Drying

* Drying is commonly the last stage in a manufacture process.

* Drying is the final removal of water from material (usually by heat).

- Non-thermal drying
  1. As Squeezing wetted sponge
  2. Adsorption by desiccant (desiccation)
  3. Extraction.

Purposes of drying

- In pharmaceutical technology, drying is carried out for one or more of the following reasons:

  1. To avoid or eliminate moisture which may lead to corrosion and decrease the product or drug stability.
  2. To improve or keep the good properties of a material, e.g. flowability, compressibility.
  3. To reduce the cost of transportation of large volume materials (liquids)
  4. To make the material easy or more suitable for handling.
  5. Preservative.
  6. The final step in: Evaporation- Filtration- Crystallization.
Difference between drying and evaporation

1- In **drying** processes, the main operation usually carried out on **solid materials**, e.g. powders, or products.

2- **Drying** in most of the cases means the removal of relatively **small amounts** of water from **solids**. **Evaporation** includes the removal of **large amounts of water** from solutions.

3- In most cases, **drying** involves the **removal** of water at **temperatures below** its boiling **point**, whereas **evaporation** means the **removal** of water **by boiling** a solution.

4- In **drying**, water is usually removed by **circulating air** over the **material** in order to **carry away** the **water vapour**, while in **evaporation**, water is removed from the material as **pure water vapour** mixed with **other gases**.
Classification of dryers

• Based on **solid handling** (static bed dryer-moving bed-fluidized bed).
• Based on **heat transfer** (direct dryers-Indirect-IR or radiant heat).

Dryers for Dilute Solutions and Suspensions

• The objective of these **dryers** is to **spread the liquid** to a large **surface area for heat** and **mass transfer** for collecting the **dry solid**.

• **Two main types are used:**
• The first, **spreading** the liquid to a thin film.
• The second, dispersing the liquid **to a spray** of small droplets.
Drum Dryer (Film Drying)

- It consists of a drum of about 0.75-1.5 m in diameter and 2-4 m in length, heated internally, usually by steam, and rotated on its longitudinal axis.

- **Operation:** The liquid is applied to the surface and spread to a film, this may be done in various ways, but the simplest method is that shown in the diagram, where the drum dips into a feed pan. Drying rate is controlled by using a suitable speed of rotation and the drum temperature. The product is scraped from the surface of the drum by means of a doctor knife.

- Fig. Drum dryer
Advantages of the drum dryer

1- The method gives rapid drying, the thin film spread over a large area resulting in rapid heat and mass transfer.
2- The equipment is compact, occupying much less space than other dryers.

3- Heating time is short, being only a few seconds.
4- The drum can be enclosed in a vacuum jacket, enabling the temperature of drying to be reduced.
5- The product is obtained in flake form, which is convenient for many purposes.

• **The only disadvantage**: is that operating conditions are critical and it is necessary to introduce careful control on feed rate, film thickness, speed of drum rotation and drum temperature.

• **Uses**: 1- It can handle a variety of materials, either as solutions or as suspensions e.g. starch products, ferrous salts and suspensions of kaolin.
Spray Dryer

The spray dryer provides a large surface area for heat and mass transfer by atomizing the liquid to small droplets. These are sprayed into a stream of hot air, so that each droplet dries to a solid particle.

- The drying chamber resembles the cyclone ensuring good circulation of air, to facilitate heat and mass transfer, and that dried particles are separated by the centrifugal action.....
A, control panel; B, coating champer; C, PARTICLIS being treated; D, process air flow; E, air distribution plate; F, nozzle for applying film coatings.
• The character of the particles is controlled by the **droplet form**; hence the type of **atomizer** is important.

• Rotary atomizer is preferable than jet which is easily blocked. Liquid is fed to the disc of the atomizer which is rotated at high speed (up to 20,000 rpm), a film is formed and spread as uniform spray. In addition, the rotary atomizer is effective with suspensions. It can be operated efficiently at various feed rates.

• **Fig. Rotary atomizer**
Characterization of spray dried products;

The products are uniform in appearance and have characteristic shape, in the form of hollow spheres with a small hole. This arises from the drying process, since the droplet enters the hot air stream, and dries on the outside to form an outer crust with liquid still in the center. This liquid then vaporizes, the vapour escaping by blowing a hole in the sphere.

