

## MASS AND ENERGY BALANCE SMJC 2223

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An evaporation-crystallization process is used to obtain solid 1) potassium sulfate from an aqueous solution of this salt. The fresh feed to the process contains 19.6 wt%  $K_2SO_4$ . The wet filter cake consists of solid  $K_2SO_4$  crystals and a 40.0 wt%  $K_2SO_4$  solution, in a ratio 10 kg crystals/kg solution. The filtrate also a 40.0% solution is recycled to join the fresh feed. Of the water fed to the evaporator, 45.0% is evaporated. The evaporator has a maximum capacity of 175 kg water evaporated/s.



Assume the process is operating at a maximum capacity. a) Draw and label a flowchart and do the degree-of-freedom analysis for the overall system, the recycle-fresh feed mixing point, the evaporator, and the crystallizer. Then write in an efficient order (minimizing simultaneous equations) the equations you would solve to determine all unknown stream variables. In each equation, circle the variable for which you would solve, but do not do the calculations.

Overall mass balances:  $\dot{m}_1 = 175 + 10 \dot{m}_2 + \dot{m}_2$ Overall K balance:  $0.196(\dot{m}_1) = 10\dot{m}_2 + \dot{m}_2(0.400)$ 

production rate of crystal: 10 m2

45% evaporation: 175 kg evaporated/s = 0.450  $\dot{m}_5$ 

W balance around:  $\dot{m}_1(0.804) + \dot{m}_3(0.600) = \dot{m}_5$ 

mass balance around :  $\dot{M}_1 + \dot{M}_3 = \dot{M}_4 + \dot{M}_5$ 

K balance around evaporator:  $M_6 = \dot{M}_4$ 

W balance around evaporator:  $\dot{M}_5 = 175 + \dot{M}_7$ 

mole fraction of K in Stream: <u>m</u> entering evaporator <u>matms</u>

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\dot{m}_1 = 175 \pm 10 \dot{m}_2 \pm \dot{m}_2
\dot{m}_1(0.196) = 10 \, m_2 + m_2(0.400) - 2
Subs 1 into 2
 0.196(175+10\dot{m}_2+\dot{m}_2)=10\dot{m}_2+\dot{m}_2(0.400)
  34.31196\dot{m}_2 + 0.196\dot{m}_2 - 10\dot{m}_2 - 0.4\dot{m}_2 = 0
                                  34.3-8.244m2=0
                                                  m_2 = 4.16 \text{ kg/c}
Subs M_2 into O
    \dot{m}_1 = 175 + 10(4.16) + 4.16
         = 220.76 Kg/s
 175 kg evaporated /s = 0.450 ms
                         \dot{m}_5 = 388.89 \text{ kg/s}
 \dot{M}_1(0.804) + \dot{M}_3(0.600) = \dot{M}_5
 (220.76)(0.804) + \dot{m}_3(0.600) = 388.89
                                 M_3 = 352.3 \text{ kg/s}
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\dot{m}_1 + \dot{m}_3 = \dot{m}_4 + \dot{m}_5
(220.76)+(352.3)=\dot{m}_4+388.89
\dot{m}_4=184.17 k9/s
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M<sub>6</sub> = M<sub>4</sub>
= 184.17 kg/s
m<sub>5</sub> = 175 + m<sub>7</sub>
m<sub>7</sub> = 388.89 - 175
= 213.89 kg/s
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Calculate the maximum production rate of solid  $K_2SO_4$ , **b**) the rate at which fresh feed must be supplied to achieve this production rate, and the ratio kg recycle/kg fresh feed. max production rate of solid K, 1)  $10\dot{m}_2 \rightarrow 10(4.16)$ = 40.16 kg(S)/s ii) fresh feed rate,  $\dot{M}_1 = 220.76 \, \text{kg/s}$ recycle ratio, iii)  $\dot{M}_3$ (kg recycle/s) 352.3 m, (kg feed /s) 220.76 =160 kg recycle kafresh feed

c) Calculate the composition and feed rate of the stream entering the crystallizer if the process is scaled to 75% of its maximum capacity.

