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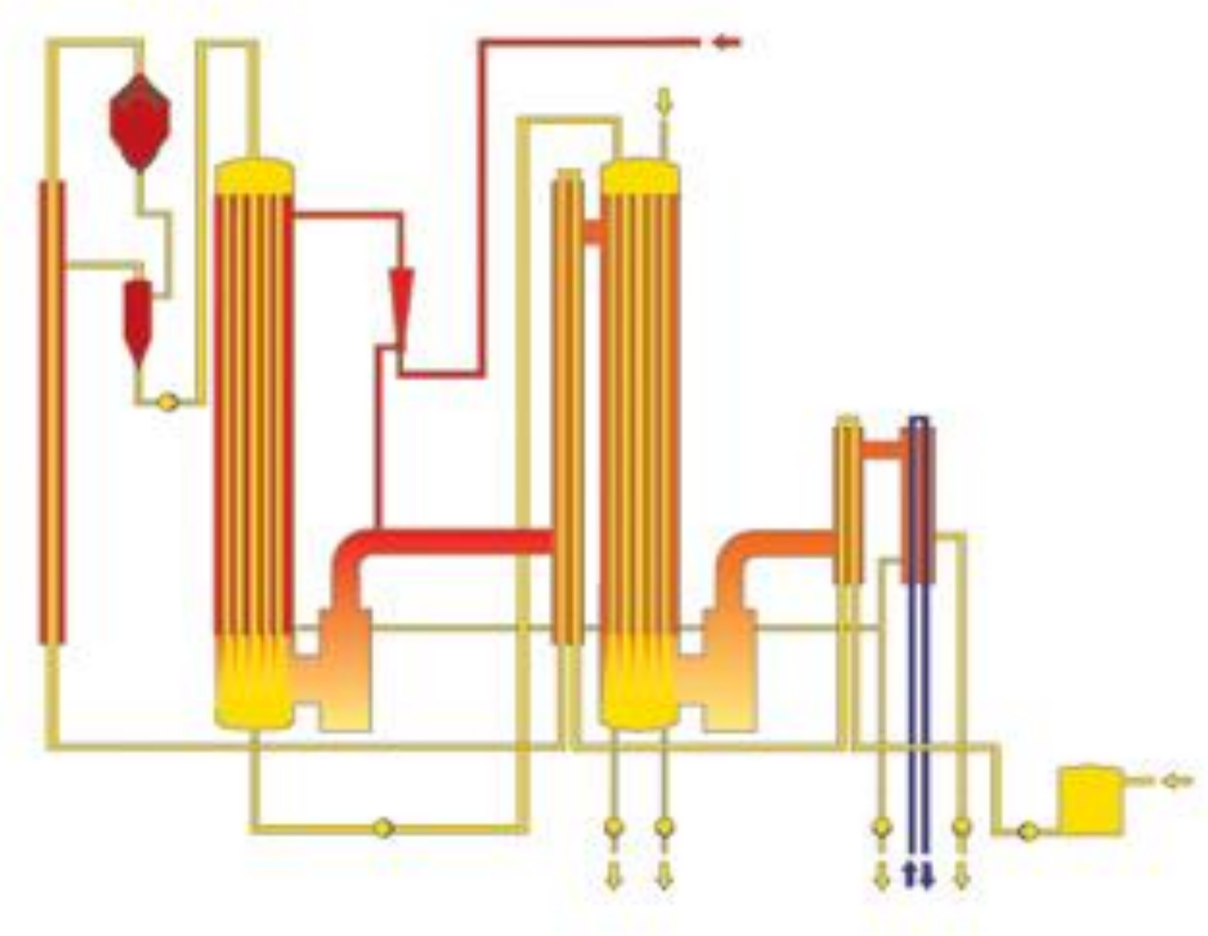
280.371 Process Engineering Operations

Evaporation Lecture 2

Professor Marie Wong

Evaporation equipment

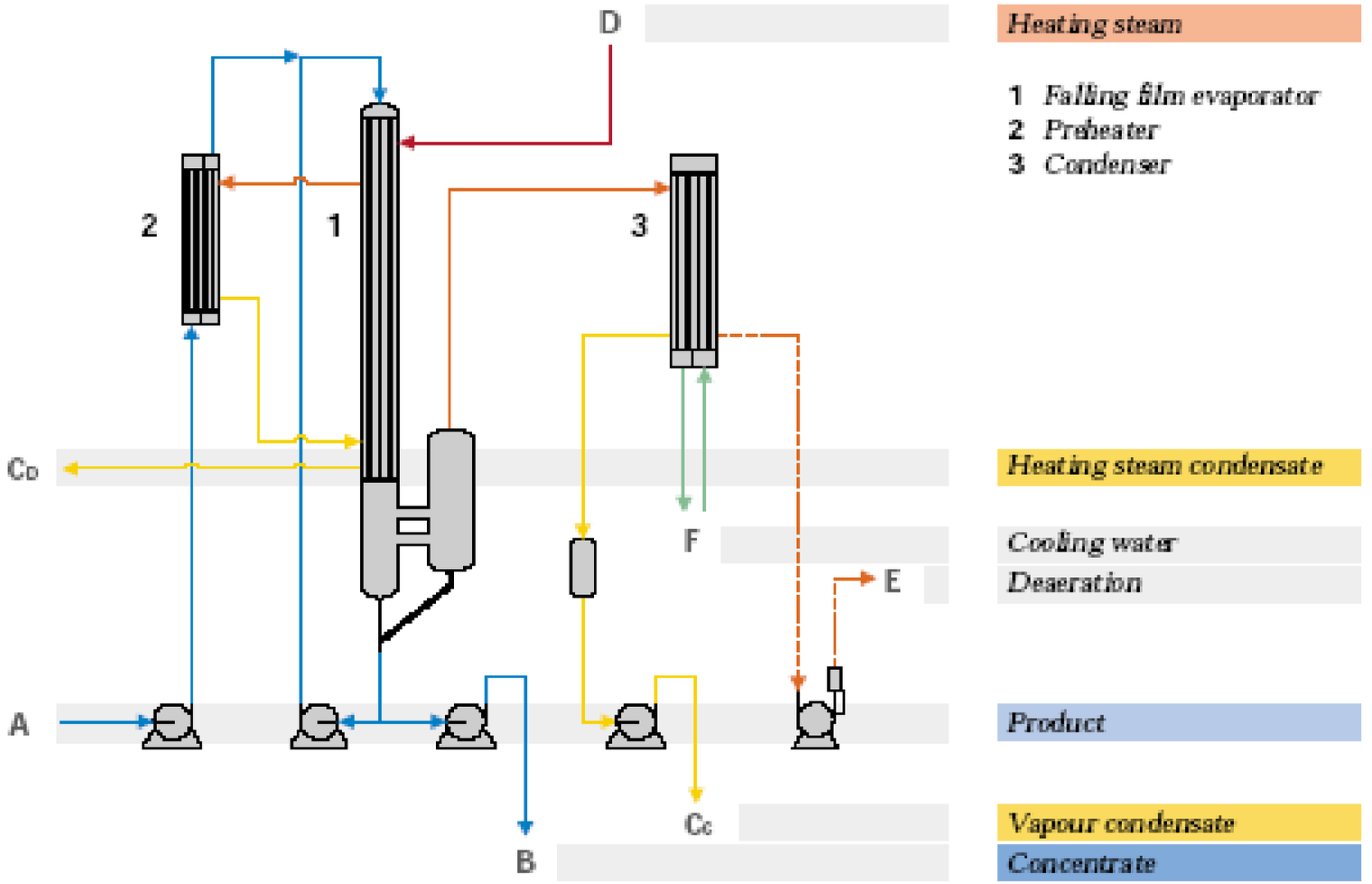


Introduction

- Items to select &/or design are
  - Feed system, including pre-heaters
  - Heat exchanger
  - Vapour-Liquid separator
  - Condenser
  - Liquid circulation device

- In some systems, these components may be integrated into a single unit

System components



Key factors - related to the solution

- Concentration of feed and subsequent solution
  - Influence of concentration on thermal & physical properties e.g. viscosity, density, solubility, boiling point rise (BPR)
- Solubility of solutes
- Temperature sensitivity of material
  - e.g. aroma or colour change, protein functionality
- Foaming or frothing
- Pressure and temperature – impact on boiling point
- Scale deposition and materials
- Requirements of crystallisation (if relevant)

Key factors – evaporator system

- Heat Exchanger (HE) capacity & performance
  - Evaporation heat load
  - Influence of process operation & liquid characteristics on U or as limiters of $\Delta\theta$
- Single or multi-stage operation
- Available $\Delta\theta$
  - Sensible heating/incomplete flashing (forced circulation)
  - Pressure drop (especially in separator) - most important for vacuum operation
  - Hydrostatic head or BPR

Key factors - evaporator system (cont.)

