CE407 SEPARATIONS

Lecture 22

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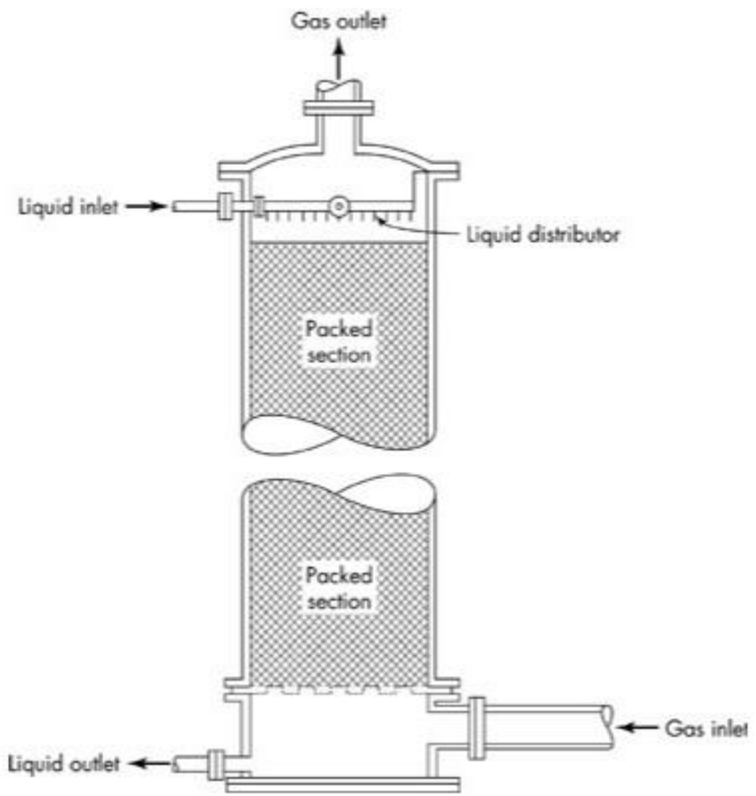
Design of Packed Towers

- Even distribution of liquid flow across the cross-sectional area of the tower
- Good wetting of the packing
  - Avoid channeling
    - More likely with stacked packing than with dumped packing
  - Minimize flow down walls
    - Diameter of tower should be > 8x the dimension of the packing
- Desire enough open space for vapor flow
  - Want to reduce ΔP through the tower



Types of Packing

- First packing was gravel
- Maximize surface area
- Lots of open space for vapor flow
- Shapes that do not “nest”
- Inexpensive construction
- Materials must be resistant to the process chemicals

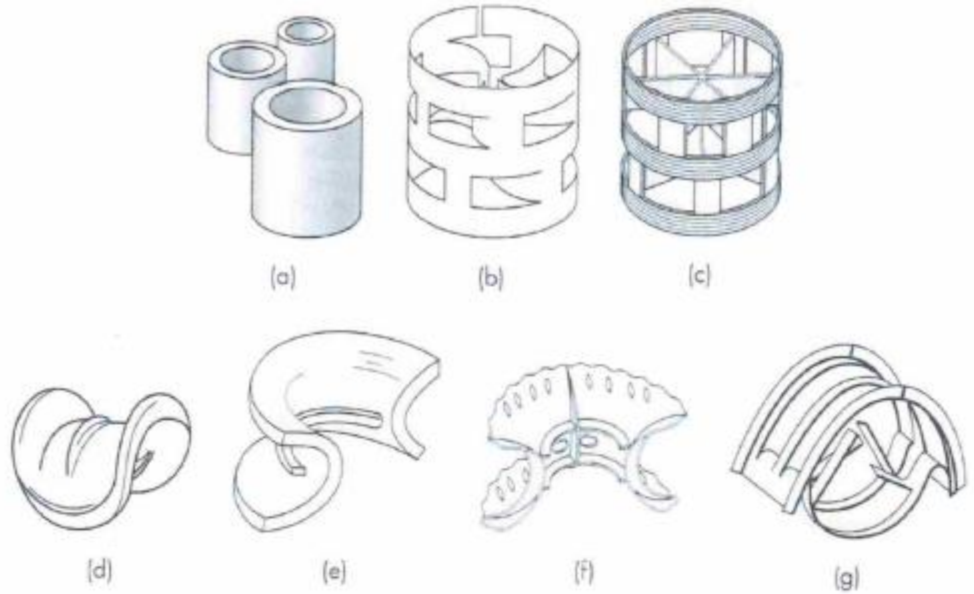


FIGURE 18.2
Common tower packings: (*a*) Raschig rings; (*b*) metal Pall ring; (*c*) plastic Pall ring; (*d*) Berl saddle; (*e*) ceramic Intalox saddle; (*f*) plastic Super Intalox saddle; (*g*) metal Intalox saddle.

