# CE407 SEPARATIONS

Lecture 23

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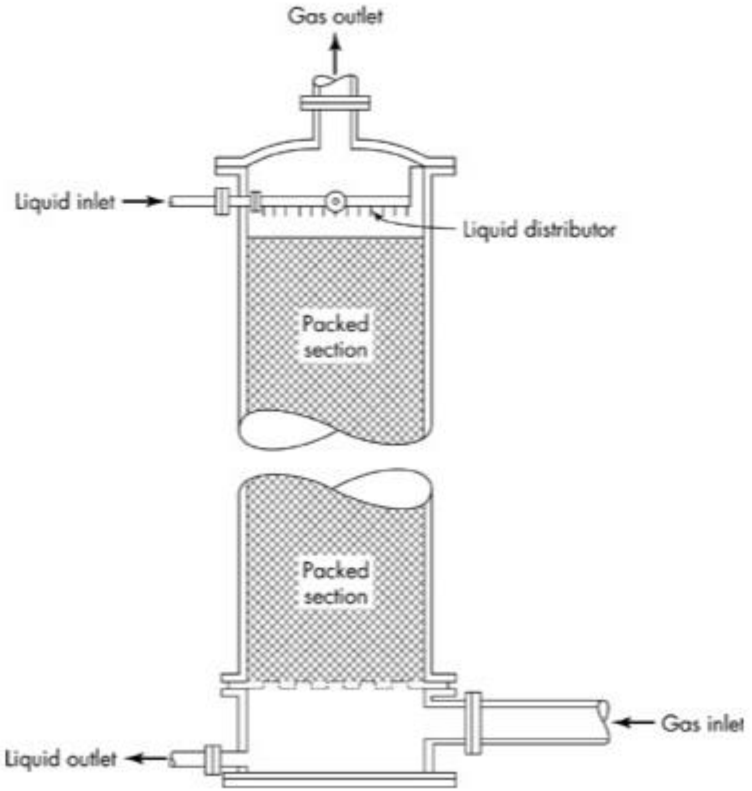
# Design of Packed Towers

- 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

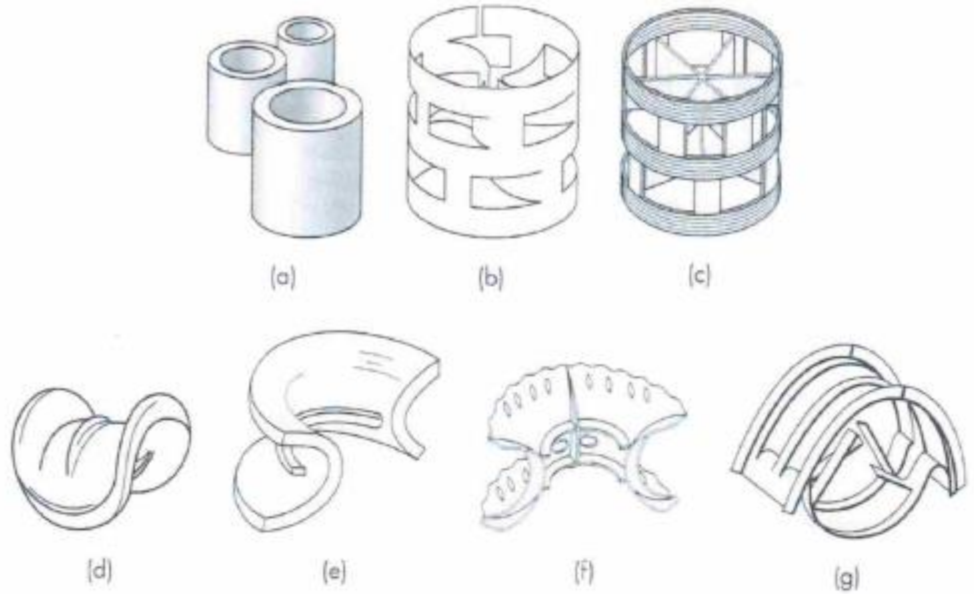



**FIGURE 18.2**
Common tower packings: (*a*) Raschig rings; (*b*) metal Pall ring; (*c*) plastic Pall ring; (*d*) Berl saddle; (*e*) ceramic Intalox saddle; (*f*) plastic Super Intalox saddle; (*g*) metal Intalox saddle.

