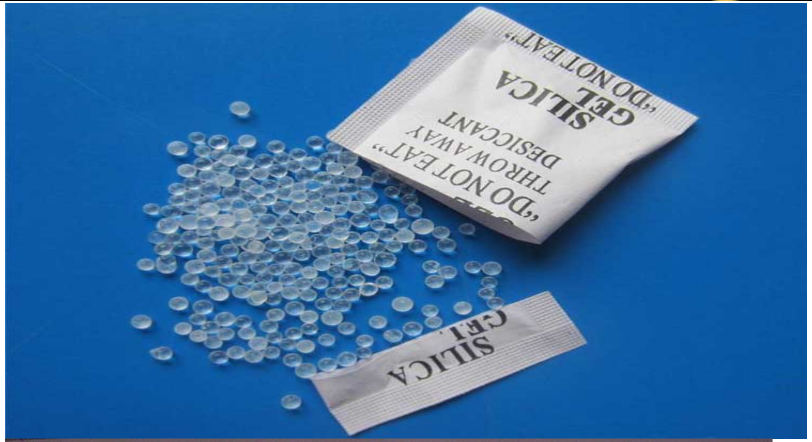
Drying Part I

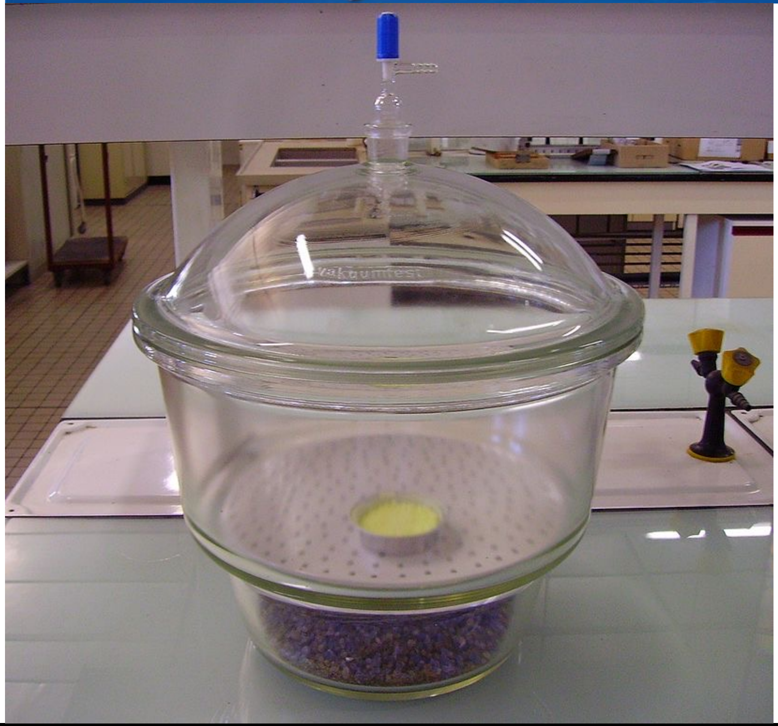
Drying

- Defined as the removal of a liquid from a material by the application of **heat.**
- It is accomplished by the transfer of a liquid from a **surface** into an unsaturated **vapor phase**.
- **Drying** and **evaporation** are distinguishable merely by the relative quantities of liquid removed from the solid.
- When solid is the larger quantity and liquid is less the process is called **drying** and vice versa.
- All drying processes of relevance to pharmaceutical manufacturing involve **evaporation or sublimation** of the liquid phase and the removal of the subsequent vapor.
- The process must provide the **latent heat** for these processes **without** a significant temperature rise.

Non-Thermal Drying

- There are non-thermal methods of drying for example:
- **Adsorption** of water from a solvent by the use of desiccants (anhydrous calcium chloride)
- **Absorption** of moisture from gases by passage through a sulfuric acid column
- Desiccation of moisture from a solid by placing it in a sealed container with moisture removing material (silica gel)





Drying
Uses (Advantages)

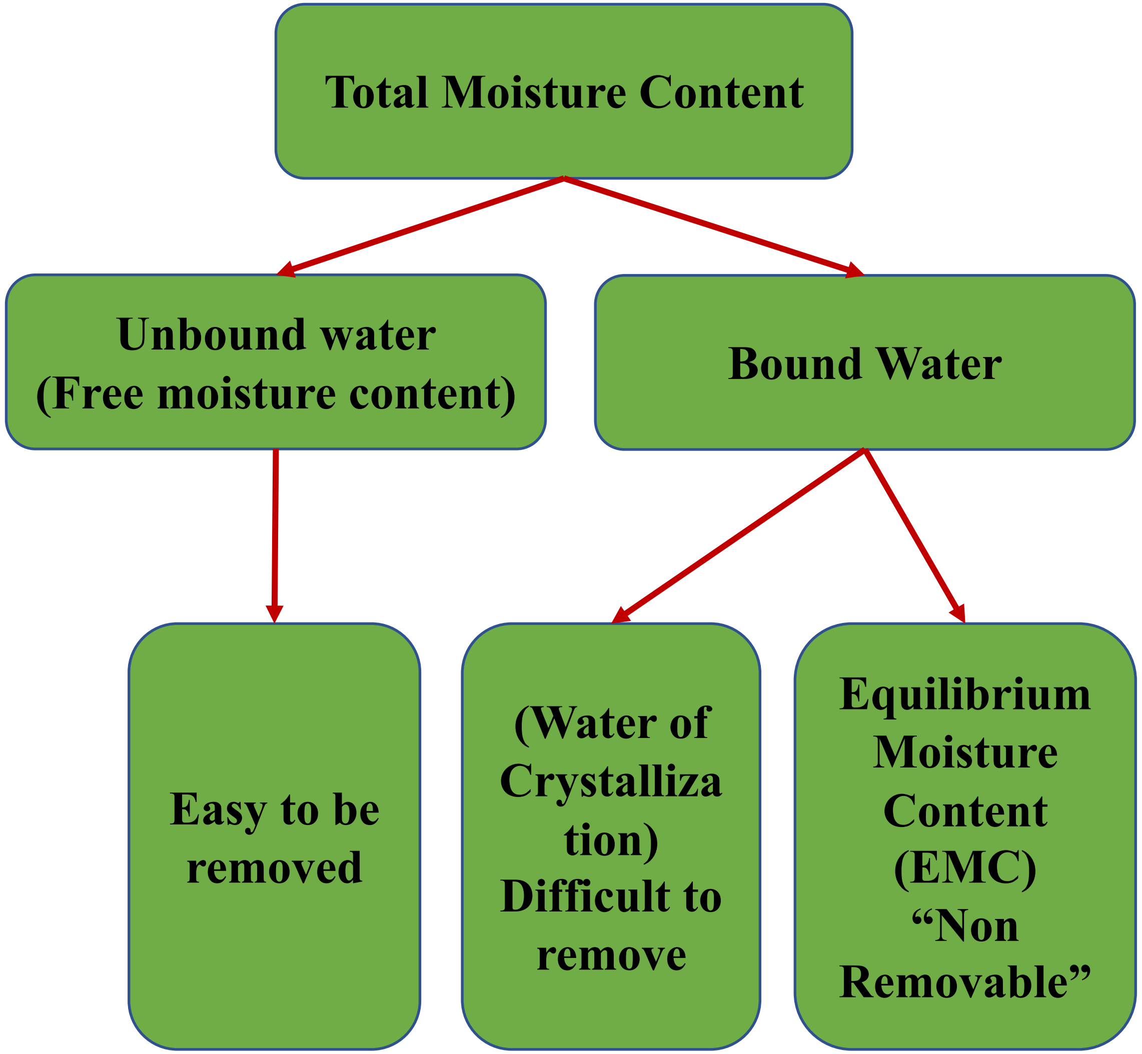
1. Drying is most commonly used in pharmaceutical manufacturing as a unit process in the **preparation of granules** which can be dispensed in bulk or converted into tablet or capsules.
2. Used in the **processing of materials** e.g. the preparation of dried aluminum hydroxide, spray drying of lactose and the preparation of powdered extracts.
3. Used to **reduce bulk and weight**, thereby lowering the cost of transportation and storage.
4. **Facilitating comminution** by making the dried substance far more friable than the original, water-containing drug.
5. The residual moisture is rendered low to **prevent product deterioration** during storage and ensure free-flowing properties during use.
6. **Stability, flow properties** and comparability are all influenced by residual moisture.