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Characteristics of Packing

- Bulk density used for mechanical design of tower
- F_p is used in calculations for ΔP and flooding
- f_p is used in estimating H_x and H_y

TABLE 18.1
Characteristics of dumped tower packings[12,15b,27]

Type	Material	Nominal size, in.	Bulk density,* lb/ft³	Total area,* ft²/ft³	Porosity ε	Packing factors† F_p	Packing factors† f_p
Raschig rings	Ceramic	$\frac{1}{2}$	55	112	0.64	580	1.52§
		1	42	58	0.74	155	1.36§
		$1\frac{1}{2}$	43	37	0.73	95	1.0
		2	41	28	0.74	65	0.92§
Pall rings	Metal	1	30	63	0.94	56	1.54
		$1\frac{1}{2}$	24	39	0.95	40	1.36
		2	22	31	0.96	27	1.09
	Plastic	1	5.5	63	0.90	55	1.36
		$1\frac{1}{2}$	4.8	39	0.91	40	1.18
Berl saddles	Ceramic	$\frac{1}{2}$	54	142	0.62	240	1.58§
		1	45	76	0.68	110	1.36§
		$1\frac{1}{2}$	40	46	0.71	65	1.07§
Intalox saddles	Ceramic	$\frac{1}{2}$	46	190	0.71	200	2.27
		1	42	78	0.73	92	1.54
		$1\frac{1}{2}$	39	59	0.76	52	1.18
		2	38	36	0.76	40	1.0
		3	36	28	0.79	22	0.64
Super Intalox saddles	Ceramic	1	—	—	—	60	1.54
		2	—	—	—	30	1.0
IMTP	Metal	1	—	—	0.97	41	1.74
		$1\frac{1}{2}$	—	—	0.98	24	1.37
		2	—	—	0.98	18	1.19
Hy-Pak	Metal	1	19	54	0.96	45	1.54
		$1\frac{1}{2}$	—	—	—	29	1.36
		2	14	29	0.97	26	1.09
Tri-Pac	Plastic	1	6.2	85	0.90	28	—
		2	4.2	48	0.93	16	—

*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. Factor f_p is discussed on page 603 in the paragraph "Performance of Other Packings." Its use is illustrated in Example 18.7.
§Based on NH_3–H_2O data; other factors based on CO_2–NaOH data.

Pressure Drop

- Simplified chart to predict when liquid hold up will begin
- Chart is specific to a particular size and design of packing
- Used to determine **Loading**
  - Loading refers to when the amount of liquid held up on the packing begins to increase
- Loading begins where the slope of the curve changes
  - Not easily determined with precision