- This method of drying allows a dry product to retain some properties of feed, e.g., a drop from an emulsion dries with continuous phase on the outside. When reconstituted, the emulsion is easily re-formed.
Advantages of the spray drying process

• 1-The droplets are small, giving a large surface area for heat transfer, so that evaporation is very rapid. The actual drying time of a droplet is only a fraction of a second, and the overall time in the dryer is only a few seconds.

• 2- Because evaporation is very rapid, the droplets do not attain a high temperature, most of the heat being used as latent heat of vaporization.

• 3- The characteristic particle form gives the product a high bulk density and, in turn, ready solubility.

• 4- The powder will have a uniform and controllable particle size.
5- The product is free-flowing, with almost spherical particles, and is especially convenient for tablet manufacture.

6- Labour costs are low, the process yielding a dry, free-flowing powder from a dilute solution, in a single operation with no handling.

7- It is possible to operate spray driers aseptically using heated filtered air to dry products such as serum hydrolysate.

8- Some spray driers operate in a closed-circuit mode with an inert gas to minimize oxidation of the product. Volatile solvents can be recovered from such systems.
Disadvantages & Uses

• The equipment is very bulky, connected to accessories, fans, heaters,)
• That is make it expensive.
• **Uses:**
• 1- Drying of any substance in **solution** or in **suspension** form.
• 2- It is most useful for drying of **thermolabile materials e.g. antibiotics**.
• 3- Suitable for **large quantities** solution.
• 4- Suitable for both **soluble** and **insoluble** substances e.g. citric acid, gelatin, starch.
• 5- It can produce spherical particles in the **respiratory range** e.g. dry powder **inhalers**.
• 6- Drying of **milk, soap and detergents** which is pharmaceutically related compounds.

• ..........................Fig. Formation of product in spray drying, Aulton, p 390
Freeze Drying

• **Freeze drying** is a process **used to dry extremely heat – sensitive materials.** It allows the drying, without excessive damage, of **proteins, blood products** and even microorganisms, which retain a small but significant viability.

• In this process the initial liquid solution or suspension is frozen, the pressure above the frozen state is reduced and the water removed by sublimation.

• Thus a liquid –to-vapour transition takes place, but here three states of matter involved: liquid to solid, then solid to vapour
The phase diagram for water

- The phase diagram for the water system is shown in the corresponding figure.

- The diagram consists of three separate areas representing the phases of water, solid, liquid, and vapour. The point O is the only point where all the three phases can coexist, and is known as the triple point.

On heating at constant atmospheric pressure ice will melt when the temperature rises to 0°C. At this constant temperature and pressure it will then change to water. Continued heating will raise the temperature of the water to 100°C where, if heat addition is continued, the liquid water will be converted into water vapour at 100°C.
If, however, solid ice is maintained at a pressure below the triple point then on heating the ice will sublime and pass directly to water vapour without passing through the liquid phase.

This sublimation, and therefore drying, can occur at a temperature below 0°C.

This will only happen if the pressure is prevented from rising above the triple point pressure.

It may be thought that as the process takes place at a low temperature the heat required to sublime the ice will be small.
Freeze Dryer
Limitations of the freeze drying process.

• The freeze drying of products such as blood plasma, although simple in theory, presents a number of practical problems:–

• 1-The depression of the freezing point caused by the presence of dissolved solutes means that the solution must be cooled below the normal freezing temperature for pure water (-10-30).

• 2-Sublimation can only occur at the frozen surface and is slow process (1mm thickness of ice per hour). So, the surface area must therefore be increased and

• 3-the liquid thickness prior to freezing be reduced in order to reduce the thickness of ice to be sublimated.

• 4-At low pressure large volumes of water vapour are produced which must be removed to prevent the pressure rising above the triple point pressure.

