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Multiple Effect Evaporator System

Keywords: Multiple Effect Evaporator, Feed Arrangements, Optimum No. of Effects

The chief factor influencing the economy of an evaporator system is the number of effects. By increasing the number of effects we can increase the economy of an evaporator system. The first effect of a multiple effect evaporator is the effect to which the raw steam is fed, vapors obtained from first effect act as a heating medium for another effect.

Different types of feed arrangement of multiple effect evaporators -:

1)FORWARD FEED ARRANGEMENT : In this arrangement the feed and steam introduced in the first effect and pressure in the first effect is highest and pressure in last effect is minimum, so transfer of feed from one effect to another can be done without pump.

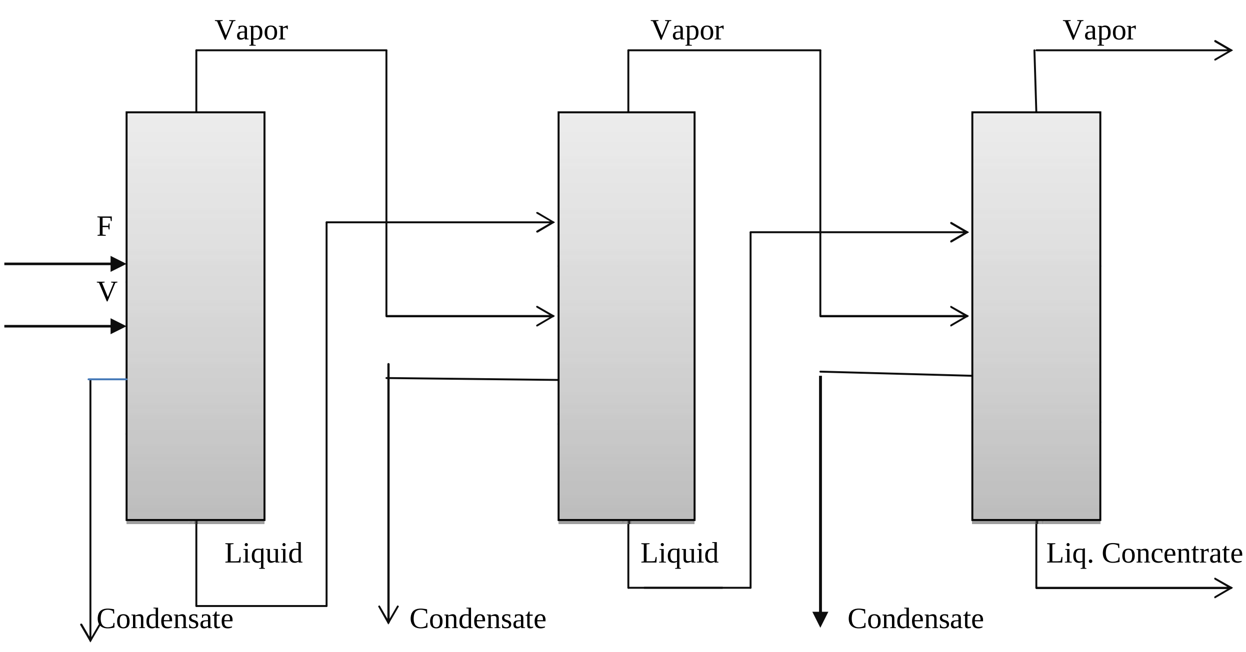

Fig. 22.1: Forward feed arrangement in Multi effect Evaporator

2) BACKWARD FEED ARRANGEMENT: In this arrangement feed is introduced in last effect and steam is introduced in first effect. For transfer of feed, it requires pump since the flow is from low pressure to higher pressure. Concentrated liquid is obtained in first effect.