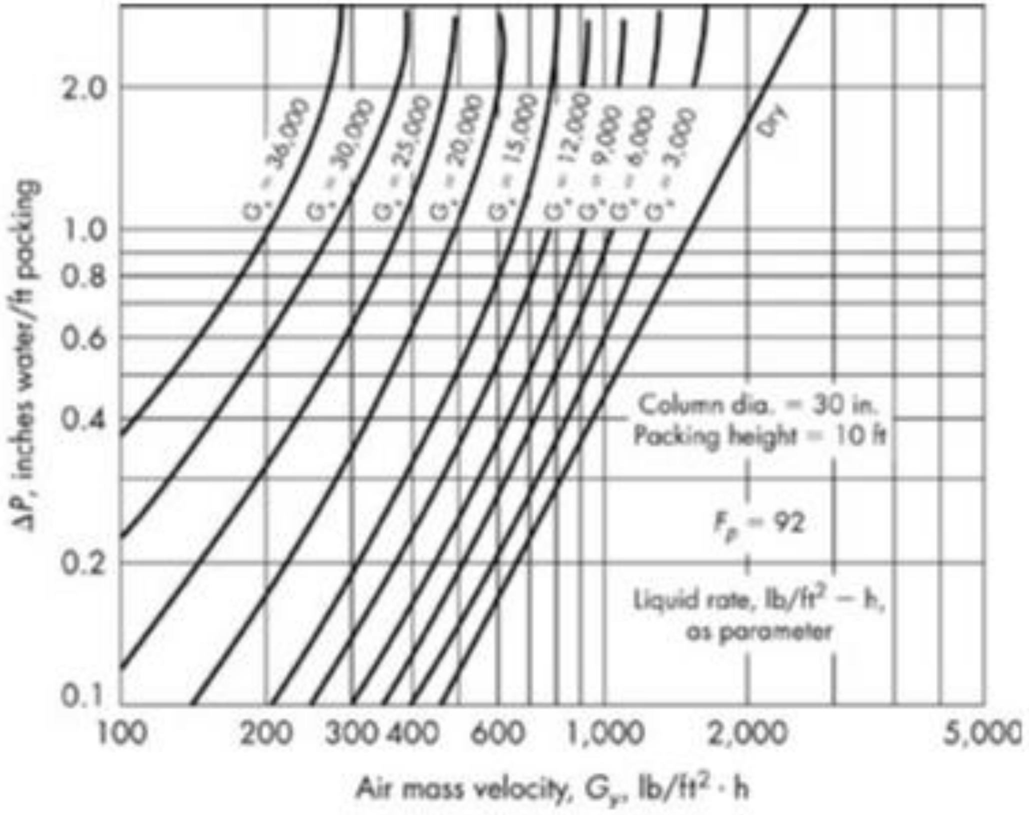

FIGURE 18.4
Pressure drop in a packed tower for air-water system with 1-in. Intalox saddles. (1,000 $lb/ft^2 \cdot h$ = 1.356 $kg/m^2 \cdot s$; 1 in. H_2O/ft = 817 Pa/m)

Flooding

- Flooding refers to when the liquid hold up is so much that the void space in the packing all fills with liquid
- Flooding is **BAD**
  - Liquid becomes continuous and you have low surface area and therefore low mass transfer
- Operating somewhat near flooding conditions is actually good
  - Fully wet the packing and therefore maximize surface area available for mass transfer
- Typical flooding graph is shown
  - It is specific to a particular size and design of packing
  - Calculate the mass velocity of the liquid
  - Use appropriate curve to determine predicted mass velocity of vapor that will lead to flooding

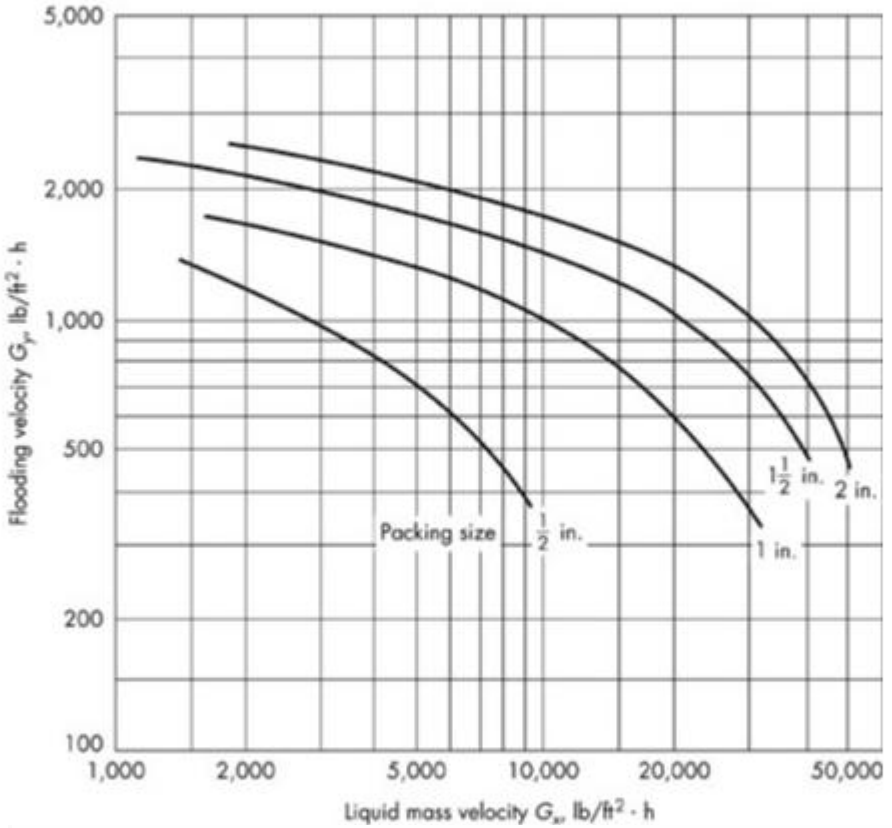

FIGURE 18.5
Flooding velocities in ceramic Intalox saddles, air-water system. (1,000 lb/ft^2 · h = 1.356 kg/m^2 · s)