- Configuration of evaporator
  - Economic considerations
  - Number of effects
  - Vapour recompression
  - Utilities available
  - Energy resources available
- Batch or continuous
- Vapours lost or collected and condensed

Classification of Evaporator Systems

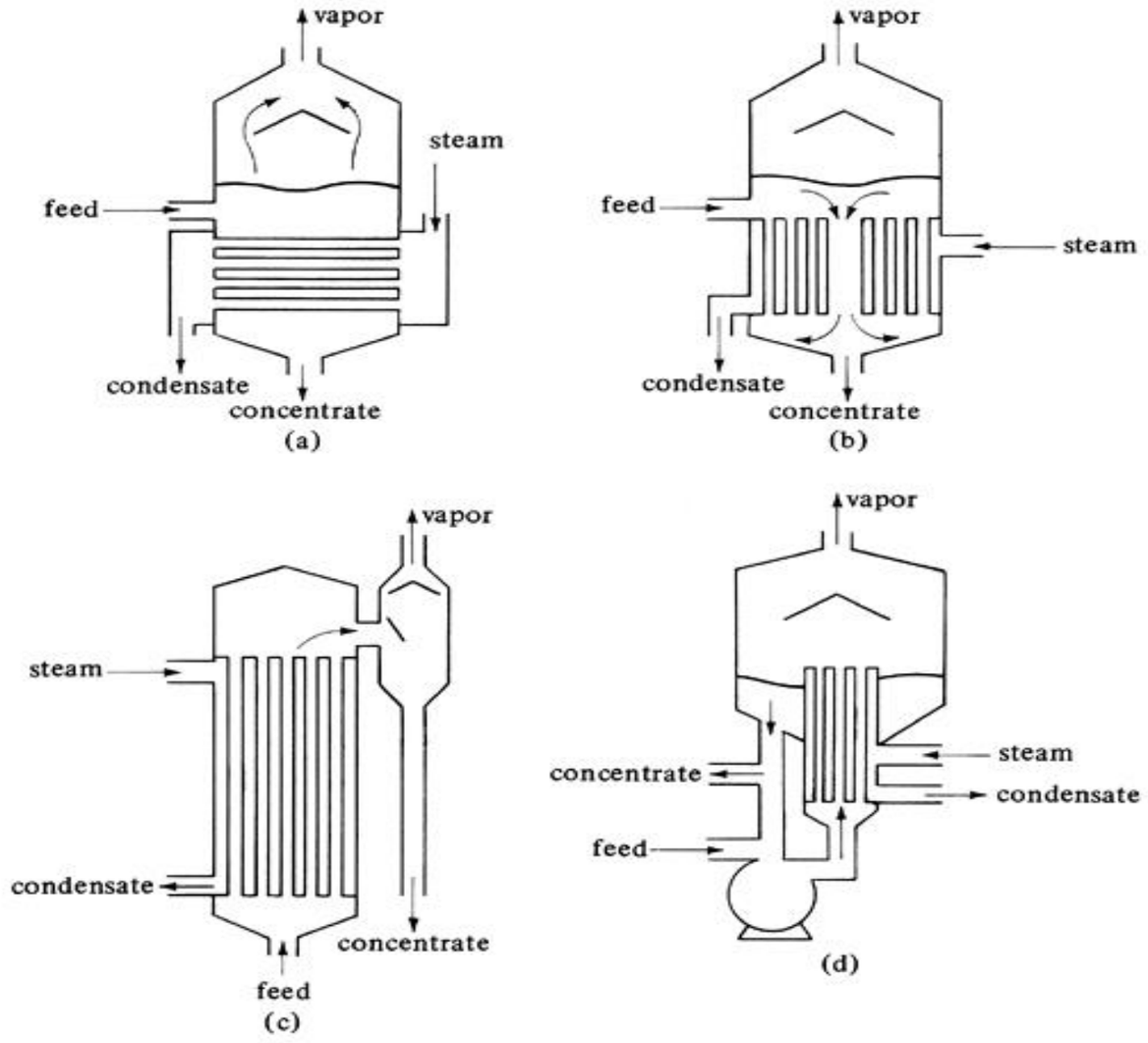
Based on

- Mode of heat transfer (direct vs indirect)
- Passage of fluid (flow strategies)
- Type of recirculation employed

Evaporator types

Major categories

Different types of evaporators: (a) horizontal-tube type, (b) vertical-tube type, (c) long-tube vertical type, (d) forced-circulation type.



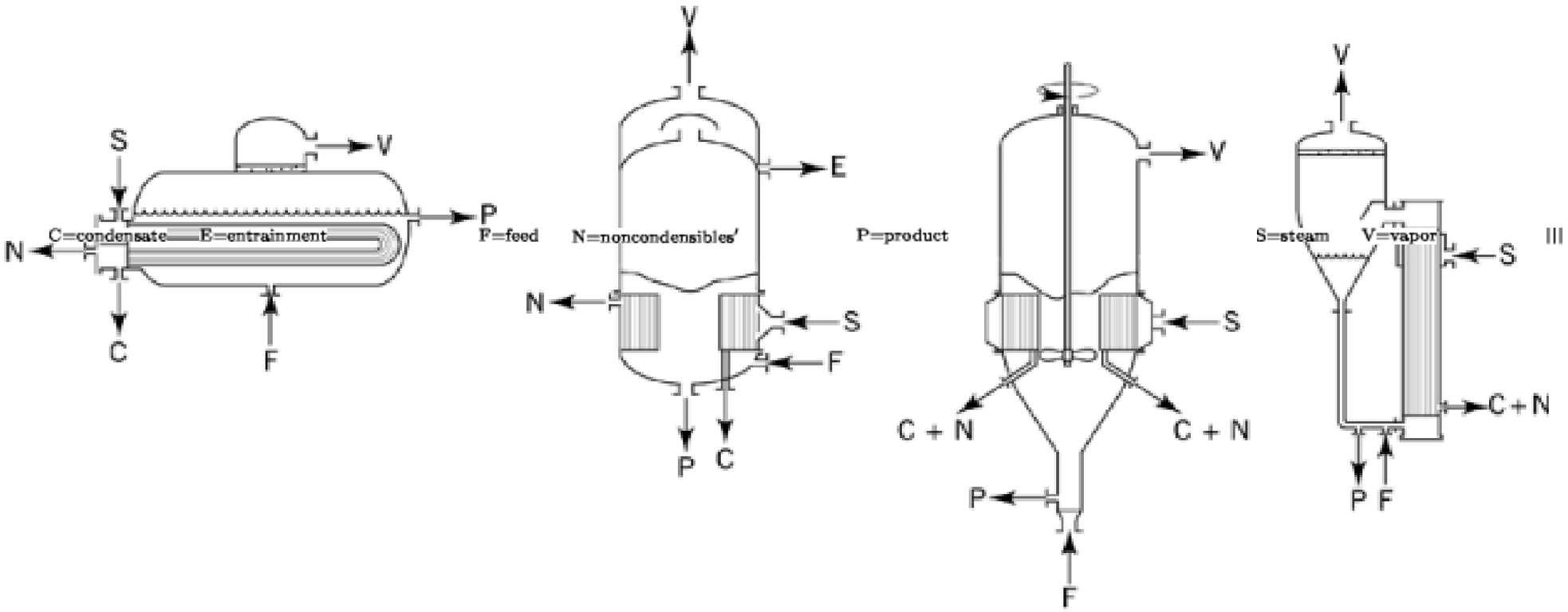
Heat exchangers

- Internal or external
- Horizontal or vertical
  - Vertical more common
    - Better circulation, especially for viscous solutions
    - Solution flow usually inside HE tubes
- Long or short tubes
  - Choice influenced by residence time & buildings headroom
    - Single pass/ short residence time → long tube
- Plate and frame
- In some systems, HE is pressurised and flash evaporation occurs only as liquid leaves HE

Liquid circulation

- Forced or natural
- Natural
  - Driven by density difference
  - Lower circulation velocity, less control
  - Lower costs
- Forced = external pump
  - Constant circulation → good heat transfer
  - Useful for viscous or crystallising solutions

