

# CE407 SEPARATIONS

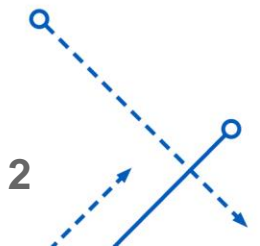
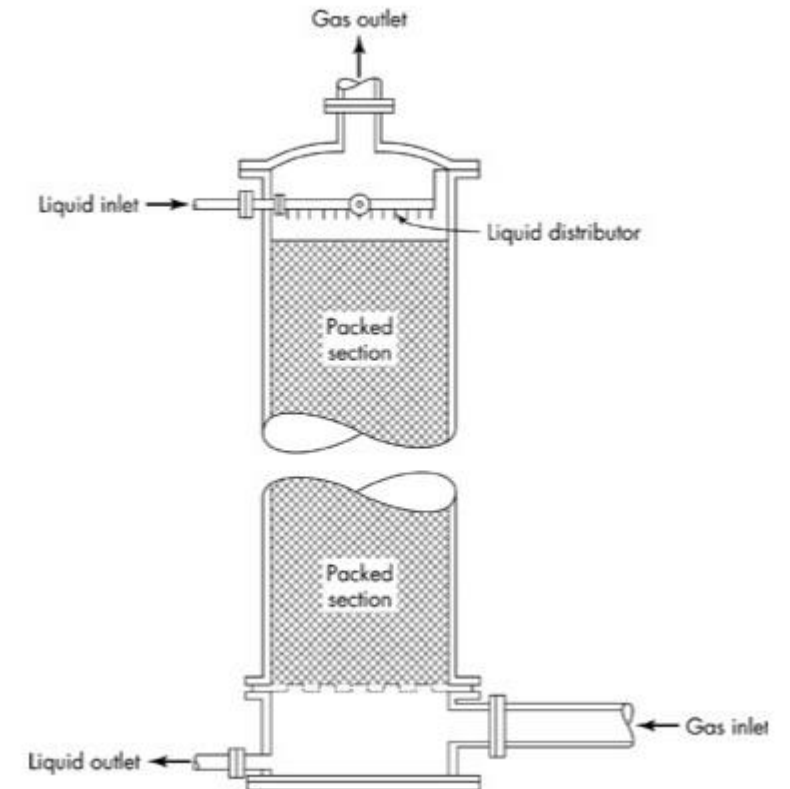
Lecture 23

Instructor: David Courtemanche



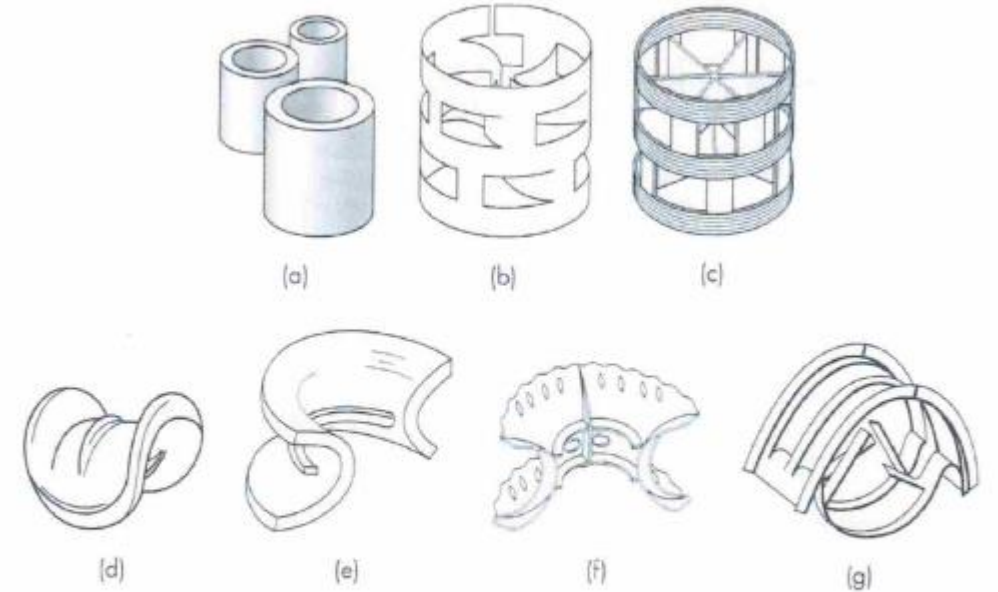
# Design of Packed Towers

- 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  $\Delta P$  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.

