

STUDY ATRIPLE-EFFECT EVAPORATOR FOR PRODUCTION OF CONCENTRATED SODIUM HYDROXIDE

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ABSTRACT

Caustic soda is the one of the most important products for the different chemical industries, in this aspect, the factors affecting the steam economy in the multiple - Effect evaporators were investigated .These factors include, the feed compositions, steam's pressure and the feed introduction positions. It was found that the feed compositions are very important, the lower the concentration ,the better is the economy. Therefore, it is feasible to introduce diluted feed rather than very concentrated one. It was also found that the best location for feed introduction is the first evaporator, the claim that positions in evaporator II and III may be better for steam economy is found not applicable in this case. One the other hand the steam pressure has appositve effect in the steam economy, the lower the pressure the better is steam economy.

Keywords: Caustic soda, evaporator, feed introduction, steam economy.

INTRODUCTION:

Evaporation ordinary means vaporization of liquid or that of a solvent from a solution In chemical engineering terminology, evaporation means removal of a part of the solvent from a solution of non-volatile solute by evaporation. The objective of vaporization is to concentrate the solution, it is one of the more important operations in the process for the manufacture of caustic soda ^[1].

Evaporators used in the process industry mostly have tubular heating surface. An adequate number of tubes are provided through which the solution circulates. The tubes are heated by steam that condenses on their outer surface. The velocity of the circulation of the solution through the tubes should be reasonably high so that higher inside heat transfer coefficient is attained and formation of deposits or scales on the inner surface is reduced ^[2].

Manufacturing of caustic soda :

An electrolytic process produces caustic soda commercially. Brine, is electrolyzed in mercury cell, diaphragm cell or membrane cell. The co-production chlorine and hydrogen.in the mercury cell process, sodium –mercury amalgam is formed in the cell. The amalgam is sent a decomposer where it is reacted with water to from liquid NaOH, hydrogen and free mercury.

The free mercury is returned to electrolytic cell. The resulting caustic soda solution is then inventoried in storage tanks. The solution is shipped in tank trucks, tank cars or barges.in the membrane process a solution of approximately (30%wt) in strength is formed .the solution is then sent to evaporators, which concentrate it to strength of

(50%wt) by removing the appropriate amount of water. The resulting caustic soda solution is inventoried in a storage tanks prior to shipping^[3].

Objectives of the study :

To study the effect of evaporation conditions on concentration and properties of caustic soda, to investigate the effect of feed composition, steam's pressure and feed location on steam economy of the evaporation of concentrated caustic soda.

Material and Methods:

Experimental part:

Determination of percentage sodium hydroxide and sodium chloride on electrolyte.

Caustic soda reagents used:

Hydrochloric acid C=1.008mole/L

Barium chloride solution C=10%

Phenolphthalein indicator

Caustic soda test solution preparation:

20gm from the sample either electrolyte or caustic final product was weighted in the weighting bottle (W) , the weighted sample was transferred in to 500 ml volumetric flask , the matter was diluted with diluted with distilled water to flask mark line.

Procedure:

10ml from the test solution was taken,10ml from the barium chloride (BaCl₂) was added, three drops from the phenolphthalein indicator was added, the matter titrated with hydrochloric acid (HCL) standard solution ,the volume of (HCL) (V) was recorded and applied in equation (D).

Calculations:

$$[C_{NaOH}] \% = \frac{[C_{HCL}] \times [V_{HCL}] \times 40 \times 100}{W \times 20} \quad (1)$$

[V_{HCL}]: Titrated hydrochloric acid volume (ml)

[C_{HCL}]: Concentration of hydrochloric acid ($\frac{mol}{L}$)

[W]: Weight of sample (gm)

$$[C_{NaOH}] \% = \frac{[1.008] \times [V_{HCL}] \times 40 \times 100}{20 \times 20} = 10.32$$

Results:

[V_{HCL}] = 1.0238ml (from titration)

$$[C_{HCL}] = 1.008 \frac{mol}{L} \quad (\text{given})$$

$$[W] = 20 \text{ gm} \quad (\text{given})$$

$$[C_{NaOH}] \% = 10.32 \quad (\text{equation}) (1)$$

Sodium chloride reagents used:

$$AgNO_3 \quad C=0.1013 \frac{mol}{L}$$

-Potassium chromate indicator.

-30% Acetic acid solution.

-Phenolphthalein indicator.

Sodium chloride test solution preparation :

(20 gm) from the sample was weighted in weighting bottle (W) , the weighted sample was transferred into 500ml volumetric flask, the matter was diluted with distilled water flask mark line.

Procedure :

(10 ml) from test solution was taken into 250conical flask,1-2drops phenolphthalein indicator was added, Acetic acid was used to neutralize, three drops of (K_2CrO_4) indicator was added,the matter titrated with ($AgNO_3$) indicator, the volume of ($AgNO_3$) was recorded and applied in equation (1) .

