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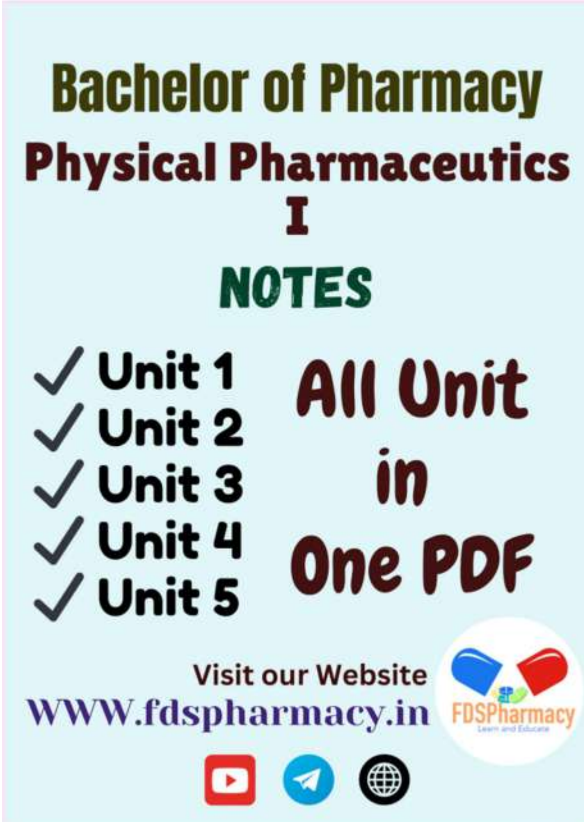
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PHARMACEUTICAL ENGINEERING
UNIT 3

TOPIC :

- **Drying :** Objectives, applications & mechanism of drying process, measurements & applications of Equilibrium Moisture content, rate of drying curve. principles, construction, working, uses, merits and demerits of Tray dryer, drum dryer spray dryer, fluidized bed dryer, vacuum dryer, freeze dryer.

Drying

- Drying is a unit operation in which a liquid (generally water) present in a wet solid is removed by the application of heat, resulting in a solid product with reduced moisture content. It is an essential step in many pharmaceutical and industrial processes to ensure product stability, quality, and usability.

Objectives of Drying

- **Reduction of moisture content** – To bring the material to a desired moisture level for safe storage, processing, or application.
- **Enhancement of product stability** – By preventing microbial growth, chemical degradation, and spoilage caused by moisture.
- **Improvement of physical properties** – Ensures better flowability, reduced stickiness, and easier handling of powders or granules.
- **Ease of transportation and storage** – Dry products are lighter, less bulky, and cheaper to store and transport.
- **Better appearance and effectiveness** – Maintains look, feel, and performance of the product.
- **Improved shelf life** – By reducing moisture, the risk of decomposition and spoilage is minimized.
- **Facilitation of dosage form production** – Drying is essential in tablet, capsule, and other solid dosage form manufacturing.

Applications of Drying in Pharmacy

1. **Formation of Solid Dosage Forms**
    - Drying removes moisture from granules, powders, and wet masses during the manufacture of tablets and capsules.
2. **Stabilization of Formulations**
    - Reduces degradation and prevents microbial growth in drugs and excipients.
3. **Preparation of APIs (Active Pharmaceutical Ingredients)**
    - APIs are dried after synthesis to attain required purity, stability, and specific physical properties (e.g., particle size, flow).
4. **Freeze Drying (Lyophilization)**
    - Used for heat-sensitive drugs like vaccines, proteins, enzymes, and biological products.
    - Removes water by sublimation, preserving structural and therapeutic activity.
5. **Prolongation of Shelf Life**
    - Dried pharmaceutical products are less prone to spoilage, extending their usability period.
6. **Improved Packaging and Handling**
    - Drying ensures that materials do not cake, lump, or stick, allowing uniform filling and packaging

Mechanism of Drying

Drying is a **combined heat and mass transfer process**.

1. **Heat Transfer**
   - Heat is transferred from the heating medium (such as hot air, steam, or radiation) to the wet solid.
   - This heat raises the temperature of the solid and provides the energy needed for evaporation of moisture**.**
2. **Mass Transfer**
   - Moisture inside the solid moves to the surface.
   - At the surface, this moisture is converted into vapor and then transferred to the surrounding air.

Thus, drying involves simultaneous heat transfer (into the material) and mass transfer (moisture removal from material to air).