Terms in Drying Process

- An understanding of this operation requires some preliminary explanation of the following important terms.
- **Moisture content of wet solids**:
- **Definition**: The moisture content of a wet solid is expressed as <u>kg of moisture associated with 1 kg of the moisture free or ‘bone-dry’ solid</u>.
- **Bone Dry**: a condition where **zero** moisture is left in the material (mostly theoretical term)
- Thus, a moisture content of 0.4 means that 0.4 kg of water is present per kg of the ‘bone-dry’ solid that will remain after complete drying.
- It is sometimes calculated as percentage moisture content; thus this example would be quoted as 40% moisture content.

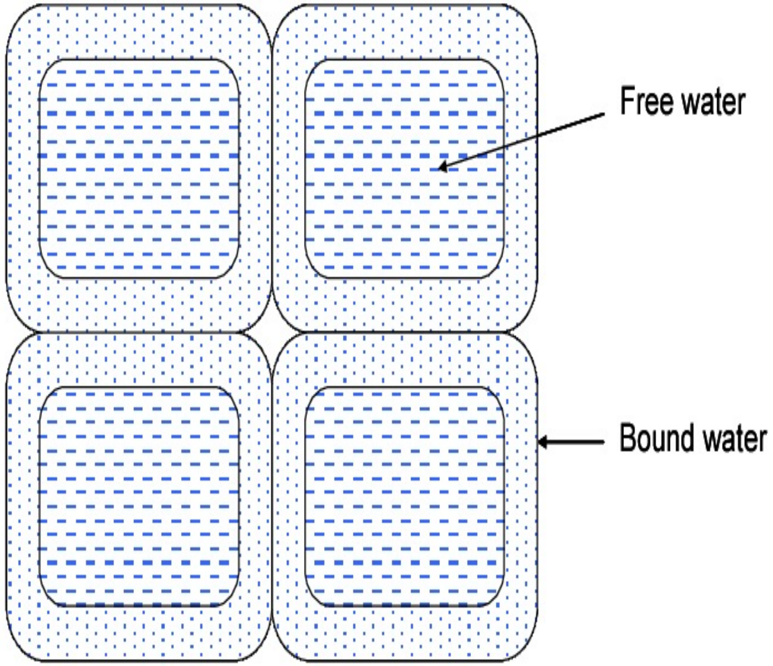
Total Moisture Content

- **Three** types of moisture content : unbound water, bound water, equilibrium moisture content.
- These types are called **total moisture content which is**:
- The total amount of liquid associated with a wet solid.
- Some of this water can be easily removed by the simple evaporative processes employed by most pharmaceutical dryers and some cannot.



Total Moisture Content
Unbound Water

- The amount of **easily** removable water (unbound water) is known as the **free moisture content.**
- The unbound water associated with a wet solid **exists as a liquid** and it exerts its full vapor pressure.
- It can be removed readily by evaporation.
- Removing this water **will not** resulted in a completely dry solid since some water present in the atmosphere.

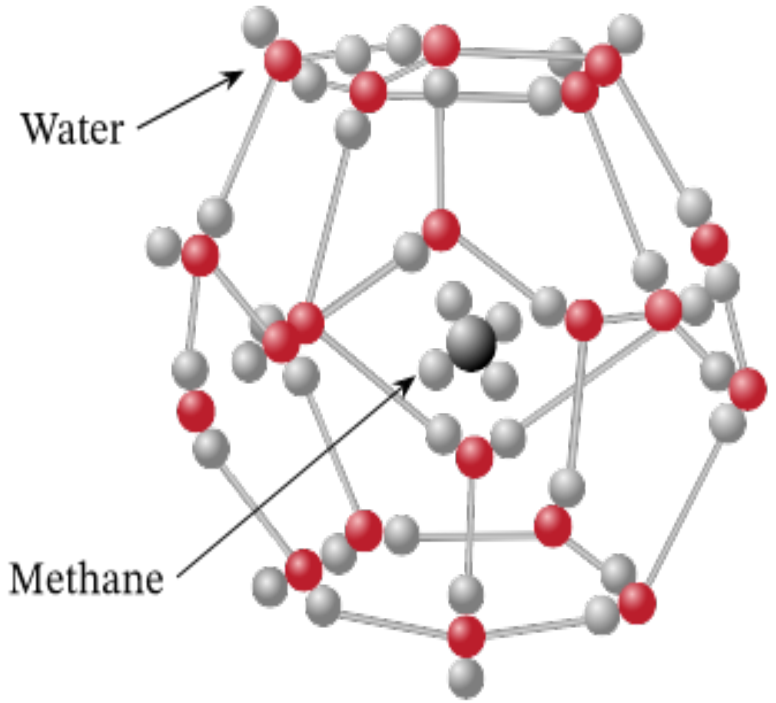


Total Moisture Content
Bound water

- The moisture content of the water that is more **difficult** to remove in practice (bound water).
- Part of the moisture present in a wet solid may be adsorbed **on surfaces** of the solid or be absorbed **within its structure** to such an extent that it is prevented from developing its **full vapor pressure** and therefore from being easily removed by evaporation.
- This is called **bound water (water for crystallization)**.

