

OPERATION OF EVAPORATORS

When a single evaporator is used for concentration, the vapour issuing out of it is condensed and discarded. This type of operation is called single-effect evaporation. When a number of effects are used in series, such that the vapour coming out of one effect is used as a heating medium in the steam chest of the next effect, it is called multiple effect evaporation. Single effect evaporation is simple but fails to utilize the steam effectively, while multiple effect evaporators evaporate more quantity of water per kilogram of steam consumed in the evaporation process. This brings about a saving in the steam cost, but at the same time, the cost of material and installation of the evaporator system increases because of the large number of effects involved. There has to be trade-off between the material cost and the steam cost and the number of effects giving the minimum total cost is the most thermo-economic solution. Although the number of effects in some cases go upto seventeen but usually should not exceed seven, because beyond this, the material and installation cost of the evaporator effects offset the saving achieved in the steam cost.

The driving force for heat transfer is the difference in temperature between the steam in the tubes/coils and the product in the pan. The steam temperature is a function of the steam pressure. Water boils at 100°C at one atm., but at other pressures the boiling point changes. At its boiling point, the steam condenses in the coils and gives up its latent heat. If the steam temperature is too high, burn-on/fouling increases so there are limits to how high steam temperatures can go. The product is also at its boiling point. The boiling point can be elevated with an increase in solute concentration. This boiling point elevation works on the same principles as freezing point depression.

Two or more evaporator units can be run in sequence to produce a multiple effect evaporator. Each effect would consist a heat transfer surface, a vapour separator, as well as a vacuum source and a condenser. There are two advantages to multiple effect evaporators:

- a. Economy – they evaporate more water per Kg steam by re-using vapours as heat sources in subsequent effects
- b. Improve heat transfer – due to the viscous effects of the products as they become more concentrated

Each effect operates at a lower pressure and temperature than the effect preceding it to maintain a temperature difference and continue the evaporation procedure.

The vapours are removed from the preceding effect at the boiling temperature of the product at that effect so that no temperature difference would exist if the vacuum were not increased.

The overall economy of the system is best improved if evaporators are operated in multiple effects, the heat of vaporisation from one effect being used as the heat source for further evaporation at a lower temperature in the next effect.

Feeding Arrangement.

Depending upon the directions of flow of the heating medium and of the feed or the liquor, multiple-effect evaporators are classified into following four categories.

- a. Forward Feed
- b. Backward Feed
- c. Mixed Feed
- d. Parallel Feed

Forward Feed

The usual method of feeding a multiple –effect evaporator is to pump the thin liquid into the first effect and send it in turn through the other effects, as shown in figure 1.9 (a). This is called forward feed. The concentration of the liquid increase from the first effect to the last effect. This pattern of liquid flow is the simplest. It require a pump for feeding dilute solution to the first effect, however, can be done without pumps, since the flow is in the direction of decreasing pressure, and control valves in the transfer line are all that is required.

Advantages

- a. Simple to operate
- b. Less expensive
- c. The liquid flow from one effect to the next effect driven by the partial differential between successive effects so no pump is required
- d. Less chance of deterioration of heat sensitive material

Disadvantages

- a. Reduced rate of heat transfer in second and higher effects
- b. Feed should not below the boiling point because this reduces steam economy by consuming external steam to supply sensible heat

Backward Feed

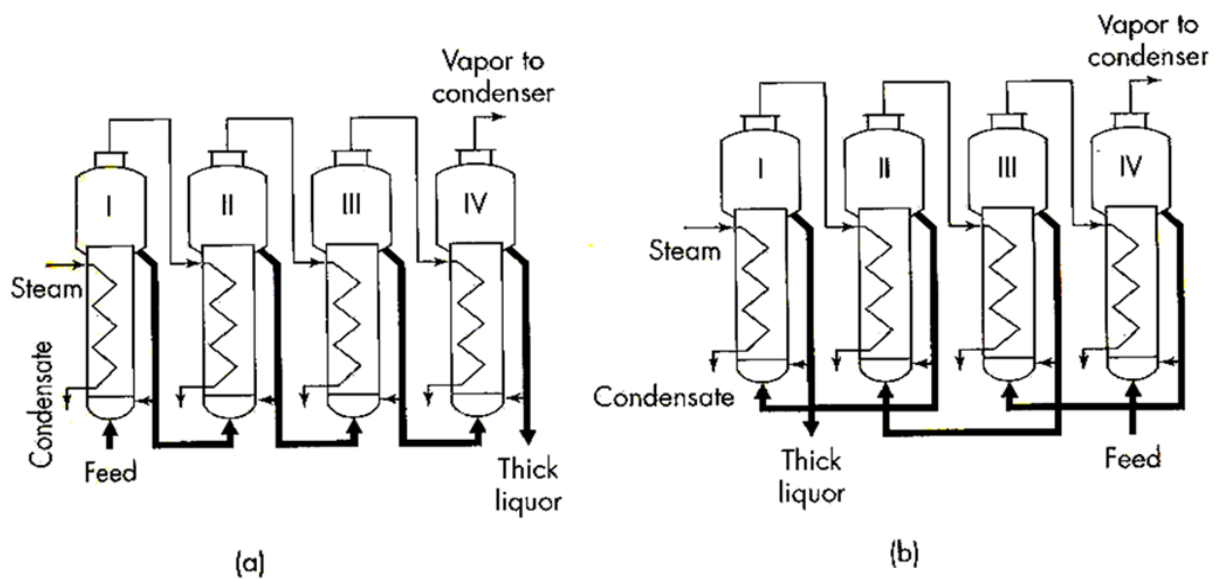
Another common method is backward feed, in which dilute liquid is fed to the last effect and then pumped through the successive effects to the first, as shown in figure 1.9 (b). This method requires a pump between each pair of effects in addition to the thick liquor pump, since the flow is from low pressure to high pressure. Backward feed often gives a higher capacity than forward feed when the thick liquor is viscous, but it may give a lower economy than forward feed when the feed liquor is cold.