Pressure Drop

- Generalized Correlation for Pressure Drop
- x axis

$$\frac{G_x}{G_y}\sqrt{\frac{\rho_y}{\rho_x - \rho_y}}$$

- y axis

$$\frac{G_y^2\ F_p\ \mu_x^{0.1}}{g_c(\rho_x - \rho_y)\rho_y}$$

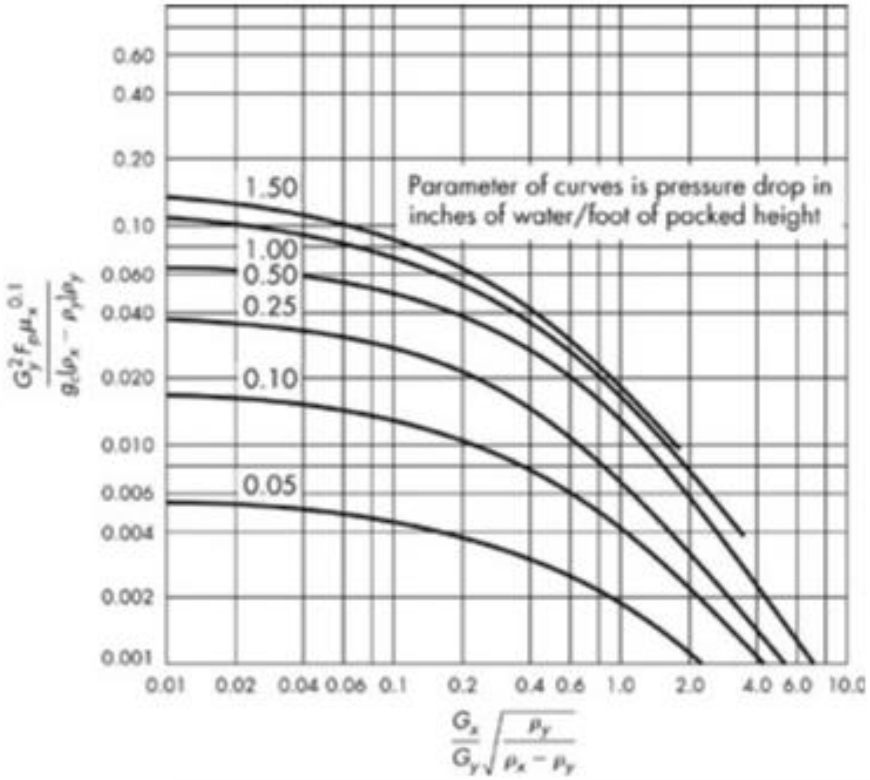

FIGURE 18.6
Generalized correlation for pressure drop in packed columns. (1 in. H_2O/ft = 817 Pa/m) (*After Eckert.*[3])

Alternate Pressure Drop Correlation

- x axis

$$\frac{G_x}{G_y}\sqrt{\frac{\rho_y}{\rho_x}}$$

- y axis

$$C_s\ F_p^{0.5}\ \nu^{0.05}$$

- $C_s = u_0\sqrt{\frac{\rho_y}{\rho_x - \rho_y}}$
  - Where u_0 is the superficial velocity
    - Volumetric flow rate divided by cross-sectional area of the tower, $S = \frac{\pi D^2}{4}$
    - Area ignores fact that packing takes up some of the space

