# Topic 2, Evaporation

## Last lecture

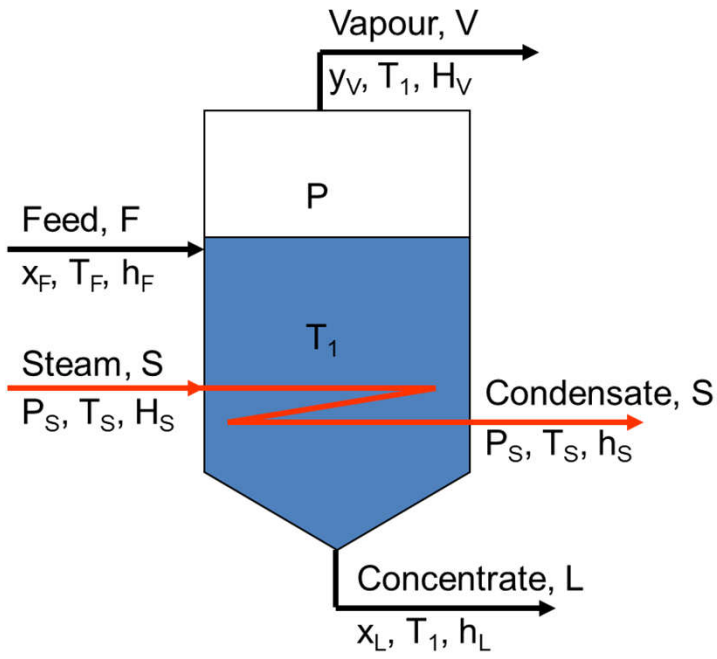
- ✓ Introduction to Heat and mass transfer operation.

## This lecture

- ✓ Describe the process of evaporation
- ✓ Industrial examples of evaporation processes
- ✓ Properties that affect evaporation processes
- ✓ Types of evaporation equipment
- ✓ Explain how the overall heat transfer coefficient is calculated for evaporation
- ✓ Perform heat and material balances on evaporation units and processes

# Definitions

Evaporation is the process that changes liquid water to gaseous water. The vapor from a boiling liquid solution is removed and a more concentrated solution remains




**Application:**

- The concentration of aqueous solutions of sugar, sodium chloride, sodium hydroxide, glycerol, glue, milk, and orange juice.
- Evaporate seawater to provide drinking water

# Factors affecting evaporation

## 1. Concentration in the liquid:

- The liquid feed to an evaporator is relatively dilute
- The viscosity is low

⇨ Relatively high heat-transfer coefficients

- Increasing evaporation rate lead to having more viscous fluid

⇨ Adequate circulation and/or turbulence must be present

## 2. Solubility:

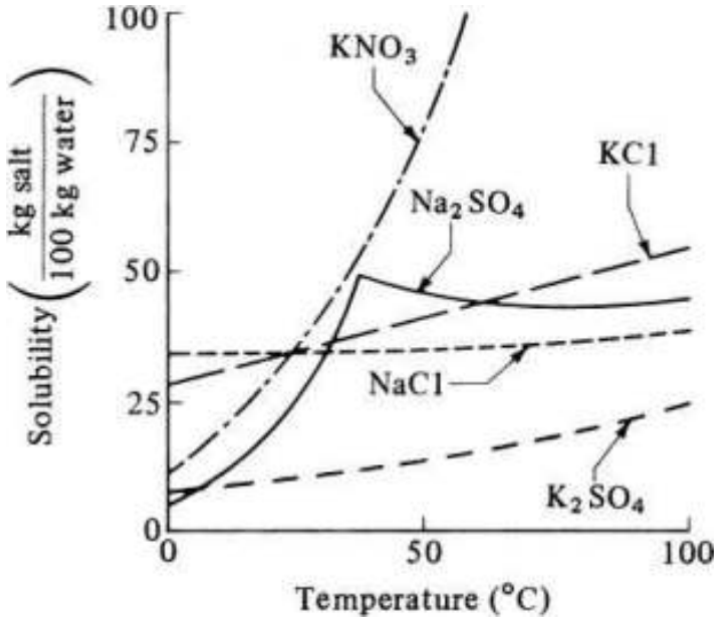
- As solutions are heated and the concentration of the solute or salt increases

