GAS ABSORPTION TECHNIQUES - EXERCISE

Design packed bed tower

A 10,000 acfm (283,2 m^3/min) exhaust from a heat treating process contains 25 mole percent ammonia, and the average exhaust conditions are 30°C and 1.0 atm. The efficiency of ammonia removal is 95% based on the following design parameters:

- Average tower temperature is 30°C
- Tower preassure is 1.0 atm
- Pure water is used as absorbing liquid
- Water rate is 1.5 times minimum
- Packing is 1.0-in. Ceramic Rasching rings

Estimate:

- Lmin
- The diameter of the packed tower

Use annexes:

- «00_ANNEX 4b_Solubility data»
- « 00_ANNEX 1_Conversion Unit»

Design packed bed tower

CA	xe	Pa	ye
g NH3/100 g H2O	mole NH3/mole liquid	mm Hg	mole NH3/mole gas
0	0,00	0	0,00
2	0,02	19,3	0,03
3	0,03	29,6	0,04
4	0,04	40,1	0,05
5	0,05	51	0,07
7,5	0,07	79,7	0,10
10	0,10	110	0,14
15	0,14	179	0,24
20	0,17	260	0,34
25	0,21	352	0,46

$$ye = \frac{P_A}{760} \qquad xe = \frac{\frac{C_A}{17}}{\frac{C_A}{17} + \frac{100}{18}}$$

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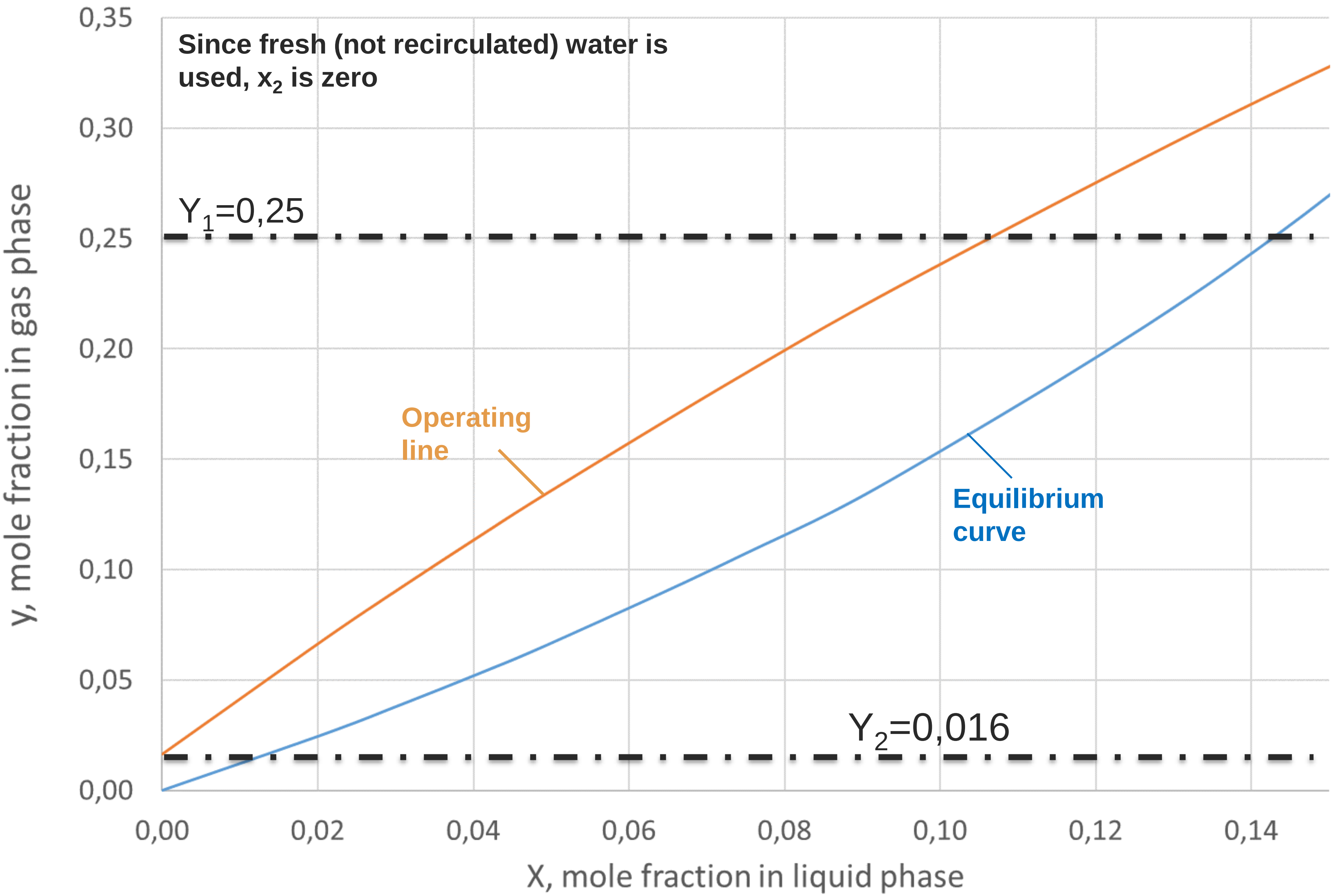
Table B.4 Solubility Data for NH_3 and SO_2 in Water

