SECTION 2.4

CENTRIFUGAL PUMP PRIMING

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A centrifugal pump is primed when the passageways of the pump are filled with the liquid to be pumped. The liquid replaces the air, gas, or vapor in the passageways. This may be done manually or automatically.

When a pump is first put into service, its passageways are filled with air. If the suction supply is above atmospheric pressure, this air will be trapped in the pump and compressed somewhat when the suction valve is opened. Priming is accomplished by venting the entrapped air out of the pump through a valve provided for this purpose.

Unlike a positive displacement pump, a centrifugal pump that takes its suction from a supply located below the pump, which is under atmospheric pressure, cannot start and prime itself (unless designed to be self-priming, as described later in this section). At its rated capacity, a positive displacement pump will develop the necessary pressure to exhaust air from its chambers and from the suction piping. Centrifugal pumps can also pump air at their rated capacity, but only at a pressure equivalent to the rated head of the pump. Because the specific weight of air is approximately $\frac{1}{800}$ that of water, a centrifugal pump can produce only $\frac{1}{800}$ of its rated liquid pressure. For every 1 ft (1 m) water has to be raised to prime a pump, the pump must produce a discharge head of air of approximately 800 ft (m). It is therefore apparent that the head required for a conventional centrifugal pump to be self-priming and to lift a large column of liquid (and in some cases to discharge against an additional static liquid head) when pumping air is considerably greater than the rating of the pump. Centrifugal pumps that operate with a suction lift can be primed by providing (1) a foot valve in the suction line, (2) a single-chamber priming tank in the suction line or a two-chamber priming tank in the suction and discharge lines, (3) a priming inductor at the inlet of the suction line, or (4) some form of vacuum-producing device.

FOOT VALVES

A foot valve is a form of check valve installed at the bottom, or foot, of a suction line. When the pump stops and the ports of the foot valve close, the liquid cannot drain back to the suction well if the valve seats tightly. Foot valves were very commonly used in early installations of centrifugal pumps. Except for certain applications, their use is now much less common.

A foot valve does not always seat tightly, and the pump occasionally loses its prime. However, the rate of leakage is generally small, and it is possible to restore the pump to service by filling and starting it promptly. This tendency to malfunction is increased if the liquid contains small particles of foreign matter, such as sand, and foot valves should not be used for such service. Another disadvantage of foot valves is their unusually high frictional loss.

The pump can be filled through a funnel attached to the priming connection or from an overhead tank or any other source of liquid. If a check valve is used on the pump and the discharge line remains full of liquid, a small bypass around the valve permits the liquid in the discharge line to be used for repriming the pump when the foot valve has leaked. Provision must be made for filling all the passageways and for venting out the air.

PRIMING CHAMBERS

The Single-Chamber Tank A single-chamber primer is a tank with a bottom outlet that is level with the pump suction nozzle and directly connected to it. An inlet at the top of the tank connects with the suction line (Figure 1). The size of the tank must be such that the volume contained between the top of the outlet and the bottom of the inlet is approximately three times the volume of the suction pipe. When the pump is shut down, the liquid in the suction line may leak out, but the liquid in the tank below the suction inlet cannot run back to the supply. When the pump is started, it will pump this entrapped liquid out of the priming chamber, creating a vacuum in the tank. The atmospheric pressure on the supply will force the liquid up the suction line into the priming chamber.

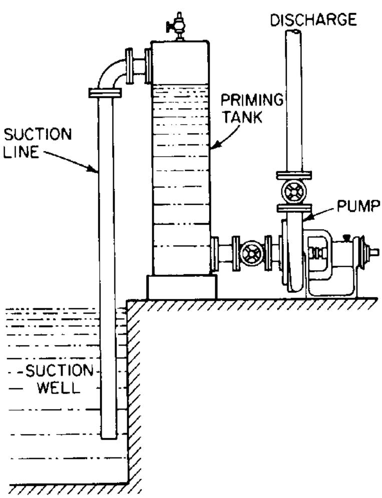


FIGURE 1 Single-chamber priming tank

Each time the pump is stopped and restarted, a quantity of liquid in the priming tank must be removed to create the required vacuum. Because of possible back siphoning, the liquid volume in the tank is reduced. Unless the priming tank is refilled, it has limited use. Automatic refilling of the priming tank cannot occur if the pump has a discharge check valve unless there is sufficient backflow from the discharge system before the check valve seats.