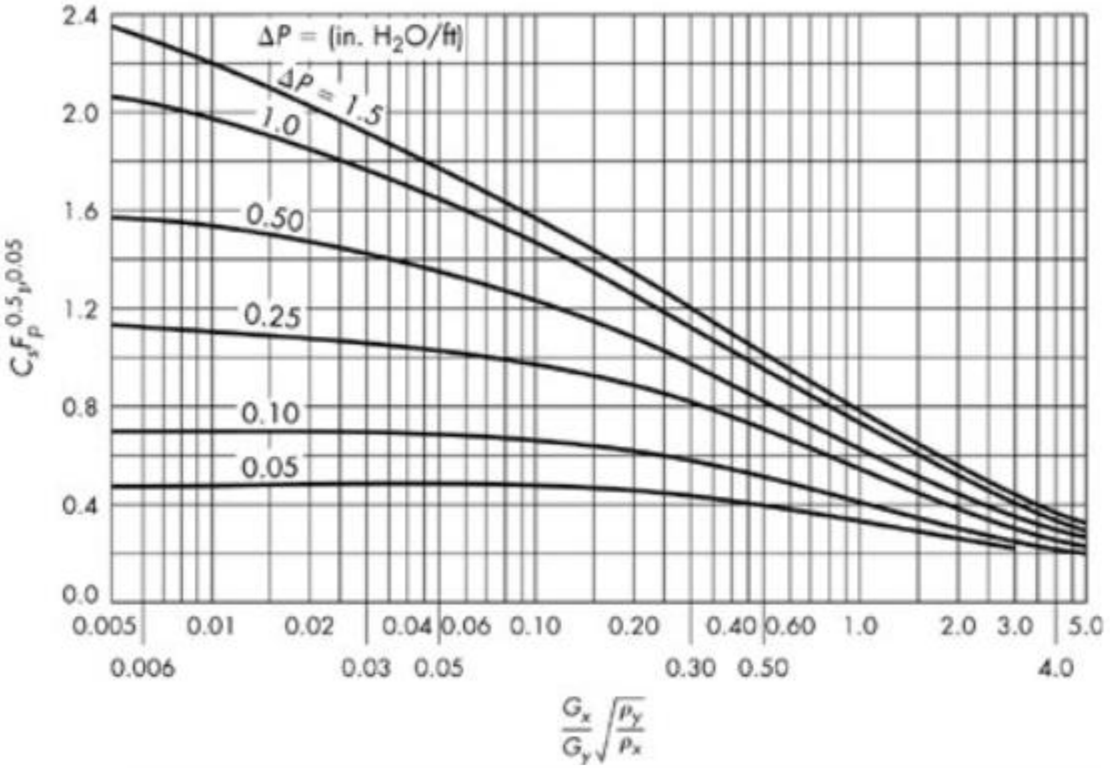

FIGURE 18.7
Alternate generalized pressure drop correlation. (1 in. H_2O/ft = 817 Pa/m)

Empirical Flooding Relationship

- Gives us an allowable pressure drop to use for predicting flooding

$$10 < F_p < 60 \qquad \Delta P_{flood} = 0.115\, F_p^{\,0.7} \ inches\ H_2O/ft$$

$$F_p > 60 \qquad \Delta P_{flood} = 2.0 \ inches\ H_2O/ft$$

Example 18.1, pp 573 in McCSH

- A tower packed with 1" ceramic Intalox saddles is to be built to treat 25,000 ft^3 of entering gas per hour.
- The ammonia content of the entering gas is 2% by volume. Ammonia-free water is used as absorbant.
- The temperature of the entering gas and the water is 68 F (= 528 R) and the pressure is 1 atmosphere.
- The ratio of liquid flow to gas flow is 1.25 lb of liquid per lb of gas.
- If the design pressure drop is 0.5 in H_2O per foot of packing, what should be the mass velocity of the gas and the diameter of the tower?

Example 18.1, pp 573 in McCSH

- Use Figure 18.7
- $\rho_x = 62.3\ \frac{lb_m}{ft^3}$, the density of water
- ρ_y
  - Average Molecular weight is:

    0.98 * 28.96 + 0.02 * 17.03 = 28.72

    - Note that percent by volume is the same as molar percent
  - $\frac{n}{V} = \frac{P}{RT} = \frac{1\ atm}{0.73024\ \frac{ft^3\ atm}{°R\ lb\text{–}mol} * 528\ R} = 0.00259\ \frac{lb\text{–}mol}{ft^3}$
- $\rho_y = MW * \frac{n}{V} = 28.72\frac{lb_m}{lb\text{–}mol} * 0.00259\ \frac{lb\text{–}mol}{ft^3} = 0.0745\ \frac{lb_m}{ft^3}$
- $\frac{G_x}{G_y}\sqrt{\frac{\rho_y}{\rho_x}} = 1.25\sqrt{\frac{0.0745}{62.3}} = 0.0432$
- For $\Delta P = 0.5"\ wc$: $C_S\ F_p^{0.5}\ \nu^{0.05} = 1.38$

