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PHARMACEUTICAL ENGINEERING

UNIT 2

TOPIC :

- **Evaporation :** Objectives, applications and factors influencing evaporation, differences between evaporation and other heat process. principles, construction, working, uses, merits and demerits of Steam jacketed kettle, horizontal tube evaporator, climbing film evaporator, forced circulation evaporator, multiple effect evaporator& Economy of multiple effect evaporator.

EVAPORATION

Evaporation is the process by which a liquid changes into its gaseous state at a temperature below its boiling point.
It primarily occurs at the surface of the liquid, where molecules with sufficient energy escape into the surrounding air.

Mechanism of Evaporation

- Molecules in a liquid are in constant motion and possess different amounts of kinetic energy.
- At the surface, some molecules have enough energy to overcome intermolecular forces and surface tension, allowing them to escape as vapor.
- The process continues until equilibrium is reached between the liquid and vapor phases.

Factors Affecting Evaporation

1. **Temperature**
    - Higher temperature increases the kinetic energy of molecules, making it easier for them to escape.
    - Example: Clothes dry faster on a hot sunny day.
2. **Surface Area**
    - A larger surface area allows more molecules to be exposed, increasing evaporation.
    - Example: Spreading clothes helps them dry quickly.
3. **Humidity**
    - High humidity decreases evaporation as the air is already saturated with water vapor.
    - Example: Clothes dry slowly during the rainy season.
4. **Wind Speed**
    - Wind carries away vapor molecules, lowering humidity near the surface and promoting faster evaporation.

5. **Pressure**
    - Lower atmospheric pressure reduces the resistance for molecules to escape, enhancing evaporation.
6. **Boiling Point of Liquid**
    - Liquids with low boiling points (e.g., alcohol, acetone) evaporate faster than liquids with high boiling points (e.g., water).

Objectives of Evaporation

- To increase concentration of a solution by removing solvent.
- To separate or purify substances by removing volatile components.
- To reduce volume of liquids for easier handling and storage.
- To remove moisture and obtain dry or semi-dry products.

Applications of Evaporation

- **Food Industry**: Concentration of fruit juices, milk, etc.
- **Pharmaceutical Industry**: Concentration and purification of drugs, extracts, and syrups.
- **Water Treatment**: Removal of impurities and preparation of distilled water.
- **Textile Industry**: Drying fabrics and fibers.
- **Chemical Industry**: Concentration of caustic soda, salts, and other solutions.

Equipments Used in Evaporation

1. **Steam Jacketed Kettle**
2. **Horizontal Tube Evaporator**
3. **Climbing Film Evaporator**
4. **Forced Circulation Evaporator**
5. **Multiple Effect Evaporator**

Difference Between Evaporation and Other Heat Processes

1. **Evaporation vs Boiling**
   - **Evaporation:**
     - Occurs only at the surface of the liquid.
     - Takes place at any temperature below boiling point.
     - Is usually a slow process.
   - **Boiling:**
     - Occurs throughout the entire liquid mass.
     - Takes place only when the liquid reaches its boiling point.
     - Is a rapid process.
2. **Evaporation vs Distillation**
   - **Evaporation:**
     - Purpose: Concentration of solution or removal of solvent.
     - No recovery of solvent (it is usually lost to surroundings).
     - Simpler process, mainly based on surface vaporization.
   - **Distillation:**
     - Purpose: Separation and purification of components based on boiling point differences.
     - Both solute and solvent can be recovered.
     - Requires more complex apparatus like condenser.
3. **Evaporation vs Drying**
   - **Evaporation:**
     - Removes moisture mainly from liquids or solutions.
     - Converts solution into concentrated liquid or slurry.
   - **Drying:**
     - Removes moisture mainly from solids (wet solid materials).
     - Produces dry powder, granules, or solid product.
4. **Evaporation vs Sublimation**
   - **Evaporation:**
     - Phase change: Liquid → Gas.
     - Occurs below boiling point at liquid surface.
   - **Sublimation:**
     - Phase change: Solid → Gas (without passing through liquid phase).
     - Requires specific conditions (e.g., low pressure).

