International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
www.ijset.com, Volume No.1, Issue No.3, pg:01-05 01 July 2012

Design, Modelling and Simulation of Multiple Effect Evaporators

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ABSTRACT Evaporation is the removal of solvent as vapor from a solution. It is the operation which is used for concentration of solution. There could be single effect evaporator or multiple effect evaporators. With addition of each effect steam economy of the system also increases. Evaporators are integral part of a number of a process industries like Pulp and Paper, Sugar, Caustic Soda, Pharmaceuticals, Desalination, Dairy and Food Processing etc. Caustic Soda Industry is of present interest. The system consists of quadruple effect having falling film evaporator as each effect. There is forward feed flow. Designing of this system has been done. This paper describes a steady state model of multiple effect evaporators for simulation purpose. The model includes overall as well as component mass balance equations, energy balance equations and heat transfer rate equations for area calculation for all the effects. Each effect in the process is represented by a number of variables which are related by the energy and material balance equations for the feed, product and vapor flow for forward feed. The code has been developed using SCILAB. Results of the present approach are validated with industrial data.

Keywords— Multiple Effect Evaporator, Caustic Soda solution, forward feed, SCILAB

1 INTRODUCTION:

1.1 Introduction to Evaporation Technology

Evaporation is the removal of solvent as vapor from a solution or slurry.

For the overwhelming majority of evaporation systems the solvent is water. The objective is usually to concentrate a solution; hence, the vapor is not the desired product and may or may not be recovered depending on its value. Therefore, evaporation usually is achieved by vaporizing a portion of the solvent producing a concentrated solution, thick liquor, or slurry.

Evaporation often encroaches upon the operations known as distillation, drying, and crystallization. In evaporation, no attempt is made to separate components of the vapor. This distinguishes evaporation from distillation. Evaporation is distinguished from drying in that the residue is always a liquid. The desired product may be a solid, but the heat must be transferred in the evaporator to a solution or a suspension of the solid in a liquid. The liquid may be highly viscous or a slurry. Evaporation differs from crystallization in that evaporation is concerned with concentrating a solution rather than producing or building crystals.

Evaporator Elements:

Three principal elements are of concern in evaporator design: heat transfer, vapor-liquid separation, and efficient energy consumption. The units in which heat transfer takes place are called heating units or calandrias. The vapor-liquid separators are called bodies, vapor heads, or flash chambers. The term body is also employed to label the basic building module of an evaporator, comprising one heating element and one flash chamber.

1.2 Types of Evaporators

Evaporators are often classified as follows:
(1) Heating medium separated from evaporating liquid by tubular heating surfaces,
(2) Heating medium confined by coils, jackets, double walls, flat plates, etc.,
(3) Heating medium brought into direct contact with evaporating liquid, and
(4) Heating with solar radiation.

Evaporators with tubular heating surfaces dominate the field. Circulation of the liquid past the surface may be induced by boiling (natural circulation) or by mechanical methods (forced circulation). In forced circulation, boiling may or may not occur on the heating surface. There are many types of evaporators which are named below:

- Horizontal Tube Evaporators
- Horizontal Spray Film Evaporators
- Long Tube Vertical Evaporators

- Rising or Climbing Film Evaporators
- Falling Film Evaporators
- Rising-Falling Film Evaporators
- Short Tube Vertical Evaporators
  - Inclined Tube Evaporators
  - Basket Type Evaporators
- Forced Circulation Evaporators
- Agitated thin Film Evaporators or wiped film evaporator
- Plate Evaporators

Falling Film Evaporators:

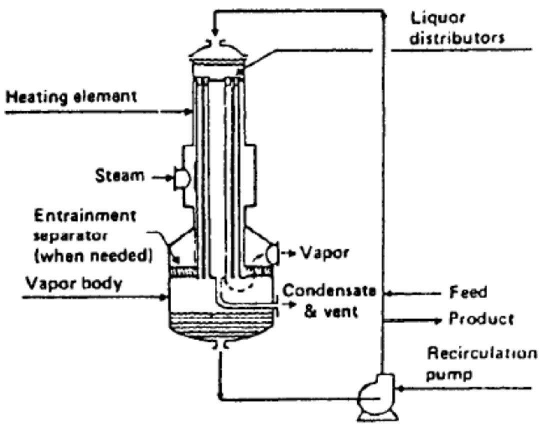

Figure 1: Falling Film Evaporators

The falling film version of the long tube evaporator (Figure 1) eliminates the problems associated with hydrostatic head. Liquid is fed at the top of long tubes and allowed to fall down the walls as a film. This requires that temperature differences be relatively low.Vapor and liquid are usually separated at the bottom of the tubes. Sometimes vapor is allowed to flow up the tube counter to the liquid. Pressure drop is low and boiling point rises are minimal. The falling film evaporator is widely used for concentrating heat sensitive products because the residence time is low. They are also suited for handling viscous fluids. Falling film units are also easily staged.