Natural circulation systems



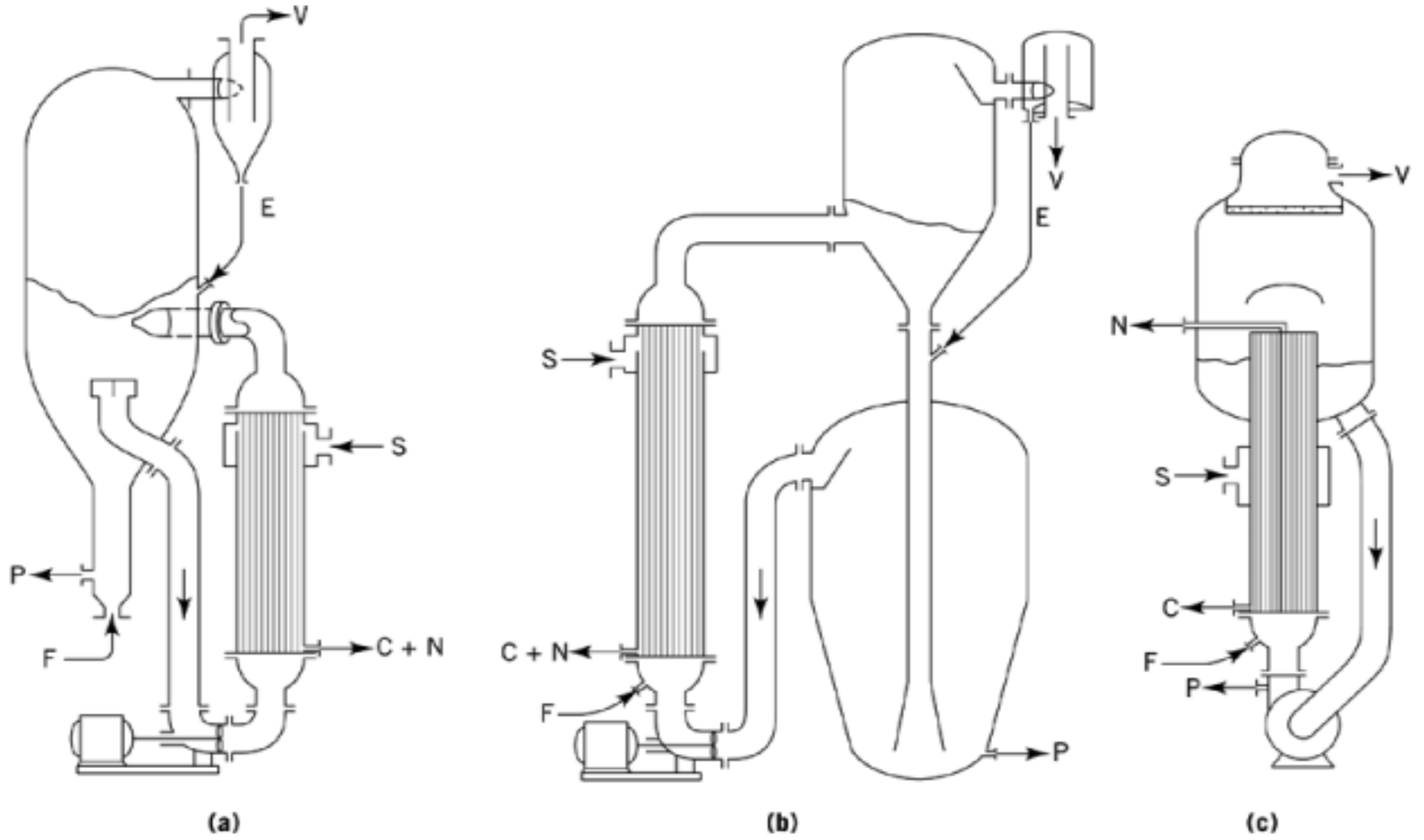
(a) horizontal-tube

(b) short-tube vertical

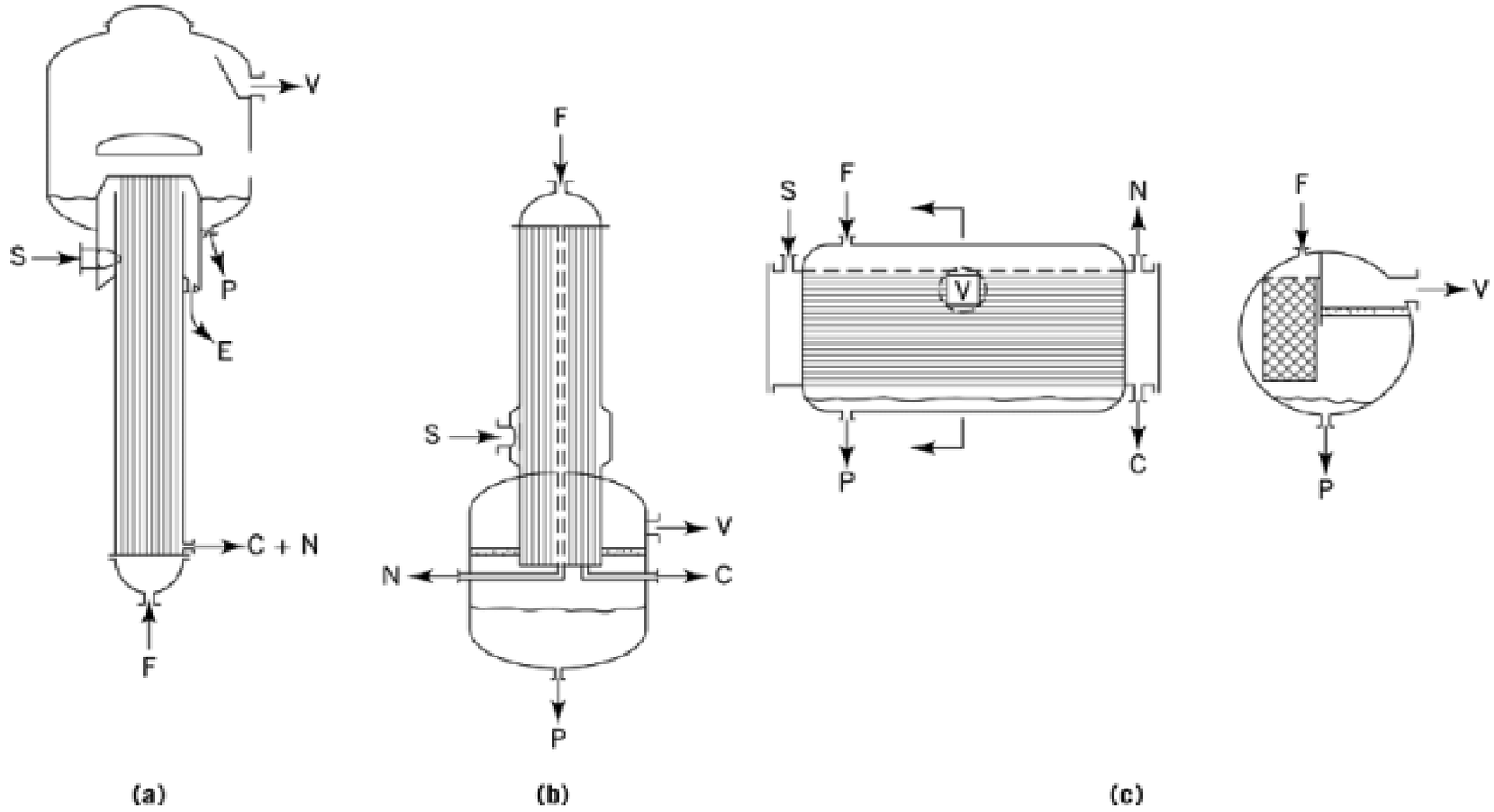
(c) propeller calandria

(d) long-tube recirculating.

