CBE 34487

6/25/20

MULTI STAGE OPERATIONS

CONSIDER A LIQUID MIXTURE

Thermodynamic Equilibrium Diagrams

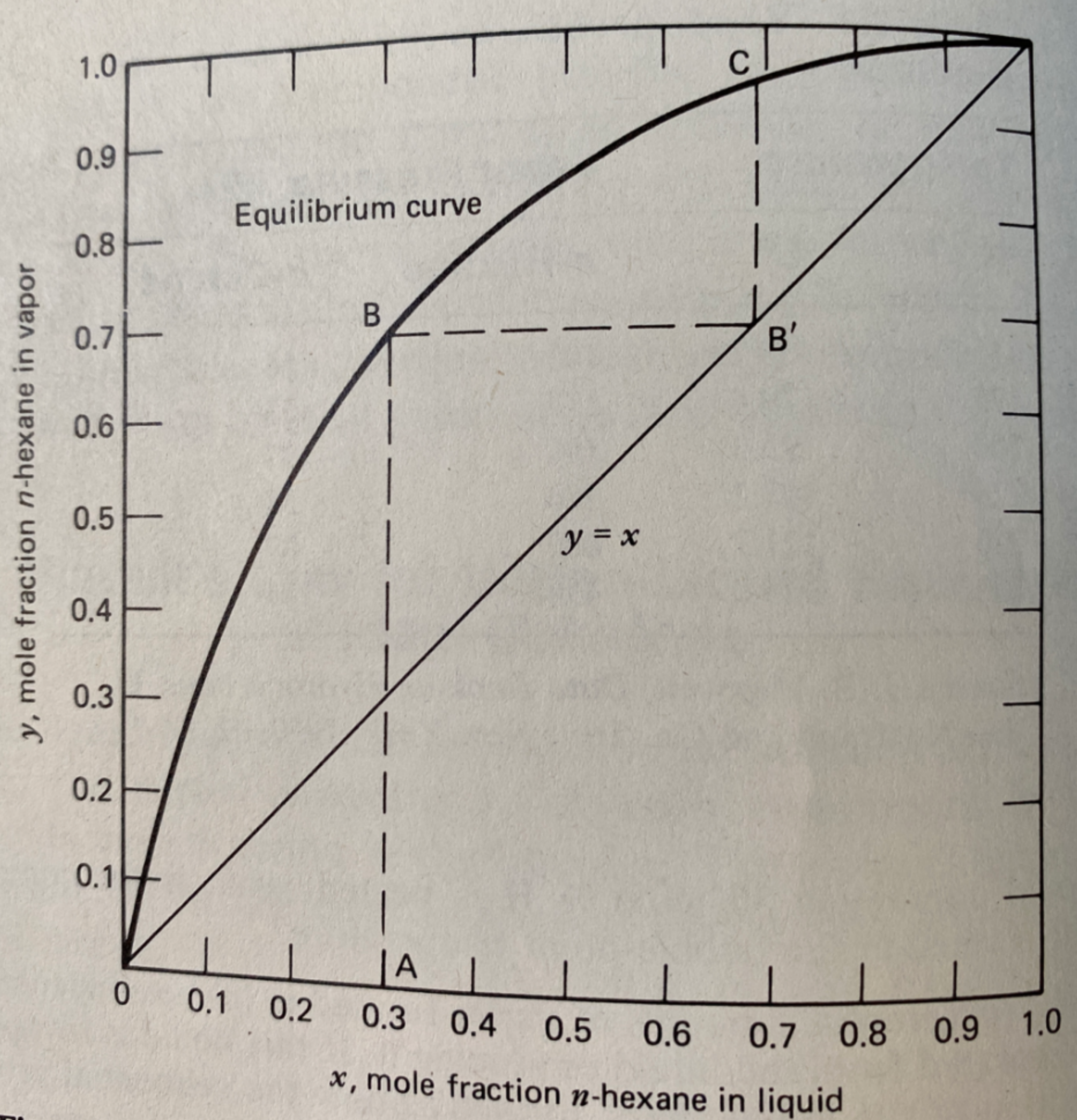


Figure 3.3. The x-y diagram for n-hexane–n-octane, at 101 kPa. (E. J. Henley and E. M. Rosen, *Material and Energy Balance Computations*, John Wiley & Sons, New York, © 1969.)

SUPPOSE $x = .3$

$y = .7$

IT IS DESIRED TO GET HEXANE AT ~ 0.99 PURITY ?

WHAT CAN YOU DO. ?

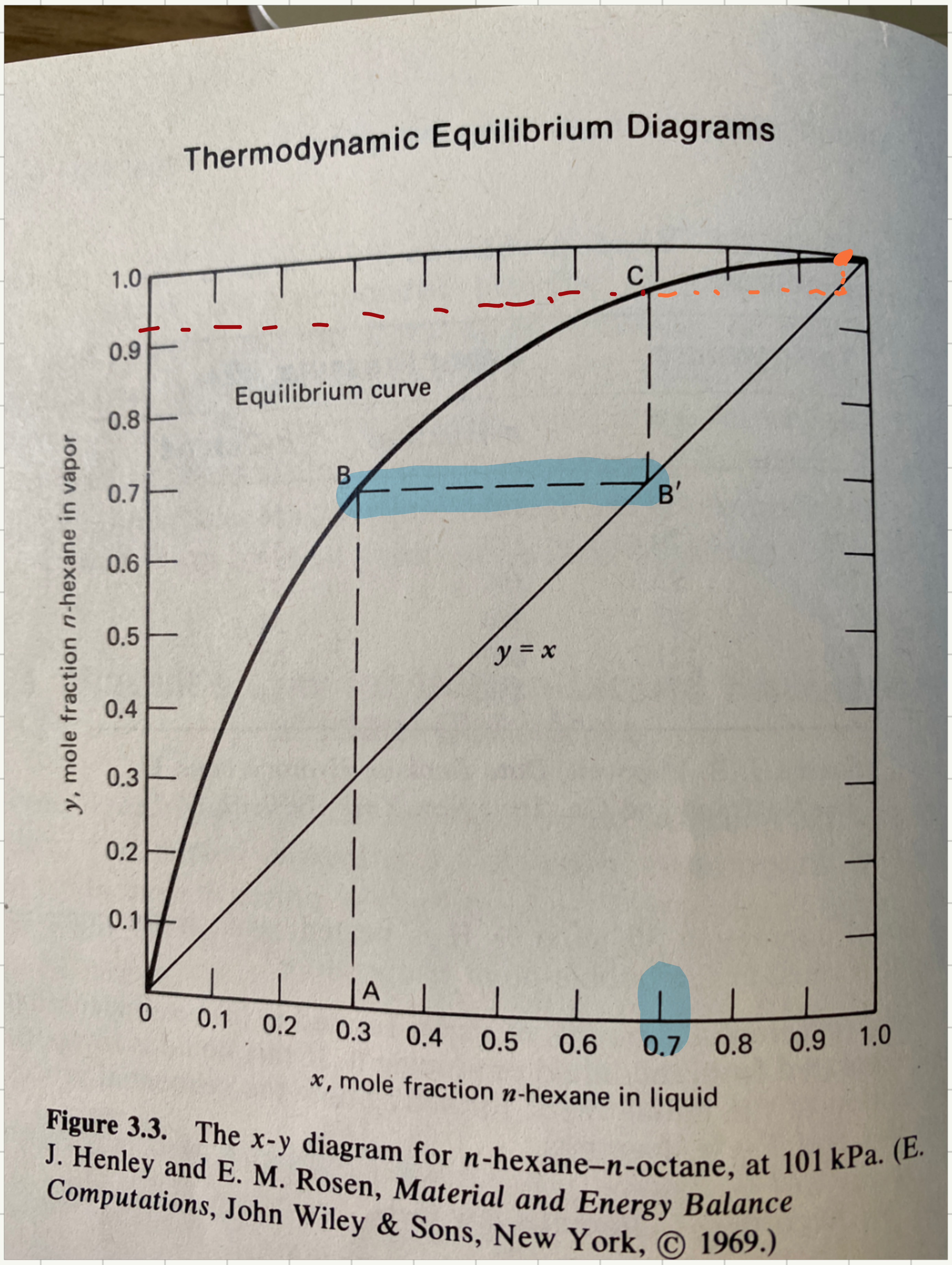


Figure 3.3. The x-y diagram for n-hexane–n-octane, at 101 kPa. (E. J. Henley and E. M. Rosen, *Material and Energy Balance Computations*, John Wiley & Sons, New York, © 1969.)

WE COULD COLLECT SOME OF THE VAPOR AND CONDENSE. OF COURSE, IF WE PICKED A SIGNIFICANT FRACTION, THE CONCENTRATION WOULD DROP..

NOW WE HAVE VAPOR AT y=.93

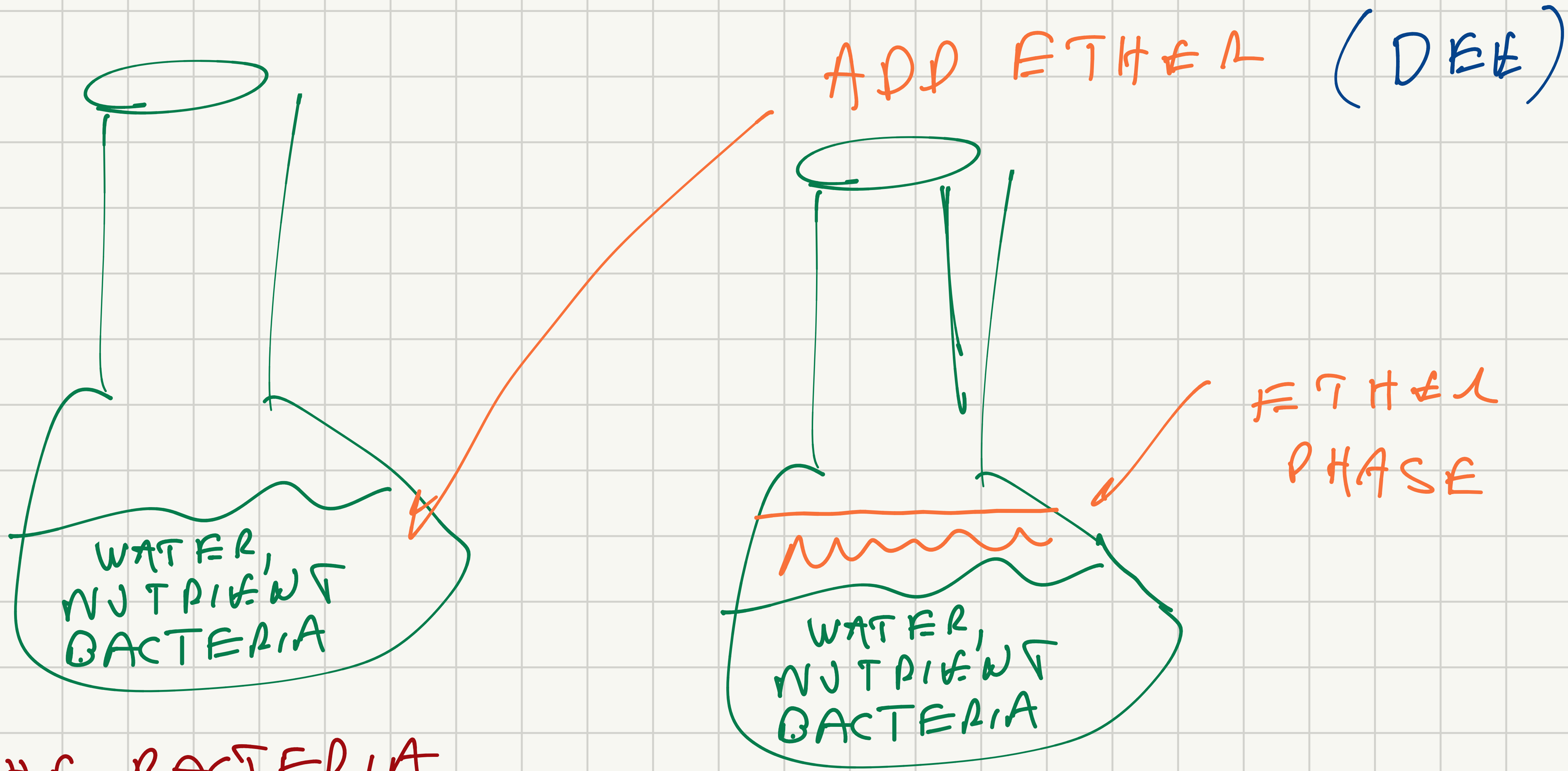
NOW CONDENSE THIS AND X=.93

IF WE VAPORIZE AGAIN, WE WOULD BE CLOSE TO .99

OF COURSE WE WOULD HAVE ONLY A SMALL AMOUNT OF PRODUCT.

