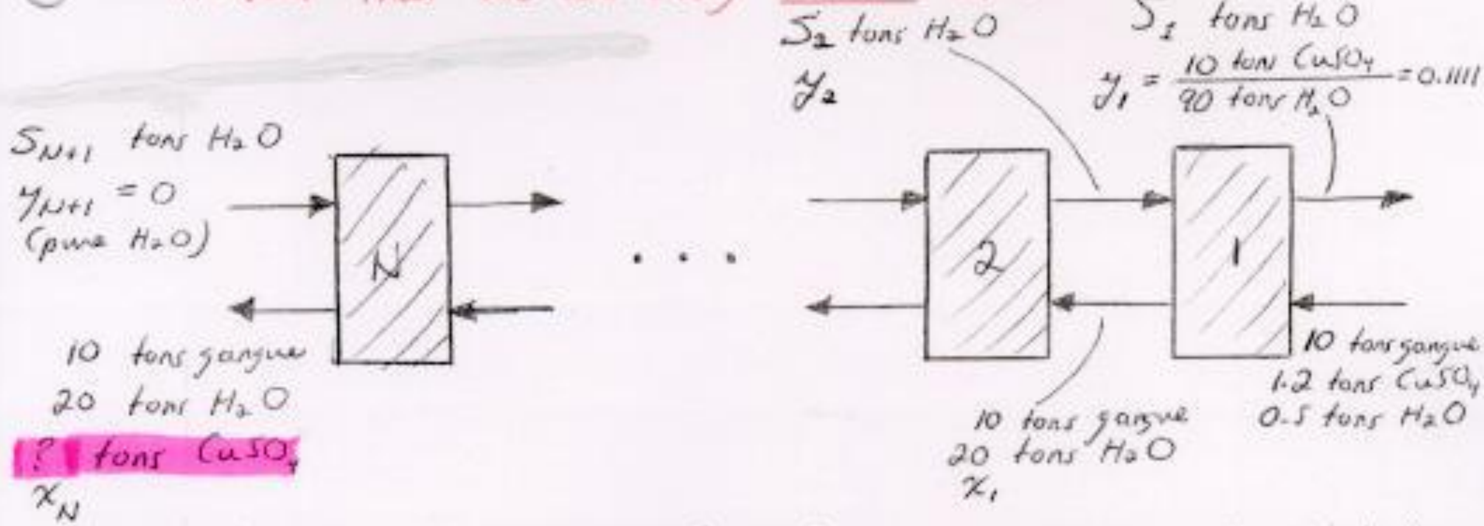
PROBLEMS

23.1. Roasted copper ore containing the copper as $CuSO_4$ is to be extracted in a countercurrent stage extractor. Each hour a charge consisting of 10 tons of inert solids, 1.2 tons of copper sulfate, and 0.5 ton of water is to be treated. The strong solution produced is to consist of 90% H_2O and 10% $CuSO_4$ by weight. The recovery of $CuSO_4$ is to be 98 percent of that in the ore. Pure water is to be used as the fresh solvent. After each stage, 1 ton of inert solids retains 2 tons of water plus the copper sulfate dissolved in that water. Equilibrium is attained in each stage. How many stages are required?

"gangue" = insoluble rock

Method (1): use solvent amounts + mass ratio.

Notation S for amounts in overflow (V phase) emphasizes the fact that we are using solvent amts.



I. Preliminaries and overall balances around entire extraction battery

Recover 98% of the $CuSO_4$ in the ore $\Rightarrow$

$(1-0.98) \times 1.2$ tons = **0.024 tons $CuSO_4$ remaining in exiting solid**

$$x_N = \frac{0.024 \text{ tons } CuSO_4}{20 \text{ tons } H_2O} = 0.0012$$

Note: 1 ton inert gangue retains 2 tons of H_2O (plus additional mass of dissolved $CuSO_4$), not 2 tons of solution. This retention is independent of concentration of $CuSO_4$ in the solution.