Total Moisture Content
Bound water

- **Water of crystallization**.
- The material contains that water is called hydrates ex. Ampicillin trihydrate, calcium phosphate dihydrate.
- If that water does not exist the material is called **anhydrous**.
- **Adsorbed** water is attached to the surface of the solid as individual water molecules which may form a mono- (or bi-) layer on the solid surface.
- **Absorbed** bound water exists as a liquid but is trapped in capillaries within the solid by surface tension

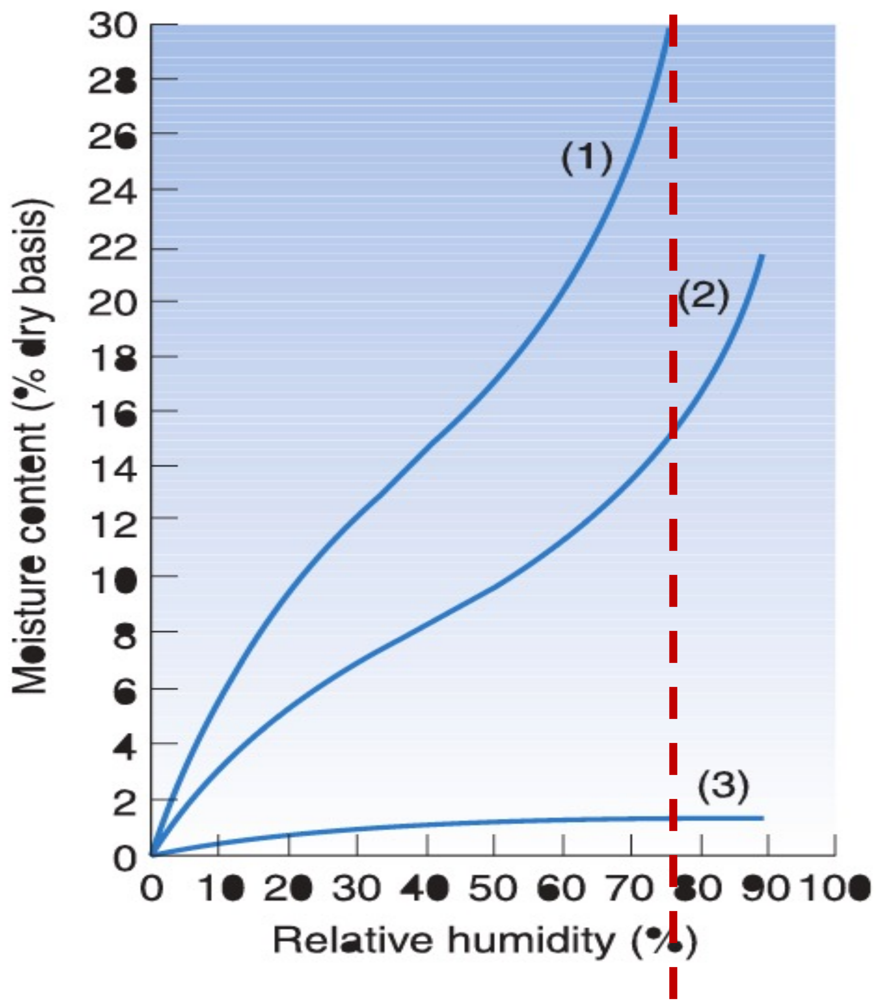


Total Moisture Content
EMC

- Part of bound water that is non removable is called the **equilibrium moisture content (EMC)**.
- The moisture content of a material that is in equilibrium with an atmosphere of a given **relative humidity and temperature** is called the equilibrium moisture content (EMC) of the material at that certain humidity.
- At EMC, **no evaporation** happens because the vapor pressure of the material is equal to that of the atmosphere around it.
- Evaporative drying processes **will not remove** all the possible moisture present in a wet product because the drying solid equilibrates with the moisture that is naturally present in air.
- Its value **will change** with the **temperature** and **humidity** of the air, and **with the nature of the solid**.

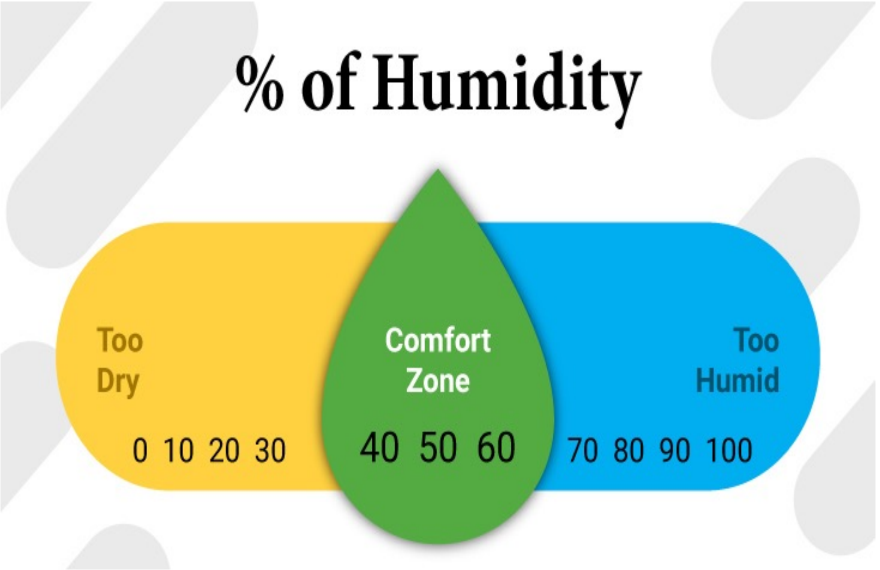
Effect of Solid Type on EMC

- The equilibrium moisture content of a solid exposed to moist air varies with the **relative humidity** and with the **nature of the solid** at a given **temperature**.
- If we assume that the atmospheric conditions are of the order of **20 ˚C and 70–75%** relative humidity, a **mineral** such as kaolin (3) will contain about 1% bound moisture, while a starch-based product (1) may have as much as 30% or more.