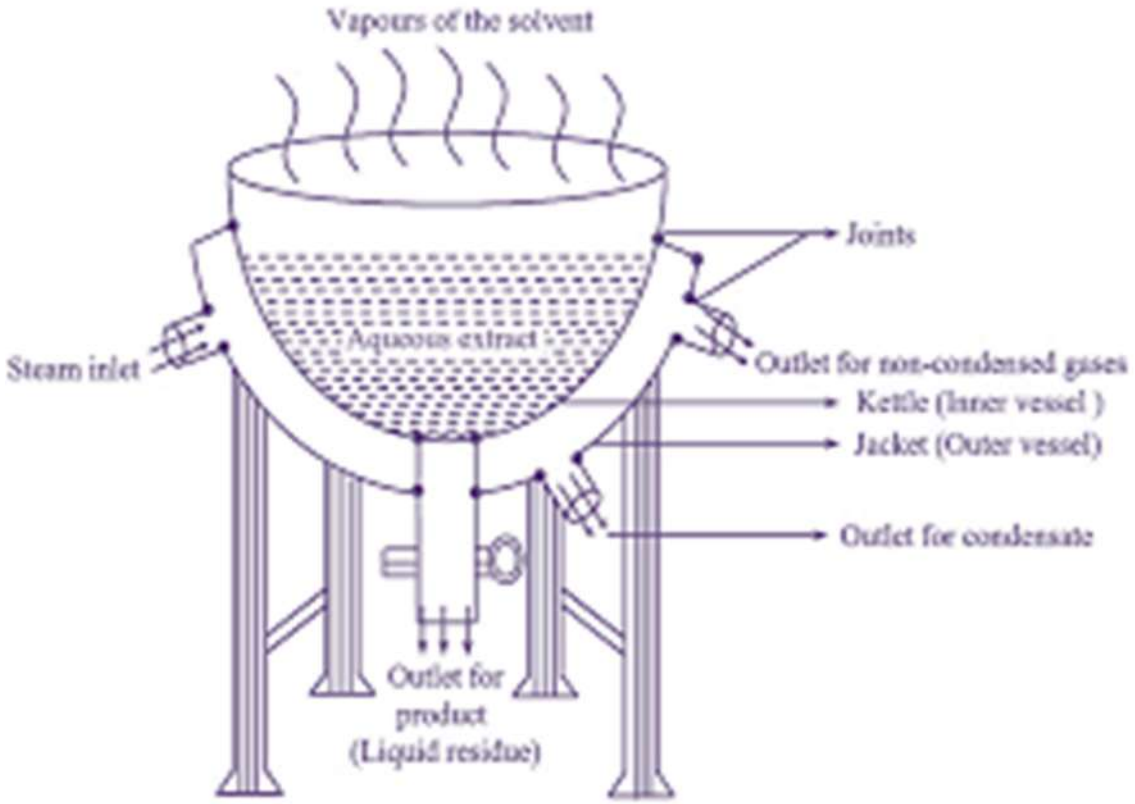
Steam Jacketed Kettle

Principle

- A Steam Jacketed Kettle works on the principle of heat transfer by conduction and convection, where steam is circulated in the outer jacket to heat the contents (liquid/semi-solid) inside the kettle.
- Heat is uniformly distributed, avoiding localized overheating.

Construction

1. Kettle – Cylindrical or hemispherical vessel made of heat-conductive material (stainless steel, copper, etc.).
2. Steam Jacket – A surrounding chamber (double wall) where steam circulates to transfer heat.
3. Steam Inlet – Connection through which steam enters the jacket.
4. Steam Outlet/Condensate Outlet – Allows condensed steam (water) to exit.
5. Support/Stand – Provides stability and easy operation.
6. Manhole & Outlet Valve – For cleaning and removal of processed material.



Working

- Steam from an external boiler enters the jacket surrounding the kettle.
- Heat from steam is transferred through the kettle walls to the contents inside.
- The temperature is controlled by regulating the steam pressure and flow.
- After heat transfer, steam condenses into water and exits through the steam outlet.

Advantages

- Efficient and uniform heat transfer.
- Prevents scorching or localized overheating.
- Easy operation and cleaning.
- Suitable for viscous and semi-solid materials.

Disadvantages

- Depends on continuous steam supply.
- Risk of corrosion if material is not resistant.
- Higher installation and maintenance cost compared to simple vessels.

Applications

- Food Processing Industry – Cooking, boiling, concentrating syrups, jams, sauces.
- Pharmaceutical Industry – Preparation of ointments, syrups, extracts, and emulsions.
- Cosmetics Industry – Preparation of creams, lotions, and gels.

