CE 407 Notes
Leaching more examples with composition-dependent underflow

Example 1

The year is 2355, and human colonies on Mars are suffering heavy casualties from alien attacks. Martian Space Command (MSC) is hard pressed for sodium chloride needed to fuel its crystal-drive defensive battle cruisers. But there is hope, for scientists have discovered vast deposits of salt shale near the Martian polar caps; this contains 0.2 tons NaCl per ton of insoluble rock. Water to dissolve this salt is readily available in the form of ice, which can easily be melted using a solar furnace. Moreover, archaeologists on Earth have discovered a copy of McCabe, Smith and Harriott in what was once the Buffalo area, and its tattered pages speak of a marvelous, long-forgotten process called <u>leaching</u> whereby soluble materials can be extracted from solids.

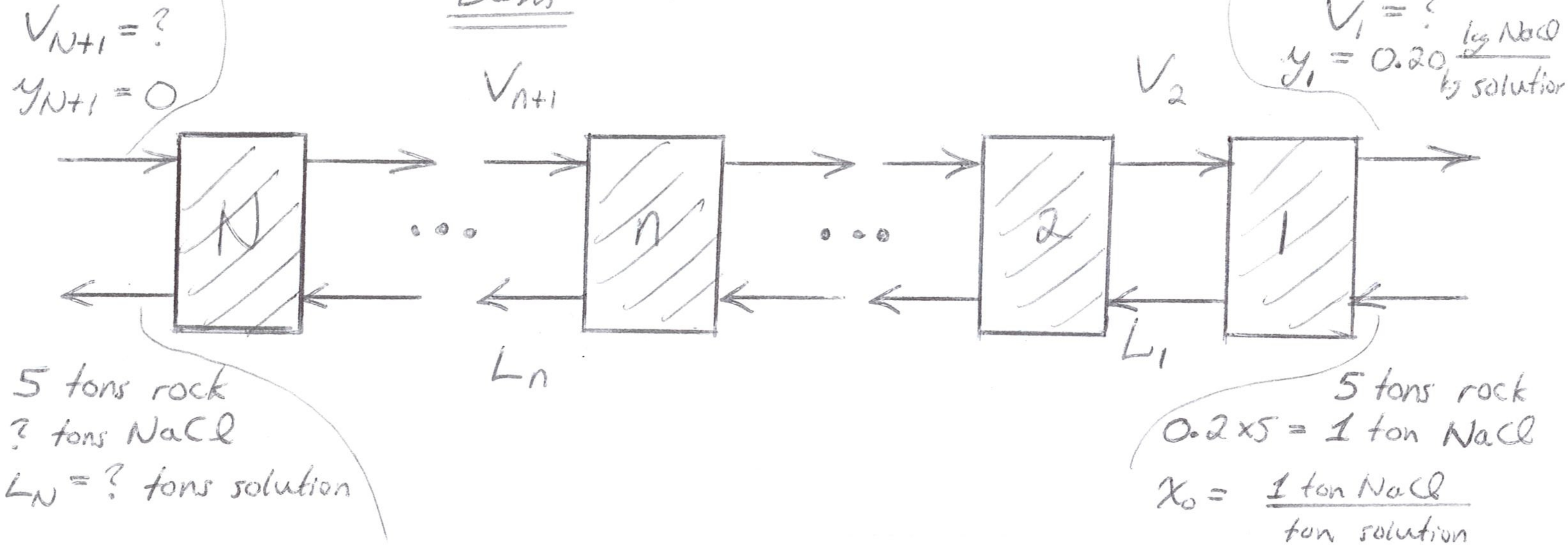
MSC would like to process 5 tons of salt shale per hour (based on completely exhausted rock), and 85 % recovery of salt is desired. Water enters the countercurrent extraction battery in a pure (salt-free) state. The exiting extract should have NaCl mass fraction equal to 0.2. Retention of solution (water + salt) by the shale is as follows:

solution concentration in mass percent NaCl	tons solution retained per ton of exhausted rock
0	0.30
4	0.50
8	0.80
12	1.00
16	1.10
20	1.15

(a) What must be the flow rate of the entering water? (b) How many ideal stages are needed?

Note: For salt concentrations lying between the values listed in the table, use linear interpolation.