# Characteristics of Packing

- Bulk density used for mechanical design of tower
- $F_p$  is used in calculations for  $\Delta P$  and flooding
- $f_p$  is used in estimating  $H_x$  and  $H_y$

TABLE 18.1  
Characteristics of dumped tower packings<sup>12,15b,27</sup>

Type	Material	Nominal size, in.	Bulk density, <sup>†</sup> lb/ft <sup>3</sup>	Total area, <sup>†</sup> ft <sup>2</sup> /ft <sup>3</sup>	Porosity $\epsilon$	Packing factors <sup>‡</sup>	
						$F_p$	$f_p$
Raschig rings	Ceramic	1/2	55	112	0.64	580	1.52§
		1	42	58	0.74	155	1.36§
		1 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 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 1/2	4.8	39	0.91	40	1.18
Berl saddles	Ceramic	1 1/2	54	142	0.62	240	1.58§
		1	45	76	0.68	110	1.36§
		1 1/4	40	46	0.71	65	1.07§
Intalox saddles	Ceramic	1 1/2	46	190	0.71	200	2.27
		1	42	78	0.73	92	1.54
		1 1/2	39	59	0.76	52	1.18
		2	38	36	0.76	40	1.0
Super Intalox saddles	Ceramic	3	36	28	0.79	22	0.64
		1	—	—	—	60	1.54
		2	—	—	—	30	1.0
IMTP	Metal	1	—	—	0.97	41	1.74
		1 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 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	—

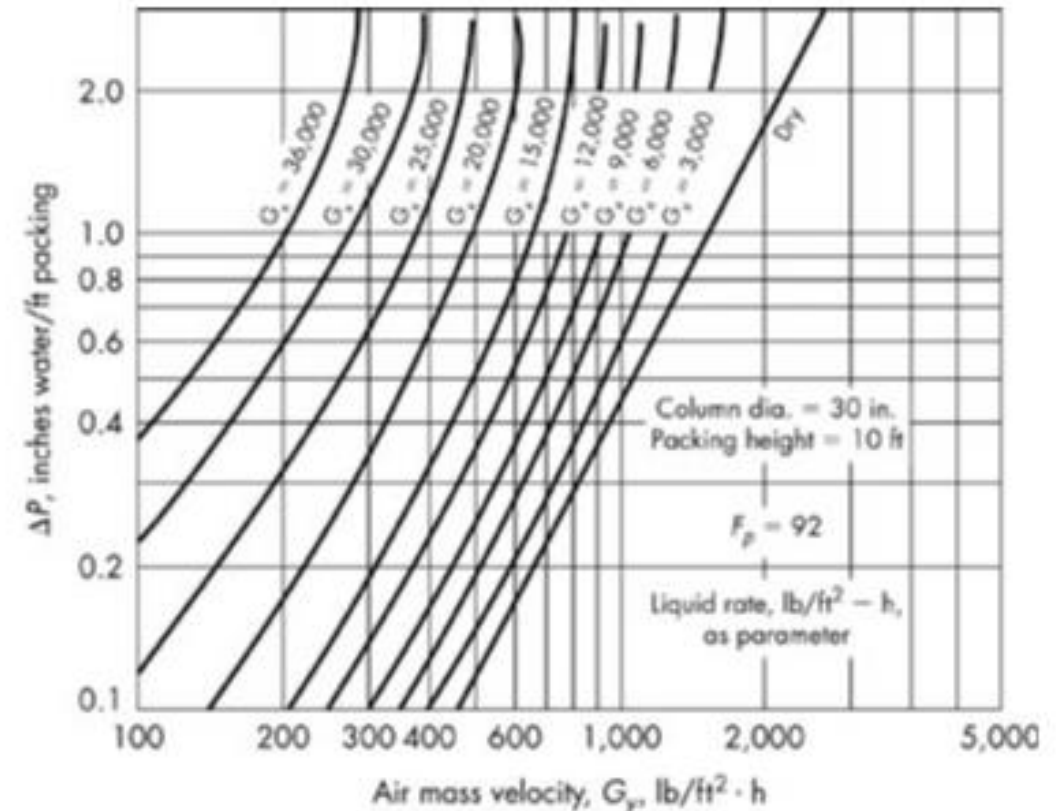
<sup>†</sup>Bulk density and total area are given per unit volume of column.

