9

Compressed Air and Water Systems

9–1 INTRODUCTION

Construction Applications

Compressed air is widely used as a power source for construction tools and equipment. While hydraulic power is gradually replacing compressed air as the power source for rock drills (see Chapter 8), compressed air is still required for cleaning out the drill hole produced by a hydraulic drill. Some of the other uses for compressed air in construction include paint spraying, the pneumatic application of concrete (shotcrete), conveying cement, pumping water, and operating pneumatic tools. Common pneumatic construction tools include spaders (or trench diggers), concrete vibrators, drills (steel and wood), grinders, hammers, paving breakers, sandblasting guns, saws (circular, chain, and reciprocating), staple guns, nailers, tampers, and wrenches.

Pumps and water supply systems are utilized in construction to dewater excavations and to supply water for cleaning equipment and aggregates, for mixing and curing concrete, for aiding soil compaction, and for jetting piles into place.

Construction Manager's Responsibilities

The construction manager must be able to select the appropriate type and size of air compressor or pump for a construction operation and to design the associated air or water supply system. Sections 9–2 and 9–3 provide guidance in performing these tasks.

9–2 COMPRESSED AIR SYSTEMS

Types of Compressors

Air compressors may be classified as positive displacement compressors or dynamic compressors according to the method by which they compress air. *Positive displacement* *compressors* achieve compression by reducing the air volume within a confined space. Positive displacement compressor types include reciprocating compressors, rotary vane compressors, and rotary screw compressors. *Dynamic compressors* achieve compression by using fans or impellers to increase air velocity and pressure. The principal type of dynamic compressor used in construction is the centrifugal compressor. Rotary compressors, both positive displacement and dynamic, are smaller, lighter, and quieter than are reciprocating compressors of similar capacity. As a result, most compressors used in construction are rotary compressors.

A schematic diagram of a rotary vane air compressor system is shown in Figure 9–1. This compressor is classified as a two-stage, oil-flooded, sliding-vane rotary compressor. Oil is injected into each compressor stage for lubrication and cooling. An *oil separator* removes the oil from the output air. The oil is then cooled and returned for reuse. The output of the compressor's first stage is cooled by an *intercooler* to increase the efficiency of the second-stage compressor. The *receiver* serves as a compressed air reservoir, provides additional cooling of the air leaving the compressor, reduces pressure fluctuations in the output, and permits water to settle out of the compressed air. Compressors can sometimes operate satisfactorily without a receiver in the system.

The principle of operation of a sliding-vane rotary compressor is as follows (refer to Figure 9–1). As the compressor rotor turns, centrifugal force causes the vanes to maintain contact with the cylinder. Air intake occurs while the volume of air trapped between two adjacent vanes is increasing, creating a partial vacuum. As rotation continues, the volume of air trapped between adjacent vanes decreases, compressing the trapped air. The compressed air is exhausted on the opposite side of the cylinder as the volume trapped between vanes approaches a minimum.

Compressors are available as portable units (skid- or wheel-mounted) or stationary units. Although portable units are most often used in construction work, stationary compressors may be employed in quarries and similar permanent installations. Portable units are available in capacities from 75 to over 2000 cu ft/min (2.1 to 56.6 m^3/min). Figure 9–2 shows a small portable air compressor being used to power two pneumatic paving breakers. Since pneumatic tools normally require air at 90 psig (lb/sq in. gauge) (621 kPa) to deliver rated performance, compressors usually operate in the pressure range of 90 to 125 psig (621 to 862 kPa).

A rotary screw or helical screw air compressor utilizes two mating rotating helical rotors to achieve compression (see Figure 9–3). The main or male rotor is driven by the power source. The mating gate or female rotor is usually driven by timing gears attached to the main rotor but may be driven directly by the main rotor in an oil-flooded unit. The principle of operation is as follows. Air enters at the inlet end, where the volume between mating lobes is large. As the rotors turn, the trapped volume becomes smaller and moves toward the discharge end. The trapped volume reaches a minimum as it lines up with the discharge port and the compressed air is exhausted. The advantages of rotary screw compressors include high efficiency, few moving parts, low maintenance, and long life.

Required Compressor Capacity

Air compressor ratings indicate capacity as the volume of "standard" air or "free" air at standard conditions which the compressor will deliver at a specified discharge pressure.

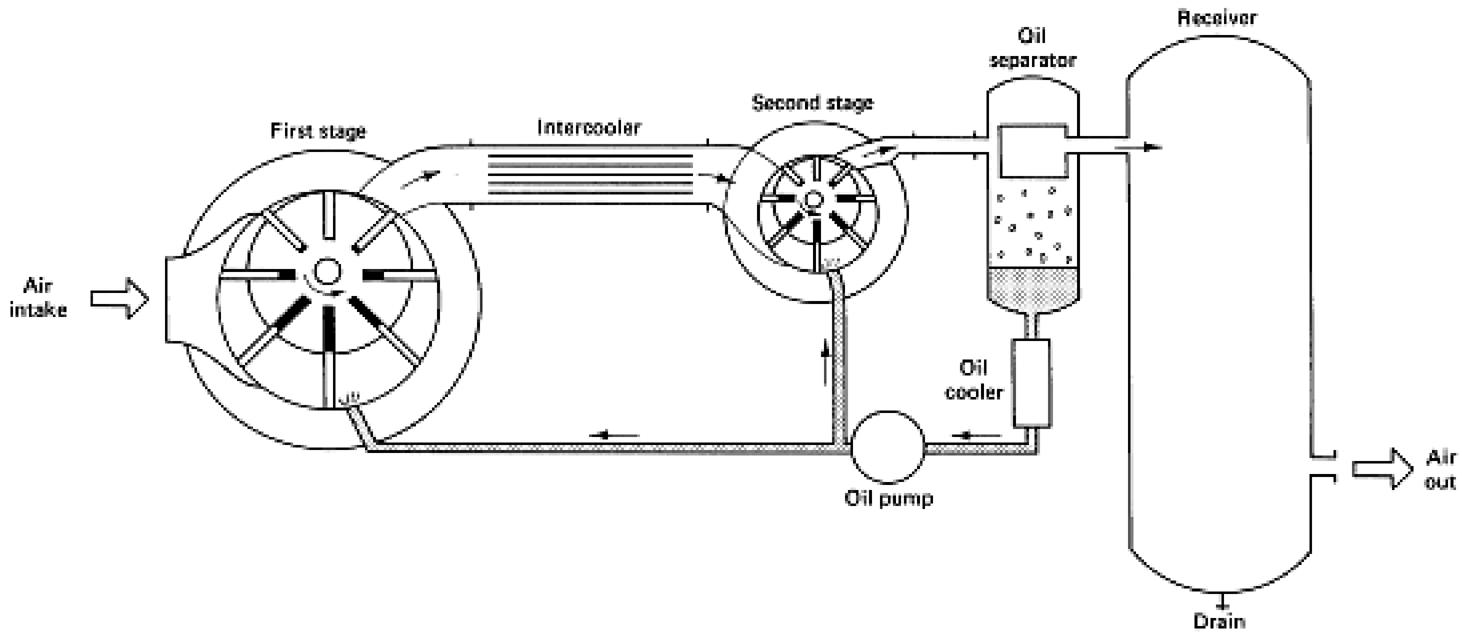

Figure 9–1 Schematic of sliding-vane rotary air compressor.

Figure 9–2 Small portable air compressor powering pneumatic tools. (Courtesy of Ingersoll-Rand Company)

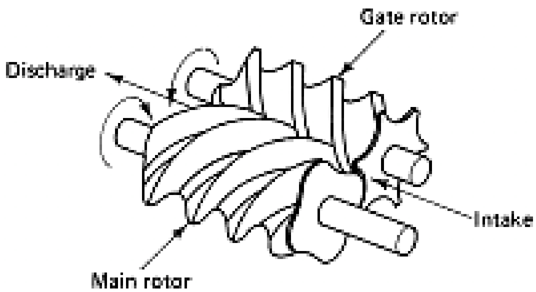

Figure 9–3 Rotary screw air compressor.