Calculations :

$$[C_{NaCL}] \% = \frac{[C_{AgNO_3}] \times [V_{AgNO_3}] \times 58.44 \times 100}{W \times 20}$$

$$[V_{AgNO_3}] = \text{Titrate } V_{AgNO_3} \quad (\text{ml})$$

$$[C_{AgNO_3}] = \text{concentration of } V_{AgNO_3} \quad \left(\frac{mol}{L}\right)$$

$$[C_{NaCL}] \% = \frac{[0.1013] \times [V_{AgNO_3}] \times 58.44 \times 100}{W \times 20} = 12.72$$

Results:

$$[V_{AgNO_3}] = 8.599 \text{ ml} \quad (\text{from titration})$$

$$[C_{AgNO_3}] = 0.1013 \frac{mol}{L} \quad (\text{given})$$

$$[W] = 20 \text{ gm} \quad (\text{given})$$

$$[C_{NaCL}] = 12.72 \quad (\text{equation}) (1)$$

(Personal contact Ibn hayyan caustic soda factory- Albagair industrial area)

Results and Discussions:

Multi – effect evaporator calculation:

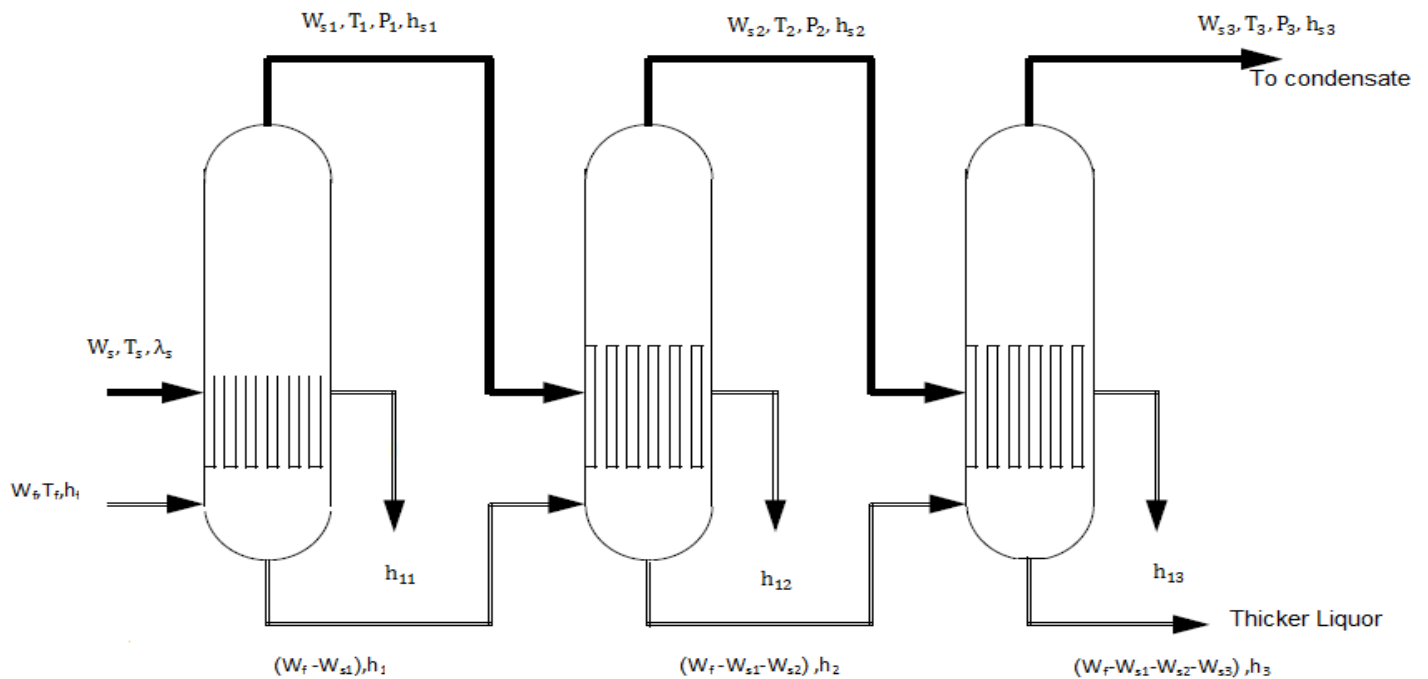
Saturated steam (Flow rate = W_s , Temperature = T_s , Pressure = P_s) enters the steam chest of the first effect, the liquid in the (effect-I) boils at temperature (T_{b1}). This is also the temperature of vapor (or steam) generated in this effect. the pressure in the vapor space is maintained at (P_1), the boiling point of pure solvent at this pressure is (T_{w1}), so the boiling point elevation in the (effect-I) is ($T_{b1} - T_{w1}$), and the vapor generated is superheated vapor .

The saturation temperature is (T_{w1}) which is the boiling point of pure water at pressure (P_1) prevailing in the vapor space. Solution from (effect-I) flows to (effect-II) where the liquid boils at temperature (T_{b2}) and pressure in the vapor space is maintained at (P_2).

The boiling point of water at pressure of (P_2) is (T_{w2}), and the boiling point elevation is ($T_{b2} - T_{w2}$), the vapor from (effect-I) enters the shell or the steam chest of (effect-II) with a degree of super heat, but loses its super heat quickly by transfer of sensible heat and attains its saturation temperature of (T_{w1}). The amount of sensible heat and attains its saturation temperature of (T_{w1}).

The amount of sensible heat transferred is negligible for all practical purposes, so the temperature driving force for heat transfer to the boiling liquid in the (effect-II) is ($T_{w1} - T_{b2}$). Vapor from (effect-II) enters the shell of (effect-III) at temperature (T_{b2}). This vapor has superheat of temperature ($T_{b2} - T_{w2}$), and loses the superheat quickly and attains the saturation temperature of (T_{w2}).