Forced circulation systems



Film systems

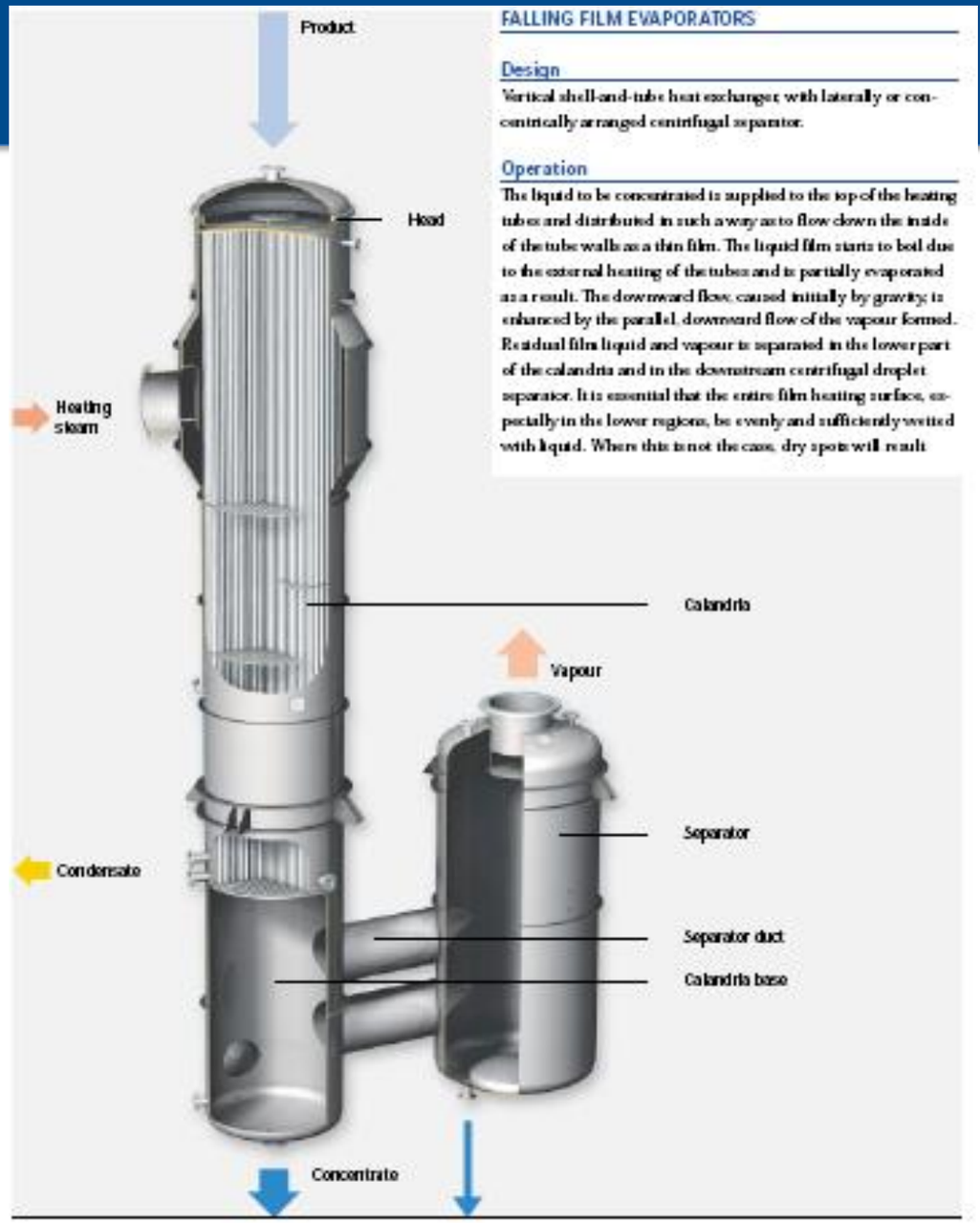


Rising film

Falling film

Falling film evaporators

- Single pass, liquid distributed as film on inside of long vertical tubes
- Key advantages
  - Short residence time
  - Suitable for low $\Delta\theta$ operation
  - Suitable for multi-effect operation
  - High heat transfer rates possible
- Major applications
  - Concentration of liquids foods



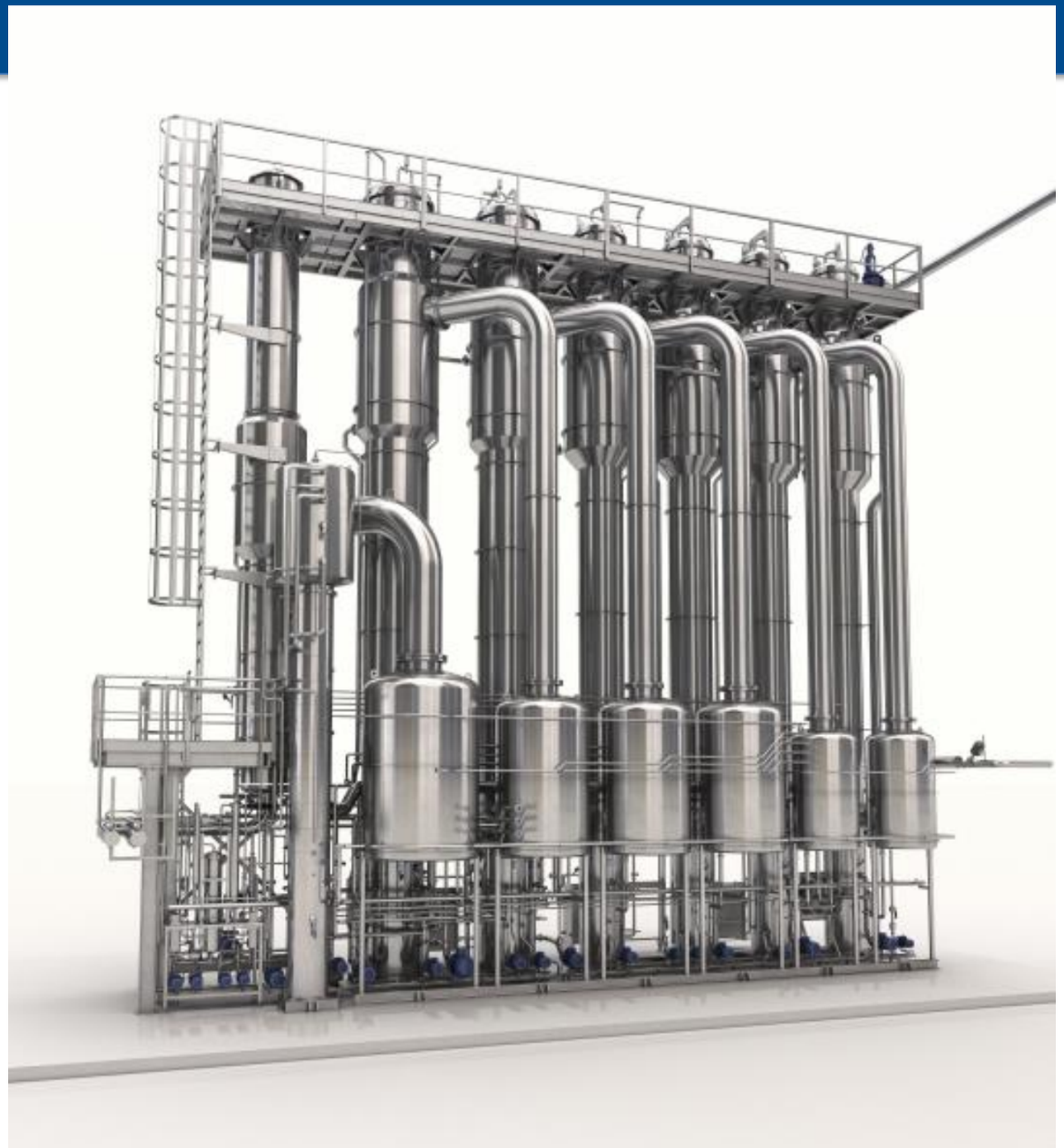
FALLING FILM EVAPORATORS

Design

Vertical shell-and-tube heat exchanger with laterally or concentrically arranged centrifugal separator.

Operation

The liquid to be concentrated is supplied to the top of the heating tubes and distributed in such a way as to flow down the inside of the tube walls as a thin film. The liquid film starts to boil due to the external heating of the tubes and is partially evaporated as a result. The downward flow, caused initially by gravity, is enhanced by the parallel, downward flow of the vapour formed. Residual film liquid and vapour is separated in the lower part of the calandria and in the downstream centrifugal droplet separator. It is essential that the entire film heating surface, especially in the lower regions, be evenly and sufficiently wetted with liquid. Where this is not the case, dry spots will result