Advantages

- The most concentrated liquor is in contact with the highest temperature steam
- Lower viscosity
- Higher heat transfer rate in first effect

Disadvantages

- Inter-effect pumps are necessary
- Higher risk of damage of the viscous product subjected to a higher temperature
- Risk of fouling



a & b Forward Feed and Backward Feed

Mixed Feed

In mixed feed, the dilute liquid enters an intermediate effect, flows in forward feed to the end of the series, and is then pumped back to the first effect for final concentration, as shown in figure 1.10 (c). This eliminates some of the pumps needed in backward feed and yet permits as the final evaporation to be done at the highest temperature.

Advantages

- Combines the simplicity of forward feed and economy of backward feed
- Useful for concentration of a highly viscous feed

Disadvantages

- More complex piping and instrumentation
- More expensive

Parallel Feed

In crystallization evaporators where slurry of crystal and mother liquor is withdrawn, feed may be admitted directly to each effect to give what is called parallel feed as shown in figure 1.10 (d). In parallel feed, there is no transfer of liquid from one effect to another

Advantages

- More suitable for use with crystallizers
- Better control

Disadvantages

- More complex arrangement
- Pumps generally required for each effect

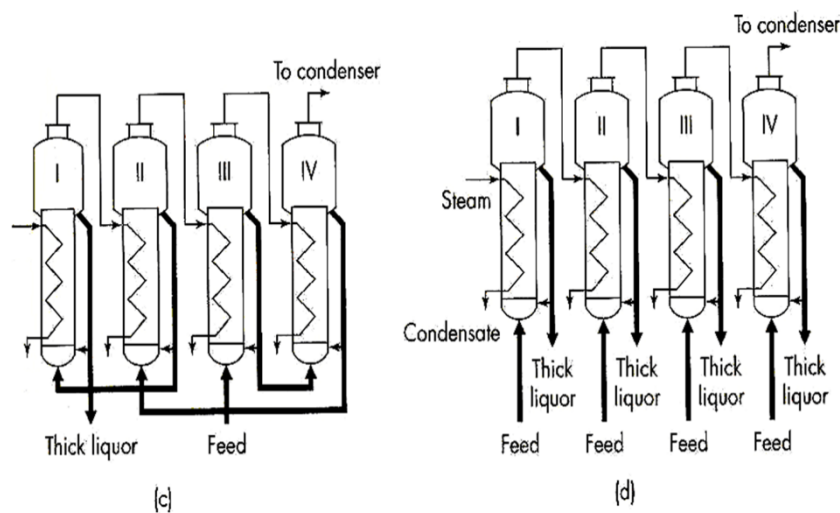


Figure 1.10 c & d Mixed Feed & Parallel Feed

Selection of suitable evaporator

The selection of the most suitable evaporator type depends on a number of factors. These are:

- throughput,
- viscosity of the solution (and its increase during evaporation),

- (iii) nature of the product and solvent (such as heat sensitivity and corrosiveness),
- (iv) fouling characteristics and,
- (v) foaming characteristics.

A selection guidelines based on these factors is given below

Evaporator type	Feed condition							Suitable for heat sensitive material
	Viscosity, cP			Foaming	Scaling or fouling	Crystals producing	Solids in suspension	
	High viscosity >1000	Medium viscosity 100 to 1000	Low viscosity <100					
Calandria (short tube vertical)	—————							No
Forced circulation	—————							yes
Falling film		=====						no
Natural circulation		=====						no
Agitated film (Single pass)	—————							yes
Long tube falling film			=====					yes
Long tube raising film			=====					yes

Selection guide of evaporators

Performance of Evaporators (Capacity and Economy)

The performance of a steam-heated evaporator is measured in terms of its capacity and economy. Capacity is defined as the number of kilogram of water vaporized per hour. Economy (or steam economy) is the number kilogram of water vaporized from all the effects per kilogram of steam used. For single effect evaporator, the steam economy is about 0.8 (<1). The capacity is about n -times that of a single effect evaporator and the economy are about $0.8n$ for n -effect evaporators. However, pumps, interconnecting pipes and valves are required for transfer of liquid from one effect to another effect that increases both equipment and operating costs.