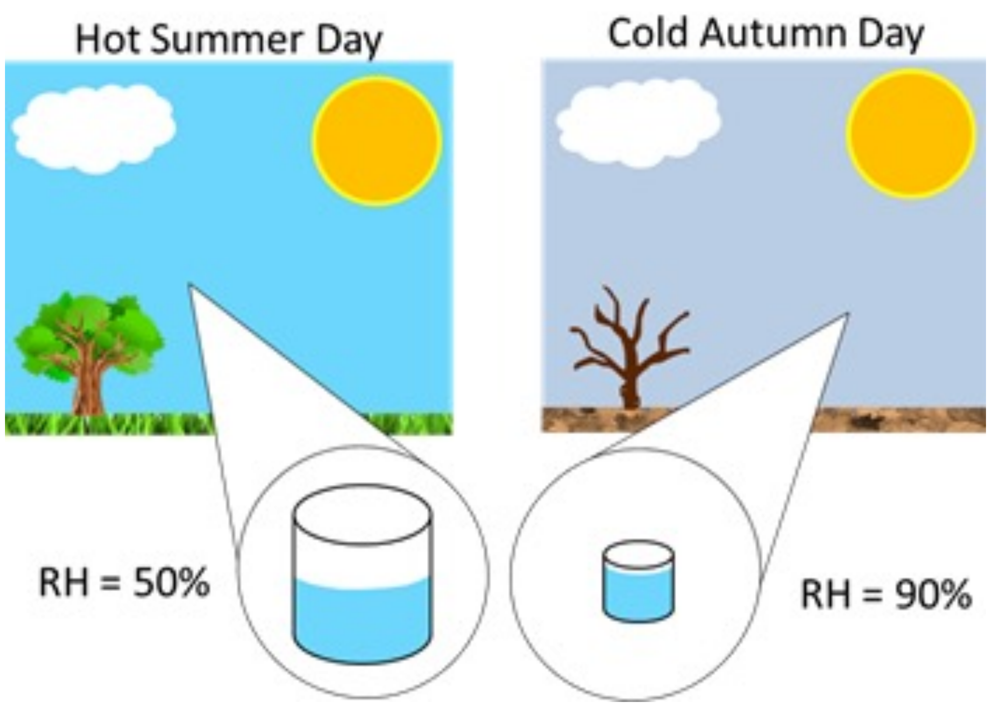
Relative Humidity of the air (RH)

- Another term that we need to know in order to understand drying is **RH**:
- Ambient air is a simple solution of water in a mixture of gases and as such follows the rules of most solutions such as increased water solubility with increasing temperature, a maximum solubility at a particular temperature (saturation) and precipitation of the solute on cooling (condensation, rain!).
- At a given temperature, air is capable of '**taking up**' (i.e. dissolving) water vapor until it is **saturated (at 100% RH**).



RH

- Lower RH can be quantified in terms of percentage relative humidity.
- **RH** is the ratio of moisture in the air at given temperature to that of moisture-saturated air at the same temperature.
- **Increasing** the temperature will increase water solubility in air and and **if** moisture content remains constant so this will lower relative humidity %.

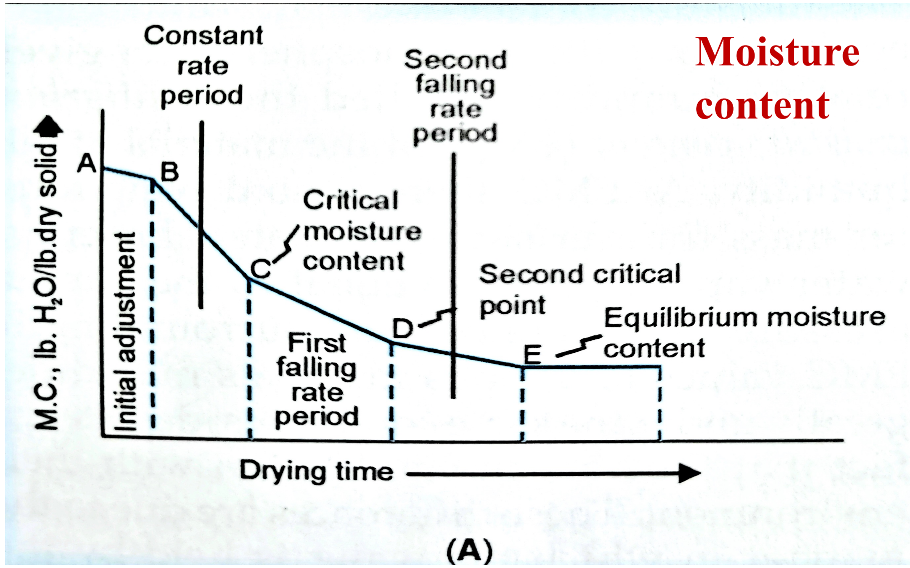


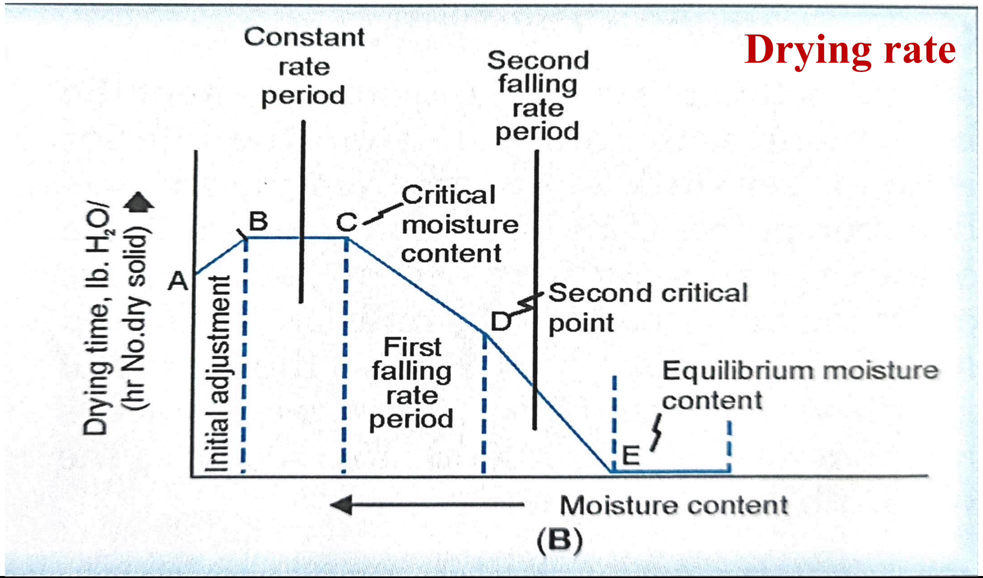
Terms in Drying

- Total Moisture Content (MC)
- Bound Water
- Unbound Water
- Water of Crystallization
- Hydrates; anhydrous
- Equilibrium Moisture Content (EMC)
- Relative Humidity (RH)