• 5-The dry material often needs to be sterile, and it must also be prevented from regaining moisture prior to the final packaging.
Stages of the freeze drying process

• **1- Freezing stage:**
  • The liquid material is frozen before the application of vacuum to avoid frothing, and several methods are used to produce a large frozen surface.
  • **a- Shell freezing:** This is employed for large volumes such as blood products. The bottles are rotated slowly and almost horizontally in a refrigerated bath. The liquid freezes in a thin shell around the inner surface of the bottle.
  • Freezing is slow and large ice crystals form, which is a drawback of this method.
  • In vertical spin freezing the bottles are spun individually in a vertical position, centrifuged and cooled by a blast of cold air. The solution super cools and freezes rapidly, with the formation of small ice crystals.
  • **b- Centrifugal evaporative freezing:** The solution is spun in small containers within a centrifuge. This prevents the foaming when a vacuum is applied. The vacuum causes boiling at room temperature. About 20% of the water is removed prior to freeze drying and there is no need for refrigeration. Ampoules are usually frozen in this way.
2 - Vacuum application stage: The containers and the frozen material must be connected to a vacuum source sufficient to drop the pressure below the triple point and remove the larger volumes of low-pressure vapour formed during drying.

3 - Sublimation stage:
- Heat of sublimation must be supplied. Under these conditions the ice slowly sublimes, leaving a porous solid which still contains about 0.5% moisture after primary drying.
- Primary drying: It can reduce the moisture content of a freeze-dried solid to around 0.5%. Further reduction can be affected by secondary drying.
- Heat transfer: Insufficient heat input prolongs the process, which is already slow, and excess heat will cause melting.
- Vapour removal: The vapour formed must be continually removed to avoid a pressure rise that would stop sublimation.
- Rate of drying: The rate of drying in freeze drying is very slow, the ice being removed at a rate of about only 1mm depth per hour.
Advantages of freeze drying

4- Secondary drying:
The removal of residual moisture at the end of primary drying is performed by raising the temperature of the solid to as high as 50 or 60°C.

5- Packaging:
Attention must be paid to packaging freeze-dried products to ensure protection from moisture. Containers should be closed without contacting the atmosphere.

Advantages of freeze drying

1- Drying takes place at very low temperatures, so the chemical decomposition, particularly hydrolysis is minimized.
2- The solution is frozen occupying the same volume as the original solution, thus, the product is light and porous.
3- The porous form of the product gives ready solubility.
4- There is no concentration of solution prior to drying. Hence, salts do not concentrate and denature proteins, as occurs with other drying methods.
5- As the process takes place under high vacuum there is little contact with air, and oxidation is minimized.
Disadvantages & Uses of freeze drying

• **Disadvantages:**
  
  - There are two main disadvantages:
  
  1. The porosity, ready solubility and complete dryness yield a very hygroscopic product. Unless products are dried in their final container and sealed in situ, packing requires special conditions.
  
  2. The process is very slow and uses complicated plant, which is very expensive. It is not a general method of drying but limited to certain types of valuable products.

• **Uses of freeze drying**
  
  The method is used for products that cannot be dried by any other heat method. These include biological products, e.g. antibiotics, blood products, vaccines, enzyme preparations and microbiological cultures.
Dryers for Solid Materials

- **Moisture content of wet solids**
  - The moisture content of a wet solid is expressed as kilograms of moisture associated with 1 kg of the moisture – free solid. Thus a moisture content of 0.4 means that 0.4 kg of removable water is present per kg of the solid. It is sometimes calculated as percentage moisture content.

- **Total moisture content**: This is the total amount of liquid associated with a wet solid. The easily removable water is known as the **free moisture content**, and the moisture which is more difficult to remove is the **equilibrium moisture content**. The easily removable water is known as **unbound water**.

- **Unbound water**: This water exists as a liquid and exerts its fully vapour pressure, it can be removed readily by evaporation. During a drying process this water is easily lost but the resulting solid is not completely free from water molecules.
• **Equilibrium moisture content:**

  The moisture content present in a solid under steady-state ambient conditions is termed the eq. moisture content. Its value changes with temperature, humidity and the nature of the solid.

• **Bound water:**

  Part of the moisture present in a wet solid may be adsorbed on surfaces of the solid or be adsorbed within its structure to such an extent to prevent it from developing its full vapour pressure and from being easily removed by evaporation. Such moisture is described as "bound" and is more difficult to remove than unbound water.
Relative humidity (RH) of air

- Air at a given temperature is capable of taking up water vapour until it is saturated (at 100% RH). If the temperature is raised then the air will be able to take up more moisture and the relative humidity falls.

- The RH of air is dependent not only on the amount of moisture in the air, but also on its temperature, as the amount of water required to saturate air is itself dependent on temperature.