# Characteristics of Packing

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

**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 $\varepsilon$ | Packing factors‡ $F_p$ | Packing factors‡ $f_p$ |
|---|---|---|---|---|---|---|---|
| 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 | Metal | 1 | 30 | 63 | 0.94 | 56 | 1.54 |
| | | 1½ | 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 |
| | | 1½ | 4.8 | 39 | 0.91 | 40 | 1.18 |
| 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 |
| Super Intalox saddles | Ceramic | 1 | — | — | — | 60 | 1.54 |
| | | 2 | — | — | — | 30 | 1.0 |
| IMTP | Metal | 1 | — | — | 0.97 | 41 | 1.74 |
| | | 1½ | — | — | 0.98 | 24 | 1.37 |
| | | 2 | — | — | 0.98 | 18 | 1.19 |
| Hy-Pak | Metal | 1 | 19 | 54 | 0.96 | 45 | 1.54 |
| | | 1½ | — | — | — | 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 slop of the curve changes
  - Not easily determined with precision

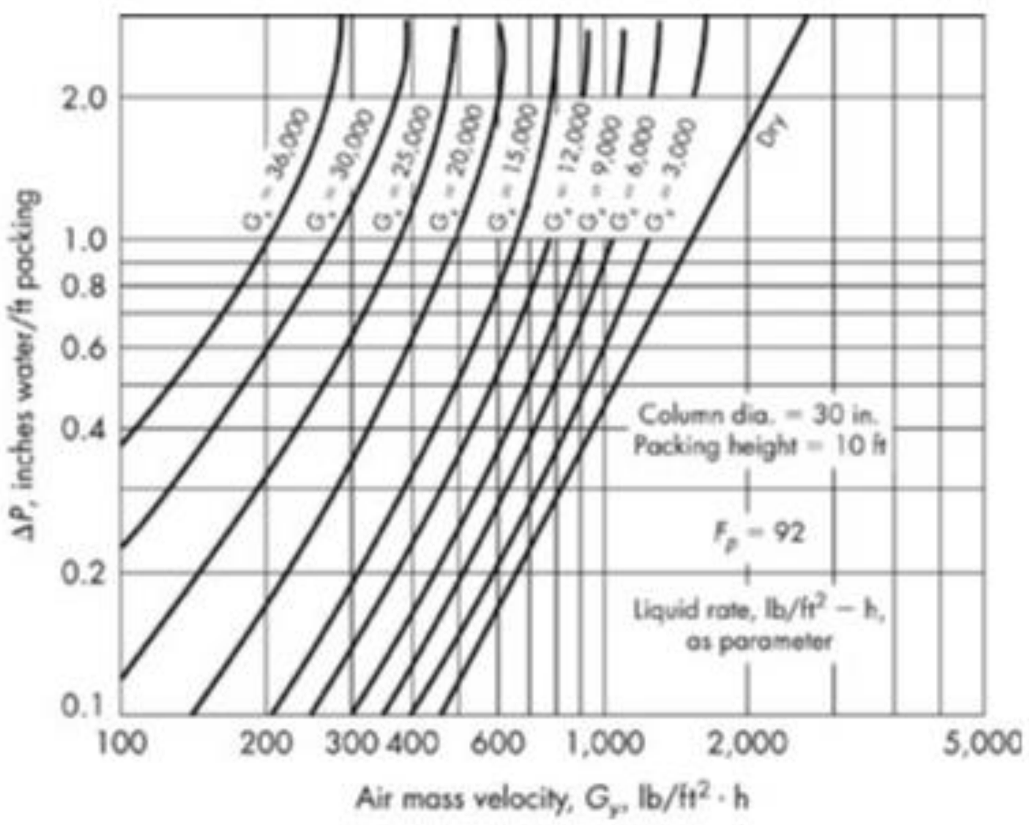



**FIGURE 18.4**
Pressure drop in a packed tower for air-water system with 1-in. Intalox saddles. (1,000 $lb/ft^2 \cdot h$ = 1.356 $kg/m^2 \cdot s$; 1 in. $H_2O/ft$ = 817 Pa/m)