Theories of Moisture Movement in Drying

The movement of moisture from inside the material to the surface can be explained by two major theories:

1. Diffusion Theory

- **Principle:** Based on molecular diffusion.
- According to this theory, moisture inside the material moves from a region of higher moisture concentration (interior) to a region of lower moisture concentration (surface).
- As drying begins, the surrounding air has low moisture content, so water molecules migrate towards the surface.
- Once the moisture reaches the surface, it evaporates into the air.
- This mechanism is particularly important for materials where moisture is uniformly distributed inside.

2. Capillary Theory

- **Principle:** Based on capillary action inside porous materials.
- In porous solids (e.g., soil, wood, paper, pharmaceutical powders), water is held in small pores or capillaries.
- These capillaries act like fine tubes that pull water from the interior toward the surface by capillary forces.
- When the water reaches the surface, it evaporates into the air.
- As surface water is lost, more moisture is pulled upward from the inner layers, maintaining a continuous flow until drying is complete.

Equilibrium Moisture Content (EMC)

Equilibrium Moisture Content is the moisture level of a pharmaceutical solid (powder, granules, tablets, etc.) at which the material neither gains nor loses moisture when exposed to specific environmental conditions.

- At this point, the vapor pressure of water within the solid equals the vapor pressure of water in the surrounding atmosphere.
- In simple terms, EMC represents the "stable moisture content" of a substance under given conditions of temperature and relative humidity.

Factors Affecting EMC

1. **Temperature**
   - With an increase in temperature, **EMC decreases**, because warm air can hold more water vapor, thus pulling moisture away from the material more effectively.
2. **Relative Humidity (RH)**
   - At **low RH**, the surrounding air promotes evaporation, lowering EMC.
   - At **high RH**, the rate of evaporation decreases, increasing EMC.
3. **Airflow (Velocity of Air)**
   - Increased airflow removes surface moisture rapidly, aiding the drying process and influencing EMC.

Importance of EMC in Drying

- Determines how much moisture needs to be removed from the material.
- Once EMC is reached, the product is considered "dry" under given conditions.
- Further drying beyond EMC is not possible unless environmental conditions (temperature, RH) are changed.
- Helps in deciding final drying time, energy requirement, and storage stability.

Measurement of Moisture Content

Moisture content in a sample is usually expressed as a percentage of water relative to dry weight:

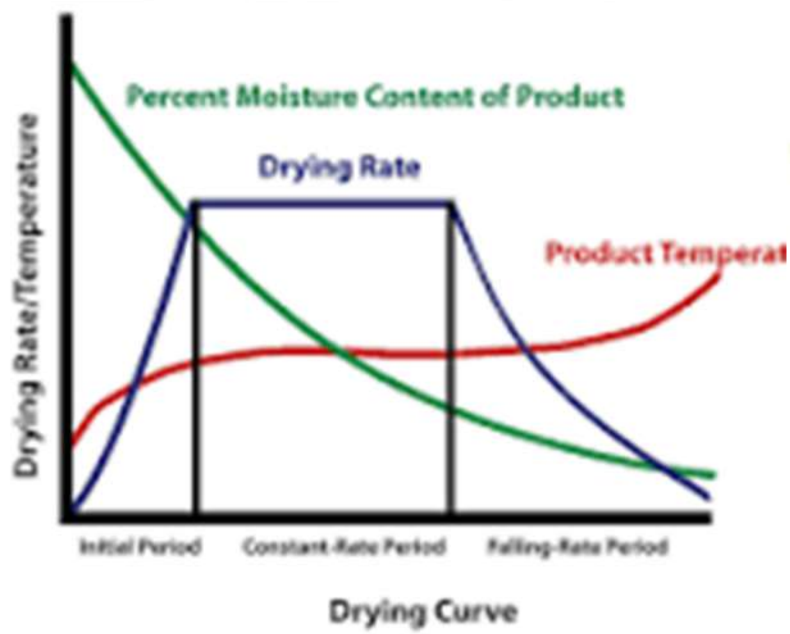
$$\%\text{Moisture Content} = \frac{\text{Weight of Water in Sample}}{\text{Weight of Dry Sample}} \times 100$$

Rate of Drying Curve

The rate of drying curve represents the relationship between the drying rate of a material and its moisture content (or drying time) during the drying process.
It helps in understanding the mechanism of moisture removal and the efficiency of drying equipment.

Typically, the curve is studied with respect to three parameters plotted against time:

- Drying rate vs. time (blue line)
- Moisture content vs. time (green line)
- Product temperature vs. time (red line)



Phases of the Drying Curve

1. Initial Period

- At the beginning of drying, the surface is wet, and moisture evaporates freely.
- The drying rate increases rapidly with time.