Standard air is defined as air at a temperature of 68° F (20° C), a pressure of 14.7 psia (lb/sq in. absolute) (100 kPa absolute), and 36% relative humidity. Since atmospheric conditions at a construction site rarely correspond exactly to standard air conditions, it may be necessary to adjust the rated compressor capacity to correspond to actual conditions. Since air is less dense at altitudes above sea level, altitude has the most pronounced effect on compressor capacity. A method for adjusting actual air demand at an altitude above sea level to standard conditions is explained later.

The quantity of compressed air required to supply a construction site is found by summing up the air demand of all individual tools and equipment. Representative air consumption values for common pneumatic construction equipment are given in Table 9–1. However, since all tools of a particular type will seldom operate simultaneously, a tool load factor or diversity factor should be applied to the total theoretical air requirement for each type of tool. Table 9–2 provides suggested values of the tool load factor to be used for

Table 9–1 Representative air consumption values of pneumatic construction equipment

Type of Equipment	Size	Air Consumption cu ft/min	Air Consumption m^3/min
Drills, rock			
Hand-held	35-lb class	55–75	1.6–2.1
	45-lb class	50–100	1.4–2.8
	55-lb class	90–110	2.5–3.1
Drifter and wagon	Light (3½-in. bore)	190–250	5.1–7.1
	Medium (4–4½-in. bore)	225–300	6.4–8.5
	Heavy (5-in. bore)	350–500	9.9–14.2
Track	Medium-weight	600–1000	17.0–28.3
	Heavyweight	900–1300	25.5–36.8
Paint sprayers		8–15	0.2–0.4
Paving breakers		40–60	1.1–1.7
Pumps, submersible	Low head	75–100	2.1–2.8
	High head	150–300	4.2–8.5
Shotcrete guns		200–300	5.7–8.5
Spaders/trench diggers		30–50	0.8–1.4
Tampers, backfill		35–50	1.0–1.4

Table 9–2 Suggested values of tool load factor for pneumatic construction tools

Number of Tools of Same Type	Diversity Factor
1–6	1.00
7–9	0.94
10–14	0.89
15–19	0.84
20–29	0.80
30 or more	0.77

various numbers of tools of the same type. Where a system is being designed to operate several different types of tools or equipment simultaneously, it may be appropriate to apply a second or job load factor to the sum of the adjusted air demand for the different types of tools. If used, the job load factor should be based on the probability that the various types of tools will operate simultaneously. Finally, an allowance should be made for leakage in the air supply system. It is customary to add 5 to 10% to the estimated air demand as a leakage loss.

Table 9–3 Air compressor altitude-adjustment factors

Altitude		Adjustment Factor
ft	*m*	
1,000	305	1.03
2,000	610	1.06
3,000	915	1.10
4,000	1220	1.14
5,000	1525	1.17
6,000	1830	1.21
7,000	2135	1.25
8,000	2440	1.30
9,000	2745	1.34
10,000	3050	1.39
11,000	3355	1.44
12,000	3660	1.49
13,000	3965	1.55
14,000	4270	1.61
15,000	4575	1.67

After the total air consumption including leakage has been determined, total air demand must be adjusted for altitude before selecting the nominal or rated size of air compressor required to supply the system. The altitude adjustment factor may be calculated as the ratio of the compression ratio at the specified altitude to the compression ratio at sea level. These adjustment factors are listed in Table 9–3.

The procedure for determining the rated capacity of the air compressor required for a project is illustrated in Example 9–1.

EXAMPLE 9–1

Determine the rated size of air compressor required to operate the following tools at an altitude of 6000 ft (1830 m). Assume a 10% leakage loss and a job load factor of 0.80.

	Rated Consumption		
Item	***cu ft/min***	***m^3/min***	**Number**
Drifter drills	215	6.1	2
Hand-held drills	90	2.5	8
Trench diggers	30	0.8	4
Tampers	40	1.1	6
Submersible pumps	80	2.3	2

SOLUTION

Use the tool diversity factors from Table 9–2.

Item		Tool Consumption cu ft/min	Tool Consumption m³/min
Drifter	= 2 × 215 × 1.00 =	430	12.2
Hand-held drills	= 8 × 90 × 0.94 =	677	19.2
Trench diggers	= 4 × 30 × 1.00 =	120	3.4
Tampers	= 6 × 40 × 1.00 =	240	6.8
Pumps	= 2 × 80 × 1.00 =	160	4.5
		1627	46.1

Applying the job diversity factor:

$$\text{Expected consumption} = 1627 \times 0.80 = 1302 \text{ cu ft/min } (36.9 \text{ m}^3\text{/min})$$

$$\text{Leakage} = 1302 \times 0.10 = 130 \text{ cu ft/min } (3.7 \text{ m}^3\text{/min})$$

$$\text{Total consumption} = 1302 + 130 = 1432 \text{ cu ft/min } (40.6 \text{ m}^3\text{/min})$$

$$\text{Altitude adjustment factor} = 1.21 \text{ (Table 9–3)}$$

$$\text{Minimum rated capacity} = 1432 \times 1.21 = 1733 \text{ cu ft/min } (49.1 \text{ m}^3\text{/min})$$

Friction Losses in Supply Systems

As compressed air travels through a supply system, the pressure of the air gradually drops as a result of friction between the air and the pipe, hose, and fittings. The pressure drop in a pipe is a function of air flow, pipe size, initial pressure, and pipe length. Table 9–4 indicates the pressure drop per 1000 ft (305 m) of clean, smooth pipe for various flows at an initial pressure of 100 psig (690 kPa). If the initial pressure is greater or less than 100 psig (690 kPa), multiply the value from Table 9–4 by the appropriate correction factor from Table 9–5. Notice that the pressure loss due to friction decreases as initial pressure increases.

The pressure drop caused by pipe fittings is most conveniently calculated by converting each fitting to an equivalent length of straight pipe of the same nominal diameter. Figure 9–4 provides a nomograph for finding the equivalent length of common pipe fittings. The equivalent length of all fittings is added to the actual length of straight pipe to obtain the total effective length of pipe. This pipe length is then used to calculate pressure drop in the pipe and fittings.

Pressure drop in hoses is calculated in the same manner as pressure drop in pipe except that values from Table 9–6 are used. Table 9–6 indicates the pressure drop per 50-ft (15.3-m) length of hose at an initial pressure of 100 psig (690 kPa). The pressure drop in manifolds or other special fittings should be based on manufacturers' data or actual measurements.

The procedure for calculating total pressure drop from receiver to individual tool is illustrated in Example 9-2.

Table 9–4 Pressure drop caused by pipe friction.* (Data from Table 10.23, *Compressed Air and Gas Handbook*, 4th ed., John P. Rollins, ed. Courtesy of Compressed Air and Gas Institute)

Flow		Nominal Diameter [in. (cm)]					
		½ (1.3)	¾ (1.9)	1 (2.5)	1¼ (3.2)	1½ (3.8)	2 (5.1)
cu ft/min	m^3/min						
10	0.3	5.5 (38)	1.0 (6.9)	0.3 (2.1)	0.1 (0.7)		
20	0.6	25.9 (178)	3.9 (27)	1.1 (7.6)	0.3 (2.1)	0.1 (0.7)	
30	0.8	58.5 (403)	9.0 (62)	2.5 (17)	0.6 (4.1)	0.3 (2.1)	
40	1.1		16.1 (111)	4.5 (31)	1.0 (6.9)	0.5 (3.4)	
50	1.4		25.1 (173)	7.0 (48)	1.6 (11)	0.7 (4.8)	0.2 (1.4)
60	1.7		36.2 (250)	10.0 (69)	2.3 (16)	1.0 (6.9)	0.3 (2.1)
70	2.0		49.4 (341)	13.7 (94)	3.2 (22)	1.4 (9.7)	0.4 (2.8)
80	2.3		64.5 (445)	17.8 (123)	4.1 (28)	1.8 (12)	0.5 (3.4)
90	2.5			22.6 (159)	5.2 (36)	2.3 (16)	0.6 (4.1)
100	2.8			27.9 (192)	6.4 (45)	2.9 (20)	0.8 (5.5)
125	3.5			48.6 (335)	10.2 (70)	4.5 (31)	1.2 (8.3)
150	4.2			62.8 (433)	14.6 (101)	6.4 (44)	1.7 (12)
175	5.0				19.8 (137)	8.7 (60)	2.4 (17)
200	5.7				25.9 (179)	11.5 (79)	3.1 (21)
250	7.1				40.4 (279)	17.9 (123)	4.8 (33)
300	8.5				58.2 (401)	25.9 (178)	6.9 (48)
350	9.9					35.1 (242)	9.4 (64)
400	11.3					45.8 (316)	12.1 (83)
450	12.7					58.0 (400)	15.4 (106)
500	14.2						19.2 (132)
600	17.0						27.6 (397)
700	19.8						37.7 (260)
800	22.6						49.0 (338)
900	25.5						60.0 (414)
1000	28.3						
1500	42.5						
2000	56.6						
2500	70.8						
3000	84.9						
4000	113						
5000	141						
10,000	283						
15,000	425						
20,000	566						
30,000	849						

*Psi (kPa) for 1000 ft (305 m) of pipe at 100 psig (690 kPa) initial pressure.