- It should be noted that in convective drying, where warm air is passed over the surface of a wet solid, the relative humidity may rise during the drying process as a result of two separate factors:
  1. Uptake of evaporated water vapour from the wet solid,
  2. The cooling of the supply air as it transfers heat to the wet solid (evaporative cooling).

- If the cooling is excessive the temperature of the air may fall to a value known as the dew point, when liquid water will condense and be deposited.
Relationship between equilibrium moisture content (EMC) and relative humidity

- The EMC of a solid exposed to moist air varies with the relative humidity (Fig 26.2, Aulton p.382). Ordinary atmospheric conditions are of the order of 20°C and 70-75% RH.

- So that if exposed to atmosphere a material such as kaolin will contain about 1% moisture, whereas a starch-based product may have as much as 30% or more. Materials exposed to humid conditions will regain moisture, and so there is no advantage in drying to moisture content lower than that which the material will have under the conditions of use.
Loss of water from wet solids

• Unbound water is easily lost by evaporation until the equilibrium moisture content of the solid is reached (Fig 26.3, Aul). Once the solid reaches its EMC, extending the time of drying will not change the moisture content as an equilibrium situation has been reached. The only way to reduce the moisture content is to reduce the RH of the ambient air. This can be done mechanically with an air-conditioning system.

• On small scale, desiccators are used.

• ...... Fig 26.2 .........Fig.26.3.................(Aul
Different techniques of drying of solids (Drying methods)

- The following points should be considered before the selection of the suitable drying method:
  - 1- Heat sensitivity the material being dried.
  - 2- Physical characteristics of the material.
  - 3- Nature of the liquid to be removed.
  - 4- The scale of the operation.
  - 5- Available sources of heat (steam, electrical).
The general principles for efficient drying can be summarized as follows

• 1- Large surface area for heat transfer.

• 2- Efficient heat transfer per unit area (to supply sufficient latent heat of vaporization or heat of sublimation in 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 vapour removal, i.e. low relative humidity air at adequate velocity.

• It is convenient to categorize pharmaceutical driers according to the heat transfer method they use, i.e. convective, conductive or radiant.
Convective Drying of Wet Solids

- I-Fixed (or static) bed convective drying e.g. tray drier

- Tray drier:

- In Fig. 26.4, the tray drier. Air flows in direction of the arrows over each shelf in turn. The wet material is spread on shallow trays resting on the shelves. Electrical elements or steam-heated pipes are positioned as shown, so that the air is periodically reheated after it has cooled by passage over the wet material on one shelf before it passes on to the next.

- Fig. 26.4.................Directed-circulation tray drier. Aul, p. 383.
Rate of drying in a bed of powder:

- The rate at which drying occurs has been found to show certain phases (fig.26.5, Aul) in which the change in moisture content is plotted against time. From A to B the relationship is linear, which is known as the **constant-rate period**, whereas from B to C the rate of loss of moisture decreases and is known as the **falling-rate period**. The end of the constant rate period, B, is referred to as the **critical moisture content**.
- The **first falling-rate period** has a linear relationship, that is, the decrease in drying rate is uniform, whereas in the **second falling-rate period** there is a continuous decrease in the rate of drying until the EMC is reached.

Each of these periods will be considered in more details.
**Constant-rate period:** It is found that the evaporation rate from the drying bed is similar to that of the solvent alone from a free liquid surface under the same conditions, indicating that the evaporation takes place from the wet surface of the solid, and that the surface remains wet in this period as a result of the liquid being replaced from below as fast as it is vaporized.

Controlling factors in this period are the rate at which heat can be transferred and the rate of removal of the vapour.
• **First falling-rate period:** As moisture is removed from the surface, a point will be reached when the **rate of vaporization** is insufficient to saturate the air in contact with the surface. Under these conditions, **the rate of drying** will be limited by the rate of **capillary transfer** of the liquid to the **surface** of the **wet bed**, and this becomes increasingly difficult as the bed dries, the **solvent level decreases** and thus has further to travel to the point of **evaporation**. Consequently, the **rate of drying decreases** continuously.
• **Second falling-rate period:** Any moisture that remains within the drying bed at the end of the first falling-rate period is unable to move, so that drying cannot take place on the surface. i.e. the drying rate depends on the movement of the vapour through the pores of the bed to the surface, in general by molecular diffusion.
• Minimal atmospheric humidity above the solid, in addition to the thermal conductivity of the solid decreases as it becomes dry, if the solid is thermostable it is safe to allow temperature gradients to increase to maintain the rate of heat transfer, but if the material is thermolabile the heating must be decreased.