<sup>‡</sup>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.

<sup>§</sup>Based on  $\text{NH}_3\text{-H}_2\text{O}$  data; other factors based on  $\text{CO}_2\text{-NaOH}$  data.

# Pressure Drop

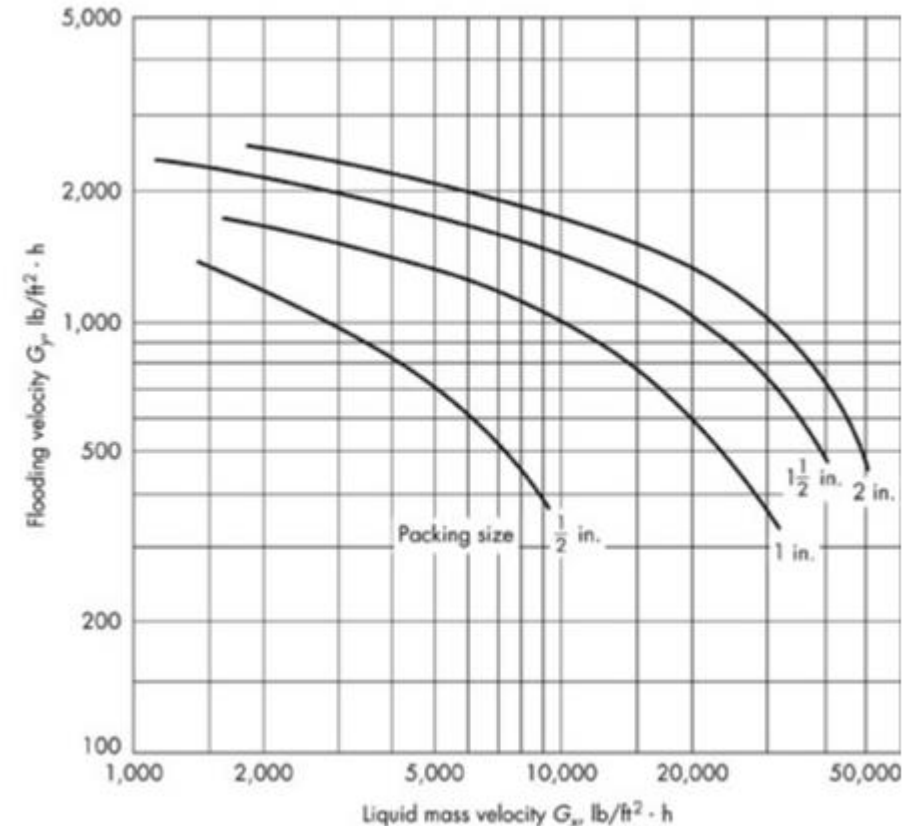
- Simplified chart to predict when liquid hold up will begin
- Chart is specific to a particular size and design of packing
- Used to determine **Loading**
  - Loading refers to when the amount of liquid held up on the packing begins to increase
- Loading begins where the slope of the curve changes
  - 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<sup>2</sup>·h = 1.356 kg/m<sup>2</sup>·s; 1 in. H<sub>2</sub>O/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<sup>2</sup>·h = 1.356 kg/m<sup>2</sup>·s)

