Diameter of Bubble Cap Trays

Here are two quick approximation methods for bubble cap tray column diameter.

Standard Velocity

The standard velocity based on total cross section is defined as:

$$U_{STD} = 0.227(\rho_L/\rho_V - 1)^{0.5}$$

The standard velocity is multiplied by a factor depending upon the service as follows:

Service	$\%U_{STD}$
Vacuum towers	110*
Refinery group**	100*
Debutanizers or other 100–250 PSIG towers	80
Depropanizers or other high pressure towers	60

*Applies for 24" tray spacing and above.
**"Refinery group" = low pressure naphtha fractionators, gasoline splitters, crude flash towers, etc.

Souders-Brown[1]

The maximum allowable mass velocity for the total column cross section is calculated as follows:

$$W = C[\rho_V(\rho_L - \rho_V)]^{1/2}$$

The value of W is intended for general application and to be multiplied by factors for specific applications as follows:

Absorbers: 0.55
Fractionating section of absorber oil stripper: 0.80
Petroleum column: 0.95
Stabilizer or stripper: 1.15

The developed equation for the Souders-Brown C factor is

$$C = (36.71 + 5.456T - 0.08486T^2)\ln S - 312.9 + 37.62T - 0.5269T^2$$

Correlation ranges are:

$C = 0$ to 700
$S = 0.1$ to 100
$T = 18$ to 36

The top, bottom, and feed sections of the column can be checked to see which gives the maximum diameter.

The Souders-Brown correlation considers entrainment as the controlling factor. For high liquid loading situations and final design, complete tray hydraulic calculations are required.

Ludwig[2] states that the Souders-Brown method appears to be conservative for a pressure range of 5 to 250 psig allowing W to be multiplied by 1.05 to 1.15 if judgment and caution are exercised.

The Souders-Brown correlation is shown in Figure 1.

Nomenclature

C = Souders-Brown maximum allowable mass velocity factor
S_{STD} = Standard maximum allowable velocity for tower cross section, ft/sec
W = Souders-Brown maximum allowable mass velocity, lbs/(ft^2 cross section) (hr)
ρ_L = Liquid density, lbs/ft^3
ρ_V = Vapor density, lbs/ft^3
T = Tray spacing, in.
S = Surface tension, dynes/cm

