Design of Gas Distributors

Several important factors—such as how to obtain adequate distribution and avoid sparge-hole plugging—must be considered in designing straight-pipe, ring and plate gas-distributors for process vessels.

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Basic to many unit operations is the need to distribute adequately a gas stream in a vessel, because maldistribution might interfere with some aspect of the process. Here, design guidelines for pipe spargers and plate distributors are presented.

Design Method for Pipe Spargers

Pipe spargers are horizontal pipes extending into vessels to allow a gas to escape, through holes or slots, into a region of lower pressure. Typical applications do not require thorough distribution of the gas over the vessel cross-section, but rather a rapid equilibration of pressure and flow profiles. Although ring spargers and branched networks can provide a more thorough distribution than can a simple pipe, analyses of flow and pressure profiles are more complicated, and capital cost is higher.

Allocation of the escape area along a pipe sparger is determined by the pressure profile in the pipe. Pipe friction, gas density, and differential pressure across the pipe must be accounted for as a function of length. The table lists equations[1] for compressible and incompressible flow of an ideal gas through a pipe sparger. Fig. 1(a) shows the coordinate system associated with these equations. The required pressure profile from the table is inserted into this equation.

$$\frac{da}{dx} = \frac{u}{C\sqrt{2g_c\rho\,[P(x) - P_e]}} \qquad (8)$$

which yields the escape area as a function of length for a constant radial flux. Physically, the escape area can be provided by a slot of varying width, nonuniform hole sizes, or nonuniform hole density. This method may also be applied to ring spargers or to the individual sections of branched distributors.

Long slots produce discharge profiles containing an axial velocity component in addition to the desired radial component. Turning vanes can be used to correct the discharge profile if necessary. One recommendation is that the vanes should project from the pipe a distance equal to twice the vane spacing.[3]

In certain applications, deposits plug distributor holes. The best way to minimize this is to use the fewest number of holes, consistent with good distribution, at the desired pressure drop. Very high pressure drops also help prevent plugging.[2]

Variations in either gas supply or process pressure change the amount of gas delivered and the discharge profile along the sparger. Either effect can be minimized by designing for a high differential pressure across the pipe. Variations in discharge profile can be minimized through smaller axial pressure gradients, generally by using larger-diameter pipes. If $[P(X) - P_e] > \frac{1}{2}P(X)$, then flow through the escape area is sonic and independent of process-pressure variations.

Distributor Plates

Perforated distributor plates are used to provide a more uniform gas distribution than can be achieved by a pipe

Sparger-Pipe Pressure Profiles as Function of Length

	Equations for Incompressible Systems	
Turbulent flow	$P(X) = P_s - (0.00117\,Q/U\rho)\,[W_{in}^3 - (W_{in} - UX)^3] - (0.0102\,QS/U\rho)\,[W_{in}^{2.58} - (W_{in} - UX)^{2.58}]$	(1)
Laminar flow	$P(X) = P_s - (8Q/U\rho)\,[W_{in}^2 - (W_{in} - UX)^2]$	(2)
	Equations for Compressible Systems	
Turbulent flow	$P(X)^2 = P_s^2 - (0.00233\,QRT/UM)\,[W_{in}^3 - (W_{in} - UX)^3] - (0.205\,SRT/UM)\,[W_{in}^{2.58} - (W_{in} - UX)^{2.58}]$	(3)
Laminar flow	$P(X)^2 = P_s^2 - (8QRT/UrM)\,[W_{in}^2 - (W_{in} - UX)^2]$	(4)
Convenience variables	$Q = 2/(g_c A^2 D)$ (5); $r = 4/(\pi D\mu)$ (6); $S = r^{-0.42}$	(7)