Mass NH_3 per 100 Masses H_2O	(a) Ammonia Partial Pressure NH_3, mm Hg 0 °C	10 °C	20 °C	30 °C	40 °C	50 °C	60 °C
100	947						
90	785						
80	636	987					
70	500	780					
60	380	600	945				
50	275	439	686				
40	190	301	470	719			
30	119	190	298	454	692		
25	89.5	144	227	352	534	825	
20	64	103.5	166	260	395	596	834
15	42.7	70.1	114	179	273	405	583
10	25.1	41.8	69.6	110	167	247	361
7.5	17.7	29.9	50.0	79.7	120	179	261
5	11.2	19.1	31.7	51.0	76.5	115	165
4		16.1	24.9	40.1	60.8	91.1	129.2
3		11.3	18.2	29.6	45.0	67.1	94.3
2			12.0	19.3	30.0	44.5	61.0
1					15.4	22.2	30.2

Mass SO_2 per 100 Masses H_2O	(b) Sulfur Dioxide Partial Pressure of SO_2, mm Hg 0 °C	7 °C	10 °C	15 °C	20 °C	30 °C	40 °C	50 °C
20	646	657						
15	474	637	726					
10	308	417	474	567	698			
7.5	228	307	349	419	517	688		
5.0	148	198	226	270	336	452	665	
2.5	69	92	105	127	161	216	322	458
1.5	38	51	59	71	92	125	186	266
1.0	23.3	31	37	44	59	79	121	172
0.7	15.2	20.6	23.6	28.0	39.0	52	87	116
0.5	9.9	13.5	15.6	19.3	26.0	36	57	82
0.3	5.1	6.9	7.9	10.0	14.1	19.7		
0.1	1.2	1.5	1.75	2.2	3.2	4.7	7.5	12.0
0.05	0.6	0.7	0.75	0.8	1.2	1.7	2.8	4.7
0.02	0.25	0.3	0.3	0.3	0.5	0.6	0.8	1.3

Adapted from Foust, Wenzel, Clump, Maus, and Anderson, *Principles of Unit Operations*, John Wiley & Sons, New York, 1960.

