Chapter 8

Well-Performance Testing Procedures

8-1. Testing Pumps. You will normally use the permanent pump for pump testing. If you use a temporary unit, it must be adequate to draw down the water and hold it at a prescribed flow rate for a period of hours. This test will determine the specific capacity of the well. You can estimate the yield of a small well by bailing water from the well rapidly if no pump is available. You must know the bailer's volume and count the number of times per minute the bailer is brought up full to estimate the GPM of the well. Accurately measuring drawdown is not possible during the test because the water level constantly fluctuates.

a. *Permanent Wells.* You should use two different testing procedures when a pump is available, depending on the intended use of the well and the available testing time. If the well will be a permanent installation and maintained in the future, you should conduct a detailed test. Measure the static water level in the well before testing, and measure the drawdown during the test. Conduct the test as follows:

- Pump at a rate that will lower the water in the well about one-third of the maximum drawdown possible (one-third the distance from the static water level to the top of the well screen) or about one-third of the rated capacity of the pump.
- Monitor and adjust the flow rate early in the test because as the drawdown increases the flow rate decreases.
- Continue pumping at a constant flow rate until the drawdown remains constant (about 1 to 4 hours).
- Record the flow rate, drawdown, and testing time. Initially, take readings rapidly, and then spread out the readings as the test continues. A reading schedule that doubles the time between readings is preferable. The recommended schedule is as follows: 0 (at the start of the test) 30 seconds, 1 minute, 2 minutes, 4 minutes, 8 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 4 hours, and so forth.
- Establish the desired, constant flow rate quickly. You must record the exact time of each reading (not the intended or scheduled time). After the drawdown stabilizes (1 to 4 hours), the pumping rate should increase to a new, constant flow rate, which will produce two-thirds of the capacity of the pump. Do not stop the pump between these test segments.
- Repeat the measurements, noting the exact time that the new flow rate was started. Try to follow the above reading schedule, starting from the time the flow rate was increased. When the drawdown stabilizes, increase the pumping rate to produce the maximum drawdown or about 90 percent of the maximum capacity of the pump. Conduct another reading schedule until the pumping level stabilizes.

You may modify the above procedure depending on well requirements and local site conditions. You should not modify the precision and accuracy of the measurements taken. Test results should become a part of the permanent records. The results are useful for evaluating the efficiency of the well in the future and for determining the need for well rehabilitation. Calculating the GPM per foot of drawdown gives the capacity of the well. You can use this information to estimate production and to regulate the pump's flow rate to prevent dewatering of the well and possible pump damage.

b. *Temporary Wells.* Conduct a single-stage test rather than the step drawdown test. To establish the flow rate, conduct a 1- to 2-minute test to determine the GPM per foot of drawdown. Let the well return to the original static water level before testing (about 1 hour). Select a flow rate that will produce about two-thirds of the available drawdown but will not reach more than 90 percent of the pump's capacity. Conduct the test as described above, but with only one segment. When the drawdown stabilizes for the selected flow rate, stop the test.

c. *Methods.* See Chapter 4 for a description of pumps used in testing and well production.

(1) Submersible-Pump Method. Use the submersible pump in well-completion kits to pump test the water well. Set the pump deep enough to attain the maximum pumping rate and drawdown. When testing a well with a screen, set the suction of the pump above the top of the screen to prevent lowering the water level below the screen. When testing a well without a screen, try not to dewater the production part of the aquifer. For proper testing, you must have a reliable power source so that testing will not be interrupted. The power must be sufficient to drive the pump at a rated speed so that full capacity can be developed.

(2) Air-Lift Method. This method is sometimes best for military field operations, especially if the well may produce sand that could damage or reduce the life of a submersible pump. An air-lift pump has two major problems. Air turbulence could make drawdown measuring difficult, and entrained air may cause considerable error in measuring the flow rate. After constructing an air-lift pump, check the pump capacity against the expected well yield. To conduct the test, set the pump according to the readings in Table 4-2.

An air compressor that puts out 350 cfm at 200 psi is suitable for performing most air-lift pumping operations. To determine the amount of air needed for pumping water, use the following equation or refer to Figure 8-1.

$$V = \frac{\dfrac{h}{C\,[\log(H+34)]}}{43}$$

where--

V = free air (actual) required to raise one gallon of water, in cubic feet.

h = total lift, in feet.

log = logarithmic value.

H = operating submergence, in feet.

C = constant (Table 8-1).

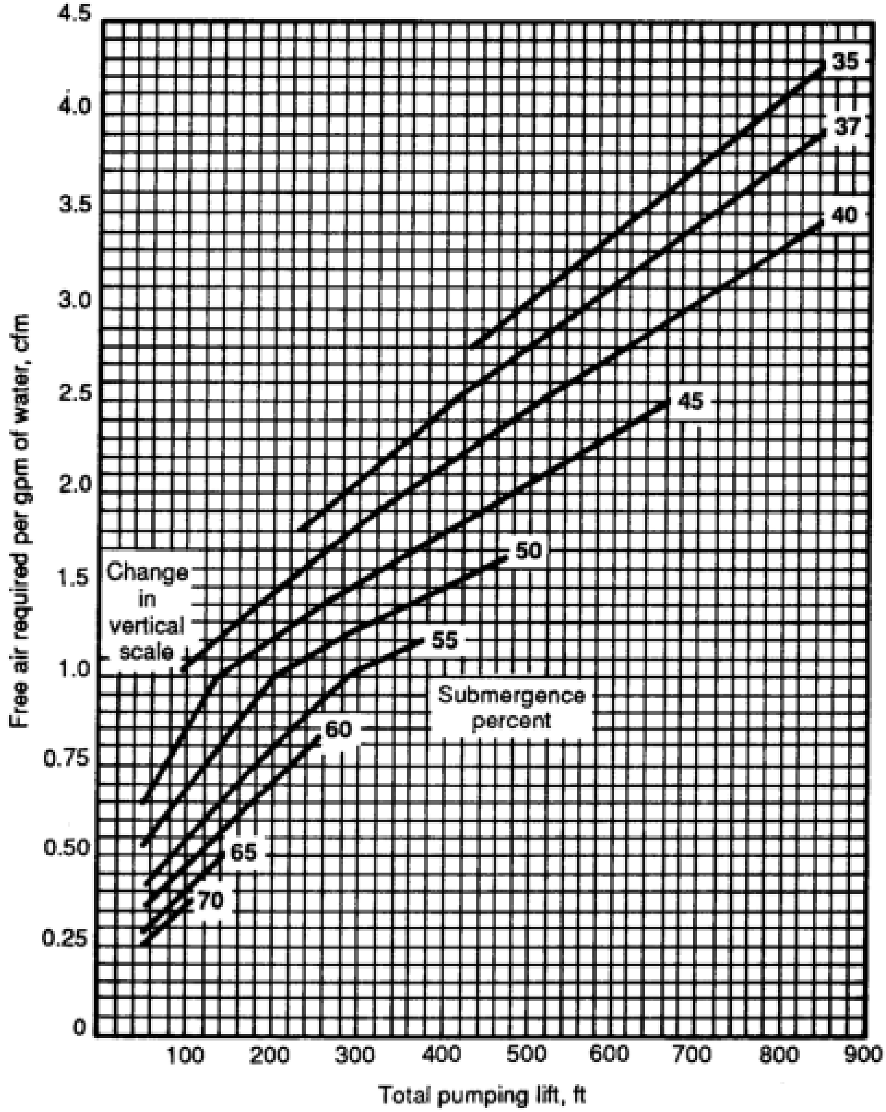

Figure 8-1. Cubic feet of air requirements for various submergences and pumping lifts

Table 8-1. Constants

Constant	Submergence (percent)
366	75
358	70
348	65
335	60
318	55
296	50
272	45
246	40
216	35

The pressure required to start pumping will be equal to the depth of water over the submerged end of the air pipe. After pumping has started, the water in the well will draw down to a working level. The air pressure required will be the total lift, in feet, from the working water level plus the friction loss in the airline. Conduct the test and try to measure flow rate and drawdown quickly. Pumping creates turbulance in the well. Use the air-line method (paragraph 8-2c) to try and measure drawdown. Because of entrained air, use the measured-container method (paragraph 8-3a) to obtain flow-rate measurements.

8-2. Measuring Water Level.

a. *Electric-Line Method.* Water levels can be measured accurately with a two-conductor, battery-powered indicator known as an M-Scope (Figure 8-2). Well-completion kits usually contain an M-Scope. The M-Scope is a battery and a meter connected in series. When the upper wire on the tip of the M-Scope in the well touches the water, the circuit is completed and the meter gives a steady reading. Measure the amount of wire in the well to determine the depth to the water level. The wire is marked at 5-foot intervals for easy measuring.