- Moisture content decreases exponentially.
- Product temperature rises as it absorbs heat.
- This period is relatively short and often neglected in calculations.

2. Constant Rate Period

- The drying rate remains constant over time.
- Moisture is present on the surface of the solid in sufficient quantity to maintain continuous evaporation.
- Percent of moisture content decreases exponentially with time.
- The product temperature remains nearly constant, close to the wet-bulb temperature of air.
- This is the most efficient period of drying, and the majority of water is removed here.

3. Falling Rate Period

- After surface water is exhausted, moisture must diffuse or move from the interior of the solid to the surface.
- The drying rate decreases gradually with time.
- Moisture removal becomes slower, controlled by diffusion or capillary action.
- Product temperature rises as less energy is used for evaporation and more is retained by the solid.
- Drying becomes less efficient in this phase.

Conclusion

- At the end of drying:
  - Drying rate is minimum (almost zero).
  - Moisture content reaches its lowest possible value (close to EMC).
  - Product temperature is maximum, approaching the temperature of the heating medium.

Tray Dryer

Principle

- Tray dryer works on the principle of convection drying.
- Heated air is circulated over the trays containing wet material.
- The moisture in the material evaporates due to heat and is carried away by the air stream.

Construction

1. **Drying Chamber**
    - A closed rectangular chamber made of metal (mild steel/stainless steel).
    - Properly insulated to avoid heat loss.
2. **Trays**
    - Perforated trays made of stainless steel or plastic are arranged in the chamber.
    - Material is spread evenly in thin layers on trays.
3. **Heating System**
    - Heaters (electric or steam) are provided to heat the air.
4. **Air Circulation System**
    - Fans or blowers circulate hot air uniformly over the trays.
5. **Exhaust System**
    - Moist air is continuously removed from the chamber through an exhaust outlet.

Working

1. Wet material is spread uniformly on trays in thin layers.
2. Heaters raise the temperature of air inside the chamber.
3. Fans/blowers circulate the hot air across the trays, ensuring uniform drying.
4. Moisture evaporates from the material and is removed with the air stream through the exhaust.
5. Drying continues until the material reaches the desired moisture content.

Advantages

- Simple in design and easy to operate.
- Economical and versatile.
- Provides uniform drying with proper air circulation.
- Suitable for both small-scale and large-scale drying (depending on model).

Disadvantages

- Time-consuming process.
- Requires manual loading and unloading (labor-intensive).
- Limited drying capacity compared to modern dryers (like spray or fluidized bed).

Applications

- Drying of powders, granules, and tablets in the pharmaceutical industry.
- Drying of fruits, vegetables, and food products.
- Used for drying chemicals, crude drugs, dyes, and intermediates.

Drum Dryer

Principle

- Drum dryer works on the principle of conduction drying.
- The wet material is applied as a thin film on the surface of a rotating heated drum.
- Heat is transferred from the hot drum surface to the wet material, causing evaporation of moisture.
- The dried material is then scraped off with the help of a blade/knife.

Construction

1. **Drum**
   - A large hollow cylindrical drum made of metal (usually stainless steel).
   - Heated internally by steam or hot water.
   - Drum rotates slowly on its axis.
2. **Feed System**
   - Wet material (slurry or solution) is fed on the surface of the rotating drum either by a trough, dip roll, or spray arrangement.
3. **Heating System**
   - Steam is passed inside the drum to provide uniform heating.
4. **Scraper Knife/Doctor Blade**
   - A sharp blade is placed in contact with the drum surface to continuously scrape off the dried film of material.
5. **Collection System**
   - The dried material is collected as flakes or powder for further processing.

Working

1. The drum is internally heated by steam.
2. Wet material (in slurry or liquid form) is applied on the external surface of the drum in a thin film.
3. As the drum rotates, the thin film of material comes in contact with the hot surface and moisture evaporates rapidly.
4. The dried layer sticks to the drum and is continuously scraped off by the knife.
5. The dried product (flakes/powder) is collected for further use.

Advantages

- ✓ Very rapid and efficient drying (high heat transfer).
- ✓ Suitable for slurries, pastes, and liquid materials.
- ✓ Continuous operation possible.
- ✓ Compact equipment with relatively low floor space requirements.

Disadvantages

- Not suitable for heat-sensitive materials (high temperature at drum surface).
- Drying may not be uniform if film thickness varies.
- Maintenance required for drum surface and scrapers.
- Limited to materials that can form thin films.

Applications

- Drying of milk to milk powder (commonly used in food industry).
- Drying of yeast, starch, fruit juices, and baby foods.
- Used in pharmaceutical industry for slurries, extracts, and suspensions.
- Also used for drying chemicals, soap, and pigments.

