# SECTION 4.2

# JET PUMP APPLICATIONS

ALEX M. JUMPETER

This section contains extensive design and application experience for a variety of jet pump configurations. Although this section concentrates on eductors (termed LJL jet pumps in Section 4.1), experience with other motive (primary) and secondary fluids is also included. The theoretical developments of Section 4.1 are the basis for what is presented here, the dimensional design ratios being generally within the ranges mentioned therein. Therefore, the only theory in this section is the empiricism that is utilized in the examples and applications presented. Refer to Section 4.1 for further explanation.

## DEFINITION OF TERMS

A definition of standard ejector terminology is as follows:

| | |
|---|---|
| *Ejector* | General name used to describe all types of jet pumps that discharge at a pressure intermediate between motive and suction pressures. |
| *Eductor* | A liquid jet pump using a liquid as motive fluid. |
| *Injector* | A particular type of jet pump that uses a condensable gas to entrain a liquid and discharge against a pressure higher than either motive or suction pressure; principally, a boiler injector. |
| *Jet Compressor* | A gas jet pump used to boost pressure of gases. |
| *Siphon* | A liquid jet pump utilizing a condensable vapor, normally steam, as the motive fluid. |

## EDUCTORS

**Design** The elements of an eductor design are shown in Figure 1. Quantities involved are defined as follows:

$P_1$ = static pressure upstream, lb/ft$^2$ (N/m$^2$)
$P_s$ = static pressure at suction (nozzle tip), lb/ft$^2$ (N/m$^2$)
$V$ = velocity, ft/s (m/s)
$\gamma_1$ = specific weight (force) of motive fluid, lb/ft$^3$ (N/m$^3$)

$$\frac{P_1 - P_s}{\gamma_1} = \text{operating head, ft (m)}$$

$P_s$ = static pressure at suction, lb/ft$^2$ (N/m$^2$)
$P_2$ = static pressure at discharge, lb/ft$^2$ (N/m$^2$)
$\gamma_2$ = specific weight (force) of mixed fluids, lb/ft$^3$ (N/m$^3$)

$$\frac{P_2 - P_s}{\gamma_2} = \text{discharge head, ft (m)}$$

The head ratio $R_H$ is defined as the ratio of the operating head to the discharge head:

$$R_H = \frac{(P_1 - P_s)/\gamma_1}{(P_2 - P_s)/\gamma_2} = \frac{(P_1 - P_s)\gamma_2}{(P_2 - P_s)\gamma_1} \tag{1}$$

Because ratios are involved, it is convenient to replace specific weight with specific gravity:

$$R_H = \frac{(P_1 - P_s)(\text{sp. gr.}_2)}{(P_2 - P_s)(\text{sp. gr.}_1)} \tag{2}$$

When the suction and motive fluids are the same, no gravity correction is required and Eq. 2 becomes

$$R_H = \frac{H_1 - H_s}{H_2 - H_s} \tag{3}$$

where $H_1 - H_s$ = operating head, ft (m)
$H_2 - H_s$ = discharge head, ft (m)

Entrainment relates the mass (flow rate) of motive fluid and suction fluid:

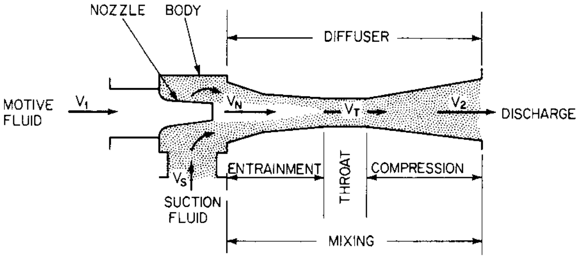

**FIGURE 1** Eductor elements and terminology

$M_1$ = mass of motive (primary) fluid, slugs (kg)
$M_s$ = mass of suction (secondary) fluid, slugs (kg)

$$R_w = \frac{M_s}{M_1} = \text{the weight operating ratio} \tag{4}$$

The volume ratio $R_q$ is then simply

$$\frac{Q_s}{Q_1} = R_w \frac{\text{sp. gr.}_1}{\text{sp. gr.}_2} \tag{5}$$

where $Q_s$ = suction (secondary) flow in volumetric units
$Q_1$ = motive (primary) flow in volumetric units

The performance of eductors is expressed here in terms of $R_H$ and $R_w$, utilizing an empirical relationship that involves an efficiency factor $\varepsilon$ as follows:

$$R_w = \epsilon\sqrt{R_H} - 1 \tag{6}$$

This equation is used to calculate the motive quantity or pressure from the operating parameters. This nozzle and diffuser diameters are calculated from the equation $Q = wAV$, using suitable nozzle and diffuser entrance coefficients. The principal problems in design concern the size and proportions of the mixing chamber, the distance between nozzle and diffuser, and the length of the diffuser. Eductor designs are based on theory and empirical constants for length and shape. The most efficient units are developed from calculated designs that are then further modified by prototype testing.

Figure 2 shows this factor plotted against *NPSH* (net positive suction head) for a single-nozzle and annular-nozzle eductor. In an annular-nozzle eductor, the motive fluid is introduced around the periphery of the suction fluid, either by a ring of nozzles (Figure 15) or by an annulus created between the inner wall of the diffuser and the outer wall of the suction nozzle (Figure 14). The *NPSH* is the head available at the centerline of the eductor to move and accelerate suction fluid entering the eductor mixing chamber. *NPSH* is the total head in feet (meters) of fluid flowing and is defined as atmospheric pressure minus suction pressure minus vapor pressure of suction or motive fluid, whichever is higher.

Increased viscosity of motive or suction fluid increases the frictional and momentum losses and therefore reduces the efficiency factor of Figure 2. Below 20 cP, the effect is minimal (approximately 5% lowering of $\varepsilon$). Above this value, the loss of performance is more noticeable and empirical data or pilot testing is used to determine sizing parameters.

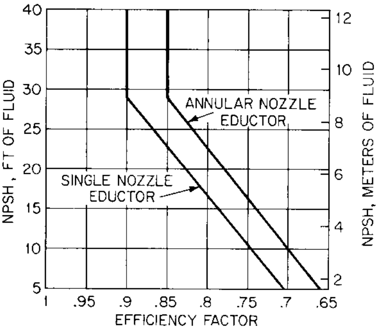

**FIGURE 2** NPSH versus efficiency factor (Schutte and Koerting)

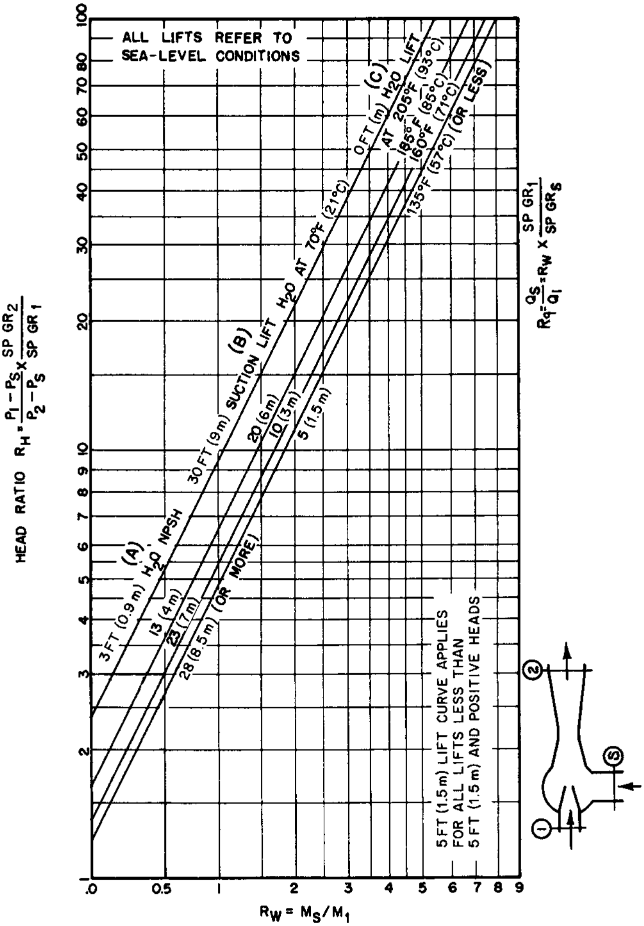

**FIGURE 3** Estimating operating ratios for liquid jet eductors. An eductor can be designed for only one head point (Schutte and Koerting)

Figure 3 shows the operating ratio $R_w$ versus the head ratio $R_H$ for various lift conditions. The efficiency factor has been incorporated into this curve.

The final size of the eductor is determined by the discharge line and is based on normal pipeline velocities, which are usually 3 to 10 ft/s (0.9 to 3 m/s). Figure 4a and 4b are used for estimating eductor size. To illustrate the use of Figures 3 and 4, consider the following example.

EXAMPLE 1 It is desired to remove 100 gpm (22.7 m$^3$/h) of water at 100°F (38°C) from a pit 20 ft (6.1 m) deep. Discharge pressure is 10 lb/in$^2$ (0.69 bar*) gage. Motive water is available at 60 lb/in$^2$ (4.1 bar) gage and 80°F (26.6°C). The eductor is to be located above the pit. Find the eductor size and motive water quantity required.

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*1 bar = $10^5$ Pa. For a discussion of bar, see *SI Units—A Commentary* in the front matter.

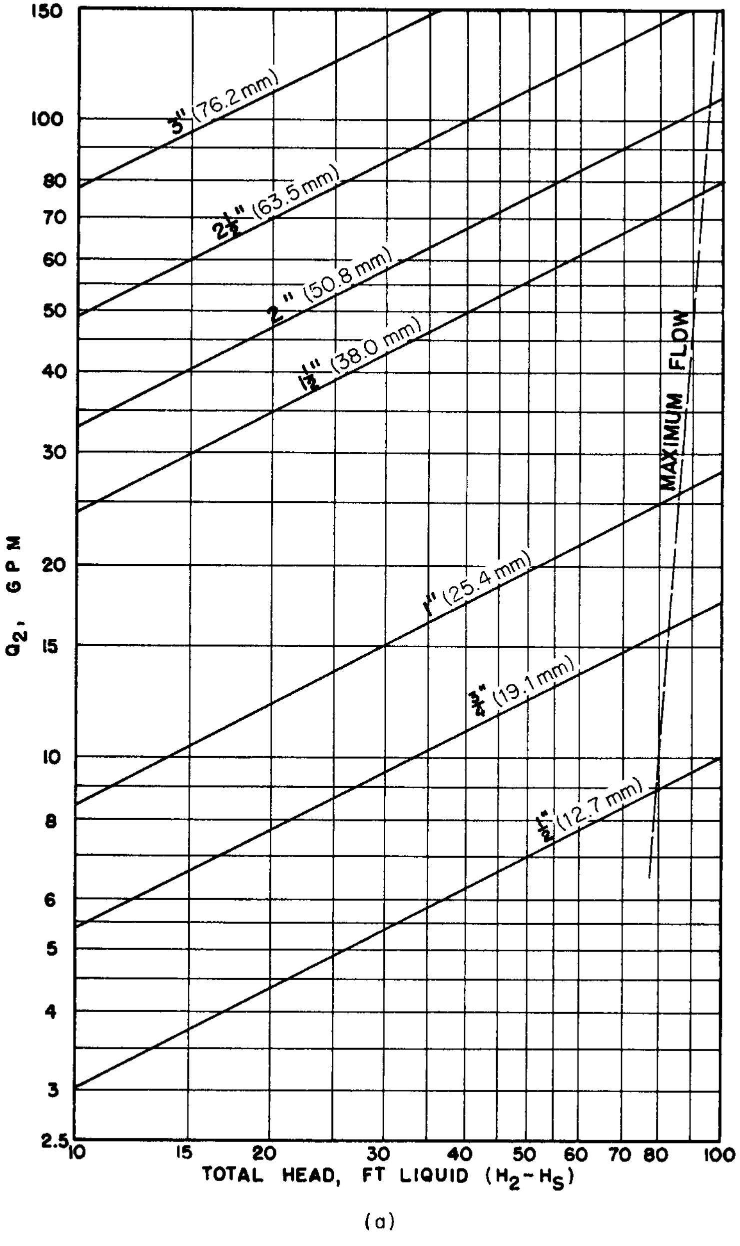

**FIGURE 4A** Sizing curve (gpm × 0.227 = m$^3$/h; ft × 0.3048 = m)

*Solution* To use Figure 3, it is necessary to determine the *NPSH* and the head ratio $R_H$. The centerline of the eductor is chosen as the datum plane, and *NPSH* is taken to be atmospheric pressure minus suction lift minus vapor pressure at 100°F (38°C):