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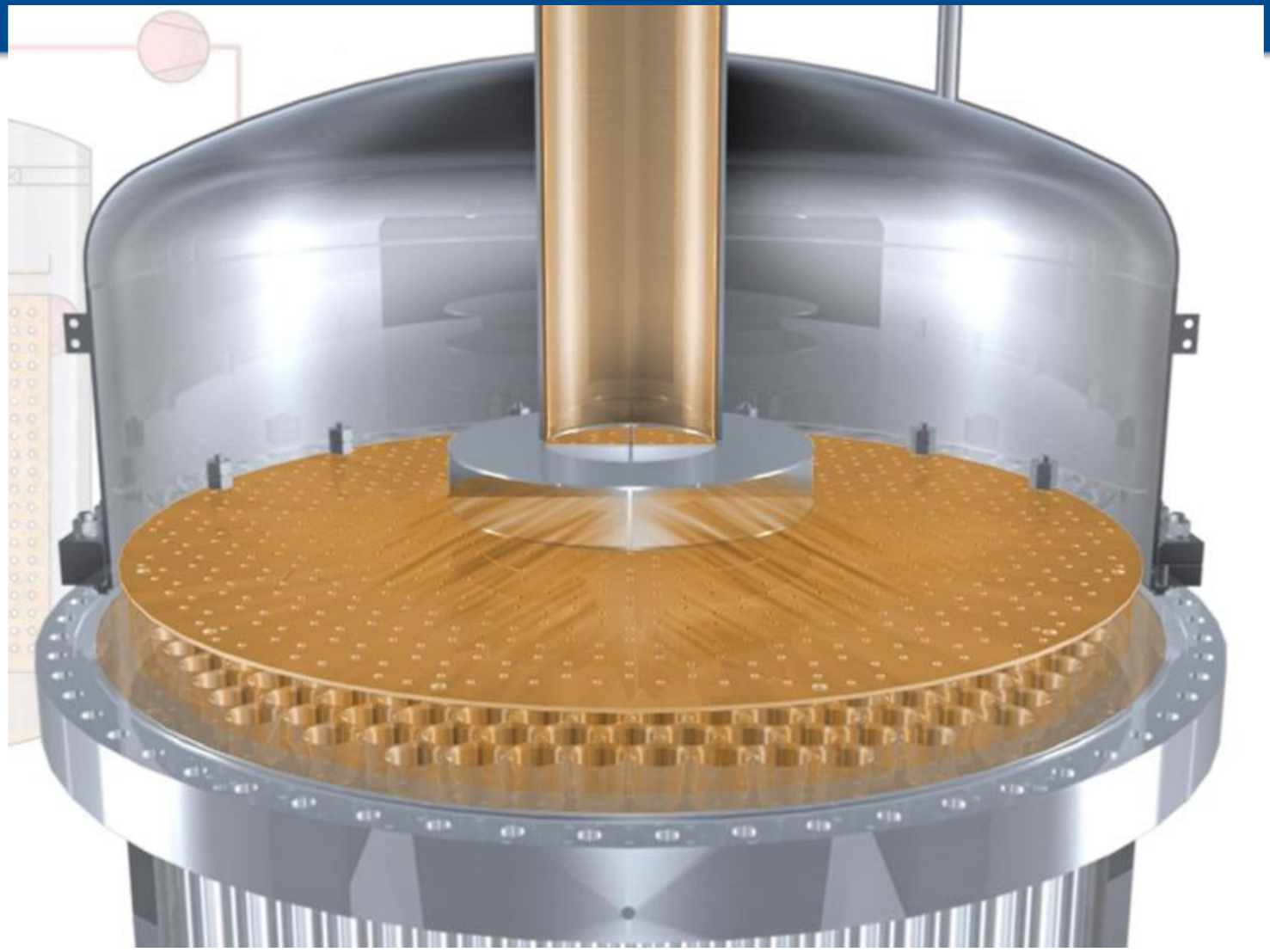
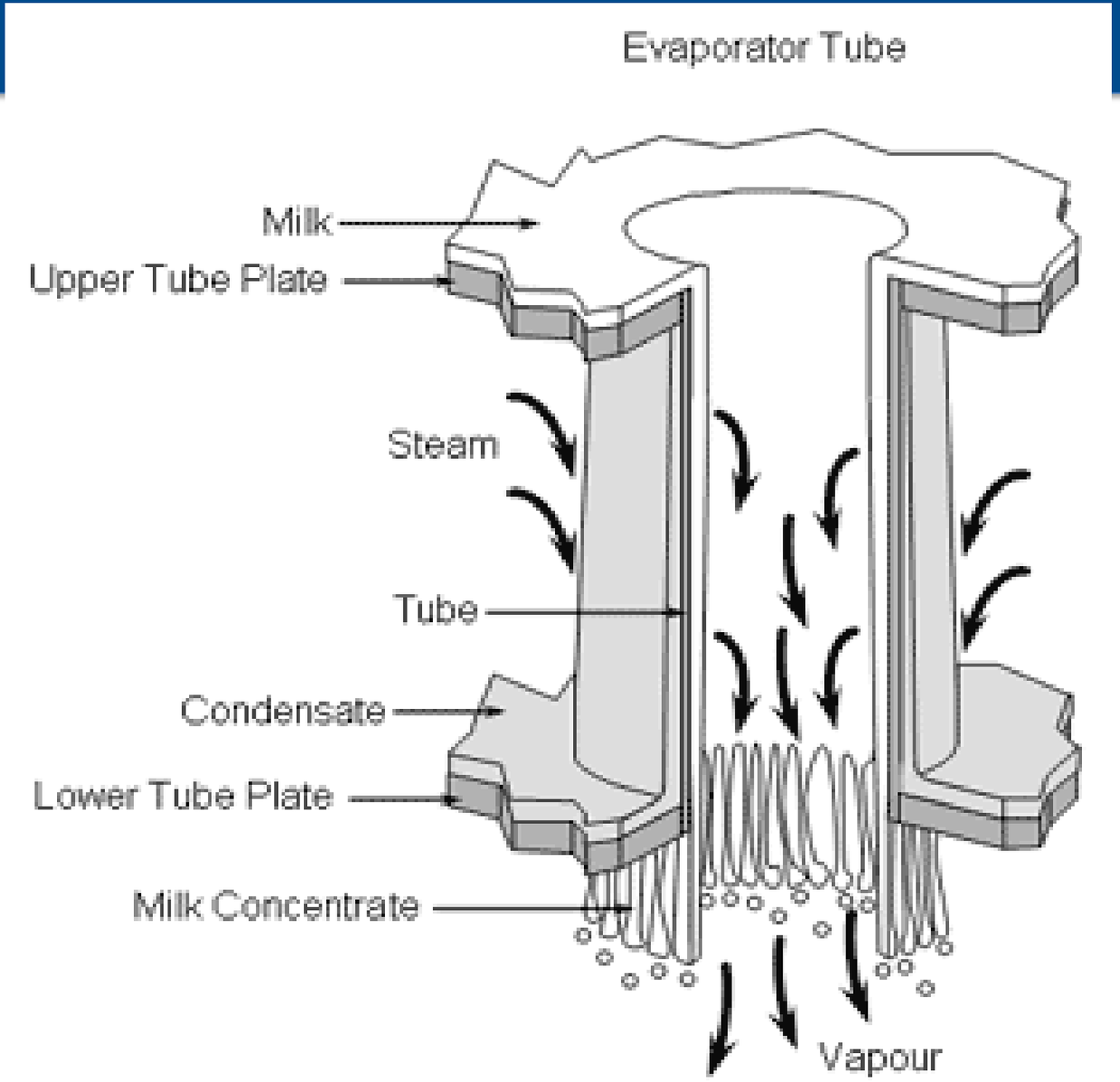
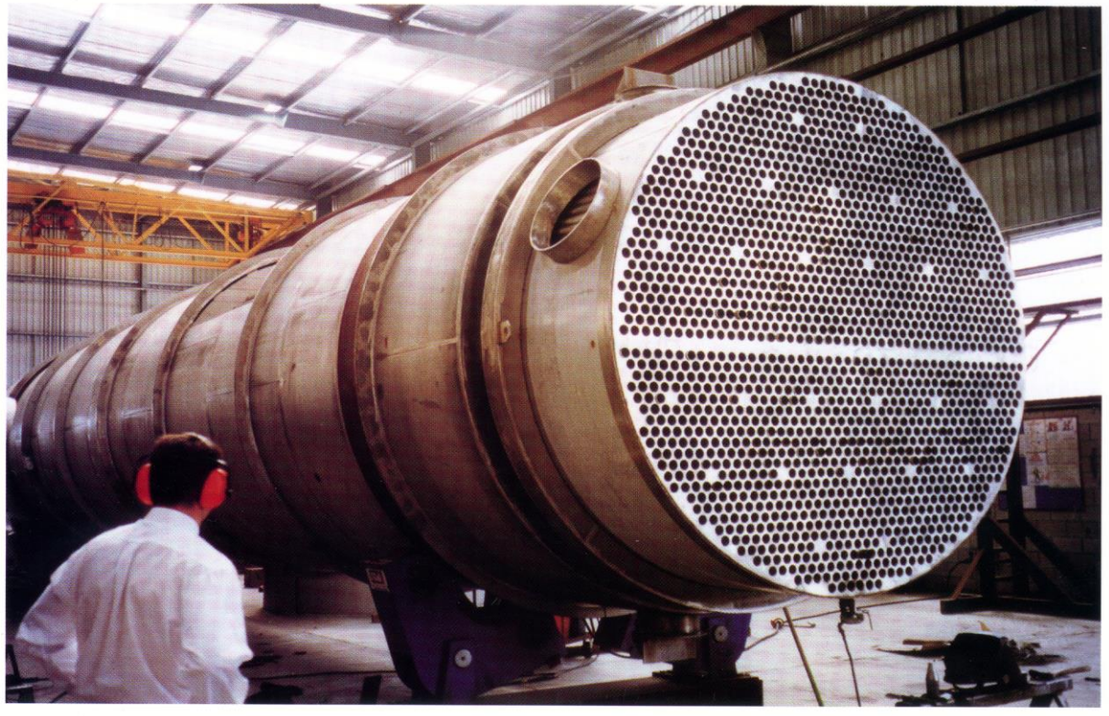