The temperature driving force in this effect consider to be ($T_{w2} - T_{b3}$) where (T_{b3}) is the boiling point of the liquid in (effect-III) operating at pressure of (P_3). The boiling temperature of water at pressure (P_3) is (T_{w3}), and the boiling point elevation in (effect III) is ($T_{b3} - T_{w3}$), since we considering a triple –effect evaporator, (effect III) is the last effect and the vapor generated is discarded in the condenser, because ($T_{b1} > T_{b2} > T_{b3}$), As soon as the liquid from the (effect-I) enters the (effect-II), it flashes, gives off some steam and attains the boiling temperature, similar phenomenon occurs when the liquid from (effect-II) enters in to (effect-III)



Material balance over the first effect:

$$W_f = W_{s1} + (W_f - W_{s1}) \tag{2}$$

Where:

W_f = feed rate enters first effect (kg/hr)

W_{s1} = The rate of vapor generated in the first effect (kg/hr)

Component balance over the first effect:

$$W_f \cdot X_f = W_{s1} \cdot Y_1 + (W_f - W_{s1}) \cdot X_1 \tag{3}$$

$$W_{s1} \cdot Y_1 = 0.0 \text{ (pure vapor)}$$

Applying below data:

$$X_f = 0.1032 \text{ (feed composition)}$$

$$W_f = 6000 \text{ kg/hr (feed rate)}$$

$$X_1 = 0.1275 \text{ (product composition of first effect)}$$

$$W_f \cdot X_f = (W_f - W_{s1}) \cdot X_1 \tag{4}$$

$$(W_f - W_{s1}) = \frac{W_f \cdot X_f}{X_1} \tag{5}$$

$$(W_f - W_{s1}) = \frac{600 \times 0.1032}{0.1275} = 4856.470588 \text{ kg/hr}$$

$$\therefore W_{s1} = 1143.529412 \text{ kg/hr}$$

Energy (Enthalpy) balance over the first effect:

$$W_f \cdot h_f + W_s \cdot \lambda_s = (W_f - W_{s1}) \cdot h_1 + (W_{s1} \cdot h_{s1}) + W_{s1} \cdot h_{11} \quad (6)$$

Where:

W_s = The flow rate of saturated steam (kg/hr)

h_f = The enthalpy of the feed (kJ/kg)

h_{s1} = The enthalpy of vapor generated in the first effect (kJ/kg)

h_1 = The enthalpy of the solution leaving the first the first effect (kJ/kg)

λ_s = Latent heat of steam (kJ/kg)

h_{11} = Enthalpy of condensate.

$W_s \cdot h_{11} = 0.0$ (no sub cooling)

Applying in equation (6).

$h_f = 448.212 \text{ kJ/kg}$ (Appendix-B)

$\lambda_s = 2046.53 \text{ kJ/kg}$ (steam table)

$h_1 = 561.57375 \text{ kJ/kg}$ (Appendix-B)

$h_{s1} = 2759.63 \text{ kJ/kg}$ (steam table)

$$W_s = \frac{((4856.470588 \times 561.57375) + (1143.529412 \times 2759.63) - (6000 \times 448.212))}{(2046.53)}$$

$$\therefore W_s = 1560.55039 \text{ kg/hr}$$

Material balance over the second effect:

$$(W_f - W_{s1}) = W_{s2} + (W_f - W_{s1} - W_{s2}) \quad (7)$$

Where:

W_{s2} = The rate of vapor generated in the second effect (kg/hr)

Component balance over the second effect:

$$(W_f - W_{s1}) \cdot X_1 = W_{s2} \cdot Y_2 + (W_f - W_{s1} - W_{s2}) \cdot X_2 \quad (8)$$

$W_{s2} \cdot Y_2 = 0.0$ (pure vapor)

Applying below data:

$$X_1 = 0.1275 \quad , \quad X_2 = 0.222$$

$$(W_f - W_{s1}) = 4856.470588 \text{kg/hr}$$

$$(W_f - W_{s1} - W_{s2}) = (W_f - W_{s1}) \cdot \left(\frac{X_1}{X_2}\right) \quad (9)$$

$$\therefore W_{s2} = 2067.281399 \text{kg/hr}$$

Energy (Enthalpy) balance over the second effect:

$$(W_f - W_{s1}) \cdot h_1 + W_{s1} \cdot h_{s1} = W_{s1} \cdot h_{s2} + (W_f - W_{s1} - W_{s2})h_2 + W_{s1} \cdot h_{12} \quad (10)$$

Where:

W_{s1} = Rate of vapor generated in the second effect (kg/hr)

h_{s2} = The enthalpy of vapor generated in second effect

h_2 = The enthalpy of solution leaving second effect

Material balance over the third effect:

$$(W_f - W_{s1} - W_{s2}) = W_{s3} + (W_f - W_{s1} - W_{s2} - W_{s3}) \quad (11)$$

Where:

W_{s3} = The rate of vapor generation in the third effect (kg/hr)

Component balance over the third effect :

$$(W_f - W_{s1} - W_{s2}) \cdot X_2 = W_{s3} \cdot Y_3 + (W_f - W_{s1} - W_{s2} - W_{s3}) \cdot X_3 \quad (12)$$

$$W_{s3} \cdot Y_3 = 0.0 \quad (\text{pure vapor})$$

$$(W_f - W_{s1} - W_{s2} - W_{s3}) = (W_f - W_{s1} - W_{s2}) \cdot \left(\frac{X_2}{X_3}\right) \quad (13)$$

$$(X_2 = 0.222)$$

$$(X_3 = 0.42)$$

$$(W_f - W_{s1} - W_{s2}) = 2789.189189 \text{kg/hr}$$

$$(W_f - W_{s1} - W_{s2} - W_{s3}) = 1474.285714 \text{kg/hr}$$

$$\therefore W_{s3} = 1314.903475 \text{kg/hr}$$

Steam economy:

$$\text{Steam economy} = \frac{\text{Water vaporized}}{\text{Steam consumption}} = \frac{\sum(W_{s1} + W_{s2} + W_{s3})}{W_s} \quad (14)$$

$$W_{s1} = 1143.529412 \text{ kg/hr}$$

$$W_{s2} = 2067.281399 \text{ kg/hr}$$

$$W_{s3} = 1314.903475 \text{ kg/hr}$$

$$W_{s4} = 1560.55039 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{1143.529412 + 2067.281399 + 1314.903475}{1560.55039} = 2.90$$

$$\therefore \text{Steam economy} = 2.90$$

Different conditions :