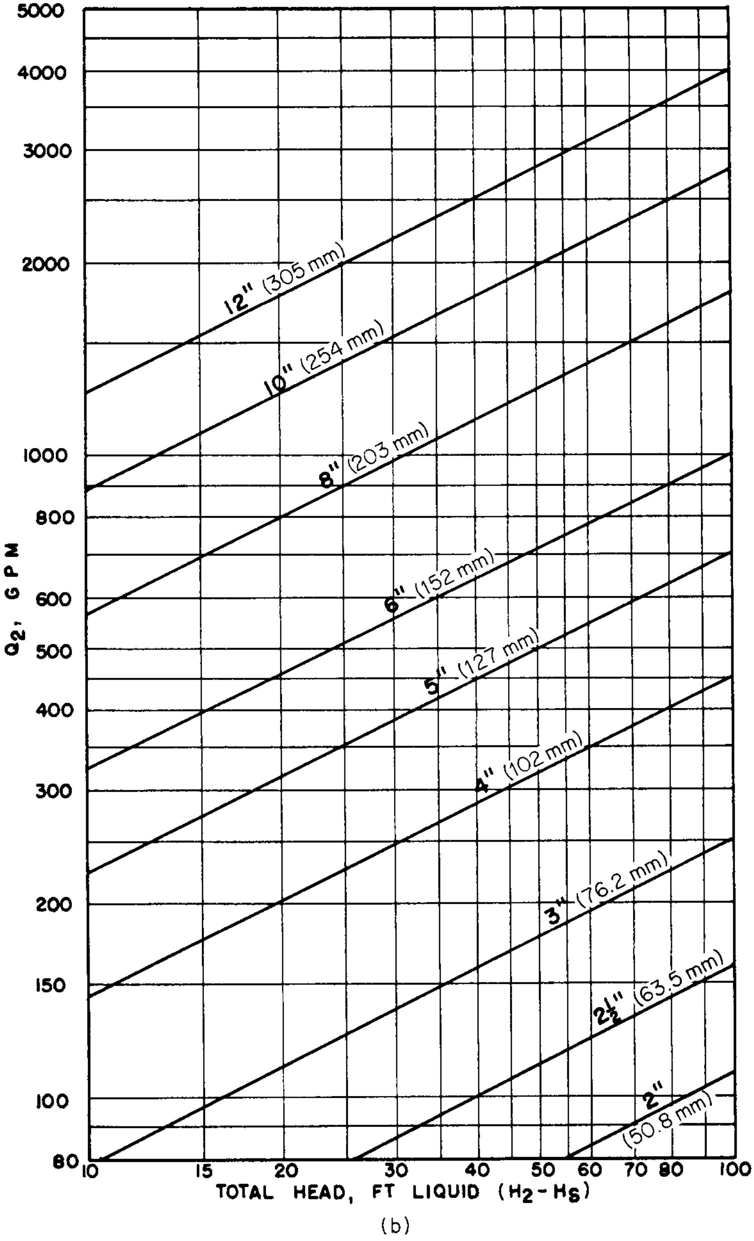

**FIGURE 4B** Sizing curve (continued)

in USCS units $$NPSH = 34 \text{ ft} - 20 \text{ ft} - 1.933 \text{ inHg} \left(\frac{13.6}{12}\right) = 11.81 \text{ ft}$$

in SI units $$NPSH = 10.36 \text{ m} - 6.1 \text{ m} - 49 \text{ mmHg} \left(\frac{13.6}{1000}\right) = 3.59 \text{ m}$$

Because motive and suction are the same fluid, it is convenient to work in feet (meters) rather than pounds per square inch (bar), and

$P_1$ = 60 lb/in$^2$ gage = 138.6 ft $H_2O$ (4.1 bar = 42 m)
$P_2$ = 10 lb/in$^2$ gage = 23.1 ft $H_2O$ (0.69 bar = 7 m)
$P_s$ = −20 ft (−6.1 m)

Then

in USCS units $$R_H = \frac{138.6 - (-20)}{23.1 - (-20)} = \frac{158.6}{43.1} = 3.68$$

in SI units $$R_H = \frac{42 - (-6.1)}{7 - (-6.1)} = 3.68$$

Enter Figure 3 at $R_H = 3.68$ and $NPSH = 11.81$ (3.59 m); read $R_w = 0.48$. Because there is no gravity correction,

in USCS units $$R_w = R_q = \frac{0.48 \text{ gal suction}}{\text{gal motive}}$$

in SI units $$R_w = R_q = \frac{0.48 \text{ m}^3 \text{ suction}}{\text{m}^3 \text{ motive}}$$

The same result can be obtained by using the efficiency factor from Figure 2. Then $R_w$ is $0.77\sqrt{R_H - 1} = 0.48$ and the required motive fluid is

in USCS units $$\frac{100 \text{ gpm suction}}{0.48} = 208 \text{ gpm at } 60 \text{ lb/in}^2 \text{ gage}$$

in SI units $$\frac{22.7 \text{ m}^3/\text{h}}{0.48} = 47.3 \text{ m}^3/\text{h at } 4.1 \text{ bar gage}$$

Discharge flow is

in USCS units $$208 + 100 = 308 \text{ gpm}$$

in SI units $$47.3 + 22.7 = 70.0 \text{ m}^3/\text{h}$$

The size is obtained from Figure 4. Enter Figure 4b at $Q_2 = 308$ gpm (70 m$^3$/h) and discharge head $(H_2 - H_3) = 23.1 - (-20) = 43.1$ ft $[7 - (-6.1) = 13.1 \text{ m}]$; read eductor size of 4 in (102 mm) based on the discharge connection.

NOTE: If there were any appreciable length of run on the discharge line, it would be necessary to calculate the pressure drop in this line and recalculate the eductor size after adding the line loss to the discharge head required. Frictional losses on the suction side must also be included. In the example chosen, however, 100 gpm (22.7 m$^3$/h) in a 4-in (102-mm) suction line 20 ft (6.1 m) long will have negligible frictional loss, less than 0.25 ft (0.08 m) $H_2O$.

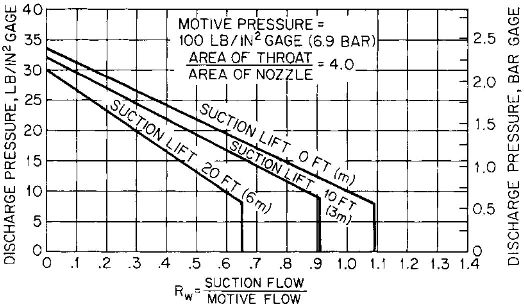

**FIGURE 5** Characteristic performance of an eductor

***Performance Characteristics*** Figure 5 illustrates the performance characteristics of eductors. Note the sharp break in flow rate below the design point. For this reason, all eductors are not designed for a peak efficiency. It is often advantageous to have a wide span of performance with lower efficiencies rather than a peak performance with very limited range. (See Section 4.1; where, also, the validity of assuming a straight-line head-vs.-suction flow characteristic is discussed.)

***Applications*** Beside the obvious advantages of being self-priming, having no moving parts, and requiring no lubrication, eductors can be made from any machinable material in addition to special materials, such as stoneware, Teflon,®* heat-resistant glass, and fiberglass. The applications throughout industry are too numerous to mention, but some of the more common will be discussed here. The type of eductor is determined by the service intended.

GENERAL PURPOSE EDUCTORS Table 1 is a capacity (flow rate) table for a general purpose eductor used for pumping and blending. This type of eductor, illustrated in Figure 6, has a broad performance span rather than a high peak efficiency point. Standard construction materials for this type of eductor are cast iron, bronze, stainless steel, and PVC. Typical uses include cesspool pumping, deep-well pumping, bilge pumping aboard ship, and condensate removal.

The following problem illustrates the use of Table 1.

EXAMPLE 2 Pump 30 gpm (6.81 $m^3$/h) of water from a sump 5 ft (0.61 m) below ground. Discharge to drain at atmospheric pressure. Motive water available is 40 lb/in$^2$ (2.8 bar) gage.

*Solution* Enter left side of Table 1 at 5 ft (1.5 m) suction lift and 0 lb/in$^2$ (bar) gage discharge pressure. Read horizontally across to 40 lb/in$^2$ (2.8 bar) gage operating water pressure. Read 9.6 gpm (2.18 $m^3$/h) suction and 7.3 gpm (1.66 $m^3$/h) operating fluid. These values are obtained in a 1-in (25.4-mm) eductor with a capacity ratio of 1.0.

To determine the capacity ratio of the required unit, divide the required suction by the quantity handled in 1-in (25.4-mm) eductor:

in USCS units $$\text{Capacity ratio} = \frac{30}{9.6} = 3.13$$

in SI units $$\text{Capacity ratio} = \frac{6.81}{2.18} = 3.13$$

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*Teflon is a registered trademark of E. I. DuPont de Nemours and Co., Inc.