Table 9–4 *(Continued)*

Nominal Diameter [in. (cm)]							
2½ (6.4)	*3 (7.6)*	*4 (10.2)*	*5 (12.7)*	*6 (15.2)*	*8 (20.3)*	*10 (25.4)*	*12 (30.5)*
0.1 (0.7)							
0.2 (1.4)							
0.2 (1.4)							
0.3 (2.1)							
0.5 (3.4)							
0.7 (4.8)	0.2 (1.4)						
0.9 (6.2)	0.3 (2.1)						
1.2 (8.3)	0.4 (2.8)						
1.8 (12)	0.6 (4.1)						
2.7 (18)	0.8 (5.5)						
3.6 (24)	1.1 (7.6)	0.3 (2.1)					
4.8 (33)	1.5 (10.3)	0.4 (2.8)					
6.0 (41)	1.9 (13)	0.5 (3.4)					
7.4 (51)	2.3 (16)	0.6 (4.1)					
10.7 (74)	3.4 (23)	0.8 (5.5)					
14.6 (101)	4.6 (32)	1.1 (7.6)	0.3 (2.1)				
19.0 (131)	6.0 (41)	1.4 (9.6)	0.4 (2.8)				
24.1 (166)	7.6 (52)	1.8 (12)	0.5 (3.4)				
29.7 (205)	9.4 (65)	2.2 (15)	0.7 (4.8)	0.2 (1.4)			
67.0 (462)	21.0 (145)	5.0 (34)	1.5 (10)	0.6 (4.1)			
	37.4 (258)	8.9 (61)	2.7 (19)	1.0 (6.9)	0.2 (1.4)		
	58.4 (403)	13.9 (96)	4.2 (29)	1.6 (11)	0.4 (2.8)		
		20.0 (138)	6.0 (41)	2.3 (16)	0.5 (3.4)		
		35.5 (245)	10.7 (74)	4.0 (28)	0.9 (6.2)	0.3 (2.1)	
		55.5 (383)	16.8 (116)	6.3 (43)	1.5 (10)	0.4 (2.8)	
			67.1 (463)	25.1 (173)	5.9 (41)	1.8 (12)	0.7 (4.8)
				56.7 (391)	13.2 (91)	4.0 (28)	1.5 (10)
					23.6 (163)	7.1 (49)	2.7 (19)
					52.1 (359)	15.9 (110)	6.2 (43)

Table 9–5 Correction factors for friction losses

Inlet Pressure		
psig	*kPa (gauge)*	**Correction Factor**
80	552	1.211
90	621	1.096
100	690	1.000
110	758	0.920
120	827	0.852
130	896	0.793

EXAMPLE 9–2

The compressed air system illustrated in Figure 9–5 is being operated with a receiver pressure of 110 psig (758 kPa). Pressure drop in the manifold is determined to be 2 psig (13.8 kPa). If all three drills are operated simultaneously, what is the pressure at the tools? Assume no line leakage.

SOLUTION

Equivalent length of fittings (Figure 9–4):

$$\begin{aligned} \text{2 globe valves at 85 ft} &= \text{170 ft (51.8 m)} \\ \text{1 standard ell at 8 ft} &= \underline{\text{8 ft (2.4 m)}} \\ &\ \text{178 ft (54.2 m)} \end{aligned}$$

$$\begin{aligned} \text{Length of pipe plus fittings} &= 1000 + 178 = 1178 \text{ ft} \\ [&= 304.8 + 54.2 = 359 \text{ m}] \end{aligned}$$

$$\begin{aligned} \text{Total flow} &= 3 \times 150 = 450 \text{ cu ft/min } (12.7 \text{ m}^3\text{/min}) \\ \text{Pressure loss per 1000 ft (305 m)} &= 1.9 \text{ psig (13.1 kPa)} \quad \text{(Table 9–4)} \\ \text{Correction factor} &= 0.92 \quad \text{(Table 9–5)} \end{aligned}$$

Pressure loss in pipe and fittings (P_f):

$$P_f = \frac{1178}{1000} \times 1.9 \times 0.92 = 2.1 \text{ psig}$$

$$\left[= \frac{359}{305} \times 13.1 \times 0.92 = 14.2 \text{ kPa} \right]$$

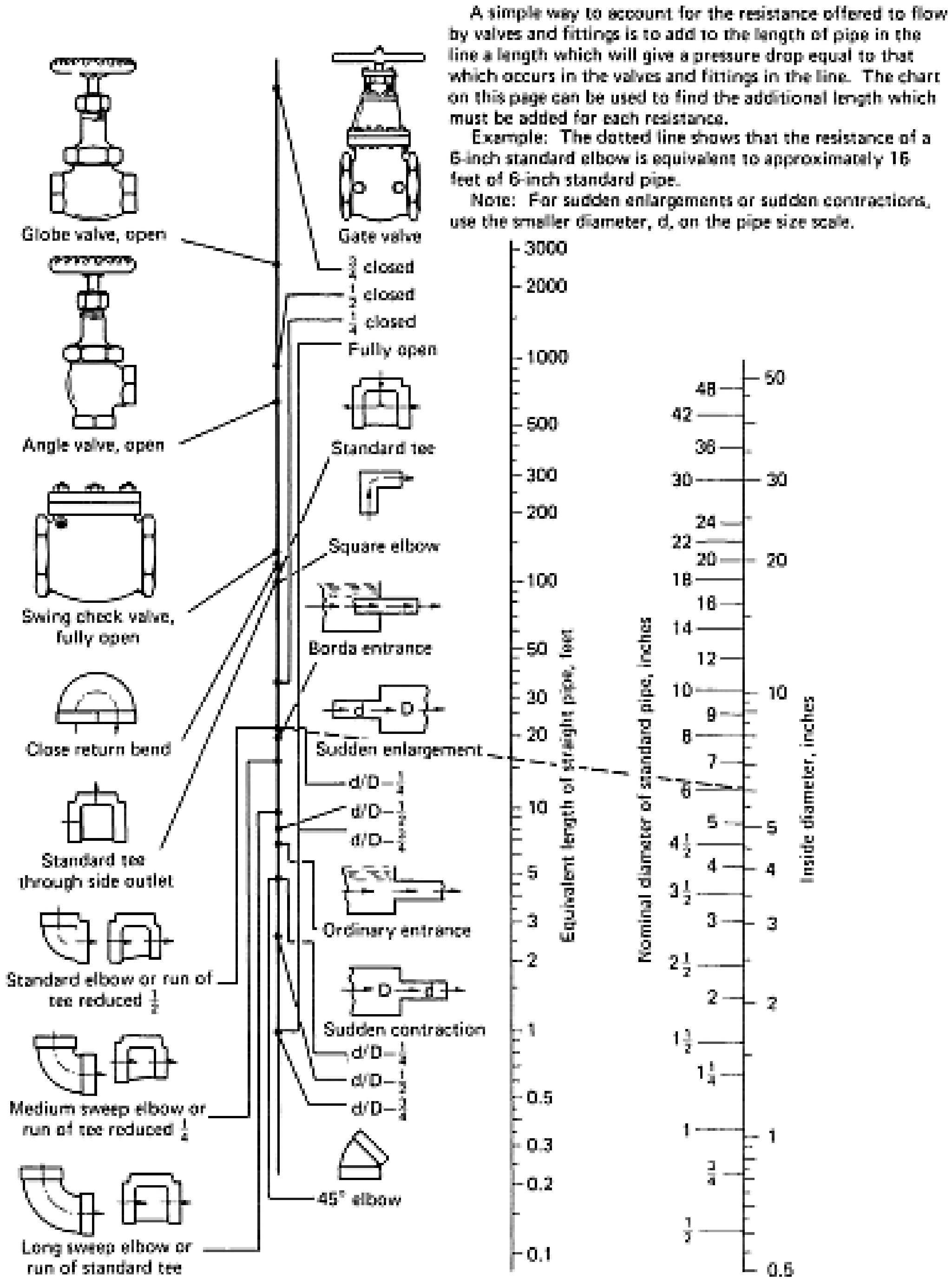

Figure 9–4 Resistance of valves and fittings to fluid flow. (Adapted from a nomograph appearing in *Contractor's Pump Manual,* 1976. Copyright © Crane Company, by permission)