-The composition of feed product and flow rate of feed were fixed

$$(X_3 = 0.42)$$

$$(W_f = 6000 \text{ kg/hr})$$

- steam consumption was fixed

$$(W_s = 1560.55039 \text{ kg/hr}).$$

- The steam economy must be changed with changing in feed composition.

- Variable feed composition given below are suggested to apply:

$$(0.05 - 0.075 - 0.1032 - 0.125 - 0.155 - 0.175 - 0.2)$$

Material balance with variable conditions:

-Use above data

-Apply it equation (1,2,5,14)

$$1/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.05)}{(0.42)} \right) = 5285.714286 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{5285.714286 \text{ kg/hr}}{1560.55039 \text{ kg/hr}} = 3.39$$

$$\therefore \text{Steam economy} = 3.39$$

$$2/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.075)}{(0.42)} \right) = 4928.571429 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{4928.571429 \text{ kg/hr}}{1560,55039 \text{ kg/hr}} = 3.16$$

$$\therefore \text{Steam economy} = 3.16$$

$$3/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.1032)}{(0.42)} \right) = 4525.7142 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{4525.7142 \text{ kg/hr}}{1560,55039 \text{ kg/hr}} = 2.900$$

$$\therefore \text{Steam economy} = 2.900$$

$$4/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.125)}{(0.42)} \right) = 4214.285714 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{4214.285714 \text{ kg/hr}}{1560,55039 \text{ kg/hr}} = 2.700$$

$$\therefore \text{Steam economy} = 2.700$$

$$5/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.155)}{(0.42)} \right) = 3785.714286 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{3785.714286 \text{ kg/hr}}{1560,55039 \text{ kg/hr}} = 2.43$$

$$\therefore \text{Steam economy} = 2.43$$

$$6/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.175)}{(0.42)} \right) = 3500 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{3500 \text{ kg/hr}}{1560,55039 \text{ kg/hr}} = 2.24$$

$$\therefore \text{Steam economy} = 2.24$$

$$7/ W_{s1} + W_{s2} + W_{s3} = \left(6000 - \frac{(6000 \times 0.2)}{(0.42)} \right) = 3142.857143 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{3142.857143 \text{ kg/hr}}{1560,55039 \text{ kg/hr}} = 2.01$$

$$\therefore \text{Steam economy} = 2.01$$

Table (1) : effect of feed composition on steam economy

X_f	X_3	$W_{s1} + W_{s2} + W_{s3}$	Steam economy
0.05	0.42	5285.714286	3.39
0.075		4928.571429	3.16
0.1032		4525.714286	2.90
0.125		4214.285714	2.70
0.155		3785.714286	2.43
0.175		3500	2.24
0.2		3142.857143	2.01

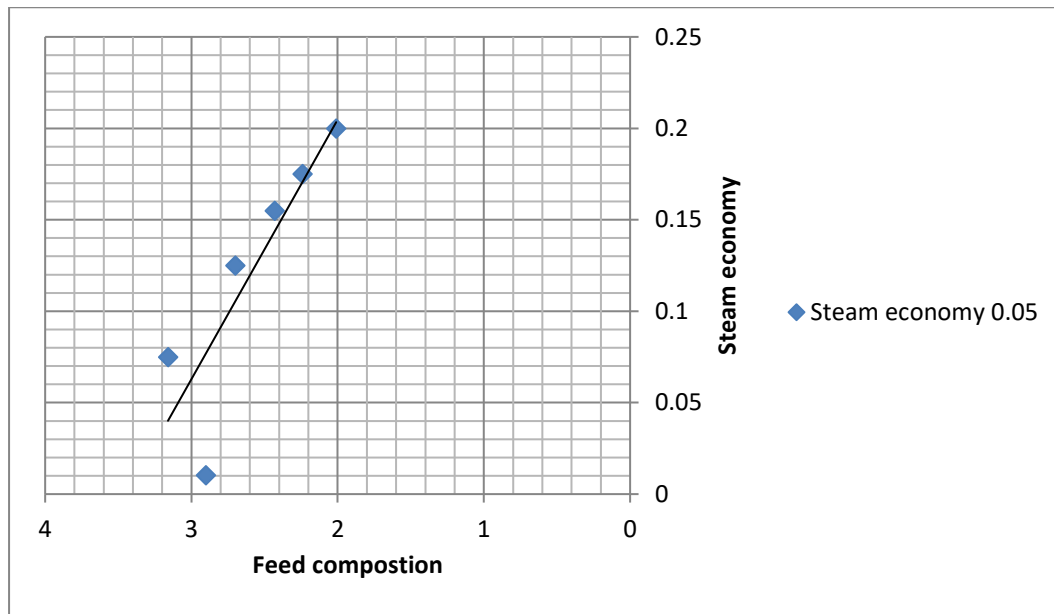


Fig (2): effect of feed composition on steam economy

Steam quality :