Spray Dryer

Principle

- Spray dryer works on the principle of convection drying.
- A liquid material (solution, suspension, or slurry) is atomized into fine droplets and sprayed into a stream of hot air.
- The fine droplets come in direct contact with the hot air, leading to rapid evaporation of moisture.
- The dried product is collected as a fine powder.

Construction

1. **Drying Chamber**
   - A large vertical cylindrical chamber (stainless steel) with a conical bottom.
   - Hot air enters from the top or bottom.
2. **Atomizer**
   - Converts liquid feed into fine droplets.
   - Types: rotary atomizer, pressure nozzle, or two-fluid nozzle.
3. **Air Heater & Blower**
   - Provides a stream of hot air at controlled temperature and velocity.
4. **Exhaust System**
   - Removes moist air after drying.
   - Cyclone separator or bag filter is often used to recover fine particles from exhaust air.
5. **Product Collector**
   - Dried powder is collected from the base of the chamber or from cyclone separator.

Working

1. Liquid feed (solution/suspension) is pumped into the atomizer.
2. Atomizer converts the liquid into a fine spray of droplets inside the hot air chamber.
3. Droplets rapidly lose moisture due to contact with hot air (convection heat transfer).
4. Dry powder particles fall to the bottom of the chamber by gravity.
5. Exhaust air carrying residual fine particles passes through a cyclone separator where particles are separated and collected.

Advantages

- Rapid drying (seconds) – suitable for large-scale production.
- Produces uniform, fine, and free-flowing powder.
- Best suited for heat-sensitive materials (low residence time at high temperature).
- Continuous operation with good control over particle size and moisture content.

Disadvantages

- Equipment is large and expensive.
- High energy consumption.
- Low thermal efficiency (due to large volume of hot air required).
- Not suitable for very viscous liquids or slurries with large solid content.

Applications

- Widely used in pharmaceutical industry for drying antibiotics, enzymes, vitamins, and heat-sensitive drugs.
- Preparation of milk powder, coffee powder, egg powder in food industry.
- Used in chemical industry for drying detergents, dyes, and ceramics.
- Employed for producing micro-encapsulated products and aerosols.

Fluidized Bed Dryer (FBD)

Principle

- Fluidized bed dryer works on the principle of fluidization of particles using hot air.
- When a stream of hot air is passed upward through a bed of moist solid particles, the particles are lifted and suspended in the air stream, behaving like a fluid.
- This intimate contact between hot air and particles leads to rapid heat and mass transfer, causing efficient drying.

Construction

1. **Drying Chamber**
    - A vertical, cylindrical container made of stainless steel.
    - Provided with a perforated bottom (air distribution plate).
2. **Air Handling Unit**
    - Includes blower/fan, air filter, and heater.
    - Supplies clean, heated air into the drying chamber.
3. **Air Distributor (Perforated Plate)**
    - Evenly distributes hot air through the solid bed, ensuring uniform fluidization.
4. **Filter Bags (Dust Collector)**
    - Located at the top of the chamber to prevent loss of fine particles with exhaust air.
5. **Exhaust System**
    - Removes moist air from the chamber.
6. **Product Container**
    - Holds the solid material to be dried.

Working

1. Wet granules or powders are placed in the product container.
2. Hot air from the blower passes through the heater and enters the drying chamber via the perforated plate.
3. The solid particles are lifted and suspended in the upward hot air stream, forming a fluidized bed.
4. Due to excellent contact between hot air and particles, moisture evaporates rapidly.
5. Dust particles carried by the exhaust air are collected by filter bags.
6. Dry product is discharged after reaching the required moisture level.

Advantages

- Rapid drying compared to tray drying (5–20 minutes).
- Uniform drying with good control over temperature.
- Highly efficient due to large surface area exposure.
- Easy handling and shorter drying time → economical for large-scale production.
- Can also be used for mixing and granulation (in modified designs).

Disadvantages

- Not suitable for sticky or gummy materials (they may block the bed).
- Requires careful control of air velocity; too high → particles may be carried away, too low → poor fluidization.
- Initial cost is high compared to tray dryers.
- Generates more dust (needs efficient filters).

Applications

- Pharmaceutical industry: drying of wet granules during tablet and capsule manufacturing.
- Food industry: drying of grains, cereals, and food powders.
- Chemical industry: drying of fertilizers, polymers, and resins.
- Used for heat-sensitive materials (short exposure time).