**TABLE 1** Capacity (flow rate) table of standard 1-in (25.4-mm) water-jet eductors, gpm[a]

| Suction lift, ft(m) | Discharge pressure, lb/in$^2$ (bar) gage | Function | Operating water pressure, lb/in$^2$ (bar) gage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10 (0.69) | 20 (1.4) | 30 (2.1) | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) |
| 0 (0) | 0 (0) | Suction | 5.85 | 8.1 | 9.5 | 10.0 | 12.0 | 12.0 | 12.0 | 12.0 |
| | | Operating | 3.55 | 5.0 | 6.1 | 7.1 | 7.9 | 8.7 | 10.0 | 11.0 |
| | 5 (0.34) | Suction | ... | 1.4 | 4.1 | 6.0 | 8.0 | 10.0 | 11.0 | 12.0 |
| | | Operating | ... | 4.9 | 6.1 | 7.0 | 7.9 | 8.6 | 10.0 | 11.0 |
| | 10 (0.69) | Suction | ... | ... | 0.28 | 2.3 | 4.8 | 6.4 | 8.8 | 11.0 |
| | | Operating | ... | ... | 5.9 | 6.8 | 7.8 | 8.5 | 9.8 | 11.0 |
| | 15 (1.0) | Suction | ... | ... | ... | ... | 1.2 | 3.4 | 5.9 | 8.6 |
| | | Operating | ... | ... | ... | ... | 7.7 | 8.4 | 9.8 | 11.0 |
| | 20 (1.4) | Suction | ... | ... | ... | ... | ... | 0.3 | 3.5 | 5.9 |
| | | Operating | ... | ... | ... | ... | ... | 8.2 | 9.7 | 11.0 |
| | 25 (1.7) | Suction | ... | ... | ... | ... | ... | ... | 0.83 | 3.9 |
| | | Operating | ... | ... | ... | ... | ... | ... | 9.6 | 11.0 |
| | 30 (2.1) | Suction | ... | ... | ... | ... | ... | ... | ... | 1.7 |
| | | Operating | ... | ... | ... | ... | ... | ... | ... | 11.0 |
| 5 (1.5) | 0 (0) | Suction | 4.4 | 6.8 | 8.6 | 9.6 | 11.0 | 11.0 | 12.0 | 12.0 |
| | | Operating | 3.9 | 5.3 | 6.4 | 7.3 | 8.1 | 8.8 | 10.0 | 11.0 |
| | 5 (0.34) | Suction | ... | 1.5 | 3.2 | 5.0 | 7.0 | 9.0 | 11.0 | 11.0 |
| | | Operating | ... | 5.2 | 6.3 | 7.2 | 8.0 | 8.7 | 10.0 | 11.0 |
| | 10 (0.69) | Suction | ... | ... | ... | 1.9 | 3.6 | 5.6 | 8.6 | 10.0 |
| | | Operating | ... | ... | ... | 7.1 | 7.9 | 8.6 | 10.0 | 11.0 |
| | 15 (1.0) | Suction | ... | ... | ... | ... | 1.1 | 2.6 | 5.8 | 8.3 |
| | | Operating | ... | ... | ... | ... | 7.8 | 8.6 | 9.9 | 11.0 |
| | 20 (1.4) | Suction | ... | ... | ... | ... | ... | ... | 3.3 | 5.6 |
| | | Operating | ... | ... | ... | ... | ... | ... | 9.8 | 11.0 |
| | 25 (1.7) | Suction | ... | ... | ... | ... | ... | ... | 0.47 | 3.6 |
| | | Operating | ... | ... | ... | ... | ... | ... | 9.8 | 11.0 |
| | 30 (2.1) | Suction | ... | ... | ... | ... | ... | ... | ... | 1.5 |
| | | Operating | ... | ... | ... | ... | ... | ... | ... | 11.0 |
| 10 (3.0) | 0 (0) | Suction | 2.0 | 4.6 | 6.7 | 8.3 | 9.0 | 10.0 | 10.0 | 10.0 |
| | | Operating | 4.2 | 5.5 | 6.6 | 7.4 | 8.2 | 9.0 | 10.0 | 11.0 |
| | 5 (0.34) | Suction | ... | ... | 2.0 | 4.3 | 5.9 | 7.7 | 9.9 | 10.0 |
| | | Operating | ... | ... | 6.5 | 7.4 | 8.2 | 8.9 | 10.0 | 11.0 |
| | 10 (0.69) | Suction | ... | ... | ... | 1.1 | 3.0 | 4.5 | 8.1 | 9.6 |
| | | Operating | ... | ... | ... | 7.3 | 8.1 | 8.8 | 10.0 | 11.0 |
| | 15 (1.0) | Suction | ... | ... | ... | ... | 1.1 | 2.1 | 5.6 | 7.3 |
| | | Operating | ... | ... | ... | ... | 8.0 | 8.7 | 10.0 | 11.0 |
| | 20 (1.4) | Suction | ... | ... | ... | ... | ... | ... | 2.8 | 5.3 |
| | | Operating | ... | ... | ... | ... | ... | ... | 9.9 | 11.0 |
| | 25 (1.7) | Suction | ... | ... | ... | ... | ... | ... | ... | 2.8 |
| | | Operating | ... | ... | ... | ... | ... | ... | ... | 11.0 |
| | 30 (2.1) | Suction | ... | ... | ... | ... | ... | ... | ... | 1.1 |
| | | Operating | ... | ... | ... | ... | ... | ... | ... | 11.0 |
| 15 (4.6) | 0 (0) | Suction | ... | 3.3 | 5.3 | 7.9 | 8.4 | 8.9 | 8.9 | 9.1 |
| | | Operating | ... | 5.7 | 6.8 | 7.6 | 8.4 | 9.1 | 10.0 | 12.0 |
| | 5 (0.34) | Suction | ... | ... | ... | 4.0 | 4.9 | 7.3 | 8.6 | 9.1 |
| | | Operating | ... | ... | ... | 7.6 | 8.3 | 9.0 | 10.0 | 11.0 |
| | 10 (0.69) | Suction | ... | ... | ... | ... | 2.4 | 4.0 | 6.4 | 8.6 |
| | | Operating | ... | ... | ... | ... | 8.2 | 9.0 | 10.0 | 11.0 |
| | 15 (1.0) | Suction | ... | ... | ... | ... | ... | ... | 4.2 | 6.8 |

**TABLE 1** Continued.

| Suction lift, ft(m) | Discharge pressure, lb/in$^2$ (bar) gage | Function | Operating water pressure, lb/in$^2$ (bar) gage 10 (0.69) | 20 (1.4) | 30 (2.1) | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Operating | . . . | . . . | . . . | . . . | . . . | . . . | 10.0 | 11.0 |
| | 20 (1.4) | Suction | . . . | . . . | . . . | . . . | . . . | . . . | 2.1 | 4.5 |
| | | Operating | . . . | . . . | . . . | . . . | . . . | . . . | 10.0 | 11.0 |
| | 25 (1.7) | Suction | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 1.9 |
| | | Operating | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 11.0 |
| | 0 (0) | Suction | . . . | 2.0 | 4.0 | 6.4 | 7.8 | 7.8 | 7.8 | 7.8 |
| | | Operating | . . . | 6.0 | 7.0 | 7.8 | 8.6 | 9.3 | 11.0 | 12.0 |
| | 5 (0.34) | Suction | . . . | . . . | . . . | 2.8 | 3.9 | 6.3 | 7.8 | 7.8 |
| | | Operating | . . . | . . . | . . . | 7.7 | 8.5 | 9.2 | 10.0 | 12.0 |
| | 10 (0.69) | Suction | . . . | . . . | . . . | . . . | 1.2 | 3.1 | 5.7 | 7.1 |
| | | Operating | . . . | . . . | . . . | . . . | 8.3 | 9.1 | 10.0 | 12.0 |
| 20 (6.1) | 15 (1.0) | Suction | . . . | . . . | . . . | . . . | . . . | . . . | 3.6 | 5.4 |
| | | Operating | . . . | . . . | . . . | . . . | . . . | . . . | 10.0 | 11.0 |
| | 20 (1.4) | Suction | . . . | . . . | . . . | . . . | . . . | . . . | 1.4 | 3.8 |
| | | Operating | . . . | . . . | . . . | . . . | . . . | . . . | 10.0 | 11.0 |
| | 25 (1.7) | Suction | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 1.5 |
| | | Operating | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 11.0 |

Relative capacities of standard sizes

| Size eductor, in (mm) | $\frac{1}{2}$ (12.7) | $\frac{3}{4}$ (19.1) | 1 (25.4) | $1\frac{1}{2}$ (38.1) | 2 (50.8) | $2\frac{1}{2}$ (63.5) | 3 (76.2) | 4 (102) | 6 (152) |
|---|---|---|---|---|---|---|---|---|---|
| Capacity ratio | 0.36 | 0.64 | 1.00 | 2.89 | 4.00 | 6.25 | 9.00 | 16.00 | 36.00 |

[a] gpm × 0.227 = $m^3$/h.
Source: Schutte and Koerting.

Referring to the bottom of Table 1, a 2-in (50.8-mm) eductor with a capacity ratio of 4.0 is obtained. The required motive flow is then

in USCS units $4(7.3) = 29.2$ gpm

in SI units $4(1.66) = 6.64\ \mathrm{m^3/h}$

and the suction capacity is

in USCS units $4(9.6) = 38.4$ gpm

in SI units $4(2.18) = 8.72\ \mathrm{m^3/h}$

A $1\frac{1}{2}$-in (38-mm) unit can handle 2.89 times the values in Table 1, or 27.7 gpm (6.3 $m^3$/h) suction when using 21 gpm (4.8 $m^3$/h) motive water at 40 lb/in$^2$ (2.8 bar) gage. If suction flow rate is not critical, some capacity can be sacrificed in order to use a smaller and therefore lower-cost eductor. If optimum performance is desired, it is necessary to size a special eductor using Figures 3 and 4.

Figure 7 illustrates more streamlined versions for higher suction lifts or applications involving the handling of slurries. This type of eductor is often used to remove condensate from vessels under vacuum. The advantage is that eductors require only 2 ft (0.61 m) *NPSH* and, being smaller than mechanical pumps, save considerable space. Further, a partial vapor load is much less likely to vapor-lock a jet pump because the venturi tube

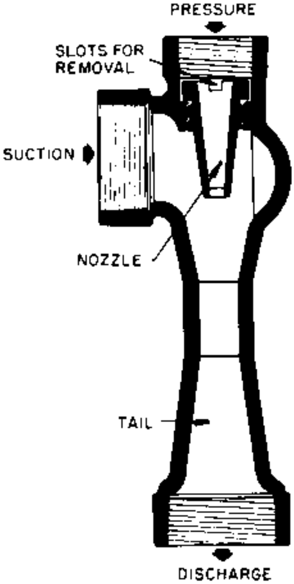


**FIGURE 6** General purpose eductor (Schutte and Koerting)

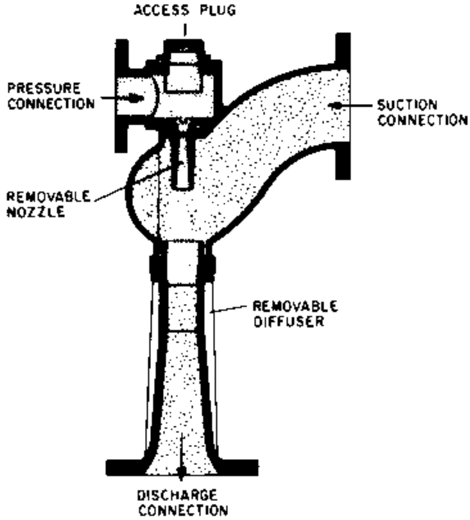


**FIGURE 7** Streamlined eductor (Schutte and Koerting)

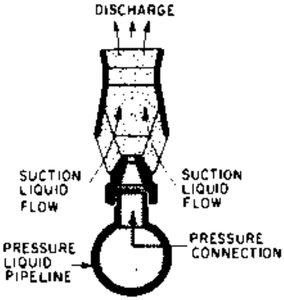


**FIGURE 8** Sparger nozzle (Schutte and Koerting)

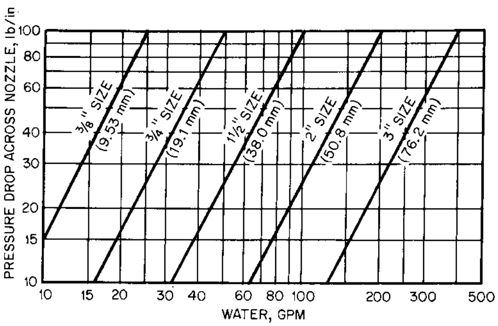


**FIGURE 9** Motive flow rate of Sparger nozzles (gpm × 0.227 = $m^3/h$; $lb/in^2 \times 0.0689$ = bar) (Schutte and Koerting)

minimizes the expansion effect of flashing vapor. Sizing is done in the manner illustrated in Example 1, using Figures 3 and 4.