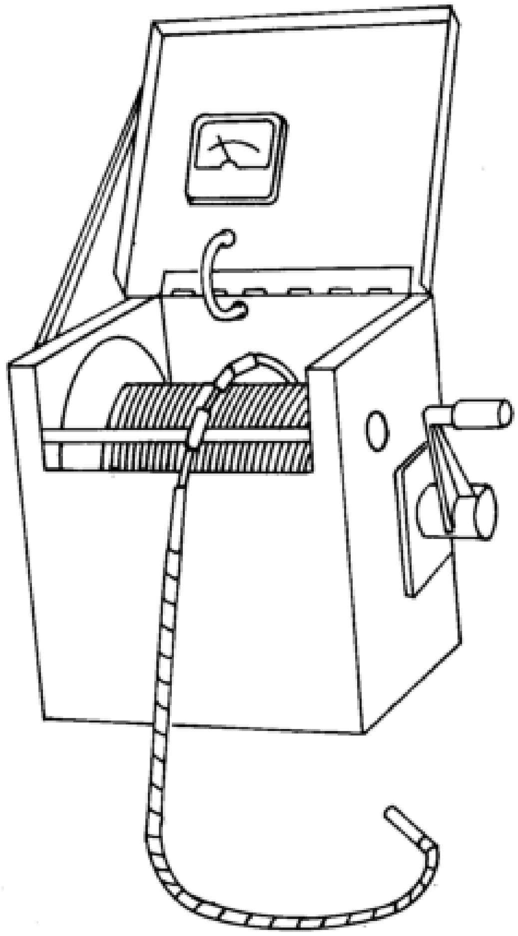

Figure 8-2. M-Scope

b. *Tape Method.* Use this method to measure the depth to the static level in a shallow well. Conduct this test as follows:

- Chalk one end of a weighted steel tape with carpenter's chalk. Lower the tape (Figure 8-3) into the well to a depth of 1 or 2 feet past the chalk. (You can use soluble felt-tip markers as an alternative to chalk.)
- Measure the wetted length of the tape and subtract the amount from the total length lowered below the reference point to obtain the water depth. This test is accurate to within 0.01 foot.

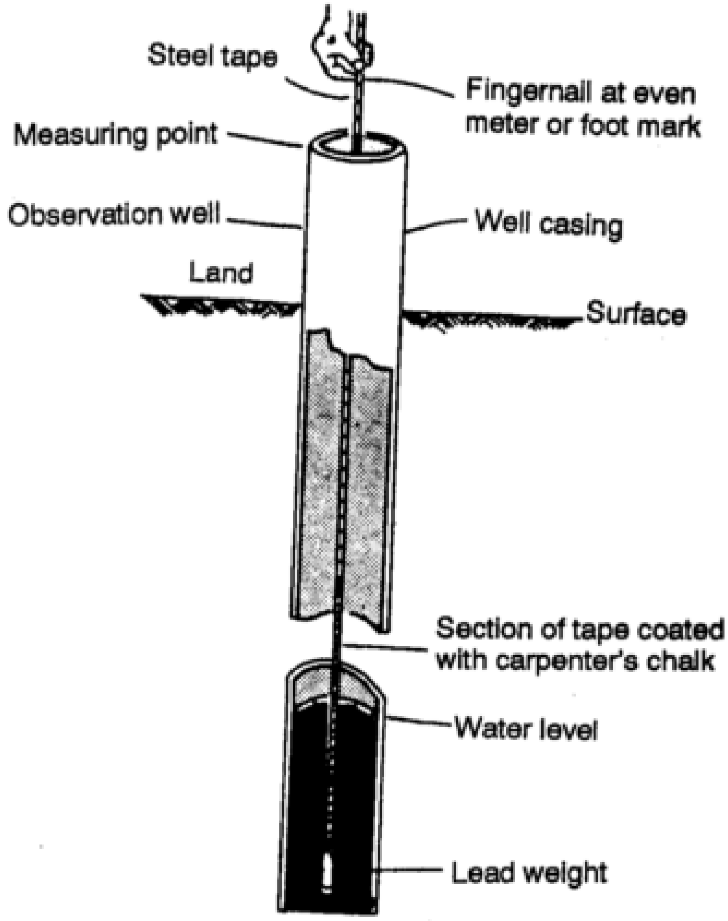

Figure 8-3. Steel-tape measurement method

c. *Air-Line Method.* You can measure the water level with an air line to follow drawdown and confirm a stable head during a test (Figure 8-4). The air line is usually 1/8- or 1/4-inch copper tubing or galvanized pipe that is long enough to extend below the lowest water level you are measuring. Fasten the air line to the pump bowls or cylinder. Install the airline with the pump. The pipe must be airtight; makeup all joints carefully. Measure the vertical length of the airline from the pressure gauge to the bottom of the line at the time of installation.

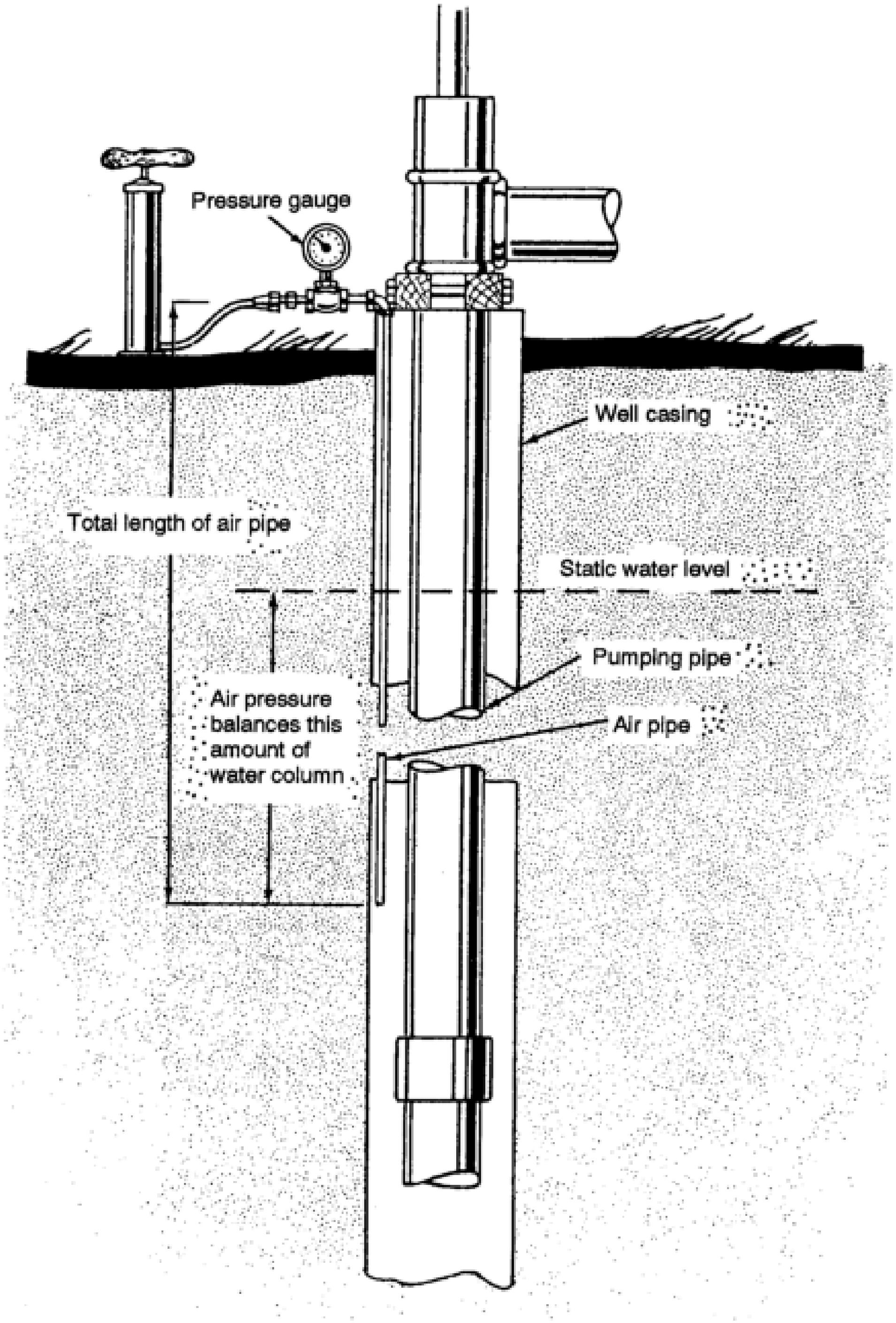

Figure 8-4. Air-line measurement method

Attach a pressure gauge to the airline at the surface with an ordinary tire valve so you can pump air into the line. Pump air into the line until you get a maximum reading. The reading should be equal to the pressure exerted by the column of water standing outside of the airline. Subtract the reading from the total vertical length of air line to get the depth to the water below the center of the gauge. Readings are measured in feet, so you may have to convert your figures.

8-3. Measuring Discharge Rate.

a. *Measured-Container Method.* You can determine the flow rate from a well or pump by measuring the time required to fill a container with a known volume. With this method, use small containers for early measurements and large containers for later measurements. Also, use an instrument, such as a stop watch, for accurate time measurements. Use the following equation:

$$FR = \frac{V(60)}{T}$$

where--

FR = flow rate, in GPM.

v = volume, in gallons.

T = time required to fill container, in seconds.

b. *Flow-Meter Method.* A turbine-type flow meter will give an acceptable flow-rate reading. These meters are used by civilians. You can also use a totalizer-type water meter when the yield is low. Use these meters to measure the total gallons pumped and determine the flow rate. To do this, record the number of gallons that have flowed within a set amount of time and compute the flow rate.

c. *Circular-Orifice Method.* A circular-orifice meter (Figure 8-5) is a device you can make to measure discharge rates. This device gives good results and is compact and easily installed. The meter consists of a sharp-edged circular orifice at the end of a horizontal discharge pipe. The orifice is from one-half to three-fourths the diameter of the pipe. The inside of the pipe must be smooth and free from obstructions for a length of 6 feet from the orifice. The discharge pipe has a small hole on one side with a rubber-tube connection. The pipe is designed so that you can measure the pressure (head) in the discharge pipe at a distance of 2 feet from the orifice.