⇨ The solubility limit of the material in the solution may be exceeded and crystals may form

- The solubility of the salt increases with temperature

⇩

The concentrated solution from the evaporator is cooled to room temperature, crystallization may occur



## 3. Temperature sensitivity of materials:

- Products of food and other biological materials, pharmaceuticals may be temperature-sensitive and degrade at higher temperatures

⇨ Apply vacuum at low temperature

## 4. Foaming or frothing:

- Caustic solutions, food solutions such as skim milk, and some fatty-acid solutions form a foam or froth during boiling

⇨ This foam accompanies the vapor coming out of the evaporator and entrainment losses occur

## 5. Pressure and temperature:

- The higher the operating pressure of the evaporator, the higher the temperature at boiling

⇨ The concentration of the dissolved material in the solution increases by evaporation, the temperature of boiling may rise

## 6. Scale deposition and materials of construction:

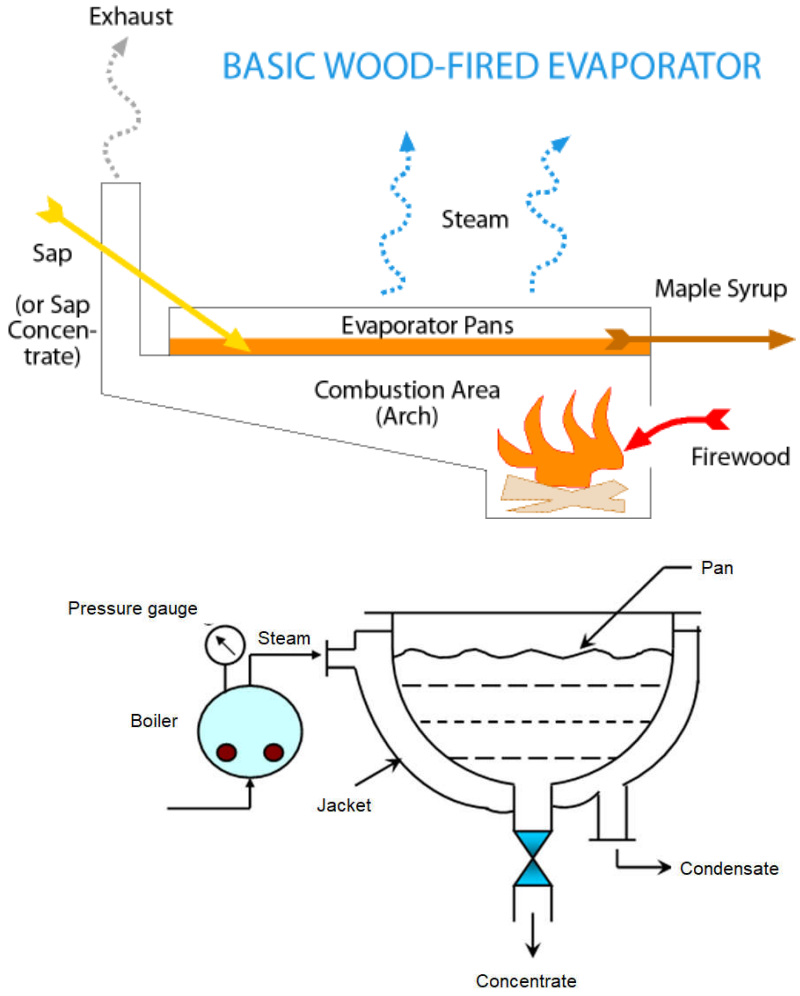
- By decreases in solubility scale may form inside the evaporator
- Many solutions attack ferrous metals get contaminated