Basis: 1 hour



I. Preliminaries and overall balances around extraction battery.

85% recovery of NaCl $\Rightarrow$ $(1-0.85)(1 \text{ ton NaCl})$

$= 0.15$ ton NaCl in exiting solid.

$L_N x_N$

Calculate x_N by trial:

Guess $x_N = 0.051$. By linear interpolation, at this value of x_N, 0.5825 tons solution are retained per ton of exhausted rock. $\therefore L_N = (0.5825)(5 \text{ tons}) = 2.91$ tons.

Check: $L_N x_N = 0.15$

$$x_N = \frac{0.15}{2.91} = 0.0515 \quad \text{(close enough)}.$$

Guess x_N. Look up retention value in table, calculate L_N, then get new value of x_N from $x_N = \frac{0.15}{L_N}$. Keep guessing until the 2 values agree.

So: $L_N = 2.91$ tons solution.

Salt balance:

$$\underbrace{1 + 0}_{\text{in}} = \underbrace{0.15 + (0.20)V_1}_{\text{out}} \Rightarrow V_1 = 4.25 \text{ tons solution}$$

($0.20 = y_1$)

Solution (salt + water) balance:

$$\underbrace{1 + V_{N+1}}_{\text{in}} = \underbrace{L_N + V_1}_{\text{out}} \Rightarrow V_{N+1} = 6.16 \text{ tons solution}$$

2.91   4.25

(this "solution" is actually pure water).

ANSWER FOR PART (a): V_{N+1} = flow rate of entering water = 6.16 tons/h

II. Balance around first stage.

Ideal stage $\Rightarrow$ exiting streams at equilibrium

$\Rightarrow x_1 = y_1 = 0.20$ tons NaCl/ton solution

Calculate L_1:

from table

$$x_1 = 0.20 \Rightarrow L_1 = (1.15)(5 \text{ tons}) = 5.75 \text{ tons solution}$$

Solution balance:

5.75   4.25

$$\underbrace{1 \text{ ton} + V_2}_{\text{in}} = \underbrace{L_1 + V_1}_{\text{out}} \Rightarrow V_2 = 9.00 \text{ tons solution}$$

Salt balance:

5.75   0.20   4.25   0.20

$$\underbrace{1 \text{ ton} + V_2 y_2}_{\text{in}} = \underbrace{L_1 x_1 + V_1 y_1}_{\text{out}} \Rightarrow y_2 = 0.1111$$

9.00

III. Intermediate point — balances for control volume enclosing stages 1 through n.

e.g. choose $x_n = 0.12$ (arbitrary)

Calculate L_n:

from table

$$x_n = 0.12 \Rightarrow L_n = (1.00)(5 \text{ tons}) = 5.00 \text{ tons solution}$$

Solution balance:

$$\underbrace{1\text{ ton} + V_{n+1}}_{\text{in}} = \underbrace{\overset{5.00}{L_n} + \overset{4.25}{V_1}}_{\text{out}} \Rightarrow V_{n+1} = 8.25 \text{ tons solution}$$

Salt balance:

$$\underbrace{1\text{ ton} + \underset{8.25}{V_{n+1}}\, y_{n+1}}_{\text{in}} = \underbrace{\underset{5.00}{L_n}\, \overset{0.12}{x_n} + \overset{4.25}{V_1}\, \overset{0.20}{y_1}} \Rightarrow$$

$$y_{n+1} = 0.0545.$$

("solution" in entering dry solid is pure NaCl)

Summary so far:

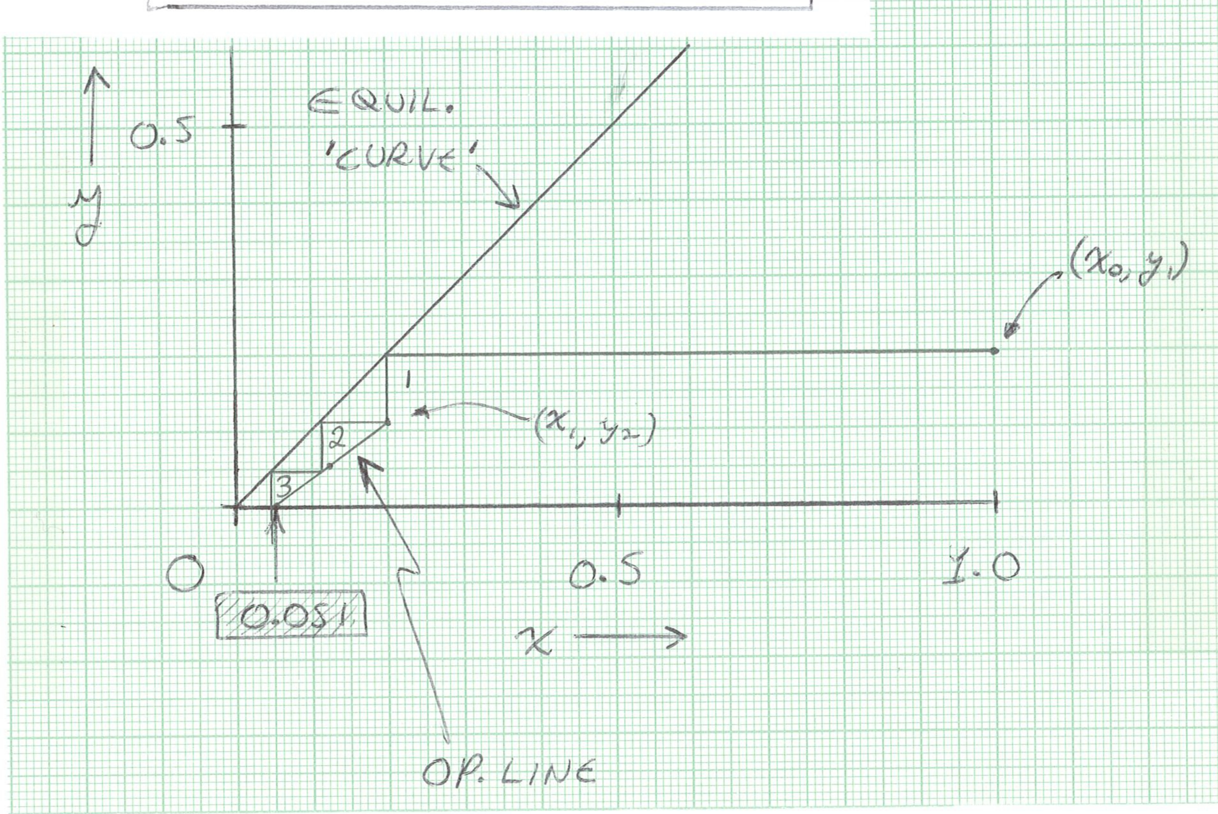
$(x_0, y_1) = (1, 0.20)$
$(x_1, y_2) = (0.20, 0.1111)$
$(x_n, y_{n+1}) = (0.12, 0.0545)$
$(x_N, y_{N+1}) = (0.051, 0)$

smooth operating line

intermediate point

McCabe-Thiele diagram shown below. From graph, need

$\boxed{\text{3 ideal stages}}$
← ANSWER FOR PART (b)



