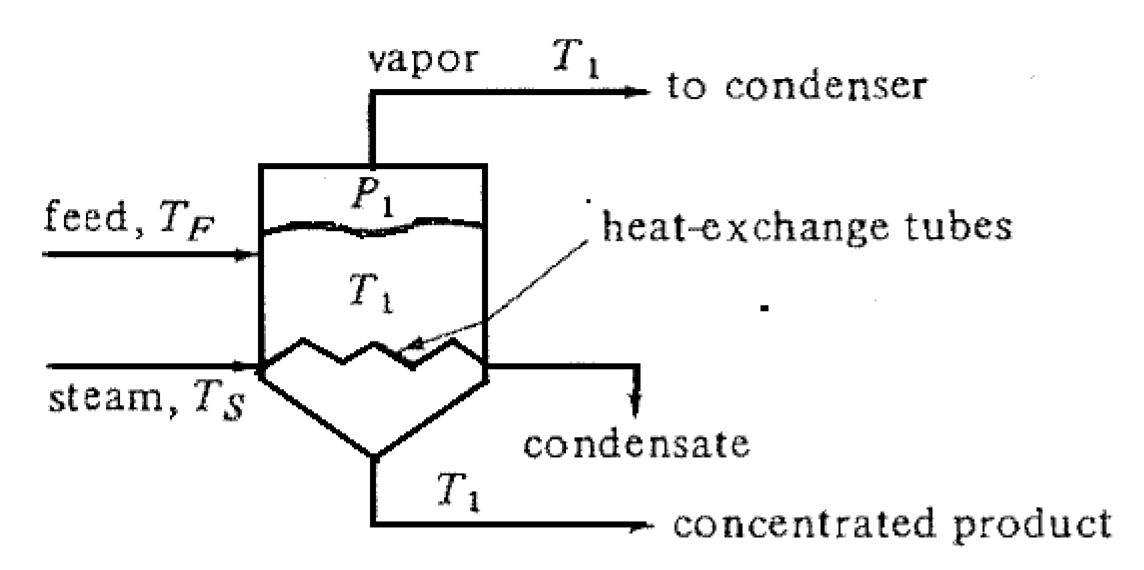
Evaporation

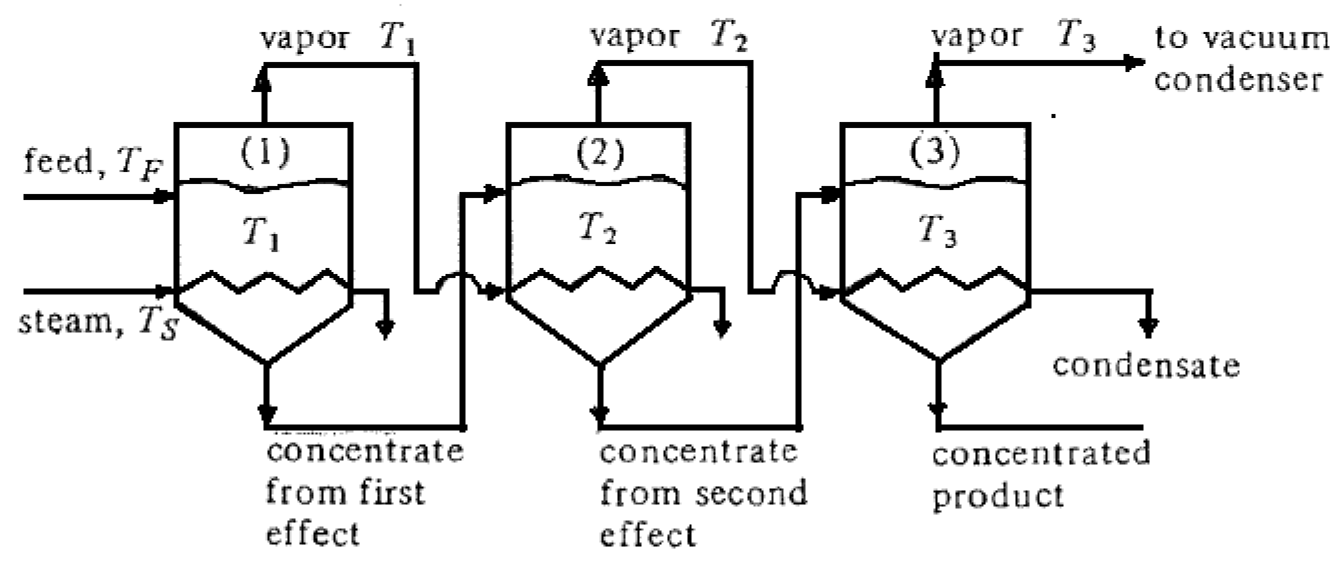
Single Effect Evaporator

- In a single effect evaporator, the feed solution enters the evaporator at a temperature of T_F
- The saturated steam which is used as the heating medium enters at a temperature of T_S
- The feed solution and steam are in indirect contact with each other across the tubes in the heat-exchange section
- The condensed steam leaves as condensate