$CuSO_4$ balance:

$$\underbrace{1.2 + 0}_{in} = \underbrace{0.1111\, S_1 + 0.024}_{out} \Rightarrow S_1 = 10.58 \text{ tons } H_2O$$

H_2O balance:

$$\underbrace{0.5 + S_{N+1}}_{in} = \underbrace{S_1 + 20}_{out} \Rightarrow S_{N+1} = 30.08 \text{ tons } H_2O$$

II. Balances around first stage.

Exiting streams at equilibrium $\Rightarrow x_1 = y_1 = 0.1111$

$$\underbrace{0.5 + S_2}_{in} = \underbrace{20 + S_1}_{out} \Rightarrow S_2 = 30.08 \text{ tons } H_2O$$

(S_1 = 10.58)

(S_2) same as S_{N+1}.
In fact $S_{N+1}, S_N, \dots, S_3, S_2$ are <u>all</u> equal because water retention by gangue is independent of solution concentration.

<u>$CuSO_4$ balance:</u>

$$\underbrace{1.2 + S_2 y_2}_{in} = S_1 y_1 + x_1 (20) \Rightarrow y_2 = 0.0730$$

(S_2 = 30.08 tons; S_1 = 10.58 tons; y_1 = 0.1111; $x_1 = y_1 = 0.1111$)

Operating line between (x_1, y_2) and (x_N, y_{N+1}) will be straight, because (i) H_2O flow rates for liquid and solid (retained H_2O) phases are constant, and (ii) we use concentration variables in units of tons $CuSO_4$ per ton H_2O.

III. Number of stages.

Going from stage 2 to N (i.e., <u>not</u> counting first stage), and using book notation,

$y_b = y_{N+1} = 0$
$x_b = x_N = 0.0012$
$y_b^* =$ liq. phase conc. in equil. with x_b
$= x_b$, because for leaching the equil. relation is $y = x$.
$= 0.0012$

$y_a = y_2 = 0.0730$
$x_a = x_1 = 0.1111$
$y_a^* =$ liq. phase conc. in equil. with x_a

From eq. (17-24) on p. 465,

$$N_{2\to N} = \frac{\log\left(\frac{y_b - y_b^*}{y_a - y_a^*}\right)}{\log\left(\frac{y_b - y_a}{y_b^* - y_a^*}\right)} = \frac{\log\left(\frac{0 - 0.0012}{0.0730 - 0.1111}\right)}{\log\left(\frac{0 - 0.0730}{0.0012 - 0.1111}\right)}$$

$$= 8.45$$

(can also use eq. (17-27) on p. 466 — is mathematically equivalent)

Total number of ideal stages required = 1 + 8.45 = **9.45 ideal stages.**

Method (2) use solution amounts & mass fraction

Composition-dependent retention of solution by rock

mass fraction $CuSO_4$ (x)	tons of solution retained per ton of (insoluble) rock
0	2
0.005	2.0101
0.01	2.0202
0.05	2.1053
0.1	2.2222

Where do these numbers come from? Consider 1 ton of rock retaining solution with $CuSO_4$ mass fraction x:

L = amt. of

$$x = \frac{CuSO_4}{CuSO_4 + \text{water}} = \frac{Lx}{Lx + 2}$$

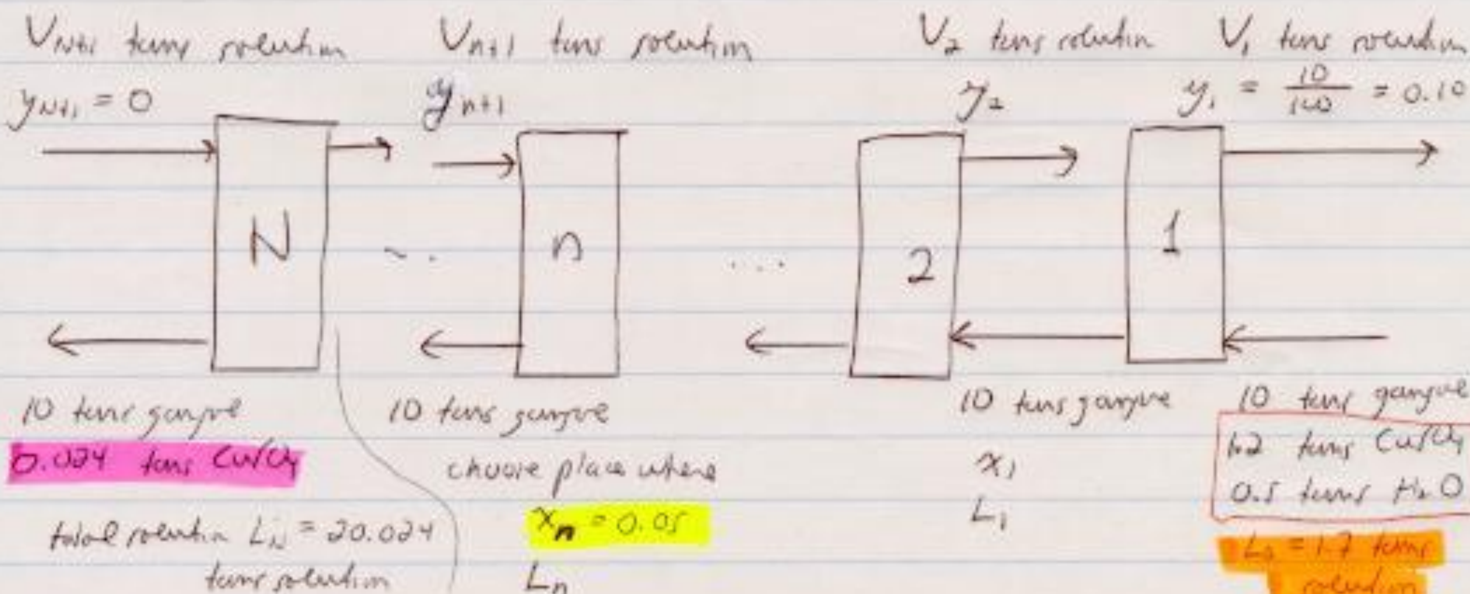
(1 ton of rock retains 2 tons of H_2O (+ $CuSO_4$ dissolved in it))

