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DESIGN OF TRIPLE EFFECT EVAPORATORS BASED ON SOLAR DESALINATION OF RED SEA WATER

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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.

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 variableswhich are related by the energy and material balance equations for the feed, product and vapor flow for forward feed. Results of the present approach are validated with industrial data.

KEYWORDS: triple evaporator; Solar Desalination; liquid separator; Red Sea Water.

I. INTRODUCTION

Evaporation, one of the main methods used for the concentration of aqueous solution ,refers to the removal of water from a solution by boiling the liquor in a suitable vessel , the evaporator ,and withdrawing the vapor .If the solution contains dissolved solids , the resulting strong liquor may become saturated so that crystals are deposited liquors. Evaporation is carried out by adding heat to solution to vaporize the solvent .The heat is supplied principally to provide the latent heat of vaporization ,and ,by adopting methods for recovery of heat from the vapor ,it has been possible to achieve great economy in heat utilization .Whilst the normal heating medium is generally low pressure exhaust steam from turbines ,special heat transfer fluids or flue gases may be used .The design of an evaporation unit require the practical application of data on heat transfer to boiling liquids ,together with a realization of what happens to the liquid during concentration .

II. EVAPORATORS UNITS

There are two main types of evaporators units; 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 expensivematerials of construction must be used as is the case withcorrosive feedstocks and when the vapor is so contaminatedso that it cannot be reused. Single effect units may be operatedin batch, semi-batch or continuous batch modes orcontinuously.

A multiple-effect evaporator is an evaporator system in whichthe vapor from one effect is used as the heating medium for asubsequent effect boiling at a lower pressure. Effects can bestaged when concentrations of the liquids in the effectspermits; staging is two or more sections operating at differentconcentrations in a single effect.

A- Evaporators Classifications

Evaporators are often classified as follows:

- Heating medium separated from evaporating liquid by tubular heating surfaces.
- Heating medium confined by coils, jackets, double walls, flat plates, etc.
- Heating medium brought into direct contact with evaporating liquid.
- Heating with solar radiation.

Evaporators with tubular heating surfaces dominatethe field. Circulation of the liquid past the surface may beinduced by boiling (natural circulation) or by mechanical methods "forced circulation". In forced circulation, boilingmay or may not occur on the heating surface.

B- Evaporators Types

There are manytypes of evaporators which are named below:

- Horizontal Tube Evaporators
- Horizontal Spray Film Evaporators
- Long Tube Vertical Evaporators
- Short Tube Vertical Evaporators
- Basket Type Evaporators
- Forced Circulation Evaporators
- Agitated thin Film Evaporators or wiped film evaporator
- Plate Evaporators

III. EVAPORATOR DESIGN

Three principal elements are of concern in evaporator design:heat transfer, vapor-liquid separation, and efficient energyconsumption. The units in which heat transfer takes place arecalled heating units or Calandra's. The vapor-liquid separatorsare called bodies, vapor heads, or flash chambers. The termbody is also employed to label the basic building module of anevaporator, comprising one heating element and one flashchamber.

The system selected is a quadruple effect evaporator systemused for concentration of saline water. Falling filmevaporator is used for this system with forward flow sequence.

Operating parameters for this system are mentioned below inthe Table 1:

Table1: Operating Parameter for quadruple system:

Sr. No	Parameter	Value
1	Total no of effects	3
2	Feed Flow rate	1Kg/S
3	Salt Inlet concentration	0.03
4	Saltout let concentration	0.6
5	Steam Temperature	110◦C
6	Feed Temperature	30◦C

IV. DESIGN MODEL

In this section we present our design calculations in three subsections; design steps, design model and calculations.