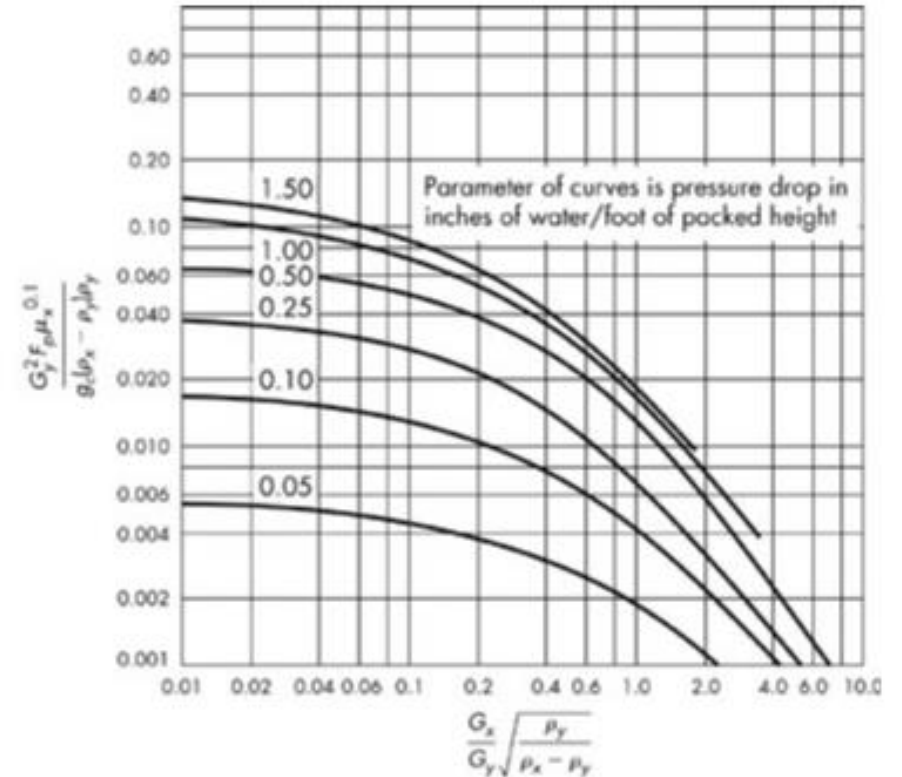
# Pressure Drop

- 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<sub>2</sub>O/ft = 817 Pa/m) (After Eckert.<sup>3</sup>)