⇨
- Decrease overall heat transfer coefficient
- Increase corrosion

# Types of Evaporation Equipment

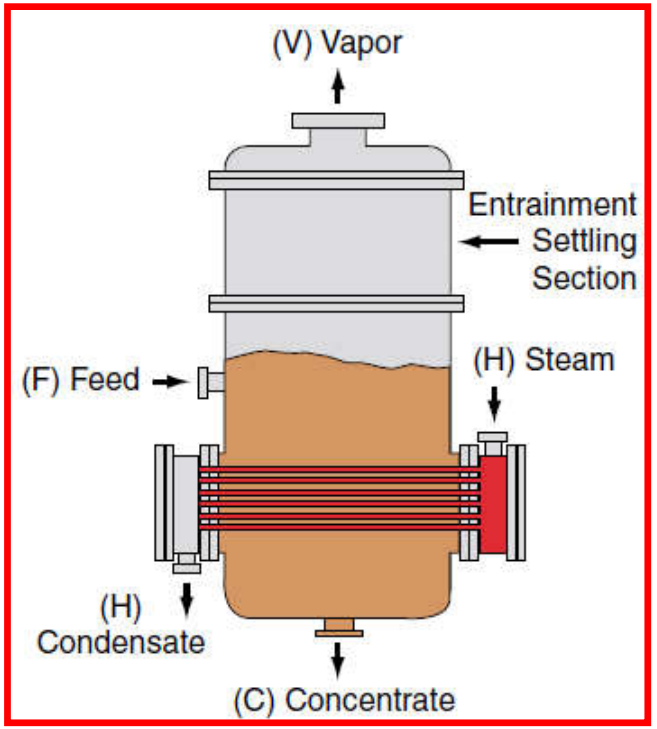
## 1. Open kettle or pan:

- An old and simple evaporator
- The heat is supplied by the condensation of steam in a jacket or in coils immersed in the liquid, or direct-fired
- Inexpensive and simple to operate
- Heat economy is poor



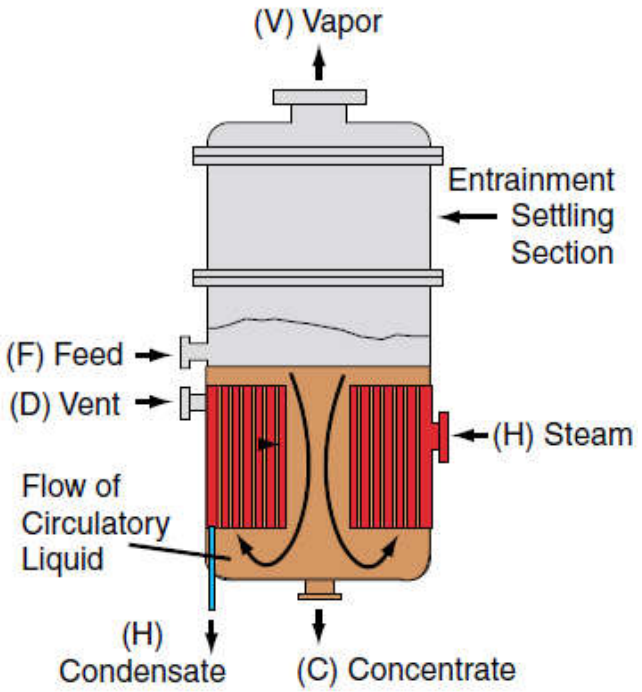
## 2. Horizontal-tube natural circulation evaporator:

- The steam enters the tubes, where it condenses, and the boiling liquid solution covers the tubes. The vapor leaves the liquid surface.
- Relatively cheap
- Poor liquid circulation, used for non-viscous liquids with high heat-transfer coefficients and liquids that do not deposit scale.