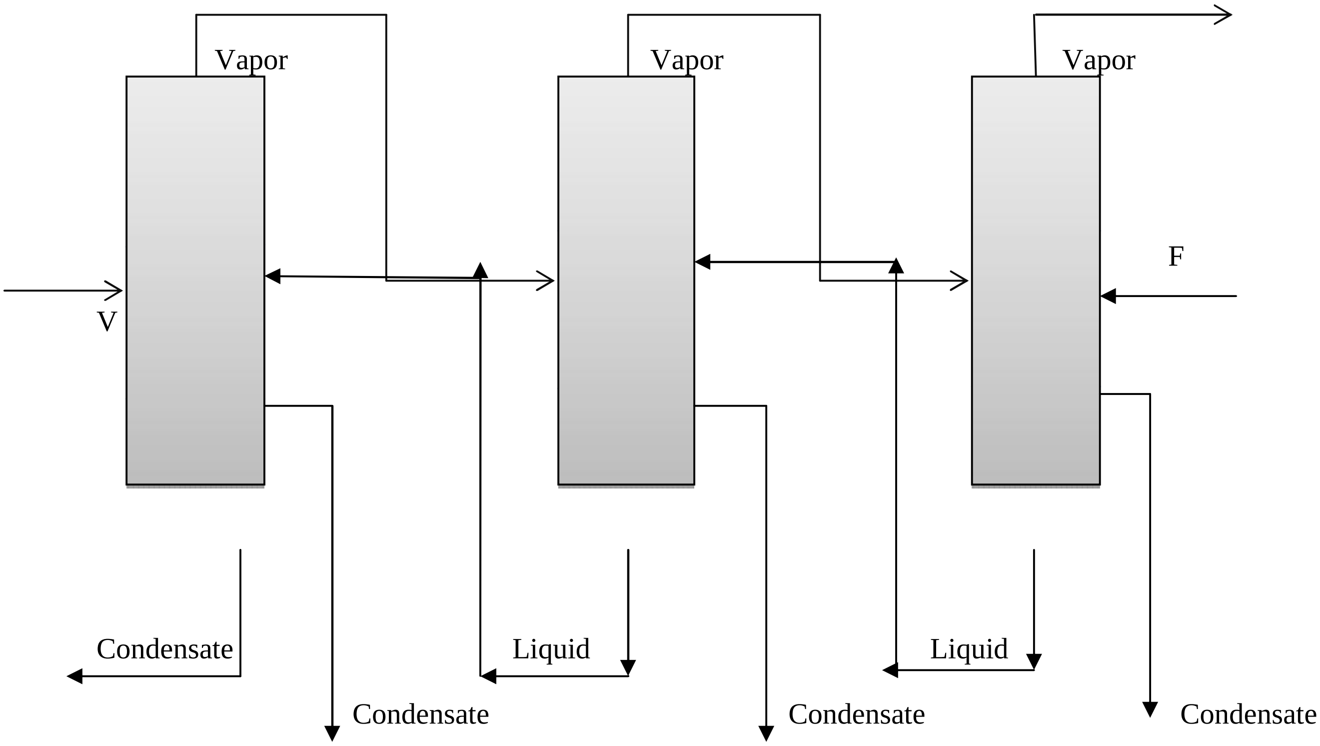

Fig. 22.2: Backward feed arrangement in Multi effect Evaporator

3) MIXED FEED ARRANGEMENT: In this arrangement feed is introduced in intermediate effect, flows in forward feed to the end of the series and is then pumped back to the first effect for final concentration. This permits the final evaporation to be done at the highest temperature.