Table 9–6 Pressure drop caused by hose friction* [psi (kPa) per 50 ft (15.3 m) of hose]. (Data from Table 10.27, *Compressed Air and Gas Handbook,* 4th ed., John P. Rollins, ed. Courtesy of Compressed Air and Gas Institute, New York, 1973)

Flow		Hose Size [in. (cm)]				
cu ft/min	m^3/min	½ (1.3)	¾ (1.9)	1 (2.5)	1¼ (3.2)	1½ (3.8)
20	0.6	1.8 (12)				
30	0.8	4.0 (28)				
40	1.1	6.8 (47)	1.0 (6.9)			
50	1.4	10.4 (72)	1.4 (9.7)			
60	1.7		2.0 (14)			
80	2.3		3.5 (24)			
100	2.8		5.2 (36)	1.2 (8.3)		
120	3.4		7.4 (51)	1.8 (12)		
140	4.0		9.9 (68)	2.4 (17)		
160	4.5		12.7 (88)	3.1 (21)		
180	5.1			3.8 (26)		
200	5.7			4.6 (32)	1.6 (11)	
220	6.2			5.5 (38)	1.9 (13)	
240	6.8			6.5 (45)	2.2 (15)	
250	7.1			7.0 (48)	2.4 (17)	
300	8.5			9.9 (68)	3.4 (23)	1.4 (9.7)
350	9.9			13.3 (92)	4.5 (31)	1.9 (13)
400	11.3				5.8 (40)	2.4 (17)
450	12.7				7.3 (50)	3.0 (21)
500	14.2				8.9 (61)	3.7 (26)
550	15.6				10.7 (74)	4.4 (30)
600	17.0				12.6 (87)	5.2 (36)

*Clean, dry air (no line lubricator), hose inlet pressure of 100 psig (690 kPa).

Pressure at hose inlet (P_h):

$$P_h = 110 - (2.1 + 2) = 105.9 \text{ psig}$$
$$[= 758 - (14.2 + 13.8) = 730 \text{ kPa}]$$

Hose pressure correction factor = 0.95 (interpolate in Table 9–5)
Pressure loss in 60-ft (18.3-m) hose (P'_f):

$$P'_f = \frac{60}{50} \times 2.7 \times 0.95 = 3.1 \text{ psig}$$
$$\left[= \frac{18.3}{15.3} \times 18.6 \times 0.95 = 21.1 \text{ kPa}\right]$$

Pressure at tool (P_t):

$$P_t = 105.9 - 3.1 = 102.8 \text{ psig}$$
$$[= 730 - 21.1 = 708.9 \text{ kPa (gauge)}]$$

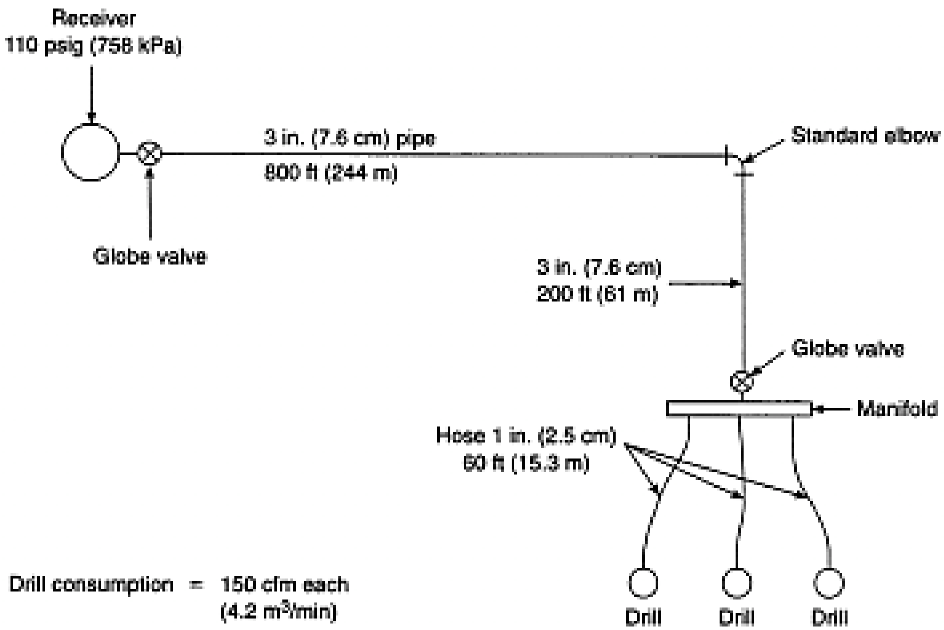

Figure 9–5 Compressed air system, Example 9–2.

Compressed Air Costs

The cost of providing compressed air power may be calculated using the methods of Chapter 17. Air cost is usually expressed in dollars per 1000 cu ft (or per cubic meter). Typical production and distribution costs range from \$0.10 to \$0.25/1000 cu ft (\$0.0036 to \$0.0088/m^3).

Leaks in the air system can be costly. For example, a ⅛-in. (0.3-cm) hole in a 100-psig (690-kPa) supply line would waste about 740,000 cu ft (20942 m^3) of air per month. At a cost of \$0.20/1000 cu ft (\$0.0071/m^3), this amounts to almost \$150 per month.

Compressed Air Safety

Compressed air systems present several unique safety hazards. A sudden release of pressure caused by rupture of a hose, pipe, or storage tank can produce an effect similar to that of an explosive detonation. An accidentally disconnected hose can inflict severe damage caused by its whipping action.

Some major precautions which should be observed in the operation of compressed air systems are the following.

- Compressed air storage tanks and receivers must meet American Society of Mechanical Engineers (ASME) code standards.
- Before performing maintenance on a compressor, cut off power by pulling fuses or disconnects and tagging the cutoff.

- Test safety valves at least once a week.
- Compressed air used for cleaning purposes must be reduced to less than 30 psi (207 kPa) and used with effective chip guarding and personal protective equipment.
- Do not exceed the manufacturer's safe operating pressure for hoses, pipes, valves, filters, and other fittings.
- Hoses exceeding ½-in (13 mm) in inside diameter must have a safety device installed at the supply source to reduce pressure in the event of hose failure.
- Pneumatic power tools must be secured to the hose in such a manner as to prevent the tool from becoming accidentally disconnected.

9–3 WATER SUPPLY SYSTEMS

Principal Types of Pumps

The principal types of pumps by method of operation include displacement pumps and centrifugal (or dynamic) pumps. *Displacement pumps* include reciprocating pumps and diaphragm pumps. Although *reciprocating pumps* are not often used in construction operations, it is well to understand the terminology used for such pumps. Double-acting reciprocating pumps have a chamber on each end of the piston so that water is pumped as the piston moves in either direction; single-acting pumps move water only when the piston travels in one direction. A simplex pump has one cylinder, a duplex pump has two cylinders, and a triplex pump has three cylinders. Thus a single-acting duplex pump is a two-cylinder reciprocating pump in which pumping occurs during only one-half of the piston travel.

Diaphragm pumps utilize flexible circular disks or diaphragms and appropriate valves to pump water. As the diaphragm is pushed back and forth, the size of the pump chamber increases and decreases to produce the pumping action. Diaphragm pumps are self-priming, capable of pumping water containing a high percentage of sand or trash, and can handle large volumes of air along with water. Hence diaphragm pumps are widely used for dewatering excavations that contain large quantities of mud or trash or have an unsteady influx of water. Standard sizes of diaphragm pump include 2 in. (5.1 cm), 3 in. (7.6 cm), 4 in. (10.2 cm), and double 4 in. (10.2 cm). Pump size designates the nominal diameter of the intake and discharge openings. A gasoline-engine-powered diaphragm pump is shown in Figure 9–6.