A- Design Steps

- First calculate of overall mass balance
- Calculate of temperature in each effect by$Q=u_1A_1\Delta T_1=u_2A_2\Delta T_2= u_3A_3\Delta T_3$
  Assuming $A_1=A_2=A_3$

$\sum\Delta T=\Delta T_1+\Delta T_2+\Delta T_3$

$\sum\Delta T=\Delta T_1+\frac{u1}{u2}\Delta T1+\frac{u1}{u3}\Delta T1$

- Calculate of energy balance by solve theseequations to obtained of steam in each effect by;$D_1+D_2+D_3=0.95$

$D_O*\lambda_0 = m_f*C_f\ (T_1-T_f)+D_1*\ \lambda_1$

$D_2*\lambda_2=(m_f-D_1)*cp_1(T_1-T_2)+\ D_1*\ \lambda_1$

$D_3*\lambda_3=(m_f-D_1.D_2)*cp_2(T_2-T_3)+D_2*\lambda_3$

- Concentration per effect is calculated by this equationfromfigure 1;component balance:

$mf=D1+mp1$……………………..(1)

$m_f*x_f=D_1*x_{D1}+m_{p1}*x_{p1}$………..(2)

$x_{D1}=0$…………………………..(3)

$m_F*x_F=m_{p1}*x_{p1}$……………….…(4)

From e.g(1):

$m_{p1}=m_F-D_1$

$m_F*x_f=(m_f-D_1)*x_{p1}$

$xp1=\frac{mf*xF}{(mf-D1)}$………………..….(5)

Similarly for effect 2 and 3:

$x_{p2}=\frac{mf*xF}{(mf-D1-D2)}$………………...(6)

$x_{p3}=\frac{mf*xF}{(mf-D1-D2-D3)}$ … … … … … . (7)

- Calculate of mass balance around each effect to obtained of water condensation for each effect
- Calculate amount of steam economy by: $SE=\frac{mE}{mS}$
- Then after area of each effect is calculate by:$A=\frac{DO*\lambda0}{(U*\Delta T)}$
- No of tubes are found by:$Nt=\frac{A}{(\pi*D*L)}$
- Where:

CF = specific heat of Feed, kcal/kg ◦C
CP1, CP2, CP3, = specific heat of Product in effects 1 to 3, kcal/kg ◦C
C_{C1}, C_{C2}, C_{C3}, = specific heat of Condensate in effects 1 to 3, kcal/kg .◦C
λ0 = Latent heat of Steam (to 1st effect), kcal/kg
λ1, λ2, λ3, = Latent heat of water evaporated, Kcal/kg
TF = Temperature of Feed, ◦C
T0 = saturation temperature of feed to first effect, ^{0}C
T1, T2, T3, = Temperature at which evaporation takes place in effects 1 to 3, kJ/kg ◦C
U_1,U_2,U_3=Over all heat transfer coefficient KW/m_2.K.
T_{P1}, T_{P2}, T_{P3}, = Product outlet temperature in effects 1 to 3, kJ/kg ◦C
mF = Mass flow rate of feed, kg/S
xf = Initial Total Dissolved Solids
xp_1,xp_2,xp_3 Dissolved Solids in effects 1 to 3
mP = Mass flow rate Product should be, kg/S
mE = Total water evaporated, kg/S
SE = Steam Economy
D_0= Mass flow rate of steam, kg/S
D_1, D_2, D_3 = water removed in effects 1 to 3, kg/S
m_{P1}, m_{P2}, m_{P3}, m_{P4} = Mass flow rate of Product obtained in effects 1 to 3,kg/S
m_{C1}, m_{C2}, m_{C3}, = Mass flow rate of condensate obtained in effects 1to 3,Kg/S
O.D=out side of diameter
Nt=No of tubes

B- Model Diagram

A triple Effect Evaporatorsis an evaporator system in whichthe vapor from one effect is used as the heating medium for asubsequent effect boiling at a lower pressure .