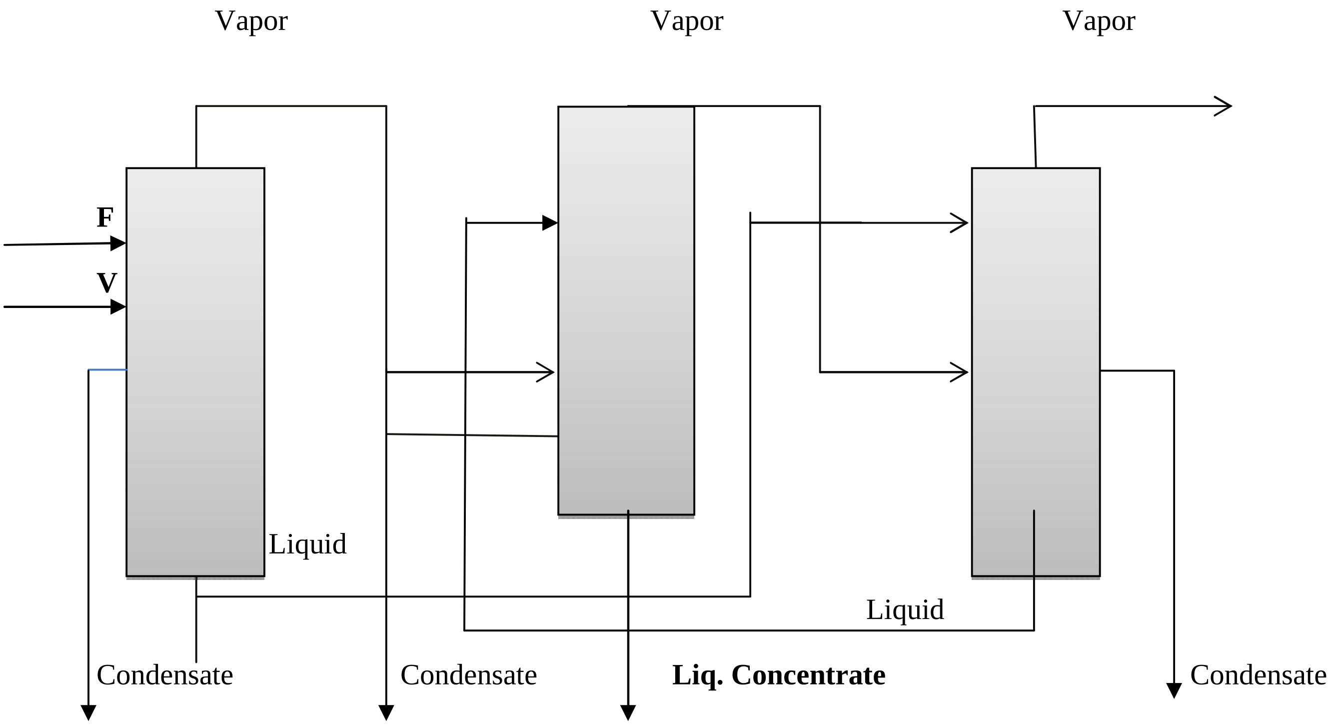

Fig. 22.3: Mixed feed arrangement in Multi effect Evaporator

ANALYSIS OF MULTIPLE EFFECT EVAPORATOR SYSTEM :

With the increasing trend in the cost of coal, fuel oil it becomes to use the vapors of previous effect in the steam chest of following effect. This requires the multiple effect evaporator system .As the number of effect increases the steam economy increases on the other side capital cost will be more.

There is economic balance between the fixed cost and the operating cost so that one can select the optimum number of effects.

Fixed cost :

According to Coston and Lindey,the annual fixed cost of a multiple effect evaporator is approximately proportional to the 0.75 power of the number of effects.

$V_1 = C_1/A^* N^{0.75}$

The estimated cost of a single effect (C_1) can be obtained from a number of sources once the heat transfer surfaces requirements are known.

