16 APRIL 2021 MODULE 4 F. MORRISON
CM3120

Requests for today?

2Ap21

- 4.3 (see also Example 5 Module 4 Lecture II)
- 4.17
- 4.8
- 4.11
-
-

0.5

17. (WRF) Ammonia (NH_3) will be absorbed from an air mixture at $293K$ and $1.0\ atm$ in a countercurrent packed tower, using water as the absorption solvent. The total inlet gas molar flow rate (air plus NH_3) is $5.03 \times 10^{-4}\ kmol/s$ and the ammonia composition in the inlet gas is 0.0352% mole fraction. Ammonia-free water (species B) at a mass flow rate of $L_S = 9.46 \times 10^{-3} kg/s$ will be used as the absorption solvent. If the ammonia concentration in the outlet gas is reduced to a mole fraction of 0.0129, determine the ratio of the operating solvent molar flow rate to the minimum molar solvent flow rate. Equilibrium data for the NH_3-water-air system at the tower's temperature and pressure are given by $Y_A = mX_A$, where $m = 0.82$ and Y_A is the molar ratio of ammonia to air in the gas and X_A is the molar ratio of ammonia to water in the liquid.

$$X_A = \frac{moles\ A}{moles\ B} = \frac{x_A}{(1-x_A)} \qquad \text{(mixture of A and liquid B)}$$

$$Y_A = \frac{moles\ A}{moles\ I} = \frac{x_A}{(1-x_A)} \qquad \text{(mixture of A and gas I)}$$

These problems are often carried out on a solute-free basis. See the notes for some help with this problem. Answer: ratio$=2.1$

A good strategy is to change the provided information to be on a solute-free basis. The solute-free gas flow rate G_s is the (constant) molar flow rate of air. The solute-free liquid flow rate is the (constant) molar flow rate of water. Convert all the mole fractions to molar ratios, performing the appropriate balances to obtain missing values. The operating line is a balance cutting through the bottom streams and an arbitrary place within the column characterized by molar ratios of X_A, Y_A. The minimum liquid flow rate L_s (for the same gas flow rate G_s is determined as discussed in class.