Vacuum Dryer

Principle

- A vacuum dryer works on the principle of drying under reduced pressure (vacuum).
- In vacuum, the boiling point of water (or solvent) decreases, so moisture can be removed at much lower temperatures.
- This makes it especially useful for heat-sensitive materials which may decompose at high temperatures.

Construction

1. **Drying Chamber**
    - A strong, airtight, cylindrical or rectangular vessel made of stainless steel.
    - Jacketed for circulation of heating medium (steam, hot water, or oil).
2. **Shelves/Trays**
    - Inside the chamber, trays or shelves hold the material to be dried.
    - Shelves are also hollow to allow passage of heating medium.
3. **Vacuum Pump**
    - Creates vacuum inside the chamber, lowering the pressure and boiling point of moisture.
4. **Heating System**
    - Heating medium (steam or hot water) circulates through the jacket and shelves to supply heat.
5. **Condenser**
    - Condenses the vaporized moisture removed under vacuum.
6. **Exhaust System**
    - Removes the condensed liquid and maintains pressure inside the chamber.

Working

1. Wet material is loaded on trays inside the chamber.
2. The chamber is closed and vacuum is applied using a vacuum pump.
3. Heating medium (steam/hot water) is circulated through the jacket and shelves.
4. Heat is transferred by conduction from the shelves to the material.
5. Due to vacuum, water (or solvent) evaporates at a much lower temperature.
6. Vaporized moisture is carried to the condenser, where it is condensed and removed.
7. Dry product is unloaded once the desired moisture content is reached.

Advantages

- Suitable for heat-sensitive and thermolabile materials (antibiotics, vitamins, enzymes).
- Drying occurs at low temperature → prevents decomposition.
- Solvents can be recovered from the condenser.
- Provides uniform drying in a closed system (reduced contamination risk).

Disadvantages

- Expensive equipment and high maintenance cost.
- Drying rate is slower compared to fluidized bed or spray dryers.
- Limited capacity (batch process).
- Requires skilled operation.

Applications

- Drying of thermolabile drugs (antibiotics, vaccines, vitamins, enzymes).
- Drying of **plant extracts** and other heat-sensitive materials.
- Used for materials that are **toxic or explosive** (safe in closed system).
- Recovery of expensive solvents during drying.

Freeze Dryer (Lyophilizer)

Principle

- Freeze dryer works on the principle of sublimation.
- In this process, water (or solvent) is first frozen and then removed directly as vapor without passing through the liquid state, under reduced pressure (vacuum).
- This allows drying at very low temperatures, making it highly suitable for heat-sensitive and thermolabile products.

Construction

1. **Drying Chamber**
    - A large insulated chamber made of stainless steel.
    - Contains shelves or trays where product is placed.
    - Equipped with refrigeration coils to freeze the product.
2. **Vacuum System**
    - A powerful vacuum pump creates low pressure inside the chamber.
3. **Condenser (Cold Trap)**
    - Maintained at very low temperature.
    - Traps and condenses the vaporized moisture (ice).
4. **Heating System**
    - Provides controlled heat (usually radiant or conductive) to supply latent heat of sublimation.
5. **Product Container**

- Materials are placed in vials, trays, or ampoules depending on the product type.

Working

1. **Freezing Stage**
    - The product solution or suspension is first frozen at very low temperature (–40°C to –80°C).
2. **Primary Drying (Sublimation Stage)**
    - Under vacuum, the ice crystals in the product directly sublimate to vapor.
    - The condenser traps this vapor as ice.
    - Almost 90% of the water is removed in this stage.
3. **Secondary Drying (Desorption Stage)**
    - Removes unfrozen bound water molecules by applying slightly higher temperature under vacuum.
    - Reduces residual moisture to less than 1–2%.
4. The final dried product is porous, stable, and can be easily reconstituted by adding water.

Advantages

- Ideal for heat-sensitive and thermolabile drugs (vaccines, enzymes, hormones, proteins).
- Provides excellent product stability and long shelf life.
- Dry product retains its structure, potency, and biological activity.
- Final product is porous → easy to rehydrate before use.

Disadvantages

- Very expensive equipment and high running cost.
- Slow process compared to other drying methods.
- Requires skilled operation and maintenance.
- Not suitable for bulk drying of cheap products.

Applications

- **Pharmaceuticals**: drying of vaccines, blood plasma, hormones, antibiotics, enzymes, proteins.

- **Food industry**: preservation of coffee, fruit juices, vegetables, and instant foods.
- **Biotechnology**: drying of microbial cultures, cell suspensions, and biological samples.
- **Diagnostics**: preparation of diagnostic kits and reagents.