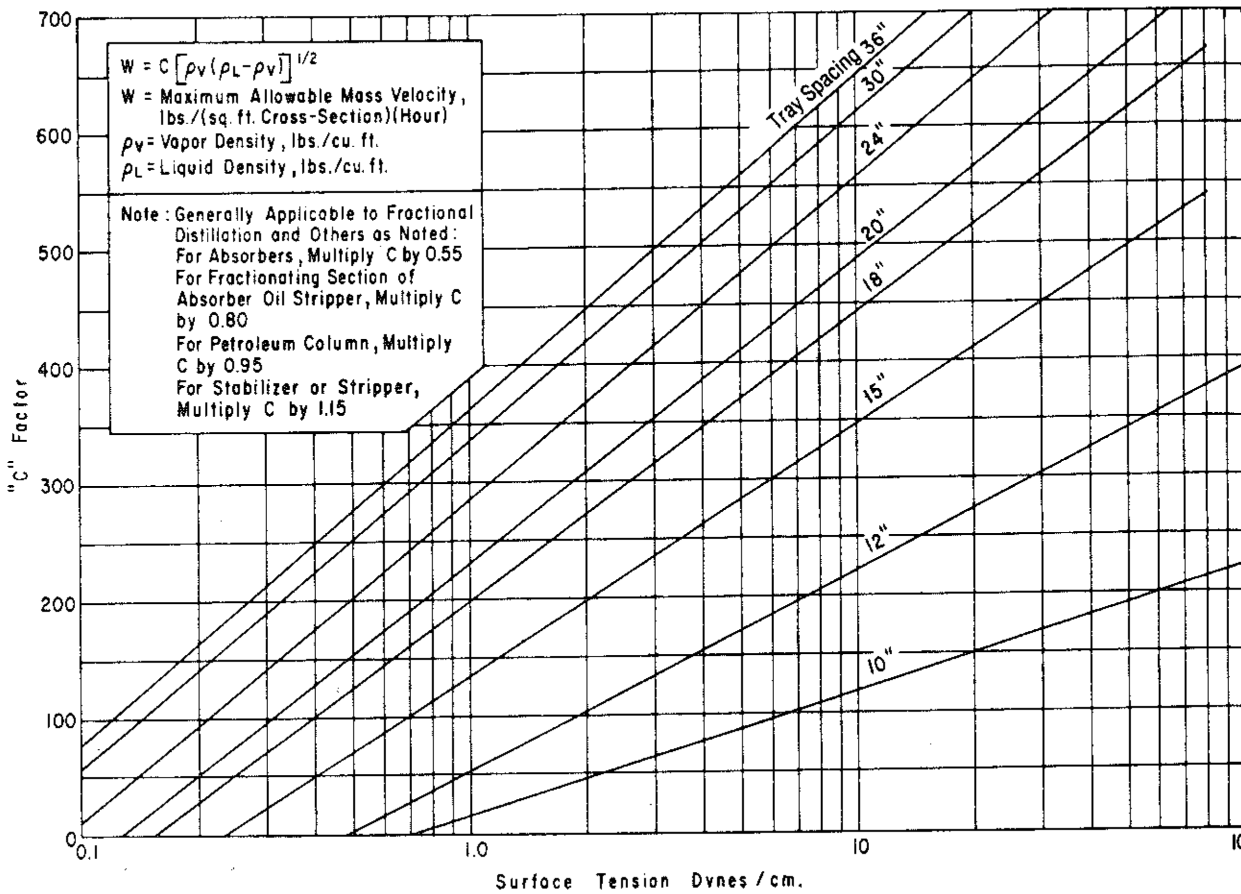

Figure 1. Souders-Brown correlation.

Sources

1. Souders, M. and Brown, G. "Design of Fractionating Columns—I Entrainment and Capacity," *Ind. Eng. Chem.*, 26, 98, (1934).
2. Ludwig, E. E., *Applied Process Design for Chemical and Petrochemical Plants, Vol. 2*, Gulf Publishing Co., 1979.

Diameter of Sieve/Valve Trays (F Factor)

The F factor is used in the expression $U = F/(\rho_v)^{0.5}$ to obtain the allowable superficial vapor velocity based on free column cross-sectional area (total column area minus the downcomer area). For foaming systems, the F factor should be multiplied by 0.75.

The F factor correlation from Frank[1] is shown in Figure 1.

The author has developed an equation for the F factor as follows:

$$F = (547 - 173.2T + 2.3194T^2)10^{-6}P + 0.32 + 0.0847T - 0.000787T^2$$

Correlation ranges are:

F = 0.8 to 2.4
P = 0 to 220
T = 18 to 36

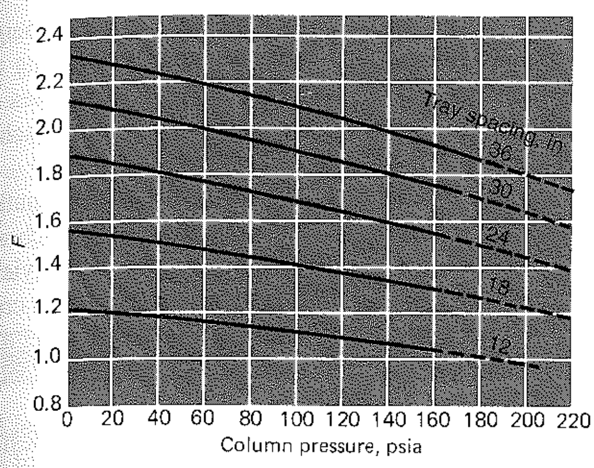

Figure 1. F Factor as a function of column pressure drop and tray spacing.

For estimating downcomer area, Frank gives Figure 2.

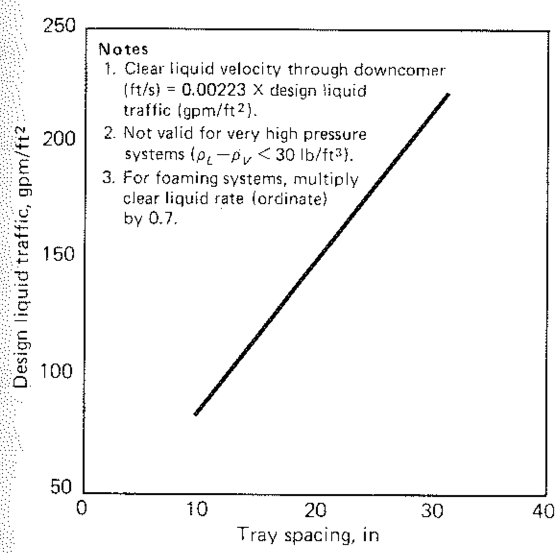

Figure 2. Estimation of downcomer area for a tray-type distillation column.

The author has developed the following equation to fit the correlation:

$$DL = 6.667T + 16.665$$

Clear liquid velocity (ft/sec) through the downcomer is then found by multiplying DL by 0.00223. The correlation is not valid if $\rho_L - \rho_V$ is less than 30 lb/ft^3 (very high pressure systems). For foaming systems, DL should be multiplied by 0.7. Frank recommends segmental downcomers of at least 5% of total column cross-sectional area, regardless of the area obtained by this correlation.