16 April 2021 F. Morrison

rf WRF
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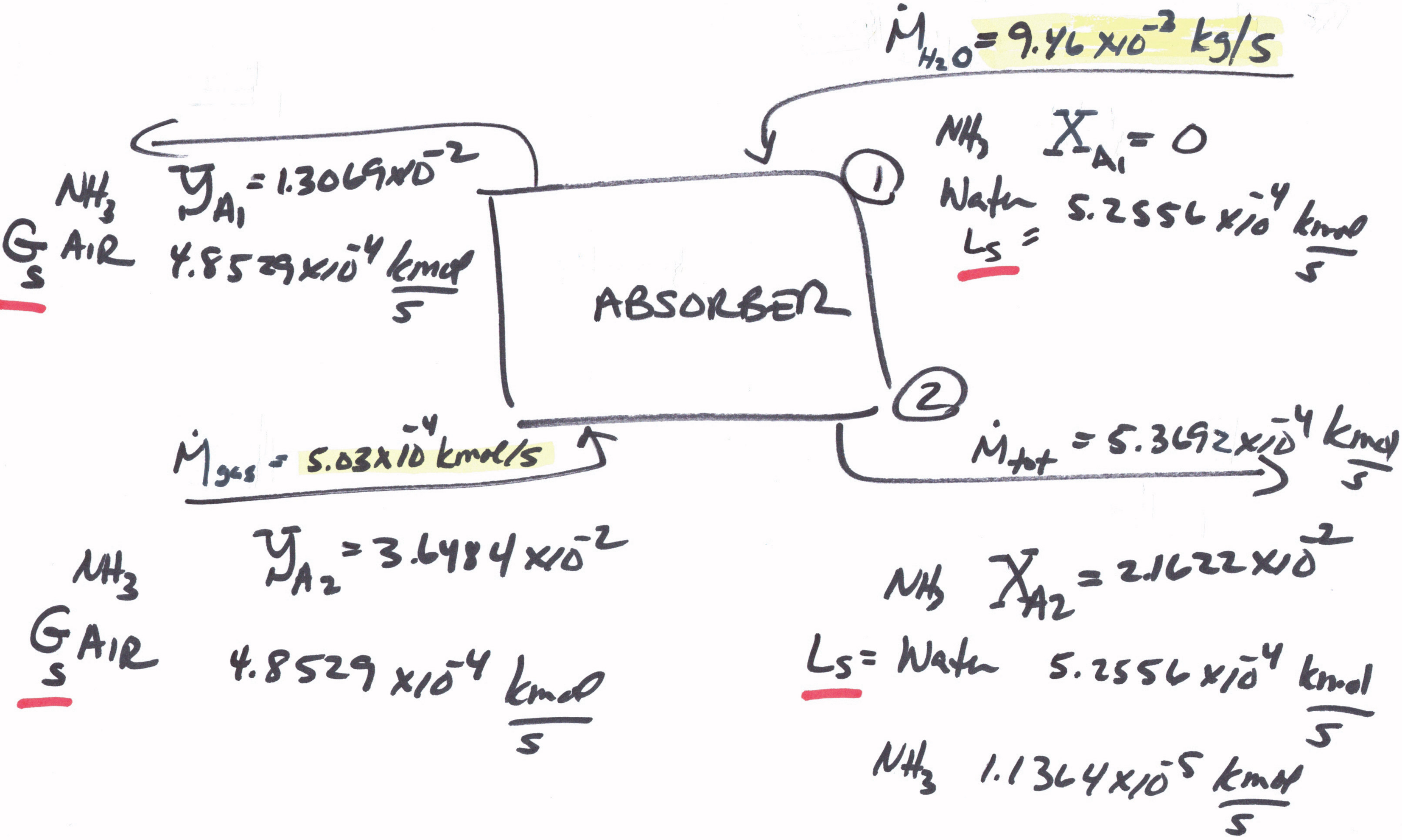
$A = NH_3$ given


$\dot{M}_{H_2O} = 9.46\times10^{-3}$ kg/s
NH$_3$ $X_{A_1} = 0$
Water $L_s = 5.2556\times10^{-4}$ $\frac{kmol}{s}$
①
NH$_3$ $Y_{A_1} = 1.3069\times10^{-2}$
G_s AIR 4.8529×10^{-4} $\frac{kmol}{s}$
ABSORBER
②
$\dot{M}_{gas} = 5.03\times10^{-4}$ kmol/s
$\dot{M}_{tot} = 5.3692\times10^{-4}$ $\frac{kmol}{s}$
NH$_3$ $Y_{A_2} = 3.6484\times10^{-2}$
G_s AIR 4.8529×10^{-4} $\frac{kmol}{s}$
NH$_3$ $X_{A_2} = 2.1622\times10^{-2}$
L_s = Water 5.2556×10^{-4} $\frac{kmol}{s}$
NH$_3$ 1.1364×10^{-5} $\frac{kmol}{s}$

BOTTOM - GAS

$$Y_A = \frac{\text{moles } NH_3}{\text{moles AIR}} = \frac{y_A}{1-y_A} \qquad \frac{\text{moles } NH_3/\cancel{\text{moles total}}}{\text{moles AIR}/\cancel{\text{moles total}}}$$

$$Y_{A_2} = \frac{0.0352}{1-0.0352} = \boxed{3.6484 \times 10^{-2}}$$

$$\text{moles } NH_3 \text{ in GAS} = y_A \dot{M}_{gas} = \left(0.0352 \frac{\text{moles A}}{\text{moles total}}\right)\left(5.03 \times 10^{-4} \frac{\text{kmol}}{s}\right)$$

$$= \boxed{1.7706 \times 10^{-5} \frac{\text{kmol}}{s}}$$

NH_3 in GAS ENTERING

$$\text{moles AIR in} = (1-y_A)\dot{M}_{gas} = \boxed{4.8529 \times 10^{-4} \frac{\text{kmol}}{s}}$$

= moles AIR out

AIR MOLAR FLOW RATE

"solute free" (in & out)

How much NH_3 exits in GAS stream?