The main problem associated with falling film units is the need to distribute the liquid evenly to all tubes. All tubes must be wetted uniformly and this may require recirculation of the liquid unless the ratio of feed to evaporation is relatively high. Recirculation can only be accomplished by pumping.

1.3 Single Effect and Multiple Effect Evaporators

Single-effect evaporators are used when the throughput is low, when a cheap supply of steam is available, when expensive materials of construction must be used as is the case with corrosive feedstocks and when the vapour is so contaminated so that it cannot be reused. Single effect units may be operated in batch, semi-batch or continuous batch modes or continuously.

A multiple-effect evaporator is an evaporator system in which the vapor from one effect is used as the heating medium for a subsequent effect boiling at a lower pressure. Effects can be staged when concentrations of the liquids in the effects permits; staging is two or more sections operating at different concentrations in a single effect.

2. PROBLEM STATEMENT

The system selected is a quadruple effect evaporator system used for concentration of Caustic Soda. Falling film evaporator is used for this system with forward flow sequence. Operating parameters for this system are mentioned below in the Table 1:

Table 1: Operating Parameter for quadruple system:

Sr. No	Parameter	Value
1	Total no of effects	4
2	Feed Flow rate	10,000 kg/hr
3	Caustic Soda Inlet concentration	0.05
4	Caustic Soda Outlet concentration	0.3
5	Steam Temperature	100◦C
6	Feed Temperature	30◦C

3. DESIGN

3.1 Design Steps

- First calculate how much amount of product will be obtained by $m_P = (m_F*x)/y$
- Then calculate how much evaporation will take place by $m_F = m_P + m_E$
- Then assume steam economy and calculate amount of steam required to achieve desired separation by $m_S = m_E$/Steam Economy
- There are two basic equations of mass and energy balance, which are solved for each effect and calculation is made for that after each effect how much calculation has been achieved.

$m_F = m_P + m_E$ --- (1)

$Q_F + Q_s = Q_C + Q_P + Q_E$ -- (2)

This two equations are solved to get m_P and m_E.

- Concentration per effect is calculated by xnew = (feed flow for that effect*xold)/(product flow from that effect)
- Calculation is repeated until desired product concentration is obtained by assuming new value of steam economy each time.
- Then after area of each effect is calculated by $A = (mS^* \lambda S) / (U^*\Delta T)$
- No of tubes are found by $Nt = A/(\pi*D*L)$
- Flow rate of pump can be found by Qv = velocity * Area * no of tubes

3.2 Diagram

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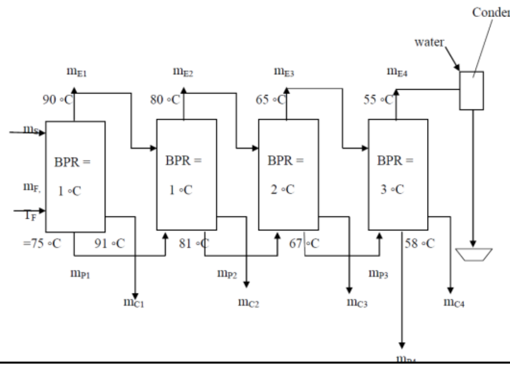


C_F = specific heat of Feed, kcal/kg ◦C
C_{P1}, C_{P2}, C_{P3}, C_{P4} = specific heat of Product in effects 1 to 4, kcal/kg ◦C
C_{C1}, C_{C2}, C_{C3}, C_{C4} = specific heat of Condensate in effects 1 to 4, kcal/kg ◦C
λ_S = Latent heat of Steam (to 1st effect), kcal/kg
λ_{E1}, λ_{E2}, λ_{E3}, λ_{E4} = Latent heat of water evaporated, kcal/kg
T_F = Temperature of Feed, ◦C
T_s = saturation temperature of feed to first effect, ◦C
T_1, T_2, T_3, T_4 = Temperature at which evaporation takes place in effects 1 to 4, kJ/kg ◦C
t_1, t_2, t_3, t_4 = Boiling Point Rise in effects 1 to 4, ◦C
T_{P1}, T_{P2}, T_{P3}, T_{P4} = Product outlet temperature in effects 1 to 4, kJ/kg ◦C
m_F = Mass flow rate of feed, kg/hr
x = Initial Total Dissolved Solids
y = Final Total Dissolved Solids
m_P = Mass flow rate Product should be, kg/hr
m_E = Total water evaporated, kg/hr
SE = Steam Economy
m_s = Mass flow rate of steam, kg/hr
m_{E1}, m_{E2}, m_{E3}, m_{E4} = water removed in effects 1 to 4, kg/hr
m_{P1}, m_{P2}, m_{P3}, m_{P4} = Mass flow rate of Product obtained in effects 1 to 4, kg/hr
m_{C1}, m_{C2}, m_{C3}, m_{C4} = Mass flow rate of condensate obtained in effects 1 to 4, kg/hr