## 3. Vertical-type natural circulation evaporator:

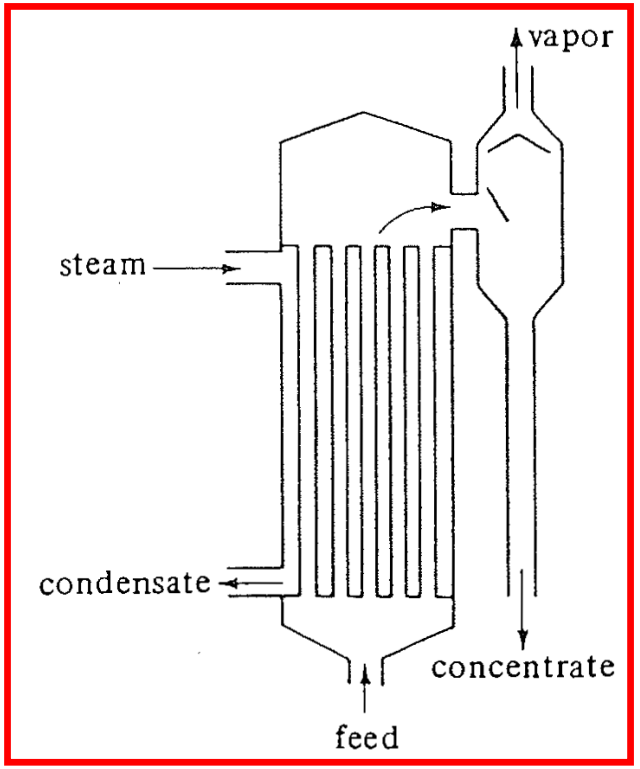
- The liquid is inside the tubes and the steam condenses outside the tubes
- Liquid rises in the tubes by natural circulation due to decreasing density with boiling (increases the heat-transfer coefficient)
- Is not used with viscous liquids and high temperature sensitive materials
- This type is widely used in the sugar, salt, and caustic-soda industries




Tubes are around 1-2 m long

## 4. Long-tube vertical-type evaporator:

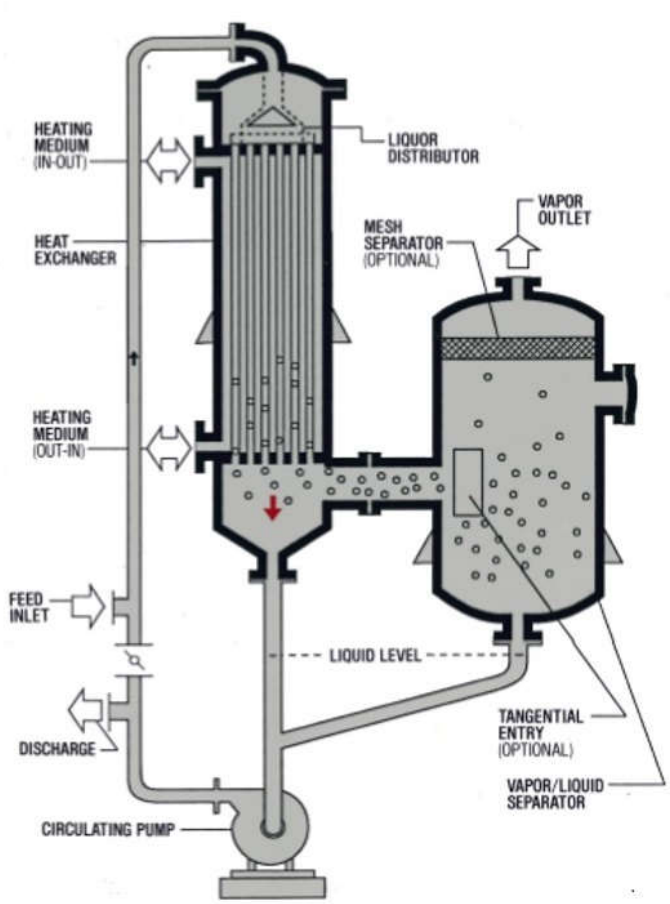
- The liquid is inside the tubes and the steam condenses outside the tubes
- High heat-transfer coefficient on the steam side
  - The formation of vapor bubbles inside the tubes causes a pumping action
  - Lead to high liquid velocities
- Contact times is quite low
- Widely used for producing condensed milk