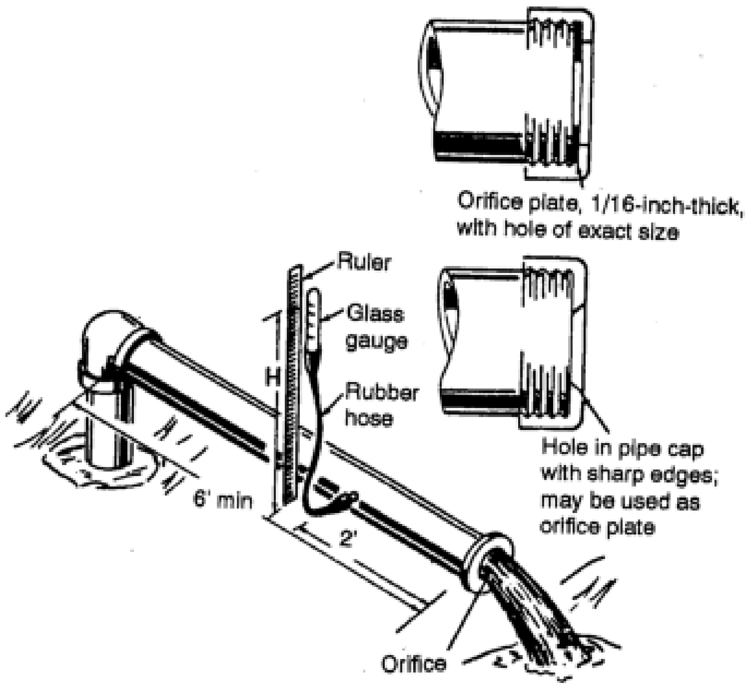

Figure 8-5. Circular-orifice flow meter

The length of hose and ruler depends on the pipe size you use (Table 8-2). The discharge pipe must be horizontal, and the stream must fall free from the orifice. The orifice must be vertical and centered in the discharge pipe. The combination of pipe and orifice diameters for a given test should be such that the head measured will be at least three times the diameter of the orifice.

Table 8-2. Circular-orifice flow measurements

Head of Water In Tube Above Center of Orifice (Inches)	4-Inch Pipe, 2 1/2-Inch Opening (GPM)	4-Inch Pipe, 3-Inch Opening (GPM)	6-Inch Pipe, 3-Inch Opening (GPM)	6-Inch Pipe, 4-Inch Opening (GPM)	6-Inch Pipe, 5-Inch Opening (GPM)	8-Inch Pipe, 4-Inch Opening (GPM)	8-Inch Pipe, 5-Inch Opening (GPM)	8-Inch Pipe, 6-Inch Opening (GPM)
6	62	102						
7	66	110	88					
8	70	118	94	180	350	170	280	440
9	75	126	100	190	370	180	295	465
10	80	132	106	200	390	190	310	490
12	87	145	115	220	425	210	340	540
14	94	156	125	238	460	225	370	580
16	100	168	132	253	490	240	390	620
18	106	178	140	268	520	255	415	660
20	112	188	150	283	550	270	440	695
22	118	198	158	298	575	280	460	725
25	125	210	168	318	610	300	490	780
30	138	230	182	350	670	330	540	850
35	150	250	198	375	725	360	580	920
40	160	265	210	400	780	380	620	980
45	170	280	223	425	820	400	660	1,040
50	180	300	235	450	870	425	700	1,100
60	195	325	260	490	950	465	760	1,200

d. *Open-Pipe Method.* With this method, the pipe is fully open and you measure the distance the water stream travels parallel to the pipe at a 12-inch vertical drop (Figure 8-6). Use the following procedure:

- Step 1. Measure the inside diameter of the pipe and the distance the stream travels parallel to the pipe at a 12-inch vertical drop. Your results will be in inches.
- Step 2. Estimate the flow from the pipe diameter and the distance the stream travels (Table 8-3). Your results will be in GPM.

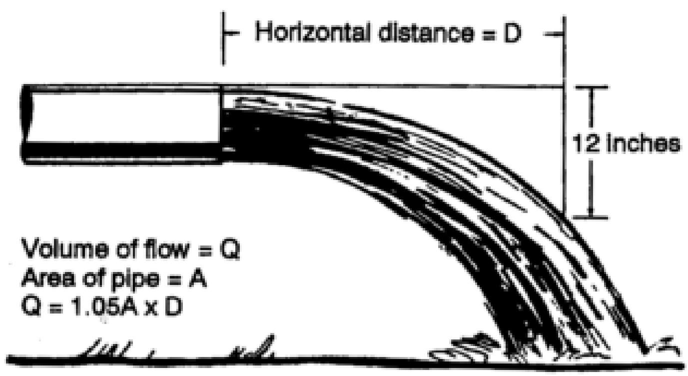

Figure 8-6. Open-pipe-flow measurement method

Table 8-3. Open-pipe-flow measurements

Pipe Diameter (Inches)	Horizontal Distance (D) (Inches)									
	12	14	16	18	20	22	24	26	28	30
2	41	48	55	61	68	75	82	89	96	102
3	90	105	120	135	150	165	180	195	210	225
4	150	181	207	232	258	284	310	336	361	387
6	352	410	470	528	587	645	705	762	821	880
8	610	712	813	915	1,017	1,119	1,221	1,322	1,425	1,527
10	960	1,120	1,280	1,440	1,600	1,760	1,930	2,080	2,240	2,400
12	1,378	1,607	1,835	2,032	2,286	2,521	2,760	2,980	3,210	3,430

For partially filled pipes, measure either the water depth or the freeboard. Divide the diameter by the water depth to get a percentage ratio. Measure the stream as above and calculate the discharge. The actual discharge will be, approximately, the value for a full pipe of the same diameter multiplied by the correction factor from Table 8-4.

Table 8-4. Correction factors

Percent	Factor	Percent	Factor
5	0.981	55	0.436
10	0.948	60	0.375
15	0.905	65	0.312
20	0.858	70	0.253
25	0.805	75	0.195
30	0.747	80	0.142
35	0.688	85	0.095
40	0.627	90	0.052
45	0.564	95	0.019
50	0.500	100	0.000

Chapter 4
Pumps

4-1. Fundamentals.

a. *Pump Types.* Pumps may be classified according to use (for shallow or deep wells), design (variable or positive displacement), or method of operation (rotary, reciprocating, centrifugal, jet, or airlift). This chapter deals with shallow- and deep-well pumps. Shallow-well pumps (suction-lift pumps) are normally installed above ground, on or near the top of the well casing. Deep-well pumps are installed in the well casing with the pump inlets submerged below the pumping level. These inlets are always under a positive head and do not require suction to move or pump the water.

b. *Selection Criteria.* Consider the following items when selecting a pump:

- Size of the well.
- Quantity of water to be pumped.
- Drawdown and pumping levels.
- Type of available power.
- Yield of the well.
- Estimated total pumping head.

Well yield is frequently overlooked when selecting a pump for small wells. Installing a pump that can handle a large discharge capacity can either temporarily drain a small well or exceed the maximum possible suction lift. Therefore, pumping requirements and well characteristics must be matched to determine the optimum pump for each installation. Table 4-1 provides a general guide for use in pump selection. Military well drillers deploying with well-completion kits will normally use the deep-well submersible pumps that are supplied with the kits.

Table 4-1. Guide to pump selection

Type of Pump	Practical Suction Lift[1]	Usual Well-Pumping Depths	Usual Pressure Heads	Advantages	Disadvantages	Remarks
Reciprocating: 1. Shallow well	22 to 26 feet	22 to 26 feet	100 to 200 feet	1. Positive action 2. Discharge against variable heads 3. Pumps water containing sand and silt 4. Especially adapted to low capacity and high lifts	1. Pulsating discharge 2. Subject to vibration and noise 3. Maintenance cost may be high 4. May cause destructive pressure if operated against closed valve	1. Best suited for capacities of 5 to 25 GPM against moderate to high heads 2. Adaptable to hand operation 3. Can be installed in very small diameter wells (2-inch casing) 4. Pump must be set directly over well (deep well only)
2. Deep well	22 to 25 feet	Up to 600 feet	Up to 600 feet above cylinder			
Centrifugal: 1. Shallow well a. Straight centrifugal (single stage)	20 feet maximum	10 to 20 feet	100 to 150 feet	1. Smooth, even flow 2. Pumps water containing sand and silt 3. Pressure on system is even and free from shock 4. Low-starting torque 5. Usually reliable and good service life	1. Loses prime easily 2. Efficiency depends on operating under design heads and speed	Very efficient pump for capacities above 50 GPM and heads up to about 150 feet
b. Regenerative vane turbine type (single impeller)	28 feet maximum	28 feet	100 to 200 feet		Same as straight centrifugal except maintains priming easily	Reduction in pressure with increased capacity not as severe as straight centrifugal
2. Deep well a. Vertical line shaft turbine (multistage)	Impellers submerged	50 to 300 feet	100 to 800 feet	Same as shallow-well turbine	1. Efficiency depends on operating under design head and speed 2. Requires straight well large enough for turbine bowl and housing 3. Lubrication and alignment of shaft critical 4. Abrasion from sand	
b. Submersible turbine (multistage)	Pump and motor submerged	50 to 400 feet	80 to 900 feet	1. Same as shallow-well turbine 2. Easy to frost proof installation 3. Short pump shaft to motor	1. Repair to motor or pump requires pulling from well 2. Sealing of electrical equipment from water vapor critical 3. Abrasion from sand	Difficulty with sealing has caused uncertainty as to service life to date
Jet: 1. Shallow well	15 to 20 feet below ejector	Up to 15 to 20 feet below ejector	80 to 150 feet	1. High capacity at low heads. 2. Simple in operation 3. Does not have to be installed over the well 4. No moving parts in the well	1. Capacity reduces as lift increases 2. Air in suction or return line will stop pumping	
2. Deep well	15 to 20 feet below ejector	25 to 120 feet, 200 feet maximum	80 to 150 feet	Same as shallow-well jet	Same as shallow-well jet	The amount of water returned to ejector increases with increased lift— 50 percent of total water pumped at 50-foot lift and 75 percent at 100-foot lift
Rotary: 1. Shallow well (gear type)	22 feet	22 feet	50 to 250 feet	1. Positive action 2. Discharge constant under variable heads 3. Efficient operation	1. Subject to rapid wear if water contains sand or silt 2. Wear of gears reduces efficiency	
2. Deep well (helical-rotary type)	Usually submerged	50 to 500 feet	100 to 500 feet	1. Same as shallow-well rotary 2. Only one moving pump device in well	Same as shallow-well rotary except no gear wear	A cutless rubber stator increases life of pump; flexible drive coupling has been weak point in pump; best adapted for low capacity and high heads

[1]Practical suction lift at sea level. Reduce lift 1 foot for each 1,000 feet above sea level.