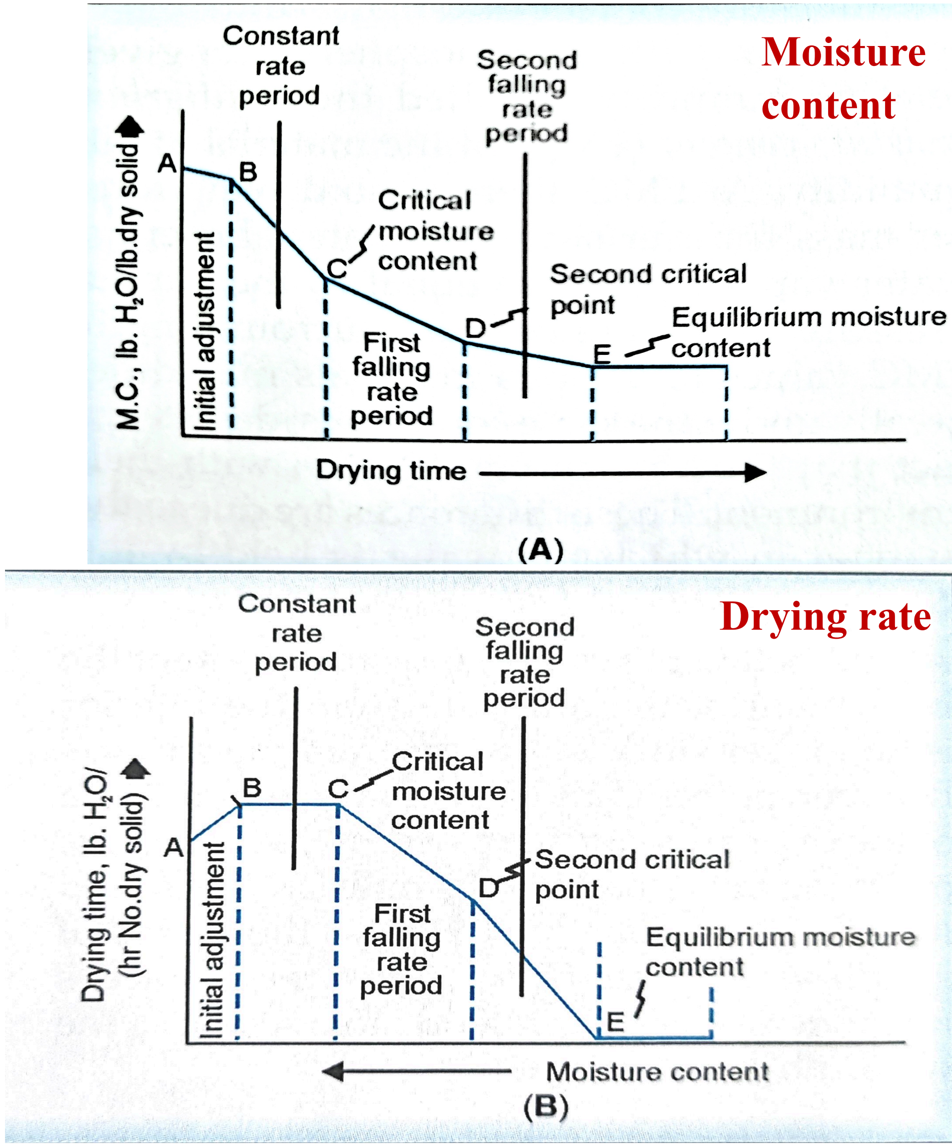
Drying process

- **A-B segment** product starts to absorb heat and moisture evaporates. This will lower the surface temperature.
- **At B rate** of heating and cooling reaches equilibrium.
- **B-C segment**: moisture evaporates from surface and being replaced by water diffusing from the interior at a rate equal to the rate of evaporation. This is **constant rate period**.
- **At point C**: water replacement will decline and dry spots starts to appear on the surface. This is **first critical moisture content point**.





- **C-D segment**: First **decrease** in drying **rate** and dry spots continue to grow.
- **At D**: surface film is **completely** evaporated. This is **second critical point.**
- **D-E segment**: second **decrease** in drying rate. Evaporation here depends on factors such as particle size due to its influence on the dimension of the pores and channel from which internal water will come out and evaporate.
- **At E**: this is equilibrium moisture content and **no** more drying will happen after this point.
- Continuous drying will **be lost of time and energy**.



Notes about drying

1. Material will **regain moisture** if exposed to humid conditions and there is **no advantage** in drying the material to a moisture content lower than the moisture in which the material will have under the condition of use.
2. Moisture can be further decreased below the EMC if we decrease the humidity of the surrounding air. This mean we are creating a **new and lower EMC**. This is done by a **special air conditioning** system in large scale. And in small scale, we use **desiccators** that contain water absorbing material such as silica gel or Phosphorus pentoxide .

- **Silica gel**. Adsorb moisture from air which will reduce the relative humidity.
- **Phosphorus pentoxide** works in an identical manner but it has an even greater affinity for the water in the storage air.

Choose of the dryer

1. **Heat sensitivity** of the material being dries
2. **Nature of the liquid** to be removed.
3. The **quantity** of product to be dried.
4. **Physical characteristics** of the material.
5. **Available** source of heat.
6. **Cost** involved.

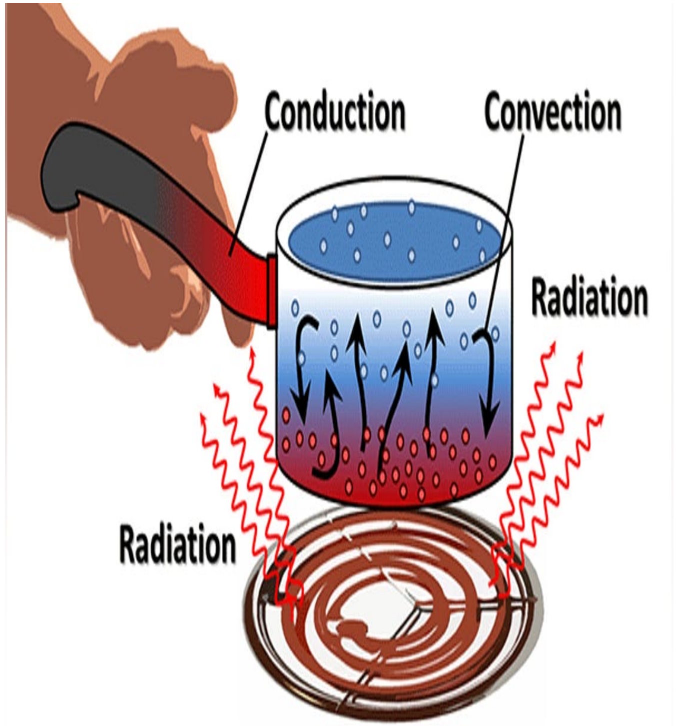
Tips for Efficient Drying

- In order to get efficient drying, it is desirable to have:

1. **Large surface** area for heat transfer.
2. **Efficient heat transfer** per unit area (to provide sufficient latent heat of vaporization or heat of sublimation in the case of freeze drying).
3. Efficient **mass transfer** of evaporated water through any surrounding boundary layers, i.e. **sufficient turbulence** to minimize boundary layer thickness.
4. **Efficient vapor removal**, i.e. low relative humidity and air is moving at adequate velocity.