> Scale to 75% of capacity (0.75)  $\dot{m}_6 + \dot{m}_7$ flow rate of Stream = 0.75(398.06) entering evaporator = 299 Kg/s

for composition,

$$K = \frac{184.17}{398.06} \times 100\% = 46.3\% K$$

$$W = \frac{213.89}{398.06} \times 100\% = 53.7\% W$$

d) The wet filter cake is subjected to another operation after leaving the filter. Suggest what it might be. Also, list what you think the principal operating costs for this process might be.

*Drying*. Principal costs are likely to be the heating cost for the evaporator and the dryer and the cooling cost for the crystallizer.

2) In an **absorption tower** (or **absorber**), a gas is contacted with a liquid under conditions such that one or more species in the gas dissolve in the liquid. A stripping **tower** (or **stripper**) also involves a gas contacting a liquid, but under conditions such that one or more components of the feed liquid come out of solution and exit in the gas leaving the tower.

A process consisting of an absorption tower and a stripping tower is used to separate the components of a gas containing 30.0 mole% carbon dioxide and the balance methane. A stream of this gas is fed to the bottom of the absorber. A liquid containing 0.500 mole% dissolved CO<sub>2</sub> and the balance methanol is recycled from the bottom of the stripper and fed to the top of the absorber. The product gas leaving the top of the absorber contains 1.00 mole% CO<sub>2</sub> and essentially all of the methane fed to the unit.

The CO<sub>2</sub>-rich liquid solvent leaving the bottom of the absorber is fed to the top of the stripper and a stream of nitrogen gas is fed to the bottom. Ninety percent of the CO<sub>2</sub> in the liquid feed to the stripper comes out of solution in the column, and the nitrogen/CO, stream leaving the column passes out to the atmosphere through a stack. The liquid stream leaving the stripping tower is the 0.500% CO<sub>2</sub> solution recycled to the absorber.

The absorber operates at temperature  $T_a$  and pressure  $P_a$  and the stripper operates at  $T_s$  and  $P_s$ . Methanol may be assumed to be nonvolatile-that is, none enters the vapor phase in either column-and  $N_2$  may be assumed insoluble in methanol. a) In your own words, explain the overall objective of this two-unit process and the functions of the absorber and stripper in the process.

Overall objective : Separate components of a CH4-CO2 mixture, recove CH4 and discharge CO2 to the atmosphere. Absorber function : Separates CO2 from CH4 . Stripper function : Removes dissolved CO2 from CH3OH so that the latter can be reused. b) The streams fed to the tops of each tower have something in common, as do the streams fed to the bottoms of each tower. What are these commonalities and what is the probable reason for them?

The top streams are liquids while the bottom streams are gases. The liquids are heavier than the gases so the liquids fall through the columns and gases rise.

Taking a basis of 100 mol/h of gas fed to the absorber, draw and label a c) flowchart of the process. For the stripper outlet gas, label the component molar flow rates rather than the total flow rates and mole fractions. Do the degree-of-freedom analysis and write in order the equations you would solve to determine all unknown stream variables *except the nitrogen flow rate entering* and leaving the stripper. Circle the variable(s) for which you would solve each equation (or set of simultaneous equations), but do not do any of the calculations yet.



- Overall : 3 unknown (n1,n5,n6) 2 balances =1DF
- Stripper : 4 unknown (n2,n3,n4,n5) 2 balances 1 percent removal (90%) = 1DF
- Absorber : 4 unknown (n1,n2,n3,n4) 3 balances = 1 DF
- Overall CH4 balances : [(0.700)(100)] (mol CH4/h) = 0.990 n1
- Overall mole balances : 100 (mol/h) = n1 +n6
- Percent CO2 stripped : 0.90 n3 = n6
- Stripper CO2 balance : n3 = n6 +0.005 n2
- Stripper CH3OH balance : n4 = 0.995 n2

d) Calculate the fractional  $CO_2$  removal in the absorber (moles absorbed/mole in gas feed) and the molar flow rate and composition of the liquid feed to the stripping tower.