Nomenclature

a	Escape area, sq.ft.
A	Flow area, sq.ft.
A_p	Cross-sectional area of plate, sq.ft.
A_{th}	Total hole area, sq.ft.
C	Orifice coefficient, dimensionless
D	Vessel dia., ft.
D_H	Hole dia., in.
D_{noz}	Nozzle dia., ft.
g_c	Gravity constant, 32.2 (lb._{mass})(ft.)/(lb._{force})(sec.^{2})
H	Distance between nozzle and bottom of distributor plate, ft.
H_{vs}	Distance between bottom of vessel and distributor plate, ft.
L	Hole pitch, in.
M	Molecular weight
P	Pressure, psia.
P_e	Process pressure, lb./sq.ft.
P_s	Supply pressure, lb./sq.ft.
ΔP_{exp}	Pressure loss through expansion, lb./sq.ft.
R	Gas constant, 1,542 (ft.)(lb.)/(°R.)(lb.-mole)
T	Temperature, deg. R.
U	Radial flux, lb./(sec.)(ft.)
V_{noz}	Nozzle velocity, ft./sec.
W_{in}	Axial flowrate, lb./sec.
X	Axial distance, ft.
μ	Viscosity, lb./(sec.)(ft.)
ρ	Density, lb./cu.ft.

or ring sparger alone. Analysis of the chamber under a distributor plate involves a complicated flow in three dimensions, as contrasted with the simple two-dimensional analysis for a pipe sparger. The situation is simplified by making the chamber large enough to eliminate acceleration effects. The entrance expansion loss, however, is increased by a larger chamber, but the loss may be minimized by using a bigger nozzle. Eq. (9) and (10) permit calculating the expansion loss for nozzles that enter a vertical vessel horizontally, as in Fig. 1(b), or are centered in the bottom head, as in Fig. 1(c).

For horizontal entry:

$$\Delta P_{exp} = \left[1 - \frac{0.785\, D_{noz}^{\ 2}}{H_{vs} D}\right]^2 \left[\frac{\rho V_{noz}^{\ 2}}{2g_c}\right] \qquad (9)$$

For vertical entry:

$$\Delta P_{exp} = \left[1 - \frac{0.785\, D_{noz}^{\ 2}}{D^2}\right]^2 \left[\frac{\rho V_{noz}^{\ 2}}{2g_c}\right] \qquad (10)$$

For good distribution, Richardson[2] recommends that $(P - P_e) > 100\Delta P_{exp}$. The area required to achieve a given pressure drop across the plate is estimated by:

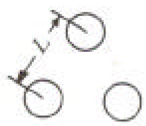
$$A_{th} = \frac{W_{in}}{C\,[2g_c(P_s - P_e)\rho]^{1/2}} \qquad (11)$$

The orifice coefficient, C, varies with flowrate, fluid properties, plate thickness, orifice size, etc. For most purposes, an average C value of 0.61 suffices.

The total hole area must now be distributed over the plate. A uniform distribution may be provided by arranging the holes on a triangular or square pitch (see below). Eq. (12) and (13) do not apply to plates with very few holes, but these may be laid out by hand.

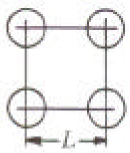
For triangular pitch:

$$L = 0.951(A_p/A_{th})^{1/2} D_H \qquad (12)$$



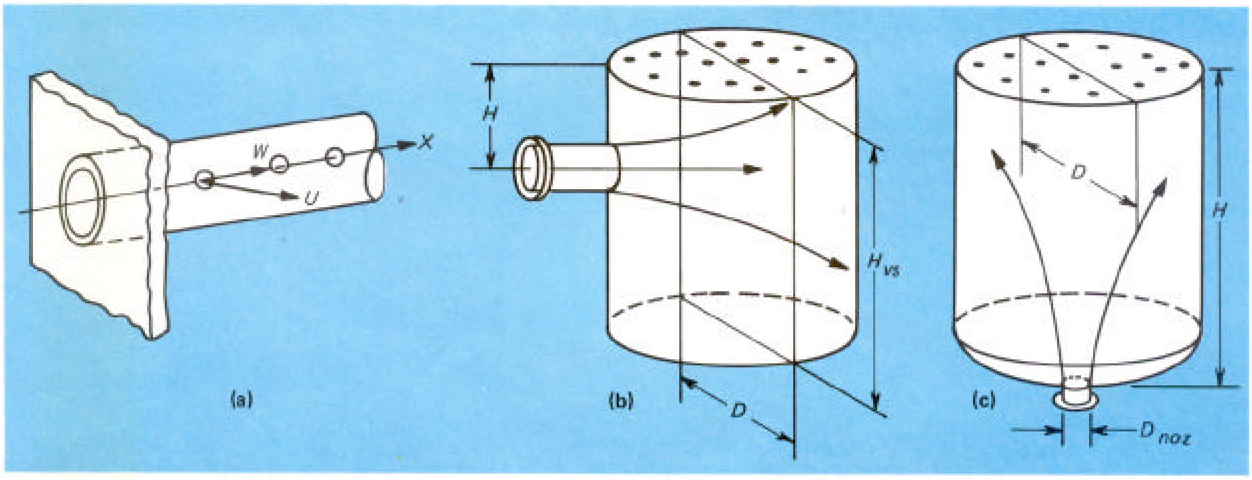
For square pitch:

$$L = 0.886(A_p/A_{th})^{1/2} D_H \qquad (13)$$

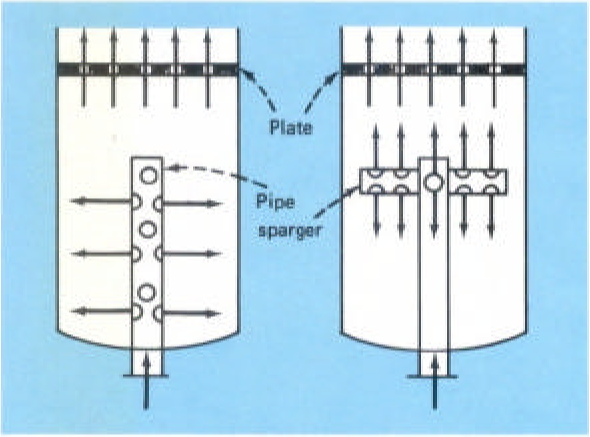


Even if there is enough chamber volume for pressures to equalize, the feed nozzle must be positioned with care. Rough guidelines can be drawn by modeling a high-velocity stream expanding into the vessel as a conical-free jet with a half-angle of about 10 deg.

A high-velocity gas stream entering horizontally into



SOME EQUATION SYMBOLS: (a) coordinates for sparger-pipe analysis; (b) gas from a horizontal nozzle into a vertical vessel; (c) gas from a vertical nozzle into a vertical vessel—Fig. 1



METHODS for introducing a high-velocity gas stream vertically into a vessel—Fig. 2

a vertical vessel expands as a free jet until: (1) it strikes the opposite wall; (2) it dissipates itself (at about 100 nozzle dia.[3]); or (3) the upper edge strikes the bottom of the distributor plate.

To eliminate the maldistribution caused by condition No. 3, place the distributor plate a distance, H, above the nozzle centerline. If:

$$D_{noz} > D/100, \text{ then } H = 0.2\,D + 0.5\,D_{noz} \quad (14)$$

$$\text{and if } D_{noz} < D/100, \text{ then } H = 18\,D_{noz} \quad (15)$$

A high-velocity gas stream entering a vertical vessel through a nozzle centered in the bottom head expands as a free jet until: (1) its diameter coincides with the vessel diameter; (2) it dissipates itself; or (3) it strikes a central portion of the plate, causing maldistribution.

