DESIGN OF MULTIPLE EFFECT FORCED-CIRCULATION EVAPORATORS AND CRYSTALLIZATION SYSTEMS

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Contents

Summary

Forced-circulation evaporators can be regarded as the most versatile type of evaporators in the range of possible applications. They are used mainly to evaporate media containing solids brought in by the feed or crystallized during evaporation. In addition, forced-circulation evaporators have large advantages, if the feed contains substances which cause encrustations.

The minimization of the energy consumption for heating and the cooling water quantity for condensation of the vapors is only one of the advantages of using multiple-effect forced-circulation evaporators, as the same effect can often also be reached by using an evaporator with a mechanical vapor recompression, if the boiling point elevation of the final product solution is not excessively high.

A plant consisting of multiple-effect forced-circulation evaporators is, however, very flexible for the optimization of crystallization processes. As the concentration occurs stepwise, there is the possibility of fractional crystallization or refining of the crystals in

the effect with the highest concentration of impurities. In addition, the process can be optimized regarding crystallization conditions and the construction material because of the different temperatures of the effect.

1. Features and Applications of Forced-circulation Evaporators

A forced-circulation evaporator comprises essentially a tube bundle heat exchanger, a flash tank, a circulating pump, and the connecting piping. The medium to be evaporated is conveyed by the circulating pump from the flash tank through the tube bundle heat exchanger and back into the flash tank. The recirculated solution flows inside the heat exchanger tubes and enters the flash tank in a superheated state, whereby flash evaporation takes place releasing vapors in the flash tank. The shell side of the heat exchanger is heated by condensing heating steam.

The construction of forced-circulation evaporators is relatively complex compared to natural circulation and falling film evaporators due to the large fluid flows to be circulated by a pump. They can, however, be regarded as the most versatile type of evaporators when it comes to range of applications.

Forced-circulation evaporators are used mainly to evaporate media containing solids or substances which induce encrustation. It is therefore possible to use forced-circulation evaporators in crystallization systems operated with solids contents of up to 50 weight-%. The circulating pump is used to generate high-flow velocities in the heat exchanger tubes. As nucleate boiling cannot then occur on the heating surfaces, no encrustation takes place. It is, of course, also possible to concentrate solutions not containing solids.

The vessels can be constructed and arranged in many different ways due to the fact that the circulating fluid phase is conveyed by force. It is normally preferable to construct the heat exchangers vertically with a single pass. To meet certain installation requirements it is, however, possible to arrange the heat exchangers horizontally as multipass constructions.

The method of feeding the solution which has been superheated in the heat exchanger into and directing it through the flash tank can be optimally adapted to the specific properties of the medium to be processed (e.g. its tendency to foam) or the requirements to be met by the product (e.g. generation of large crystals).

The heat exchanger of a forced-circulation evaporator is normally heated with steam. In principle it is, however, possible to use other heating media such as hot water or heating oil. It is also usual to use compressed vapors for heating when there is just a slight increase in the boiling point of the medium to be evaporated. This topic will be dealt with in more detail later.

2. Multiple-effect Forced-circulation Evaporator

Multiple-effect evaporators consist of several evaporator effects connected one after the other. In multiple-effect systems it is only the first effect which is heated by heating steam. The subsequent forced-circulation evaporator effects, each of which is operated at a lower pressure level than the previous one, are heated with the vapors from the previous effect. The vapors from the final forced-circulation evaporator effect are precipitated in a condenser using cooling water.

Heating steam consumption can be significantly reduced by using the vapors generated in the preceding effects for heating. The cooling water requirement can also be drastically reduced as it is only used to condense the vapors from the final effect.

A study of the capital investment costs and running costs forms the basis for determining the optimal number of effects for a multiple-effect forced-circulation evaporator system. The running costs decrease as the number of effects increases whilst a greater number of effects naturally means higher capital investment costs. In Figure 1 the qualitative running, capital investment and total costs for a multiple effect evaporator are plotted against the number of evaporator effects.