3.4 Calculations

For this system data is as follows:

m_F = 10,000 kg/hr
x = 0.05
y = 0.3
Therefore $m_P = (m_F*x)/y = 1666.67$ kg/hr
Now $m_F = m_P + m_E$
$\Rightarrow m_E = m_F - m_P$
$\Rightarrow m_E = 10000 - 1666.67$
$\Rightarrow m_E = 8333.33$ kg/hr

By each time assuming new steam economy we get final results for steam economy=3.5.

Assume Steam Economy, SE = 3.5

Total steam requirement $m_S = \frac{8333.33}{3.5}$

$\Rightarrow m_S = 2380.95$ kg/hr

Mass and Energy Balance for all the effects can be given as:

<u>For 1st effect:</u>

$m_F = m_{P1} + m_{E1}$
$\Rightarrow 10000 = m_{P1} + m_{E1}$ ------------- (1)

$Q_F + Q_s = Q_{C1} + Q_{P1} + Q_{E1}$
$\Rightarrow [m_F*C_F*\Delta T] + [m_S*\lambda_S] = [m_{C1}*C_{C1}*\Delta T] + [m_{P1}*C_{P1}*\Delta T]+[m_{E1}*\lambda_{E1}]$
$[m_F*C_F*(T_F-0)] + [m_S*\lambda_S] = [m_{C1}*C_{C1}*(T_S-0)] + [m_{P1}*C_{P1}*(T_{P1}-0)] + [m_{E1}*\lambda_{E1}]$
$\Rightarrow [10000*0.95*75] + [2380.95*539.9282] = [2380.95*1.0104*100] + [m_{P1}*0.91*91] + [m_{E1}*546.2201]$
$\Rightarrow 1757470.86 = 82.81m_{P1} + 546.2201m_{E1}$ -------------- (2)

By solving above equations (1) and (2) we get
m_{P1} = 7994.5 kg/hr
m_{E1} = 2005.5 kg/hr

<u>For 2nd effect:</u>

$m_{P1} = m_{P2} + m_{E2}$
$\Rightarrow 7994.5 = m_{P2} + m_{E2}$ ----------------- (3)

$Q_{P1} + Q_{E1} = Q_{C2} + Q_{P2} + Q_{E2}$
$\Rightarrow [m_{P1}*C_{P1}*\Delta T] + [m_{E1}*\lambda_{E1}] = [m_{C2}*C_{C2}*\Delta T] + [m_{P2}*C_{P2}*\Delta T] + [m_{E2}*\lambda_{E2}]$
$\Rightarrow [7994.5*0.91*91] + [2005.5*546.2201] = [2005.5*1.0073*90] + [m_{P2}*0.89*81] + [m_{E2}*552.3445]$
$\Rightarrow 1575656.642 = 72.09\ m_{P2} + 552.3445\ m_{E2}$ -------- (4)

By solving equations (3) and (4) we get
m_{P2} = 5913.66 kg/hr
m_{E2} = 2080.84 kg/hr

<u>For 3rd effect:</u>

$m_{P2} = m_{P3} + m_{E3}$
$\Rightarrow 5913.66 = m_{P3} + m_{E3}$ ----------------- (5)

$Q_{P2} + Q_{E2} = Q_{C3} + Q_{P3} + Q_{E3}$
$\Rightarrow [m_{P2}*C_{P2}*\Delta T] + [m_{E2}*\lambda_{E2}] = [m_{C3}*C_{C3}*\Delta T] + [m_{P3}*C_{P3}*\Delta T] + [m_{E3}*\lambda_{E3}]$
$\Rightarrow [5913.66*0.89*81] + [2080.84*552.3445] = [2080.84*1.0047*80] + [m_{P3}*0.88*67] +[m_{E3}*561.3158]$
$\Rightarrow 1408406.683 = 58.96\ m_{P3} + 561.3158\ m_{E3}$ ------ (6)

