Mathematical Modelling Of Evaporator

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Evaporation is widely employed in chemical, petrochemical, food, refrigeration, power plant and other allied industries to concentrate dilute aqueous solution to desired concentration so as to make end product suitable for further processing and marketable. It is an energy intensive operation as multitudes of thermal energy in the form of steam are used in it. In recent years, a radical increase in energy cost in relation to the capital equipment cost has caused a dramatic increase in the operating expense of the evaporators. This trend is quite likely to continue in future too, due to ever increasing rapid depletion in the reserve of fossil fuels and also their continuous consumption at alarming rates. Thus energy plays a dominating role in the design of evaporators. This emphasizes the need of energy in evaporators. one of the basic factor contributing to it is steam economy as it represents a measure of the quantity of water evaporated per unit of steam consumption. As a matter of fact, high values of steam economy are desirable in multiple effect evaporators so that the steam consumption is kept at the lowest level for a given evaporation of water.

Steam economy of a multiple effect evaporator having a specified feed arrangement depends on the number of effects, steam pressure, temperature, flow rate and concentration of feed; pressure in individual effects and physic-thermal properties of the solution. Obviously a change in any of this variable can affect the steam economy of the evaporator. Therefore, values of these variables are to be determined so that a evaporator with a given feed arrangement can operate for increased steam economy. This calls for a detailed investigation to study the parametric effect of above variables on steam economy of an evaporator for a given feed arrangement. This will also help plant engineers to revamp their existing evaporator by adjusting values of operating variables to attain improved steam economy.

It is to important to mention that in some of the cases a plant engineer doesn't have match flexibility to change the value of some of the above variable due to process constraints. For example concentration of the end product in a sugar solution, multiple effect evaporators is kept at the level of 60 ± 5 ^{0}Bx, otherwise seeding of sugar crystal will take place in the evaporator itself. Similarly, in the evaporation of caustic soda solution, concentration of the end product limited to a maximum of 50%.. as a beyond this concentration the freezing point of the caustic soda solution start rising steeply. There is another situation with the captive caustic soda plant where relatively higher sodium contents in a caustic soda solution can be tolerated and the end product concentration is restricted only to 30-35%. Thus end product concentration of a solution may be fixed by the process technology, economics and other factors. For such system values of operating variable have to determine which can yield the possible steam economy of the evaporator. This necessitates the knowledge of the parametric effect of paramagnetic variable, namely; feed temperature, feed concentration, feed rate, pressure in the last effect and the steam pressure on the concentration of end product of an evaporator with the various feed arrangement.

Mathematical Modelling Of Single Effect Evaporator :

The equation describing the single effect evaporator is developed in the following manner. Component material balance on the solute and solvent are-

$$F\,X_f = L\,X_p \qquad \text{...21.1}$$

$$F\,(1-X_f) = V + L\,(1-X_p) \qquad \text{...21.2}$$

Respectively,

Where

F = feed rate kg/sec

L = concentrated liquid rate kg/sec

V = vapour rate kg/sec

X_f = mass fraction of solute in feed

X_p =mass fraction of solute in the product

Total material balance is given by-:

$$F = V + L \qquad \text{...21.3}$$

An enthalpy balance on the process stream yields-:

$$F.h_f + Q = V.H_v + L.h_p$$

Or $$F.h_f + Q = (F- L)H_v + Lh_p + F.h_p - Fh_p$$

Or $$F\,(h_f - h_p) + Q = (F-L)\,Hv - (F-L)\,hp$$

Or $$F\,(h_f - h_p) + Q - (F-L)\,(H_v - h_p) = 0 \qquad \text{...21.4}$$

Where,

h_f = enthalpy of feed

h_p = enthalpy of product

H_v = enthalpy of vapour at the boiling point temperature of the feed, kJ/kg.

Q= rate of heat transfer across the tubes (from the steam to the thick liquor) kJ/sec

The enthalpy balance on the stream is given by-:

$$Q = V_0 (H_o - h_o) = V_o \lambda_o \qquad ...21.5$$

The rate of heat transfer Q is commonly approximated by use of the relationship-:

$$Q = UA (T_0 - T) \qquad ...21.6$$

Where-:

U = overall heat transfer coefficient

A =surface area of the tubes available for heat transfer.

To = saturation temperature of the steam entering the chest.

T = boiling point temperature of thick liquor at the pressure of the vapour space

Q. A single effect evaporator is to be designed to concentrate a 20% (by wt.) solution of sodium hydroxide to a 50% solution. The dilute solution at 200^0F is to be fed to the evaporator at the rate of 40,000lb/hr. for heating purposes; a saturated steam at 50^0F is used. Sufficient condenser area is available to maintain a pressure of 0.9492lb/in^2(absolute) in the vapour space of the evaporator. On the basis of overall heat transfer coefficients of 300 Btu/hr ft^{2} ^{0}F.

Compute

a) Heating area required.
b) Steam consumption and steam economy.

Sol-:

We know that

FX =Lx

L = (40,0000) (.2) /(.5) =16,000 lb/hr

F = V+L

V = 24,000 lb/hr

h_f (at 200^0F and 20% NaOH) =145 Btu/lb

h (at 170^0F and 50% NaOH) =200 Btu/lb.

From Keenan and Keyes –

H (at 170^oF and .94942 psia) =1,136.94 Btu/lb

λ_0 (saturated at 134.63 psia) =870.7 Btu/lb

$T_0 = 350^0F$

a) Calculation of heat transfer area

$Q = (F - L)(H-h) - F(h_F - h)$

$Q = (24{,}000)(1{,}136.94 - 200) - 40{,}000(145 - 200)$

$Q = 24.686 \times 10^6$ Btu/hr

$Q = U A(T_0 - T)$

$A = 24.686 \times 10^6/(300)(350-170) = 457.15\ ft^2$

b) Calculation of steam economy-

$V_0 = Q/\lambda_0 = 24.686 \times 10^6/870.7 = 28{,}353$ lb/hr

Steam economy $= V/V_0 = 24{,}000/28{,}353 = .84647$

Source:
http://nptel.ac.in/courses/103107096/24