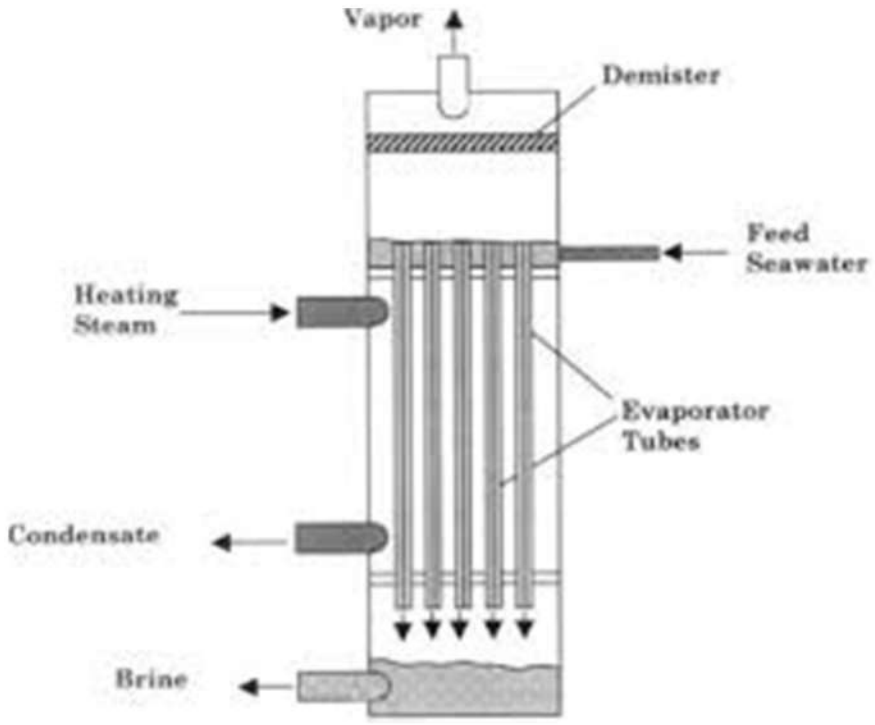
Horizontal Tube Evaporator

Principle

- Works on the principle of heat transfer by conduction and convection, where steam is passed inside horizontal tubes and the liquid to be concentrated flows outside the tubes.
- The heat from steam causes the solvent (usually water) in the liquid to evaporate, thereby concentrating the solution.

Construction

1. Evaporator Vessel (Shell) – A large cylindrical vessel that holds the liquid to be concentrated.
2. Horizontal Tubes – Bundle of tubes placed horizontally inside the shell; steam passes through these tubes.
3. Steam Inlet – Entry point for heating steam into the tubes.
4. Steam Outlet/Condensate Outlet – Allows condensate (water) formed after steam cooling to exit.
5. Liquid Feed Inlet – Entry point for the solution to be concentrated.
6. Vapor Outlet – Outlet at the top for vapor (evaporated solvent) to escape.
7. Concentrate Outlet – Bottom outlet to collect concentrated product.



Working

- Steam enters the horizontal tubes, heating their walls.
- The liquid (to be concentrated) surrounds the outer side of the tubes in the shell.
- Heat is transferred from steam (inside tubes) → tube walls → liquid (outside tubes).
- Solvent in the liquid evaporates due to heating and escapes as vapor through the vapor outlet.
- The remaining liquid becomes more concentrated and is collected from the bottom outlet.
- Condensed steam (water) leaves the tubes via the steam outlet.

Advantages

- Simple design and easy to operate.
- Provides large heating surface area.
- Suitable for non-viscous liquids.
- Maintenance is relatively easy.

Disadvantages

- Not suitable for viscous or thick liquids (as heat transfer reduces).
- Foaming liquids may cause problems.
- Scaling/fouling of tubes reduces efficiency.
- Requires more space compared to vertical evaporators.

Applications

- Used in pharmaceutical industry for concentrating heat-sensitive aqueous extracts (e.g., plant extracts, syrups).
- In food industry for concentrating fruit juices, milk, etc.
- In chemical industry for concentrating solutions of salts and other chemicals.