MIXING EDUCTORS Although any eductor is inherently a mixing device, some are specifically designed as mixers. They are used to replace mechanical agitators and are located inside the tank containing the fluid to be agitated. Figure 8 illustrates the simplest type of eductor, the *Sparger nozzle.* These units entrain a volume of suction fluid that is approximately three times the volume of motive fluid. A 20-lb/in$^2$ (1.4-bar) drop across the nozzle is recommended for proper mixing. Figure 9 shows the motive flow rates for this type

**TABLE 2** Motive flow rates of tank mixing eductors, gpm[a]

| | Pressure difference, inlet to tank, lb/in$^2$ (bar) gage | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size, in (mm) | 10 (0.69) | 20 (1.4) | 30 (2.1) | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) |
| $\frac{1}{2}$ (12.7) | 3.5 | 5.0 | 6.0 | 7.0 | 8.0 | 8.5 | 10.0 | 11.0 |
| $\frac{3}{4}$ (19.1) | 10.0 | 14.5 | 17.5 | 20.0 | 23.0 | 24.5 | 29.0 | 32.0 |
| 1 (25.4) | 14.2 | 20.0 | 25.0 | 28.0 | 30.0 | 34.5 | 40.0 | 44.5 |
| $1\frac{1}{4}$ (31.8) | 22.0 | 31.0 | 37.5 | 44.0 | 50.0 | 53.0 | 62.5 | 69.0 |
| $1\frac{1}{2}$ (38.1) | 31.5 | 45.0 | 54.0 | 63.0 | 72.0 | 76.5 | 90.0 | 99.0 |
| 2 (50.8) | 56.0 | 80.0 | 96.0 | 112.0 | 128.0 | 136.0 | 160.0 | 176.0 |
| 3 (76.2) | 126.0 | 180.0 | 216.0 | 252.0 | 288.0 | 306.0 | 360.0 | 396.0 |
| 4 (102) | 224.0 | 320.0 | 384.0 | 448.0 | 512.0 | 544.0 | 640.0 | 704.0 |
| 5 (127) | 350.0 | 500.0 | 600.0 | 700.0 | 800.0 | 850.0 | 1000.0 | 1100.0 |
| 6 (152) | 494.0 | 720.0 | 864.0 | 1008.0 | 1152.0 | 1224.0 | 1440.0 | 1584.0 |

[a] gpm × 0.227 = m$^3$/h

Source: Schutte and Koerting.

of eductor. Sparger nozzles are normally used for shallow tanks, whereas the following tank mixer described is preferred for deeper vessels.

Figure 10 illustrates a type of eductor called a *tank mixer*. It is installed under the tank containing the fluid to be agitated. Motive capacities are shown in Table 2. The units are usually custom-designed for a specific entrainment ratio, the required capacity being determined by the quantity of tank fluid, the ratio of mixture desired, and the depth of the tank being agitated.

EXAMPLE 3 It is desired to blend recycled tank fluid into a tank 20 ft (6.1 m) deep in a volume ratio of 1 motive to 1.5 suction. The tank contains 7500 gal (28.4 m$^3$), and it is desired to turn over the tank in 30 min. The motive pump will deliver 60 lb/in$^2$ (4.14 bar) gage at the eductor nozzle. What size mixing eductor is needed?

*Solution* The 500 gal (28.4 m$^3$) turned over in 30 minutes is equivalent to 250 gpm (56.8 m$^3$/h). Because the motive fluid in this case is recycled from the tank, both motive and suction fluid contribute to the tank turnover. In the ratio of 1.5 suction to 1 motive fluid, the motive quantity required to attain a circulation rate of 250 gpm (56.8 m$^3$/h) is 100 gpm (22.7 m$^3$/h). To select the size, it is necessary to obtain the differential pressure across the nozzle orifice of the eductor. Because the eductor is below the tank, the net driving head is 60 lb/in$^2$ gage $-$ 20/2.31 = 51.35 lb/in$^2$ (4.14 $-$ 6.1/10.2 = 3.54 bar) gage across the nozzle. Enter Table 2 and interpolate between 50 and 60 lb/in$^2$ (3.4 and 4.1 bar) gage. A $1\frac{1}{2}$-in (38-mm) eductor will pass only 73 gpm (16.6 m$^3$/h), whereas a 2-in (51-mm) eductor will pass 129 gpm (29.3 m$^3$/h). The selection would then be a 2-in (51-mm) mixing eductor.

SPINDLE PROPORTIONING EDUCTORS Another type of mixing eductor is illustrated in Figure 11. Typical applications of this type include mixing hydrocarbons with caustic, oxygen, or copper chloride slurries; producing emulsions; and proportioning liquids in chemical process industries. In critical applications, the regulating spindle is sometimes fitted with a diaphragm operator to achieve close control. Table 3 shows operating pressures and flow rates on several typical applications for units of this type.

SAND AND MUD EDUCTORS Figure 12 illustrates a sand and mud eductor used for pumping out wells, pits, tanks, sumps, and similar containers where there is an accumulation of

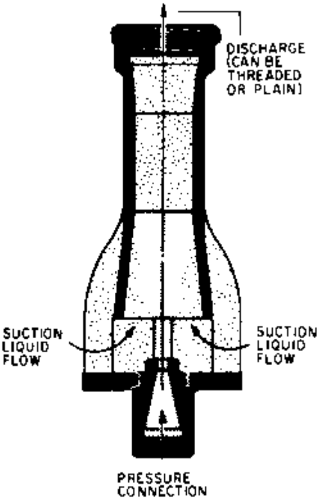


**FIGURE 10** Tank mixing eductor (Schutte and Koerting)

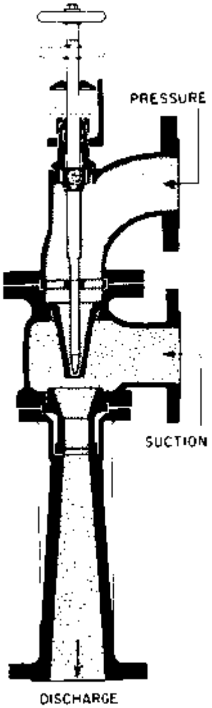


**FIGURE 11** Proportioning eductor (Schutte and Koerting)

**TABLE 3** Operating pressures and flow rates—proportioning eductor

| Motive liquid/ suction fluid | Naphtha/ copper chloride slurry | Hydrocarbon/ hydrocarbon | Gasoline/ slurry | Gasoline/ water | Sour kerosene/ kerosene slurry |
|---|---|---|---|---|---|
| Pressure, lb/in$^2$ (bar) gage | | | | | |
| Motive | 165 (11.4) | 295 (20.3) | 170 (11.7) | 75 (5.2) | 146 (10.1) |
| Suction | 40 (2.8) | 5 (0.3) | 75 (5.2) | 50 (3.4) | 60 (4.1) |
| Discharge | 75 (5.2) | 10 (0.7) | 100 (6.9) | 50 (3.4) | 70 (4.8) |
| Flow, gpm (m$^3$/h) | | | | | |
| Motive | 30 (6.8) | 10 (2.3) | 90 (20.4) | 170 (38.6) | 482 (109.5) |
| Suction | 20 (4.5) | 58 (13.2) | 74 (16.8) | 42 (9.5) | 700 (159.0) |
| Discharge | 50 (11.4) | 68 (15.4) | 164 (37.2) | 212 (48.1) | 1182 (268.5) |
| Eductor size, in (mm) | $1\frac{1}{2}$ (38.1) | 3 (76.2) | 4 (102) | 4 (102) | 6 (152) |

Source: Schutte & Koerting.

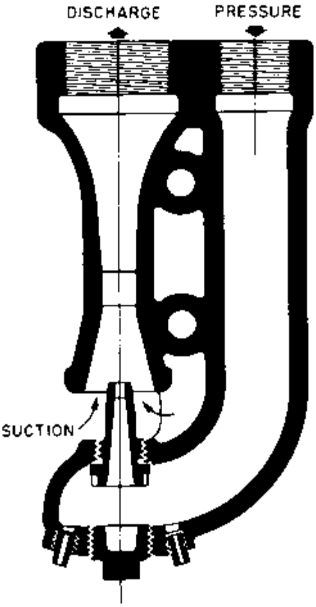


**FIGURE 12** Sand and mud eductor (Schutte and Koerting)

**TABLE 4** Relative capacities (flow rates) of sand and mud eductors

| Capacity of standard 3-in (76.2-mm) eductor | | | |
|---|---|---|---|
| Operating water pressure, lb/in$^2$ (bar) gage | 40.0 (2.8) | 50.0 (3.4) | 60.0 (4.1) |
| Total motive fluid, gpm (m$^3$/h) | 69.5 (15.8) | 77.5 (17.6) | 85.0 (19.3) |
| Net suction fluid, gpm (m$^3$/h) | 30.0 (6.8) | 34.5 (7.8) | 38.5 (8.7) |
| Maximum discharge head, ft (m) | 22.0 (6.7) | 26.0 (7.9) | 32.0 (9.8) |

| Relative capacities of standard sizes | | | | | | |
|---|---|---|---|---|---|---|
| Size eductor, in (mm) | $1\frac{1}{2}$ (38.1) | $2\frac{1}{2}$ (63.5) | 3 (76.2) | 4 (102) | 5 (127) | 6 (152) |
| Capacity ratio | 0.29 | 0.62 | 1.00 | 1.85 | 2.80 | 3.80 |

Source: Schutte and Koerting.

sand, mud, slime, or other material not easily handled by other eductors. With this type of eductor, the bottom of the pressure chamber is fitted with a ring of agitating nozzles that stirs the material in which the jet is submerged to allow maximum entrainment. Relative capacities for this type of eductor are shown in Table 4, which is used in the same manner as Table 1. The required suction flow is divided by the suction capacity selected from Table 4 under the appropriate motive pressure. This value is the capacity ratio. From the table, select the eductor by choosing the next highest capacity ratio. Actual flow rates are then determined by multiplying the values in the table by the capacity ratio of the eductor selected. Maximum discharge head is read from the table.

