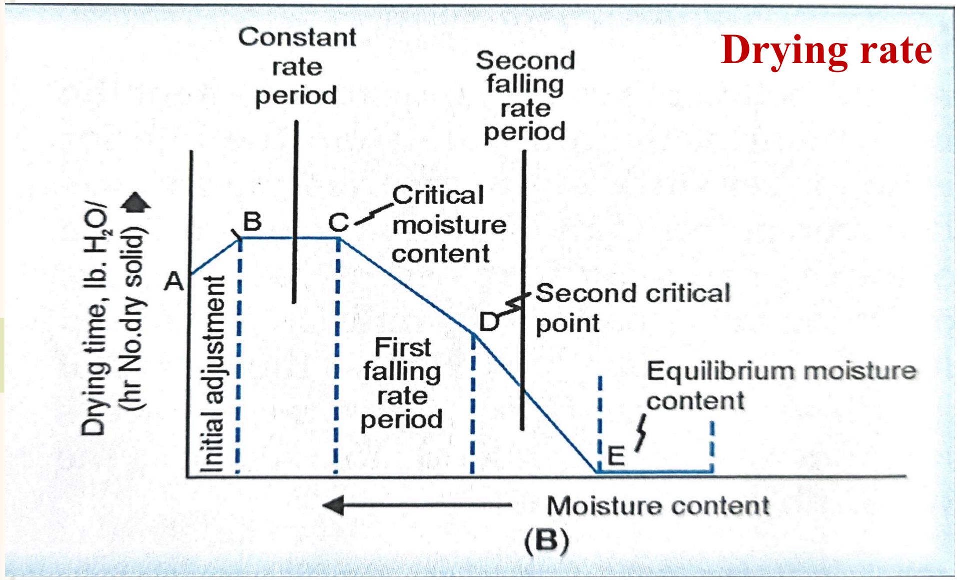




The behavior of Solids during Drying

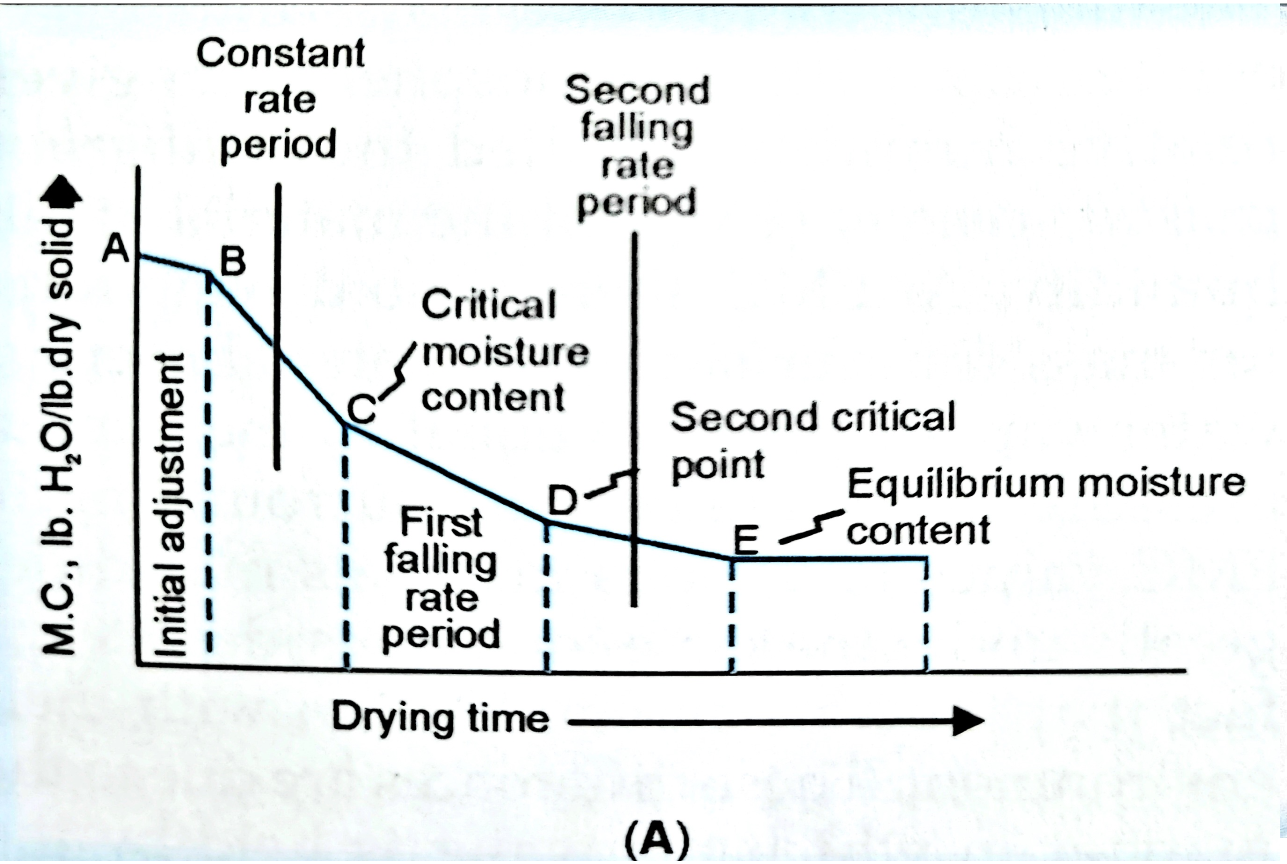
- **D-E segment**: second **falling rate period** in drying rate.
  - The drying rate falls more rapidly than the first falling rate. (**why?**)
- **At E**: This is the equilibrium moisture period begins.
  - **no** more drying will happen after this point.➔
  - Drying rate = zero
  - The temperature and moisture content remain constant.
  - Continuous drying will **be a waste of time and energy**.





The behavior of Solids during Drying

Moisture content



Drying rate