Drying Systems

- Driers can be classified according to **heat transferring method** to:
- **Convection**: air heated to a certain level and then air as a medium for transferring heat to the product, Ex. tray dryer, fluidized bed dryer.
- **Conduction**: direct contact between material and the hot surface, Ex. vacuum oven, drum dryer.
- **Radiation**: products become dry because it absorbs energy from a source that emit **electromagnetic radiation**. The absorbed energy is then converted into heat to evaporate water from these products, Ex. microwave.



Types of dryer

Most Common Dryers in Pharmaceutical Industry

- **Dryers for sample solids:**
  - Tray or shelf dryer
  - Fluidized bed dryer
  - Rotatory dryer
  - Vacuum dryer
- **Dryers for slurries, dilute solution and suspensions**
  - Drum dryer
  - Spray dryer
- **Specialized drying method**
  - Freeze drying

Convective dryer
Tray Dryer

- Air flows in the direction of the arrows over each shelf in turn.
- The wet material is spread on shallow trays on the shelves.
- Heaters are positioned so that the air is periodically reheated after has cooled by passage over the material on one shelf before it passes over the material on the next.
- **Advantages**:

1. Versatile in arrangement and design.
2. Relatively low cost.

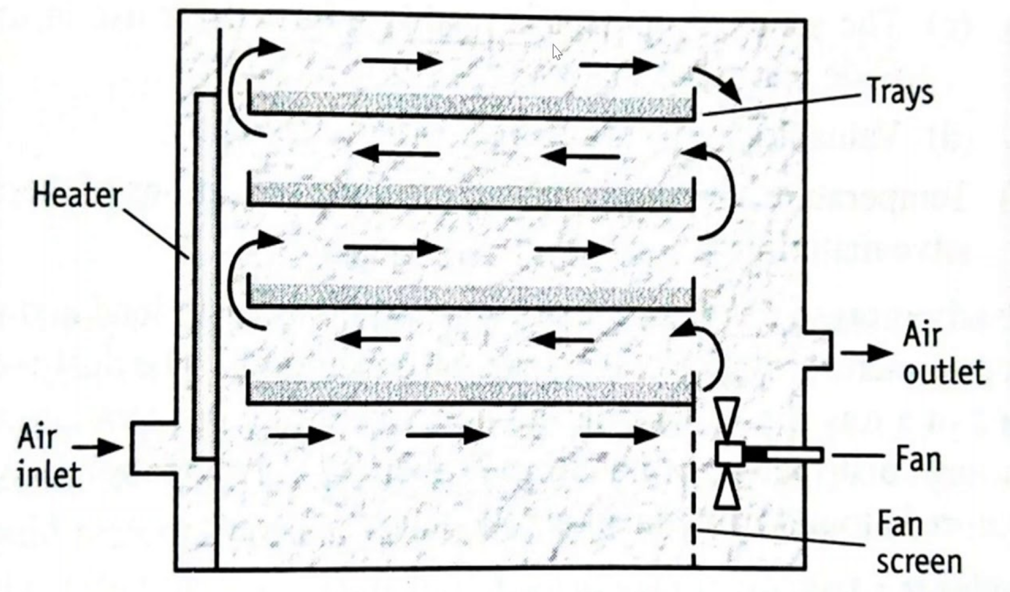


Figure 8-5. Tray dryer.

Tray Dryer

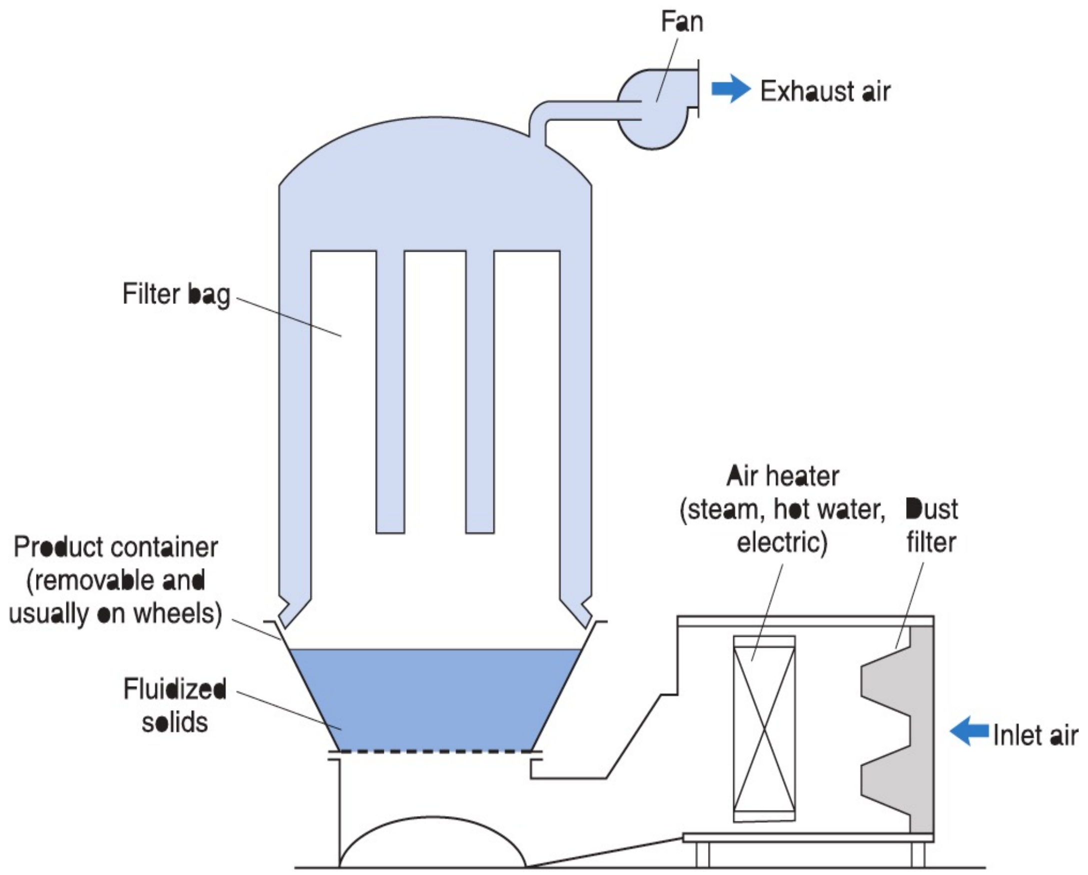
- **Disadvantages**:

1. **Slow rate of drying** which may take 24 hr to complete.
2. **Slow** rate of **loading and unloading** of trays which is a labor intensive process.
3. The passage of drying air is **limited to the top and bottom** of the tray

- Due to these disadvantages tray dryer is becoming less common with the manufacturing of more efficient dryer.

Dynamic Convective Dryer
Fluidized Bed Dryer (FBD)

- An excellent method of obtaining good contact between the warm drying air and wet particles.
- Hot air is pumped at certain pressure from the bottom that will cause the particle to raise and falls inside the main container.
- The resultant mixture of solids and gas behaves like a liquid and the solids are said to be fluidized .

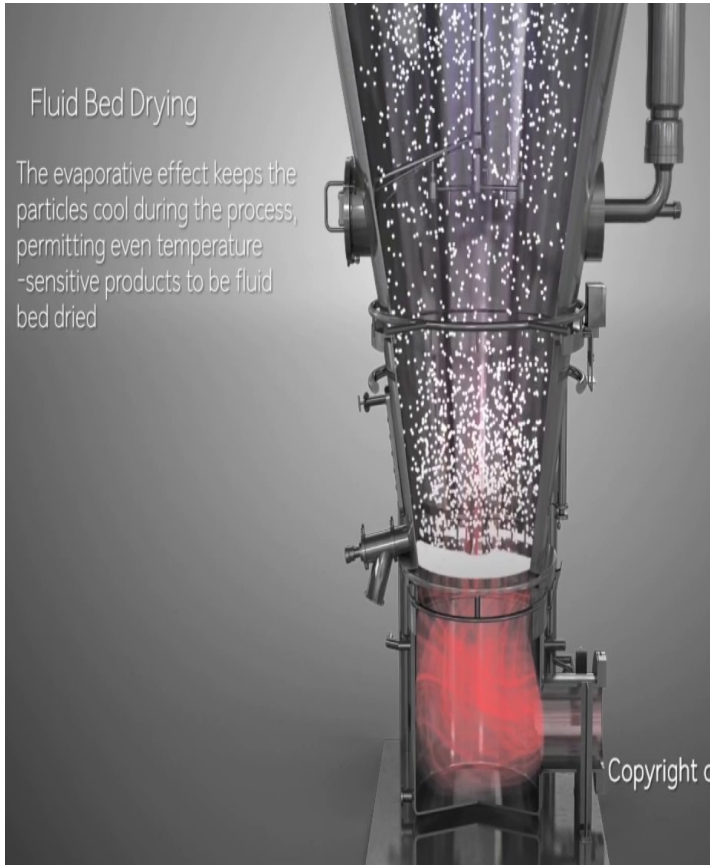


Advantaged of FBD

1. Simple **structure** and **variable capacity** available ranging from 400 g to 1200 kg.
2. **Efficient heat and mass transfer** giving high drying rates, so that drying times are short.

- Apart from obvious economic advantages, the heat challenge to thermolabile materials is minimized.

3. The fluidized state of the bed ensures that drying occurs from the surface of all the individual particles. Hence, most of the drying will occur at a constant rate.
4. **The temperature** of a fluidized bed is **uniform** throughout (as a result of the turbulence) and can be controlled precisely.



Advantages of FBD (continue)

5. **The turbulence** in a fluidized bed causes **some attrition** to the surface of the granule. This produces a more spherical free- flowing product.
6. **Keeping the granules separate** during drying also reduces the problems of aggregation and reduces the need for a sieving stage after drying.
7. The fluidization containers can be mobile, making **handling and movement** around the production area **simple**, thus reducing labor costs.
8. **Short drying times mean** that the unit has a high product output from a small floor space.

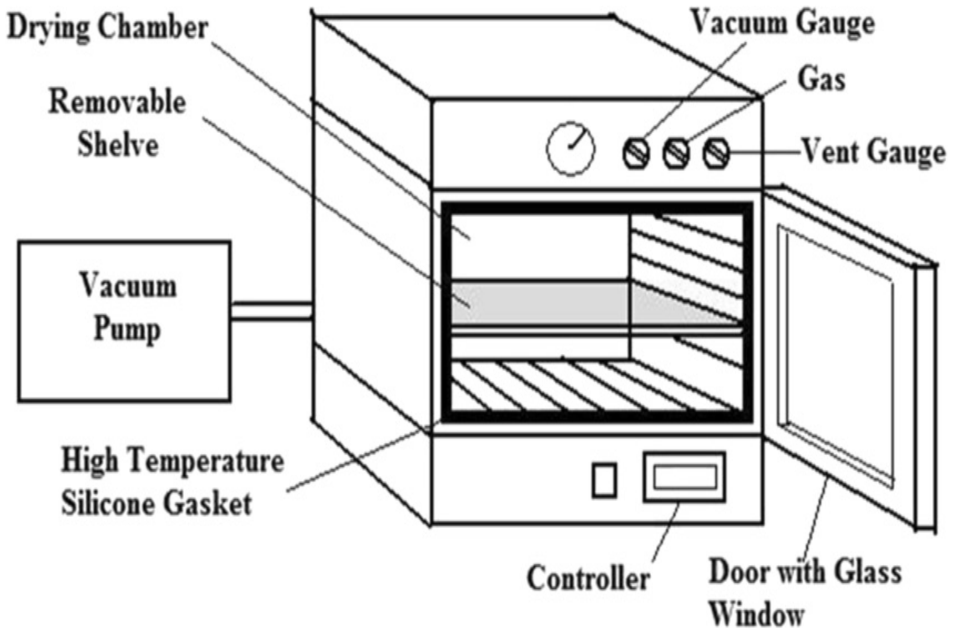
Disadvantages of FBD

1. **The turbulence** of the fluidized state may result in **excessive attrition** of some materials, with **damage to some granules** and the production of too much dust.
2. **Fine particles may** become entrained in the fluidizing air and must be collected by bag filters, with care to avoid **segregation and loss of fines**.
3. **The vigorous movement** of particles in hot dry air can lead to the **generation of charges of static electricity**, and suitable precautions must be taken.