By solving equations (5) and (6) we get
m_{P3} = 3804.12 kg/hr
m_{E3} = 2109.54 kg/hr

<u>For 4th effect:</u>

$m_{P3} = m_{P4} + m_{E4}$
$\Rightarrow 3804.12 = m_{P4} + m_{E4}$ ----------------- (7)

$Q_{P3} + Q_{E3} = Q_{C4} + Q_{P4} + Q_{E4}$
$\Rightarrow [m_{P3}*C_{P3}*\Delta T] + [m_{E3}*\lambda_{E3}] = [m_{C4}*C_{C4}*\Delta T] + [m_{P4}*C_{P4}*\Delta T] + [m_{E4}*\lambda_{E4}]$
$\Rightarrow [3804.12*0.88*67] + [2109.54*561.3158] = [2109.54*1.0017*65] + [m_{P3}*0.87*58] + [m_{E3}*567.177]$
$\Rightarrow 1271055.849 = 50.46\ m_{P4} + 567.177m_{E4}$ ---------- (8)

By solving equations (7) and (8) we get
m_{P4} = 1715.74 kg/hr
m_{E4} = 2088.38 kg/hr

The value of Final outlet Product concentration is 1715.74 kg/hr, which shows that 29.13% concentration is achieved in the final effect.

Area Calculations of effects:

$Q = U*A*\Delta T$ and $Q = m_S*\lambda_S$
Here ΔT is the temperature difference between steam inlet temperature and product outlet temperature.

Therefore $A = \frac{(mS*\lambda S)}{(U*\Delta T)}$

For 1st effect: $A_1 = \frac{(mS1*\lambda S1)}{(U1*\Delta T1)}$

$= \frac{(2380.95*539.9282)}{(1400*9)}$

$\Rightarrow A_1 = 102.03\ m^2$

For 2nd effect: $A_2 = \frac{(mS2*\lambda S2)}{(U2*\Delta T2)}$

$= \frac{(2005.5*546.2201)}{(1200*9)}$

$\Rightarrow A_2 = 101.43\ m^2$

For 3rd effect: $A_3 = \frac{(mS3*\lambda S3)}{(U3*\Delta T3)}$

$= \frac{(2080.84*552.3445)}{(1000*13)}$

$\Rightarrow A_3 = 88.41\ m^2$

For 4th effect: $A_4 = \frac{(mS4*\lambda S4)}{(U4*\Delta T4)}$

$= \frac{(2109.54*561.3158)}{(800*7)}$

$\Rightarrow A_4 = 211.45\ m^2$

To calculate no of tubes:

A = π*no of tubes * O.D. of tube * Length of tube

Therefore $N_t = \frac{A}{(\pi*D*L)}$

Take O.D. of tube = 50.8 mm and Length of tube = 6 m

For 1st effect no of tubes $N_t = \frac{A1}{(\pi*D*L)}$

$= \frac{102.03}{(\pi*50.8*0.001*6)} = 106.55 = 107$ tubes

For 2nd effect no of tubes $N_t = \frac{A2}{(\pi*D*L)}$

$= \frac{101.43}{(\pi*50.8*0.001*6)} = 105.93 = 106$ tubes

For 3rd effect no of tubes $N_t = \frac{A3}{(\pi*D*L)}$

$= \frac{88.41}{(\pi*50.8*0.001*6)} = 92.33 = 93$ tubes

For 4th effect no of tubes $N_t = \frac{A4}{(\pi*D*L)}$

$= \frac{211.45}{(\pi*50.8*0.001*6)} = 220.82 = 221$ tubes

To find the volumetric flow rate of the pump:

Q_v = velocity * Area * no of tubes
Range of velocity is 0.02 to 0.05 m/s.
Take v = 0.04 m/s

For 1st effect $Q_{v1} = N_t * A_1 * v = 107 * 102.33 * 0.04$
$= 436.69\ m^3/s$

For 2nd effect $Q_{v2} = N_t * A_2 * v = 106 * 101.43 * 0.04$
$= 430.06\ m^3/s$

For 3rd effect $Q_{v3} = N_t * A_3 * v = 93 * 88.41 * 0.04$
$= 328.89\ m^3/s$

For 4th effect $Q_{v4} = N_t * A_4 * v = 221 * 211.45 * 0.04$
$= 1869.22\ m^3/s$

4. RESULT

By following above algorithm we get result as:
Feed rate F:10000
Initial TDS x:.05
Final TDS y:.3
Steam Economy:3.5
No of Effects n:4