Operating cost :

Operating costs can be divided in to steam cost and all operating costs (labour, cooling water,power and maintenance) such that

$V_1 = h^*W^*C_2/S + V0$

H = operating time (hr/yr)

W = evaporation rate (Kg/hr)

C_2 = cost of steam (Rs/Kg)

S = steam economy

V_0 = all operating cost other than the cost of steam (Rs/Yr)

Steam economy can be expressed as:

$S = S_1+S\ _1S_2+S\ _1S_2^{\ 2}+\ldots\ldots\ldots\ldots..+S\ _1S_2^{\ N-1}$

$S = S_1\ (1-S_2^{\ N})/\ (1-S_2)$

Thus V_2 becomes

$V_2 = (1-S_2)h^*W^*C_2/S_1\ (1-S_2^{\ N}) + V_0$

Total cost

$V_T = V_1 + V_2$

$V_T = = C1/A^* N^{0.75} + (1-S2)h^*W^*C2/S1(1-S2N) + V0$

For minimum cost **$\Delta V_T/\Delta N = 0$**

$0 = C_1/N\{(N+1)^{0.75} –(N^{0.75})\} + (1-S_2)h^*W^*C_2/S_1\{[1/(1-S_2^{\ N+1})]-[1/(1-S_2^{\ N})]\}$

$Ahwc_2/C_1 = \{[(N+1)^{0.75}–(N^{0.75})] * S_1(1-S_2^{\ N})(1-S_2^{\ N+1})\}/(1-S_2)^2 *S_2^{\ N}$

Modeling of multiple effect evaporator system

Multiple effect evaporators involve a large number of state and design –variables. A change in any variable can upset the operation of the evaporator. To achieve the goal of energy conservation in multiple effect evaporators, it is necessary to know how does steam economy alter with changes in operating variables for a given end product concentration . To quantise the changes in steam economy , a functional relationship correlating it with variables should be developed. For this, it is necessary to identify all the variables which affect the steam economy of a multiple effect evaporator.

Variables of a multiple effect evaporator :

In a evaporator , the variables can be classified as geometrical-operating, and self balancing variables. As regards the geometrical variable , it is the area of heat transfer surface in each effect of an evaporator . Hence, N-effect evaporator will have N number of geometrical variables.

From industrial practices .we know that there are some operating variables which plant engineer can change them independently to annual any imbalance in the operation of an evaporator . They include: feed temperature, feed concentration ,feed flow rate,and steam temperature (pressure), saturation temperature (pressure) in the last effect. Feed arrangement (forward/backward/mixed) is also one of the operating variables. Thus , total number of operating variables is six.

As regards the vapour and liquid streams from each effect of a multiple effect evaporator, they cannot be changed independently by a plant engineer. Therefore, they are self balancing streams. The variables associated with these streams are: flow rate, temperature and concentration of liquid streams ; and saturation temperature(pressure) of each effect. However, temperature of vapour stream equals to the temperature of liquid stream. In this way , for N-effect effect evaporator the number of self balancing variables becomes 5N. It is important to point out here that the saturation temperature(pressure) of the last effect, has already been taken in to account as an operating variable . Therefore, it cannot be considered as a self- balancing variable. Flow rate of steam to the first effect is the another self-balancing variable whose value is usually not altered. Thus the total number of net self balancing variables for N-effect evaporator, becomes 5N [=5N-1+1].

The summation of geometrical, operating and self -balancing variables gives the total number of variables in an evaporator. They are equal to 6N+6[=N+6+5N].

Mathematical model:

A mathematical model of a multiple effect evaporator is a relationship amongst the geometrical, operating and self -balancing variables. This can be obtained from the equations of material balance, energy balance, heat transfer rate, and boiling point rise.

For the simplicity of the mathematical model, following **assumptions** have been made in this analysis:

1. The vapours entering in to steam chest of respective effects are at their saturation temperature.
2. There is no sub cooling of the condensate from different steam chests.
3. Condensation of vapour in steam chest occurs at constant pressure.
4. There is no carry- over of liquid droplets with vapors leaving the respective effects.
5. There is no heat dissipation to surroundings.
6. Heat transfer surface does not undergo fouling.

Design of multiple effect evaporator without boiling point elevation for forward feed :

Equations are developed for the case where boiling point elevations are negligible ,also the effect of composition on liquid enthalpy is neglected. The equations so obtained are generalized for the case where boiling point elevations cannot be neglected. For definiteness , forward feeds are employed.