4-2. Shallow-Well Pumps. These pumps are limited to the depth from which they can lift water. At sea level, the practical limit is 22 to 25 feet for most pumps. This value decreases about 1 foot for each 1,000-foot increase in elevation above sea level. The operative principle of a shallow-well pump is similar to drinking through a straw. A partial vacuum is created, and the difference between the pressure inside the straw and the liquid outside the straw forces the liquid upward to a new equilibrium.

A pump exhausts air from the intake line, thus lowering the pressure on the intake side below atmospheric pressure. The atmospheric pressure on the water in the well then forces the water up through the suction line into the pump. The atmospheric pressure is the only force available to lift water to the pump. At sea level, the force is about 14.7 pounds per square inch (psi) (about 34 feet of water). The maximum is never reached because pumps are not 100 percent efficient and because other factors (water temperature and friction or resistance to flow in the suction pipe) reduce the suction lift. Since a partial vacuum is required in the suction line, the line must be airtight if the pumps are to function properly. Threaded joints must be carefully sealed with pipe-joint compound and all connections to the pump must be tight.

a. *Pitcher Pump.* This is a surface-mounted, reciprocating or single-acting piston pump (Figure 4-1). The pump has a hand-operated plunger that works in a cylinder designed to be set on top of the well casing. The suction pipe screws into the bottom of the cylinder. The plunger has a simple ball valve that opens on the downstroke and closes on the upstroke. Usually, a check valve at the lower end of the cylinder opens on the upstroke of the pump and closes on the downstroke. Continuous upstroke and downstroke actions result in a pulsating flow of water out of the discharge pipe. By lifting the pump handle as high as possible, the check valve (lower end of the cylinder) will tilt when the plunger is forced down on top of the valve. Tilting the check valve allows the pump and suction line to drain.

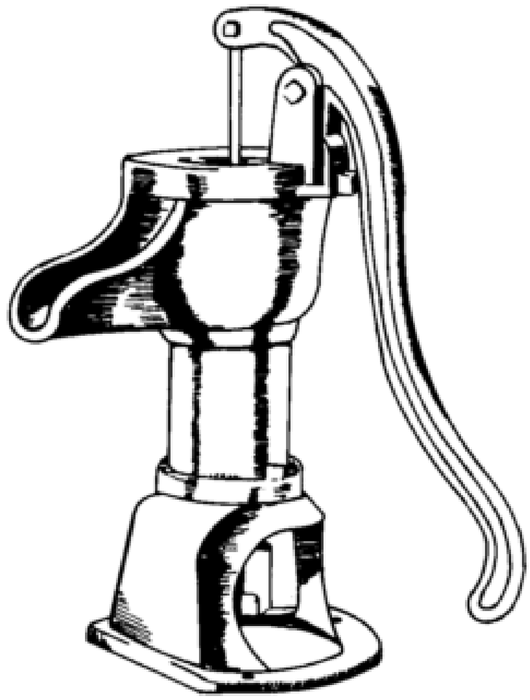

Figure 4-1. Pitcher pump

To reprime the pump after draining, pour water in the cylinder from the top of the pump. To maintain the pitcher pump, renew the plunger, check the valve leathers, and clean the suction pipe. Clean the suction pipe when it becomes clogged with sand, gravel, or other material. The pump will be noisy and the pump handle may fly up when released during the downstroke.

b. *Rotary Pump.* These pumps use a system of rotating gears (Figure 4-2) to create a suction at the inlet and force a water stream out of the discharge. The gears' teeth move away from each other at the inlet port. This action causes a partial vacuum and the water in the suction pipe rises. In the pump, the water is carried between the gear teeth and around both sides of the pump case. At the outlet, the teeth moving together and meshing causes a positive pressure that forces the water into the discharge line.

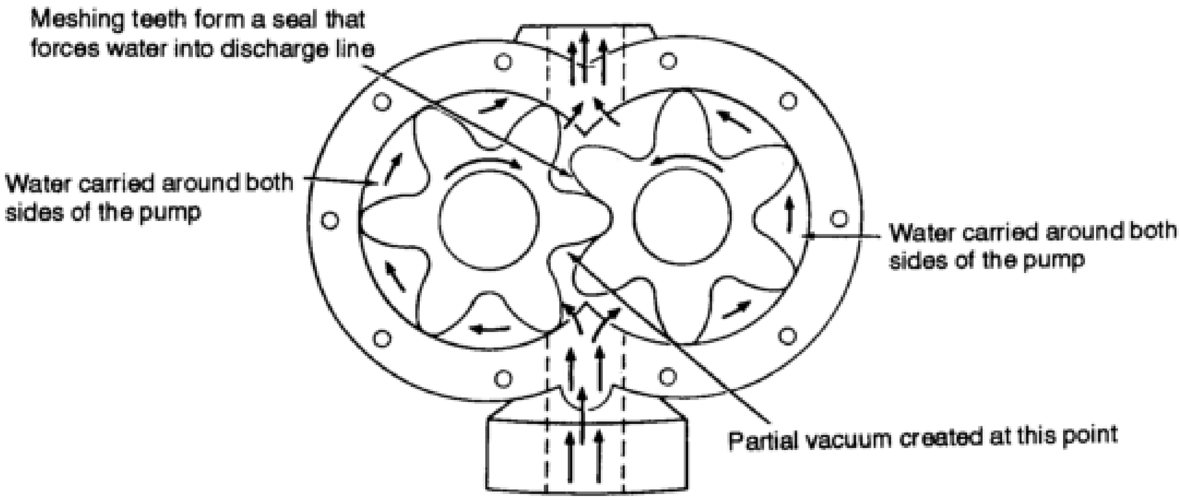

Figure 4-2. Rotary pump

In a rotary gear pump, water flows continuously and steadily with very small pulsations. The pump size and shaft rotation speed determine how much water is pumped per hour. Gear pumps are generally intended for low-speed operation. The flowing water lubricates all internal parts. Therefore, the pumps should be used for pumping water that is free of sand or grit. If sand or grit does flow through the gears, the close-fitting gear teeth will wear, thus reducing pump efficiency or lifting capacity.

c. *Centrifugal Pump.* These are variable displacement pumps in which water flows by the centrifugal force transmitted to the pump in designed channels of a rotating impeller (Figure 4-3). A closed case, with a discharge opening, surrounds the impeller. The case has a spiral-shaped channel for the water. The channel gradually widens towards the outlet opening. As water flows through the channel, speed decreases and pressure increases. The hydraulic characteristics of the pump depend on the dimensions and shape of the water passages of the impeller and the case.

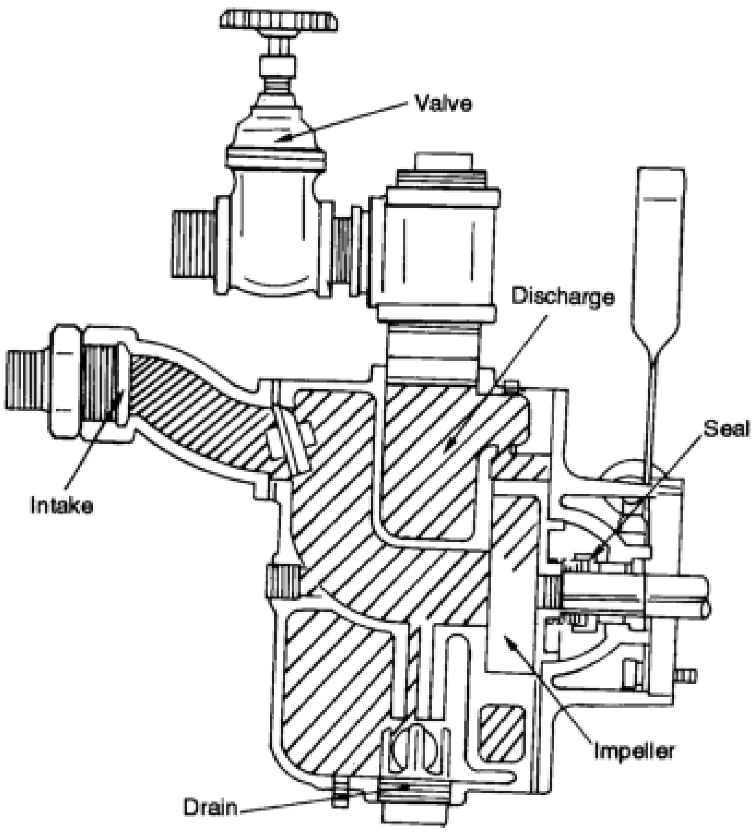

Figure 4-3. Centrifugal pump

The centrifugal pump works as follows:

- Water enters the pump at the center of the impeller and is forced out by centrifugal force. (You may have to fill the pump and suction pipe with water before starting the pump.)
- The expelled water forces the water in the casing out through the discharge pipe, producing a partial vacuum in the center.
- Atmospheric pressure acts on the surface of the water in the well and forces more water up the suction pipe and into the impeller to replace the expelled water.