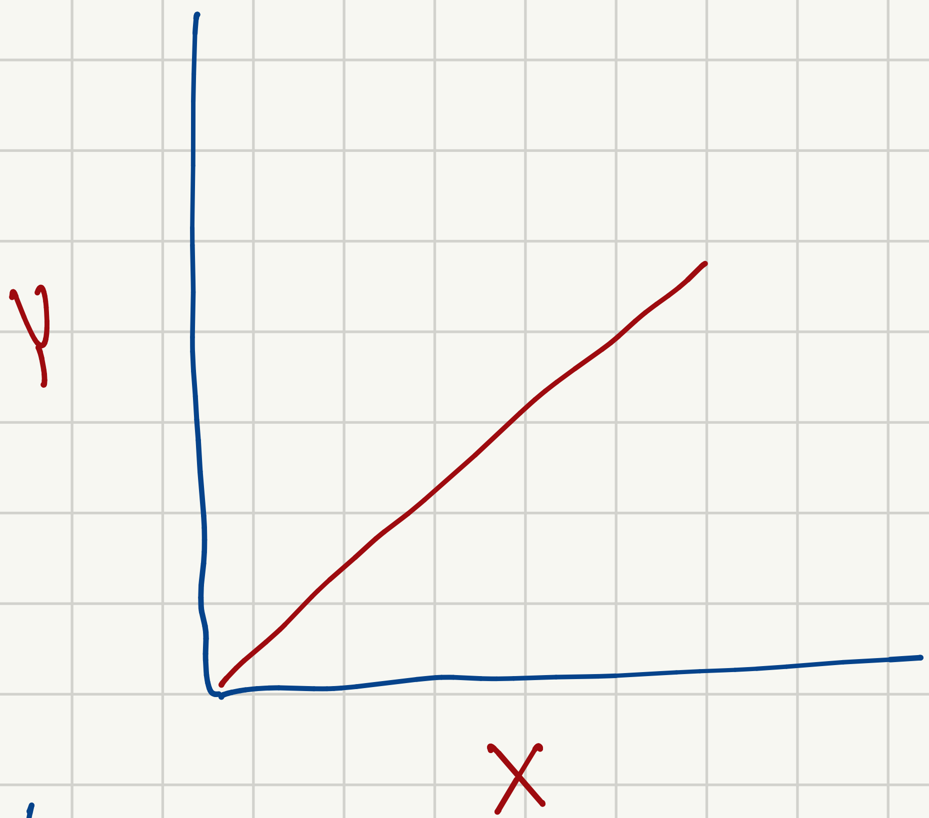
WE SEE THE PRINCIPLE !!

HOW ABOUT EXTRACTION.



THE BACTERIA HAVE PRODUCED DESIRED COMPOUND

IT IS AT LEAST A LITTLE HYDROPHOBIC

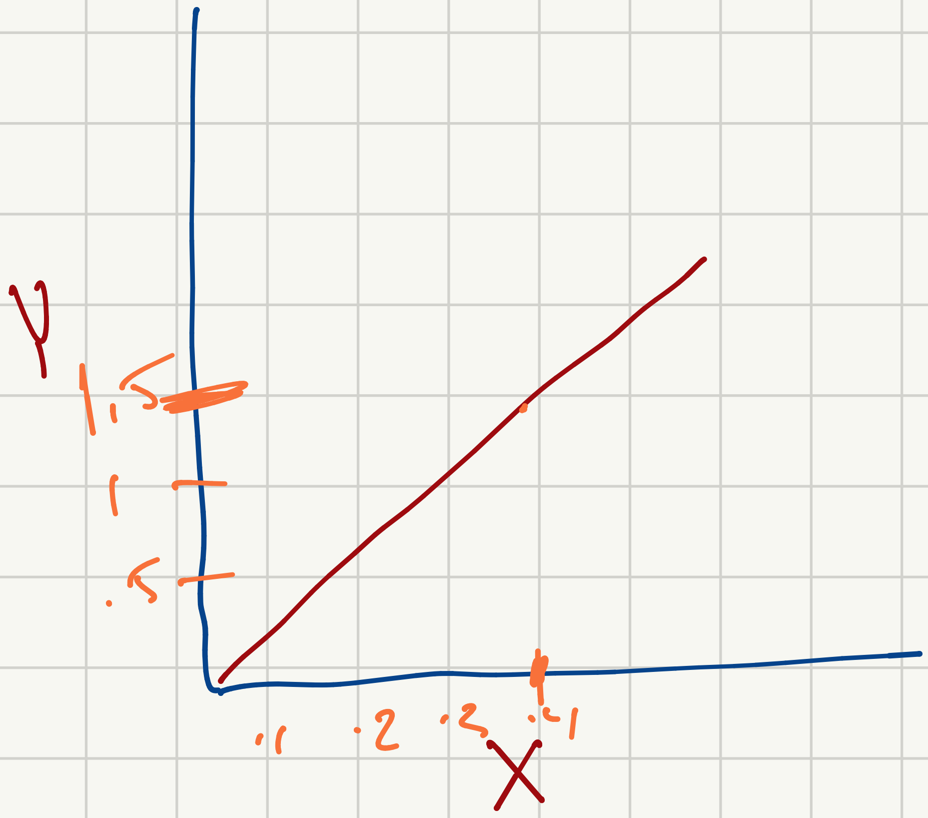


EQUILIBRIUM PARTITIONING

$$Y = m X$$

$$X = \frac{\text{MASS OF P.C.}}{\text{MASS } H_2O}$$

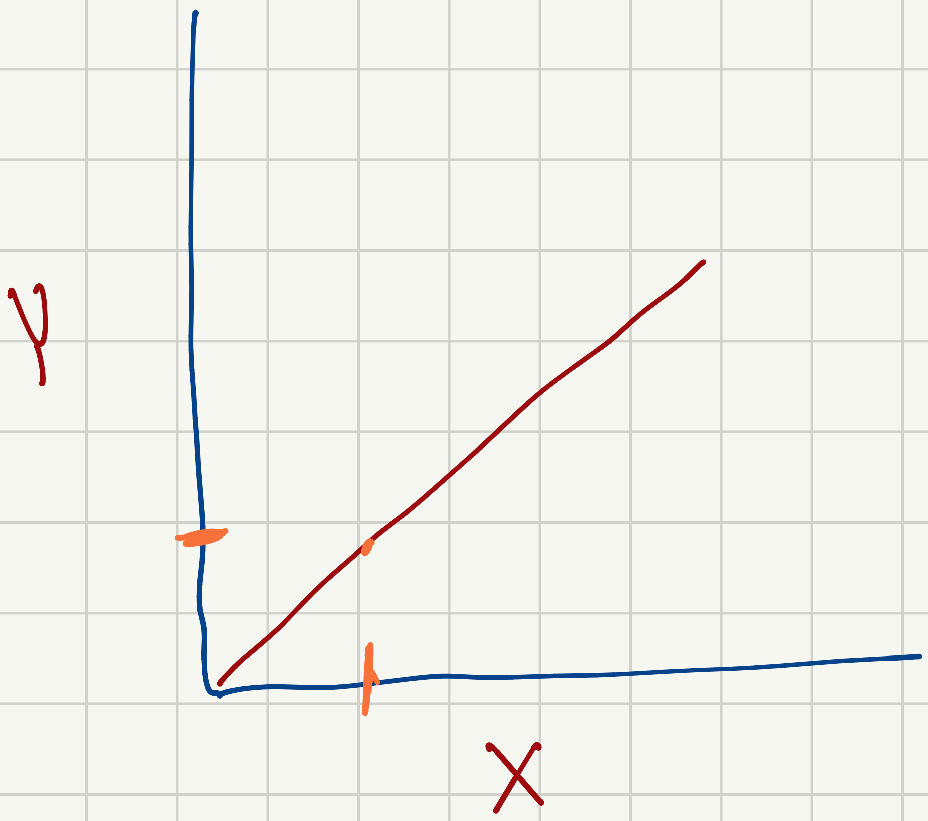
$$Y = \frac{\text{MASS OF P.C.}}{\text{MASS DEE}}$$



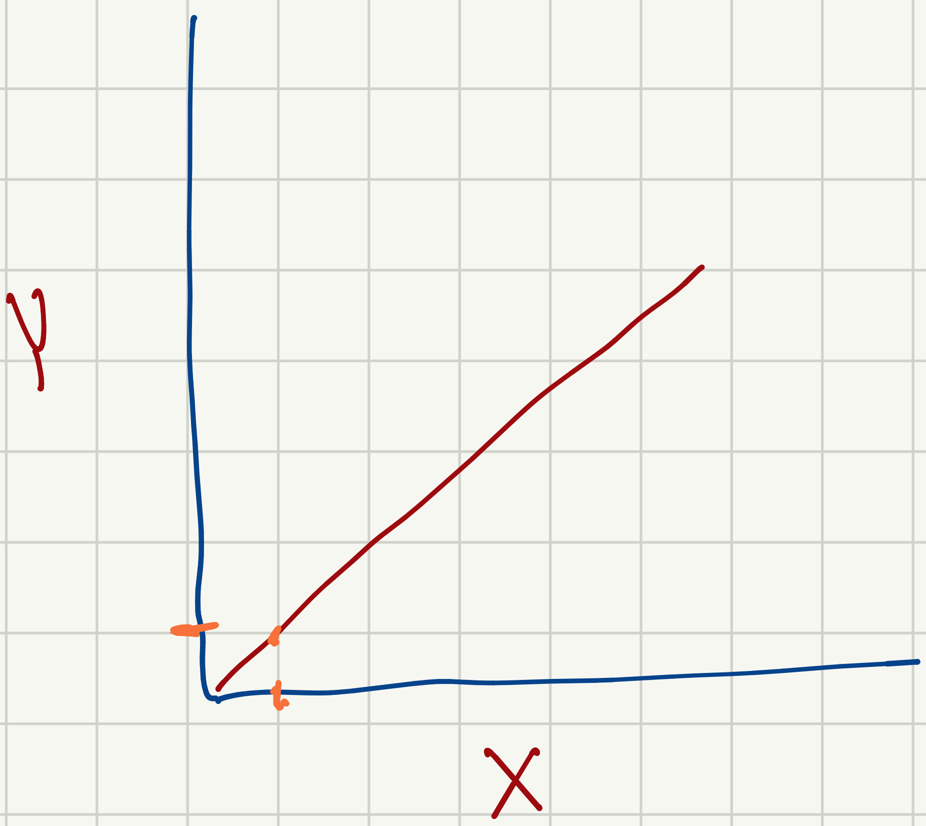
SUPPOSE WE ADD 500 ML OF DEF TO 500 BR

$X = 0.4$

$Y = 1.5$



WE COULD ADD MORE



OR MORE

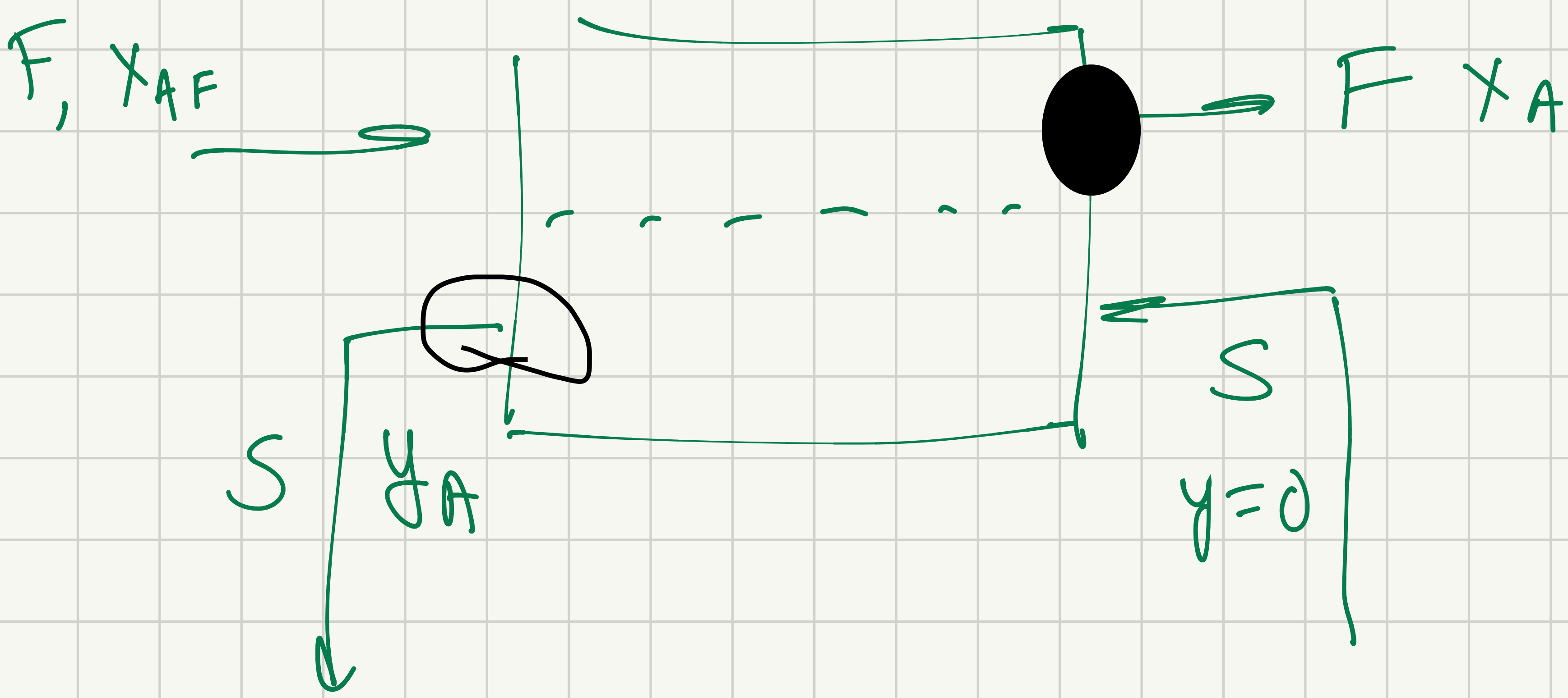
THIS ACCOMPLISHED THE GOAL OF REMOVING VALUABLE DRUG FROM BOTH BUT IT IS INCREASINGLY DILUTE!!