# 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

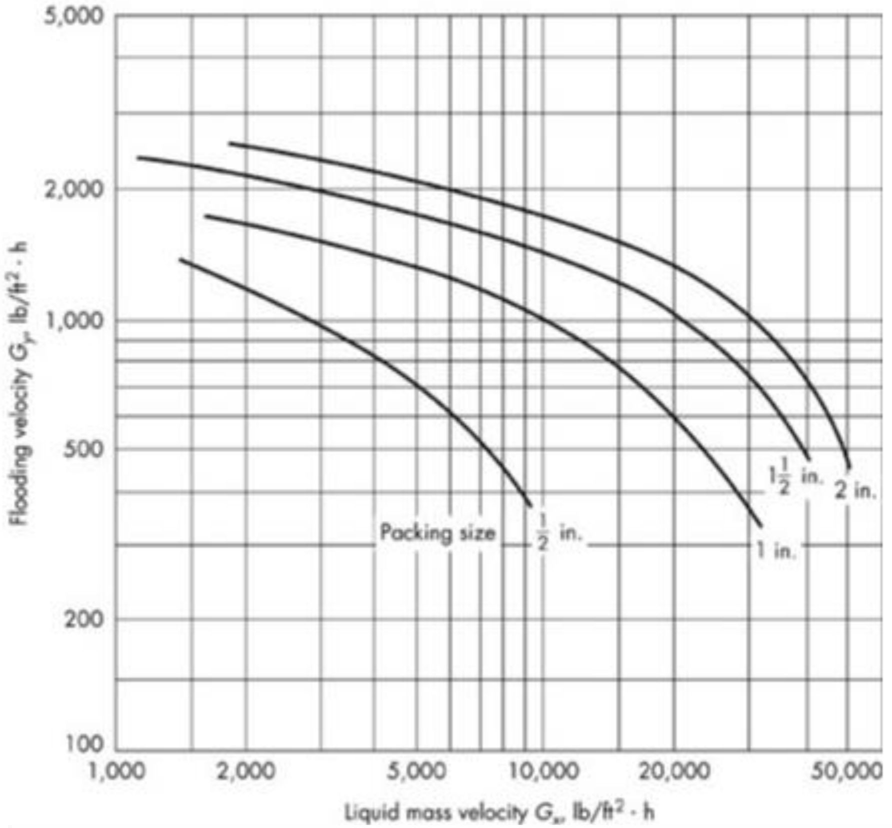



**FIGURE 18.5**
Flooding velocities in ceramic Intalox saddles, air-water system. (1,000 lb/ft$^2$ · h = 1.356 kg/m$^2$ · s)

# Pressure Drop

- Generalized Correlation for Pressure Drop
- x axis

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

- y axis

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

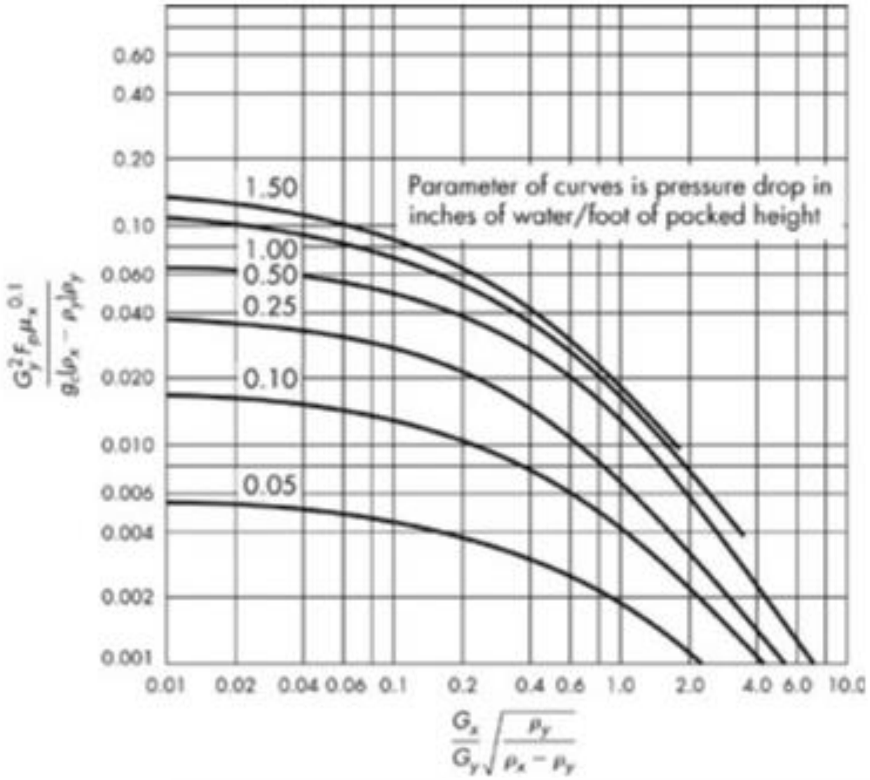



**FIGURE 18.6**
Generalized correlation for pressure drop in packed columns. (1 in. $H_2O$/ft = 817 Pa/m) (*After Eckert.*[3])