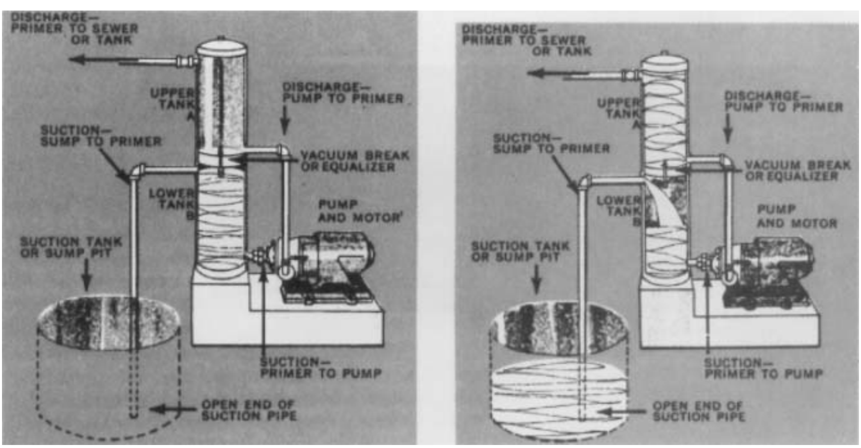
Because of their size, the use of single-chamber priming tanks is restricted to installations of relatively small pumps, usually to a 12-in (305-mm) suction line (approximately 2000 gpm [450 m^3/h]).

The Two-Chamber Tank This type of priming tank is an improvement over the single-chamber design. It consists of integral suction and discharge chambers connected by a vacuum breaker or equalizing line. The operation and automatic refilling feature of this device are shown in Figure 2. Commercial priming chambers are readily available with proper automatic vents and other features.

PRIMING INDUCTORS

If a separate source of liquid of sufficient capacity and pressure is available, it can be used to fill the suction line of the pump to be primed through the use of an inductor, as shown in Figure 3. For water, the pressure must be equal to about 4 lb/in^2 for each foot (90 kPa for each meter) of head necessary to prime the pump, measured from the lowest liquid level in the sump from which priming must be accomplished to the top of the pump. The amount of liquid necessary depends on the pressure.

Because the inductor is a positive-pressure device, leaks in the suction line or at the pump seal or stuffing box are not critical. The service liquid can be left on or turned off



Phantom View of Primer in Use with Pump Stopped (*left*)
When the pump stops, the liquid in the upper chamber runs back into the pump and lower chamber of primer by gravity, thus refilling them with liquid and keeping the pump always ready for starting.

Phantom View of Primer in Use with Pump Running (*right*)
When the pump starts, it draws liquid from the lower chamber and discharges it through the upper chamber. Withdrawal of liquid from the lower chamber creates a partial vacuum in this chamber, which causes the liquid in the sump or well to rise in the suction pipe and flow through the primer to the pump.

FIGURE 2 Two-chamber priming tank (Apco/Valve and Primer)

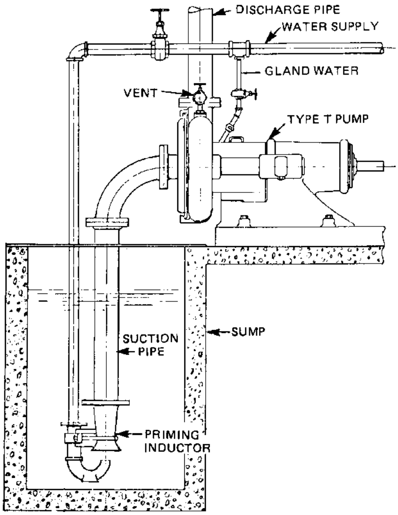


FIGURE 3 Priming inductor (Nagle Pumps)

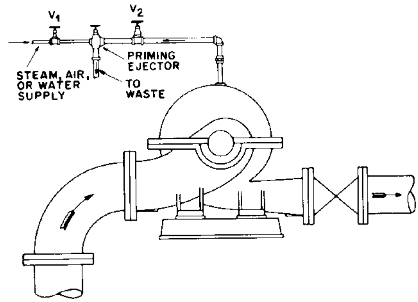


FIGURE 4 Arrangement of priming with an ejector

after pumping is initiated. If left on, the head developed by the pump (therefore the flow also) will be increased.

An additional feature of the priming inductor is that operation is possible even when the suction line is covered with sediment. When the pump and suction line are filled, backflow results, mixing the solids and the liquid.

TYPES OF VACUUM DEVICES

Almost every commercially made vacuum-producing device can be used with systems in which pumps are primed by evacuation of air. Formerly water-jet, steam-jet, or air-jet primers had wide application, but with the increase in the use of electricity as a power source, motor-driven vacuum pumps have become more popular.