TOP ("1")
GAS:

$$\xrightarrow{\hspace{6cm}}$$

$$4.8529\times10^{-4}\ \frac{\text{kmol AIR}}{\text{s}}$$

$$\frac{y_{A1}}{1-y_{A1}} = \boxed{Y_{A1} = 1.3069\times10^{-2}\ \frac{\text{mol A}}{\text{mole AIR}}}$$

$y_{A1} = 0.0129$

$$\frac{\text{kmol A}}{\text{s}} = \left(Y_{A1}\right)\left(4.8529\times10^{-4}\ \frac{\text{kmol AIR}}{\text{s}}\right)$$

NH_3 out in gas

$$= \boxed{6.3423\times10^{-6}\ \frac{\text{kmol}}{\text{s}}}$$

BOTTOM LIQUID ("2"):

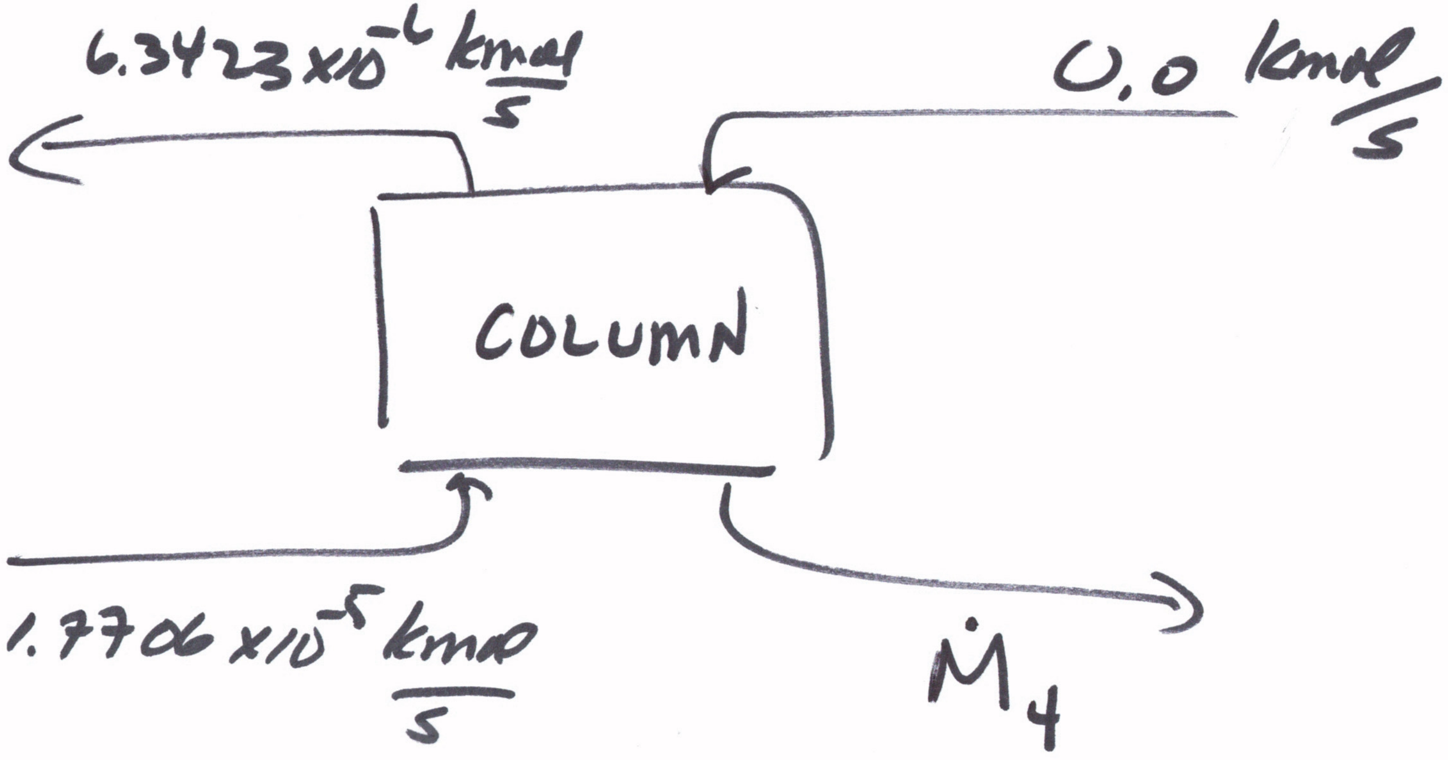
3.1

$$L_s = \text{moles water in} = \left(9.46\times10^{-3}\,\frac{\text{kg}}{\text{s}}\right)\left(\frac{\text{kmol}}{18\,\text{kg}}\right)$$

$$\boxed{L_s = 5.2556\times10^{-4}\,\frac{\text{kmol}}{\text{s}}}$$

WATER "SOLUTE-FREE" FLOW

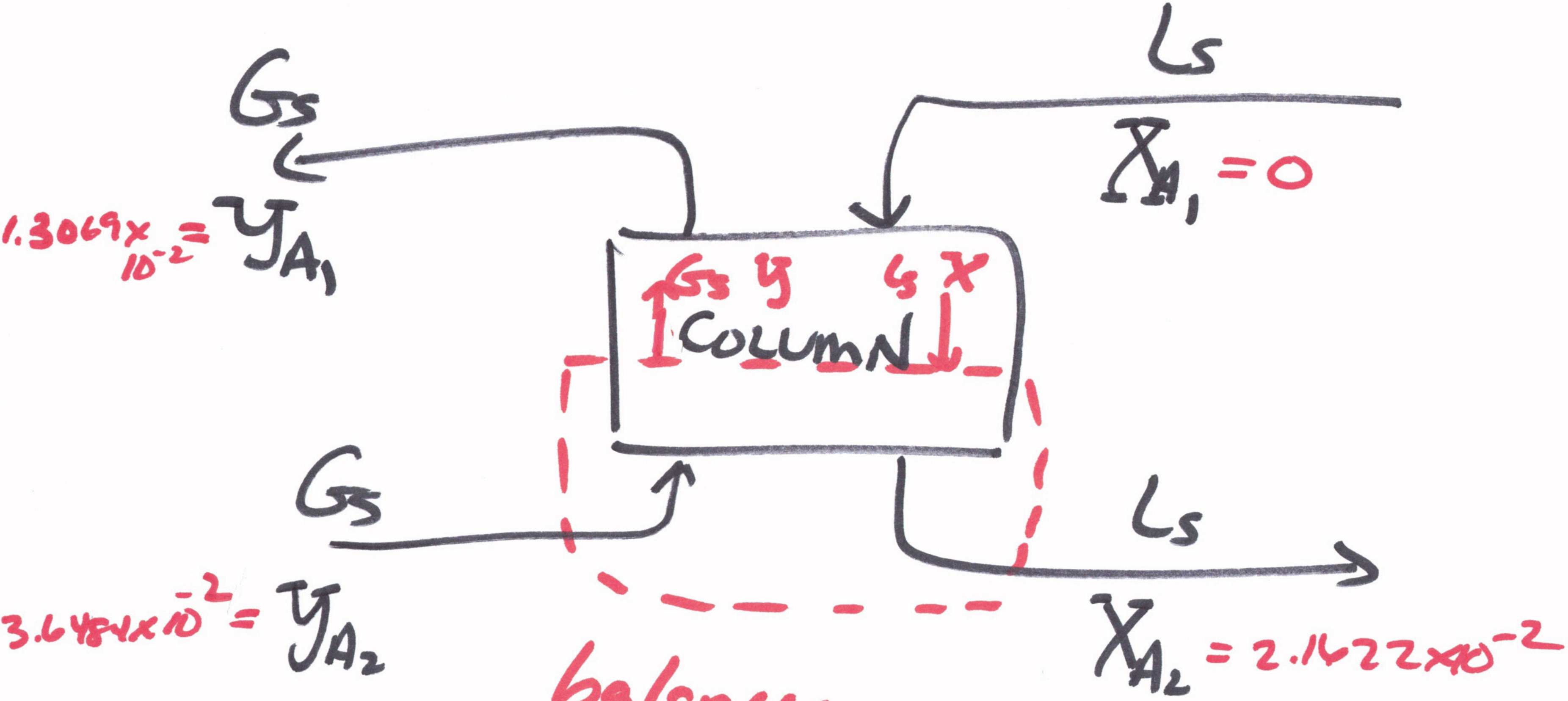
NH_3 BAL – OVERALL:



$$\dot{M}_4 = 1.1364\times10^{-5}\ \frac{kmol}{s}\ NH_3$$

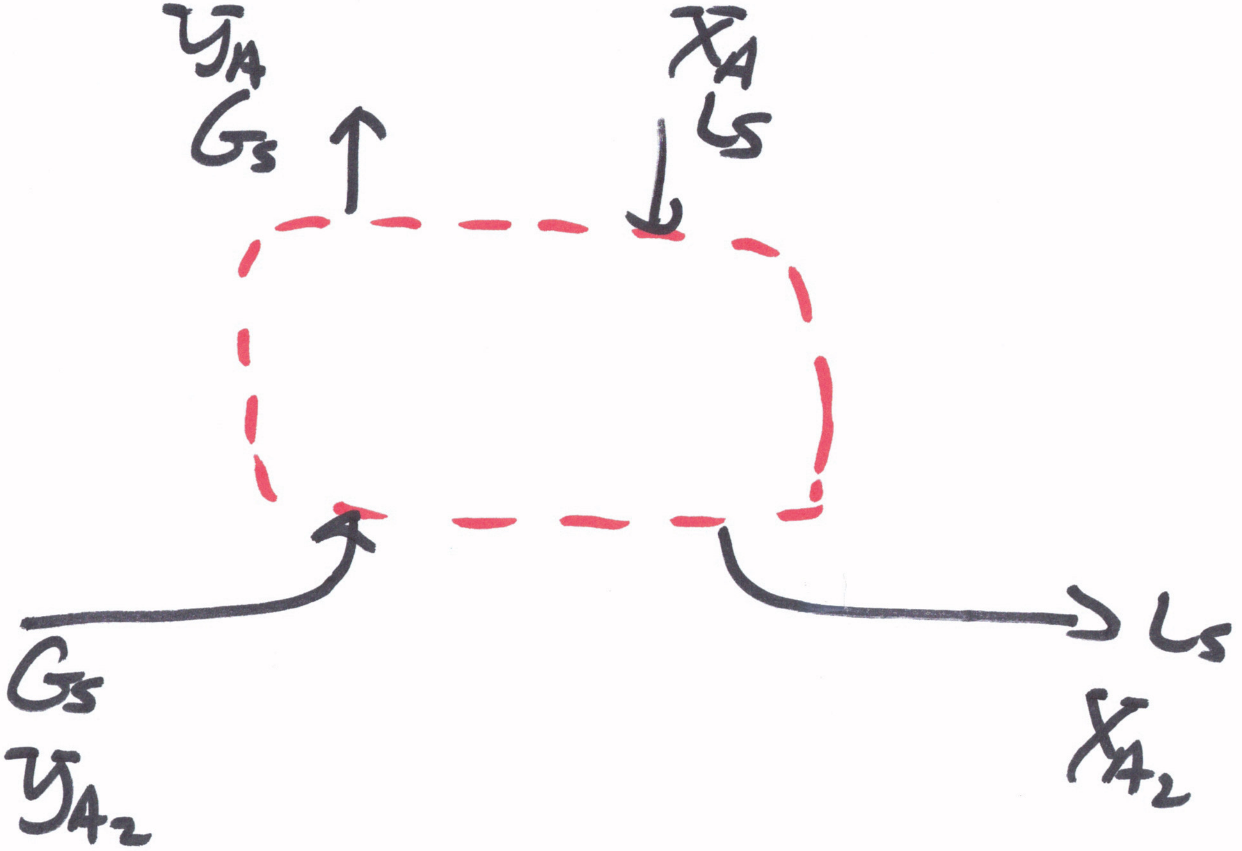
BOTTOM LIQ ("2"):