(1) Head. Head is the pressure against which a pump must work the suction-lift and friction losses and the system pressure that the pump must develop. If the head is increased and the speed is unchanged, the flow rate will decrease. To increase the flow rate, you must increase the speed or decrease the head. If you increase the head beyond the pump's (shutoff head) capacity, water will not be pumped. The impeller only churns the water inside the case; the energy expended heats the water and the pump. If such action continues, enough heat may develop to boil the water and generate steam causing the impeller to rotate in vapor rather than water. With no coolant, the bearings seize, resulting in severe pump and possible motor damage.

(2) Connections. You may have to use several pumps to meet head or flow requirements. You can connect the pumps either in series or in parallel. If you connect two centrifugal pumps in series (the discharge of the first connected to the suction of the second), the discharge capacity stays the same. However, the head capacity is the sum of both pumps head capacities. The increased head capacity is only available as discharge head. You will not gain any appreciable increase in suction lift. You can obtain the same effect by using a multistage pump that contains two or more impellers within one

casing.

If you connect two centrifugal pumps in parallel (both suctions are connected to the intake line and both discharges connected to the discharge line), the discharge head is the same as that of the individual pumps. The discharge capacity is close to the sum of the capacities of both pumps. The increased flow rates result in extra friction losses that prevent the combined flows from being the exact sum of the two pumps.

d. *Self-Priming Pump.* This pump has a priming chamber that makes repriming unnecessary when the pump is stopped for any reason other than an intentional draining. The pump is mounted on a frame with and driven by a two-cylinder, three-horsepower military standard engine (Figure 4-4). The unit is close-coupled. The impeller is secured to an adapter shaft that is fastened and keyed to the engine stub shaft. A self-adjusting mechanical seal prevents water from leaking between the pump and the engine. The pump is designed for optimum performance with a suction lift of 10 feet. You can operate the pump at greater suction lifts, but the capacity and efficiency of the unit are reduced proportionately.

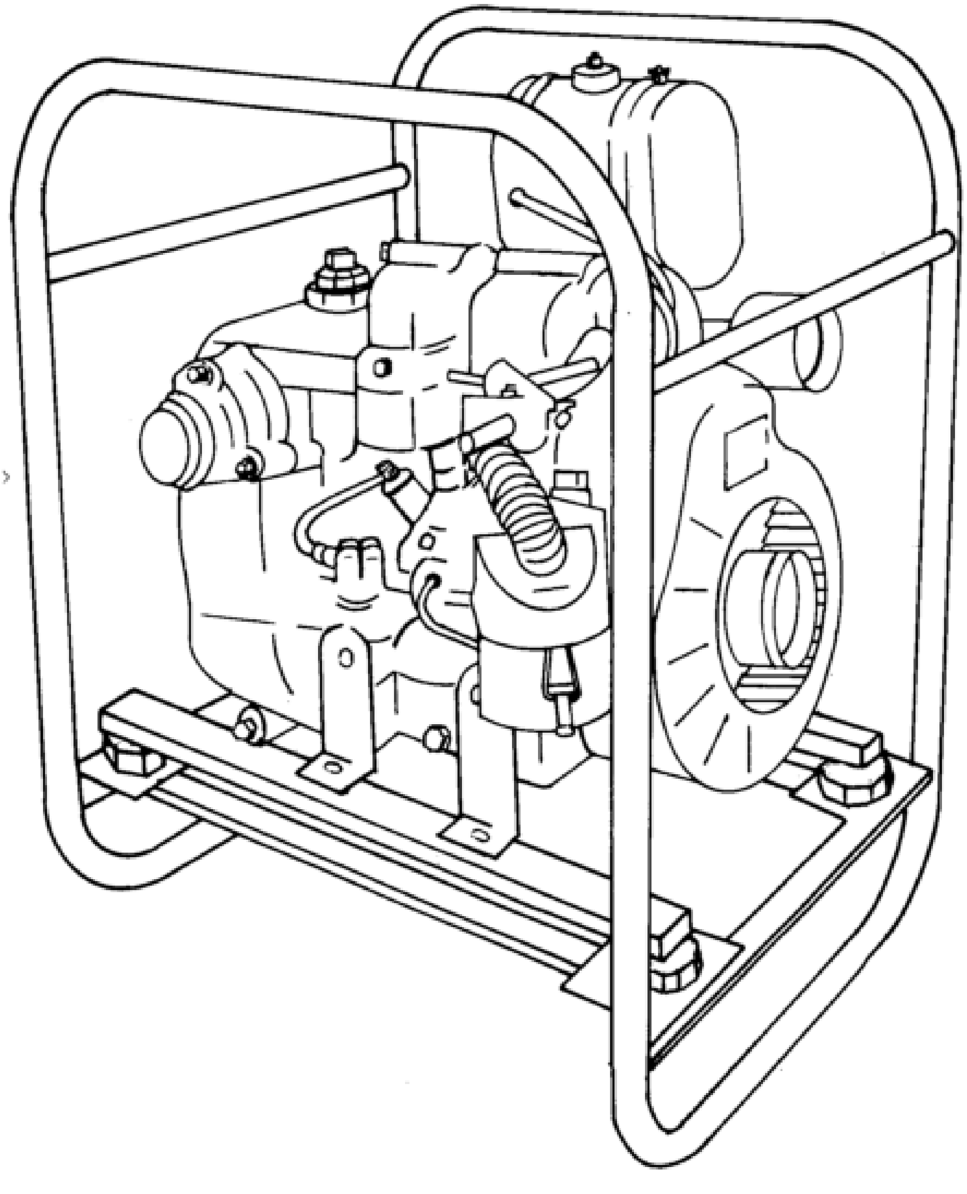

Figure 4-4. Self-priming pump

(1) Installation. Install the pump as close to the source of water supply as possible to minimize the required suction lift. Install full-sized suction piping and keep friction losses as low as possible by using the least possible number of pipe fittings (elbows, bents, unions). To ensure that joints do not leak use pipe cement or teflon tape on all joints. If you use a suction hose, try to ensure that the hose is as airtight as possible. If you have to remove the suction or discharge piping or hose frequently, you should make the connections with unions to reduce wear on the pump housing.

(2) Priming. To prime the pump, remove the priming plug on top of the pumping case, and pour water into the pump case to the discharge-opening level. Failure to fill the priming chamber may prevent priming. If the pump takes longer than 5 minutes to prime, a mechanical problem exists. A self-priming pump is normally primed from a 10-foot suction lift in 2 minutes or less, depending on the length and size of the suction pipe. If you use a valve in the discharge line, you must open it wide during priming.

If the pump fails to prime, look for the following:

- Plugged priming hole.
- Air leak in suction pipe or hose.
- Collapse of lining suction hose.
- Plugged end of suction pipe or suction strainer.
- Lack of water in pump housing.
- Clogged, worn-out, or broken impeller.
- Worn or damaged seal.

4-3. Deep-Well Pumps.

a. *Submersible Pump.* This is a centrifugal pump closely coupled with an electric motor that can operate underwater. The pump is typically multistage containing two or more impellers (depending on head requirements) housed in a bowl assembly. Because the system is designed for underwater operations, it has a waterproof electric motor, watertight seals, electric cables and connections. The motor is located beneath the bowl assembly with the water intake screen between the two units.

Military well-completion kits contain the submersible pump (Figure 4-5). The pump produces 50 GPM at 600 feet and is powered by a 15-horsepower, 460-volt, 3-phase electric motor. The pump comes with 700 feet of electrical conductor cable and 660 feet of 2-inch drop hose that supports the pump and brings the water to the surface distribution system. Currently, the submersible pump is the standard in deep-well, high-production systems.

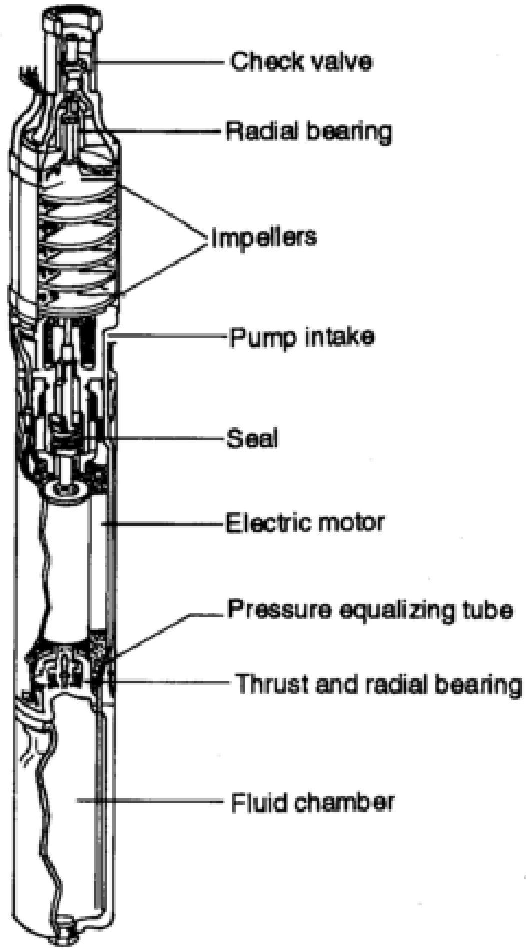

Figure 4-5. Submersible pump

DANGER

Do not handle live electrical wires when wet or while standing in water. Do not step on exposed electrical cables.