• In the operation of a tray drier it is usual to remove the dry material on the trays near the air inlet and replace them with the trays with partially dry material from further away.

• Fig 26.5 Drying curve... Critical moisture content (CMC), Equilibrium moisture content (EMC)... Ault, P.384.
II- Dynamic convective driers
Example, fluidized – bed drier.

• Good contact between the warm drying air and wet particles is found in the fluidized – bed drier.
• **Principles of fluidization.** The particulate matter is contained in a vessel, of which is perforated, enabling a fluid to pass through the bed of solids from below.
• If the air velocity through the bed is increased gradually and the pressure drop through the bed is measured, a graph of the operation shows several distinct regions, as indicated in the fig.
• **Fig.26.6.** Effect of air velocity on pressure drop through a fluidized bed...

![Graph showing effect of air velocity on pressure drop through a fluidized bed.](image-url)
Wurster Air Dryer
- At first, when the air velocity is low, (point A), flow takes place between the particles without casing disturbance, but as the velocity is increased, point (B), is reached (gravity = force of fluidization on that particle). Rearrangement of the particles occurs to offer least resistance (C), and they are suspended in the air and can move.

- At point (D), pressure drop through the bed decreases slightly because of the greater porosity. Further increase in the air velocity causes the particles to separate and move freely and the bed is fully fluidized. Any additional increase in velocity separates the particles further, that is, the expands without appreciable change in the pressure drop, until (E), when the air velocity is sufficient to transport the particles to the top of the bed.

Fig. 38.7 Effect of air velocity on pressure drop through fluidized bed
• In the region D---E fluidization is irregular, much of the air flowing through in bubbles, the term boiling bed being commonly used to describe it.
• The important fact is that to produces conditions of great turbulence, the particles mixing with good contact between them and the air. Hence if hot air is used the turbulent conditions lead to high heat and mass transfer rates, the fluidized – bed technique therefore offers a mean of rapid drying.
Advantages of fluidized-bed drying

1. Efficient heat and mass transfer give high drying rates, so that drying times are shorter than with static-bed convection driers. Economic, heat challenge to thermolabile materials is minimized.

2. The fluidized state of the bed ensures that drying occurs from the surface of all the individual particles and not just from the surface of the bed. Hence, most of the drying will be at constant rate and the falling -rate period is very short.

3. The temperature of a fluidized bed is uniform and can be controlled precisely.

4. The turbulence in a fluidized bed causes some attrition to the surface of the granule. This produces a more spherical free-flowing product.

5. The free movement of individual particles eliminates the risk of soluble materials migrating, as may occur in static beds.
Disadvantages of fluidized-bed drying

• 1-The turbulence of the fluidized state may cause 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, leading to segregation and loss of fines.

• 3-The vigorous movement of particles in hot dry air can lead to the generation of static electricity charges. The danger is increased if the fluidized material contains a volatile solvent such as isopropanol. Adequate electrical earthing is essential.
Conductive Drying of Wet Solids

• Mechanism of heat transfer:
  
• 1- Conduction:
  • The transfer of heat from one part of a body to another, without appreciable displacement of the particle is referred as conduction. This mode of heat transfer is called molecular heat transfer, because it involves the transfer of kinetic energy from one molecule to the one adjacent to it, e.g. conduction of heat along the length of a metal rod when one end is heated.

• 2- Convection:
  • The transfer of heat from one point to another in a body of fluid, such as a liquid or a gas, by a mixing process, is referred to as convection heat transfer. In most cases convection involves the transfer of heat from a solid surface to the bulk of the fluid, the change in heat induce a change in the density of the liquid e.g. the conventional currents observed when water is heated in a glass beaker.
• **3- Radiation:**

  The transfer of heat by radiant energy in the form of **electromagnetic** waves, which **travel in straight** lines at the speed of light, is **referred to** as radiation heat transfer. As a body is heated, it emits radiant energy, e.g. sun and infrared heat lamps. When this radiation strikes another body, portions may be reflected
Vacuum oven

- This equipment is a good example of **conduction drier**. The vacuum oven consists of a **jacketed vessel** to withstand **vacuum** within the oven. There are supports for the **shelves** giving a larger area for **conduction** heat transfer. The oven can be closed by a door. The oven is connected through a condenser and liquid receiver to a vacuum pump.