CONSIDER EXTRACTION

$$Y = m X$$

FEED STREAM, F [=] $\frac{\text{MASS}}{\text{TIME}}$

SOLVENT STREAM S [=] $\frac{\text{MASS}}{\text{TIME}}$



$$\cancel{y_S}^{\,0} S + x_{AF} F = F x_A + S y_A$$

(IN) (OUT)

AMOUNT REMAINING IN FEED STREAM

$$y_A = m x_A$$

$$x_{AF} F = F x_A + S m x_A$$

$$\frac{x_A}{x_{AF}} = \frac{1}{1 + \frac{mS}{F}}$$

$$\frac{x_A}{x_{AF}} = \frac{1}{1+\frac{mS}{F}}$$

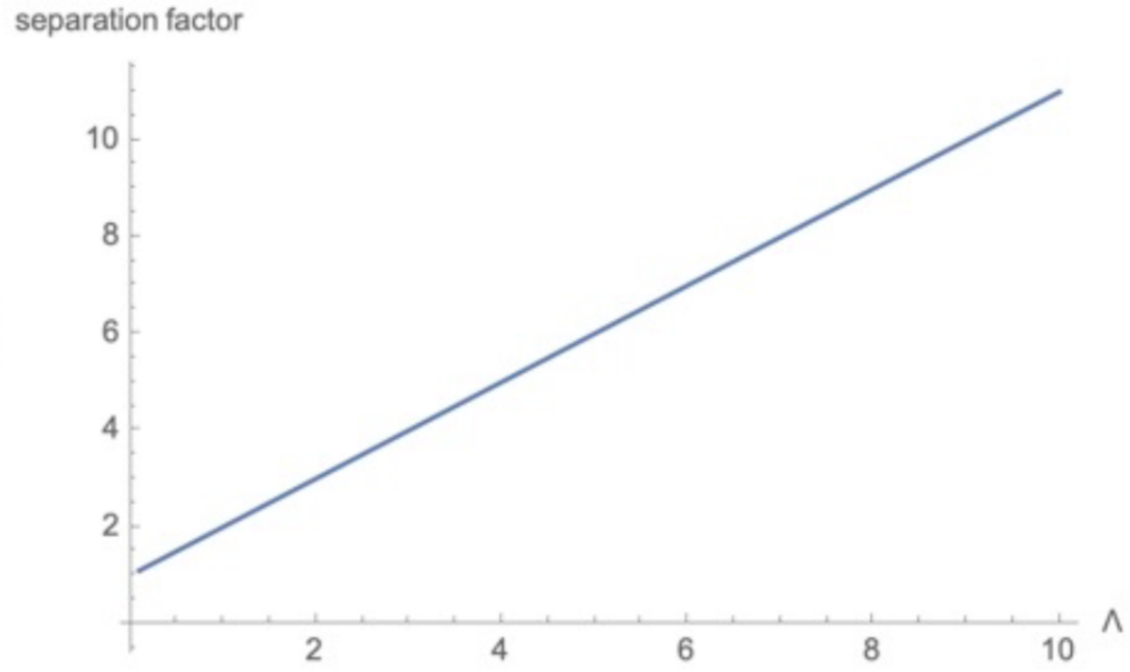
PICK, $\Lambda \equiv \frac{mS}{F}$, $\xi \equiv \frac{x_{AF}}{x_A}$

"BIGGER" IS BETTER

$$\xi = 1 + \Lambda$$

```
In[56]:= Plot[1 + Λ, {Λ, .1, 10}, AxesLabel → {"Λ", "separation factor"}]
```

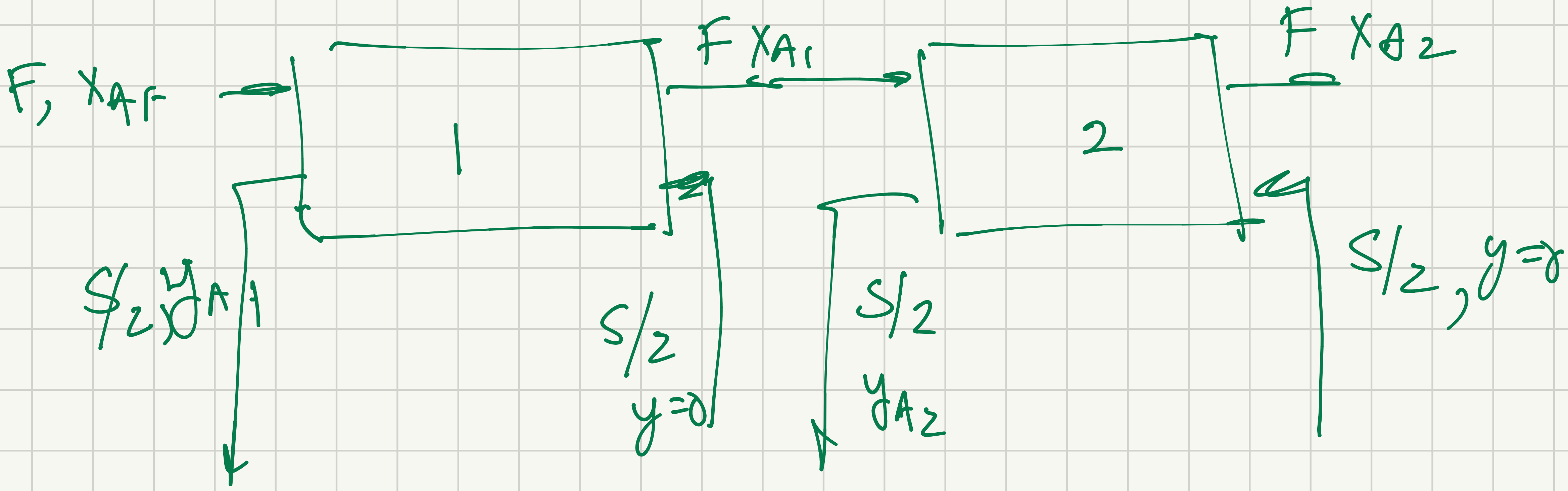
Out[56]=



m MAY BE FIXED BY CHEMISTRY

OTHERWISE MUST INCREASE S!!!

SUPPOSE



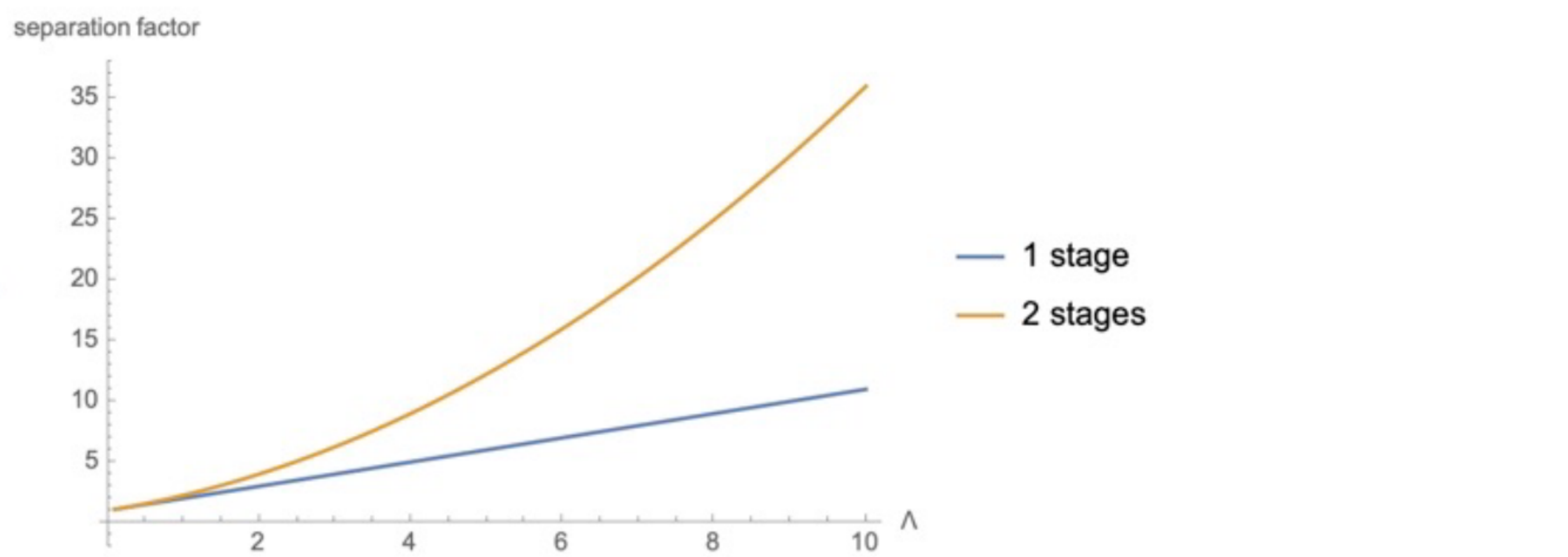
(1) $F\,x_{AF} = F\,x_{A1} + \frac{S}{2} y_{A1}$ $\qquad y = mx$

(2) $F\,x_{A1} = F\,x_{A2} + \frac{S}{2} y_{A2}$

$$\xi_2 = \left(1 + \frac{\Lambda}{2}\right)^2$$

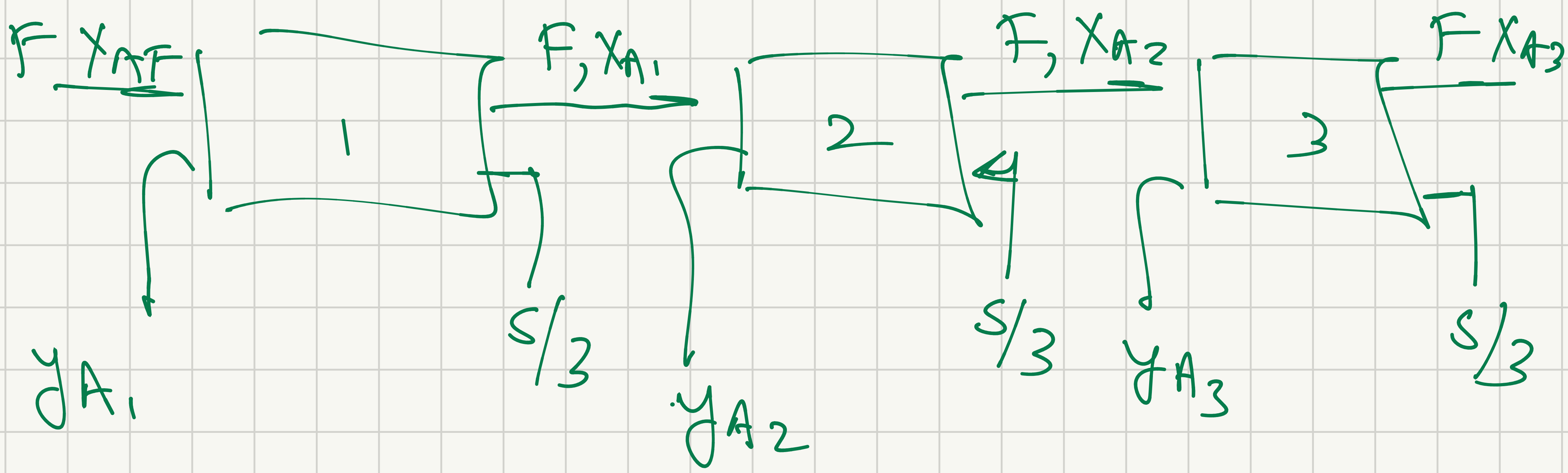
TWO STAGES IS BETTER

```
Plot[{1 + Λ, (1 + Λ/2)^2}, {Λ, .1, 10}, AxesLabel → {"Λ", "separation factor"},
 PlotLegends → {"1 stage", "2 stages"}]
```



HOW ABOUT 3 ..

CROSS CURRENT



$$F X_{AF} = F X_{A_1} + y_{A_1} \frac{S}{3}$$

$$F X_{A_1} = F X_{A_2} + y_{A_2} S/3$$

$$F X_{A_2} = F X_{A_3} + y_{A_S} S/3$$

$$\xi_3 = \frac{X_{AF}}{X_{A_3}} = \left(1 + \frac{\Delta}{3}\right)^3$$

WE CAN NOW GUESS ..

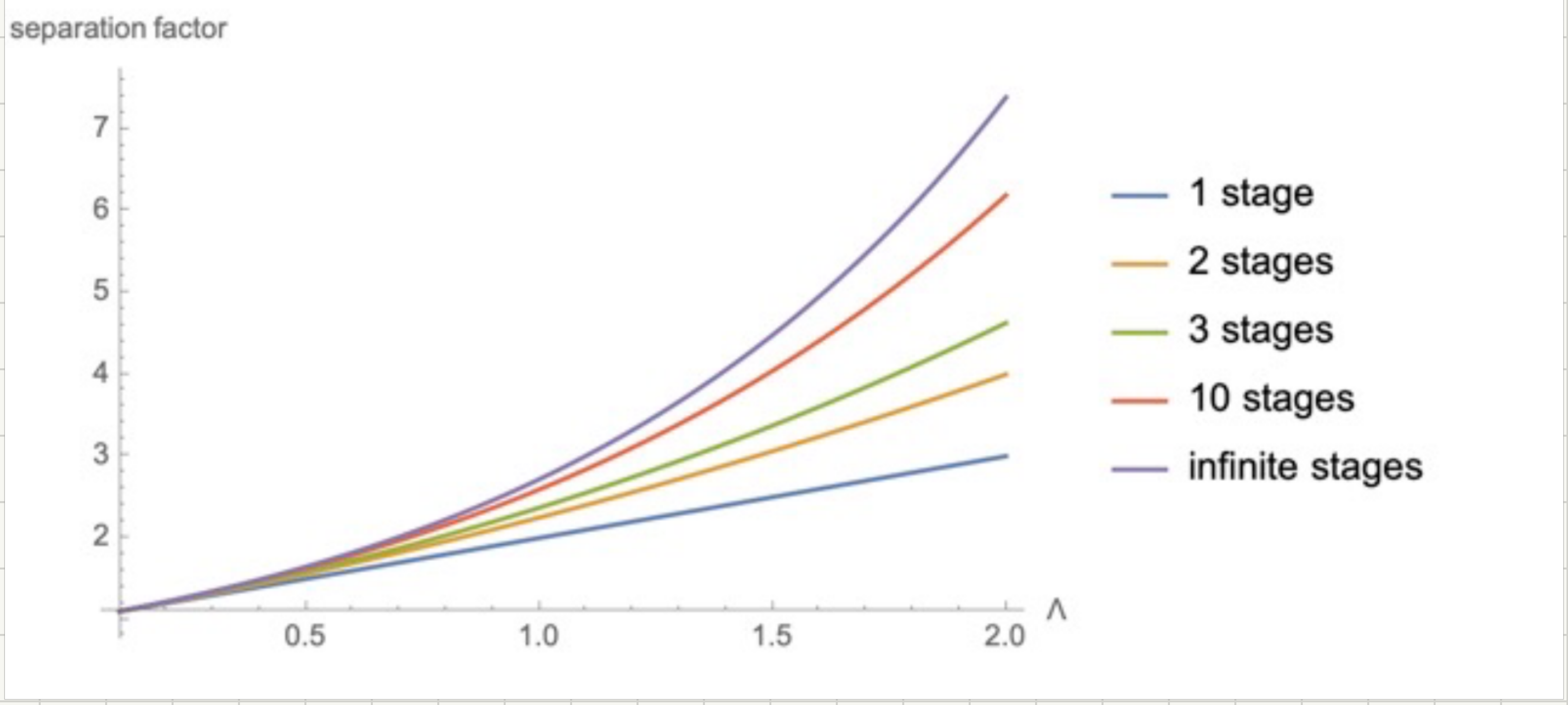
$$\xi_n = \left(1 + \frac{\Delta}{n}\right)^n$$