The following improvements have made the submersible pump a reliable pump:

- Motors, cables, and seals have very low maintenance requirements.
- Noise levels are reduced because the motor is located in the well.
- Motor operates at a cooler temperature because it is submerged.
- System does not require long drive shafts and bearings, so maintenance problems and deviations in vertical well alignment are not critical factor when using this pump.

The main disadvantage with the pump is that the entire pump and motor assemblies must be removed from the well if repairs or services are required.

b. *Turbine Pump.* The turbine (line shaft) pump is a shaft-driven, centrifugal pump. The pump is hung in a well at the lower end of a string of pipe called the column pipe. The shaft, which drives the pump, runs through the column pipe and extends from the pump to the ground surface where it is connected to a pump-head assembly. Bearings in the column pipe are used to stabilize the shaft.

The turbine pump (Figure 4-6) is a multistage pump containing several impellers or bowl assemblies. The main advantage to the turbine pump is the accessibility to the power source. The power source is either a hollow-shaft electric motor or a reciprocating engine connected by a right-angle drive and is located above ground. The main disadvantages are maintenance requirements for the shaft and bearings and the requirement that the well be vertical with no deviations for installation.

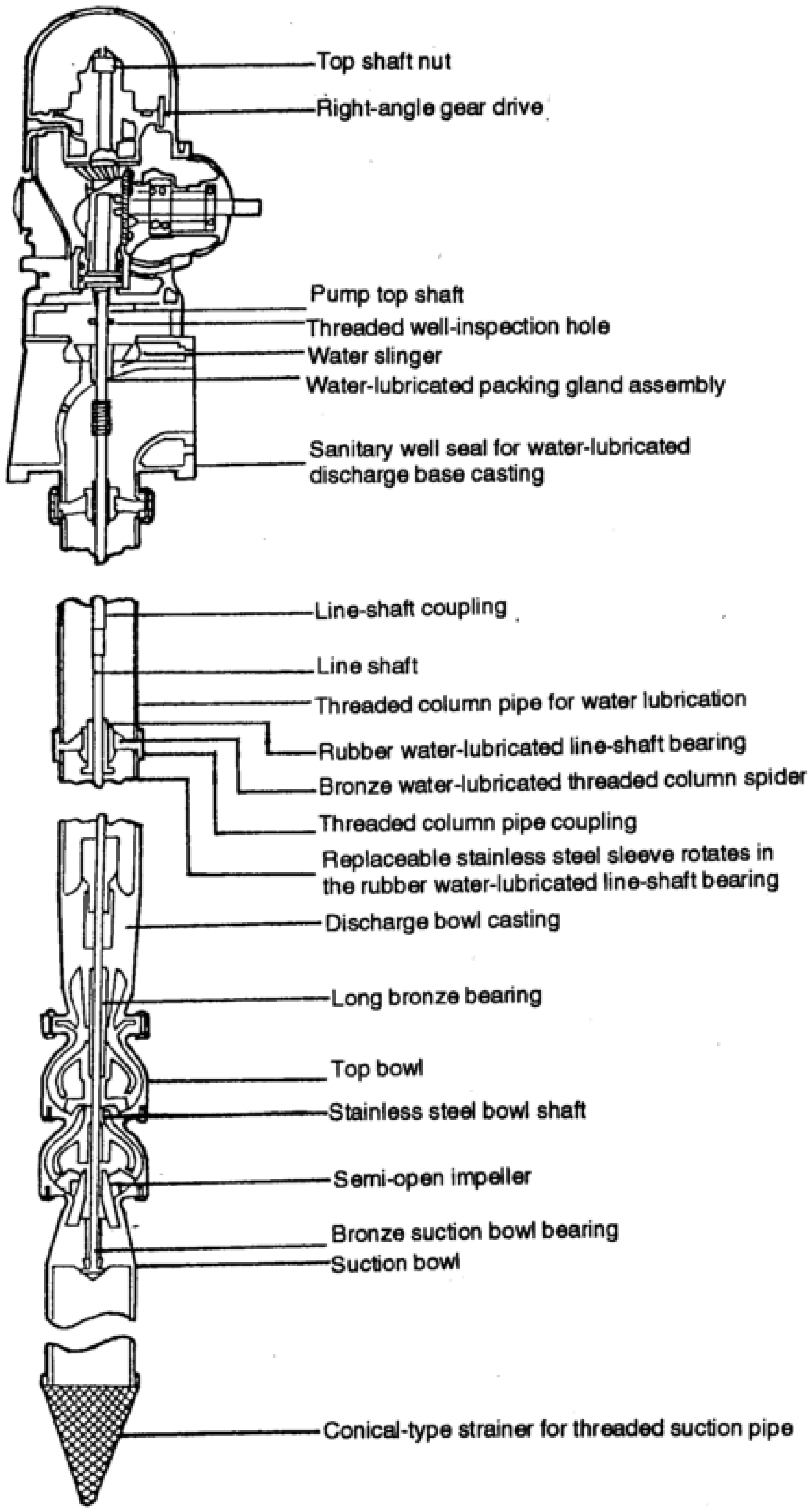

Figure 4-6. Turbine pump

c. *Helical-Rotor Pump.* This pump is a positive-displacement-, rotary-screw-, or progressing-cavity-type pump (Figure 4-7). The pump is designed for relatively low-capacity, high-lift wells that are 4 inches or larger in diameter. The main elements of the pump are a highly polished, stainless-steel helical rotor, a single-thread worm; and an outer rubber stator. The rotor is located in the stator. During the rotation process, the rotor forces a continuous stream of water forward along the cavities in the stator producing a uniform flow. The helical-rotor pump is designed to produce 50 GPM at 1,800 revolutions per minute (RPM) against a 250-foot head.

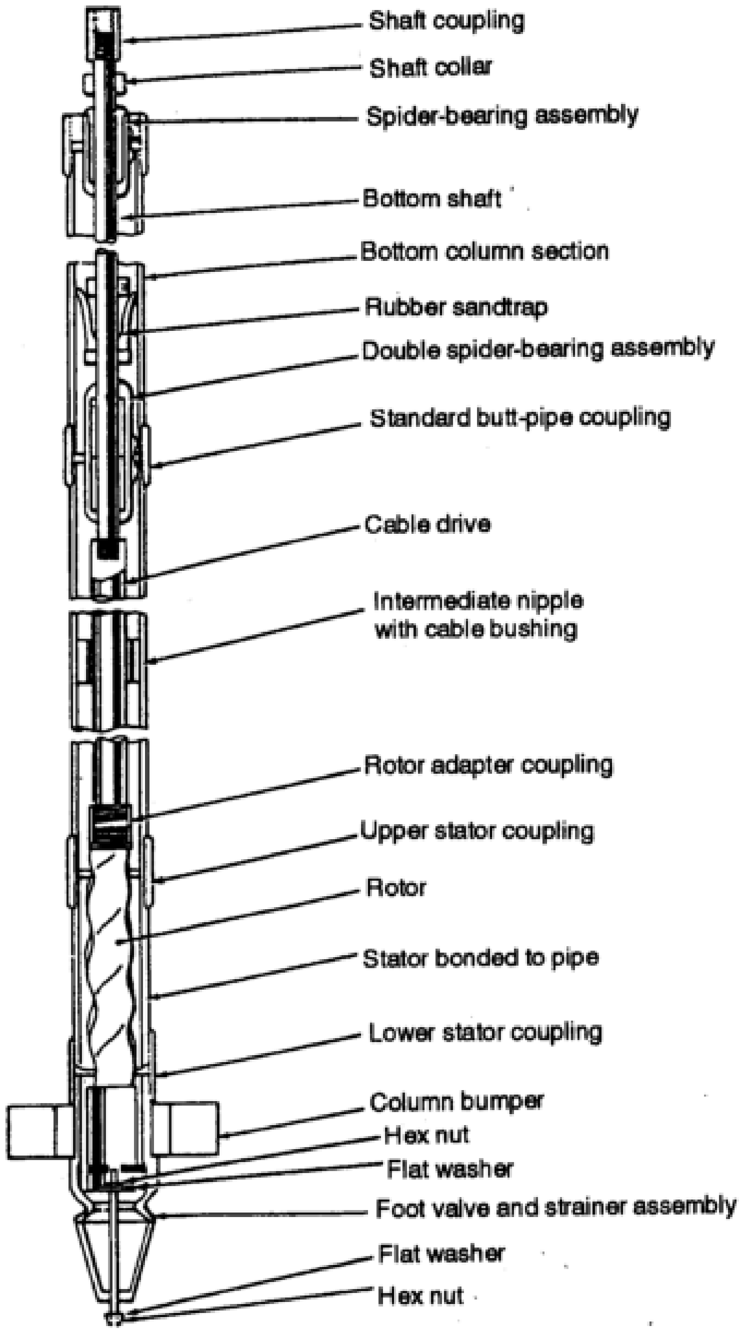

Figure 4-7. Helical-rotor pump

d. *Jet Pump.* This pump is a combination of a surface centrifugal pump, down-hole nozzle, and venturi arrangement (Figure 4-8). It can be used in small diameter wells that require a lift of 100 feet or less. The pump supplies water, under pressure, to the nozzle. The increase in velocity at the nozzle results in a decrease in pressure at that point, which in turn draws water through the foot valve into the intake pipe. The combined flow then enters the venturi where the velocity is gradually decreased and the pressure head recovered. The excess flow is discharged at the surface through a control valve, which also maintains the required recirculating flow to the nozzle.