For final design, complete tray hydraulic calculations are required.

For even faster estimates, the following rough F factor guidelines have been proposed:

Situation	F factor
Fractionating column total cross section vapor velocity	1.0–1.5
Sieve tray hole velocity to avoid weeping	>12
Disengaging equipment for separating liquid droplets from vapor	<6

Nomenclature

DL = Design downcomer liquid traffic, gpm/ft^2
F = Factor for fractionation allowable velocity
P = Column pressure, psia
T = Tray spacing, in.
ρ_L = Liquid density, lb/ft^3
ρ_V = Vapor density, lb/ft^3

Source

1. Frank, O., "Shortcuts for Distillation Design," *Chemical Engineering*, March 14, 1977.

Diameter of Sieve/Valve Trays (Smith)

Smith uses settling height as a correlating factor which is intended for use with various tray types. The correlation is shown in Figure 1. Curves are drawn for a range of settling heights from 2 to 30 inches. Here, U is the vapor velocity above the tray not occupied by downcomers.

The developed equations for the curves are (Y subscript is settling height in inches):

$$Y = A + BX + CX^2 + DX^3$$

	A	B	C	D
Y_{30}	−1.68197	−.67671	−.129274	−.0046903
Y_{24}	−1.77525	−.56550	−.083071	+.0005644
Y_{22}	−1.89712	−.59868	−.080237	+.0025895
Y_{20}	−1.96316	−.55711	−.071129	+.0024613
Y_{18}	−2.02348	−.54666	−.067666	+.0032962
Y_{16}	−2.19189	−.51473	−.045937	+.0070182
Y_{14}	−2.32803	−.44885	−.014551	+.0113270
Y_{12}	−2.47561	−.48791	−.041355	+.0067033
Y_{10}	−2.66470	−.48409	−.040218	+.0064914
Y_{8}	−2.78979	−.43728	−.030204	+.0071053
Y_{6}	−2.96224	−.42211	−.030618	+.0056176
Y_{4}	−3.08589	−.38911	+.003062	+.0122267
Y_{2}	−3.22975	−.37070	−.000118	+.0110772

Smith recommends obtaining the settling height (tray spacing minus clear liquid depth) by applying the familiar Francis Weir formula. For our purposes of rapidly checking column diameter, a faster approach is needed.

For applications having 24-in. tray spacing, the author has observed that use of a settling height of 18 inches is good enough for rough checking. The calculation yields a superficial vapor velocity that applies to the tower cross section not occupied by downcomers. A downcomer area of 10% of column area is minimum except for special cases of low liquid loading.

For high liquid loading situations and final design, complete tray hydraulic calculations are required.