- The vapour generated from the vaporized solvent is either condensed in a condenser or discarded
- The concentrated product solution is removed from the bottom
- Since the solution in the evaporator is assumed to be completely mixed, the concentrated product and the solution in the evaporator have the same composition and temperature T_1, which is the boiling point of the solution
- The temperature of the vapour is also T_1, since it is in equilibrium with the boiling solution
- The pressure is P_1 which is the vapour pressure of the solution at T_1
- The operation of a single effect evaporator is simple but steam is not utilized efficiently as about 1.1 to 1.3 kg of steam is required to vaporize 1 kg of water from solution

Multiple Effect Evaporators



- The vapours that are generated in an evaporator, are generally discarded – this leads to wastage of energy since the vapours contain latent heat
- This vapour (or steam) can be used as a source of heat in another unit operating under lower pressure and temperature
- The vapour from the second unit can be further used as a steam supply to a third unit operating at a still lower pressure and temperature
- Each unit in such a series is called an ***effect*** and the method of re-using the latent heat is called ***multiple-effect evaporation***
- In a multiple effect evaporator, more than one effect (unit) is attached to one another
- The feed is introduced in the first effect and steam is introduced in the steam chest for heating
- Partially concentrated solution flows from the first effect to the second effect as feed
- The vapour generated in the first effect has sufficient latent heat and is introduced in the steam chest of the second effect for heating
- Similarly the concentrated solution from the second effect is introduced as feed in the third effect
- The vapour from the second effect is used as a source of heat in the third effect

- The vapour from the third effect is condensed or discarded
- The vapour leaving the first effect is at the boiling point of the liquid leaving the first effect (T_1)
- If the feed to the first effect is at its boiling point, 1 kg steam will vaporize almost 1 kg of water
- In the first effect, $\Delta T = T_S - T_1$
- In case of the second effect, the transfer of heat has to occur from the condensing vapour (coming from the first effect) to the boiling liquid in the second effect
- The liquid in the second effect must boil at a temperature (T_2) considerably lower than the condensation temperature of the vapour (T_1) in order to ensure reasonable driving force for heat transfer
- This is possible if the second effect is at a suitably lower pressure, so that the liquid boils at a lower temperature
- If the first effect operates at atmospheric pressure, the second one must operate under vacuum
- The driving force in the second effect is thus, $\Delta T = T_1 - T_2$
- Similar to the second effect, the pressure in the third effect must be lower than that in the second effect – the temperature of the third effect T_3 must be less than that of second effect, T_2 $(\Delta T = T_2 - T_3)$
- In each of the second and third effects, close to 1 kg of water is evaporated
- Therefore, approximately 3 kg of water is evaporated for 1 kg of steam fed
- By using three effects , the steam economy is approximately 3 times that of a single effect

- Therefore, ***an increase in the number of effects increases the steam economy***
- However, it is not advisable to continuously increase the number of effects, as an improvement in steam economy is at the expense of the original cost of the increased effect
- Operating cost is same, but the capital cost, repair and maintenance cost increases with increase in number of effects

Feed introduction in multiple effect evaporators

Depending on the *direction of flow of the heating medium and of the feed or liquor*, multiple effect evaporators are classified as:

(i) forward feed

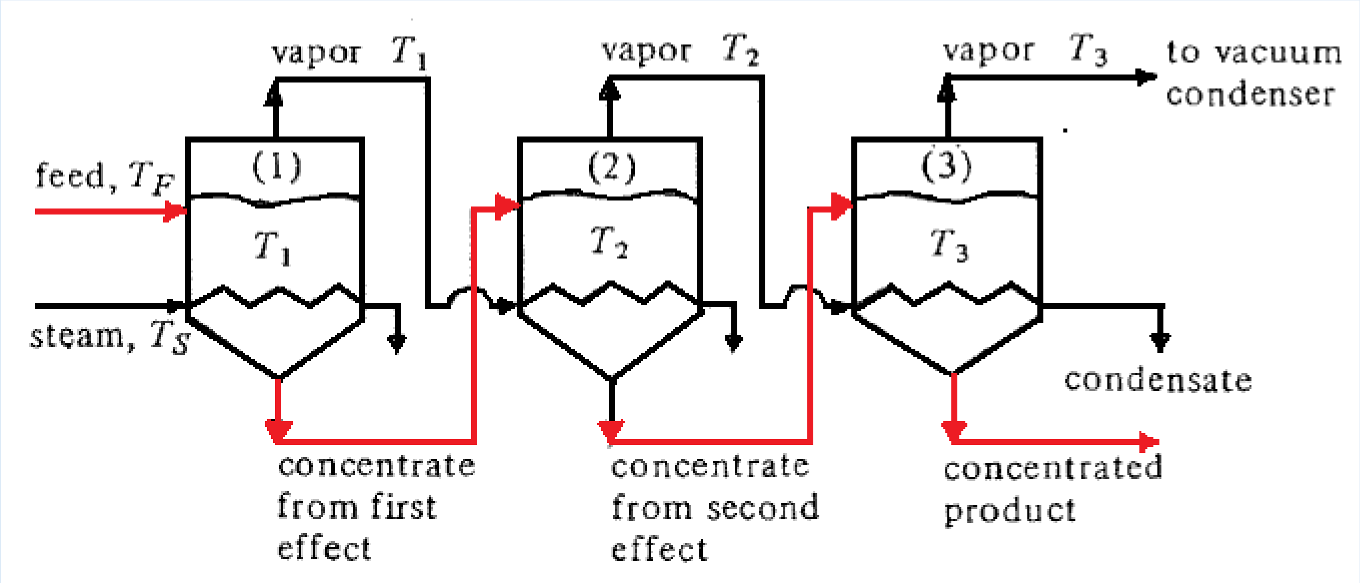
(ii) backward feed

(iii) mixed feed

(iv) parallel feed

Forward feed:

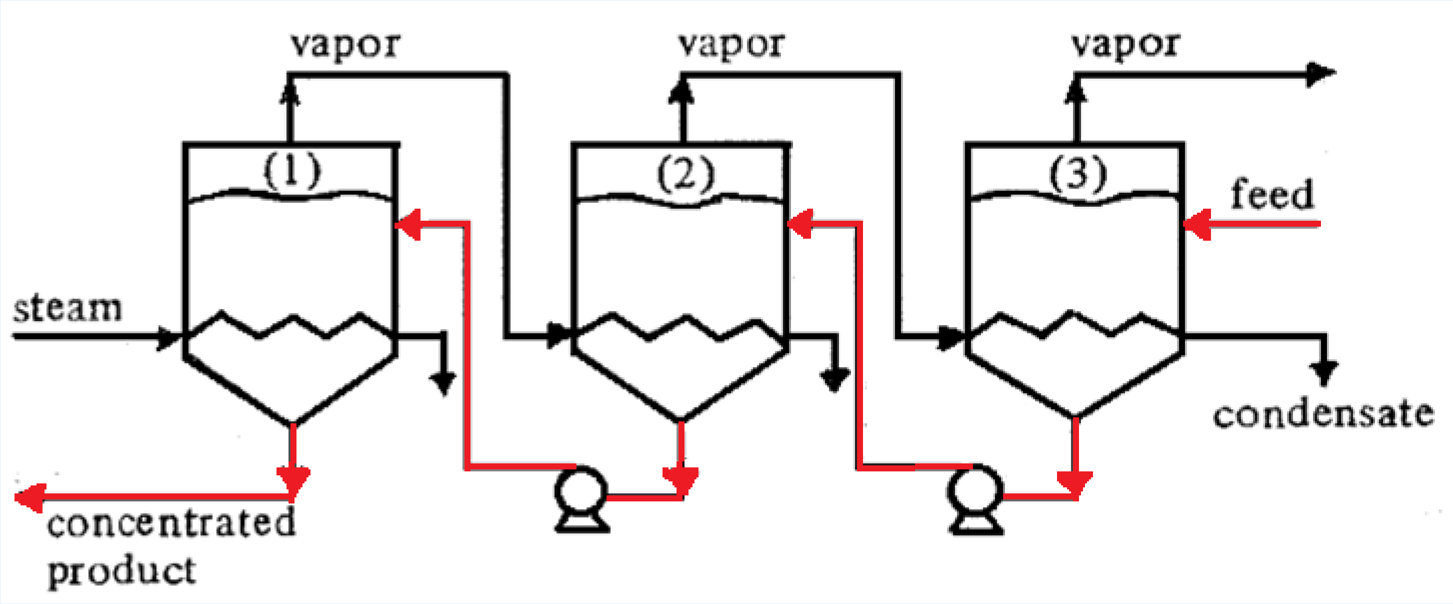
- The feed is introduced into the first effect
- Partly concentrated solution flows into the second and then the third effect, and thick concentrated solution is removed from this last effect
- The steam is introduced into the first effect, the vapour generated in the first and second effects are used as sources of heat in the second and third effects respectively