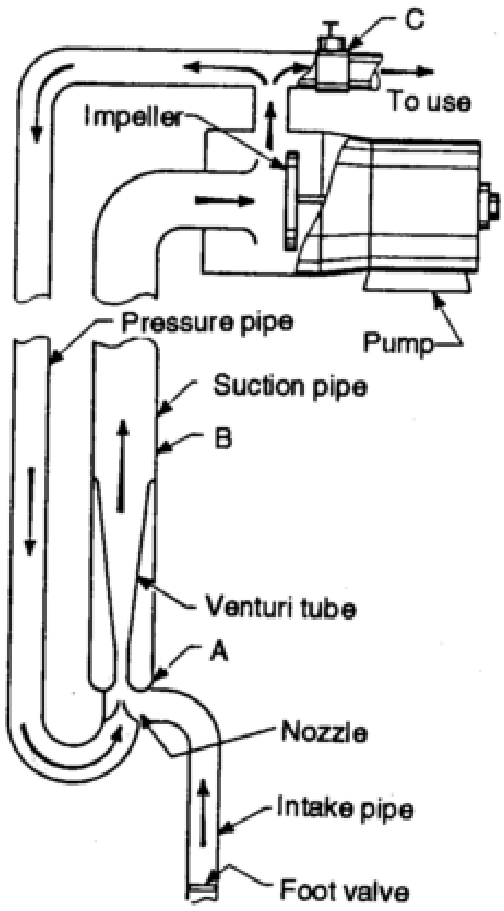

Figure 4-8. Jet pump

A jet pump's efficiency is low compared to an ordinary centrifugal pump. However, other features make the jet pump a desirable pump. They are--

- Adaptability to wells as small as 2 inches in diameter.
- Easy accessibility to all moving parts at the ground surface.
- Simple design resulting in relatively low purchase and maintenance costs.

4-4. Air-Lift Pumps.

a. *Principle.* Water can be readily pumped from a well using an air-lift pump. There are no air-lift pumps in the Army supply system; however, in the field, you can improvise and make a pump using compressed air and the proper piping arrangement. The assembly consists of a vertical discharge (eductor) pipe and a smaller air pipe. Both pipes are submerged in the well below the pumping level for about two-thirds of the pump's length. The compressed air goes through the air pipe to within a few feet of the bottom of the eductor pipe and is then released inside the eductor pipe. A mixture of air bubbles and water forms inside the eductor pipe. This mixture flows up and out the top of the eductor pipe. The pumping action that causes water to rise as long as compressed air is supplied is the difference in hydrostatic pressure inside and outside the pipe resulting from the lowered specific gravity of the mixed column of water and air bubbles. The energy operating the air lift is contained in the compressed air and released in the form of bubbles in the water. Figure 4-9 shows the operating air-lift principle.

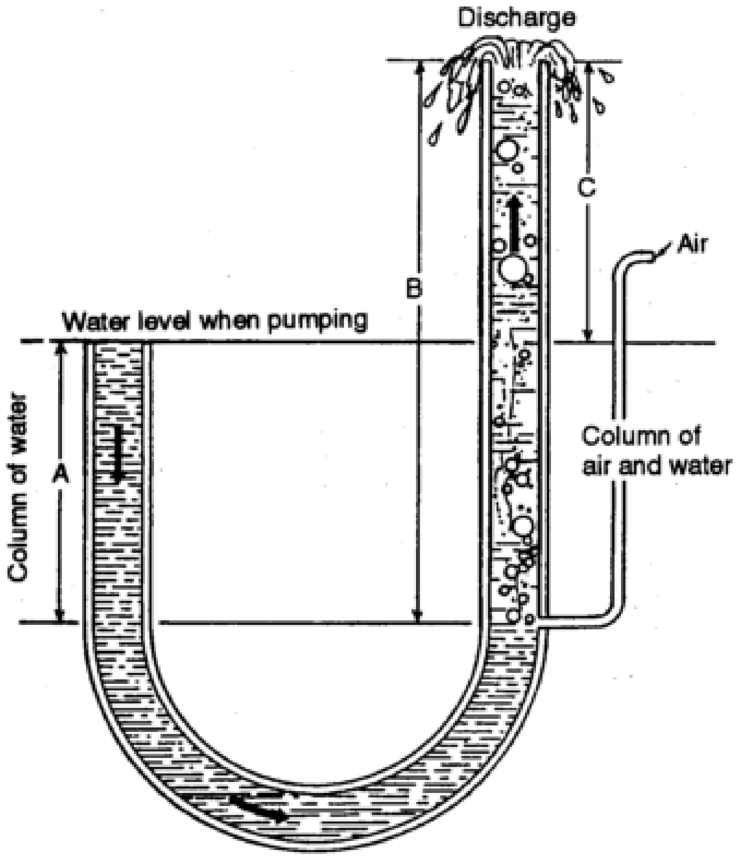

Figure 4-9. Air-lift principle

> **WARNING**
>
> **Air and fluids under pressure can cause injury. Make sure all air couplings are tight and that lines and hoses are in good condition.**

You should arrange an air lift with the air pipe inside the eductor pipe (Figure 4-10). You can use this arrangement for test pumping wells and for well development. You can use the well casing for the eductor pipe. However, to pump sand and mud from the bottom of a well during well development and completion, use a separate eductor pipe. This type of pump is also useful in wells that, because of faulty design, produce sand with the water. This condition will quickly create excessive wear on most pumps. By setting the educator pipe to the bottom of the screen, sand will be removed before it fills the screen.

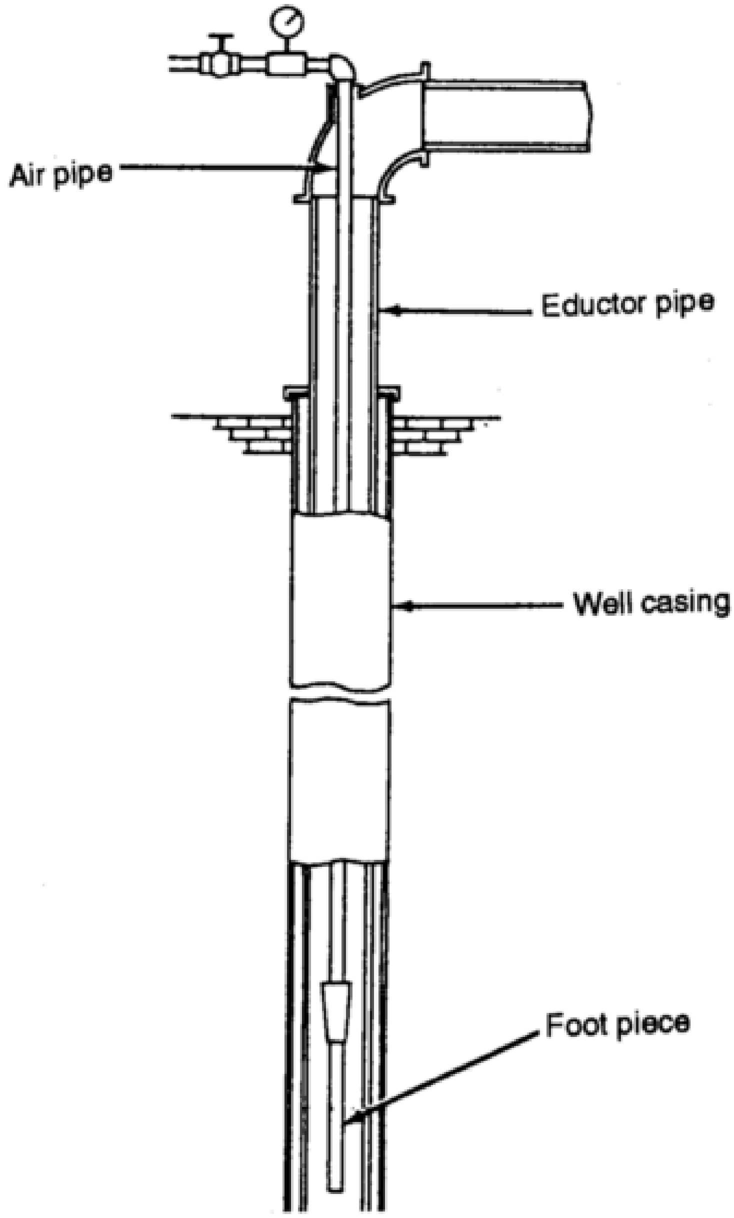

Figure 4-10. Air pipe in an eductor pipe

b. *Installation Design.*

(1) Submergence. Submergence is the proportion (percentage) of the length of the air pipe that is submerged below the pumping level. Use the following formula and Figure 4-11 to determine submergence percentage:

$$\% submergence = \frac{x}{y} \; x \; 100$$

where—

x = *vertical distance from A to C.*
y = *vertical distance from C to D.*

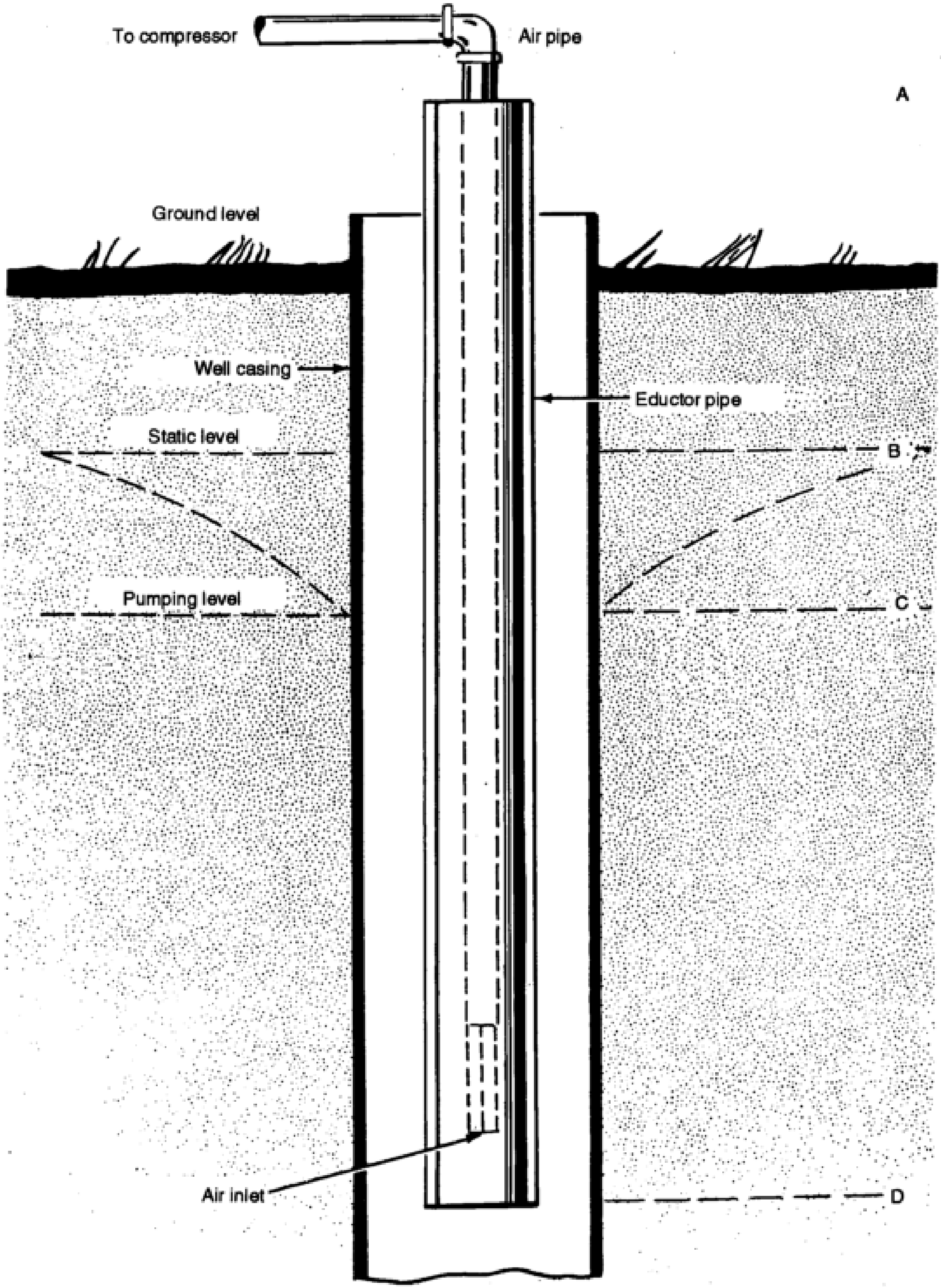

Figure 4-11. Submergence percentage

(2) Air Pressure. To calculate the required air pressure to start the air lift, you must know the length of air pipe submerged below the static level. See Figure 4-11, area from point B to point D, for the starting air pressure. Divide the area from point C to D by 2.31 (constant/conversion factor) to get the required air pressure (psi).

(3) Compressors. The 350 cubic feet per minute (cfm) compressor on military drilling rigs, such as the LP-12, is sufficient for operating an air lift. With a submergence of 60 percent, a lift not exceeding 50 feet and the compressor delivering 350 cfm

of air, a well can be pumped at over 200 GPM. If you need more air, use another compressor in parallel. The maximum pressure that the compressor will produce is 200 psi, which is enough to start an airlift with about 420 feet of air pipe submerged.

CAUTION

Operate compressors upwind of the drilling rig. If you do not, dust could damage the equipment.

(4) Correct Air Amounts. For efficiency, the compressor must deliver the correct amount of air. Too much air causes excessive friction in the pipe lines and waste of air from incomplete expansion in the discharge pipe. Too little air results in a reduced yield and a surging, intermittent discharge. To calculate air-compressor requirements, see Table 4-2.

Table 4-2. Pump readings

Total Depth (feet)	Submergence (percent)
Up to 50	66 to 70
50 to 100	55 to 66
100 to 200	50 to 55
200 to 300	43 to 50
300 to 400	40 to 43
400 to 500	33 to 40

(5) Performance and Efficiency. The performance and efficiency of an air lift vary greatly with the percent of submergence and the amount of lift. Generally, a submergence of 60 percent or more is desirable. If a well has a considerable pumping-level depth, you will have to use a lesser submergence percent. However, if the submergence is too low, the air lift will not operate. See Table 4-3 for performance data for air-lift pumps corresponding to different submergence conditions and lifts. The values are for properly proportioned air and eductor pipes with minimum frictional losses. The efficiencies indicated in terms of gallons of water per cubic foot of air probably cannot be fully attained in military field operations.

Table 4-3. Submergence for air-lift pumping

Lift (feet)	Submergence (percent)	Lift (percent)	Rating	Submergence (feet)	Starting Air Pressure (psi)	Gallons of Water (per cubic foot of air)	Cubic Feet of Air (per gallon of water)	Total Length of Air Line (feet)
25	54	46	Minimum	29	13	4.55	0.22	54
	68	32	Best	53	23	8.34	0.12	78
	76	24	Maximum	79	34	14.30	0.07	104
50	51	49	Minimum	52	23	2.50	0.40	102
	65	35	Best	93	40	4.35	0.23	143
	72	28	Maximum	129	56	6.57	0.15	179
100	47	53	Minimum	89	38	1.43	0.70	189
	60	40	Best	150	65	2.70	0.37	250
	67	33	Maximum	203	88	3.70	0.27	303
150	43	57	Minimum	113	49	1.05	0.95	263
	55	45	Best	183	79	2.04	0.49	333
	62	38	Maximum	245	106	2.70	0.37	395
200	41	59	Minimum	139	60	0.85	1.18	339
	52	48	Best	216	94	1.54	0.65	416
	59	41	Maximum	288	125	1.89	0.53	488
250	39	61	Minimum	160	69	0.71	1.41	410
	49	51	Best	240	104	1.21	0.83	490
	56	44	Maximum	318	138	1.45	0.69	568
300	37	63	Minimum	176	76	0.60	1.67	476
	47	53	Best	266	115	0.96	1.04	566
	53	47	Maximum	339	147	1.18	0.85	639
350	36	64	Minimum	197	85	0.53	1.88	547
	46	55	Best	287	124	0.80	1.25	637
	50	50	Maximum	350	151	0.94	1.06	700
400	35	65	Minimum	215	93	0.48	2.07	615
	43	57	Best	302	130	0.69	1.45	702
	48	52	Maximum	369	160	0.79	1.26	769
450	34	66	Minimum	232	100	0.44	2.27	682
	42	58	Best	326	141	0.61	1.65	776
	47	53	Maximum	399	173	0.68	1.48	849
500	34	66	Minimum	258	112	0.41	2.46	758
	41	59	Best	348	150	0.54	1.85	848
	46	54	Maximum	426	184	0.60	1.66	926
550	34	66	Minimum	283	123	0.38	2.65	833
	40	60	Best	367	159	0.49	2.05	917
	45	55	Maximum	450	195	0.54	1.86	1,000
600	33	67	Minimum	296	128	0.36	2.81	896
	40	60	Best	400	173	0.45	2.25	1,000
	44	56	Maximum	471	204	0.49	2.06	1,071
650	33	67	Minimum	320	139	0.34	2.94	962
	39	61	Best	416	180	0.42	2.40	1,066
	43	57	Maximum	490	212	0.44	2.26	1,140
700	33	67	Minimum	345	149	0.33	3.00	1,045
	39	61	Best	448	194	0.39	2.55	1,148
	43	57	Maximum	528	228	0.42	2.40	1,228

(6) Foot Piece. For best efficiency, the end of the air pipe should have a foot piece (Figure 4-10). This device breaks the air into small streams so that the bubbles formed will be as small as possible. You can make a foot piece by drilling numerous small holes in a short section of pipe.

(7) Discharge Pipe. You can approximate the discharge-pipe length from Table 4-3. Lower submergence than those shown result in a lower pumping efficiency. The planned pumping rate must not cause an excessive drop in the water level, reducing the submergence. The two chief losses in the discharge pipe are air slipping through the water and the water friction in the discharge line. As the velocity of discharge increases, slippage decreases and friction increases. Eductor intake loss occurs at the lower end of the pipe due to friction and to the energy required to accelerate the flow of water into the pipe.