Specifications: F , X_F,T_F,T_o,P_o,P_3(ort_3),X_3(orl_3),U_1,U_2,U_3,equal areas, forward feed, negligible boiling point elevations.

To find : V_0, T_1,L_1,T_2,L_2 and A

Actually ,four additional dependent variables exist; namely: V_1,V_2,X_1,X_2

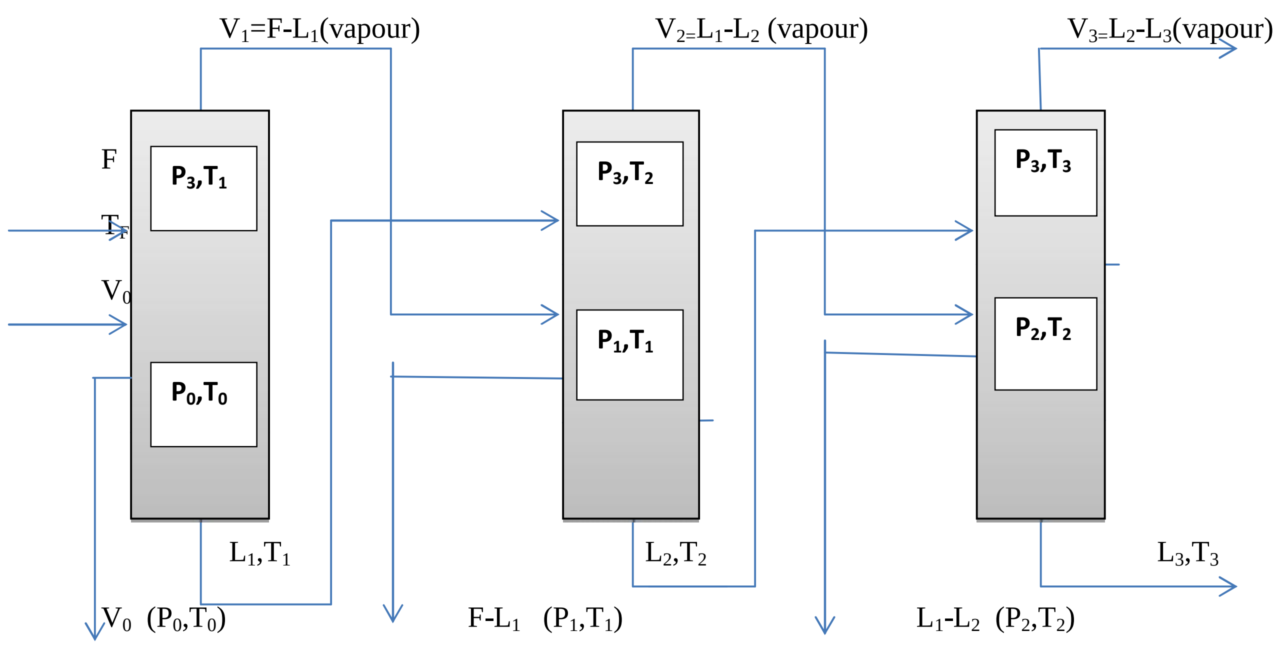

Fig. 22.1: Triple Effect Evaporator with Forward feed Arrangement

Equations of energy balance and heat transfer rate for all three effects are-:

Effect -1:

Enthalpy balance:

$$F(h_f-h_1)+V_0\lambda_0=(F-L_1)\lambda_1 \quad \text{…22.1}$$

Rate equation:

$$U_1A(T_0-T_1)=V_0\lambda \quad \text{…22.2}$$

Effect -2:

Enthalpy balance:

$L_1(h_1-h_2)+(F-L_1)\lambda=(L_1-L_2)\lambda_2$ …22.3

Rate equation:

$U_2A(T_1-T_2)=(F-L_1)\lambda_1$ …22.4

Effect -3 :

Enthalpy balance:

$L_2(h_2-h_3)+(L_1-L_2)\lambda_2=(L_2-L_3)\lambda_3$ …22.5

Rate equation:

$U_3A(T_2-T_3) = (L_1-L_2)\lambda_2$

The above equation describing the triple effect evaporator system constitute a set of nonlinear algebraic equations that may be solved in variety of way, one of which is **Newton raphson method** which we will learn in next lecture.