Centrifugal pumps are available in a number of models and types. Conventional centrifugal pumps must have the impeller surrounded by water before they will operate. Self-priming centrifugal pumps utilize a water reservoir built into the pump housing to create sufficient pumping action to remove air from the suction line and fully prime the pump. Most centrifugal pumps utilized in construction are of the self-priming variety.

In the United States, the Contractors Pump Bureau (CPB) has developed standards for self-priming centrifugal pumps, submersible pumps, and diaphragm pumps designed for construction service. Self-priming centrifugal pumps certified by the Contractors Pump Bureau include M-, MT-, and MTC-rated pumps. M-rated pumps are available in sizes of 1½-in. (3.8 cm) to 10 in. (25.4 cm), with capacities of 5000 to 200,000 gal (18,925 to

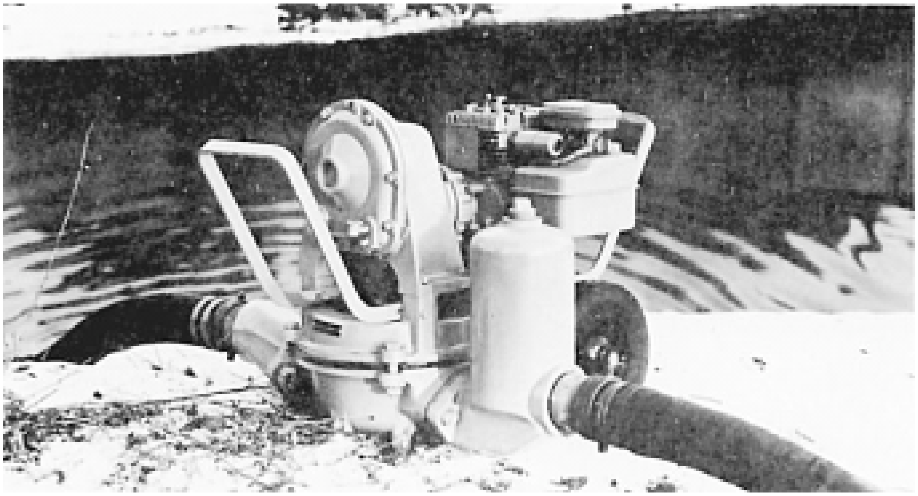

Figure 9–6 Gas-powered diaphragm pump. (Courtesy of Crane Pumps & Systems)

757,000 ℓ) per hour. A contractors 3-in. self-priming centrifugal pump is shown in Figure 9–7. M-rated pumps are required to pass spherical solids having a diameter equal to 25% of the nominal pump size and to handle up to 10% solids by volume. MT-rated or trash pumps are designed to handle up to 40% solids by volume. The maximum diameter of spherical solids that they can handle ranges from 1 in. (2.5 cm) for a 1½-in. (3.8-cm) pump to 2½ in. (6.4 cm) for a 6-in. (15.2-cm) pump. MTC-rated pumps are compact light-weight trash pumps designed for easy portability. Sizes range from 1½-in. (3.8 cm) to 4 in. (10.2 cm) with capacities of 5000 to 23,000 gal/h (18 925 to 83 220 ℓ/h). The maximum diameter of spherical particles which they must pass is 50% of the nominal pump size. A compact 2-in. centrifugal trash pump is shown in Figure 9–8.

Submersible pumps are centrifugal pumps designed to operate within the body of the fluid which they are pumping. Submersible pumps may be powered by electricity, hydraulic fluid, or compressed air. Of these, electric and hydraulic models are most common. Electric pumps are simpler to set up and use since they do not require any hydraulic power source. However, hydraulic pumps are small and powerful and can run dry. Submersible pumps are available in both low-head and high-head models, as well as trash models. Since submersible pumps operate submerged, suction lines and priming problems are eliminated, and pump noise is reduced.

Determining Required Head

In water supply systems, pressure is expressed as the equivalent height of a column of water (feet or meters). This unit of measure is called *head.* The total head that a pump must overcome is the sum of the static head (difference in elevation between two points) and the friction head (loss of pressure due to friction). For the usual pumping system, *static head* is

Figure 9–7 Self-priming centrifugal pump at dam construction site. (Courtesy of Crane Pumps & Systems)

Figure 9–8 Stow's CP-20H 2-in. centrifugal trash pump. (Courtesy of STOW Construction Equipment)

the inlet) and the point of free discharge. If the outlet pipe is below the discharge surface, static head is the difference in elevation between the surface of the source and the surface of the discharge water.

Friction head is calculated in a manner similar to pressure loss in a compressed air system. That is, all fittings are converted to an equivalent pipe length using Figure 9–4. The length of pipe plus the equivalent length of fittings is then multiplied by the appropriate friction factor from Table 9–7. The friction loss for any hose in the system must be calculated separately by multiplying its length by the appropriate factor from Table 9–8. Total friction head is then found as the sum of pipe friction and hose friction. Static head is then added to obtain total head. The procedure is illustrated in Example 9–3.

EXAMPLE 9–3

Water must be pumped from a pond to an open discharge 40 ft (12.2 m) above the pump. The line from the pump to discharge consists of 340 ft (103.7 m) of 4-in. (10.2-cm) pipe equipped with a check valve and three standard elbows. The pump is located 10 ft (3.1 m) above the pond water level. The intake line consists of a 20-ft (6.1-m) hose 4 in. (10.2 cm) in diameter equipped with a foot valve. Find the total head that the pump must produce for a flow of 280 gal/min (1060 ℓ/min). The equivalent length of the foot valve is 70 ft (21.4 m).

SOLUTION

Equivalent length of fittings (Figure 9–4):

$$\begin{aligned} \text{3 elbows at 11 ft (3.4 m)} &= \text{33 ft (10.1 m)} \\ \text{1 foot valve at 70 ft (21.4 m)} &= \text{70 ft (21.4 m)} \\ \text{1 check valve at 25 ft (7.6 m)} &= \underline{\text{25 ft (7.6 m)}} \\ \text{Total} &= \text{128 ft (39.1 m)} \\ \text{Length of straight pipe} &= \underline{\text{340 ft (103.7 m)}} \\ \text{Total equivalent pipe length} &= \text{468 ft (142.8 m)} \end{aligned}$$

$$h_f(\text{pipe}) = \frac{468}{100} \times 5.4 = 25.3 \text{ ft}$$

$$\left[= \frac{142.8}{100} \times 5.4 = 7.7 \text{ m} \right]$$

$$h_f(\text{hose}) = \frac{20}{100} \times 4.3 = 0.9 \text{ ft}$$

$$\left[= \frac{6.1}{100} \times 4.3 = 0.3 \text{ m} \right]$$

$$\text{Static head} = 40 + 10 = 50 \text{ ft (15.3 m)}$$

$$\text{Total head} = 50 + 25.3 + 0.9 = 76.2 \text{ ft}$$

$$[= 15.3 + 7.7 + 0.3 = 23.3 \text{ m}]$$

Table 9–7 Water friction (head) in pipe.* (Courtesy of Contractors Pump Bureau, Association of Equipment Manufacturers (AEM))

Flow		Pipe Size [in. (cm)]													
gal/min	ℓ/min	½ (1.3)	¾ (1.9)	1 (2.5)	1¼ (3.2)	1½ (3.8)	2 (5.1)	2½ (6.4)	3 (7.6)	4 (10.2)	5 (12.7)	6 (15.2)	8 (20.3)	10 (25.4)	12 (30.5)
2	8	4.8	1.2												
3	11	10.2	2.7	0.82											
4	15	17.4	4.5	1.39	0.37										
5	19	26.5	6.8	2.11	0.55										
10	38	95.0	24.7	7.61	1.98	0.93	0.31	0.11							
15	57		52.0	16.3	4.22	1.95	0.70	0.23							
20	76		88.0	27.3	7.21	3.38	1.18	0.40							
25	95			41.6	10.8	5.07	1.75	0.60	0.25						
30	114			57.8	15.3	7.15	2.45	0.84	0.35						
35	132			77.4	20.3	9.55	3.31	1.1	0.46						
40	151				26.0	12.2	4.29	1.4	0.59	0.14					
45	170				32.5	15.1	5.33	1.8	0.75	0.18					
50	189				39.0	18.5	6.43	2.2	0.90	0.22					
60	227				56.8	26.6	9.05	3.0	1.3	0.32					
70	265				73.5	35.1	11.9	4.0	1.7	0.41	0.14				
75	284					39.0	13.6	4.6	2.0	0.48	0.16				
80	303					44.8	15.4	5.0	2.3	0.58	0.18				
90	341					55.5	18.9	6.3	2.7	0.68	0.22				
100	379					66.3	23.3	7.8	3.2	0.79	0.27	0.09			
125	473						35.1	11.8	4.9	1.2	0.42	0.18			
150	578						49.4	16.6	6.8	1.7	0.57	0.21			
175	662						66.3	22.0	9.1	2.2	0.77	0.31			
200	757							28.0	11.6	2.9	0.96	0.40			
225	852							35.5	14.5	3.5	1.2	0.48			
250	946							43.0	17.7	4.4	1.5	0.60	0.15		