- For different values of pressure the latent heat of steam vary.
- The economy of steam vary with steam pressure and steam latent heat.
- Latent heat has been taken from steam table
- Apply equation (6and14)

$$W_{sn} = \frac{[(W_f - W_{s1})h_1 + (W_{s1} \times h_{s1}) - (W_f h_f)]}{\lambda_{sn}} \tag{15}$$

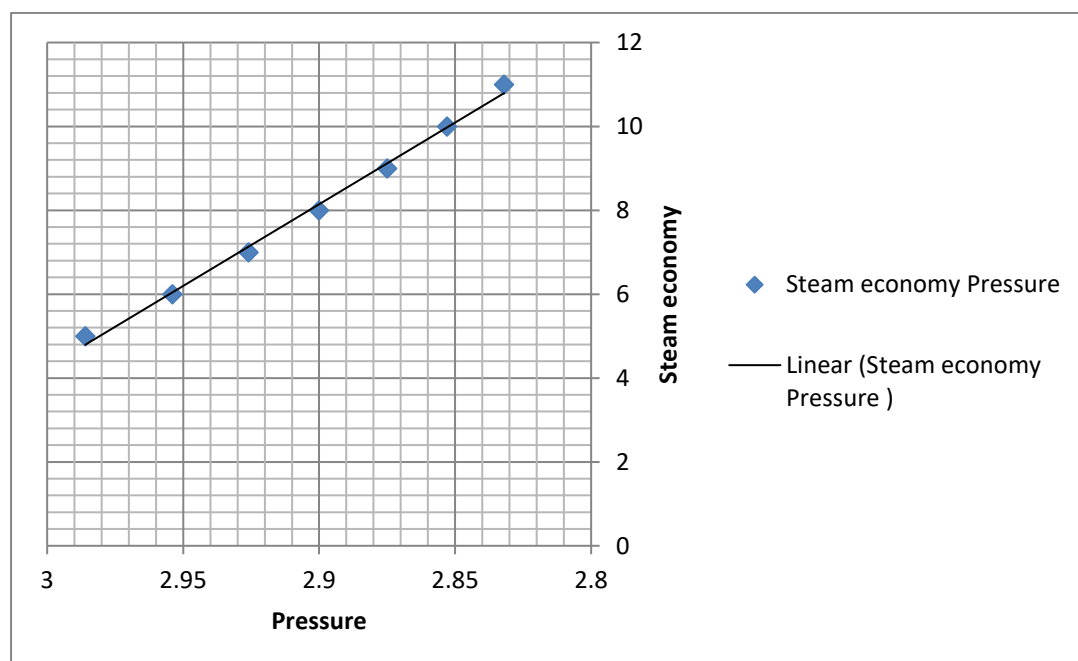
$$W_{sn} = \frac{[(4856.470588 \times 561.57375) + (1143.529412 \times 2759.63) - (6000 \times 448.212)]}{\lambda_{sn}}$$

$$W_{sn} = \frac{[3193712.471]}{\lambda_{sn}} \tag{16}$$

$$\text{Steam economy} = \frac{\sum(W_{s1} + W_{s2} + W_{s3})}{W_{sn}} = \frac{4525,714286}{W_{sn}}$$

Table (2) : Effect of steam's pressure on economy

Pressure P_s	Latent heat λ_{sn}	Steam flow rate W_{sn}	Steam economy
Bar	Kj/kg	Kg/hr	
5	2107.42	1515.460834	2.986
6	2085.03	1531.734541	2.954
7	2064.62	1546.651914	2.926
8	2046.53	1560.550039	2.9
9	2029.49	1573.652426	2.875
10	2013.56	1586.102461	2.853
11	1998.55	1598.014796	2.832



Fig(3): effect of steam's pressure on steam economy

Effect of feed introduction on steam economy:

Mathematical model (the feed introduced to the second effect) :

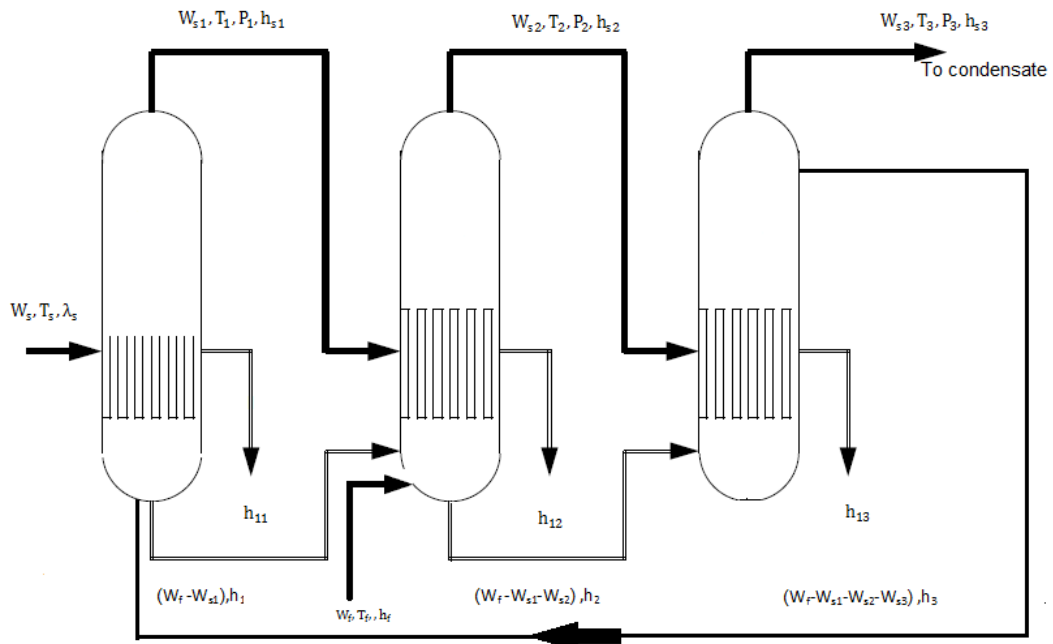


Fig (4):the feed introduced to the second effect

Material balance over the second over the second effect:

$$W_f = W_{s2} + (W_f - W_{s2}) \tag{17}$$

Where:

W_f = feed enters second effect (kg/hr)

W_{s2} =The rate of vapor generated in the second effect (kg/hr)

Component balance over the second effect :

$$W_f \cdot X_f = W_{s2} \cdot Y_2 + (W_f - W_{s2}) \cdot X_2 \tag{18}$$

$$W_{s2} \cdot Y_2 = 0.0 \quad (\text{pure vapor})$$

Applying below data:

$$X_f = 0.1032 \quad (\text{feed composition})$$

$$W_f = 6000\text{kg/hr} \quad (\text{feed rate})$$

$$X_2 = 0.1275 \quad (\text{composition of the solution leaving second effect})$$

$$W_f \cdot X_f = (W_f - W_{s2}) \cdot X_2 \tag{19}$$

$$(W_f - W_{s2}) = \frac{W_f \cdot X_f}{X_2} \tag{20}$$

$$(W_f - W_{s2}) = \frac{6000 \times 0.1032}{0.1275} = 4856.470588 \text{ kg/hr}$$

$$\therefore W_{s2} = 1143.529412 \text{ kg/hr}$$

Material balance over the third effect :

$$(W_f - W_{s2}) = W_{s3} + (W_f - W_{s2} - W_{s3}) \quad (21)$$

Where :

W_f = feed rate enters second effect (kg/hr)

W_{s3} = The rate of vapor generated in the third effect (kg/hr)

Component balance over the third effect :

$$(W_f - W_{s2}) \cdot X_2 = W_{s3} \cdot Y_3 + (W_f - W_{s2} - W_{s3}) \cdot X_3 \quad (22)$$

$$W_{s3} \cdot Y_3 = 0.0 \quad (\text{Pure vapor})$$

Applying below data:

$$X_2 = 0.1275 \quad (\text{feed composition})$$

$$X_3 = 0.222 \quad (\text{composition of the solution leaving third effect})$$

$$(W_f - W_{s2}) = 4856.470588 \text{ kg/hr}$$

$$(W_f - W_{s2} - W_{s3}) = \frac{(W_f - W_{s2}) \cdot X_2}{X_3} \quad (23)$$

$$(W_f - W_{s2} - W_{s3}) = \frac{48456.470588 \times 0.1275}{0.222} = 2789.189189 \text{ kg/hr}$$

$$\therefore W_{s3} = 2067.281399 \text{ kg/hr}$$

Material balance over the first effect :

$$(W_f - W_{s2} - W_{s3}) = W_{s1} + (W_f - W_{s2} - W_{s3} - W_{s1}) \quad (24)$$

Where:

W_f = feed rate enters second effect (kg/hr)

W_{s1} = The rate of vapor generated in the first effect (kg/hr)

Component balance over the first effect:

$$(W_f - W_{s2} - W_{s3}) \cdot X_3 = W_{s1} \cdot Y_1 + (W_f - W_{s2} - W_{s3} - W_{s1}) \cdot X_1 \quad (25)$$

$$W_{s1} \cdot Y_1 = 0.0 \quad (\text{pure vapor})$$

Applying below data:

$$X_1 = 0.42 \quad (\text{product composition})$$

$$X_3 = 0.222 \quad (\text{composition of the solution leaving third effect})$$

$$(W_f - W_{s2} - W_{s3}) = 2789.189189 \text{ kg/hr}$$

$$(W_f - W_{s2} - W_{s3} - W_{s1}) = \frac{(W_f - W_{s2} - W_{s3}) \cdot X_3}{X_1} \quad (26)$$

$$(W_f - W_{s2} - W_{s3} - W_{s1}) = \frac{2789.189189 \times 0.222}{0.42} = 1474.285714 \text{ kg/hr}$$

Energy (Enthalpy) balance over the first effect :

$$W_s \cdot \lambda_s + (W_f - W_{s2} - W_{s3}) \cdot h_3 = W_{s1} \cdot h_{s1} + (W_f - W_{s1} - W_{s2} - W_{s3}) \cdot h_1 \quad (27)$$

Where :

$$W_s = \text{The flow rate of saturated steam} \quad (\text{kg/hr})$$

$$h_3 = \text{The enthalpy of the solution leaving third effect} \quad (\text{kJ/kg})$$

$$h_{s1} = \text{The enthalpy of the vapor generated in the first effect} \quad (\text{kJ/kg})$$

$$h_1 = \text{The enthalpy of product solution} \quad (\text{kJ/kg})$$

$$\lambda_s = \text{Latent heat of steam}$$

Applying equation :

$$h_3 = 321.67 \text{ kJ/kg} \quad (\text{Sodium hydroxide enthalpy table B})$$

$$\lambda_s = 2046.53 \text{ kJ/kg} \quad (\text{steam table A})$$

$$h_1 = 630.24 \text{ kJ/kg} \quad (\text{Sodium hydroxide enthalpy table B})$$

$$h_{s1} = 2759.63 \text{ kJ/hr}$$

$$W_s = \frac{((1314.903475 \times 2759.63) + (1474(1474.285714 \times 630.24) - (2789.189 \times 321.67))}{(2046.53)}$$

$$\therefore W_s = 1788.687397 \text{ kg/hr}$$

$$\therefore \text{Steam economy} = \frac{4525.714286}{1788.6873897} = 2.530$$

Mathematical model (the feed introduced to the third effect):