Tubes are around 3-10 m long

## 5. Falling-film-type evaporator:

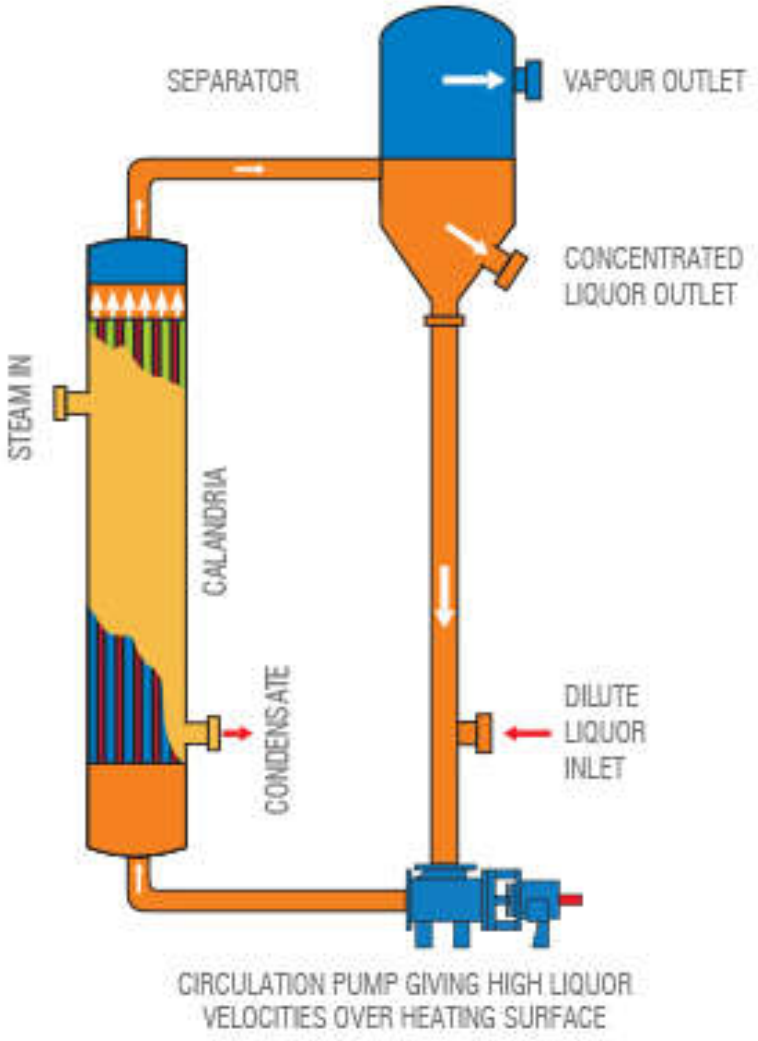
- The liquid is fed to the top of the tubes and flows down the walls as a thin film
- Vapor–liquid separation usually takes place at the bottom
- The heat-transfer coefficients are high
- The holdup time is very small (5 to 10 s)
- Used for concentrating heat-sensitive materials such as orange juice and other fruit juices



Types of Evaporation Equipment

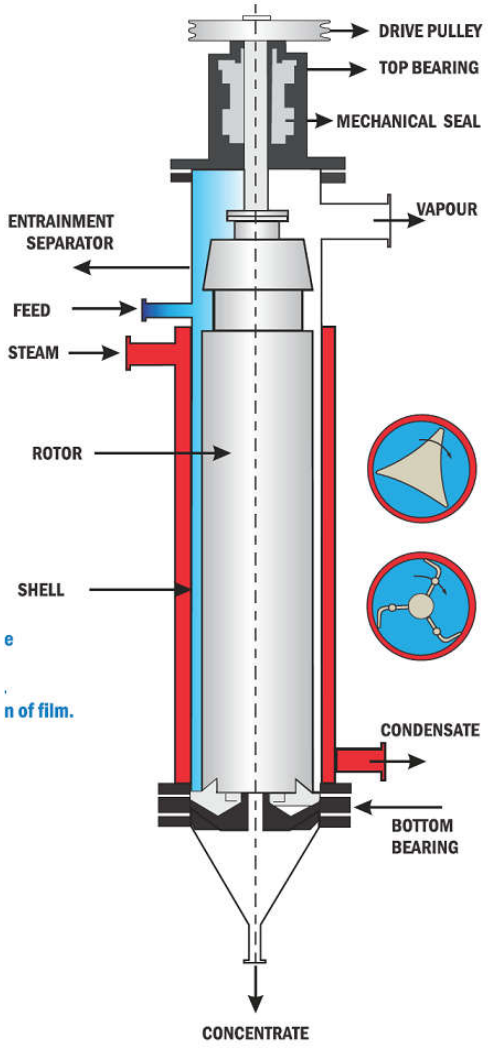
## 6. Forced-circulation-type evaporator:

- The liquid film heat-transfer coefficient can be increased by pumping to cause forced circulation of the liquid inside the tubes
- The vertical tubes are usually shorter than in the long-tube type
- Very useful for viscous liquids



## 7. Agitated-film evaporator:

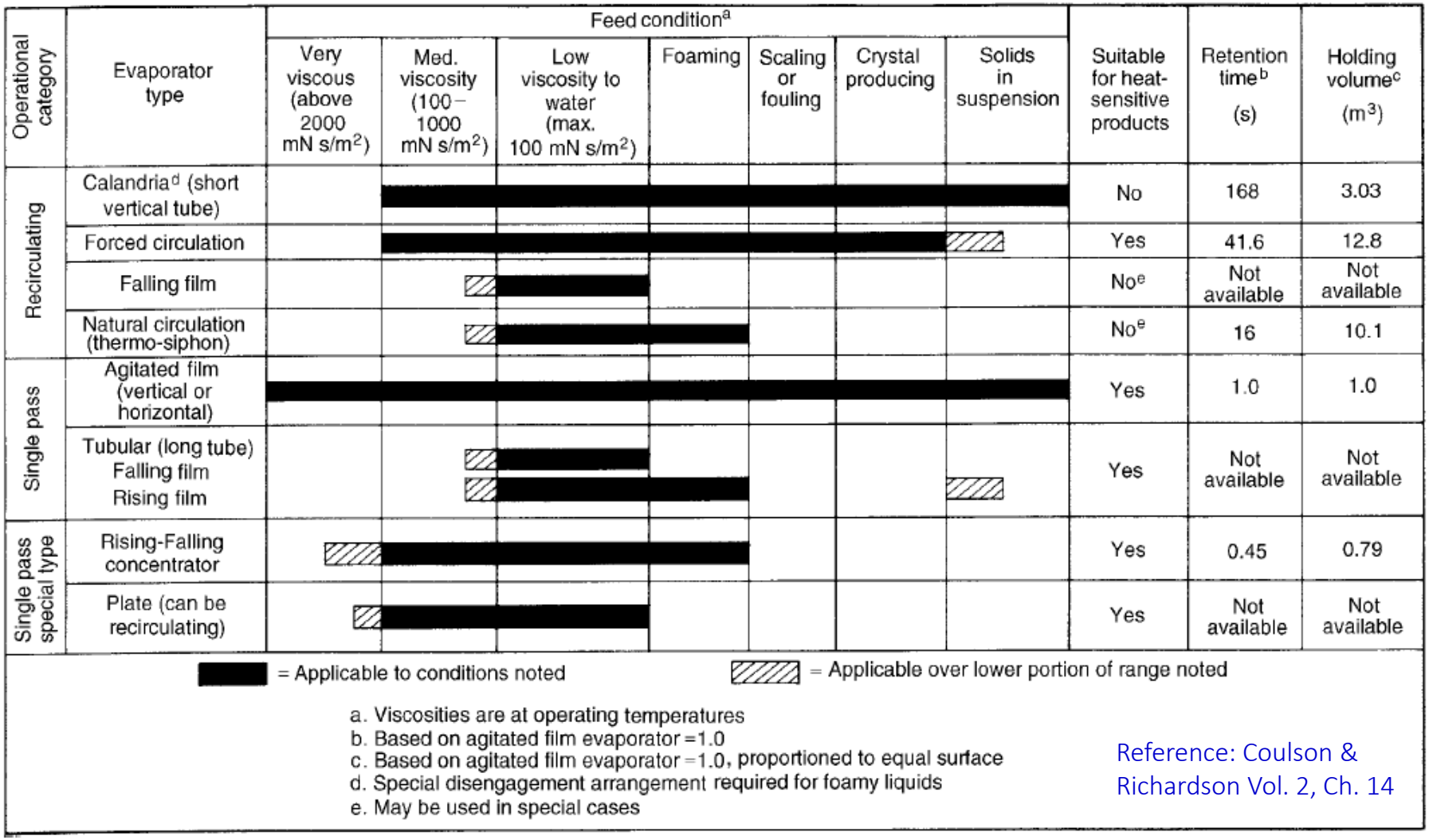
- Liquid enters at the top of the tube and as it flows downward, it is spread out into a turbulent film by the vertical agitator blades
- Mechanical agitation of the film
  - Increases turbulence in this liquid film
  - Increases the heat-transfer coefficient
- Useful with highly viscous materials
- Used with heat-sensitive viscous materials such as rubber latex, gelatin, antibiotics, and fruit juices
- High cost and small capacity