$$X_{A_2} = \frac{\text{moles } NH_3}{\text{moles Water}} = \frac{1.1364\times10^{-5}}{5.2556\times10^{-4}} = \boxed{\overset{X_{A_2}}{2.1622\times10^{-2}}}$$



balance determines operating line

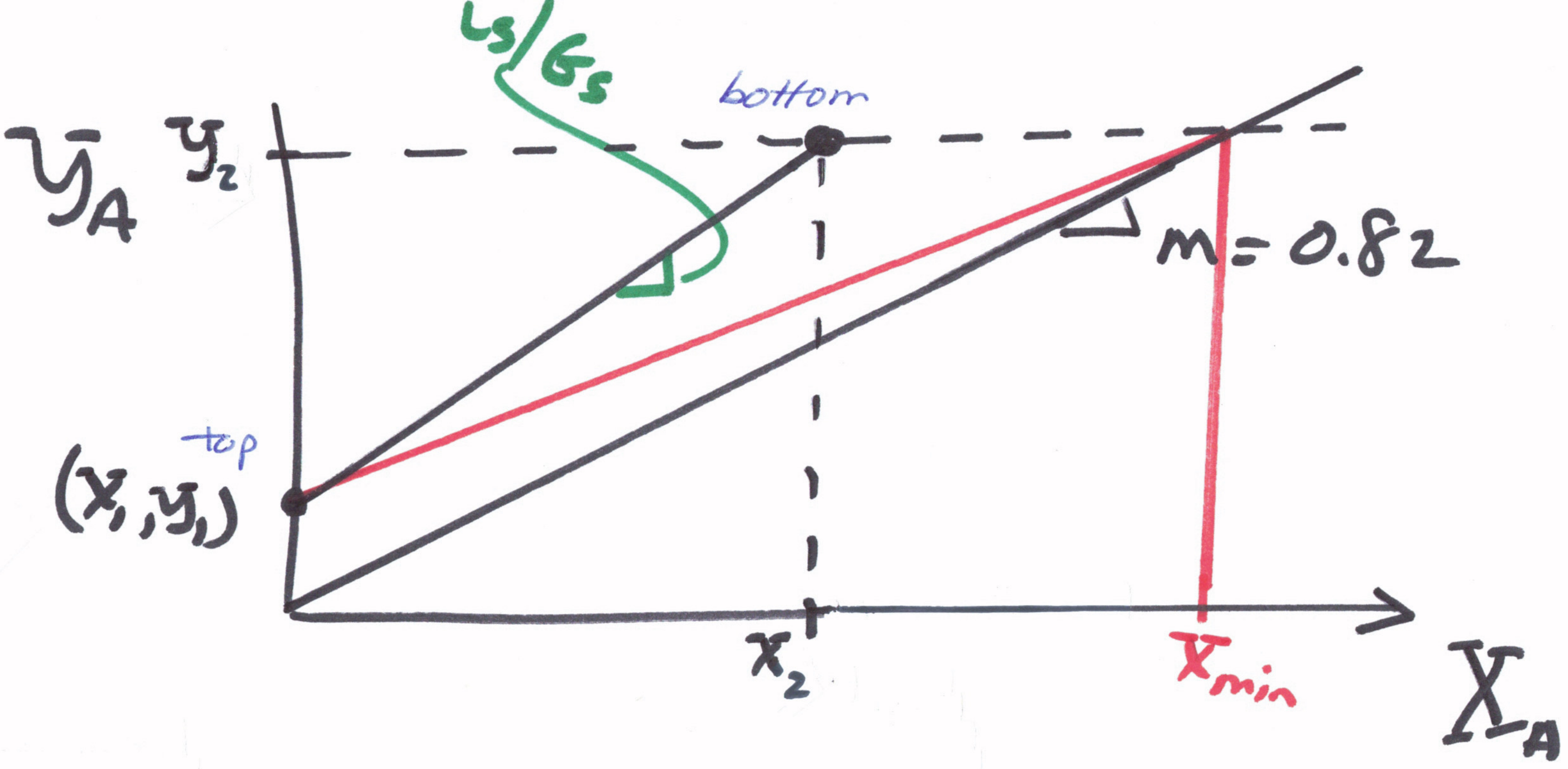
operating line – both phases, species A:



$$\frac{\cancel{G_s}}{\cancel{G_s}} y_{A_2} + \frac{L_s}{G_s} X_A = \frac{\cancel{G_s}}{\cancel{G_s}} y_A + \frac{L_s}{G_s} X_{A_2} \quad *$$

$$\boxed{y_A = \frac{L_s}{G_s} X_A + y_{A_2} - \frac{L_s}{G_s} X_{A_2}}$$

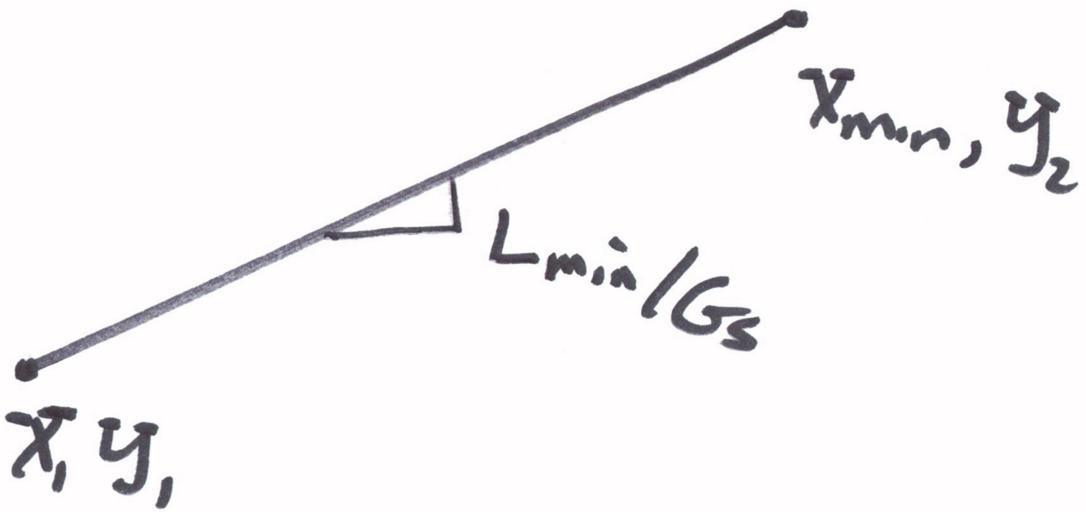
SLOPE = L_s/G_s



$$m=0.82$$

$$(X_{min})(\text{slope}) = y_2$$

$$\bar{X}_{min} = \frac{y_2}{(\text{slope})} = \frac{3.6484\times10^{-2}}{0.82} = \underbrace{4.4493\times10^{-2}}_{\bar{X}_{min}}$$



$$\text{slope} = \frac{y_2 - y_1}{x_{min} - x_1} = \frac{L_{min}}{G_s}$$

$$L_{min} = \frac{(3.648\times10^{-2}) - (1.3069\times10^{-2})}{(4.4493\times10^{-2}) - 0}\left(4.8529\times10^{-4}\,\frac{\text{kmol}}{\text{s}}\right)$$

