Feeding of Multiple Effect Evaporators

In a two effect evaporator, the temperature in the steam chest is higher in the first than in the second effect.

In order that the steam provided by the evaporation in the first effect will boil off liquid in the second effect, the boiling temperature in the second effect must be lower and so that effect must be under lower pressure.

Consequently, the pressure in the second effect must be reduced below that in the first. In some cases, the first effect may be at a pressure above atmospheric; or the first effect may be at atmospheric pressure and the second and subsequent effects have therefore to be under increasingly lower pressures.

Feeding of Multiple Effect Evaporators

Often many of the later effects are under vacuum. Under these conditions, the liquid feed progress is simplest if it passes from effect one to effect two, to effect three, and so on, as in these circumstances the feed will flow without pumping.

This is called **forward feed**. It means that the most concentrated liquids will occur in the last effect. Alternatively, feed may pass in the reverse direction, starting in the last effect and proceeding to the first, but in this case the liquid has to be pumped from one effect to the next against the pressure drops.

This is called **backward feed** and because the concentrated viscous liquids can be handled at the highest temperatures in the first effects it usually offers larger evaporation capacity than forward feed systems, but it may be disadvantageous from the viewpoint of product quality.

Advantages of Multiple Effect Evaporators

At first sight, it may seem that the multiple effect evaporator has all the advantages, the heat is used over and over again and we appear to be getting the evaporation in the second and subsequent effects for nothing in terms of energy costs. Closer examination shows, however, that there is a price to be paid for the heat economy.

In the first effect, $q_1 = U_1 A_1 \Delta T_1$ and in the second effect, $q_2 = U_2 A_2 \Delta T_2$.

We shall now consider a single-effect evaporator, working under the same pressure as the first effect

$q_s = U_s A_s \Delta T_s$, where subscript s indicates the single-effect evaporator.

Advantages of Multiple Effect Evaporators

Since the overall conditions are the same, $\Delta T_s = \Delta T_1 + \Delta T_2$, as the overall temperature drop is between the steam-condensing temperature in the first effect and the evaporating temperature in the second effect. Each successive steam chest in the multiple-effect evaporator condenses at the same temperature as that at which the previous effect is evaporating.

Now, consider the case in which $U_1 = U_2 = U_s$, and $A_1 = A_2$. The problem then becomes to find A_s for the single-effect evaporator that will evaporate the same quantity as the two effects.

$\Delta T_1 = \Delta T_2$ **and** $\Delta T_s = \Delta T_1 + \Delta T_2 = 2\Delta T_1$

$\Delta T_1 = 0.5\Delta T_s$

Now $q_1 + q_2 = U_1 A_1 \Delta T_1 + U_2 A_2 \Delta T_2 = U_1 (A_1 + A_2)\, \Delta T_s/2$

but $q_1 + q_2 = q_s$ **and** $q_s = U A_s \Delta T_s$

so that $(A_1 + A_2)/2 = 2A_1/2 = A_s$

That is $A_1 = A_2 = A_s$

Advantages of Multiple Effect Evaporators

The analysis shows that if the same total quantity is to be evaporated, then the heat transfer surface of each of the two effects must be the same as that for a single effect evaporator working between the same overall conditions.

The analysis can be extended to cover any number of effects and leads to the same conclusions.

In multiple effect evaporators, steam economy has to be paid for by increased capital costs of the evaporators.

Since the heat transfer areas are generally equal in the various effects and since in a sense what you are buying in an evaporator is suitable heat transfer surface, the n effects will cost approximately n times as much as a single effect.

Advantages of Multiple Effect Evaporators

Comparative costs of the auxiliary equipment do not altogether follow the same pattern. Condenser requirements are less for multiple effect evaporators.

The condensation duty is distributed between the steam chests of the effects, except for the first one, and so condenser and cooling water requirements will be less.

The optimum design of evaporation plant must then be based on a balance between operating costs which are lower for multiple effects because of their reduced steam consumption, and capital charges which will be lower for fewer evaporators.

STEAM CONSUMPTION AND RUNNING COSTS OF EVAPORATORS

Number of effects	Steam consumption (kg steam/kg water evaporated)	Total running cost (relative to a single-effect evaporator)
One	1.1	1
Two	0.57	0.52
Three	0.40	0.37