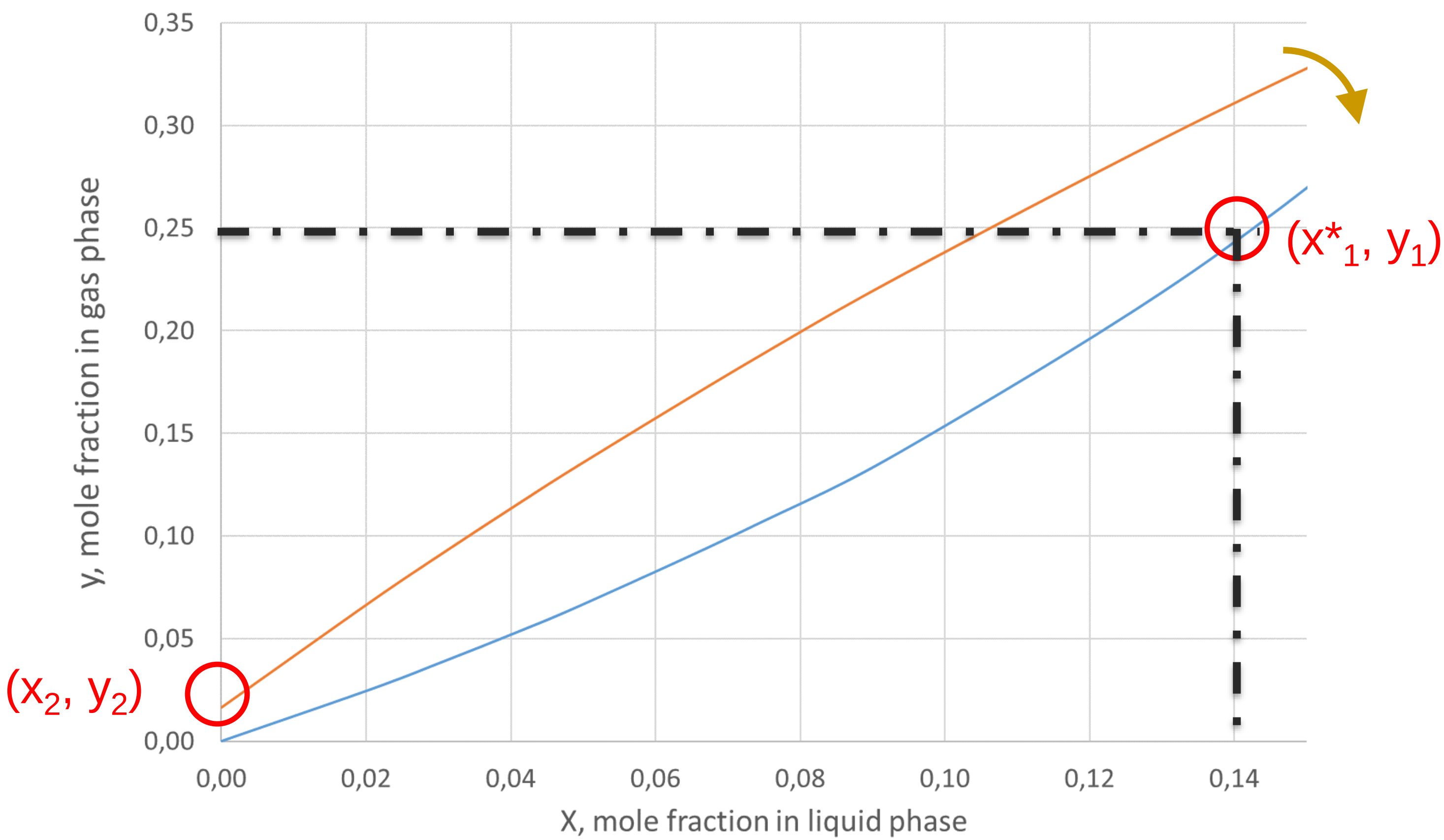
Graphical representation of the driving force



Minimum slope operating line

The operating lines are not straight, the minimum slope operating lines is defined as the straight line connecting points (x_2, y_2 and x^*_1, y_1 and has slope ($L'm_{min}/G'm$)

$$G'_m * \left(\frac{y_1}{1-y_1} - \frac{y_2}{1-y_2}\right) = L'_{m,min} * \left(\frac{x*_1}{1-x*_1} - \frac{x_2}{1-x_2}\right)$$