- Calculate the value for x axis
- Go to the curve that corresponds to the pressure drop that you are trying to target
- Read off the value of the y axis
- Calculate the value for $G_y$

# 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

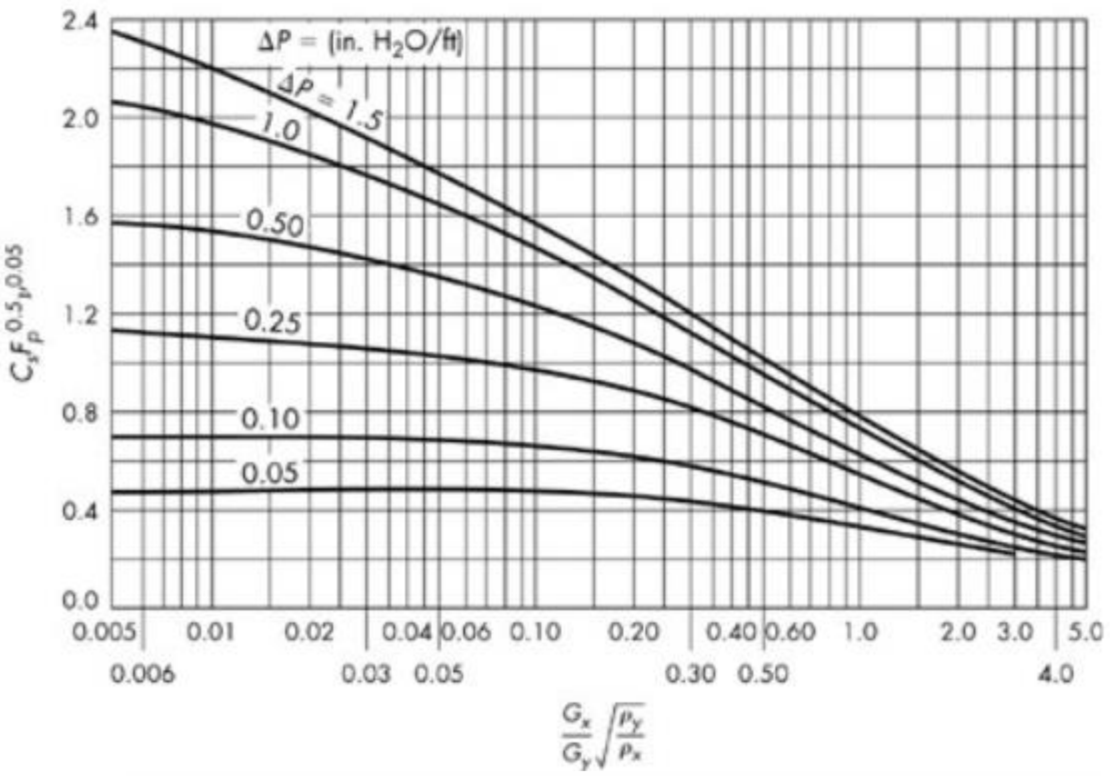



FIGURE 18.7
Alternate generalized pressure drop correlation. (1 in. $H_2O$/ft = 817 Pa/m)

# 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 absorbent.
- 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 H2O 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