SOLIDS-HANDLING EDUCTORS Figure 13 illustrates a specific type of eductor called a *hopper eductor,* made for handling slurries or dry solids in granular form and used for eject-

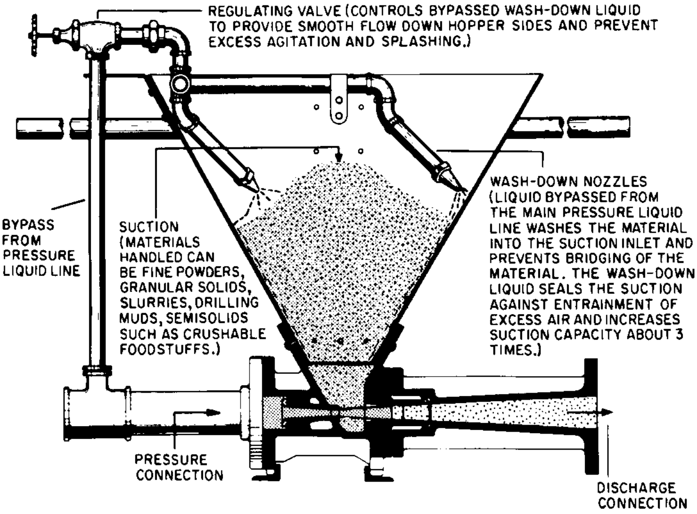


**FIGURE 13** Hopper eductor (Schutte and Koerting)

**TABLE 5** Relative capacities (flow rates) of hopper eductors

| Capacity of standard $1\frac{1}{2}$-in (38-mm) eductor | | | | |
|---|---|---|---|---|
| Operating water pressure, lb/in$^2$ (bar) gage | 30 (2.1) | 40 (2.8) | 50 (3.4) | 60 (4.1) |
| Suction capacity, ft$^3$/h (m$^3$/h) | 13 (0.37) | 36 (1.0) | 72 (2.0) | 90 (2.5) |
| Maximum discharge pressure, lb/in$^2$ (bar) gage | 14 (1.0) | 17 (1.1) | 18 (1.2) | 20 (1.4) |
| Motive water consumption, gpm (m$^3$/h)[a] | 35 (7.9) | 40 (9.1) | 45 (10.2) | 50 (11.4) |

| Relative capacities of standard sizes | | | | | |
|---|---|---|---|---|---|
| Size, in (mm) | $1\frac{1}{2}$ (38.1) | 2 (50.8) | 3 (76.2) | 4 (102) | 6 (152) |
| Capacity ratio | 1.00 | 1.60 | 3.50 | 6.00 | 18.00 |

[a] Based on using approximately 10% motive water through washdown nozzles.
Source: Schutte and Koerting

ing sludges from tank bottoms, pumping sand from filter beds, and washing or conveying granular materials. Typical construction is cast iron with hardened steel nozzle and throat bushings. In operation, the washdown nozzles are adjusted to provide smooth flow down the hopper sides, thus preventing bridging of the material being handled and also sealing the eductor suction against excess quantities of air. Without this seal, the capacities shown in Table 5 should be divided by approximately 3. Table 6 shows typical materials handled by this eductor and their bulk density. Use of the capacity table for hopper eductors is similar to use of Tables 1 and 4, except the suction quantities required are expressed in cubic feet (cubic meters). Capacity ratio is determined by dividing the value in the table into the required suction flow, and the next largest size eductor is selected.

Another type of solids-handling eductor is illustrated in Figure 14. This *annular-orifice eductor* is used where the material being handled tends to agglomerate and gum up when wetted and has been used successfully for handling and mixing hard-to-wet solids. In this

**TABLE 6** Typical materials handled by hopper eductors

| Material | Approx. bulk density, lb/ft$^3$ (kg/m$^3$) | |
|---|---|---|
| Borax | 50–55 | (800–880) |
| Charcoal | 18–28 | (290–450) |
| Diatomaceous earth | 10–20 | (160–320) |
| Lime, pebble | 56 | (900) |
| Lime, powdered | 32–40 | (510–640) |
| Fly ash | 35–40 | (560–640) |
| Mash | 60–65 | (960–1040) |
| Rosin | 67 | (1070) |
| Salt, granulated | 45–51 | (720–820) |
| Salt, rock | 70–80 | (1120–1280) |
| Sand, damp | 75–85 | (1200–1360) |
| Sand, dry | 90–100 | (1440–1600) |
| Sawdust, dry | 13 | (210) |
| Soda ash, light | 20–35 | (320–560) |
| Sodium nitrate, dry | 80 | (1280) |
| Sulfur, powdered | 50–60 | (800–960) |
| Wheat | 48 | (770) |
| Zinc oxide, powdered, dry | 10–35 | (160–560) |

Source: Schutte and Koerting.

unit, intimate mixing occurs in the throat, and the device is virtually clogproof. Normally this unit is installed directly over the tank into which the mixture is discharged. Table 7 shows capacities for this type of unit.

Capacity Table 7 is similar to Table 5, and the selection method is the same as discussed previously.

MULTINOZZLE EDUCTORS Figure 15 illustrates an annular multinozzle eductor designed for special applications where the suction fluid contains solids or semisolids. It is used primarily for large flows at low discharge heads. Because these units have relatively large air-handling capacities, they are well suited for priming large pumps, such as dredging pumps, where air pockets can cause these pumps to lose their prime. These eductors are designed by using the basic equations for head ratio. The appropriate efficiency factor is selected from Figure 2, and the volumetric flow ratio is calculated. Figure 4 is used to size the eductor after discharge flow has been determined.

DEEP-WELL EDUCTORS The eductor illustrated in Figure 16 is typical of those used in conjunction with a mechanical pump for commercial and residential water supply from a deep well. The eductor is used to lift water from a level below barometric height up to a level where the suction of the motive pump at the surface can lift the water the remaining distance.

In operation, the eductor is fitted with hoses connected to the suction and discharge of the motive pump and dropped into the well casing. An initial prime is required, which is maintained by the foot valve at the suction of the eductor. When the surface pump is activated, pressure water through the eductor entrains water from the well, lifting it high enough to enable the mechanical pump to carry it to the surface. A bypass valve at the surface diverts the suction quantity to a receiving tank.

Capacities of these units depend on the depth of the well and the centrifugal pump. The standard commercial unit has 1-in (25-mm) pressure and $1\frac{1}{4}$-in (32-mm) discharge connections and is available with a variety of nozzle and diffuser combinations for use with standard centrifugal pumps at varying depths. The following example illustrates how to calculate this type of unit.

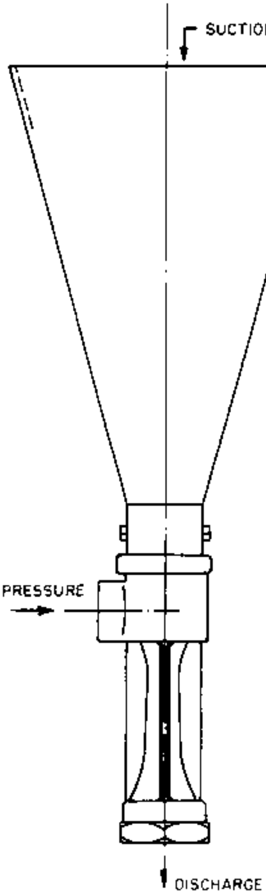


**FIGURE 14** Annual eductor (Schutte and Koerting)

EXAMPLE 4 A centrifugal pump with a capacity of 100 gpm (22.7 $m^3$/h) at a total discharge head of 150 ft (45.7 m) and requiring 10 ft (3.05 m) NPSH is available to operate an eductor to pump water at 50 ft (15.2 m) below grade. Find the quantity of water that can be delivered at 60 lb/$in^2$ (4.1 bar) gage (see Figure 17).

*Solution* The available operating head is 138.6 ft + 50 ft − frictional loss (42.2 + 15.2 − frictional loss). As a first assumption, the frictional loss is ignored and the head ratio is 188.6/40.83 = 4.62 (57.4/12.38 = 4.62). From Figure 2 at NPSH 33.6 ft (10.24 m), $\varepsilon = 0.9$ and

$$R_w = R_q = 0.9\sqrt{4.62} - 1 = 0.934$$

(from Eqs. 5 and 6)

With $Q_R$ fixed at 100 gpm (22.7 $m^3$/h),

**TABLE 7** Relative capacities (flow rates) of annual eductors

| Capacity of standard $1\frac{1}{2}$-in (38.1-mm) mixing eductor, 5 lb/in$^2$ (0.34 bar) gage discharge pressure | | | | | |
|---|---|---|---|---|---|
| Motive pressure, lb/in$^2$(bar) gage | 30 (2.1) | 40 (2.8) | 60 (4.1) | 80 (5.5) | 100 (6.9) |
| Entrainment, ft$^3$/h (m$^3$/h) | 2.6 (0.07) | 7.1 (0.20) | 17.9 (0.51) | 22.0 (0.62) | 23.8 (0.67) |
| Motive flow, gpm (m$^3$/h) | 12.7 (2.88) | 14.6 (3.31) | 17.9 (4.06) | 20.7 (4.70) | 23.1 (5.24) |

| Relative capacities of standard sizes | | | | | | |
|---|---|---|---|---|---|---|
| Size, in (mm) | $1\frac{1}{4}$ (31.8) | $1\frac{1}{2}$ (38.1) | 2 (50.8) | $2\frac{1}{2}$ (63.5) | 3 (76.2) | 4 (102) |
| Capacity ratio | 0.62 | 1.00 | 1.43 | 2.86 | 4.76 | 8.80 |

Source: Schutte and Koerting.