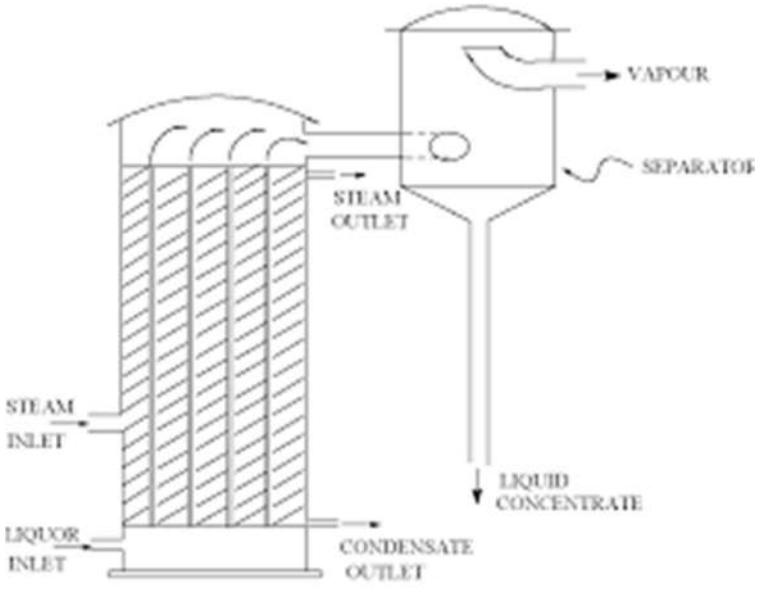
Climbing Film Evaporator

Principle

- Works on the principle of thin film evaporation.
- When a liquid is fed into vertical tubes heated from outside by steam, boiling starts at the bottom.
- The generated vapors push the liquid upward along the tube walls as a thin film.
- The film climbs upward due to vapor pressure and evaporation continues along the tube length.
- This ensures rapid evaporation with minimal liquid hold-up.

Construction

1. Long Vertical Tubes – Heat transfer tubes placed vertically inside a shell.
2. Steam Jacket (Shell Side) – Steam flows outside the vertical tubes, heating the liquid inside the tubes.
3. Liquid Feed Inlet – At the bottom of tubes where the liquid enters.
4. Vapor–Liquid Separator – At the top, separates the vapor from concentrated liquid.
5. Vapor Outlet – Removes the solvent vapors.
6. Concentrate Outlet – Collects concentrated liquid product.
7. Condensate Outlet – Removes condensed steam from the shell.



Working

- Feed liquid enters the bottom of vertical tubes.
- Steam supplied outside the tubes heats the liquid.
- As boiling starts, vapor bubbles form and rise upward.
- The vapor pushes the liquid upwards along the tube walls as a climbing thin film.
- During upward movement, more evaporation occurs → film becomes thinner and more concentrated.
- At the top, vapor and concentrated liquid are separated in the separator.
- Vapors leave through the vapor outlet, and concentrated liquid exits from the concentrate outlet.

Advantages

- Efficient heat transfer due to thin liquid film.
- Short residence time → suitable for heat-sensitive materials.
- Requires less floor space (vertical design).
- High capacity, continuous operation possible.

Disadvantages

- Not suitable for highly viscous liquids (film formation becomes poor).
- Foaming liquids may cause operational problems.
- More costly and complex compared to simple evaporators.

Applications

- Concentration of heat-sensitive materials such as antibiotics, enzymes, herbal extracts, and vitamins.
- Used in pharmaceutical industry for syrups and extracts.
- In food industry for fruit juices, milk, and natural products.
- In chemical industry for thermolabile solutions.

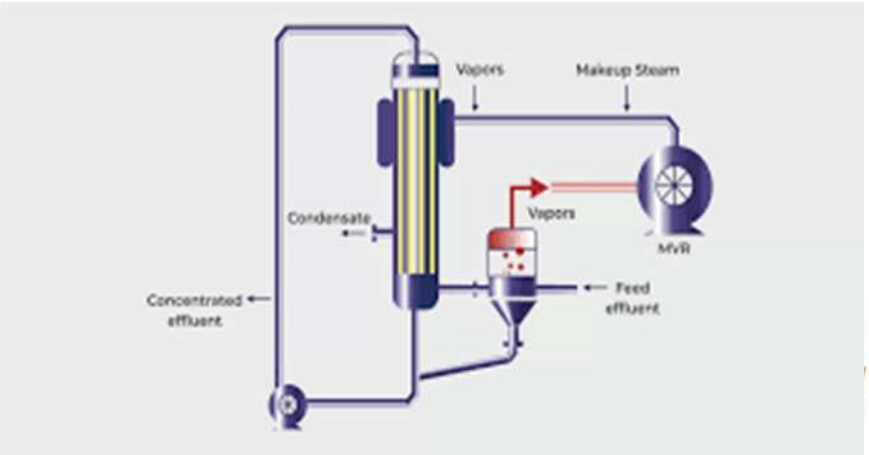
Forced Circulation Evaporator

Principle

- Works on the principle of forced convection.
- A pump is used to circulate liquid at high velocity through the heating tubes, preventing deposition or crystallization.
- Heat transfer occurs efficiently as the liquid is continuously agitated and recirculated, reducing scaling and allowing concentration of viscous or crystallizing solutions.