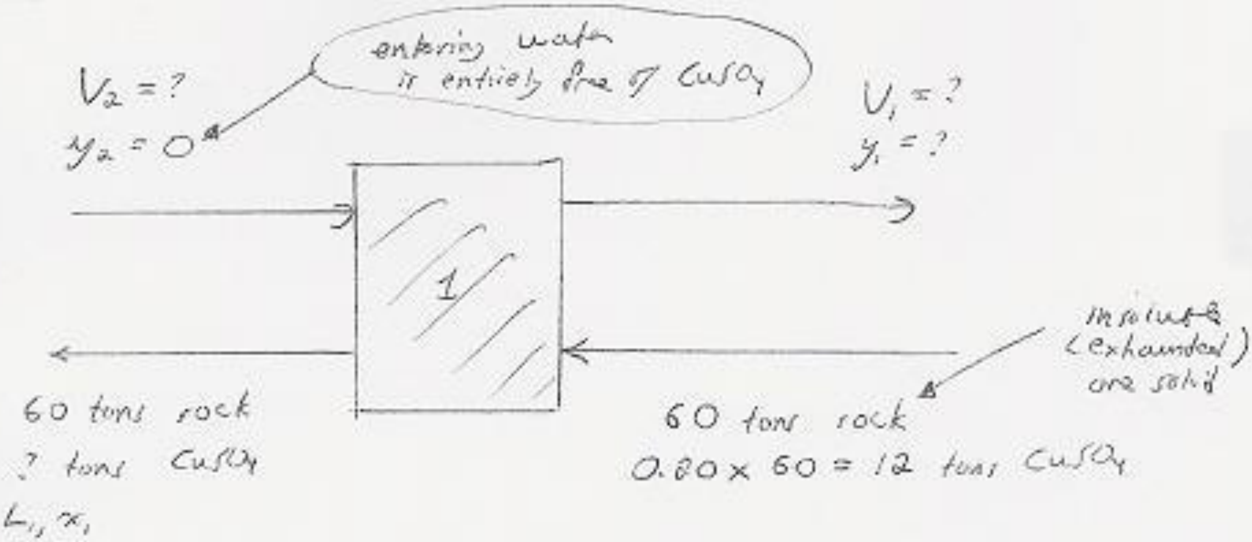
Example 2

$CuSO_4$ is to be leached from copper ore by means of water in a solid extractor comprising one ideal stage. Entrainment of solution by the ore is found by experiment to be as follows:

entrained solution concentration (mass fr. $CuSO_4$)	tons of solution entrained / ton of rock
0	1.45
0.02	1.60
0.04	1.75
0.06	1.90

The entering (unextracted) ore contains 0.20 tons of $CuSO_4$ (and no water) per ton of exhausted ore solid. A 65% recovery of $CuSO_4$ should be achieved. Ore is to be processed at a rate such that 60 tons of exhausted ore solid pass through the extractor per hour. The entering water is entirely free of $CuSO_4$. Given these specifications, what must be the flow rate of the entering water?

Basis: 1 hour



I. Preliminaries:

65 % recovery of $CuSO_4 \Rightarrow (1-0.65)(12 \text{ tons } CuSO_4)$
$= 4.2$ tons $CuSO_4$ in exiting solid

$\boxed{x_1 = 0.04 \text{ by trial \& error}}$ see next page

$L_1 = (1.75)(60 \text{ tons}) = 105$ tons solution

tons entrained solution per ton exhausted ore solid

$$x_1 = \frac{4.2 \text{ tons } CuSO_4}{105 \text{ tons solution}} = 0.040$$

Ideal stage $\Rightarrow$ $y_1 = x_1 = 0.040$

II. Material balance:

$CuSO_4$ $\quad \underbrace{12 + 0}_{in} = \underbrace{4.2 + V_1 y_1}_{out} \Rightarrow V_1 = 195$ tons

0.040

Trial & error

Guess $x_1 = 0.02 \Rightarrow$

$$L_1 = \frac{1.60 \text{ tons solution}}{\text{ton rock}} \times 60 \text{ tons rock}$$

$$= 96 \text{ tons solution}$$

$$\Rightarrow x_1 = \frac{4.2 \text{ tons } CuSO_4}{96 \text{ tons solution}} = \cancel{0.04375}$$

bad guess $\neq 0.02$

Guess $x_1 = 0.06 \Rightarrow$

$$L_1 = \frac{1.90 \text{ tons solution}}{\text{ton rock}} \times 60 \text{ tons rock}$$

$$= 114 \text{ tons solution}$$

$$\Rightarrow x_1 = \frac{4.2 \text{ tons } CuSO_4}{114 \text{ tons solution}} = \cancel{0.03684}$$

bad guess $\neq 0.06$

Guess $x_1 = 0.04 \Rightarrow$

$$L_1 = \frac{1.75 \text{ tons solution}}{\text{ton rock}} \times 60 \text{ tons rock}$$

$$= 105 \text{ tons solution}$$

$$\Rightarrow x_1 = \frac{4.2 \text{ tons } CuSO_4}{105 \text{ tons solution}} = 0.0400$$

BINGO!

Solution ($CuSO_4$ + water)

$$\underbrace{12 + V_2}_{\text{in}} = \underbrace{\overset{105}{L_1} + \overset{195}{V_1}}_{\text{out}} \Rightarrow V_2 = 288 \text{ tons}$$

(in 1 h)

"solution" in incoming ore is pure $CuSO_4$

$\boxed{\therefore \text{ flow rate of entering water is } 288 \text{ tons/h}}$