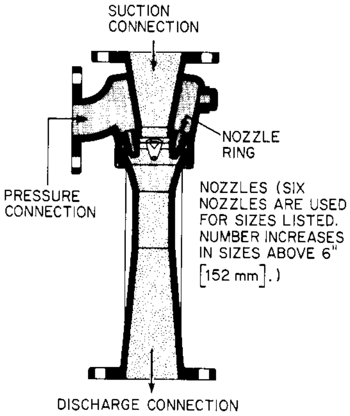


**FIGURE 15** Multinozzle eductor (Schutte and Koerting)

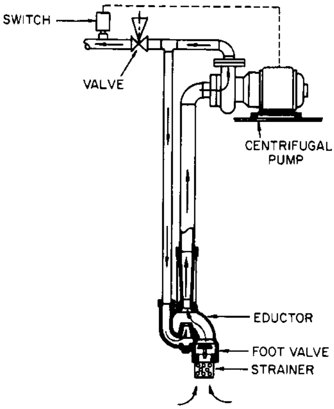


**FIGURE 16** Centrifugal-jet pump combination

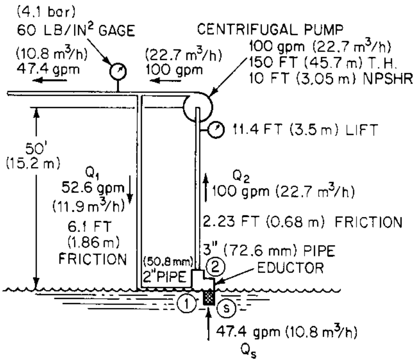


**FIGURE 17** Centrifugal-jet pump for Example 4

in USCS units $$Q_1 = \frac{100}{1 + R_q} = \frac{100}{1.934} = 51.7 \text{ gpm}$$

in SI units $$Q_1 = \frac{22.7}{1.934} = 11.7 \text{ m}^3\text{/h}$$

The motive line size is now chosen by selecting a reasonable velocity and frictional loss. Choosing a 2-in (51-mm) pipe size, velocity is 5.57 ft/s (1.70 m/s) and frictional loss is 6.1 ft$H_2O$ (1.86 m$H_2O$). The revised operating head becomes $188.6 - 6.1 = 182.5$ ft $(57.4 - 1.86 = 55.6$ m) and

in USCS units $$R_q = 0.9\sqrt{182.5/40.83} - 1 = 0.9$$

in SI units $$R_q = 0.9\sqrt{55.6/12.38} - 1 = 0.9$$

then $Q_1 = 100/1.9 = 52.6$ gpm ($22.7/1.9 = 11.9$ m$^3$/h). (This value is close enough so that a third trial is not necessary.) The suction flow that can be delivered is then

in USCS units $$100 - 52.6 = 47.4 \text{ gpm}$$

in SI units $$22.7 - 11.9 = 10.8 \text{ m}^3\text{/h}$$

PRIMING EDUCTORS—WATER-JET EXHAUSTERS Eductors are often used as priming devices for mechanical pumps. In this application, the eductor is used to remove air rather than water. Liquid jets are not well suited for pumping noncondensables; therefore, the capacities are low. However, the volume being primed is usually small, and so the low capacity is not a factor. When larger volumes are involved, such as condenser water boxes, it is more feasible to use an exhauster. The water-jet eductor of Figure 6 is converted to a water-jet exhauster by replacing the jet nozzle with a solid-cone spray nozzle. Evacuating rates and capacity tables for such a unit are shown in Figure 18 and Table 8. Eductors have approximately one-fifth the air-handling capacities of water-jet exhausters when supplied with similar motive quantities and pressures.

EXAMPLE 5 From Figure 18 and Table 8, determine size and water consumption to exhaust 15 standard ft$^3$/min (0.42 m$^3$/min) of air at 20 inHg (508 mmHg) abs discharging to atmosphere using 60 lb/in$^2$ (4.14 bar) gage motive water at 80°F (27°C).

*Solution* Enter Figure 18 at 80°F (27°C) (1); read horizontally to the suction pressure 20 inHg (508 mmHg) abs (2); project vertical line to 60 lb/in$^2$ (4.14 bar) gage motive pressure (3); project a horizontal line for the capacity of a 1-in (25-mm) exhauster (4); divide desired flow by the capacity of a 1-in (25-mm) unit, which is 1.9 standard ft$^3$/min, (0.054 m$^3$/min), to find capacity ratio: $15/1.9 = 7.9$ ($0.42/0.054 = 7.9$).

The capacity ratio table shows that a 3-in (76-mm) exhauster with a capacity ratio of 9.0 is required. The motive water quantity from Table 8 is 86 gpm (19.5 m$^3$/h). *Note:* Table 8 gives water consumption at 15 inHg (381 mmHg) abs; because flow varies as the square of pressure differential across the nozzle, the exact flow is obtained as follows:

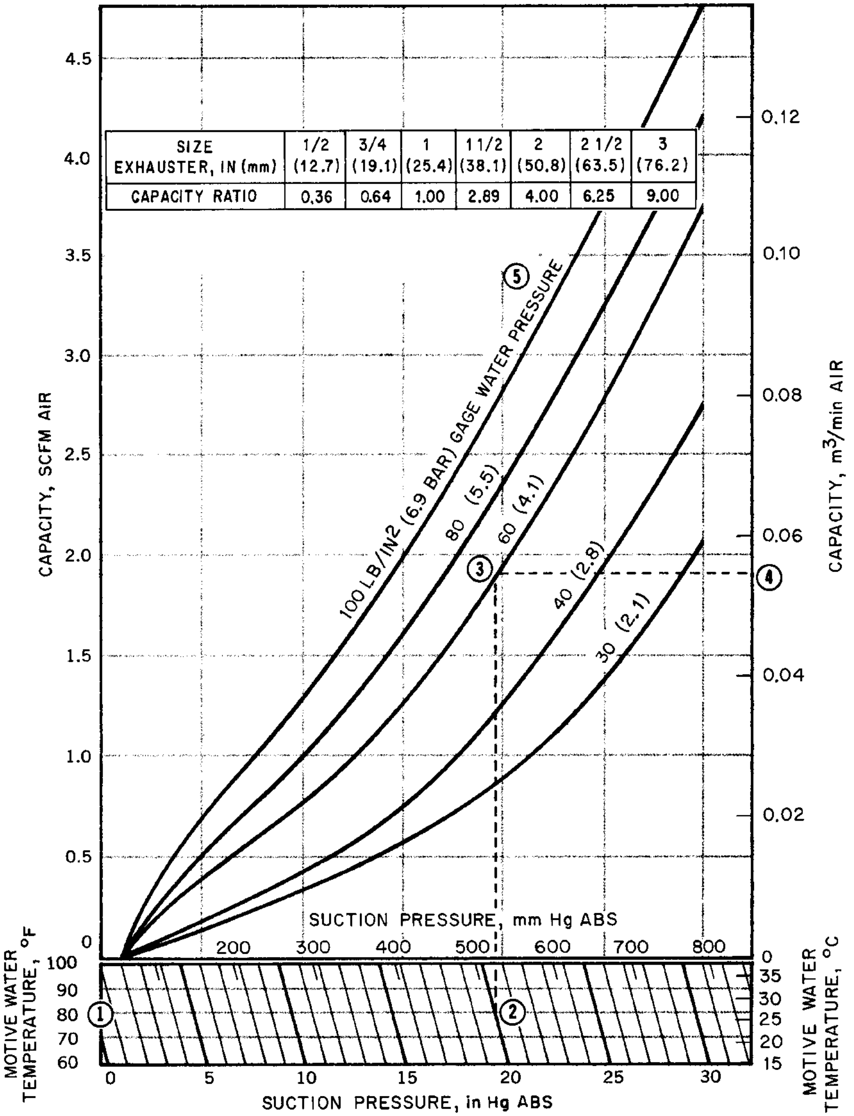
Nozzle upstream pressure:

in USGS units $$60 + 14.7 = 74.7 \text{ lb/in}^2 \text{ abs}$$

in SI units $$4.14 + 1.01 = 5.15 \text{ bar abs}$$

Nozzle downstream pressure:

in USCS units $$20 \text{ inHg abs} \left(\frac{14.7 \text{ lb/in}^2}{30 \text{ inHg}}\right) = 9.8 \text{ lb/in}^2 \text{ abs}$$



| SIZE EXHAUSTER, IN (mm) | 1/2 (12.7) | 3/4 (19.1) | 1 (25.4) | 1 1/2 (38.1) | 2 (50.8) | 2 1/2 (63.5) | 3 (76.2) |
|---|---|---|---|---|---|---|---|
| CAPACITY RATIO | 0.36 | 0.64 | 1.00 | 2.89 | 4.00 | 6.25 | 9.00 |

**FIGURE 18** Capacity curve of water-jet exhausters (Schutte and Koerting)

in SI units $\quad 508 \text{ mmHg abs} \left(\frac{1.01 \text{ bar}}{762 \text{ mmHg}}\right) = 0.67 \text{ bar abs}$

Operating differential:

in USCS units $\quad 74.7 - 9.8 = 64.9 \text{ lb/in}^2$

in SI units $\quad 5.15 - 0.67 = 4.48 \text{ bar}$

**TABLE 8** Approximate water consumption of water-jet exhausters, gpm[a, b]

| | Water pressure, lb/in² (bar) gage | | | | |
|---|---|---|---|---|---|
| Size, in (mm) | 30 (2.1) | 40 (2.8) | 60 (4.1) | 80 (5.5) | 100 (6.9) |
| $\frac{1}{2}$ (12.7) | 2.6 | 2.9 | 3.4 | 3.8 | 4.2 |
| $\frac{3}{4}$ (19.1) | 4.6 | 5.3 | 6.4 | 7.4 | 8.3 |
| 1 (25.4) | 6.2 | 6.8 | 8.1 | 9 | 10 |
| $1\frac{1}{2}$ (38.1) | 20 | 23 | 27 | 30 | 32 |
| 2 (50.8) | 28 | 31 | 36 | 41 | 45 |
| $2\frac{1}{2}$ (63.5) | 46 | 51 | 60 | 67 | 73 |
| 3 (76.2) | 66 | 73 | 86 | 96 | 106 |

[a] gpm × 0.227 = m³/h

[b] All flows at 15 in (381 mm) Hg abs.

Source: Schutte and Koerting.

Table differential:

in USCS units $$74.7 - 15\left(\frac{14.7}{30}\right) = 67.35 \text{ lb/in}^2$$

in SI units $$5.15 - 381\left(\frac{1.01}{762}\right) = 4.64 \text{ bar}$$

Actual flow:

in USCS units $$86\left(\frac{64.9}{67.35}\right)^{1/2} = 84.4 \text{ gpm}$$

in SI units $$19.5\left(\frac{4.48}{4.64}\right)^{1/2} = 19.2 \text{ m}^3\text{/h}$$

## SIPHONS

**Operation** As previously defined, the term *siphon* refers to a jet pump utilizing a condensable vapor to entrain a liquid and discharge to a pressure intermediate between motive and suction pressure. The principal motive fluid is steam.

In an eductor, the high-pressure motive fluid enters through a nozzle and creates a vacuum by jet action, which causes suction fluid to enter the mixing chamber. The siphon of Figure 19 is identical to the eductor of Figure 6 except that, unlike the eductor, the siphon motive nozzle is a converging-diverging nozzle to achieve maximum velocity at the nozzle tip. The velocity is supersonic at this point. The motive fluid is condensed into the suction fluid on contact and imparts its energy to the liquid, thus impelling it through the diffuser. The diffuser section is the same as an eductor diffuser, and it converts the velocity energy to pressure at the discharge. To achieve maximum performance, the siphon nozzle must be expanded to the desired suction pressure in order to achieve the highest possible velocity. Because negligible radiation losses are encountered, the siphon is 100% thermally efficient in that the heat in the incoming water plus the heat in the operating steam must equal the heat of the mixture plus its mechanical energy. Furthermore, the momentum of the incoming water plus the momentum of the expanded steam is equal to the momentum of the discharge mixture less impact and frictional losses.