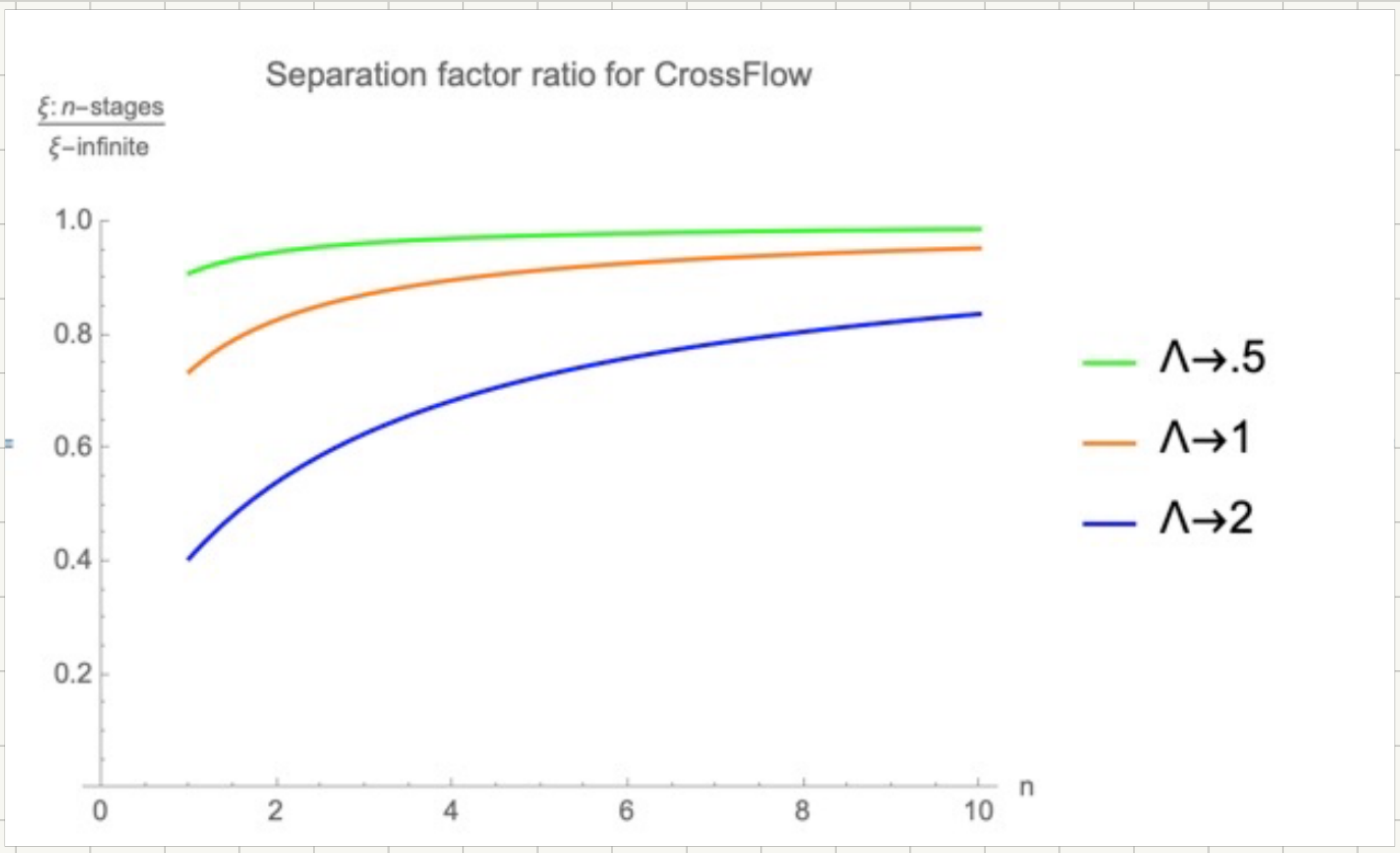
AS $n \to \infty$ . . . .

$$\xi_{\infty} = \text{Exp}(\Lambda)$$

WHICH SEEMS REALLY GOOD!!

```
Plot[ {1 + Λ, (1 + Λ / 2) ^2, (1 + Λ / 3) ^3, (1 + Λ / 10) ^10,  Exp[Λ]}, {Λ
 AxesLabel → {"Λ", "separation factor"},
 PlotLegends → {"1 stage", "2 stages", "3 stages", "10 stages", "infi
```





IF $\Lambda > 1$

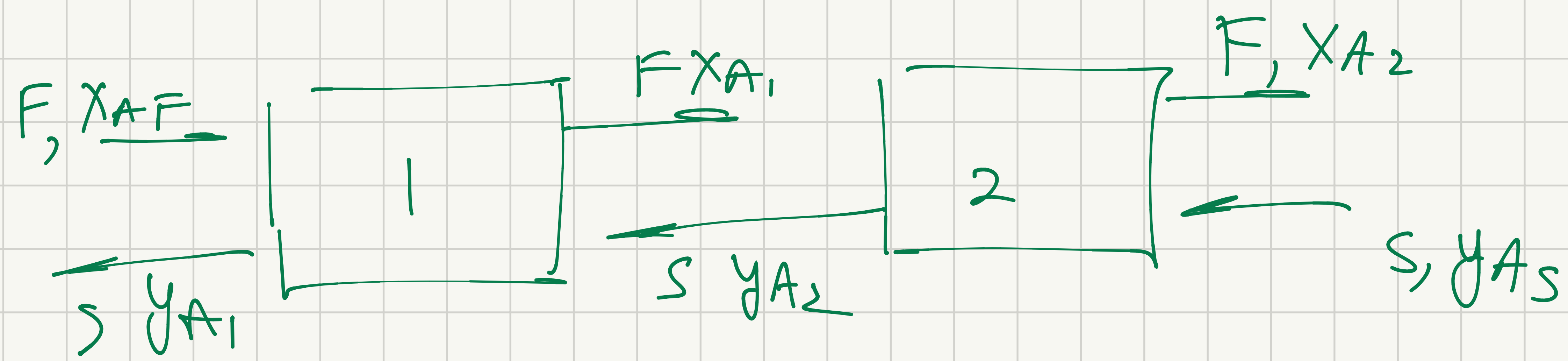
MORE STAGES HELPS FOR QUITE A LOT OF STAGES

IF YOU NEED IT!!

HOWEVER... WE CAN DO EVEN BETTER!!

(CAN AN EXPONENTIAL BE BEAT?)

COUNTER CURRENT



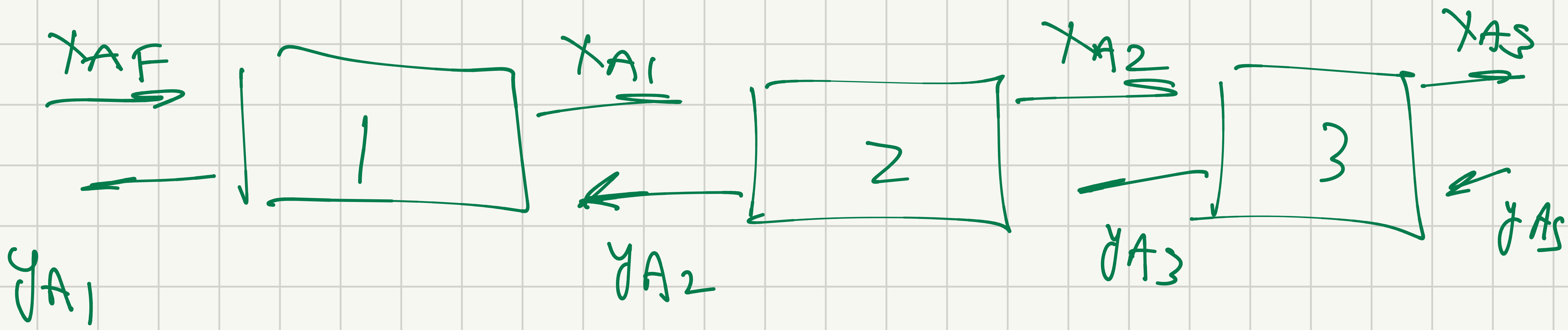
(1) $$F x_{AF} + S y_{A2} = F x_{A1} + S y_{A1}$$

(2) $$F x_{A1} + S y_{AS} = F x_{A2} + S y_{A2}$$

$$x_{A2} = \frac{x_{AF}}{1 + \Lambda + \Lambda^2}$$

$$\xi_2 = 1 + \Lambda + \Lambda^2$$

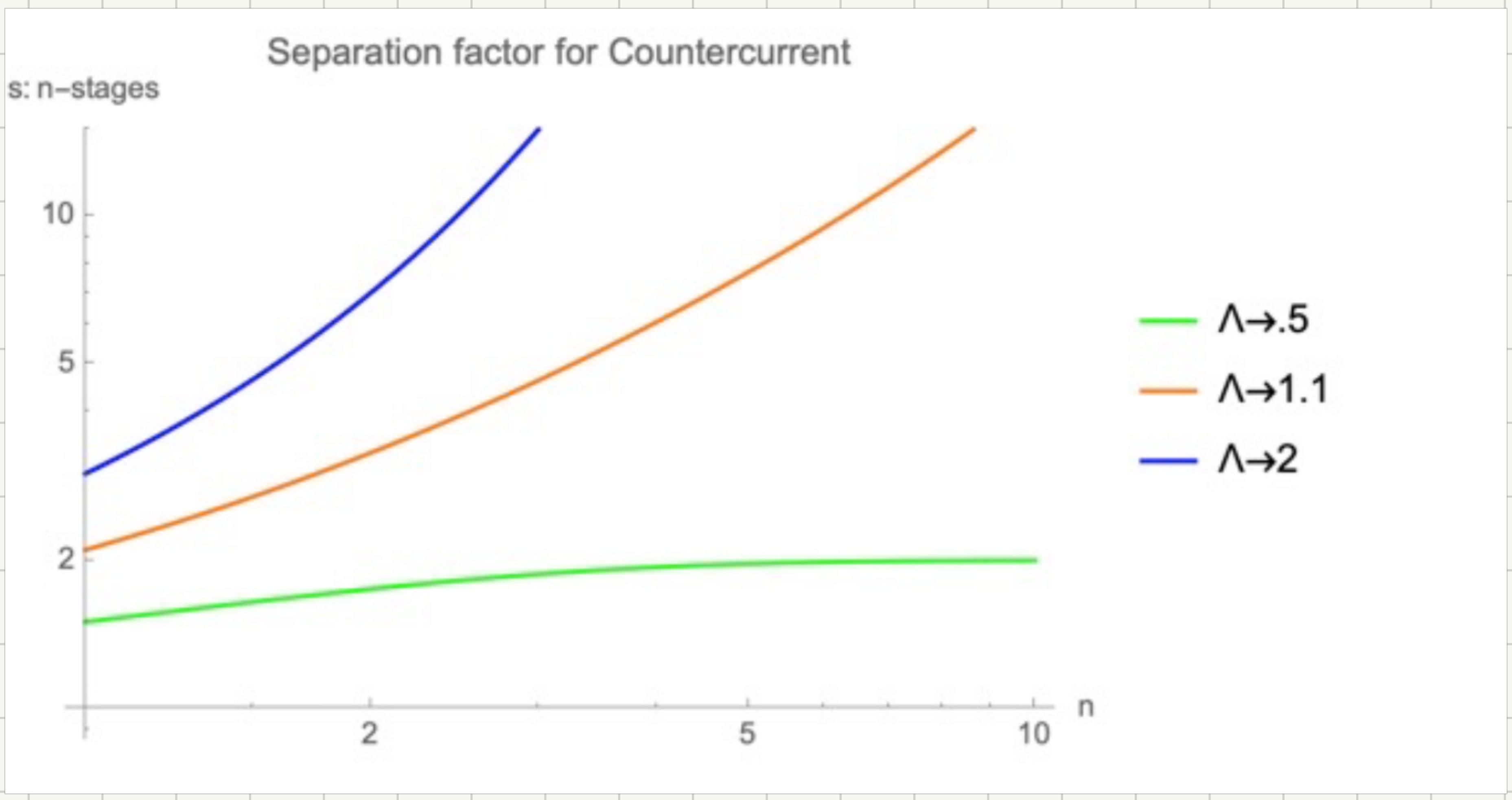
LET'S CHECK 3 ....