Minimum slope operating line

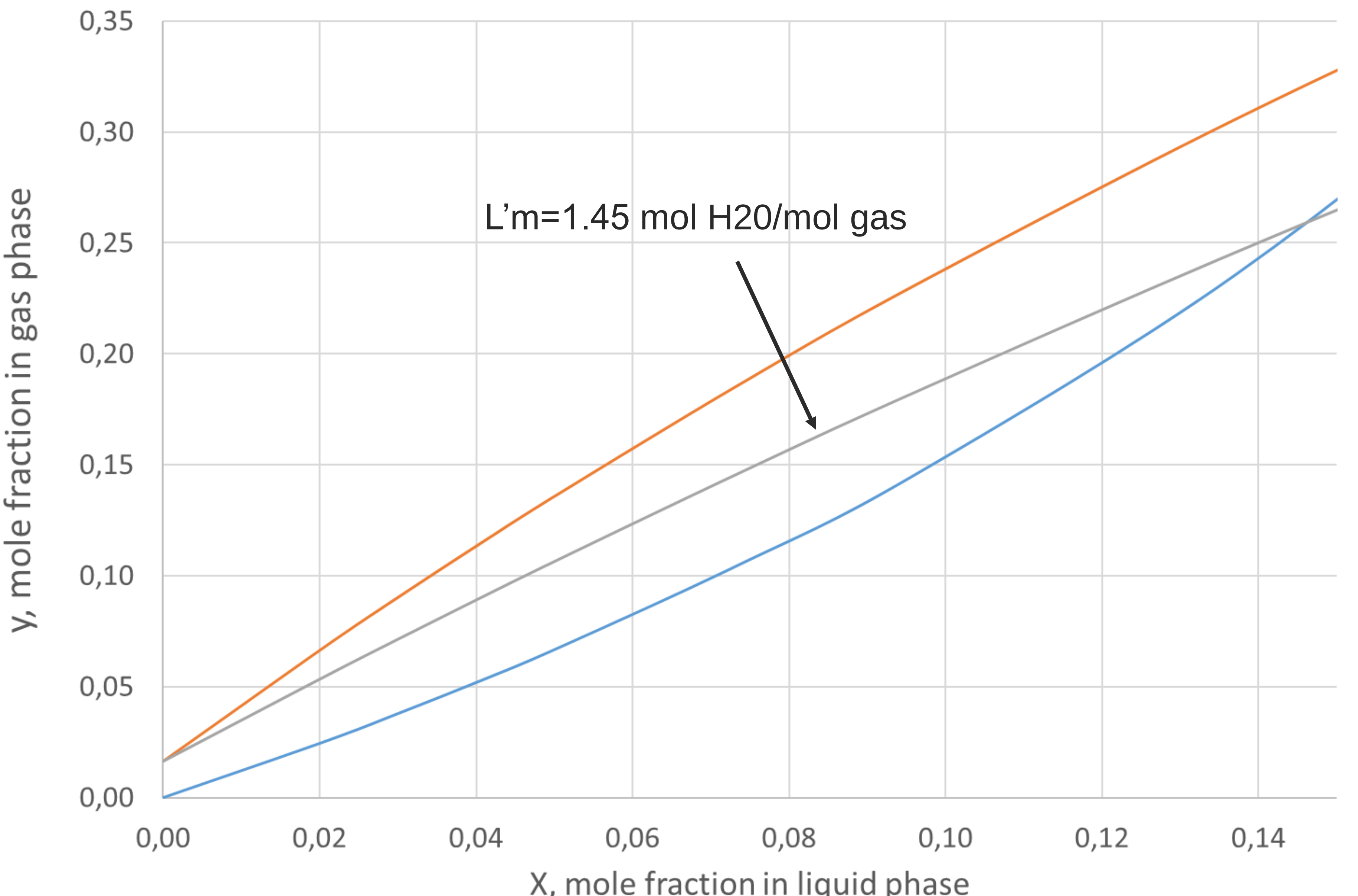
$$0.75 * \left(\frac{0.25}{1-0.25} - \frac{0.0164}{1-0.0164}\right) = L'_{m,min} * \left(\frac{0.14}{1-0.14} - \frac{0}{1-0}\right)$$