It is important that the motive steam be condensed in the suction liquid prior to the throat for proper operation. If condensation does not occur, full available energy is not transferred. Furthermore, energy must be expended to recompress the uncondensed

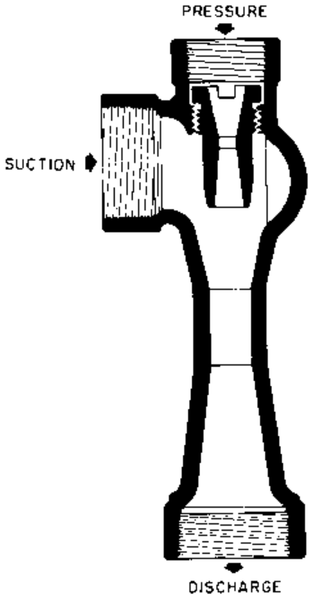


**FIGURE 19** Standard siphon (Schutte and Koerting)

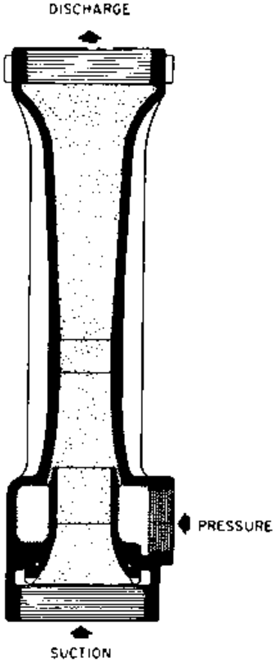


**FIGURE 20** Annular siphon (Schutte and Koerting)

steam. For this reason, discharge temperature cannot exceed the boiling point at the discharge pressure. The fact that energy is required to recompress any uncondensed steam explains why air is a very poor motive fluid for liquid pumping.

STANDARD SIPHONS Tables 9 and 10 illustrate the capacity and operating characteristics of standard siphons. These tables are similar to the eductor capacity tables. To size a unit, read the suction capacity of a $1\frac{1}{2}$-in (38-mm) unit from Table 9 at the appropriate motive steam pressure, suction lift, and discharge head. Divide the desired suction flow by this capacity to find the capacity ratio. From Table 10, find the unit with the next largest capacity ratio. Read the motive steam required under the proper motive pressure.

Standard materials of construction are cast iron, bronze, stainless, steel, and Pyrex®. If desired, special capacity ratios can be achieved by using a custom-designed unit. Sizes over 6 in (152 mm) can be fabricated of any suitable material.

ANNULAR SIPHONS Figure 20 illustrates an annular siphon. This unit is identical to the eductor of Figure 14 except that steam is the motive fluid. Capacity Table 11 is used in the same manner as previous examples. This type of siphon is used when inline flow is desired or when the suction liquid contains some solids. Units are available in cast iron through an 8-in (203-mm) size. Special materials or fabricated designs are also available.

## OTHER JET PUMP DEVICES

***Air Siphons*** As previously mentioned, air is a very poor motive fluid for entraining a liquid because energy must be expended in compressing the air back to the discharge pressure. There are, however, applications where it is necessary to sample a liquid with no dilution.

**TABLE 9** Relative capacities of steam-jet siphons, gpm[a]

| Suction lift, ft (m) | Suction temp., °F[b] | Operating steam pressure, lb/in² (bar) gage | | | | | | | | Operating steam pressure, lb/in² (bar) gage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) | 120 (8.3) | 160 (11) | 240 (16) | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) | 120 (8.3) | 160 (11) | 240 (16) |
| | | 0-ft (m) discharge head | | | | | | | | 20-ft (6.1-m) discharge head | | | | | | | |
| 1 (0.3) | 70 | 52 | 51 | 51 | 49 | 46 | 43 | 37 | 30 | 36 | 47 | 48 | 48 | 45 | 41 | 35 | 29 |
| | 90 | 45 | 44 | 43 | 42 | 40 | 37 | 33 | 26 | 37 | 44 | 43 | 43 | 41 | 38 | 33 | 26 |
| | 110 | 40 | 38 | 36 | 36 | 35 | 33 | 28 | 22 | 38 | 39 | 37 | 37 | 36 | 34 | 30 | 23 |
| | 130 | 35 | 32 | 30 | 30 | 29 | 29 | 25 | . . . | 35 | 33 | 31 | 31 | 30 | 29 | 25 | . . . |
| | 150 | 26 | 25 | 24 | 24 | 24 | 24 | 21 | . . . | 26 | 25 | 24 | 24 | 23 | 22 | 20 | . . . |
| | 165 | 17 | 17 | 17 | 18 | 18 | 17 | 17 | . . . | 17 | 17 | 17 | 17 | 17 | 17 | 16 | . . . |
| 10 (3.0) | 70 | 38 | 38 | 37 | 35 | 30 | 28 | 25 | 20 | 27 | 36 | 37 | 35 | 31 | 29 | 25 | 19 |
| | 90 | 34 | 34 | 33 | 30 | 27 | 25 | 21 | 17 | 26 | 32 | 32 | 29 | 26 | 23 | 20 | 17 |
| | 110 | 28 | 27 | 26 | 25 | 23 | 21 | 18 | . . . | 26 | 27 | 27 | 25 | 23 | 21 | 18 | . . . |
| | 130 | 21 | 21 | 21 | 20 | 18 | 16 | 14 | . . . | 21 | 22 | 22 | 21 | 18 | 16 | 14 | . . . |
| | 145 | 16 | 16 | 16 | 16 | 14 | 12 | . . . | . . . | 16 | 16 | 16 | 16 | 14 | 12 | . . . | . . . |
| 15 (4.6) | 70 | 34 | 32 | 30 | 26 | 23 | 21 | 18 | 14 | 24 | 33 | 32 | 27 | 24 | 23 | 19 | 15 |
| | 90 | 29 | 28 | 26 | 23 | 20 | 18 | 16 | 12 | 23 | 28 | 27 | 23 | 20 | 19 | 16 | 12 |
| | 110 | 24 | 23 | 22 | 19 | 17 | 15 | 13 | . . . | 23 | 23 | 22 | 19 | 17 | 15 | 13 | . . . |
| | 130 | 17 | 17 | 17 | 15 | 13 | 11 | . . . | . . . | 17 | 17 | 17 | 14 | 13 | . . . | . . . | . . . |
| | 145 | 10 | 12 | 11 | 9 | . . . | . . . | . . . | . . . | 11 | 11 | 10 | 10 | . . . | . . . | . . . | . . . |
| 20 (6.1) | 70 | 26 | 23 | 21 | 18 | 16 | 15 | 13 | . . . | 24 | 24 | 22 | 19 | 17 | 15 | 12 | . . . |
| | 90 | 22 | 19 | 17 | 15 | 14 | 12 | 11 | . . . | 19 | 20 | 18 | 15 | 14 | 12 | 11 | . . . |
| | 110 | 18 | 16 | 14 | 12 | 11 | 10 | . . . | . . . | 17 | 16 | 14 | 12 | 11 | . . . | . . . | . . . |
| | 125 | 13 | 12 | 11 | . . . | . . . | . . . | . . . | . . . | 12 | 11 | 10 | . . . | . . . | . . . | . . . | . . . |

**TABLE 9** Continued.

| Suction lift, ft (m) | Suction temp., °F[b] | Operating steam pressure, lb/in$^2$ (bar) gage | | | | | | | | Operating steam pressure, lb/in$^2$ (bar) gage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) | 120 (8.3) | 160 (11) | 240 (16) | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) | 120 (8.3) | 160 (11) | 240 (16) |
| | | 40-ft (12.2-m) discharge head | | | | | | | | 50-ft (15.2-m) discharge head | | | | | | | |
| 1 (0.3) | 70 | . . . | 20 | 33 | 47 | 44 | 41 | 36 | 29 | . . . | . . . | 18 | 44 | 44 | 41 | 36 | 28 |
| | 90 | . . . | 18 | 36 | 43 | 42 | 39 | 34 | 27 | . . . | . . . | 21 | 42 | 42 | 39 | 34 | 27 |
| | 110 | . . . | 20 | 36 | 37 | 37 | 35 | 30 | 24 | . . . | . . . | 24 | 37 | 36 | 34 | 30 | 24 |
| | 130 | . . . | 23 | 31 | 31 | 30 | 29 | 25 | . . . | . . . | . . . | 26 | 30 | 30 | 29 | 25 | . . . |
| | 150 | . . . | 24 | 24 | 24 | 24 | 24 | 20 | . . . | . . . | . . . | 24 | 24 | 24 | 24 | 20 | . . . |
| | 165 | . . . | 17 | 18 | 18 | 18 | 18 | 16 | . . . | . . . | . . . | 18 | 18 | 18 | 18 | 16 | . . . |
| 10 (3.0) | 70 | . . . | . . . | 24 | 34 | 30 | 27 | 24 | 18 | . . . | . . . | . . . | 35 | 30 | 27 | 23 | 18 |
| | 90 | . . . | . . . | 26 | 29 | 26 | 24 | 20 | 17 | . . . | . . . | . . . | 29 | 27 | 24 | 21 | 17 |
| | 110 | . . . | . . . | 27 | 26 | 23 | 20 | 18 | . . . | . . . | . . . | . . . | 25 | 23 | 20 | 18 | . . . |
| | 130 | . . . | . . . | 22 | 21 | 19 | 16 | 14 | . . . | . . . | . . . | . . . | 21 | 19 | 17 | 14 | . . . |
| | 145 | . . . | . . . | 16 | 16 | 14 | 12 | . . . | . . . | . . . | . . . | . . . | 16 | 14 | 13 | . . . | . . . |
| 15 (4.6) | 70 | . . . | . . . | 23 | 28 | 24 | 22 | 19 | 15 | . . . | . . . | . . . | 27 | 24 | 21 | 18 | 14 |
| | 90 | . . . | . . . | 20 | 24 | 20 | 18 | 16 | . . . | . . . | . . . | . . . | 24 | 21 | 18 | 16 | . . . |
| | 110 | . . . | . . . | 21 | 19 | 17 | 15 | . . . | . . . | . . . | . . . | . . . | 19 | 17 | 15 | . . . | . . . |
| | 130 | . . . | . . . | 17 | 14 | 12 | . . . | . . . | . . . | . . . | . . . | . . . | 14 | . . . | . . . | . . . | . . . |
| | 145 | . . . | . . . | 11 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| 20 (6.1) | 70 | . . . | . . . | 21 | 19 | 16 | 15 | 12 | . . . | . . . | . . . | . . . | . . . | 16 | 15 | . . . | . . . |
| | 90 | . . . | . . . | 18 | 16 | 14 | 13 | 11 | . . . | . . . | . . . | . . . | . . . | 15[C] | 13[C] | . . . | . . . |
| | 110 | . . . | . . . | . . . | 11 | 10 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |

[a] gpm = 0.227 m$^3$/h

[b] °C = (°F − 32)/1.8

[c] Suction temperature 85°F (29.4°C)

Source: Schutte and Koerting.