- The flow of the solution from one effect to another occurs spontaneously (without the use of pumps) because it flows in the direction of decreasing pressure. The flow behaviour is shown in the diagram above
- The boiling temperature decreases from effect to effect
- This method of operation is used when *the feed is hot* or when *the final concentrated product might be damaged at high temperature*

Backward feed:

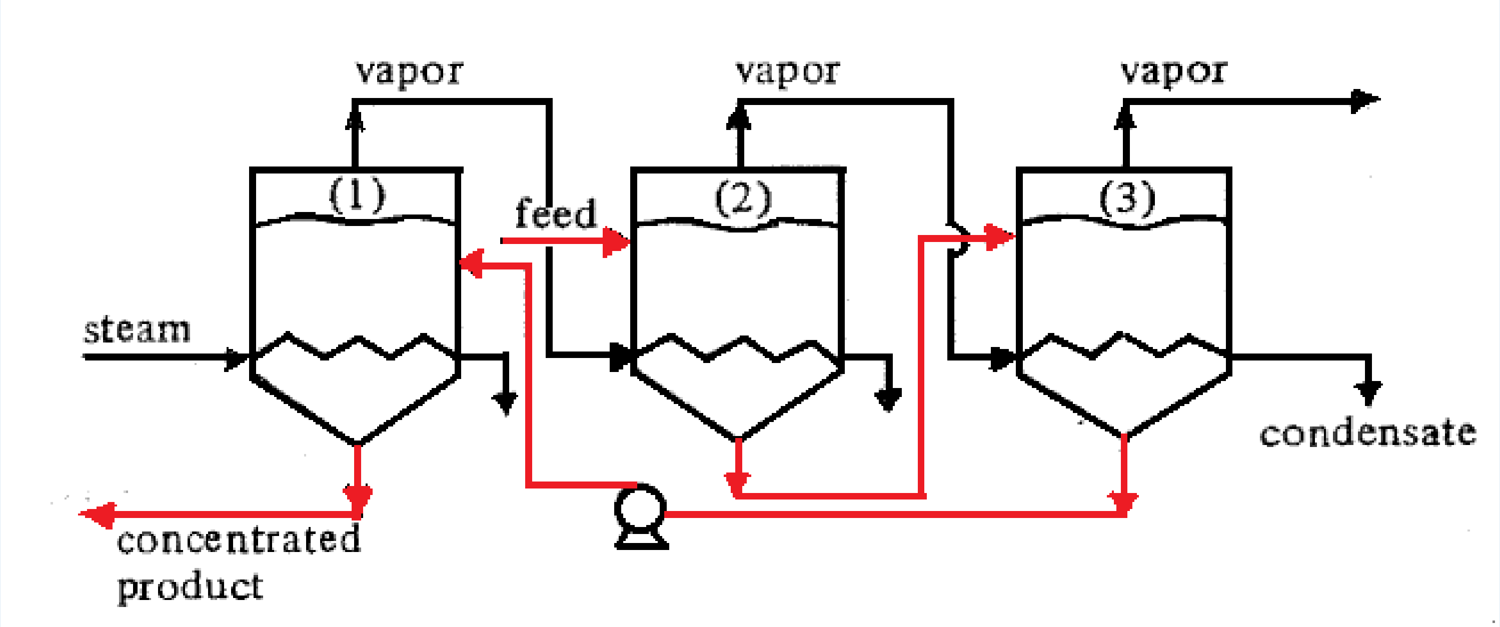
- In this operation, the feed is introduced in the last and coldest effect, and continues to move in the backward direction until the concentrated product leaves the first effect. The flow behaviour is shown in the diagram alongside



- Pumps are used to maintain the flow of solution from lower to higher pressure
- This method of reverse feed is *advantageous* when the *fresh feed is cold*. Here, the cold feed absorbs heat from the vapour in the last effect, which does not have any potential for reuse - if this had happened in the first effect, a large portion of the heat supplied by steam would be used to increase the feed temperature to saturation and then vaporize the feed solution, leading to lower amounts of vapour being formed (this would consequently lower the heat supplied by vapour in the second effect)
- A smaller amount of liquid (since the solution gets progressively concentrated) is heated to higher temperatures in the second and third effects
- Backward feed also has an advantage when the *concentrated product is highly viscous* – high viscosity leads to lower heat transfer coefficient
- The first effect (which has the most concentrated product) has the highest temperature – the high temperature reduces the viscosity of the most concentrated liquor to give a reasonable heat transfer coefficient