Table 9–7 *(Continued)*

275	1041	21.2	5.2	1.8	0.75	0.18		
300	1136	24.7	6.1	2.0	0.84	0.21		
325	1230	29.1	7.0	2.3	0.92	0.24		
350	1325	33.8	8.0	2.7	1.0	0.27		
375	1419		9.2	3.1	1.2	0.31		
400	1514		10.4	3.5	1.4	0.35		
450	1703		12.9	4.4	1.7	0.45	0.14	
500	1893		15.6	5.3	2.2	0.53	0.18	0.08
600	2271		22.4	6.2	3.1	0.74	0.25	0.10
700	2650		30.4	9.9	4.1	1.0	0.34	0.14
800	3028				5.2	1.3	0.44	0.18
900	3407				6.6	1.6	0.54	0.22
1000	3785				7.8	2.0	0.65	0.27
1100	4164				9.3	2.3	0.78	0.32
1200	4542				10.8	2.7	0.95	0.37
1300	4921				12.7	3.1	1.1	0.42
1400	5299				14.7	3.6	1.2	0.48
1500	5678				16.8	4.1	1.4	0.55
1600	6056					4.7	1.6	0.65
1800	6813					5.6	2.0	0.78
2000	7570					7.0	2.4	0.93
2500	9463						3.5	1.5
3000	11355						5.1	2.1
3500	13248						6.5	2.7
4000	15140							3.5
4500	17033							4.5
5000	18925							5.5

*Values are ft/100 ft or m/100 m.

Table 9–8 Water friction (head) in hose.* (Courtesy of Contractors Pump Bureau, Association of Equipment Manufacturers (AEM))

Flow		Hose Size [in. (cm)]											
		⅜	¾	1	1¼	1½	2	2½	3	4	5	6	8
gal/min	ℓ/min	(1.0)	(1.9)	(2.5)	(3.2)	(3.8)	(5.1)	(6.4)	(7.6)	(10.2)	(12.7)	(15.2)	(20.3)
1.5	5.7	2.3	0.97										
2.5	9.5	6.0	2.5										
5	19	21.4	8.9	2.2	0.74	0.3							
10	38	76.8	31.8	7.8	2.64	1.0	0.2						
15	57		68.5	16.8	5.7	2.3	0.5						
20	76			28.7	9.6	3.9	0.9	0.32					
25	95			43.2	14.7	6.0	1.4	0.51					
30	114			61.2	20.7	8.5	2.0	0.70	0.3				
35	132			80.5	27.6	11.2	2.7	0.93	0.4				
40	151				35.0	14.3	3.5	1.2	0.5				
45	170				43.0	17.7	4.3	1.5	0.6				
50	189				52.7	21.8	5.2	1.8	0.7				
60	227				73.5	30.2	7.3	2.5	1.0				
70	265					40.4	9.8	3.3	1.3				
80	303					52.0	12.6	4.3	1.7				
90	341					64.2	15.7	5.3	2.1	0.5			
100	379					77.4	18.9	6.5	2.6	0.6			
125	473						28.6	9.8	4.0	0.9			
150	568						40.7	13.8	5.6	1.3			
175	662						53.4	18.1	7.4	1.8			
200	757						68.5	23.4	9.6	2.3	0.8	0.32	
225	852							29.0	11.9	2.9	1.0	0.40	
250	946							35.0	14.8	3.5	1.2	0.49	
275	1041							42.0	17.2	4.2	1.4	0.58	
300	1136							49.0	20.3	4.9	1.7	0.69	

Table 9–8 *(Continued)*

325	1230	23.5	5.7	2.0	0.80	
350	1325	27.0	6.6	2.3	0.90	
375	1419	30.7	7.4	2.6	1.0	
400	1514		8.4	2.9	1.1	0.28
450	1703		10.5	3.6	1.4	0.35
500	1893		12.7	4.3	1.7	0.43
600	2271		17.8	6.1	2.4	0.60
700	2650		23.7	8.1	3.3	0.80
800	3028			10.3	4.2	1.1
900	3407			12.8	5.2	1.3
1000	3785			15.6	6.4	1.6
1100	4164			18.5	7.6	1.9
1200	4542				9.2	2.3
1300	4921				10.0	2.6
1400	5299				11.9	3.0
1500	5678				13.6	3.3
1600	6056					3.7
1800	6813					4.7
2000	7570					5.7
2500	9463					8.6
3000	11355					12.2

*Values are ft/100 ft or m/100 m.

Pump Selection

The capacity of a centrifugal pump depends on the pump size and horsepower, the resistance of the system (total head), and the elevation of the pump above the source water level. After the total head and the height of the pump above water have been established, the minimum size of rated self-priming centrifugal pump that will provide the required capacity may be selected from the minimum capacity tables published by the Contractors Pump Bureau. The capacity table for M-rated pumps is reproduced in Table 9–9. Linear interpolation may be used to estimate capacity for values of total head and height of pump not shown in the table. The procedure for pump selection is illustrated in Example 9–4.

EXAMPLE 9–4

Determine the minimum size of M-rated centrifugal pump required to pump 280 gal/min (1060 ℓ/min) through the system of Example 9–3.

SOLUTION

$$\text{Height of pump above source water} = 10 \text{ ft } (3.1\text{m})$$

$$\text{Required total head} = 76.2 \text{ ft } (23.3 \text{ m})$$

$$\text{Capacity of 40-M pump} = 535 - \left(\frac{76.2 - 70.0}{80 - 70}\right)(535 - 465)$$

$$= 535 - 43 = 492 \text{ gal/min}$$

$$\left[= 2025 - \left(\frac{23.3 - 21.3}{24.4 - 21.3}\right)(2025 - 1760)\right.$$

$$\left.= 2025 - 171 = 1854 \ \ell/\text{min}\right]$$

The 40-M pump is satisfactory.

Effect of Altitude and Temperature

The maximum lift (height of pump above the source water level) at which a centrifugal pump will theoretically operate is equal to the atmospheric pressure minus the vapor pressure of water at the prevailing temperature. At a temperature of 68° F (20° C), for example, the maximum theoretical lift at sea level is 33.1 ft (10.1 m). The maximum practical lift is somewhat less: about 23 ft (7.0 m) at sea level at a temperature at 68° F (20° C). Figure 9–9 illustrates the effect of temperature and altitude on the maximum practical suction lift.

Table 9–9 Minimum capacity [gal (ℓ)/min] of M-rated centrifugal pumps (Courtesy of Contractors Pump Bureau)

Model 5-M (1½-in.)

Total Head Including Friction	Height of Pump Above Water [ft (m)]			
	10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
15 (4.6)	85 (321.7)	—	—	—
20 (6.1)	84 (317.9)	68 (257.4)	—	—
25 (7.6)	82 (310.4)	67 (253.6)	—	—
30 (9.1)	79 (299.0)	66 (249.8)	49 (185.5)	35 (132.5)
40 (12.2)	71 (268.7)	60 (227.1)	46 (174.1)	33 (124.9)
50 (15.2)	59 (223.3)	52 (196.8)	41 (155.2)	28 (106.0)
60 (18.3)	42 (159.0)	40 (151.4)	32 (121.1)	22 (83.3)
70 (21.3)	22 (83.3)	22 (83.3)	20 (75.0)	12 (45.4)

Model 8-M (2-in.)