## 8. Open-pan solar evaporator:

- A very old process uses solar evaporation in open pans
- Used for salt concentration and crystallization.

# Selection of Evaporation Equipment



| Operational category | Evaporator type | Feed condition[a]: Very viscous (above 2000 mN s/m²) | Med. viscosity (100–1000 mN s/m²) | Low viscosity to water (max. 100 mN s/m²) | Foaming | Scaling or fouling | Crystal producing | Solids in suspension | Suitable for heat-sensitive products | Retention time[b] (s) | Holding volume[c] (m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Recirculating | Calandria[d] (short vertical tube) | | ■ | ■ | ■ | ■ | ■ | ■ | No | 168 | 3.03 |
| | Forced circulation | | ■ | ■ | ■ | ■ | ■ | ▨ | Yes | 41.6 | 12.8 |
| | Falling film | | ▨ | ■ | | | | | No[e] | Not available | Not available |
| | Natural circulation (thermo-siphon) | | ▨ | ■ | ■ | | | | No[e] | 16 | 10.1 |
| Single pass | Agitated film (vertical or horizontal) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | Yes | 1.0 | 1.0 |
| | Tubular (long tube) Falling film Rising film | | ▨ | ■ | ■ | ■ | | ▨ | Yes | Not available | Not available |
| Single pass special type | Rising-Falling concentrator | ▨ | ■ | ■ | ■ | | | | Yes | 0.45 | 0.79 |
| | Plate (can be recirculating) | | ▨ | ■ | | | | | Yes | Not available | Not available |

■ = Applicable to conditions noted ▨ = Applicable over lower portion of range noted

a. Viscosities are at operating temperatures
b. Based on agitated film evaporator = 1.0
c. Based on agitated film evaporator = 1.0, proportioned to equal surface
d. Special disengagement arrangement required for foamy liquids
e. May be used in special cases

Reference: Coulson & Richardson Vol. 2, Ch. 14

| | Short tube | Long tube | | Vertical flow | | Forced circulating | | |
|---|---|---|---|---|---|---|---|---|
| | | Natural flow | Forced flow | Natural flow | Forced flow | Vertical | Horizontal | Mixer film |
| Low viscosity fluid | A | A | A | A | A | A | A | X |
| High viscosity fluid | D | B | B | B | B | A | A | A |
| Sludge | D | B | B | D | D | A | A | A |
| Boiler cleaning or salting | C | D | E | D | E | B | B | A |
| Corrosive liquids | C, E | C, A | C, A | C, A | C, B | C, B | C, B | C, D |
| Crystal-formation fluids | D | B | B | E | E | B | B | A |
| Bubbling fluid | D | B | B | E | E | B | B | D |
| Heat-sensitive liquids | D | A | D | A | D | B | B | B |
| Conjoined, sticky fluid | X | X | X | X | X | E | B | B |
| High capacity | D | A | A | B | B | A | A | E |
| Using as a multiple-effective | A | A | B | A | B | A | A | E |
| Process feed | B | B | D | D | D | D | D | D |
| Limited vertical field | A | E | E | E | E | D | A | D |
| Small pressure difference | D | D | D | A | A | D | D | A |
| OTHER CRITERIA | | | | | | | | |
| Resistance value | A | A | A | B | B | B | B | D |
| Power consumption | A | A | A | A | A | B | B | B |
| Easy cleaning | A | B | B | B | B | B | B | B |
| Heat transfer efficiency | D | B | B | B | B | A | A | A |

Letters: A: Perfect or unlimited, B: Modest limits or problems, C: Minor problems in high value parts, D: limited, E: very limited, X: Not acceptable