$$\frac{x_{A3}}{x_{AF}} = \frac{1}{1+\Lambda+\Lambda^2+\Lambda^3}$$

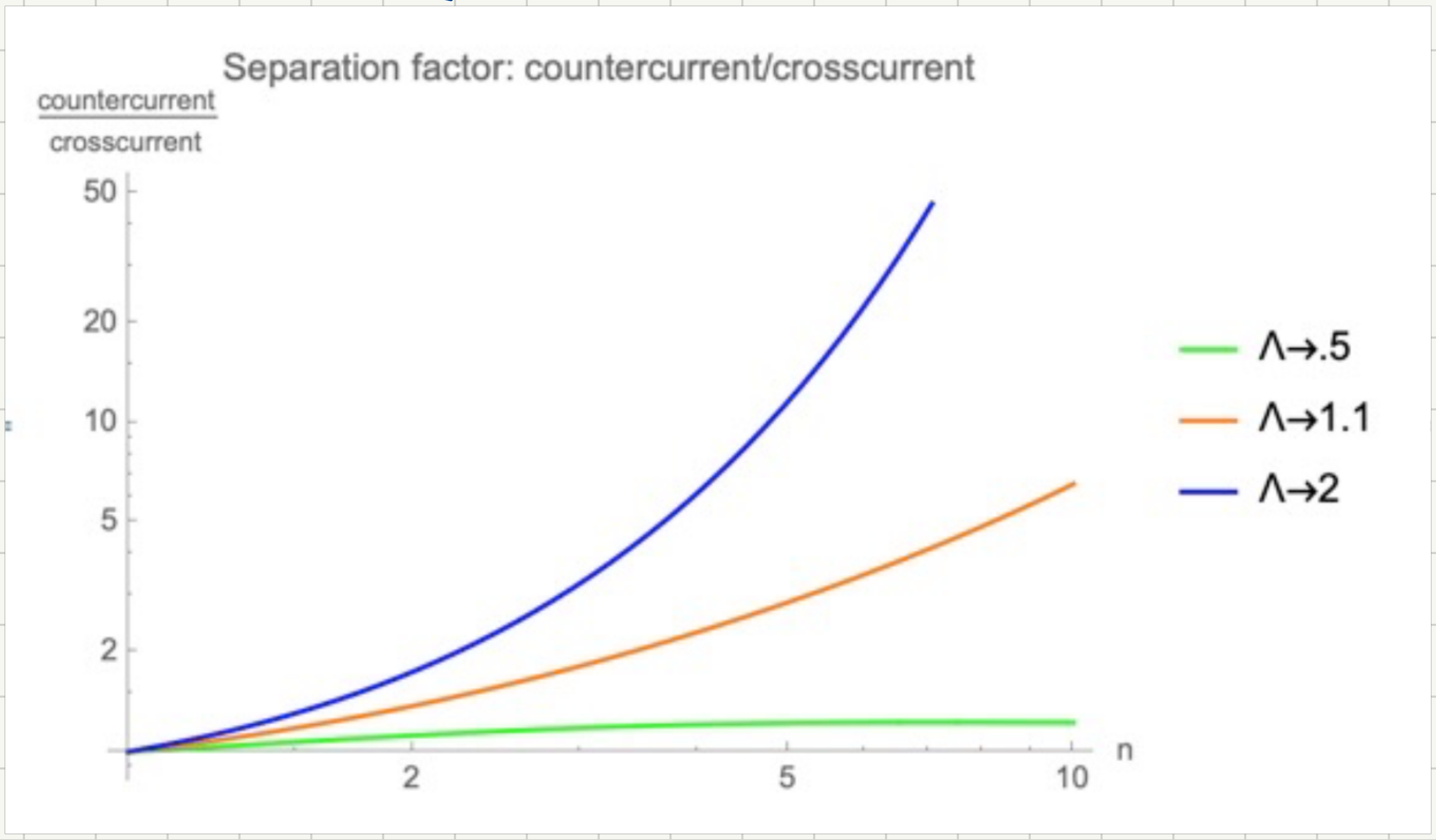
SO WE HAVE

$$\xi_n = \sum_{i=0}^{n} \Lambda^i$$



IF $\Lambda > 0$ CAN GET AS LARGE OF ξ AS YOU NEED

WE COMPARE CROSSCURRENT TO COUNTERCURRENT...



IF $\Lambda > 1$, SUBSTANTIAL BENEFIT

CROSSCURRENT $\xi_\infty = \exp(\Lambda)$

IF Λ IS LIMITED, ξ IS LIMITED

COUNTERCURRENT

$$\xi_\infty = \sum_{i=0}^{\infty} \Lambda^i$$

IF $\Lambda > 1$ ξ IS UNLIMITED.

SO ALMOST ALWAYS... COUNTERCURRENT.

KEY DIMENSIONLESS PARAMETER:

$$\Lambda \equiv \frac{mS}{F}$$

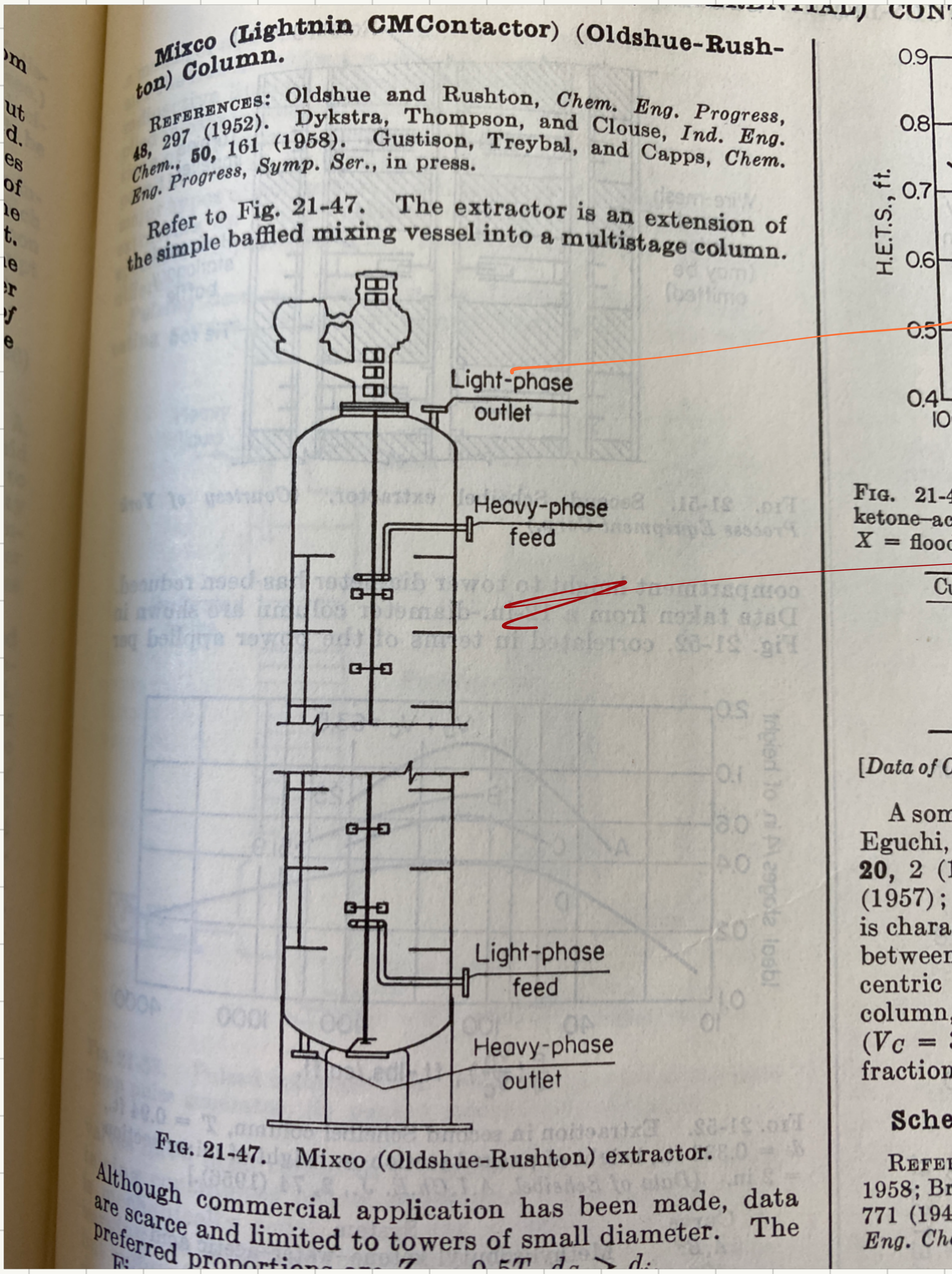
$$\xi_n = \sum_{i=0}^{n} \Lambda^{n}$$

$$\xi_n = \frac{\Lambda^{n+1} - 1}{\Lambda - 1}$$

$$n = \frac{\ln\left(1 + (\Lambda - 1)\xi_n\right)}{\ln(\Lambda)} - 1$$

KREMSER EQ

EXTRACTION COLUMN



Mixco (Lightnin CMContactor) (Oldshue-Rushton) Column.

REFERENCES: Oldshue and Rushton, *Chem. Eng. Progress*, **48**, 297 (1952). Dykstra, Thompson, and Clouse, *Ind. Eng. Chem.*, **50**, 161 (1958). Gustison, Treybal, and Capps, *Chem. Eng. Progress, Symp. Ser.*, in press.

Refer to Fig. 21-47. The extractor is an extension of the simple baffled mixing vessel into a multistage column.

FIG. 21-47. Mixco (Oldshue-Rushton) extractor.

Although commercial application has been made, data are scarce and limited to towers of small diameter. The preferred proportions are ...

→ MAYBE, EVAPORATE SOLVENT CRYSTALLIZE PRODUCT

PROBABLY NEVER ACCULATION IN EQ.

PLUS NEVER ALLOWED TO SEPARATE INTO PHASES

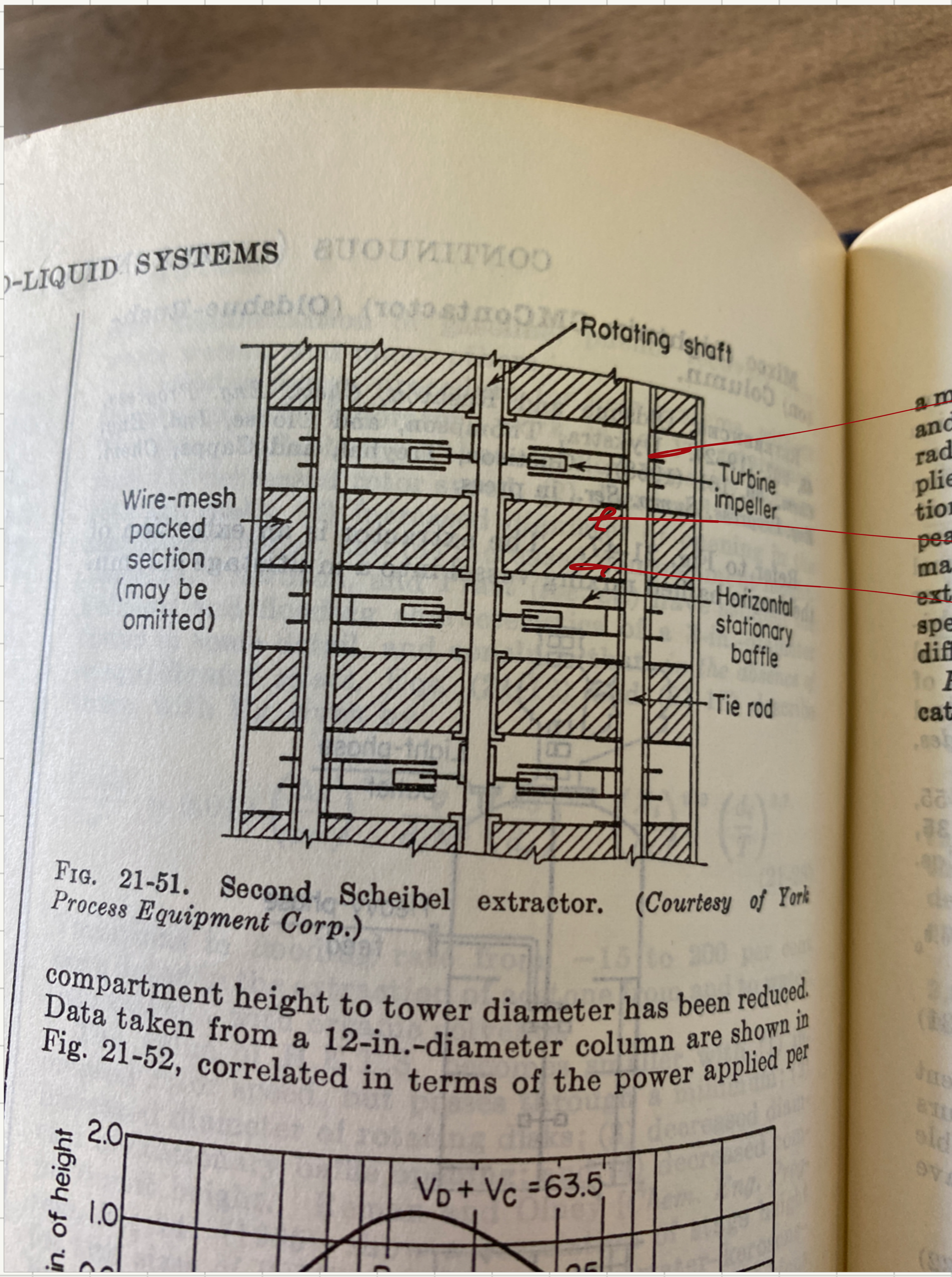
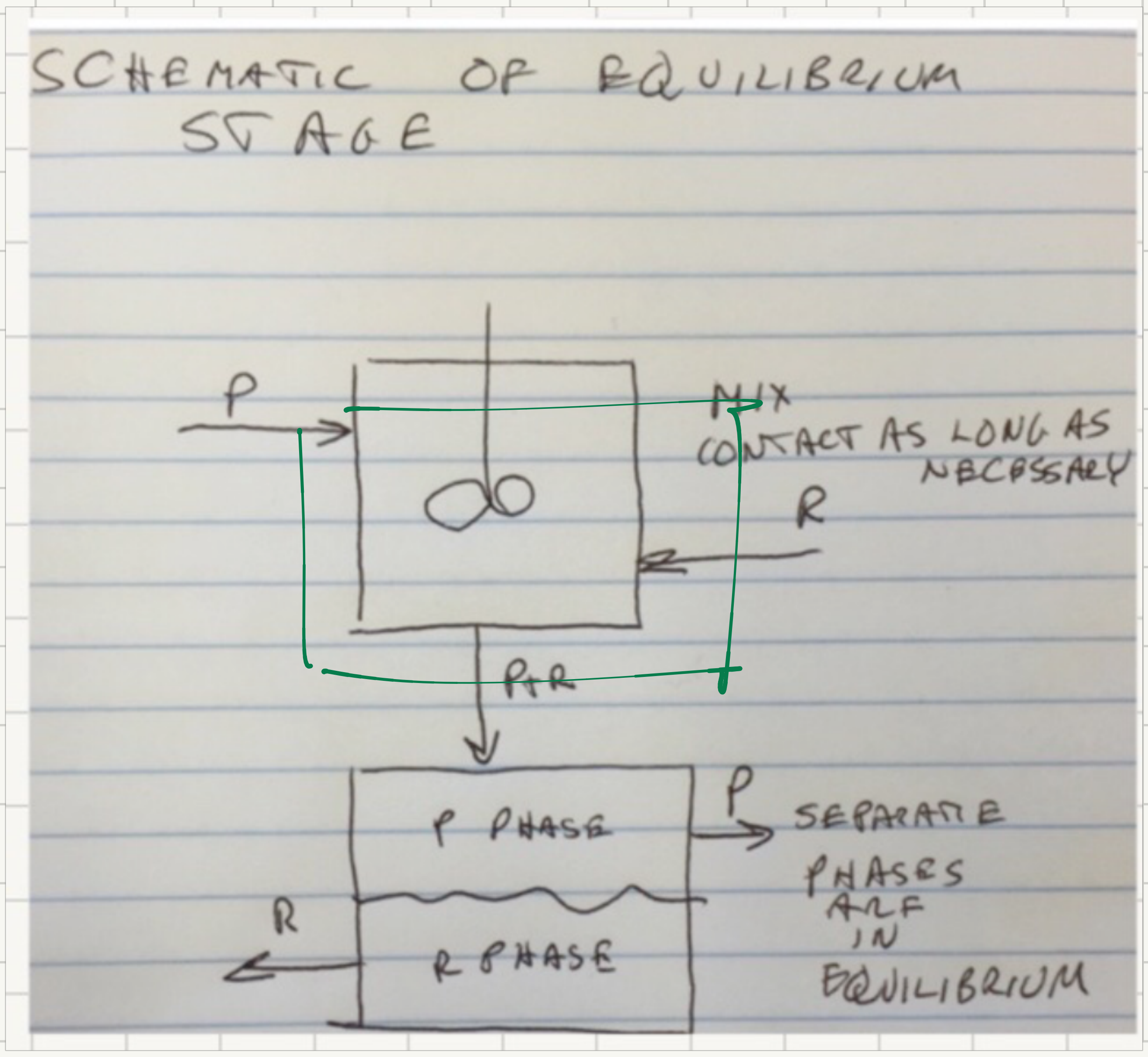