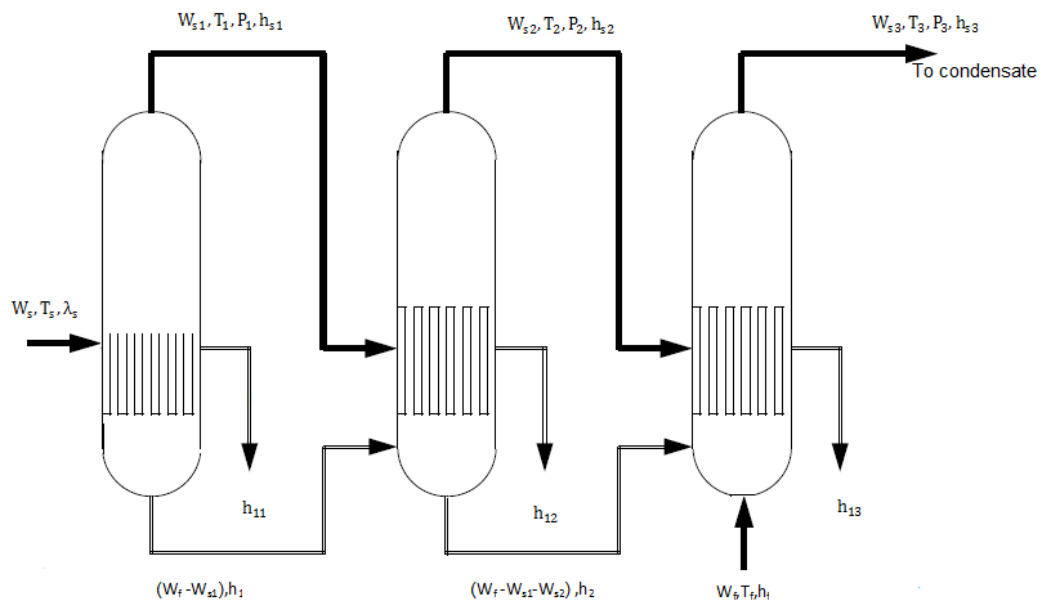


Fig (5):the feed introduced to the Third effect

Material balance over the third effect :

$$W_f = W_{s3} + (W_f - W_{s3}) \tag{28}$$

Where:

W_f = feed enters third effect (kg/hr)

W_{s3} = The rate of vapor generated in third effect (kg/hr)

Component balance over the third effect:

$$W_f \cdot X_f = W_{s3} \cdot Y_3 + (W_f - W_{s3}) \cdot X_3 \tag{29}$$

$$W_{s3} \cdot Y_3 = 0.0 \quad (\text{pure vapor})$$

Applying below data:

$$X_f = 0.1032 \quad (\text{feed composition})$$

$$W_f = 6000 \text{ kg/hr}$$

$$X_3 = 0.1275 \quad (\text{composition of the solution leaving third effect})$$

$$W_f \cdot X_f = (W_f - W_{s3}) \cdot X_3 \tag{30}$$

$$(W_f - W_{s3}) = \frac{W_f \cdot X_f}{X_3} \tag{31}$$

$$(W_f - W_{s3}) = \frac{6000 \times 0.1032}{0.01275} = 4856.470588 \text{ kg/hr}$$

$$\therefore W_{s3} = 1143.529412 \text{ kg/hr}$$

Material balance over the second effect :

$$(W_f - W_{s3}) = W_{s2} + (W_f - W_{s2} - W_{s3}) \quad (32)$$

Where:

W_f = feed rate enters second effect (kg/hr)

W_{s2} = The rate of vapor generated in the second effect (kg/hr)

Component balance over the second effect :

$$(W_f - W_{s3}) \cdot X_3 = W_{s2} \cdot Y_2 + (W_f - W_{s2} - W_{s3}) \cdot X_2 \quad (33)$$

$$W_{s2} \cdot Y_2 = 0.0 \quad (\text{pure vapor})$$

Applying below data:

$$X_2 = 0.222 \quad (\text{feed composition})$$

$$X_3 = 0.1275 \quad (\text{composition of the solution leaving third effect})$$

$$(W_f - W_{s3}) = 4856.470588 \text{ kg/hr}$$

$$(W_f - W_{s2} - W_{s3}) = \frac{(W_f - W_{s3}) \cdot X_3}{X_2} \quad (34)$$

$$(W_f - W_{s2} - W_{s3}) = \frac{4856.470588 \times 0.1275}{0.222} = 2789.189189 \text{ kg/hr}$$

$$\therefore W_{s2} = 2067.281399 \text{ kg/hr}$$

Material balance over the first effect :

$$(W_f - W_{s2} - W_{s3}) = W_{s1} + (W_f - W_{s2} - W_{s3} - W_{s1}) \quad (35)$$

Where:

W_f = feed rate enters second effect (kg/hr)

W_{s1} = The rate of vapor generated in the first effect (kg/hr)