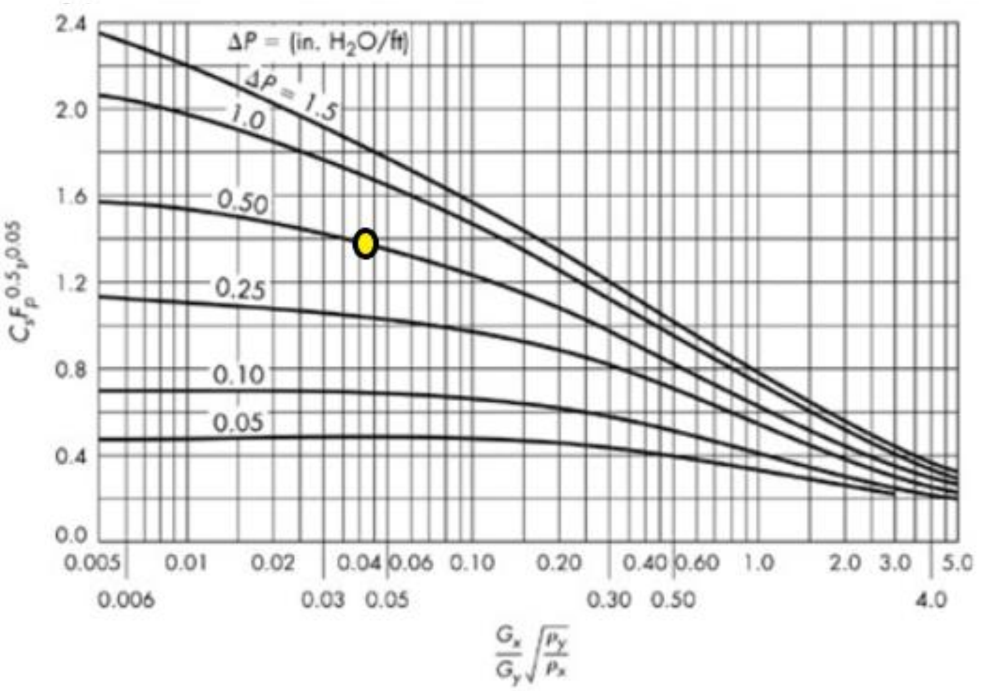



**FIGURE 18.7**
Alternate generalized pressure drop correlation. (1 in. $H_2O$/ft = 817 Pa/m)

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| | | 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 |

# Example 18.1, pp 573 in McCSH

# Example 18.1, pp 573 in McCSH

- Use Figure 18.7
- $\rho_x = 62.3 \frac{lb_m}{ft^3}$, 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
  - $\frac{n}{V} = \frac{P}{RT} = \frac{1\ atm}{0.73024 \frac{ft^3\ atm}{°R\ lb-mol} * 528\ R} = 0.00259 \frac{lb-mol}{ft^3}$
- $\rho_y = MW * \frac{n}{V} = 28.72 \frac{lb_m}{lb-mol} * 0.00259 \frac{lb-mol}{ft^3} = 0.0745 \frac{lb_m}{ft^3}$
- $\frac{G_x}{G_y}\sqrt{\frac{\rho_y}{\rho_x}} = 1.25\sqrt{\frac{0.0745}{62.3}} = 0.0432$
- For $\Delta P = 0.5"\ wc$: $C_s F_p^{0.5} \nu^{0.05} = 1.38$

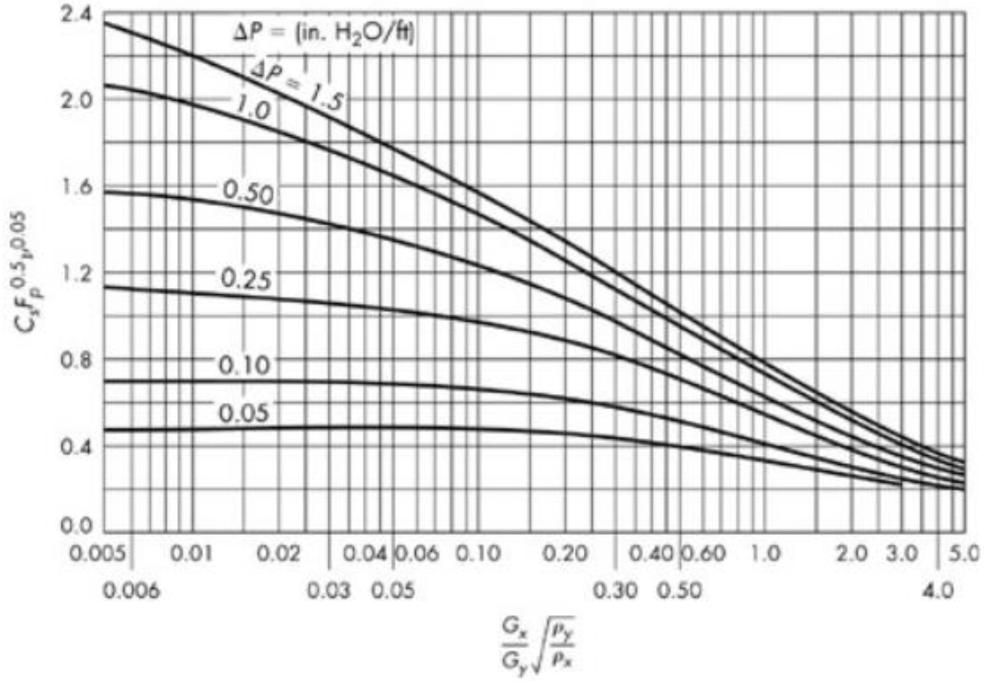


FIGURE 18.7
Alternate generalized pressure drop correlation. (1 in. $H_2O$/ft = 817 Pa/m)

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# 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

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

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

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