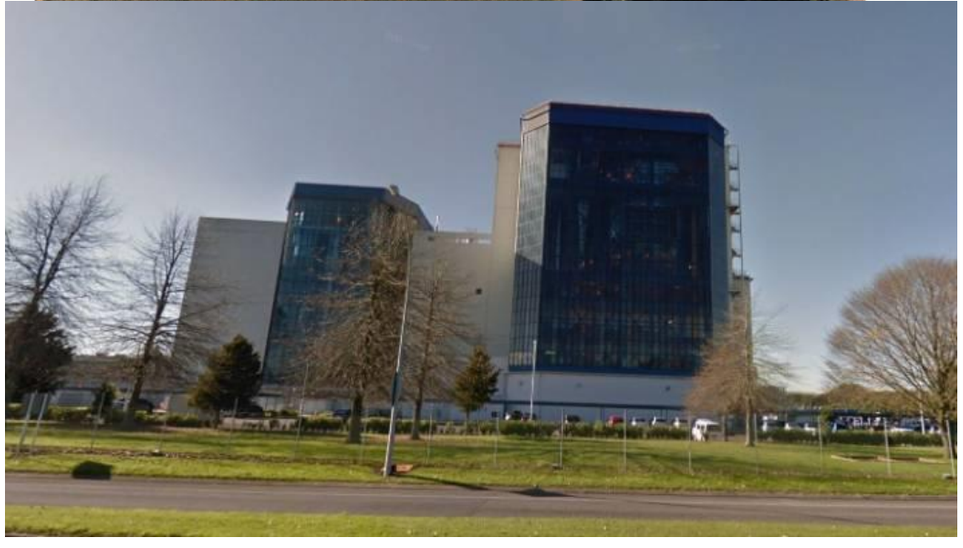

Evaporator Tube
Milk
Upper Tube Plate
Steam
Tube
Condensate
Lower Tube Plate
Milk Concentrate
Vapour

Fonterra, Te Rapa



Evaporator calendria under construction.

Te Rapa



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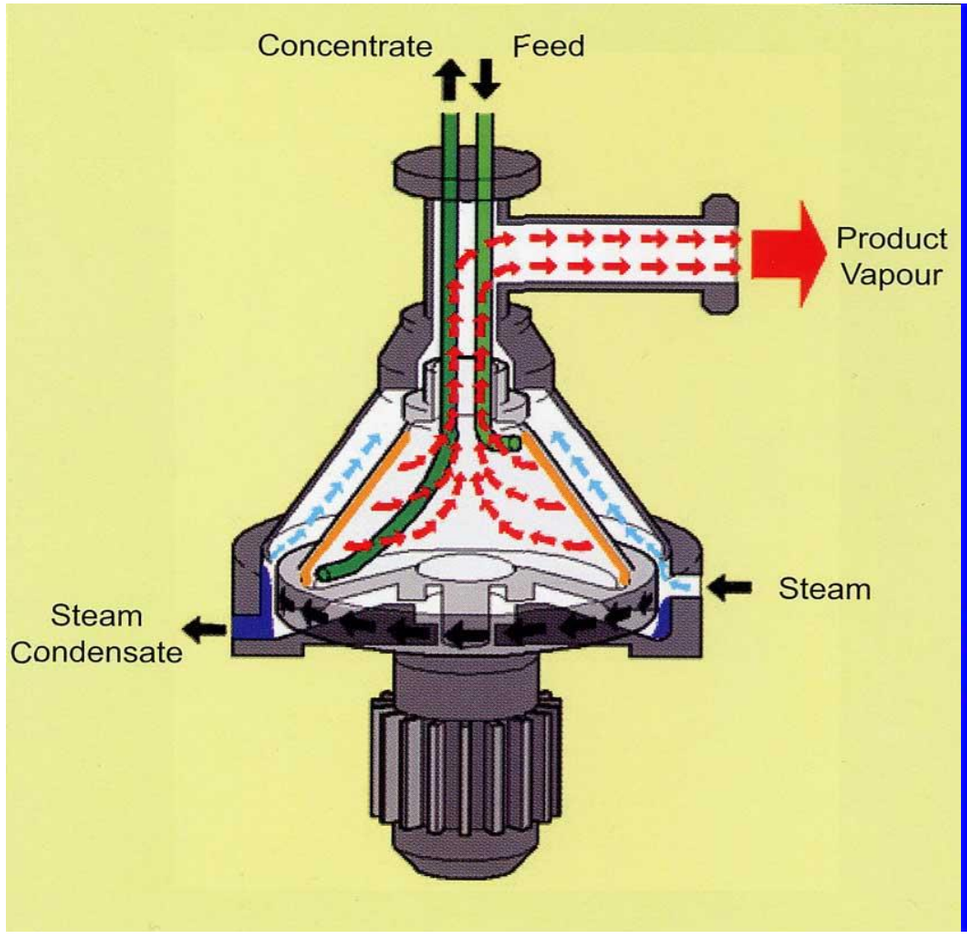
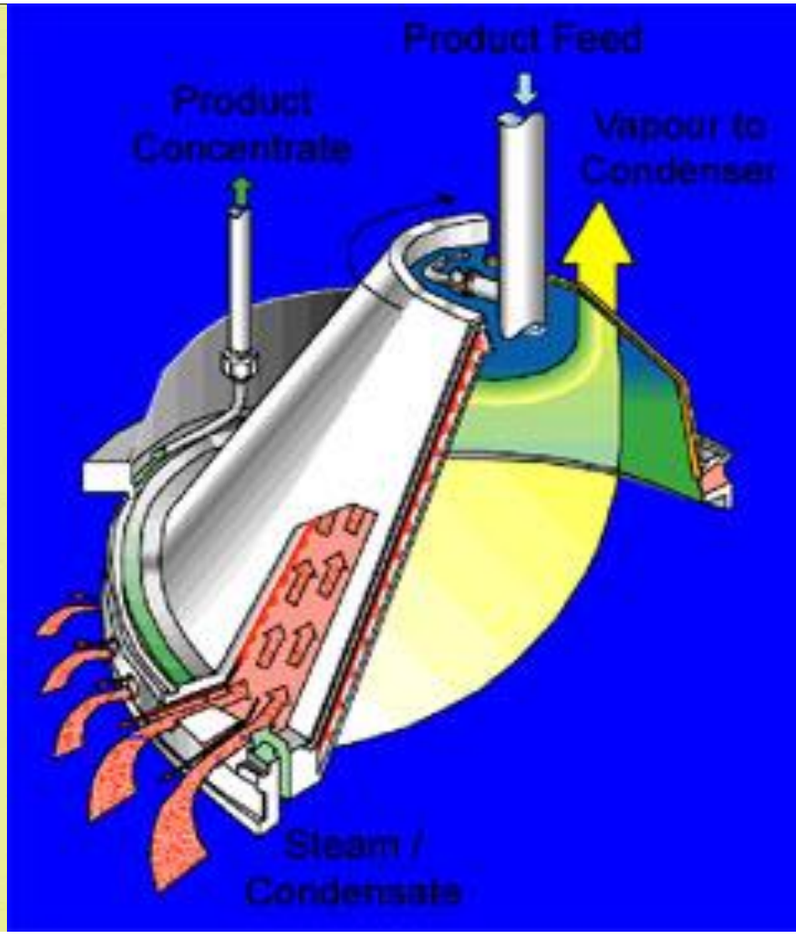
Other thin-film types

- Centrifugal
- Wiped-film, scraped surface
- Plate and frame heat exchanger

Centrifugal/Conical evaporators

- Centrifugal force produces a thin film on HT surface
- V-L separation in same chamber at HT
- Very low hold up time
  - Good for sensitive products
  - Expensive
- “Centritherm®”