# 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

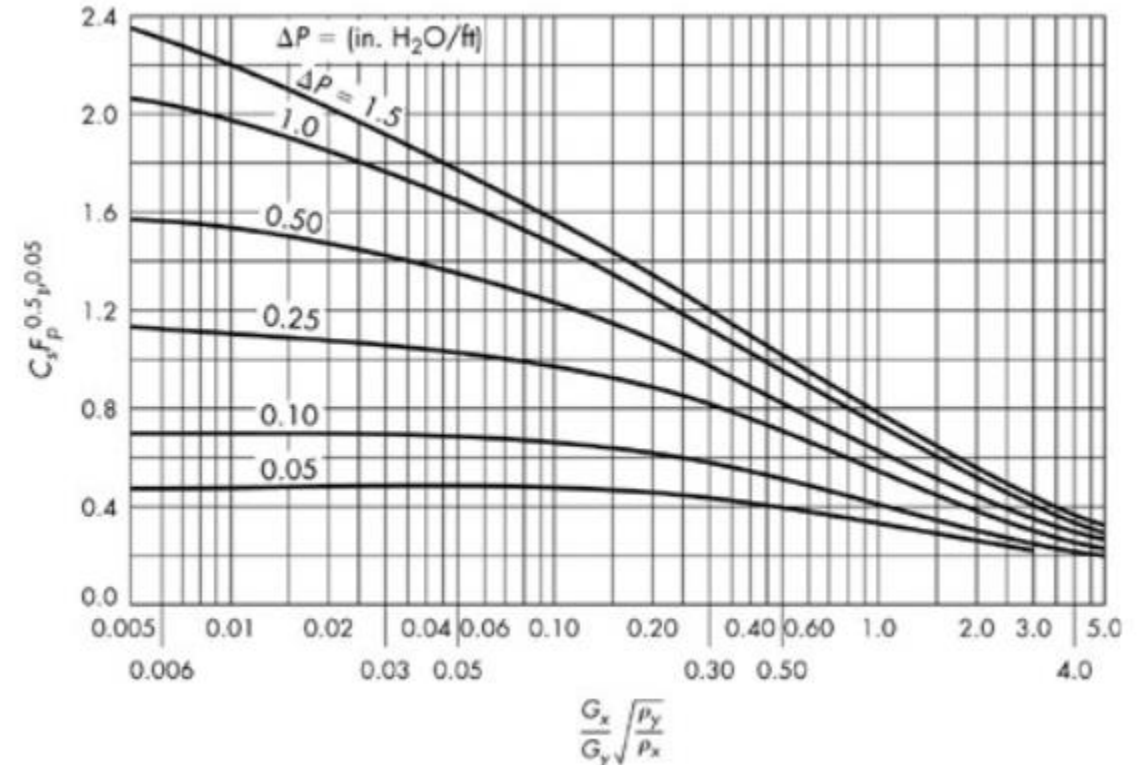


FIGURE 18.7  
 Alternate generalized pressure drop correlation. (1 in. H<sub>2</sub>O/ft = 817 Pa/m)



# Empirical Flooding Relationship

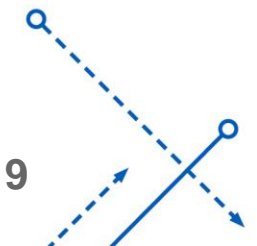
- Gives us an allowable pressure drop to use for predicting flooding

$$10 < F_p < 60$$

$$\Delta P_{flood} = 0.115 F_p^{0.7} \text{ inches } H_2O/ft$$

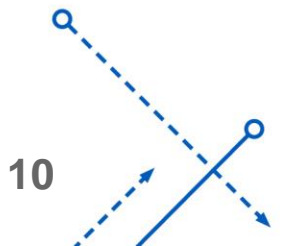
$$F_p > 60$$

$$\Delta P_{flood} = 2.0 \text{ inches } H_2O/ft$$



## Example 18.1, pp 573 in McCSH

- A tower packed with 1" ceramic Intalox saddles is to be built to treat 25,000 ft<sup>3</sup> 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<sub>2</sub>O 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
- $\rho_x = 62.3 \frac{\text{lb}_m}{\text{ft}^3}$ , the density of water
- $\rho_y$ 
  - 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
  - $\frac{n}{V} = \frac{P}{RT} = \frac{1 \text{ atm}}{0.73024 \frac{\text{ft}^3 \text{ atm}}{\text{R lb-mol}} * 528 \text{ R}} = 0.00259 \frac{\text{lb-mol}}{\text{ft}^3}$
- $\rho_y = MW * \frac{n}{V} = 28.72 \frac{\text{lb}_m}{\text{lb-mol}} * 0.00259 \frac{\text{lb-mol}}{\text{ft}^3} = 0.0745 \frac{\text{lb}_m}{\text{ft}^3}$
- $\frac{G_x}{G_y} \sqrt{\frac{\rho_y}{\rho_x}} = 1.25 \sqrt{\frac{0.0745}{62.3}} = 0.0432$
- For  $\Delta P = 0.5'' \text{ wc}$ :  $C_S F_p^{0.5} v^{0.05} = 1.38$