  Operating **pressure** can be as **low as 0.03-0.03 bar**, at which **pressures** water boils at **25-35 C**.

- **Advantages of vacuum oven:**
  - Drying takes place at a low temperature.
  - There is little air present, so, there is minimum risk of oxidation.
VACUM DRUM DRYER

A, drying roll; B, casing; C, trunnions; D, rotary joint; E, feed pump; F, feed-inlet pipe; G, drumfeeder; H, spreader; J, doctor knife; K, doctor-knife-adjusting handwheels; L, product conveyor; M, product-receiver shut-off valve; N, product receivers; P, sight glass; Q, vapor outlet; R, manhole
Radiation Drying of Wet Solids

• **Radiant heat transmission:**

  Heat transmission by radiant heat differs from heat transfer by conduction or convection in that no transfer medium (solid, liquid or gaseous) need be present. Heat energy in the form of radiation can cross empty space or travel through the atmosphere virtually without loss. If it falls on a body capable of absorbing it then it appears as heat, although a proportion may be reflected or transmitted.

• **Use of infrared radiation :**

  Infrared heating has been used to dry wet granules, but it suffers from the disadvantage that it is absorbed very quickly and does not penetrate far into the wet mass. The surface layers dry quickly and the absorption of further energy then raises the temperature of the dry material to a high value. For this reason infrared radiation is now seldom used as a heat source in pharmaceutical manufacture.
The use of microwave radiation

• Although energy in the **IR region** is more easily generated there are other, **longer**, wavelengths that can generate heat when the radiation is absorbed by a wet solid. Microwave radiation in the wavelength range 10 mm to 1m penetrates much better than IR radiation. Microwave driers are used now in pharmaceutical industry.

• **Generation and action of microwaves**

  • Microwaves are **produced** by an electronic **device** known as a **magnetron**. Microwave energy can be reflected down through a **window** into a drying **chamber**.
  
  • 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 small polar molecules such as water, the electrons in the molecule try to resonate in sympathy with the radiation and the resulting molecular “Friction” results in the generation of heat. Dry solids do not resonate as well as water, so further heating may be avoided once the water is removed.

• The absorption of the microwave energy is far greater for small polar molecules than for larger and less polar molecules (methanol-ethanol-water are larger than starch and lactose which is larger and less polar molecules). This is indicated by the value of the loss factors of each substance. The loss factor is a measure of the ratio of the microwave energy absorbed by individual molecules, the higher the number the greater the absorption of microwave energy.
A microwave drier for granulates

- Figure 26.9 (Aul, p.388) is a sketch of microwave drier. It is designed to operate under a slight vacuum. This in itself is not essential for the use of microwaves, but the air flow allows the continuous removal of evaporated solvent. The radiation is generated by multiple magnetrons. The radiation passes through a window into the drying chamber, where it is absorbed by the liquid in the wet granules contained on a tray. The heat generated in the mass drives off the moisture and the evolved vapour is drawn away in the air flow as it is formed. When drying is nearly complete the radiation field intensity will rise, as the dry solids do not absorb as readily as water. This rise is detected and the magnetrons are progressively turned off automatically, to give an accurate control of the final moisture content and minimize the danger of over-heating.

Fig.26.9 Microwave drier
Advantages of microwave drying:

• 1- It provides rapid drying at low temperature.

• 2- The thermal efficiency is high, as the drier casing and the air remain cool. Most of the microwave energy is absorbed by the liquid in the wet material.

• 3- The bed is stationary, avoiding the problems of dust and attrition.

• 4- Solute migration is reduced as there is uniform heating of the wet mass.

• 5- Equipment is highly efficient; all the requirements of product and operator safety follow the GMP considerations.

• 6- Granulation end-point can be detected by measuring the residual microwave energy, (it is rises sharply when there is little solvent left to evaporate).
Disadvantages of microwave drying:

1- The batch size of microwave driers is smaller than those available for fluidized-bed driers.

2- Care must be taken to shield operators from the microwave radiation, which can cause damage to organs such as the eyes and testes. This is ensured by “Failsafe” devices preventing the generation of microwaves until the drying chamber is sealed.