-LIQUID SYSTEMS

FIG. 21-51. Second Scheibel extractor. (*Courtesy of York Process Equipment Corp.*)

compartment height to tower diameter has been reduced. Data taken from a 12-in.-diameter column are shown in Fig. 21-52, correlated in terms of the power applied per



IDEALLY AN EXTRACTOR LOOKS MORE LIKE THIS . . .

FOR DISTALLATION

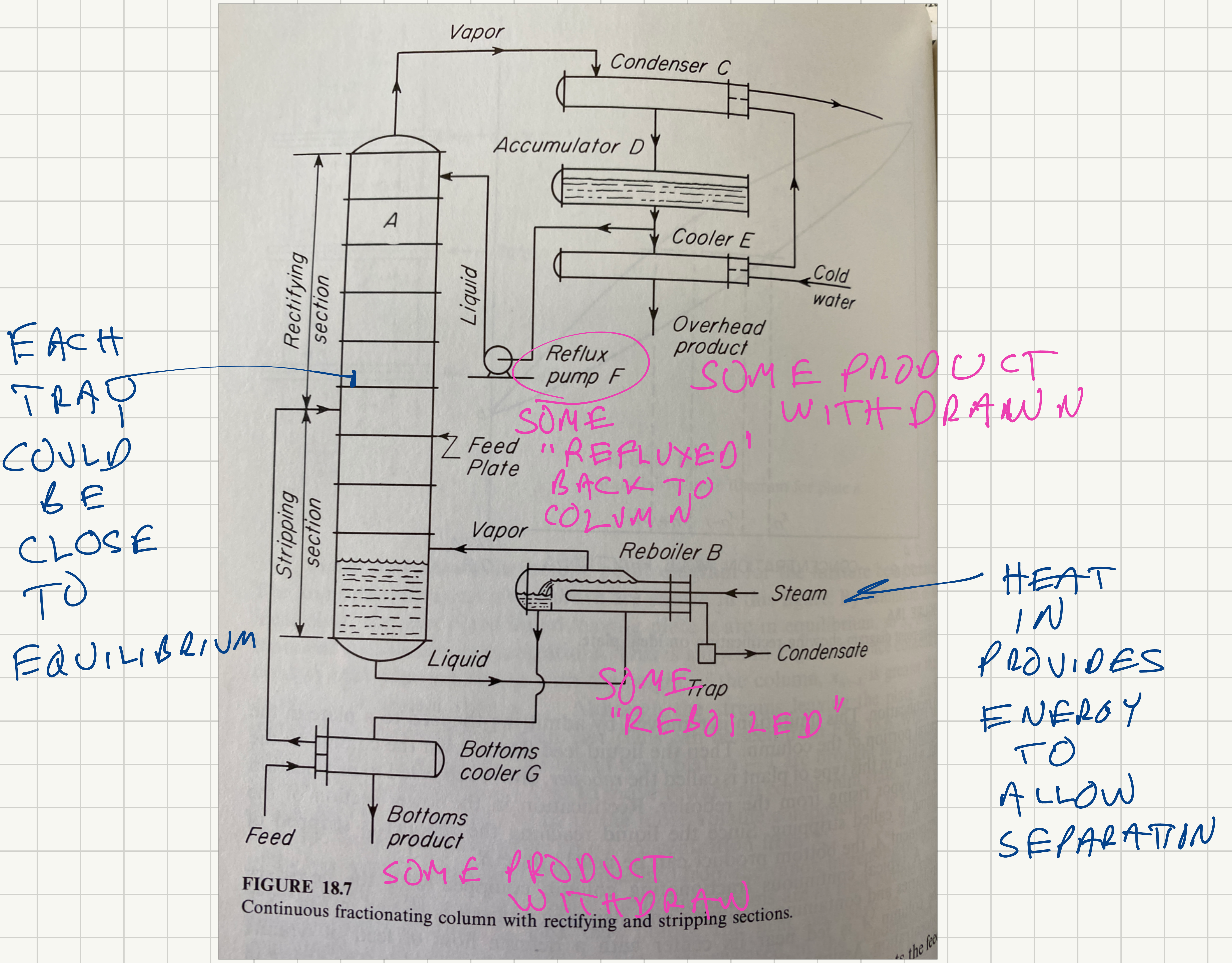


FIGURE 18.7
Continuous fractionating column with rectifying and stripping sections.

INHERENT TRADEOFF BETWEEN # TRAYS + RATE OF HEATING

CAPITAL COSTS

OPERATING COSTS

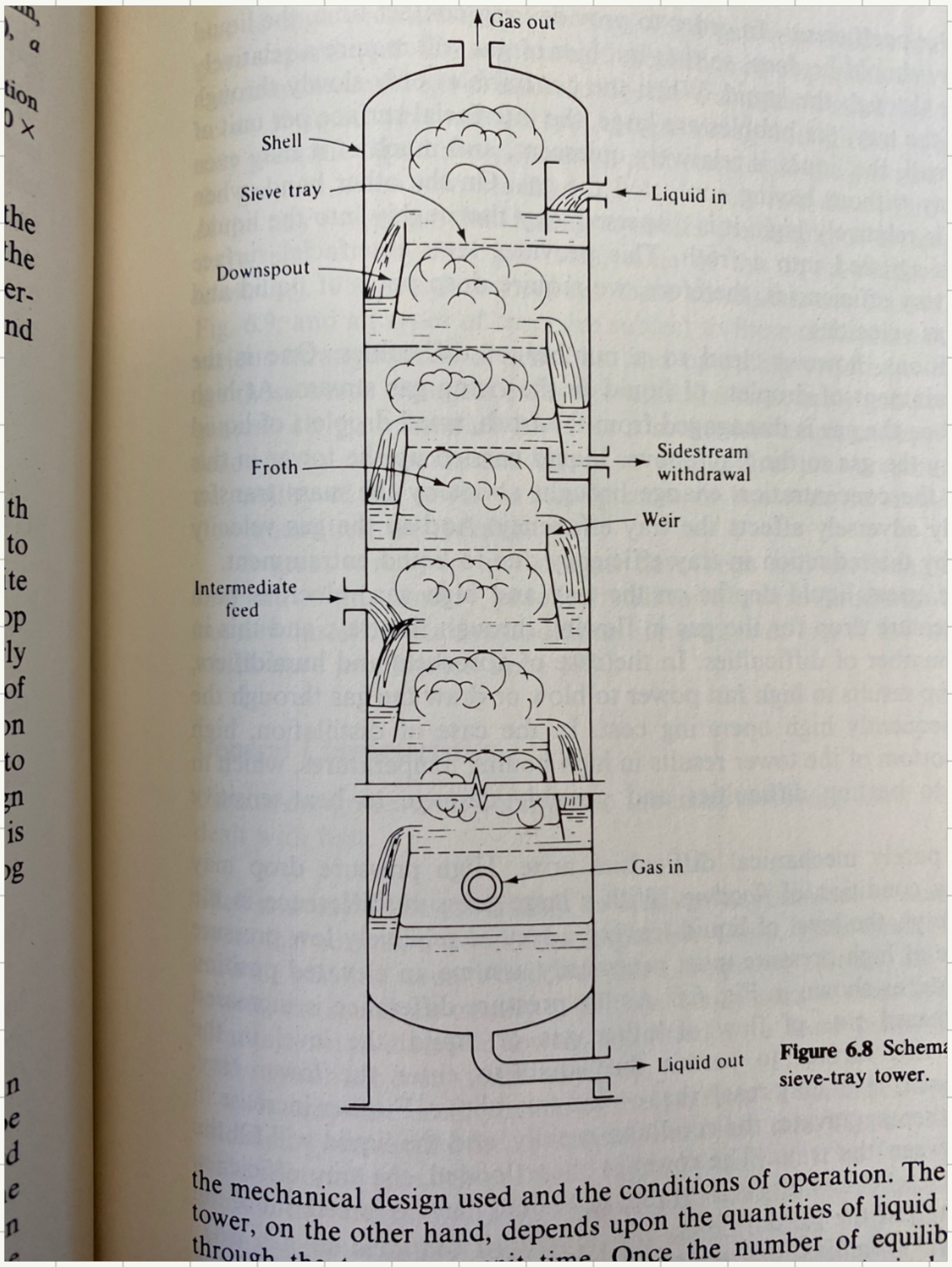
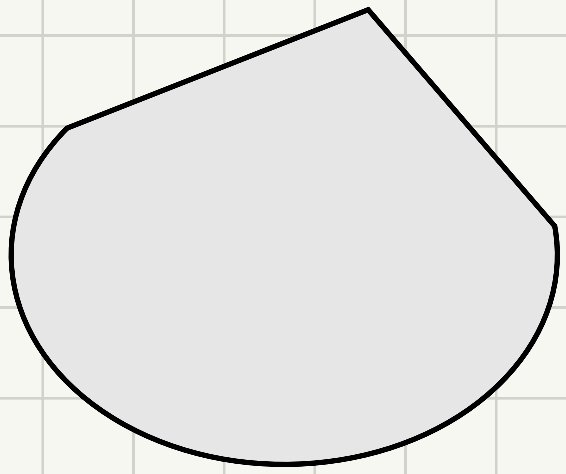


Figure 6.8 Schema
sieve-tray tower.

the mechanical design used and the conditions of operation. The tower, on the other hand, depends upon the quantities of liquid through ... Once the number of equilib