Total Head Including Friction	Height of Pump Above Water [ft (m)]			
	10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
20 (6.1)	135 (511.0)	—	—	—
25 (7.6)	134 (507.2)	117 (442.8)	—	—
30 (9.1)	132 (499.6)	115 (435.3)	93 (352.0)	65 (246.0)
40 (12.2)	123 (465.6)	109 (412.6)	88 (333.1)	63 (238.5)
50 (15.2)	109 (412.6)	99 (374.7)	81 (306.6)	59 (223.3)
60 (18.3)	90 (340.7)	84 (317.9)	70 (265.0)	51 (193.0)
70 (21.3)	66 (249.8)	65 (246.0)	57 (215.7)	41 (155.2)
80 (24.4)	40 (151.4)	40 (151.4)	40 (151.4)	28 (106.0)

Model 7-M (2-in.)

Total Head Including Friction	Height of Pump Above Water [ft (m)]			
	10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
20 (6.1)	117 (442.8)	—	—	—
30 (9.1)	116 (439.1)	102 (386.1)	82 (310.4)	—
40 (12.2)	105 (397.4)	100 (378.5)	80 (302.8)	58 (219.5)
50 (15.2)	92 (348.2)	90 (340.7)	76 (287.7)	55 (208.2)
60 (18.3)	70 (265.0)	70 (265.0)	70 (265.0)	55 (208.2)
70 (21.3)	40 (151.4)	40 (151.4)	40 (151.4)	40 (151.4)

Model 10-M (2-in.)

Total Head Including Friction	Height of Pump Above Water [ft (m)]			
	10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
25 (7.6)	166 (628.3)	—	—	—
30 (9.1)	165 (624.5)	140 (529.9)	110 (416.4)	—
40 (12.2)	158 (598.0)	140 (529.9)	110 (416.4)	75 (283.9)
50 (15.2)	145 (548.8)	130 (492.1)	106 (401.2)	70 (265.0)
60 (18.3)	126 (476.9)	117 (442.8)	97 (367.1)	68 (257.4)
70 (21.3)	102 (386.1)	100 (378.5)	85 (321.7)	60 (227.1)
80 (24.4)	74 (280.1)	74 (280.1)	68 (257.4)	48 (181.7)
90 (27.4)	40 (151.4)	40 (151.4)	40 (151.4)	32 (121.1)

Continued

Table 9–9 *(Continued)*

Model 15-M (3-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]* 10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
20 (6.1)	259 (980.3)	—	—	—
30 (9.1)	250 (946.3)	210 (794.9)	200 (757.0)	—
40 (12.2)	241 (912.2)	207 (783.5)	177 (669.9)	160 (605.6)
50 (15.2)	225 (851.6)	202 (764.6)	172 (651.0)	140 (529.9)
60 (18.3)	197 (745.6)	197 (745.6)	169 (639.7)	140 (529.9)
70 (21.3)	160 (605.6)	160 (605.6)	160 (605.6)	138 (522.3)
80 (24.4)	125 (473.1)	125 (473.1)	125 (473.1)	125 (473.1)
90 (27.4)	96 (363.4)	96 (363.4)	96 (363.4)	96 (363.4)

Model 20-M (3-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]* 10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
30 (9.1)	333 (1,260.0)	280 (1,059.8)	235 (889.5)	165 (624.5)
40 (12.2)	315 (1,192.3)	270 (1,022.0)	230 (870.6)	162 (613.2)
50 (15.2)	290 (1,097.7)	255 (965.2)	220 (832.7)	154 (582.9)
60 (18.3)	255 (965.2)	235 (889.5)	205 (775.9)	143 (541.3)
70 (21.3)	212 (802.4)	209 (791.1)	184 (696.4)	130 (492.1)
80 (24.4)	165 (624.5)	165 (624.5)	157 (594.2)	114 (431.5)
90 (27.4)	116 (439.1)	116 (439.1)	116 (439.1)	94 (355.8)
100 (30.5)	60 (227.1)	60 (227.1)	60 (227.1)	60 (227.1)

Model 18-M (3-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]* 10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
25 (7.6)	301 (1,139.3)	—	—	—
30 (9.1)	295 (1,116.6)	255 (965.2)	200 (757.0)	—
40 (12.2)	276 (1,044.7)	250 (946.3)	200 (757.0)	162 (613.2)
50 (15.2)	250 (946.3)	237 (897.0)	198 (749.4)	159 (601.8)
60 (18.3)	216 (817.6)	212 (802.4)	182 (688.9)	146 (552.6)
70 (21.3)	174 (658.6)	174 (658.6)	158 (598.0)	127 (480.7)
80 (24.4)	129 (488.3)	129 (488.3)	125 (473.1)	104 (393.6)
90 (27.4)	82 (310.4)	82 (310.4)	82 (310.4)	74 (280.1)
95 (29.0)	57 (215.7)	57 (215.7)	57 (215.7)	57 (215.7)

Model 40-M (4-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]* 10 (3.0)	15 (4.6)	20 (6.1)	25 (7.6)
25 (7.6)	665 (2,517.0)	—	—	—
30 (9.1)	660 (2,498.1)	575 (2,176.4)	475 (1,797.9)	355 (1,343.7)
40 (12.2)	645 (2,441.3)	565 (2,138.5)	465 (1,760.0)	350 (1,324.8)
50 (15.2)	620 (2,346.7)	545 (2,062.8)	455 (1,722.2)	345 (1,305.8)
60 (18.3)	585 (2,214.2)	510 (1,930.3)	435 (1,646.5)	335 (1,268.0)
70 (21.3)	535 (2,025.0)	475 (1,797.9)	410 (1,551.9)	315 (1,192.3)
80 (24.4)	465 (1,760.0)	410 (1,551.9)	365 (1,381.5)	280 (975.8)
90 (27.4)	375 (1,419.4)	325 (1,230.1)	300 (1,135.5)	220 (832.7)
100 (30.5)	250 (946.3)	215 (813.8)	195 (738.1)	145 (548.8)
110 (33.5)	65 (246.0)	60 (227.1)	50 (189.2)	40 (151.4)

Continued

Table 9–9 *(Continued)*

Model 90-M (6-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]*			
	10 (3.0)	**15 (4.6)**	**20 (6.1)**	**25 (7.6)**
25 (7.6)	1,500 (5,677.5)	—	—	—
30 (9.1)	1,480 (5,601.8)	1,280 (4,844.8)	1,050 (3,974.3)	790 (2,990.1)
40 (12.2)	1,430 (5,412.6)	1,230 (4,655.6)	1,020 (3,860.7)	780 (2,952.3)
50 (15.2)	1,350 (5,109.8)	1,160 (4,390.6)	970 (3,671.5)	735 (2,782.0)
60 (18.3)	1,225 (4,636.6)	1,050 (3,974.2)	900 (3,406.5)	690 (2,611.7)
70 (21.3)	1,050 (3,974.2)	900 (3,406.5)	775 (2,933.4)	610 (2,308.9)
80 (24.4)	800 (3,028.0)	680 (2,573.8)	600 (2,271.0)	490 (1,854.7)
90 (27.4)	450 (1,703.3)	400 (1,514.0)	365 (1,381.5)	300 (1,135.5)
100 (30.5)	100 (378.5)	100 (378.5)	100 (378.5)	100 (378.5)

Model 200-M (10-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]*			
	10 (3.0)	**15 (4.6)**	**20 (6.1)**	**25 (7.6)**
20 (6.1)	3,350 (12,679.8)	3,000 (11,355.0)	—	—
30 (9.1)	3,000 (11,355.0)	2,800 (10,598.0)	2,500 (9,462.5)	1,550 (5,866.8)
40 (12.2)	2,500 (9,462.5)	2,500 (9,462.5)	2,250 (8,516.3)	1,500 (5,677.5)
50 (15.2)	2,000 (7,570.0)	2,000 (7,570.0)	2,000 (7,570.0)	1,350 (5,109.8)
60 (18.3)	1,300 (4,920.5)	1,300 (4,920.5)	1,300 (4,920.5)	1,150 (4,352.8)
70 (21.3)	500 (1,892.5)	500 (1,892.5)	500 (1,892.5)	500 (1,892.5)

Model 125-M (8-in.)