$L'_{m,min}$=1.457 mol H2O/mol gas

The actual water rate is:

$L'_{m,a}$=1.5*1.457=2.186 mol H2O/mol gas

Minimum slope operating line: graphical representation



Tower section

We base the calculation on 1 mole of entering gas

Molecular weight of enetering gas= 0.75*29+0.25*17= 26 g/mol

Conversion factors
1 lbm(pound mass) = 453.59237 g
1 ft = 0,3048 m

Density of water =ρx= 62.15 lb/ft^3

Density of air =ρy= (P*MW)/ (R*T)= 0.0652 lb/ft^3

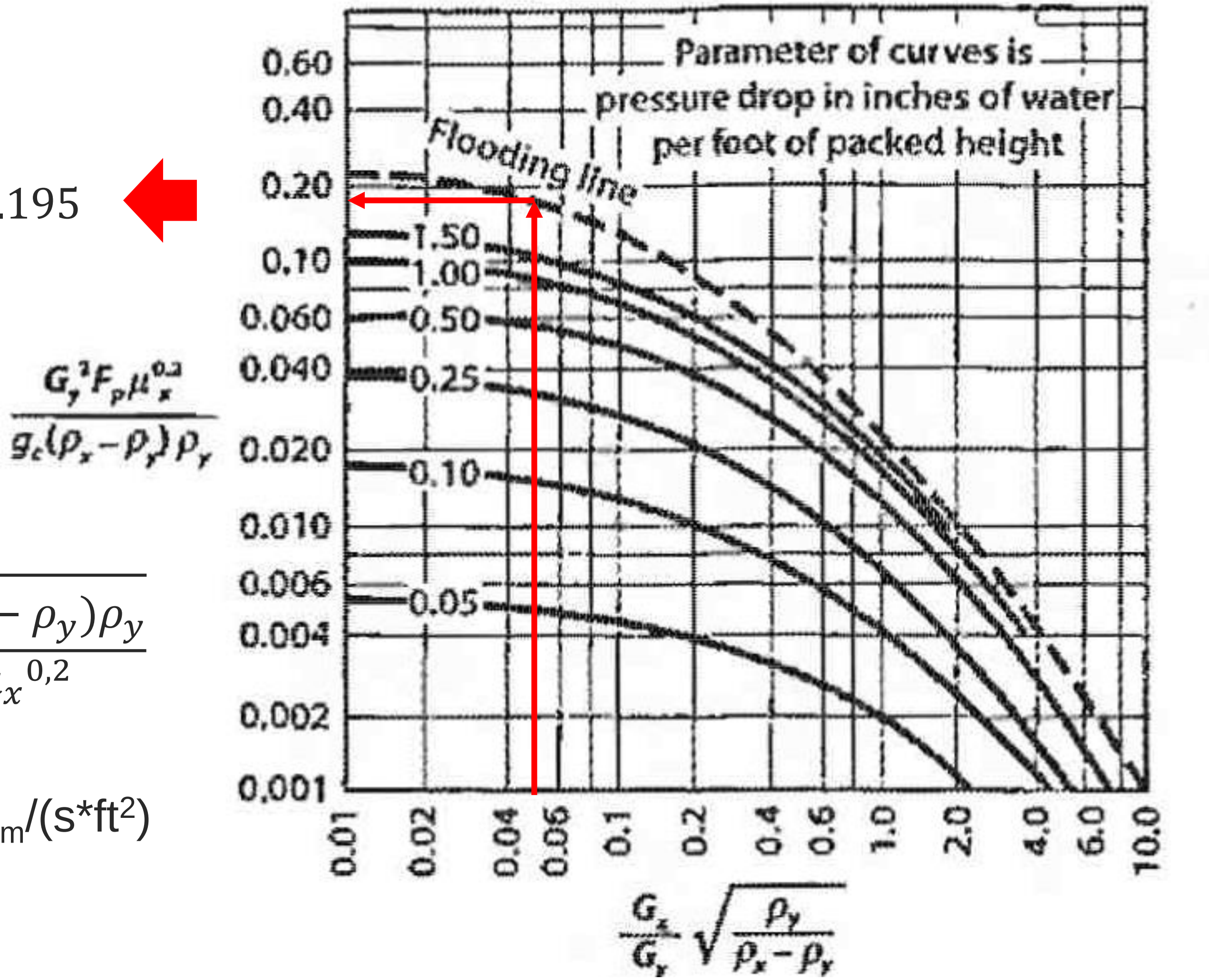
$$\frac{G_x}{G_y} * \sqrt{\frac{\rho_y}{\rho_x - \rho_y}} = \frac{L}{G} * \sqrt{\frac{\rho_y}{\rho_x - \rho_y}} = \frac{2.186 * 18}{1.0 * 26} * \sqrt{\frac{0.0652}{62.15 - 0.0652}} = 0.047$$