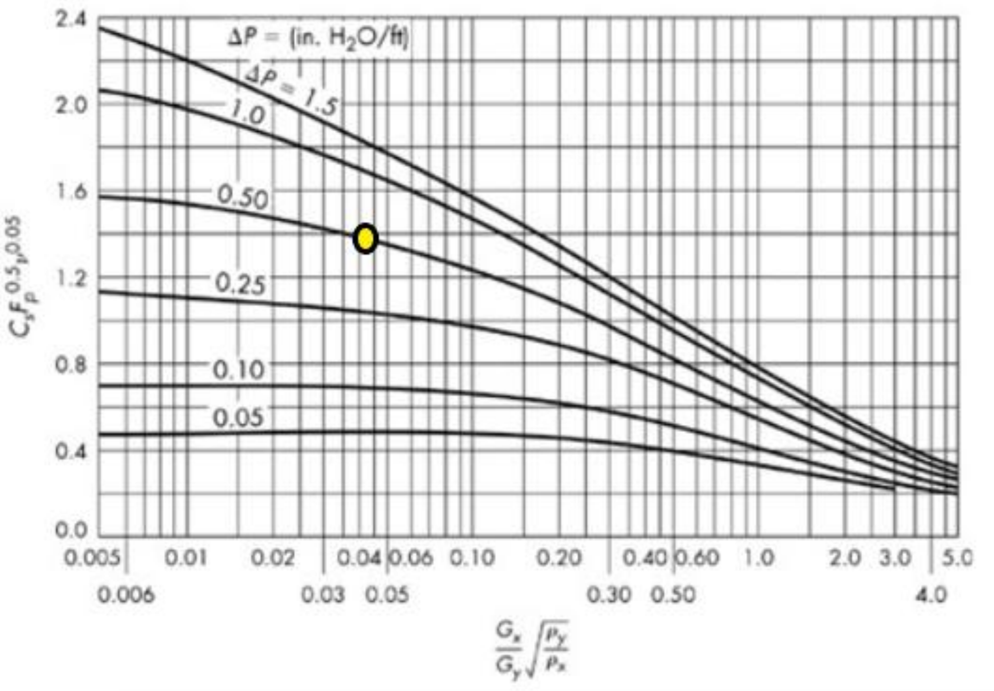

FIGURE 18.7
Alternate generalized pressure drop correlation. (1 in. H_2O/ft = 817 Pa/m)

Example 18.1, pp 573 in McCSH

- $C_S\, F_p^{0.5}\, \nu^{0.05} = 1.38$
- $F_p^{0.5} = \sqrt{92} = 9.59$
- $\nu^{0.5} = 1^{0.05} = 1$ (kinematic viscosity of water = 1 cS)
- $C_S = \frac{1.38}{9.59 * 1} = 0.144$
- $C_s = u_0 \sqrt{\frac{\rho_y}{\rho_x - \rho_y}}$ can be rearranged to $u_0 = C_s \sqrt{\frac{\rho_x - \rho_y}{\rho_y}}$
- $u_0 = 0.144 \sqrt{\frac{62.3 - 0.0745}{0.0745}} = 4.16\ ^{ft}/_{s}$
- $G_y = u_0 * \rho_y = 4.16\ ^{ft}/_{s} * 0.0745 \frac{lb_m}{ft^3} * \frac{3600\ s}{hr} = 1116 \frac{lb_m}{ft^2\ hr}$
- $G_x = 1.25 * G_y = 1.25 * 1116 \frac{lb_m}{ft^2\ hr} = 1395 \frac{lb_m}{ft^2\ hr}$

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Example 18.1, pp 573 in McCSH

- $G_y = 1116 \frac{lb_m}{ft^2\ hr}$
- $G_x = 1395 \frac{lb_m}{ft^2\ hr}$

- $total\ gas\ mass\ flow = Volumetric\ Flow * \rho_y = 25,000\ \frac{ft^3}{hr} * 0.0745\ \frac{lb_m}{ft^3} = 1863 \frac{lb_m}{hr}$
- $G_y * Area = total\ gas\ mass\ flow$ $\qquad Area = {total\ mass\ flow}/{G_y}$

- $Area = S = \frac{1863 \frac{lb_m}{hr}}{1116 \frac{lb_m}{ft^2\ hr}} = 1.67 ft^2$
- $D = \left(\frac{4 * S}{\pi}\right)^{1/2} = \left(\frac{4 * 1.67 ft^2}{\pi}\right)^{1/2} = 1.46\ ft$