FLOWS WITHIN
A COLUMN



SIEVE TRAY

BOILING
MIXTURE

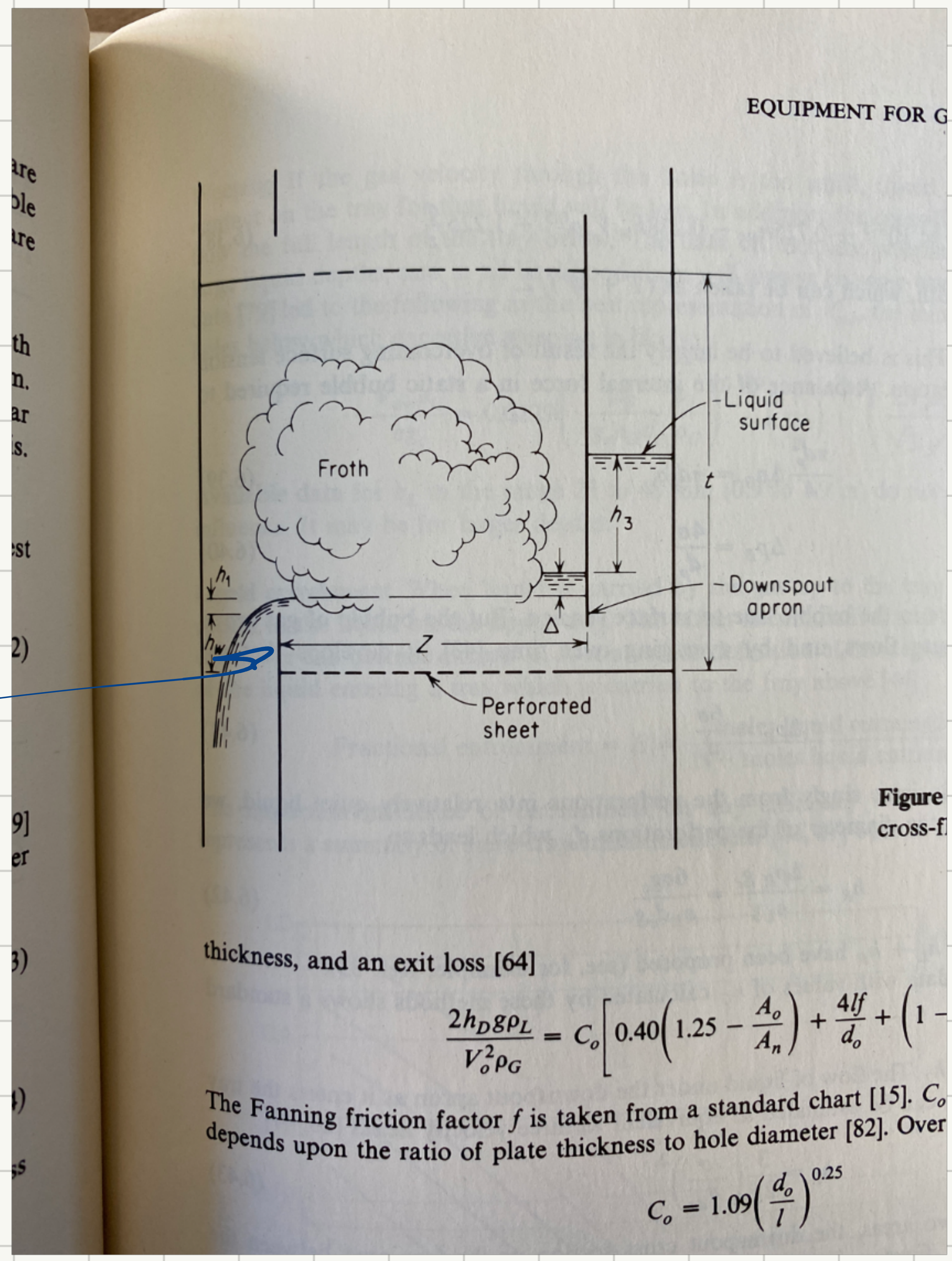


Figure
cross-f

thickness, and an exit loss [64]

$$\frac{2h_D g\rho_L}{V_o^2\rho_G} = C_o\left[0.40\left(1.25 - \frac{A_o}{A_n}\right) + \frac{4lf}{d_o} + (1 -\right.$$

The Fanning friction factor f is taken from a standard chart [15]. C_o depends upon the ratio of plate thickness to hole diameter [82]. Over

$$C_o = 1.09\left(\frac{d_o}{l}\right)^{0.25}$$

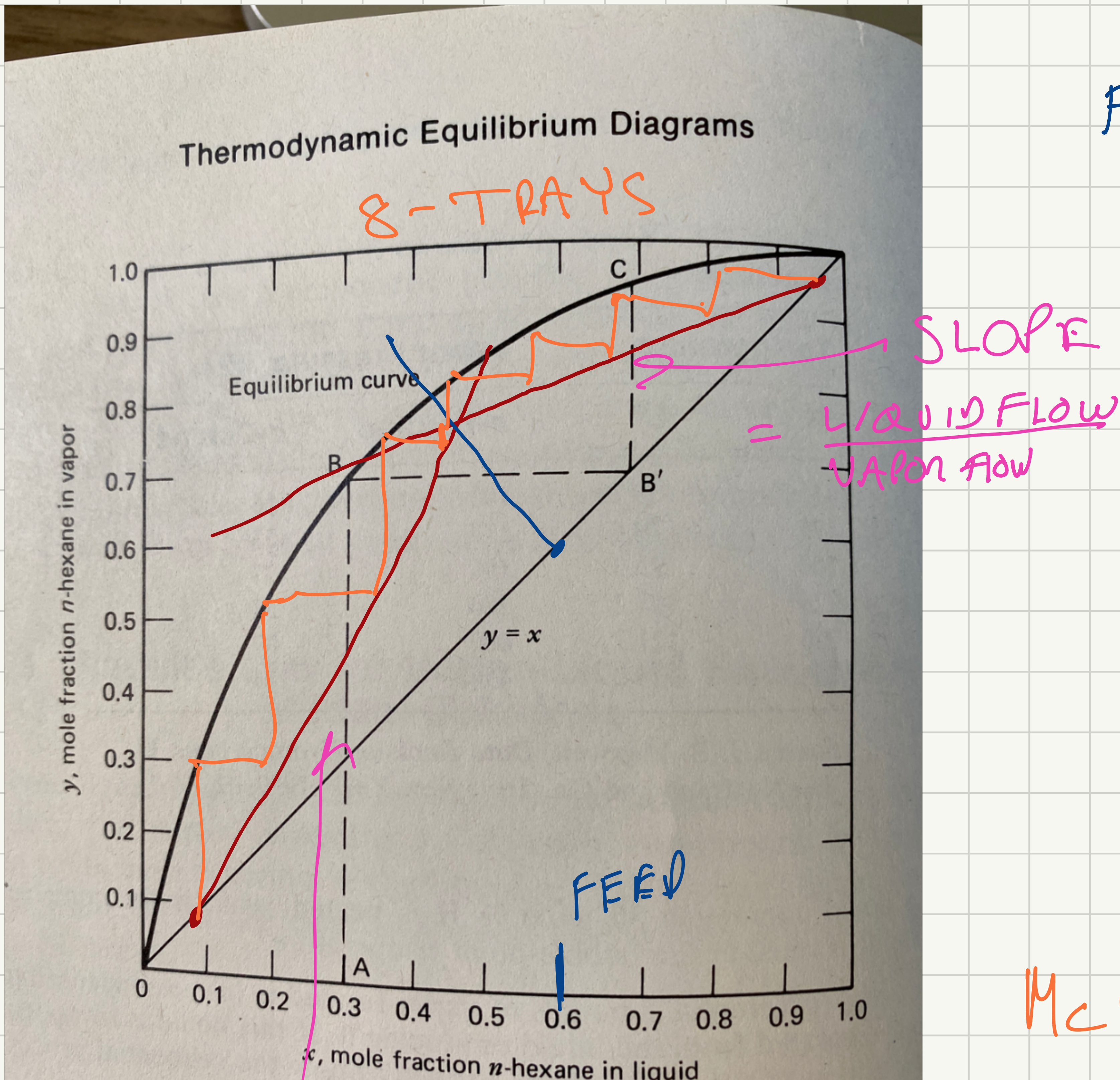


Figure 3.3. The *x-y* diagram for *n*-hexane–*n*-octane, at 101 kPa. (E. J. Henley and E. M. Rosen, *Material and Energy Balance Computations*, John Wiley & Sons, New York, © 1969.)

FROM THIS y–x DIAGRAM AND MASS BALANCES

COMPONENT MASS BALANCE GIVES "OPERATING" LINE

McCABE-THIELE METHOD

WE TOOK A FEED OF

$x_H = .6$

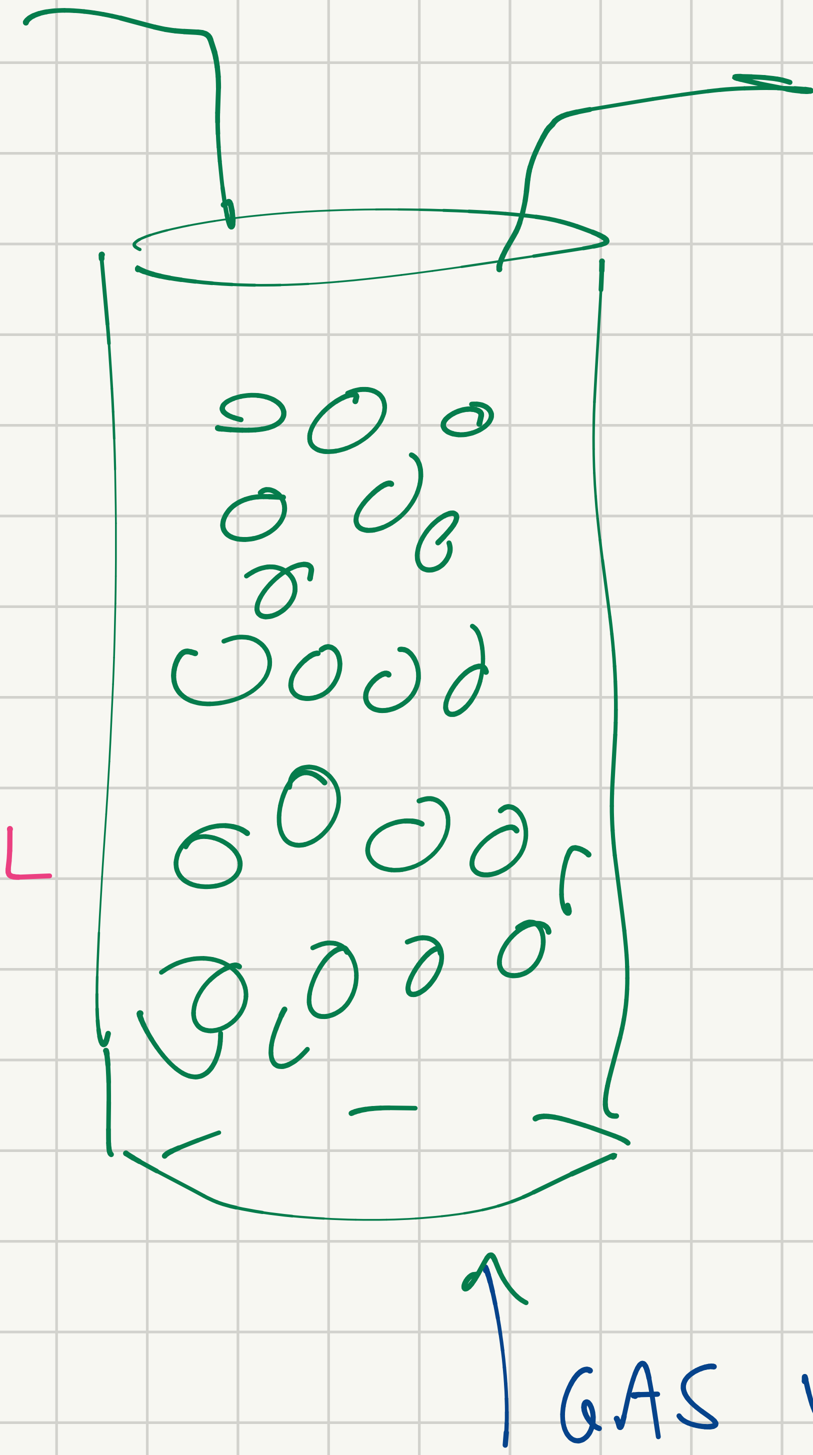
AND SEPARATED IT INTO

$x_H = .95$

& $x_H = .1$

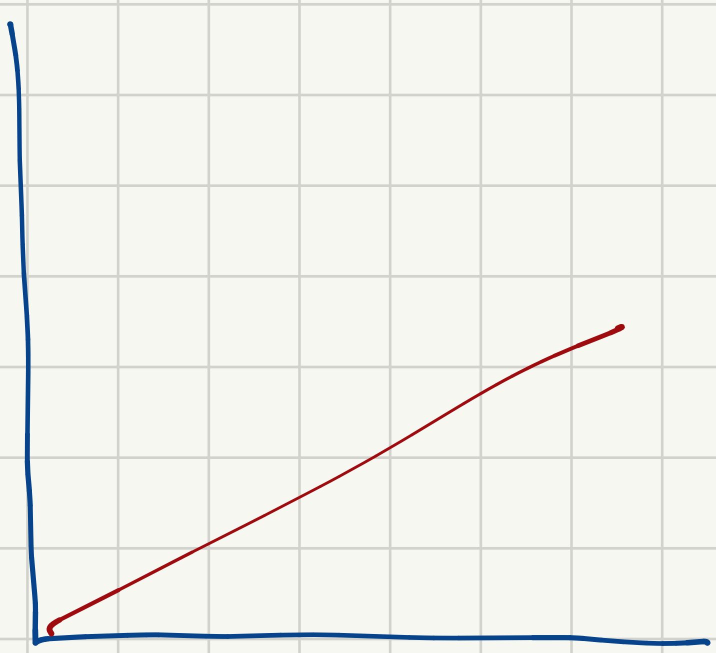
USING 8 EQUILIBRIUM STAGES

AS IT TURNS OUT, YOU DON'T ACTUALLY HAVE TO USE EQUILIBRIUM STAGES.