Design of multiple effect evaporator with boiling point rise for forward feed:

Most solutions that are concentrated in evaporators are mixtures of water and non-volatile salt. The boiling temperature of the solution some times depend on the salt concentration. The difference between the temperature(T) of boiling solution and the temperature of boiling water (pure) at the same pressure is known as boiling point rise(BPR).thus

$\mathbf{T = T_W + BPR}$

BPR is a function of the solute concentration. A graph called the **Dhuring chart** is commomnly used to determine BPR.

Calculation procedure:

Specifications:

F,X_F,T_F,thick liquid composition(X_P),P,saturated steam pressure(P_0),heat capacity(C_P), overall heat transfer coefficient(U).

To find: Heat transfer area(A)

Step-1:

Corresponding to evaporator temperature find out the boiling point of pure water,T_W.

Step-2:

From the figures/empirical correlation determine the solution temperature/BPR at T_W,X_P. This temperature is also the temperature of the superheated water vapour leaving the evaporator.

Step-3:

A total mass balance and a component material balance are used to calculate the flow rates.

$F = V + L$

$X_F F = LX_P$

Step-4:

Calculate /determine the enthalpies of three process streams

1) Enthalpy of water vapour from the superheated steam tables by solution temperature and pressure of the evaporator.
2) The enthalpy of the solution can be calculated from there heat capacities .
   $H = C_P(T-T_R)$
   It can also be calculated by the plots or empirical correlations.
3) Latent heat of vaporization taken from steam table at corresponding steam pressure.

Step-5:

Now , write the enthalpy balance

$F(h_f-h_p) + V_0\ \lambda_0 = (F-L)(H_V - h_p)$

Or, $V_0 = [\ (F-L)(H_V - h_p) - F(h_f-h_p)]/\lambda_0$

Step-6:

From the rate equation

$V_0\ \lambda_0 = UA(T_0 - Ŧ_1)$

$A = V_0\lambda_0/U(T_0-Ŧ_1)$

Equations for all three effects are-:

Effect -1:

$F[h(T_f,X_f)-h(Ŧ_1,X_1)]+ V_0\ \lambda_0 -(F-L_1)[H(Ŧ_1) - h(Ŧ_1,X_1)]=0$

$U_1A_1\ (T_0 - Ŧ_1)\ - V_0\ \lambda_0\ =0$

$X_F\ F - L_1\ X_1 = 0$

Effect -2:

$L_1[h(\text{Ŧ}_1,X_1)-h(\text{Ŧ}_2)]+ (F-L_1)[H(\text{Ŧ}_1)–h(T_1)]- (L_1-L_2)[H(\text{Ŧ}_2)-h(\text{Ŧ}_2)]=0$

$U_2\ A_2\ (T_1 –\text{Ŧ}_2)- (F-L_1)[H(\text{Ŧ}_1)-h(T_1)] = 0$

$L_1\ X_1 – L_2\ X_2 = 0$

Effect -3:

$L_2[h(\text{Ŧ}_2,X_2)-h(\text{Ŧ}_3, X_3)] + (L_1-L_2)[H(\text{Ŧ}_2) –h(T_2)]– (L_2-L_3)[H(\text{Ŧ}_3)-h (\text{Ŧ}_3, X_3)]= 0$

$U_3\ A_3\ (T_2 –\text{Ŧ}_3)-(L_1-L_2)[H-h]=0$

$L_2\ X_2 – L_3\ X_3 = 0$