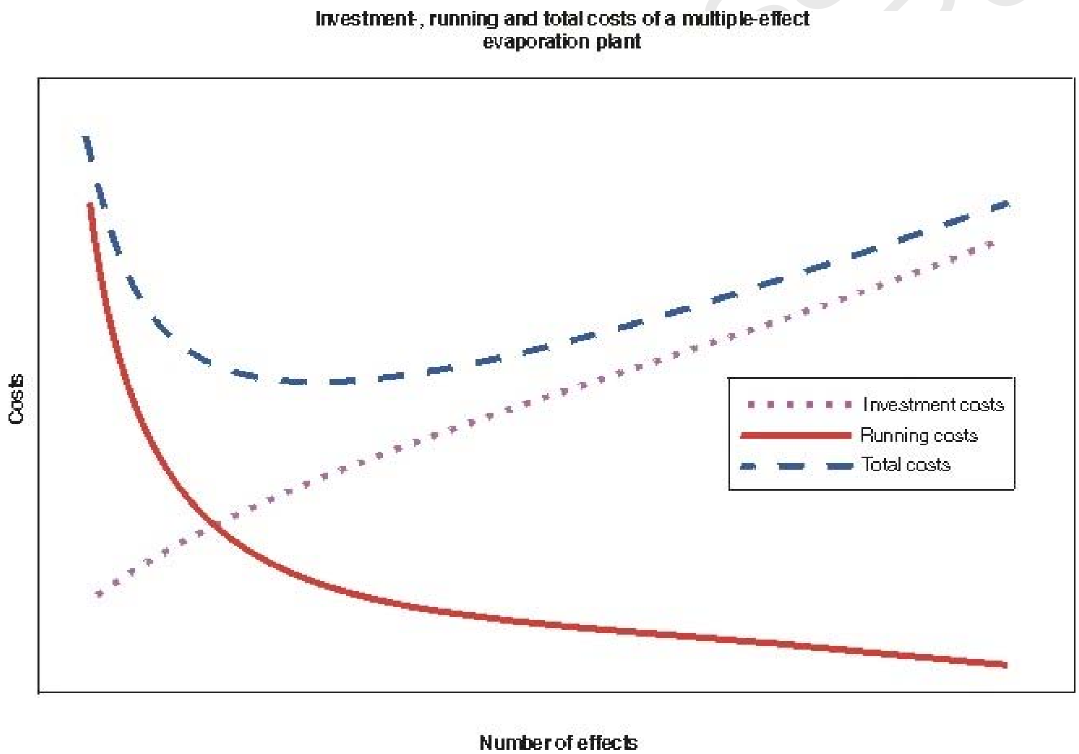

Figure 1. Running, capital investment, and total cost plotted over the number of effects.

The number of evaporator effects is not only restricted by the increasing capital investment costs but also by the elevation in the boiling point in the individual effects caused by the substances contained in the water. An adequate temperature difference between one effect and the next is essential to provide the motive force for heat transfer if the vapors from one effect are to be used to heat the succeeding effect. Consequently, the corresponding pressure in one effect must be less than the pressure in the preceding effect. However, the temperature difference resulting from the pressure difference is reduced to some extent by the rise in boiling temperature in the relevant evaporator effect. The maximum number of effects in a multiple-effect evaporator system is restricted by the vacuum which can be economically achieved in the final stage.

The multiple-effect construction also provides other benefits in addition to heating medium savings which can also be achieved by installing a vapor compressor for certain applications.

(a) If heat transfer is poor due to the properties of the final concentrate to be produced, it is possible to install less heating surface overall; in a multiple-effect evaporation system most evaporation takes place in the first effect(s) which provide more favorable heat transfer conditions, the concentrations in the mother liquor being low.
(b) As the initial concentrates in the first effects are often considerably less corrosive than the final concentrate, these parts of the system can be made of less high quality and therefore cheaper materials for certain applications.
(c) Multiple-effect crystallization systems can be used to obtain a product with a higher degree of purity. In the individual effects of a multiple-effect system a large proportion of the escort salts can be crystallized out and segregated by fractional crystallization before the actual target substances reach the final effect for crystallization.
(d) In multiple-effect systems it is also possible to refine the salt to be crystallized if this is contaminated by the high concentration of other substances in the mother liquor in the final effect. By redissolving the salt which crystallizes in the final effect, e.g. with the feed to the evaporation system, the target product concentrates in the first effects and can be crystallized out of a mother liquor which is only slightly contaminated with escort substances.

3. Thermodynamic Design

The thermodynamic design of multiple-effect forced-circulation evaporator systems includes determining the total energy requirement and the distribution of the heat flows to the individual effects and the final condenser as a basis for calculating the heating surface area required for each effect.

The thermodynamic design is closely linked to the corresponding mass balances, as the properties of the substances depend on the concentrations and the operating temperatures in the individual effects.

The hydraulic design must also be taken into account because it has a considerable influence on the effective temperature difference as a motive force for heat transfer.

The minimum and maximum operating temperature limits are generally determined by the available heating steam temperature, the resistance of the materials at high temperatures and possibly by the thermal stress of the medium to be processed as well as the temperature of the available cooling medium. The presence of substances which cause encrustation in the solution to be processed also restricts the admissible temperature gradient between the steam and fluid side in the heat exchanger.

Inert gas accumulation occurring during the evaporation process can also have a significant influence on heat transfer as parts of active heat transfer areas are blanketed by these gases. Steam consumption goes up because of the fact that some of the heating steam is wasted in purging the inert gases from the heat exchangers.

The thermodynamic design can only be carried out iteratively because the mass and heat balances are influenced by heat transfer in various respects. Computer programs link the mass and heat balance to the heat exchanger calculation to resolve this. The program must also take into account the concentration and temperature dependence of the properties of the material.

When carrying out the thermodynamic design for a multiple-effect forced-circulation evaporator system the procedure is basically as follows.

(a) The number of effects, the series connection of the effects, and the inlet and outlet mass flows are determined for the overall plant.
(b) The water flow to be evaporated is then calculated from the total mass balance.
(c) The mass flows and vessel dimensions are calculated iteratively by resolving the mass and energy balances.

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Bibliography and Suggestions for further study

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