Wiped Film/Agitated Thin Film

- Very viscous foods
- Continual sweeping of boundary layer at HT surface
- High temperature differentials
- Tomato paste & gelatine solutions
- “Contherm®”

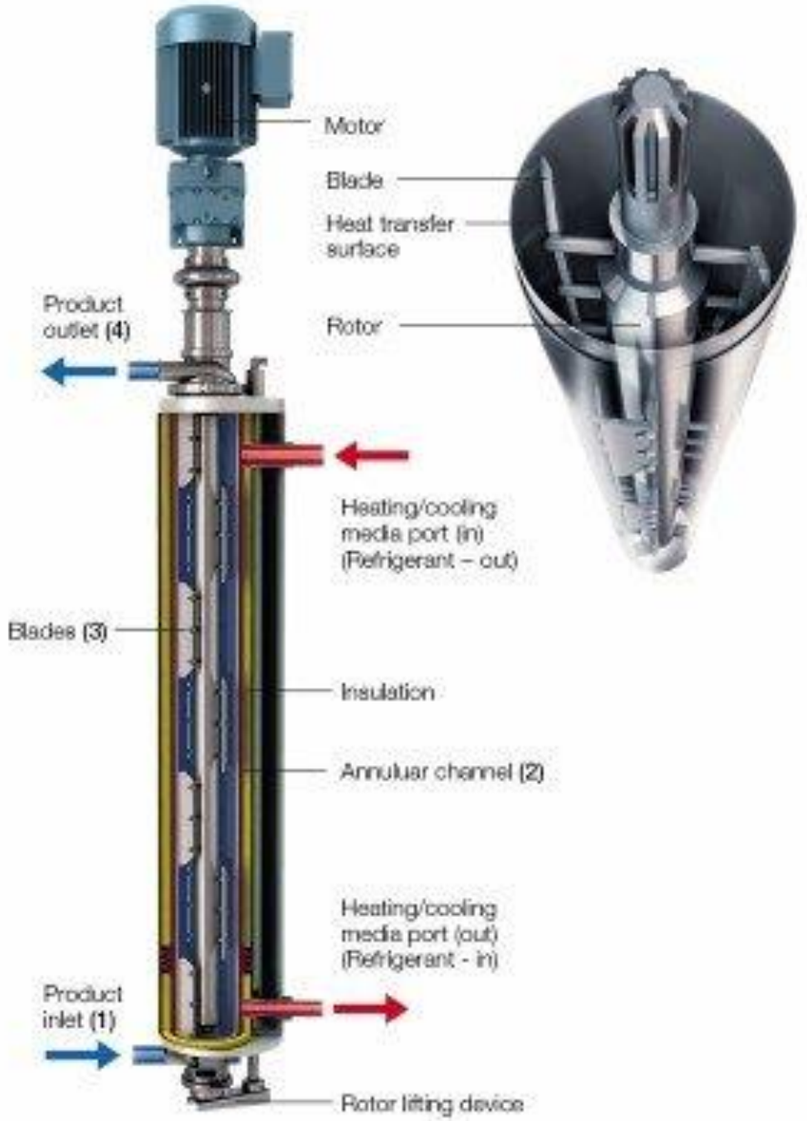
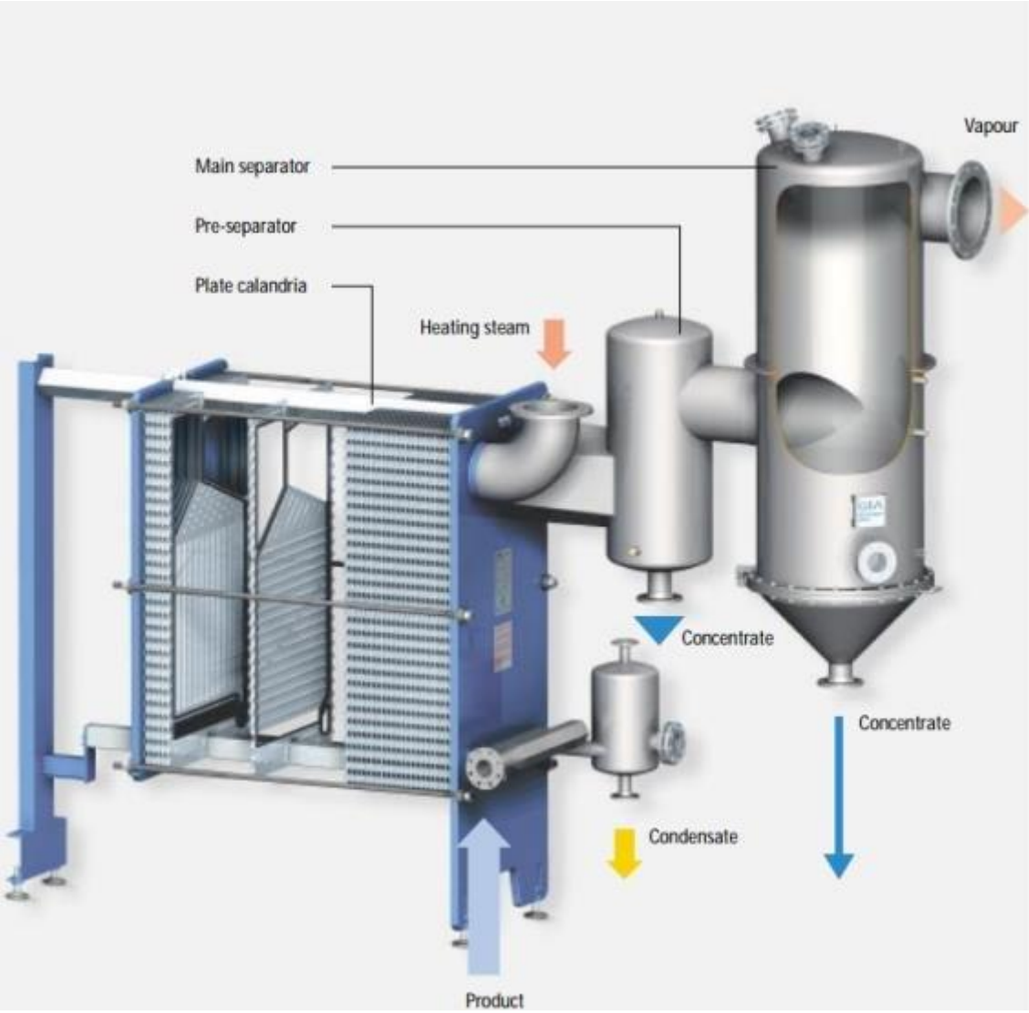
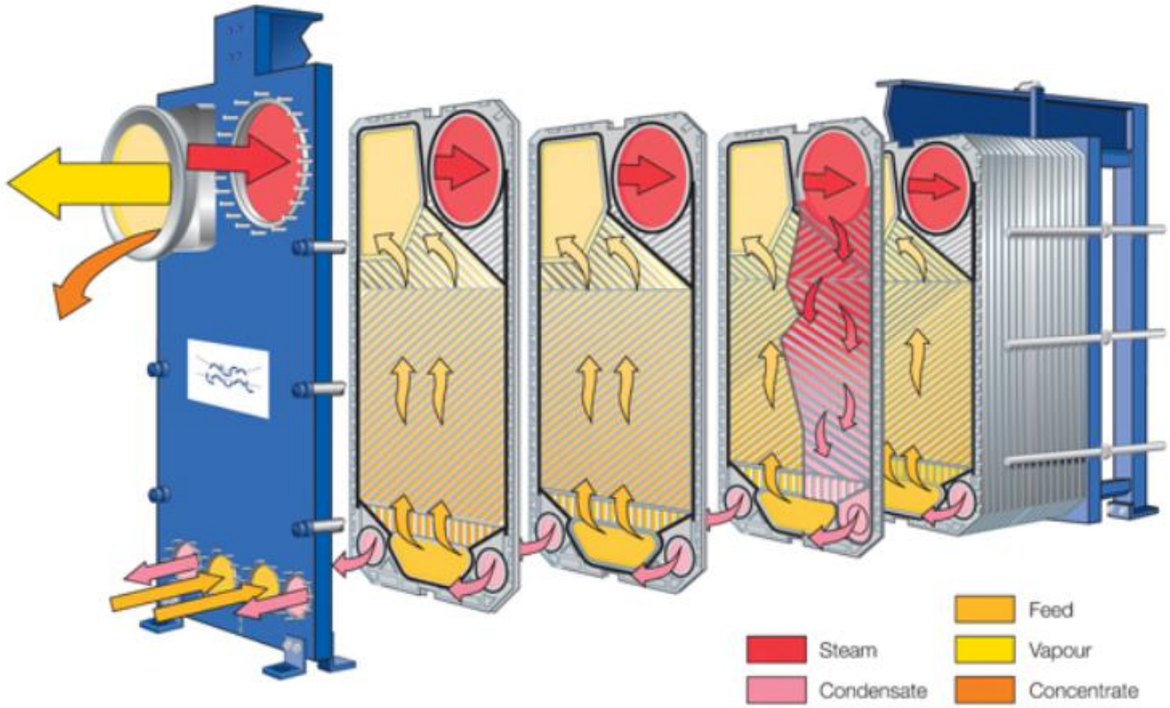