Ejectors Priming ejectors work on the jet principle, typically using steam, compressed air, or water as the operating medium. A typical installation for priming with an ejector is shown in Figure 4. Valve V_1 is opened to start the ejector, and then valve V_2 is opened. When all the air has been exhausted from the pump, liquid will be drawn into and discharged from the ejector. When this occurs, the pump is primed and valves V_2, and V_1 are closed, in that order.

An ejector can be used to prime a number of pumps if it is connected to a header through which the individual pumps are vented through isolating valves.

Dry Vacuum Pumps Dry vacuum pumps, which may be of either the reciprocating or the rotary oil-seal type, cannot accommodate mixtures of air and liquid. When they are used in priming systems, some protective device must be interposed between the centrifugal pump and the dry vacuum pump to prevent liquid from entering the vacuum pump. The dry vacuum pump is used extensively for central priming systems.

Wet Vacuum Pumps Any rotary, rotative, or reciprocating pump that can handle air or a mixture of air and liquid is classified as a wet vacuum pump. The most common type

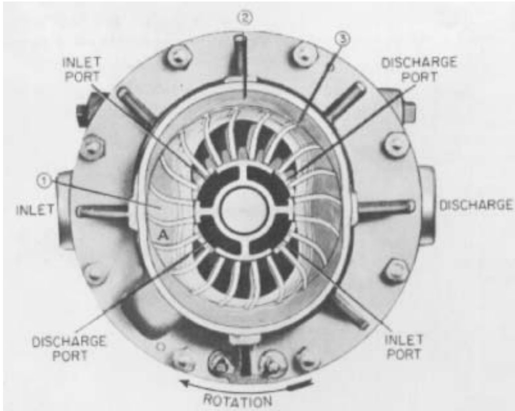


FIGURE 5 Operating principle of the Nash Hytor pump (Nash Engineering)

used in priming systems is shown in Figure 5. This is a centrifugal displacement type of pump consisting of a round, multiblade rotor revolving freely in an elliptical casing partially filled with liquid. The curved rotor blades project radially from the hub and, with the side shrouds, form a series of pockets and buckets around the periphery.

The rotor revolves at a speed high enough to throw the liquid out from the center by centrifugal force. This forms a solid ring of liquid revolving in the casing at the same speed as the rotor, but following the elliptical shape of the casing. It will be readily seen that this forces the liquid to alternately enter and recede from the buckets as the rotor at high velocity.

Referring to Figure 5 and following through a complete cycle of operation in a given chamber, we start at point *A* with the chamber (1) full of liquid. Because of the effect of the centrifugal force, the liquid follows the casing, withdraws from the rotor, and pulls air through the inlet port, which is connected to the pump inlet. At (2) the liquid has been thrown outwardly from the chamber in the rotor and has been replaced with air. As rotation continues, the converging wall of the casing at (3) forces the liquid back into the rotor chamber, compressing the air trapped in the chamber and forcing it out through the discharge port, which is connected with the pump discharge. The rotor chamber is now full of liquid and ready to repeat the cycle. This cycle takes place twice in each revolution.

If a solid stream of liquid circulates in this pump in place of air or of an air and liquid mixture, the pump will not be damaged but it will require more power. For this reason, in automatic priming systems using this type of vacuum pump, a separating chamber or trap is provided so liquid will not reach the pump. Liquid needed for sealing a wet vacuum pump can be supplied from a source under pressure, with the shutoff valve operated manually or through a solenoid connected with the motor control. It is, however, preferable to provide an independent sealing liquid supply by mounting the vacuum pump on a base containing a reservoir. This is particularly desirable in locations where freezing *may* occur, as a solution of antifreeze can be used in the reservoir.

CENTRAL PRIMING SYSTEMS

If there is more than one centrifugal pump to be primed in an installation, one priming device can be made to serve all the pumps. Such an arrangement is called a central priming system (Figure 6). If the priming device and the venting of the pumps are automatically controlled, the system is called a central automatic priming system.