E:

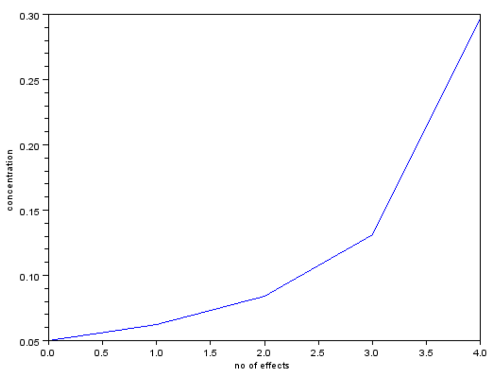
2850.8772
2565.9655
2695.9422
2779.3583
2768.772

P:

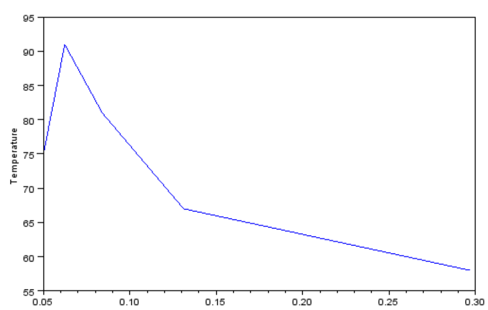
13000.
10434.035
7738.0923
4958.734
2189.962

x:

0.05
0.0622961
0.0840000
0.1310818
0.2968088



Plot of Concentration vs. no of effects



Plot of Temperature vs. concentration

5. CONCLUSION

This system shows that results are obtained for steam economy 3.5. As system is of caustic soda concentration the same methodology could be applied for any other caustic soda concentration system to get results.

6. REFERENCES:

1. Kern, D.Q., 1950, Process Heat Transfer, McGraw-Hill, USA.
2. McCabe, W.L., Smith J.C., Harriot P., 1993, Unit Operations of Chemical Engineering, 5th Ed., McGraw Hill, USA.
3. Richardson, J.F., Harker J.H., Backhurst J.R., 2002, Particle Technology and Separation Processes, 5th Ed., 2 Vol., Linacre House, Jordan Hill, Oxford.
4. Sinnott R.K., 2005, Chemical Engineering Design, 4th Ed., 6 Vol., Linacre House, Jordan Hill, Oxford.
5. Bhatt, B.I. & Vora S.M., 2004, “Stoichiometry”, 4th Ed., Tata McGraw-Hill Publishing Co. Ltd., New Delhi.
6. Thakore S.B. & Bhatt B.I., 2007, “Introduction to Process Engineering and Design”, Tata McGraw Hill Publishing Co. Ltd., New Delhi.
7. Perry R.H. & Green D., 1984, Perry’s Chemical Engineer’s Handbook, 6th Ed., McGraw Hill, USA.
8. Minton P.E., 1986, Handbook of Evaporation Technology, Noyes Publications, USA.
9. Miranda, V.,& Simpson, R., 2005, Modelling and simulation of an industrial multiple effect evaporator: Tomato concentrate, Journal of Food Engineering 66, Pages 203–210.
10. Kaya D. & Sarac HI., 2007, Mathematical modeling of multiple-effect evaporators and energy economy. Energy 32, Pages 1536–1542.
11. Bhargava, R., Khanam, S., Mohanty, B., & Ray, A. K; 2008, Simulation of flat falling film evaporator system for concentration of black liquor, Computers and Chemical Engineering 32, Pages 3213–3223.
12. Kumar D., Kumar V., & Singh V; 2010, To study the Parametric effects on Optimality of various Feeding sequences of a Multiple Effect Evaporators in Paper Industry using Mathematical Modeling and Simulation with MATLAB, World Academy of Science, Engineering and Technology 72, Pages 114-121
13. Khanam, S., Mohanty, B., 2011, Development of a new model for multiple effect evaporator system, Computers and Chemical Engineering 35, Pages 1983-1993.
14. Khanam, S., Mohanty, B., 2010, Placement of condensate flash tanks in multiple effect evaporator system, Desalination 262, Pages 64-71
15. Khanam, S., Mohanty, B., 2010, Energy reduction schemes for multiple effect evaporator systems, Applied Energy 87, Pages 1102-1111.
16. M.H. Khademi, M.R. Rahimpour, A. Jahanmiri., 2009, Simulation and Optimization of a six-effect evaporator in a desalination process, Chemical Engineering Processing: Process Intensification 48, Pages 339-347