or $1 = \frac{L}{Lx+2}$ or $L = \frac{2}{1-x}$ = amt. of solution retained by one ton of rock

Now ready to solve problem.

I. Prelim. + overall balances

Given $x_N = 0.0012$. Interpolate in table ⇒
1 ton of rock retains 2.0024 tons of solution ⇒
L_N = (10 tons of rock)(2.0024 tons solution / ton rock)
= 20.024 tons solution
⇒ x_N = 0.024 tons $CuSO_4$ / 20.024 tons solution
= 0.0012 same! given good.



CuSO₄ balance: $\underbrace{1.2 + 0}_{in} = y_1 V_1 + 0.024$ (0.10)

⇒ V_1 = 11.760 tons solution

Solution balance: $\underbrace{1.7 + V_{N+1}}_{in} = \underbrace{V_1 + 20.024}_{out}$ (11.760)

$\Rightarrow V_{N+1} = 30.084$ tons solution

II. Balance around 1st stage.

Equil.: $x_1 = y_1 = 0.10 \Rightarrow L_1 = (10)(2.2222)$ (from table)

$= 22.222$ tons solution

Solution balance:

$$\underbrace{1.7 + V_2}_{in} = \underbrace{V_1 + L_1}_{out}$$

(11.760)

$\Rightarrow V_2 = 32.282$ tons solution

$CuSO_4$ balance:

$$\underbrace{1.2 + y_2 V_2}_{in} = \underbrace{y_1 V_1 + x_1 L_1}_{out}$$

(0.10) (11.760) (0.10) (22.222)

$\Rightarrow y_2 = 0.06809$

III. Intermediate point.

Consider control vol. from right end of apparatus to point where $x_n = 0.05$. From table $\Rightarrow$

$L_n = (10)(2.1053) = 21.053$ tons solution

Solution balance:

$$\underbrace{1.7 + V_{n+1}}_{in} = \underbrace{V_1 + L_n}_{out}$$

(11.760)

$\Rightarrow V_{n+1} = 31.113$ tons solution

$CuSO_4$ balance:

$$\underbrace{1.2 + y_{n+1} V_{n+1}}_{in} = \underbrace{y_1 V_1 + x_n L_n}_{out}$$

(0.10) (11.760) (0.05) (21.053)

$\Rightarrow y_{n+1} = 0.03306$

IV. So:

$$(x_0, y_1) = (0.7059, 0.1)$$
$$(x_1, y_2) = (0.1, 0.06809)$$
$$\vdots$$
$$(x_n, y_{n+1}) = (0.05, 0.03306)$$
$$\vdots$$
$$(x_N, y_{N+1}) = (0.0012, 0)$$

Construct op. diagram 4 count stages (next page)
⟹ need **≈ 10 stages**   Same answer as by Method (1)!

Book 2:1 in terms of mass fraction