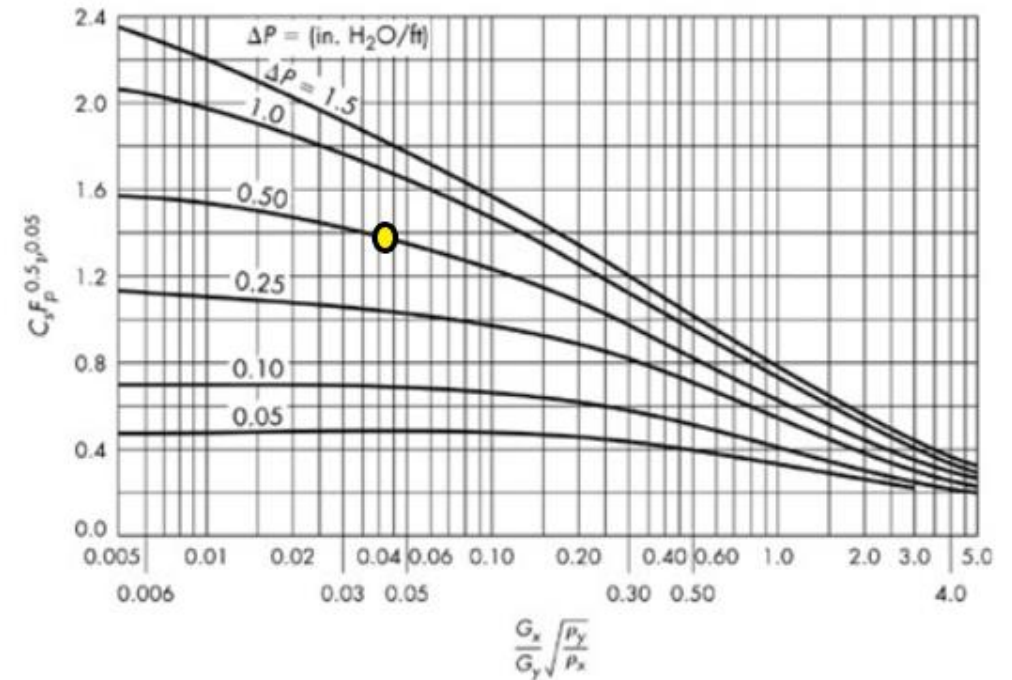


FIGURE 18.7

Alternate generalized pressure drop correlation. (1 in. H<sub>2</sub>O/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  $u_0 = C_S \sqrt{\frac{\rho_x - \rho_y}{\rho_y}}$
- $u_0 = 0.144 \sqrt{\frac{62.3 - 0.0745}{0.0745}} = 4.16 \text{ ft/s}$
- $G_y = u_0 * \rho_y = 4.16 \text{ ft/s} * 0.0745 \frac{\text{lb}_m}{\text{ft}^3} * \frac{3600 \text{ s}}{\text{hr}} = 1116 \frac{\text{lb}_m}{\text{ft}^2 \text{ hr}}$
- $G_x = 1.25 * G_y = 1.25 * 1116 \frac{\text{lb}_m}{\text{ft}^2 \text{ hr}} = 1395 \frac{\text{lb}_m}{\text{ft}^2 \text{ hr}}$

TABLE 18.1  
Characteristics of dumped tower packings<sup>12,150,27</sup>

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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* \*  $\rho_y = 25,000 \frac{ft^3}{hr} * 0.0745 \frac{lb_m}{ft^3} = 1863 \frac{lb_m}{hr}$
- $G_y * Area = \text{total gas mass flow}$                        $Area = \frac{\text{total mass flow}}{G_y}$
- $Area = S = \frac{1863 \frac{lb_m}{hr}}{1116 \frac{lb_m}{ft^2 hr}} = 1.67 ft^2$
- $D = \left(\frac{4 * S}{\pi}\right)^{1/2} = \left(\frac{4 * 1.67 ft^2}{\pi}\right)^{1/2} = 1.46 ft$