- A mixture of air with a fine dust of organic materials such as starch and lactose can explode violently if ignited by sparking caused by static charges.
- The danger is increased if the fluidized material contains a **volatile solvent**
- Adequate **electrical earthing** is essential and, naturally, is fitted as standard on all modern dryers.

Conductive dryer of wet solids
Vacuum Oven Dryer

- In this process, the wet solid is in **thermal contact** with a hot surface and the bulk of heat transfer occurs by **conduction**.
- The vacuum oven consists of a **strong jacketed vessel** which closes by an **airtight door**. This vessel is connected to a **vacuum pump**.
- During drying process, **pressure is dropped** below the saturation pressure of the solvent and this **will generate a vapor** that is collected by the pump.
- Operating pressure can be as low as 0.03–0.06 bar, at which water boils at 25–35˚C.

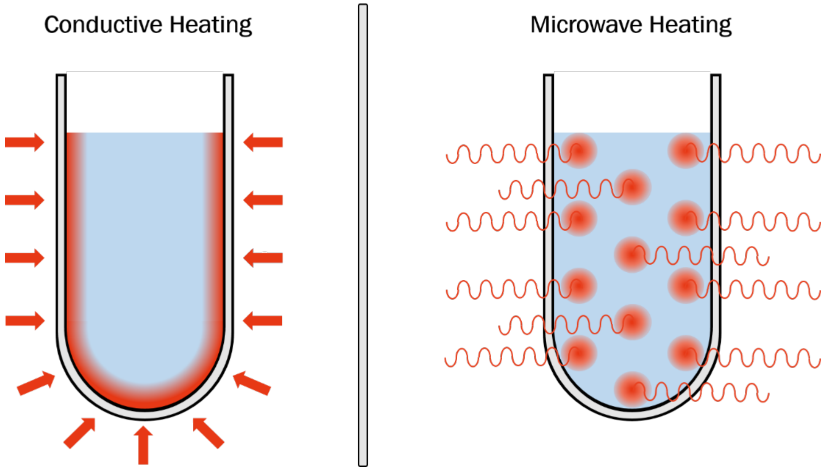


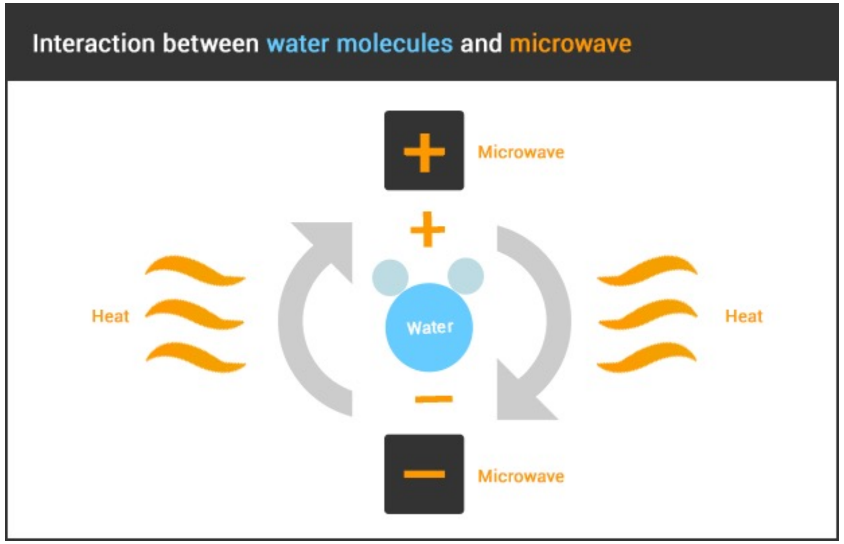
Vacuum Oven Dryer

- **Advantages**:
- Low temperature can be used which is beneficial in drying of thermolabile materials.
- **Disadvantage**:
- Large in size and complex build which is relatively expensive.
- Long drying time.

Radiation drying of wet solids

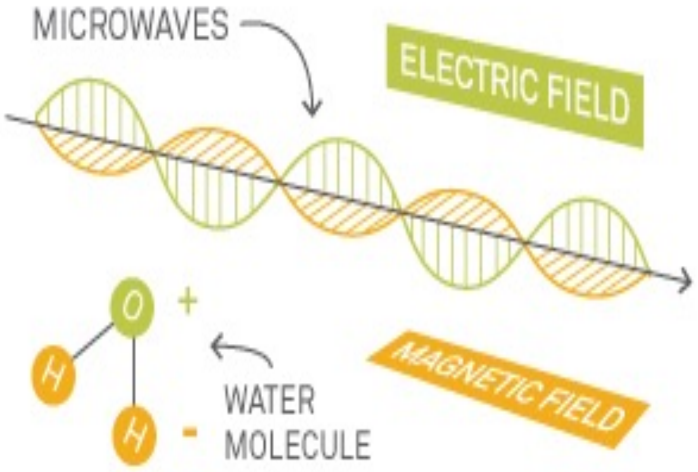
- **Radiation heat transfer**:
- Heat transmission by radiation differs from heat transfer by conduction or convection in that no transfer medium (solid, liquid or gaseous) needs be present.





Microwave Radiation

- **Microwave Radiation:**
- Microwave radiation in the wavelength range 10 mm to 1 m has been found to be an efficient **heating and drying method**.
- The penetration of microwaves into the wet product is so good that **heat is generated uniformly within the solid**.
- When microwaves fall on substances of suitable electronic structure (i.e. small polar molecules, such as water), the electrons in the molecule attempt to **resonate in sympathy** with the radiation. The resulting **molecular 'friction' generates heat**.
- The large molecules of the solids **do not resonate** as well as the water molecules, so further heating may be avoided once the water is removed.



Microware Drying

- **Advantages**:

1. **Rapid** drying at **low temperature**.
2. **The thermal efficiency is high**. Most of the microwave energy is absorbed by the liquid in the wet material (somewhat selective).
3. The material bed is stationary, so avoiding attrition and generation of dust.
4. **Drying end-point is possible** by measuring the microwave energy which **will raise sharply when there is little solvent left** to evaporate because the solids do not absorb radiation as readily as water.

- **Disadvantages**:

1. **Smaller batch size** that can be dried compared to the fluidized bed dryer.
2. **Some safety hazards** from the microwave radiation which can cause damage to organs such as the eyes.
3. Relatively **Expansive**.