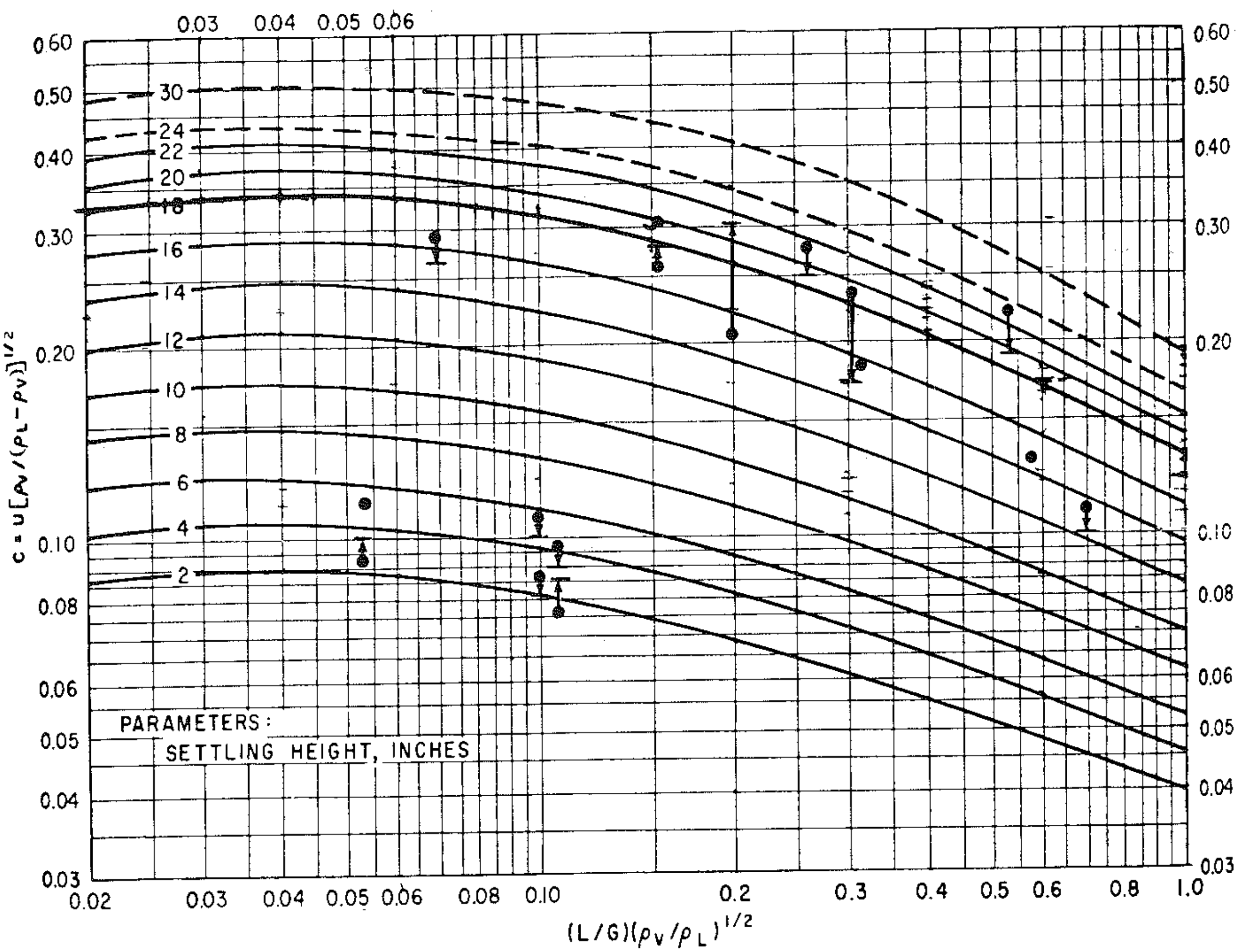

Figure 1. The vapor velocity function is plotted against a capacity factor with parameters of settling heights.

Nomenclature

G = Vapor rate, lb/hr
L = Liquid rate, lb/hr
U = Superficial vapor velocity above the tray not occupied by downcomers, ft/sec
ρ_L = Liquid density, lb/ft^3
ρ_V = Vapor density, lb/ft^3

Sources

1. Smith, R., Dresser, T., and Ohlswager, S., "Tower Capacity Rating Ignores Trays," *Hydrocarbon Processing and Petroleum Refiner*, May 1963.
2. The equations were generated using FLEXCURV V.2, Gulf Publishing Co.

Diameter of Sieve/Valve Trays (Lieberman)

Lieberman gives two rules of thumb for troubleshooting fractionators that could also be used as checks on a design. First, the pressure drops across a section of trays must not exceed 22% of the space between the tray decks, to avoid incipient flood. Mathematically, hold

$$P/(SG)(T_n)(T_s) < 22\%$$

where

P = Pressure drop in inches of water
SG = Specific gravity of the liquid on the tray at the appropriate temperature
T_n = Number of trays
T_s = Tray spacing, in.

For sieve trays, a spray height of 15 inches is obtained when the jetting factor is 6–7.

$$\text{jetting factor} = U^2\rho_V/\rho_L$$

Where:

U = Hole vapor velocity, ft/sec
ρ_L = Liquid density
ρ_V = Vapor density

For a 15-inch spray height, a tray spacing of at least 21 inches is recommended.

Source

Lieberman, N. P., *Process Design For Reliable Operations*, 2nd Ed., Gulf Publishing Co., 1989.

Diameter of Ballast Trays

Calculation/Procedure for Ballast Tray Minimum Tower Diameter

The following method will give quick approximate results, but for complete detailed rating, use the Glitsch Manual.[1]

1. Determine vapor capacity factor CAF.

   $CAF = CAF_o \times \text{System Factor}$

   The proper system factor can be found in Table 1.

2. For $\rho_V < 0.17$ use

   $$CAF_o = (TS)^{0.65} \times (\rho_V)^{1/6}/12$$

   For $\rho_V > 0.17$ use

   $$12-30''\text{TS: } CAF_0 = (0.58 - 3.29/(TS) - [(TS \times \rho_V - TS)/1560]$$

   $$36\ \&\ 48''\text{ TS: } CAF_o = (0.579 - 3.29/TS) - [(0.415TS \times \rho_V - TS)/1560] - 0.0095\rho_V$$

3. The capacity factor CAF_o increases with increasing tray spacing up to a limiting value. Limits reached

Table 1
System Factors[1]

Service	System Factor
Non-foaming, regular systems	1.00
Fluorine systems, e.g., BF_3., Freon	.90
Moderate foaming, e.g., oil absorbers, amine and glycol regenerators	.85
Heavy foaming, e.g., amine and glycol absorbers	.73
Severe foaming, e.g., MEK units	.60
Foam-stable systems, e.g., caustic regenerators	.30–.60

RULES OF THUMB FOR CHEMICAL ENGINEERS

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