Component balance over the first effect :

$$(W_f - W_{s2} - W_{s3}) \cdot X_2 = W_{s1} \cdot Y_1 + (W_f - W_{s2} - W_{s3} - W_{s1}) \cdot X_1 \quad (36)$$

$$W_{s1} \cdot Y_1 = 0.0 \quad (\text{pure vapor})$$

Applying below data:

$$X_1 = 0.42 \quad (\text{product composition})$$

$$X_2 = 0.222 \quad (\text{composition of the solution leaving second effect})$$

$$(W_f - W_{s2} - W_{s3}) = 2789.189189 \text{ kg/hr}$$

$$(W_f - W_{s2} - W_{s3} - W_{s1}) = \frac{(W_f - W_{s2} - W_{s3}) \cdot X_2}{X_1} \quad (37)$$

$$(W_f - W_{s2} - W_{s3} - W_{s1}) = \frac{2789.189189 \times 0.222}{0.42} = 1474.285714 \text{ kg/hr}$$

$$\therefore W_{s1} = 1314.903475 \text{ kg/hr}$$

Energy (Enthalpy) balance over first effect:

$$W_s \cdot \lambda_s + (W_f - W_{s2} - W_{s3}) \cdot h_2 = W_{s1} \cdot h_{s1} + (W_f - W_{s1} - W_{s2} - W_{s3}) \cdot h_1 \quad (38)$$

Where:

W_s = The flow rate of saturated steam

h_2 = The enthalpy of the solution leaving second effect (kJ/kg)

h_{s1} = The enthalpy of vapor generated in the first effect (kJ/kg)

h_1 = The enthalpy of product solution (kJ/kg)

λ_s = Latent heat of steam

Applying in equation :

$$h_2 = 447.534 \text{ kJ/kg} \quad (\text{Sodium hydroxide enthalpy table B})$$

$$h_1 = 630.24 \text{ kJ/kg} \quad (\text{Sodium hydroxide enthalpy table B})$$

$$h_{s1} = 2759.63 \text{ kJ/kg} \quad (\text{Steam table A})$$

$$\lambda_s = 2046.53 \quad (\text{Steam table A})$$

$$W_s = \frac{((1314.903475 \times 2759.63) + (1474.285714 \times 630.24) - (2789.189189 \times 447.534))}{(2046.53)}$$

$$\therefore W_s = 1617.148984 \text{ kg/hr}$$

$$\text{Steam economy} = \frac{4525.714286}{1617.148984} = 2.799$$

Table(3): effect of feed location on steam economy :

Feed location	Steam economy
Effect-I	2.9
Effect-II	2.530
Effect-III	2.799

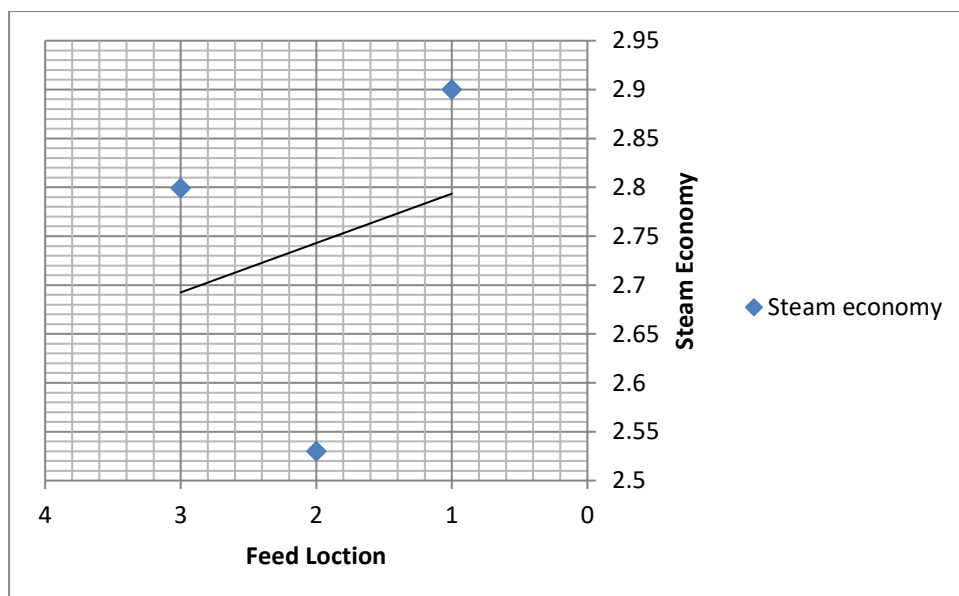


Fig (6):Effect of feed location on steam economy

RESULT AND DISCUSSION

From table(1),(2),(3) and figures (2),(3),(6), it is clear that, both feed composition and steam pressure affect the steam economy, the greater the steam pressure and the more concentrated feed reduced the steam economy, this is because high feed composition increases the boiling of evaporator mixture, but using high steam pressure which means high steam pressure which means high temperature, this affects the rate of heat losses, there for decreases the steam economy. Hence, in selection of steam quality this factor must be observed. From table (3), it is seen that the feed introduction location is very important, sometimes different locations of the feed are recommended, however, it is found that for the evaporation of caustic soda the introduction of the feed in the (first effect) evaporator gives the higher steam economy, this is agreement with (Ibn hayyan) feed introduction point. It must be noted that, the steam economy is highest in the first effect and decline from (2.9g)to(2.77g) in the last effect.

CONCLUSION

It is concluded that the steam economy depends on the pressure of steam, feed compositions and feed- locations

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