Construction

1. Heat Exchanger (Calandria/Tubes):
    - A vertical or horizontal tube bundle where steam is supplied outside the tubes, and liquid flows inside.
2. Circulating Pump:
    - A strong pump that forces the liquid through tubes at high velocity.
3. Separator Chamber:
    - Located above the heat exchanger, separates vapors from the concentrated liquid.
4. Vapor Outlet:
    - Removes generated vapors from the separator.
5. Concentrate Outlet:
    - Removes concentrated liquid or slurry.
6. Steam Inlet & Condensate Outlet:
    - Steam enters the shell for heating, and condensate is removed after heat transfer.



Working

- Feed liquid enters the system and is continuously circulated by the pump through the heating tubes.
- Steam heats the liquid inside the tubes, and boiling occurs either in the tubes or in the separator depending on design.
- The high velocity of circulation prevents settling, scaling, and deposition.
- Vapors formed are sent to the separator, where they are separated from the concentrated product.
- Concentrated liquid is withdrawn while vapors are condensed or further processed.

Advantages

- Suitable for viscous and crystallizing liquids (e.g., sugar, salts).
- Prevents scaling and tube blockage.
- Provides uniform heat transfer due to forced convection.
- Can handle large volumes and continuous operation.

Disadvantages

- Requires a powerful pump → higher energy consumption.
- High maintenance cost due to moving parts (pump).
- More complex and expensive compared to natural circulation evaporators.

Applications

- Used in the pharmaceutical industry for concentrating syrups, antibiotics, and heat-sensitive solutions.
- In chemical industry for crystallizing solutions (e.g., sodium chloride, sodium hydroxide).
- In food industry for concentrating fruit juices, milk, and sugar solutions.
- Ideal for corrosive, viscous, and scaling-prone liquids.

Multiple Effect Evaporator (Mee)

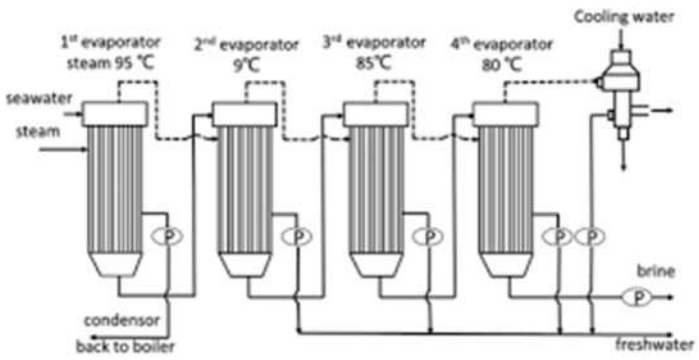
Principle

- Works on the principle of using steam economy.
- The vapor generated from one effect (evaporator) is used as the heating medium for the next effect.
- This reduces overall steam consumption and increases efficiency.
- Heat transfer occurs by conduction and convection across heating surfaces.

Construction

A Multiple Effect Evaporator consists of:

1. Series of Evaporator Effects (2–7 or more vessels):
    - Arranged in forward feed, backward feed, or mixed feed sequence.
    - Each effect consists of a heating chamber (tubes), vapor separator, and liquid outlet.
2. Steam Inlet (First Effect):
    - Fresh steam is supplied to the first evaporator.
3. Vapor Connections:
    - Vapor from one effect is passed as heating steam to the next effect.
4. Condensate Outlet:
    - Removes condensate formed during heat transfer.
5. Product Outlet:
    - Withdraws concentrated liquid after the last effect.
6. Vacuum System (optional):
    - Often used to operate at reduced pressures, especially for heat-sensitive liquids.



Working

- Feed liquid enters the first effect, where it is heated by fresh steam.
- Vapor generated in the first effect is passed to the second effect as the heating medium.
- This process is repeated in subsequent effects, with each effect operating at a progressively lower pressure and temperature.
- The liquid becomes more concentrated as it passes through successive effects.
- Finally, the concentrated product is removed from the last effect, and uncondensed vapors may be condensed in a condenser.

Advantages

- Economical steam usage: Saves energy by reusing vapor.
- High efficiency compared to single-effect evaporators.
- Suitable for large-scale production.
- Can handle heat-sensitive materials under vacuum.

Disadvantages

- High initial cost due to complex design.
- Requires large space for installation.
- Difficult to clean and maintain compared to single-effect evaporators.
- Not suitable for liquids that cause heavy scaling.

Applications

- Pharmaceutical industry: Concentration of heat-sensitive drugs, syrups, and enzymes.
- Food industry: Concentrating fruit juices, milk, and sugar solutions.
- Chemical industry: For salts, caustic soda, and other bulk chemicals.
- Wastewater treatment: For reducing effluent volume in industries.