Tower section

$$\frac{G_y{}^2 * F_p * \mu_x{}^{0,2}}{gc * (\rho_x - \rho_y)\rho_y} = 0.195$$

$$G_y = \sqrt{0.195 * \frac{gc * (\rho_x - \rho_y)\rho_y}{F_p * \mu_x{}^{0,2}}}$$

G_y = gas mass flux $lb_m/(s*ft^2)$



Tower section

$$G_y = \sqrt{0.195 * \frac{gc * (\rho_x - \rho_y)\rho_y}{F_p * \mu_x^{0,2}}}$$

- gc=units conversion factors =32.17 ft*lbm/s^2*lbf
- μ_x = liquid viscosity cp (0.8)
- ρ_x = liquid density lbm/ft^3
- ρ_y = gas density lbm/ft^3

G_y=0.413 lb$_m$/(s*ft^2)
≈ 2016 g/s *m^2

Actual flow G_y *= G_y/2=
≈ 1008 g/s *m^2

Table 13.4 Tower Packing Characteristics

Type	Material	Nominal Size, in.	Bulk Density,† lb$_m$/ft^3	Total Area,† ft^2/ft^3	Porosity ε	Packing Factors‡ F_p	Packing Factors‡ f_p
Berl saddles	Ceramic	½	54	142	0.62	240	§1.58
		1	45	76	0.68	110	§1.36
		1½	40	46	0.71	65	§1.07
Intalox saddles	Ceramic	½	46	190	0.71	200	2.27
		1	42	78	0.73	92	1.54
		1½	39	59	0.76	52	1.18
		2	38	36	0.76	40	1.0
		3	36	28	0.79	22	0.64
Raschig rings	Ceramic	½	55	112	0.64	580	§1.52
		1	42	58	0.74	155	§1.36
		1½	43	37	0.73	95	1.0
		2	41	28	0.74	65	§0.92
Pall rings	Steel	1	30	63	0.94	48	1.54
		1½	24	39	0.95	28	1.36
		2	22	31	0.96	20	1.09
	Polypropylene	1	5.5	63	0.90	52	1.36
		1½	4.8	39	0.91	40	1.18

† Bulk density and total area are given per unit volume of column.
‡ Factor F_p is a pressure-drop factor and f_p a relative mass-transfer coefficient.
§ Based on NH_3–H_2O data; other factors based on CO_2–NaOH data.

Adapted from McCabe et al., 1985.

Packing is 1.0-in. Ceramic Rasching rings
F_p=155

Tower section

G = 283.2 m^3/min =4.72 m^3/s

Use the ideal gas law to convert the units g/s !!!!

G = 4935.7 g/s

Therefore, the section of the tower can be estimated as:

S= G/G'= 4935/1008= 4,89 m^2

$$diameter = \sqrt{\frac{S * 4}{\pi}} \approx 2.5\ m$$