Mixed feed:

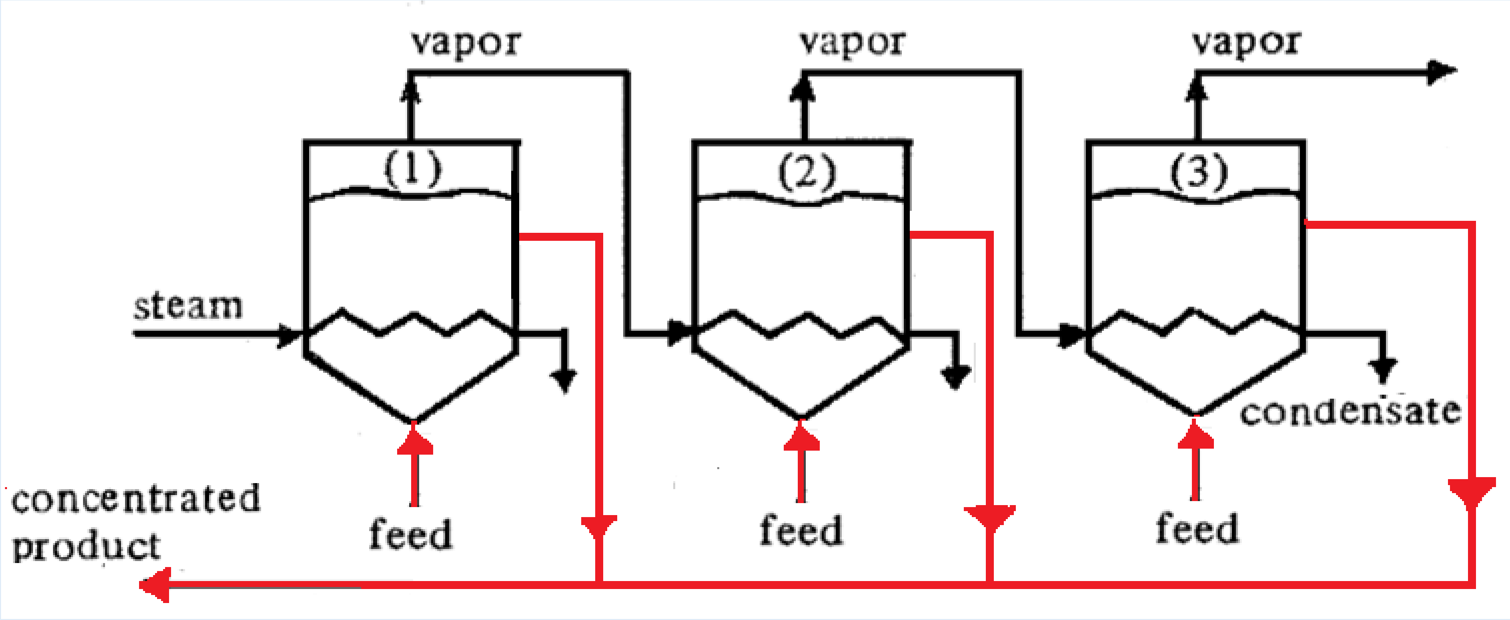
- The mixed feed arrangement is a compromise between forward and backward feed.
- The dilute feed enters the intermediate effect and flows to the next higher effect till it reaches the final effect
- Partially concentrated feed is introduced to the effect before the one to which the feed was introduced
- The concentrated feed then flows in the backward mode towards the first effect



- Thick liquor is withdrawn from the first effect
- The flow behaviour is shown in the diagram above
- This method of operation *allows the elimination of the pumps* (usually needed in backward feed) in the forward part *of the operation* (section to the right hand side of the feed effect)
- This mode also allows the *final concentration of the product to be done at the highest temperature* (in the first effect) – this helps to deal with very viscous products

Parallel feed:

- In this mode of operation, the feed is introduced in each of the effects and the concentrated solution is removed from each separately
- In this case, there is no transfer of liquid from one effect to another effect
- The flow behaviour is shown in the diagram alongside
- The successive effects operate under gradually decreasing pressure so that the vapour generated in one can act as a heating medium in the next
- This kind of operation is *used for the crystallization process*



- Crystals start separating as the solution gets partially concentrated, the product is not a concentrated liquid but a slurry
- Flow of such slurries from one effect to another is not easy or desirable and is hence removed from each effect