The dimension H (Fig. 1c) above the inlet nozzle elevation, which prevents maldistribution, is:

$$H = 3(D - D_{noz}), \text{ when } D_{noz} > D/36 \quad (16)$$

$$\text{and } H = 100\,D_{noz}, \text{ when } D_{noz} < D/36 \quad (17)$$

The vertical dimensions required can be reduced by placing spargers under a distributor plate (Fig. 2).

Sample Calculations

Example 1—It is desired to uniformly distribute 0.19 lb./sec. of a gas into a process through a 1.049-in.-I.D. pipe, 20 ft. long. Gas properties are $\mu = 1.344 \times 10^{-5}$ lb./(ft.)(sec.)—0.02 cp.—and $\rho = 0.17$ lb./cu.ft. Gas supply conditions are 4,752 lb./sq.ft. absolute pressure and 500° R. The external absolute pressure is 4,608 lb./sq.ft. Find the required area distribution.

From the equations in the table, calculate Q, r and S:

$$Q = 2\Big/\left\{(32.2)\left[\frac{\pi(1.049)^2}{4(12)^2}\right]^2\left(\frac{1.049}{12}\right)\right\} = 1.972 \times 10^4$$

$$r = 4\Big/\left[\pi\left(\frac{1.049}{12}\right)(1.344 \times 10^{-5})\right] = 1.084 \times 10^6$$

$$S = (1.084 \times 10^6)^{-0.42} = 2.92 \times 10^{-3}$$

From a listing of pressures and escape areas made at 4-ft. increments along the sparger, a pressure profile for turbulent compressible flow is chosen. The orifice coefficient is assumed to be 0.61, and $U = 0.19/20 = 0.0095$ lb./(ft.)(sec.). Once the area distribution is established, a slot or hole pattern consistent with process needs (such as bubble size) is specified. The pressures are calculated from Eq. (3), and the escape areas from Eq. (8):

Increment, X, Ft.	Internal Pressure, Lb./Sq.Ft.	Escape Area, Sq. In.
0–4	4,752	0.224
4–8	4,705	0.275
8–12	4,676	0.329
12–16	4,661	0.373
16–20	4,656	0.394
	Σ, sq. in., =	1.595

Example 2—Of the gas in Example 1, 0.3 lb./sec. is to be introduced into a 12-in.-I.D. vertical vessel, through a 4.026-in.-I.D. horizontal nozzle. A distributor plate is to be placed 2 ft. above the vessel's bottom. Determine the hole area needed for the plate, and the position of the nozzle in the vessel.

The available $\Delta P = 4{,}752 - 4{,}608 = 144$ lb./sq.ft. The hole area needed by the distributor is given by Eq. (11):

$$A_{th} = \frac{0.3}{(0.61)\,[(2)(32.2)(144)(0.17)]^{1/2}} = 0.012 \text{ sq.ft.}$$

$$= 1.8 \text{ sq.in.}$$

The velocity of gas in the nozzle is:

$$V_{noz} = \frac{0.3}{(0.17)\,(\pi/4)(4.026/12)^2} = 20.0 \text{ ft./sec.}$$

and the expansion pressure loss, by Eq. (9), is:

$$\Delta P_{exp} = \left[1 - \frac{0.785(4.026/12)^2}{(2)(12/12)}\right]^2\left[\frac{(0.17)(20.0)^2}{(2)(32.2)}\right]$$

$$= 1.00 \text{ lb./sq.ft.}$$

Since this ΔP_{exp} value is less than 1% of the available ΔP, it meets Richardson's criterion.[2] Eq. (14) gives the minimum distance between the bottom of the plate and the centerline of the nozzle:

$$H = (0.2)(12) + (0.4)(4.026) = 4.4 \text{ in.}$$ ■

References

1. Cooper, H. W., *Chem. Eng.*, Oct. 28, 1963, p. 148.
2. Richardson, D. R., *Chem. Eng.*, May 1, 1961, p. 83.
3. "Chemical Engineers' Handbook," Perry, J. H., ed., McGraw-Hill, New York (1963).

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