Plate and Frame Heat Exchanger



www.gea.com



www.alfalaval.com

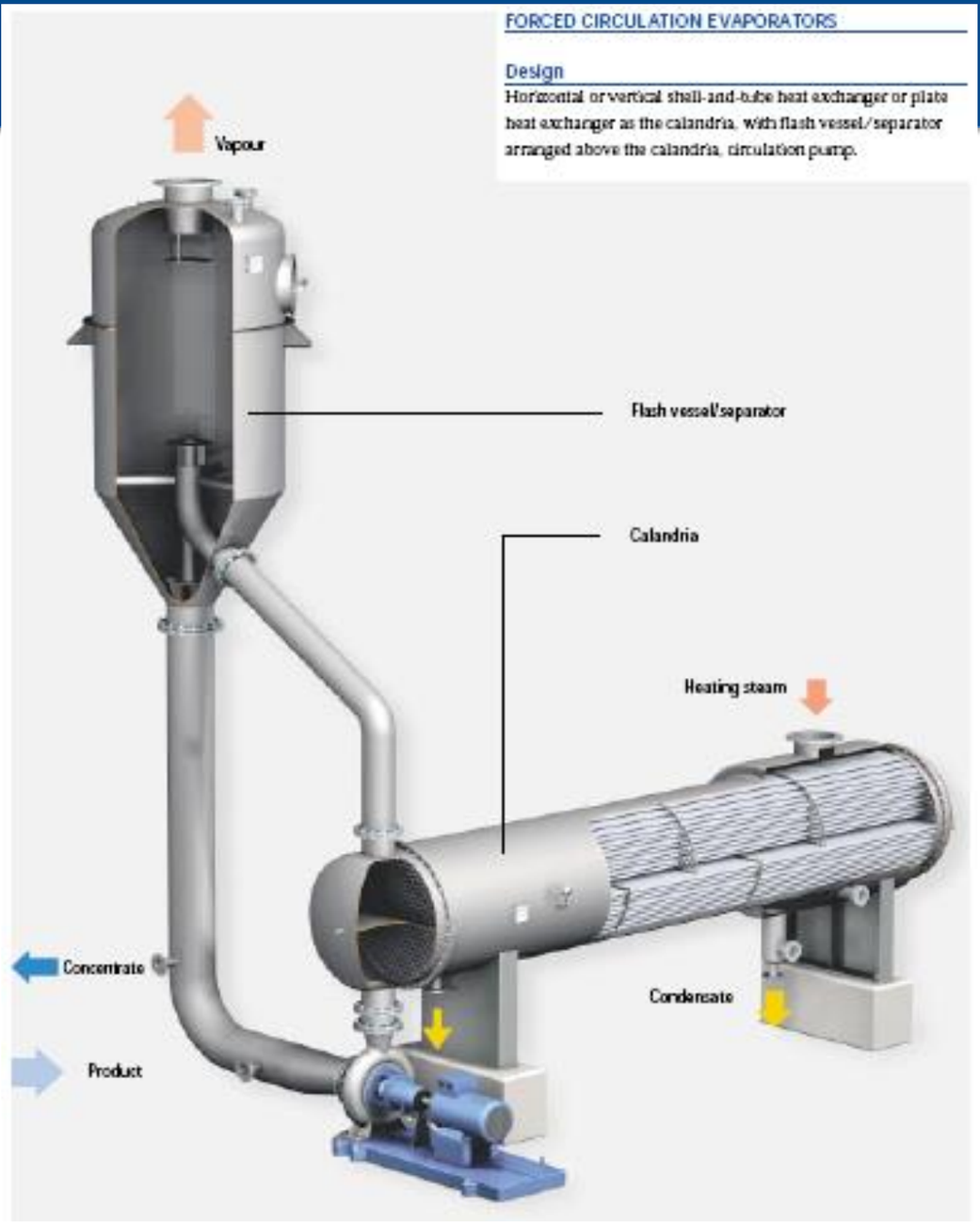
Forced circulation types

- Key advantages
  - High heat transfer rates
  - Positive, controlled circulation
  - Minimisation of fouling or scaling risks
- Disadvantages
  - High capital and operating costs
  - Long residence time
- Major applications
  - Crystalline and corrosive solutions
  - Higher solids content
  - High viscosity solutions

FORCED CIRCULATION EVAPORATORS

Design

Horizontal or vertical shell-and-tube heat exchanger or plate heat exchanger as the calandria, with flash vessel/separator arranged above the calandria, circulation pump.



Liquid flow

- Single pass or recirculating
  - Single pass → short residence time → thermally sensitive products
  - Recirculating → long residence time → high turbulence → fouling or crystallising products

- Falling film or rising film
  - Falling film very commonly used for heat sensitive products

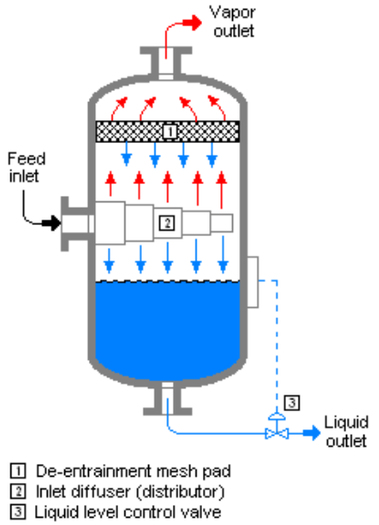
Selection of key components

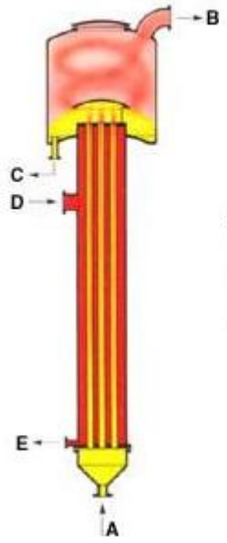
- Items to select &/or design are
  - Feed system, incl. preheaters
  - Heat exchanger
  - Vapour-Liquid separator
  - Condenser
  - Liquid circulation device

Vapour-Liquid (V-L) separator

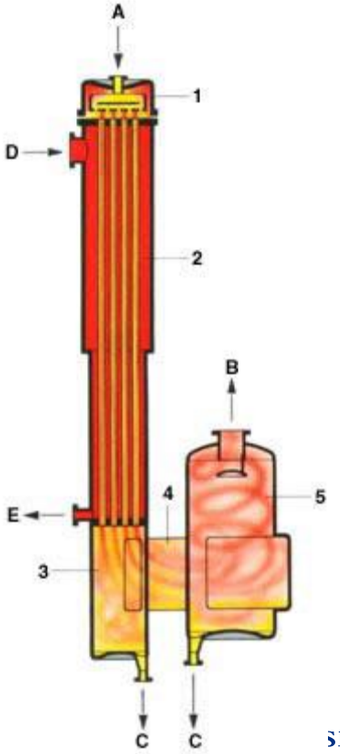
- Two options
  - Gravity separation – usually integral
  - Cyclone – separate

- Cyclones
  - More effective separation
  - Greater pressure drop → lower overall $\Delta\theta$





A: Product
B: Vapor
C: Concentrate
D: Heating Steam
E: Condensate



Condenser

- Indirect
  - Typically external Shell & Tube HE
  - Reduced risk of product contamination
  - Lower pumping duty
- Direct
  - Vapour condensed in cold water spray
  - Lower capital costs
  - Greater pumping costs
  - Lower θ_{cond} possible → higher overall $\Delta\theta$

Vacuum production

- Condensation process
- Mechanical pump
- Steam jet injector system

Pre-heaters

- Small heat exchangers
- Feed enters at boiling point

Question 3: Evaporator selection

What evaporator components would you consider using for the following tasks and why?

(a) Concentrating a low viscosity, corrosive salt solution to give a crystalline product.

(b) Concentrating a fruit juice.

(c) Concentrating a non-corrosive, non-heat sensitive liquid solution.

(d) Concentrating a corrosive liquid solution inside a building with a low ceiling.