Total Head Including Friction	*Height of Pump Above Water [ft (m)]*			
	10 (3.0)	**15 (4.6)**	**20 (6.1)**	**25 (7.6)**
25 (7.6)	2,100 (7,948.5)	1,850 (7,002.3)	1,570 (5,942.5)	—
30 (9.1)	2,060 (7,797.1)	1,820 (6,888.7)	1,560 (5,904.6)	1,200 (4,542.0)
40 (12.2)	1,960 (7,418.6)	1,740 (6,585.9)	1,520 (5,753.2)	1,170 (4,428.5)
50 (15.2)	1,800 (6,813.0)	1,620 (6,131.7)	1,450 (5,488.3)	1,140 (4,314.9)
60 (18.3)	1,640 (6,207.4)	1,500 (5,677.5)	1,360 (5,147.6)	1,090 (4,125.7)
70 (21.3)	1,460 (5,526.1)	1,340 (5,071.9)	1,250 (4,731.3)	1,015 (3,840.8)
80 (24.4)	1,250 (4,731.3)	1,170 (4,428.5)	1,110 (4,201.4)	950 (3,595.8)
90 (27.4)	1,020 (3,860.7)	980 (3,709.3)	940 (3,557.9)	840 (3,179.4)
100 (30.5)	800 (3,028.0)	760 (2,876.6)	710 (2,687.4)	680 (2,573.8)
110 (33.5)	570 (2,157.5)	540 (2,043.9)	500 (1,892.5)	470 (1,779.0)
120 (36.6)	275 (1,040.9)	245 (927.3)	240 (908.4)	240 (908.4)

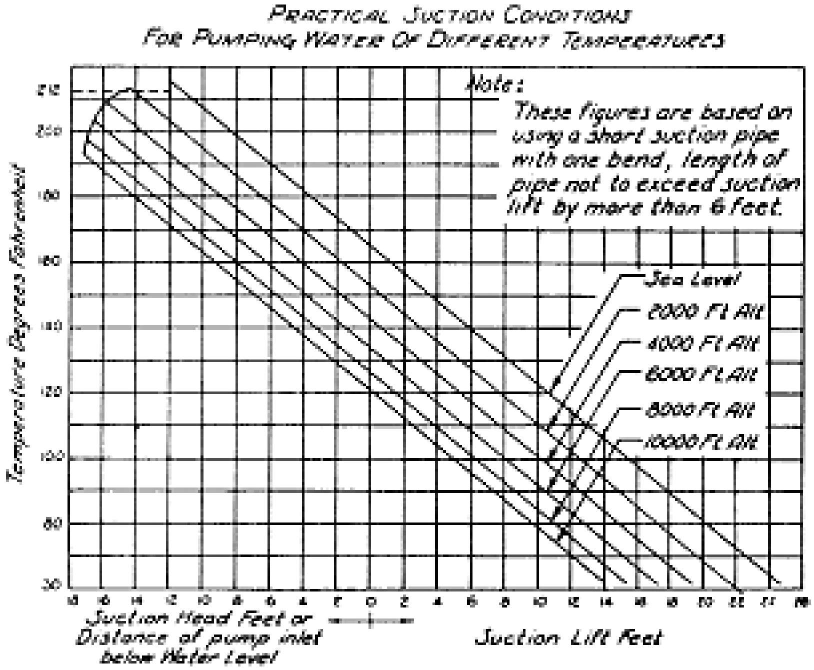

Figure 9–9 Maximum practical suction lift for centrifugal pumps. (Courtesy of Contractors Pump Bureau of Construction Industry Manufacturers Association)

Special Types of Pumps

It is sometimes necessary to pump water in situations where the vertical distance between the source water level and the ground surface exceeds the maximum practical lift for conventional pumps. In such a situation submersible pumps are a logical choice. When construction-type submersible pumps cannot be used, deep-well submersible pumps capable of operating in wells up to 500 ft (152.5 m) deep are available.

Jet pumps and air-lift pumps are two other types of pumps capable of lifting water more than 33 ft (10 m). *Jet pumps* recirculate a portion of the pump output to a venturi tube located below the source water level and then back to the pump inlet. Low pressure in the venturi tube draws water from the source into the recirculating line, where it flows to the pump inlet. While jet pumps are relatively inefficient, they are capable of lifting water 100 ft (30.5 m) or more. Other advantages of jet pumps include simplicity, ease of maintenance, the ability to operate in wells having diameters as small as 2 in. (5.1 cm), and the ability to locate the pump mechanism on the surface or even at some distance from the well. *Airlift pumps* discharge compressed air below the source water level inside a discharge line. The air bubbles formed within the discharge line lower the specific gravity of the water and air mixture enough to cause the mixture to flow up through the discharge line. The pump discharge must be fed into an open tank for deaeration if the water is to be repumped by a conventional pump. Air-lift pumps have low efficiency and a limited lift capability. They are principally used for testing new wells and for cleaning and dewatering drilled pier excavations.

PROBLEMS

1. You are designing an air delivery system to supply three hand-held rock drills requiring 110 cu ft/min (3.1 m^3/min) each. The receiver of the air compressor will be operated at 110 psig (785 kPa). The fixed air supply system will consist of 1400 ft (427 m) of pipe and a manifold. Each drill will be connected to the manifold by 80 ft (24.4 m) of 1-in. (2.5-cm) hose. Manifold pressure loss is rated at 2.5 psig (17.2 kPa). Determine the minimum size of pipe required to maintain a pressure of at least 90 psig (621 kPa) at each drill when all drills are operating simultaneously. Assume a 7% line leakage.
2. What types of pumps might be used to dewater an excavation in a situation where the suction lift for a conventional centrifugal pump would exceed 32 ft (9.8 m)?
3. What is the maximum practical suction lift for a centrifugal pump located at an altitude of 6000 ft (1830 m) when the temperature is 95° F (35° C)?
4. An M-rated self-priming centrifugal pump will be used to dewater a trench during pipeline construction. The required pumping volume is estimated at 200 gal/min (757 ℓ/min). The pump will be located 10 ft (3.1 m) above the trench bottom. The suction line will consist of 25 ft (7.6 m) of 3-in. (7.6-cm) hose, and the discharge line will consist of 75 ft (22.8 m) of 3-in. (7.6-cm) hose. Water will be discharged 20 ft (6.1 m) above pump level. What is the total head developed? What is the minimum-size pump required?
5. Water must be pumped from a stream to a water tank several hundred feet (meters) away. The discharge point will be 50 ft (15.3 m) above the stream. The pipeline from the pump to the tank will consist of 340 ft (104 m) of 4-in. (10.2-cm) straight pipe, three standard elbows, and a check valve. The pump will be located 10 ft (3.1 m) above the stream. The suction line will consist of 20 ft (6.1 m) of 4-in. (10.2-cm) hose equipped with a foot valve [equivalent straight pipe length = 70 ft (21.4 m)]. If the required flow is 280 gal/m (1060 ℓ/min), find the total head that the pump must overcome. What is the minimum-size M-rated pump required for this system?
6. A compressed air system consists of a compressor and receiver, 1500 ft (458 m) of 4-in. (10.2-cm) pipe, two gate valves, six standard elbows, and a manifold. Four rock drills requiring 200 cu ft/min (5.7 m^3/min) each are connected to the manifold by 1¼-in. (3.2-cm) hoses 100 ft (30.5 m) long. Pressure drop in the manifold is 3 psig (20 kPa) and line leakage is 5%. Determine the pressure at the drill when all four drills are operating simultaneously and receiver pressure is 100 psig (690 kPa).
7. Estimate the air consumption of the following equipment to be used on a rock excavation project. Assume an 8% leakage loss, a job load factor of 0.90, and average values

of tool air consumption from Table 9–1. What is the minimum rated size of air compressor required if the project is located at an altitude of 6000 ft (1830 m)?

Equipment	Number
Medium-weight track drill	2
Heavy-weight track drill	1
55-lb hand-held drill	5

8. Explain the method by which air compressor capacity is rated.
9. How does the friction loss in a compressed air pipeline vary with pressure?
10. Develop a computer program which will determine the minimum rated size of air compressor required to service a compressed air system. Input should include (for each tool type) the type of tool, the number of tools, and the expected air consumption per tool. Additional input should include the job load factor, the leakage allowance, and the altitude adjustment factor. Solve Problem 7 using your program.

REFERENCES

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