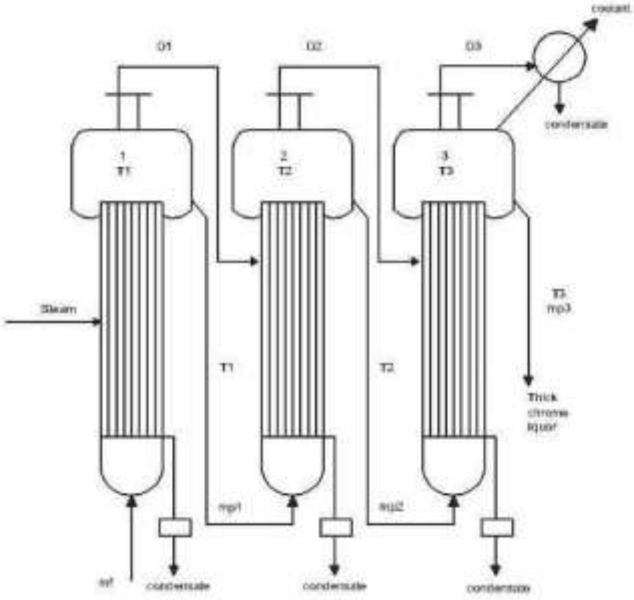

Figure 1:triple Effect Evaporators

A- Calculations

Table 2: Mass Balance

Current	Solid Kg/S	Liquid Kg/S	Total Kg/S
Feed	**0.035**	**0.965**	**1**
Product	**0.035**	**0.015**	**0.05**
Evaporation	**_**	**0.95**	**0.95**

In this section we calculate temperature ineach effectas in the following Equion's;

U1= 2.5KW/m2.K,**U2=2**KW/m2.K**; U3=1.6**KW/m2.K

$\sum\Delta T = \Delta T_1 + \Delta T_2 + \Delta T_3 = \mathbf{40^0C}$

$\sum\Delta T = \Delta T_1 + \frac{u1}{u2}\Delta T1 + \frac{u1}{u3}\Delta T1$

$\Delta T1 = \frac{40}{1+\frac{2.5}{2}+\frac{2.5}{1.6}} = 10.50^0\mathbf{C}$

$$\Delta T2 = \frac{U1}{U2}\Delta T1$$

$\Delta T2 = \frac{2.5}{2} * 10.50 = 13.125^0\mathbf{C}$

$T_1 = T0 - \Delta T1$

$T1 = 110 - 10.50 = 99.5^0\mathbf{C}$

$T_2 = 86.4^0\mathbf{C}$

- From steam table:

Table 3: Steam Table Parameters

T ℃	λkcal/kg
T0= 110	λ0=2230.038
T1=99.5	λ1=**2256.816**
T2=86.4	λ2=2292.444
T3=70	λ3=2333.938

- D1+D2+D3=0.95………………. (8)
- $D_O*\lambda_0 = m_f*C_f\ (T_1-T_f) + D_1*\lambda_1$

D_O*2230.038 = 1*4.17005 (99.5-30) +D_1* 2256.816…………………………………(9)

- $D_2*\lambda_2=(m_f-D_1)*cp_1(T_1-T_2)+ D_1*\lambda_1$

D_2*2292.444=(1-D_1)*3.92(99.5-86.4)+ D_1* 2256.816…………………………….…….(10)

- $D_3*\lambda_3=(m_f-D_1.D_2)*cp_2(T_2-T_3)+D_2*\lambda_2$

D_3*2333.938=(1-D_1.D_2)*3.92 (86.4 70)+D_2*2292.444………………………(11)

- By solving above equations (8) and (9) and (10) and (11) we get:

D_O = 0.461Kg/S
D_1 = 0.327 Kg/S
D_2 = 0.337 Kg/S
D_3 = 0.287 Kg/S

- For 1^{th}effect;we calculate concentrateof salt

From e.g(5):

$$xp1 = \frac{1 * 0.03}{(1 - 0.327)} = 0.04$$

- For 2^{nd} effectwe calculateconcentrateof salt

From e.g(6):

$$xp2 = \frac{1 * 0.03}{(1 - 0.327 - 0{,}337)} = 0{,}089$$

- The Mass Balance for all the effects can be givenas:

For 1^{st}effect:

$$SE = \frac{0{,}95}{0.461} = 2.06$$

A1=A2=A3=$\frac{DO*\lambda 0}{(U*\Delta T)}$

A=$\frac{0.461*2230.0038}{(2{,}5*10.50)} = 39m^2$

- To calculate no of tubes:

A=л*no of tubes*O. D of tube *length of tube

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

Nt=$\frac{A}{(л*D*L)}$

Nt=$\frac{39}{(л*6*0.0508)} = 40.7 \cong 41 tubes$

V. CONCLUSION

This system shows that results are obtained for steameconomy 2.06 As the system is of saline water concentration the same methodology could be applied for any other saline water concentration system to get results.

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