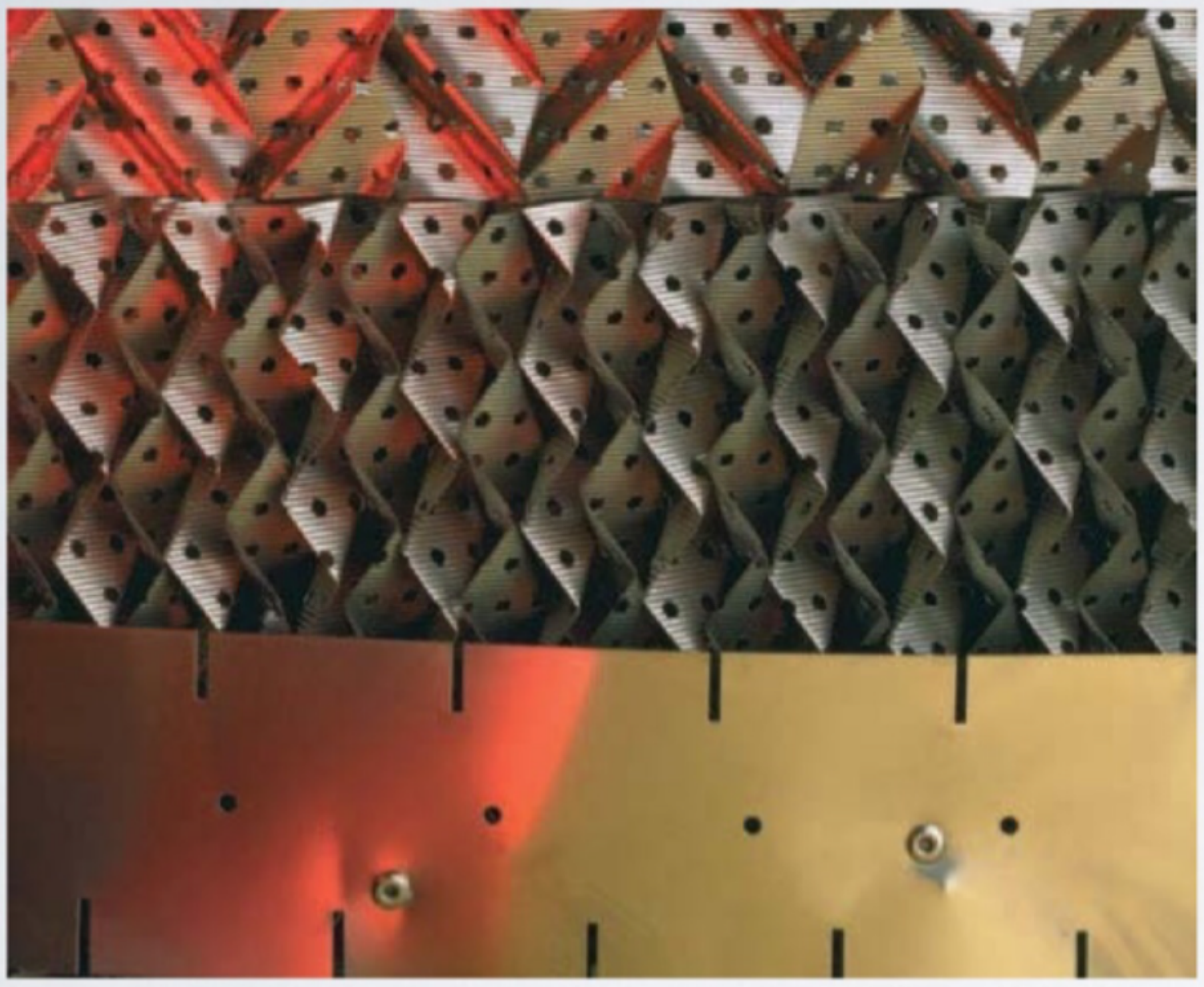


CAN GET ARBITRARY PURITY IF SOLVENT IS "A-FREE"

HENRY'S LAW



$$y_A = m\, x_A$$



Structured

"DUMPED" PACKING

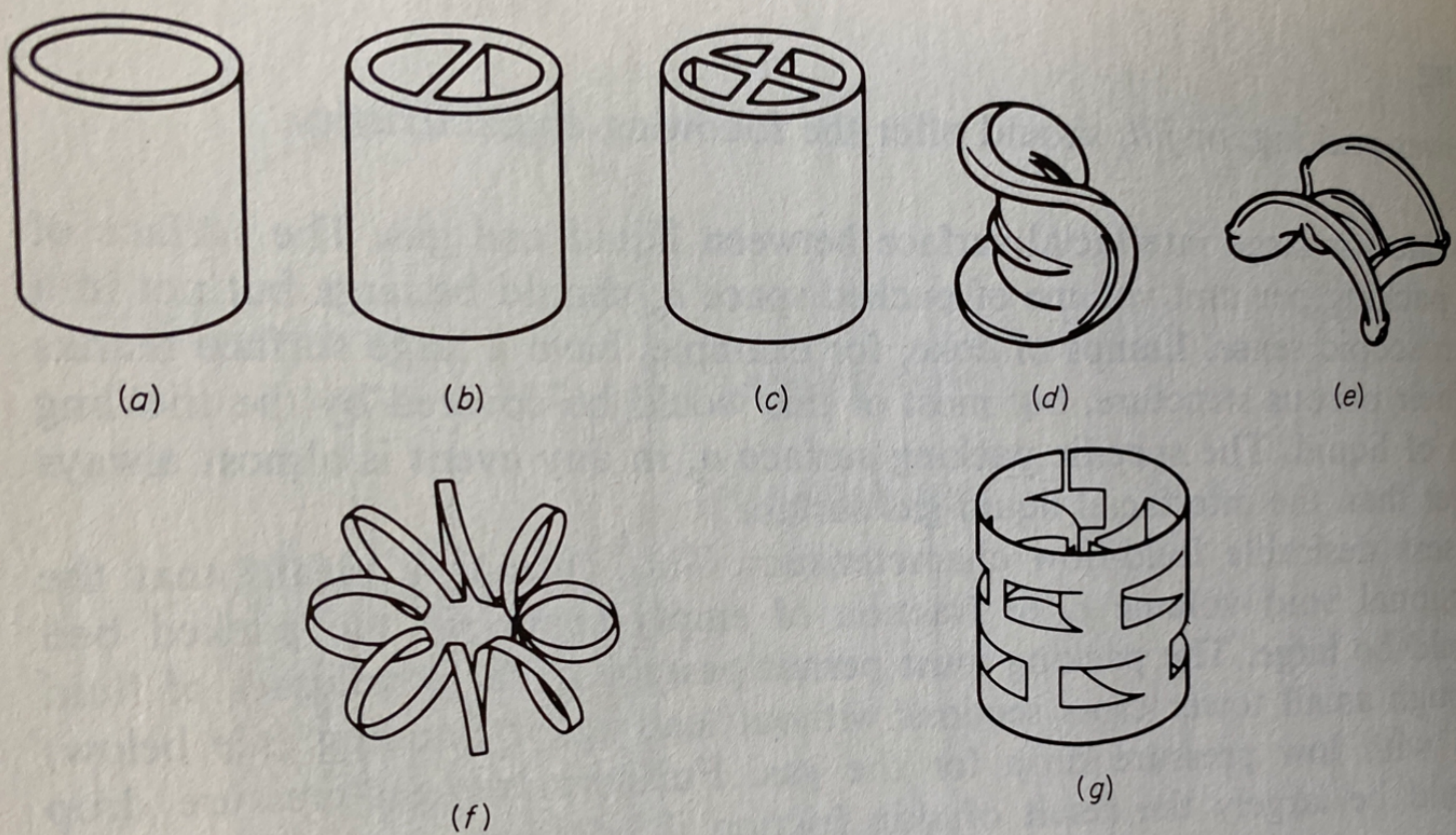


Figure 6.28 Some random tower packings: (*a*) Raschig rings, (*b*) Lessing ring, (*c*) partition ring, (*d*) Berl saddle *(courtesy of Maurice A. Knight)*, (*e*) Intalox saddle *(Chemical Processing Products Division, Norton Co.)*, (*f*) Tellerette *(Ceilcote Company, Inc.)*, and (*g*) pall ring *(Chemical Processing Products Division, Norton Co.)*.

...offer larger specific surface (and

A IS KEY DIMENSIONLESS PARAMETER $A \equiv \frac{L}{mG}$

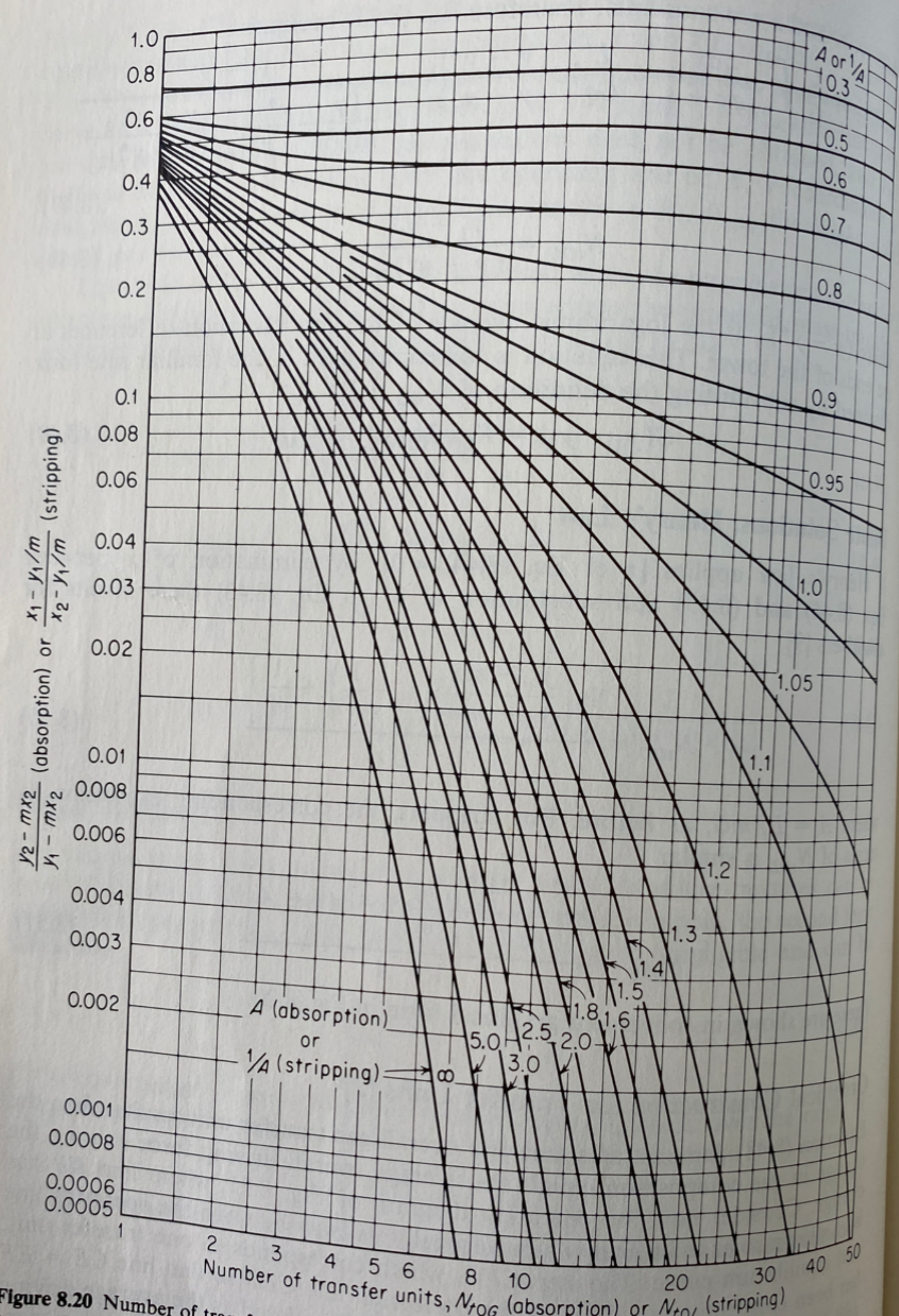


Figure 8.20 Number of transfer units for absorbers or strippers with constant absorption or stripping factor.

N_{TOG}

$Z = N_{TOG} H_{OG}$

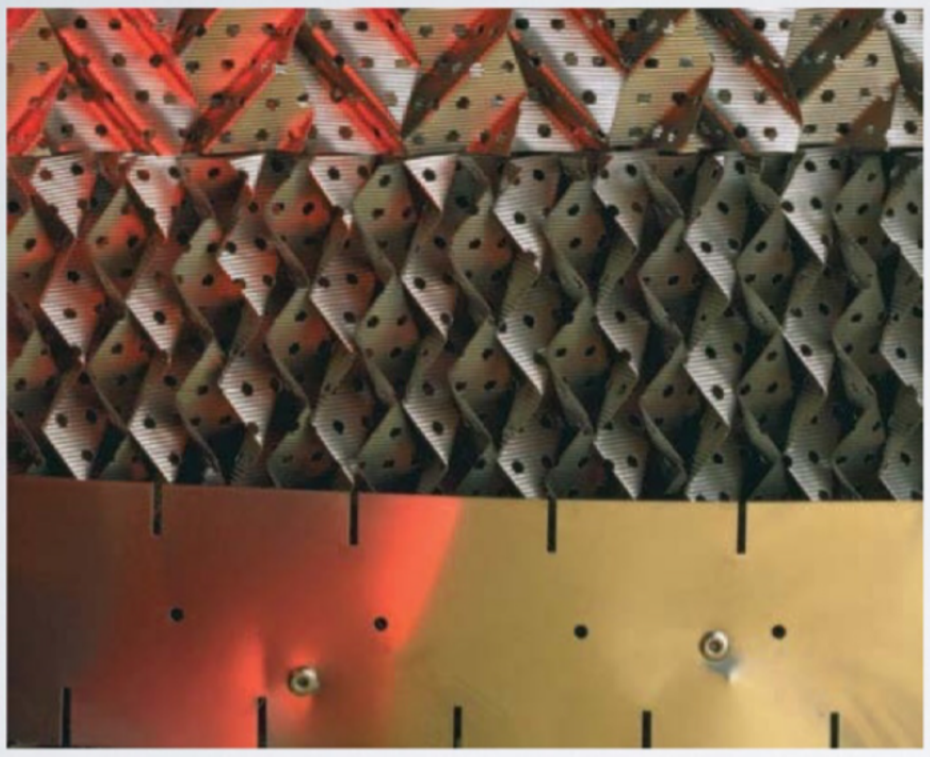
$H_{OG} = \frac{G}{\text{RATE OF MASSTRANSFER}}$

UNIT OPERATIONS

GAS ABSORBER

THE GAS ABSORBER IN THE IMPERIAL COLLEGE PILOT USES AN MEA IN WATER LIQUID TO ABSORB CO_2 FROM A MIXTURE IN N_2

ABSORBER AND STRIPPER



Structured

Random

Both give:

- high surface area between liquid and gas (350 m^2/m^3)
- continuous mixing of liquid and gas and they flow through column
- high fraction of "void" space so that the pressure drop is low