Input + generation -output-consumption =accumulation Input = output Material balance for CH4 =

 $(100 \text{ mol}/h)(0.70) = (\dot{n}, \text{ mol}/h)(0.990)$  $\dot{n}_{1} = 70.707 \text{ mol}/h$ 

Overall balances :

$$\frac{100 \text{ mol}}{h} = \dot{n}_{1} \pm \dot{n}_{6}$$
  

$$\frac{100 \text{ mol}}{h} = 70.707 \text{ mol}/h \pm \dot{n}_{6}$$
  

$$\dot{n}_{6} = 29.293 \text{ mol} \cos 2/h$$

% CO<sub>2</sub> stripped : 0.90  $\dot{n}_3 = \dot{n}_6$ 0.90  $\dot{n}_3 = 29.298mol CO_2/h$  $\dot{n}_3 = 32.548mol CO_2/h$  Stripper Cosbalance:

 $\dot{n}_3 = \dot{n}_6 + 0.005 \,\dot{n}_2$ 32.548 mol CO2/h = 29.293mol CO2/h + 0.005  $\dot{n}_2$  $\dot{n}_2 = 651.0 \, \text{mol}/\text{h}$ 

Stripper CH<sub>3</sub>OH balance:  $\dot{n}_4 = 0.995 \dot{n}_3$   $\dot{n}_4 = 0.995 (651.0 \text{ mol}/h)$  $\dot{n}_4 = 647.7 \text{ mol} \text{ cH}_3\text{OH/h}$  Fractional CO, absorption:

$$f_{co_2} = \frac{(0.30)(100) - (0.01)(70.707)}{(0.30)(100)} - \frac{(0.01)(70.707)}{(0.30)(100)}$$

= 0.976 mol CO2 absorbed/mol fed

Total molar flow rate of liquid feed to stripper:

 $\dot{n}_3 + \dot{n}_4 = 32.548 \text{ mol}/h + 647.7 \text{ mol}/h$ = 680 mol/h

mole fraction CO2:

$$\begin{aligned} \chi_{3} &= \frac{\dot{n}_{3}}{\dot{n}_{3} + \dot{n}_{4}} \\ &= \frac{32 - 548 \text{ mol } CO_{2} / 1}{(32 - 548 + 647 - 7) \text{ mol} / 1} \\ &= 0.0478 \text{ mol } CO_{2} / \text{mol} \end{aligned}$$

e) Calculate the molar feed rate of gas to the absorber required to produce an absorber product gas flow rate of 1000 kg/h.

## e) At absorber,

molar feed rate of gas = ? (new)product gas flow rate = 1000 kg/h = 1.0 × 106g/h

$$MW_1 = 0.01(44 g \cos 2/mol) + 0.99(16g CH_4/mol)$$
  
= 16-28 g/mol

$$(\dot{n}_1)_{\text{new}} = (1-0 \times 10^6 \text{ g/h})(10-28 \text{ g/mol}) =$$
  
= 6-142 × 10<sup>4</sup> mol/h

$$(\dot{n}_{\text{feed}})_{\text{new}} = (100 \text{ mol/h}) \left[ \frac{6.142 \times 104 \text{ mol/h}}{70.707 \text{ mol/h}} \right]$$
  
= 8.69 × 104 mol/h

f) Would you guess that Ts would be higher or lower than Ta? Explain. (Hint: Think about what happens when you heat a carbonated soft drink and what you want to happen in the stripper. What about the relationship of Ps to Pa?

Ta < Ts : The higher temperature in the stripper will help drive off the gas

Pa > Ps : The higher pressure in the absorber will help dissolve the gas in the liquid g) What properties of methanol would you guess make it the solvent of choice for process. (In more general term, what would you look for when choosing a solvent for an absorption stripping process to separate one gas from another?)

The methanol must have a high solubility for CO2, a low solubility for CH4, and a low volatility(not reactive in high temperature) at the stripping process.