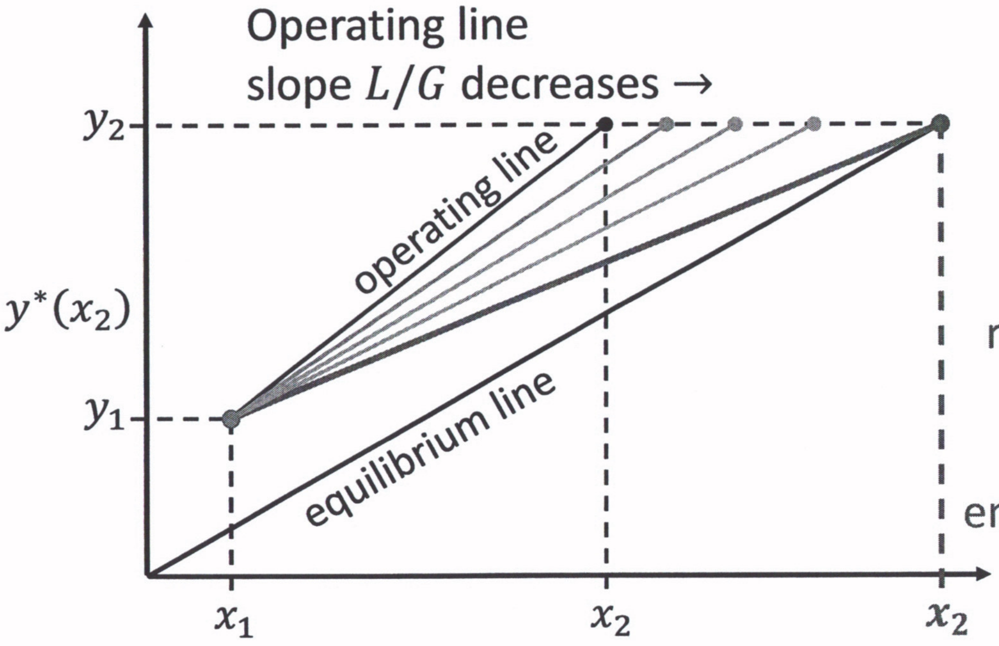
$$L_{min} = 2.55346\times10^{-4}\,\frac{\text{kmol}}{\text{s}}$$

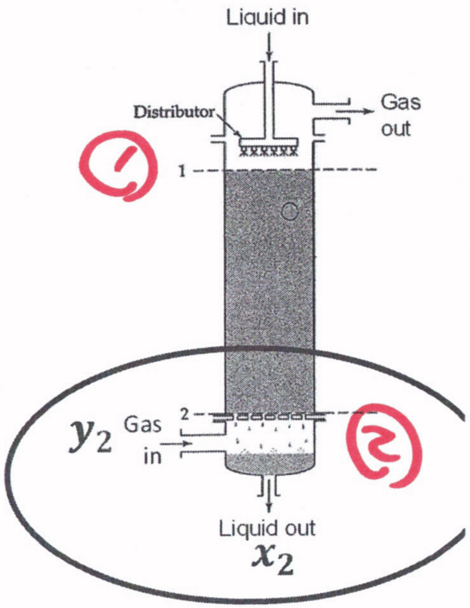
$L_s/L_{min} = 2.06$ ~ Twice the min //

1

Mass Transfer in an Absorption Column:

- operating line slope $= \frac{L}{G}$
- equilibrium line slope $= H = m$





Minimum slope, minimum L/G ratio, results when exit liquid condition x_2 is in equilibrium with the entering gas condition y_2

(cannot go lower)