**TABLE 10** Steam consumption of steam-jet siphons, lb/h[a]

| Siphon size, in (mm) | Capacity ratio | Operating steam pressure, lb/in² (bar) gage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 40 (2.8) | 50 (3.4) | 60 (4.1) | 80 (5.5) | 100 (6.9) | 120 (8.3) | 160 (11.0) | 240 (16.5) |
| ½ (12.7) | 0.125 | 40 | 47 | 54 | 69 | 83 | 97 | 126 | 84 |
| ¾ (19.1) | 0.222 | 70 | 83 | 96 | 122 | 147 | 173 | 222 | 322 |
| 1 (25.4) | 0.346 | 110 | 130 | 150 | 190 | 230 | 270 | 350 | 510 |
| 1½ (38.1) | 1.000 | 318 | 376 | 434 | 550 | 665 | 780 | 1,012 | 1,475 |
| 2 (50.8) | 1.38 | 440 | 520 | 600 | 761 | 920 | 1,080 | 1,400 | 2,040 |
| 2½ (63.5) | 2.0 | 635 | 750 | 865 | 1,100 | 1,329 | 1,558 | 2,020 | 2,940 |
| 3 (76.2) | 3.11 | 990 | 1,170 | 1,350 | 1,710 | 2,065 | 2,425 | 3,145 | 4,590 |
| 4 (102) | 5.54 | 1,760 | 2,085 | 2,400 | 3,045 | 3,685 | 4,320 | 5,500 | 8,170 |
| 6 (152) | 12.45 | 3,960 | 4,680 | 5,400 | 6,850 | 8,280 | 9,710 | 12,600 | 18,360 |

[a] Lb/h × 0.454 = kg/h

Source: Schutte and Koerting.

**TABLE 11** Relative capacities of annular siphons

| Capacity of standard 3-in (76.2-mm) siphon, water temperature 100°F (37.8°C), 0 suction lift | | | | |
|---|---|---|---|---|
| Steam pressure, lb/in² (bar) gage | 50 (3.45) | 75 (5.17) | 100 (6.90) | 125 (8.62) |
| Steam consumption, lb/h (kg/h) | 1180 (535) | 1620 (735) | 2060 (934) | 2490 (1130) |
| Max back pressure, lb/in² (bar) gage at zero flow | 12 (0.83) | 18 (1.24) | 22 (1.52) | 35 (2.41) |
| Suction capacity, gpm (m³/h) | 140 (31.8) | 130 (29.5) | 120 (27.2) | 110 (25) |
| Discharge pressure, lb/in² (bar) gage | 5 (0.34) | 8 (0.55) | 12 (0.83) | 30 (2.07) |

| Relative capacities of standard sizes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size, in (mm) | 1¼ (31.8) | 1½ (38.1) | 2 (50.8) | 2½ (63.5) | 3 (76.2) | 4 (102) | 6 (152) | 8 (203) |
| Capacity ratio | 0.13 | 0.21 | 0.30 | 0.60 | 1.00 | 1.85 | 4.0 | 7.1 |

Source: Schutte and Koerting.

Small units (less than 1 gpm, 0.23 m³/h) can be supplied for limited discharge pressures, as indicated by Figure 21. With air as the motive fluid, the suction liquid can be very close to its boiling point and only a very slight *NPSH* is required.

When air is used as a motive fluid, the smaller sizes operate more efficiently because the air is more intimately mixed with a suction fluid. In larger sizes, the tendency is for the fluid to be discharged in slugs because intimate mixing does not readily occur. This has a detrimental effect on the performance and especially on available discharge head.

***Air-Lift Eductors*** Air-lift pumps are frequently used for difficult pumping operations. Compressed air is forced into the bottom of a pipe submerged in the liquid to be pumped. The expanding air, as it rises up the pipe, entrains the suction fluid.

If compressed air is not available, it is possible to lift water higher than 34 ft (10 m) with the use of an eductor-air-lift combination. Figure 22 illustrates the suction capacity

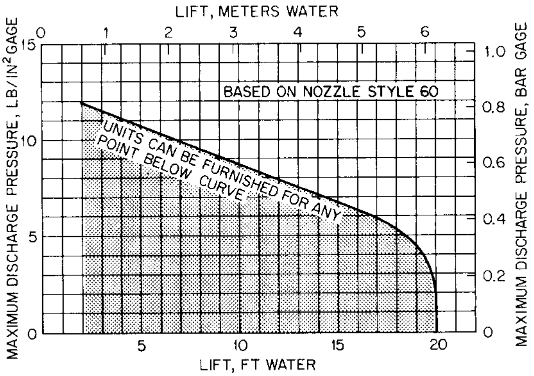


**FIGURE 21** Air pumping liquid (Schutte and Koerting)

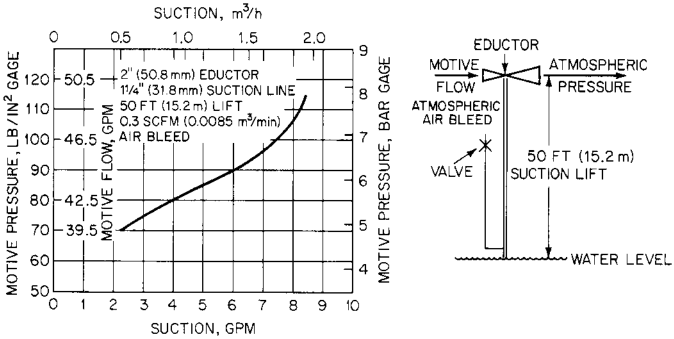


**FIGURE 22** Suction capacity of eductor-air-lift combination (gpm × 0.227 = m³/h)

of a 2-in (51-mm) eductor drawing water from a 50-ft (15-m) depth and discharging it to the atmosphere. In operation, an air line from the atmosphere enters the suction pipe near the water level. As the eductor creates a vacuum in this line, atmospheric pressure forces air into the suction pipe. After it is in the line, the rising air carries the suction fluid to the surface and both fluids are discharged to the atmosphere through the eductor.

No sizing data are presented because this type of pump is best specified according to specific conditions.

***Boiler Injectors*** The boiler injector is a jet pump utilizing steam as a motive fluid to entrain water, and it is used as a boiler feedwater heater and pump. It differs from a siphon in that the discharge pressure is higher than either motive or suction pressure. This is achieved by the double-tube design shown in Figure 23. In operation, the lower nozzle is activated by pulling the handle partway back. The lower jet creates a vacuum in the chamber, causing water to be induced into the unit. When water is spilling out the overflow, the handle is drawn back all the way. This closes the overflow and simultaneously admits motive steam to the upper jet. This second jet, which is of the straight or forcing type, picks up the discharge from the first jet and imparts a velocity to the water through the discharge tube. The energy contained is sufficient to open the check valve and discharge against the boiler pressure.

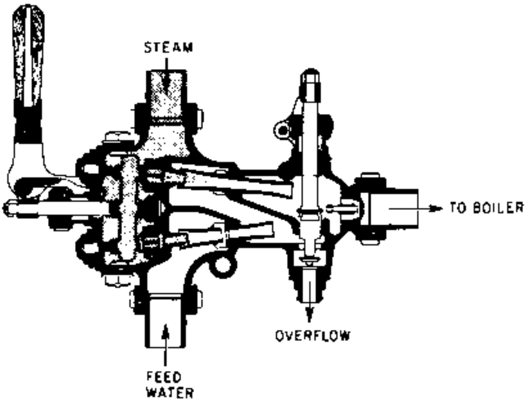


**FIGURE 23** Boiler injector, starting position (Schutte and Koerting)

**TABLE 12** Capacities of boiler injectors, gph[a]

| Size no. | Size iron pipe conn., in (mm) | Size copper pipe OD, in (mm) | Size overflow (drip funnel) pipe, in (mm) | Steam pressure, lb/in$^2$ (bar) 50 (3.45) | 100 (6.90) | 150 (10.34) | 200 (13.79) | 250 (17.24) |
|---|---|---|---|---|---|---|---|---|
| 0 | $\frac{1}{4}$ (12.7) | $\frac{3}{8}$ (9.53) | $\frac{1}{4}$ (12.7) | 80 | 100 | 110 | 100 | 90 |
| 1 | $\frac{3}{8}$ (9.53) | $\frac{1}{2}$ (12.7) | $\frac{1}{4}$ (12.7) | 110 | 140 | 180 | 140 | 130 |
| 2 | $\frac{1}{2}$ (12.7) | $\frac{5}{8}$ (15.9) | $\frac{3}{8}$ (9.33) | 170 | 210 | 230 | 200 | 190 |
| 3 | $\frac{3}{4}$ (19.1) | $\frac{7}{8}$ (22.2) | $\frac{1}{2}$ (12.7) | 280 | 340 | 400 | 340 | 320 |
| $3\frac{1}{2}$ | $\frac{3}{4}$ (19.1) | $\frac{7}{8}$ (22.2) | $\frac{1}{2}$ (12.7) | 400 | 470 | 550 | 470 | 440 |
| 4 | 1 (25.4) | $1\frac{1}{8}$ (28.6) | $\frac{3}{4}$ (19.1) | 530 | 620 | 720 | 620 | 590 |
| 5 | $1\frac{1}{4}$ (31.8) | $1\frac{1}{2}$ (38.1) | 1 (25.4) | 680 | 800 | 920 | 800 | 750 |
| 6 | $1\frac{1}{4}$ (31.8) | $1\frac{1}{2}$ (38.1) | 1 (25.4) | 820 | 990 | 1130 | 990 | 930 |
| 7 | $1\frac{1}{2}$ (38.1) | $1\frac{3}{4}$ (44.4) | $1\frac{1}{4}$ (31.8) | 1070 | 1370 | 1610 | 1370 | 1290 |
| 8 | $1\frac{1}{2}$ (38.1) | $1\frac{3}{4}$ (44.4) | 1 (31.8) | 1400 | 1800 | 2100 | 1800 | 1700 |
| 9 | 2 (50.8) | $2\frac{1}{4}$ (57.2) | $1\frac{1}{2}$ (38.1) | 1700 | 2100 | 2500 | 2100 | 2000 |
| 10 | 2 (50.8) | $2\frac{1}{4}$ (57.2) | $1\frac{1}{2}$ (38.1) | 2000 | 2500 | 2900 | 2500 | 2300 |
| 11 | $2\frac{1}{2}$ (63.5) | $2\frac{3}{4}$ (69.8) | 2 (50.8) | 2500 | 3000 | 3500 | 3000 | 2800 |
| 12 | $2\frac{1}{2}$ (63.5) | $2\frac{3}{4}$ (69.8) | 2 (30.8) | 3000 | 3600 | 4300 | 3600 | 3400 |
| 14 | 3 (76.2) | $3\frac{1}{4}$ (82.6) | $2\frac{1}{2}$ (63.5) | 3900 | 4600 | 5500 | 4600 | 4400 |
| 16 | 3 (76.2) | $3\frac{1}{4}$ (82.6) | $2\frac{1}{2}$ (63.5) | 5000 | 6000 | 7000 | 6000 | 5700 |

[a] gph × 0.00379 = m$^3$/h

Source: Schutte and Koerting.

The now obsolete steam locomotives were the largest users of this type of injector. Principal use at present is as a backup to a regular boiler-feed pump. Capacity Table 12 illustrates the range of capacities available for the double-tube injector.