Vacuum-Controlled Automatic Priming System A vacuum-controlled automatic priming system consists of a vacuum pump exhausting a tank. The pump is controlled by

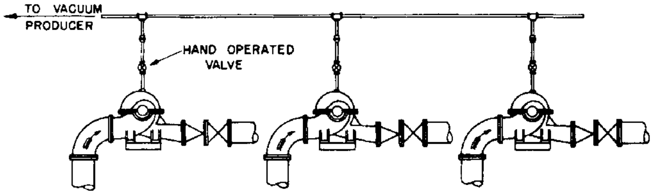


FIGURE 6 Connections for a central priming system

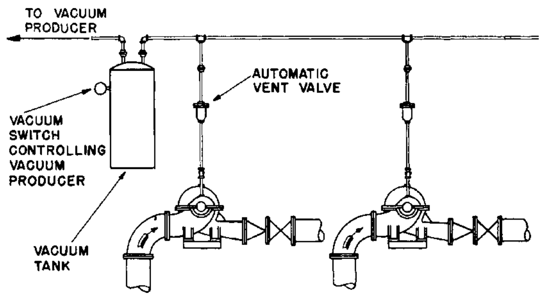


FIGURE 7 Vacuum-controlled central automatic priming

a vacuum switch and maintains a vacuum in the tank of 2 to 6 in Hg (50 to 150 mm Hg) above the amount needed to prime the pumps with the greatest suction lift. The priming connections on each pump served by the system are connected to the vacuum tank by automatic vent valves and piping (Figure 7). The vacuum tank is provided with a gage glass and a drain. If liquid is detected in the vacuum tank as the result of leakage in a vent valve, the tank can be drained. Automatic vent valves consist of a body containing a float that actuates a valve located in the upper part. The bottom of the body is connected to the space being vented. As air is vented out of the valve, water rises in the body until the float is lifted, and the valve is closed.

A typical vent valve designed basically for vacuum priming systems is illustrated in Figure 8. The valve is provided with auxiliary tapped openings on the lower part of the body for connection to any auxiliary vent points on the system—for instance, when air is to be exhausted simultaneously from the high point of the discharge volute and the high point of the suction passageways. When one or more of these vent points are points of higher pressure, such as the top of the volute of the pump, an orifice is used in the vent line to limit the flow of liquid. Otherwise, a relatively high constant flow of liquid from the discharge back to the suction would take place, causing a constant loss. Where a unit is used more or less constantly, a separate valve should be used for each venting point.

The system shown in Figure 7 is the most commonly used of central automatic priming systems. It can use either wet or dry motor-driven vacuum pumps. Most central priming systems are provided with two vacuum pumps. The usual practice is to have the control of one vacuum pump switched on at some predetermined vacuum and the control of the second switched on at a slightly lower vacuum.

Combination dry reciprocating-type vacuum pump and vacuum tank units are commercially available in various sizes. The operation of a typical unit can be explained as follows, referring to Figure 9.

The primer automatically stops and start itself to maintain a minimum vacuum in its tank at all times, regardless of whether the centrifugal pumps it serves are operating or not.

A vacuum header is run from the primer to the centrifugal pumps, and connection is made to the priming valve mounted on each pump. The vacuum in the primer tank

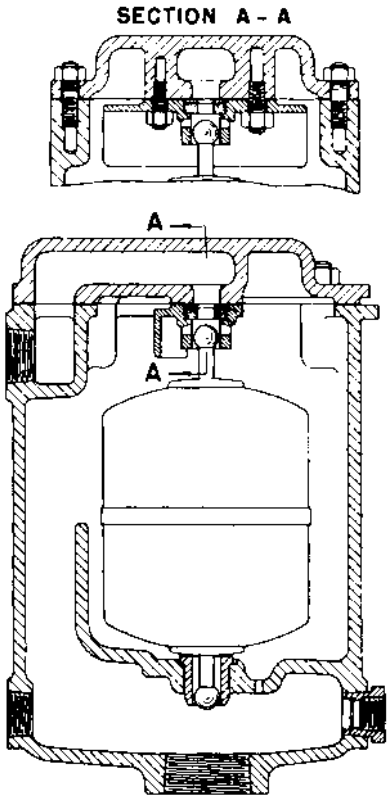


FIGURE 8 Automatic vent valve (Nash Engineering)

removes the air from the pump and suction line via the vacuum header and priming valve. Liquid rises up the suction line and fills the pump. The liquid cannot enter the vacuum header because the float mechanism in the priming valve closes when the liquid reaches it.

If, for any reason, the liquid level in the pump drops, the priming valve immediately opens and the vacuum restores the liquid level.

The pumps are thus kept permanently primed.

Automatic priming systems using ejectors are also feasible, and several such systems are commercially available.

SELF-CONTAINED UNITS

Centrifugal pumps are available with various designs of priming equipment that makes them self-contained units. Some have automatic priming devices, which are basically attachments to the pump and become inactive after the priming is accomplished. Other units, which are self-priming pumps, incorporate a hydraulic device that can function as a wet vacuum pump during the priming period (see below). For stationary use, the automatically primed type is more efficient. The self-priming designs are generally more compact and are preferred for portable or semiportable use.

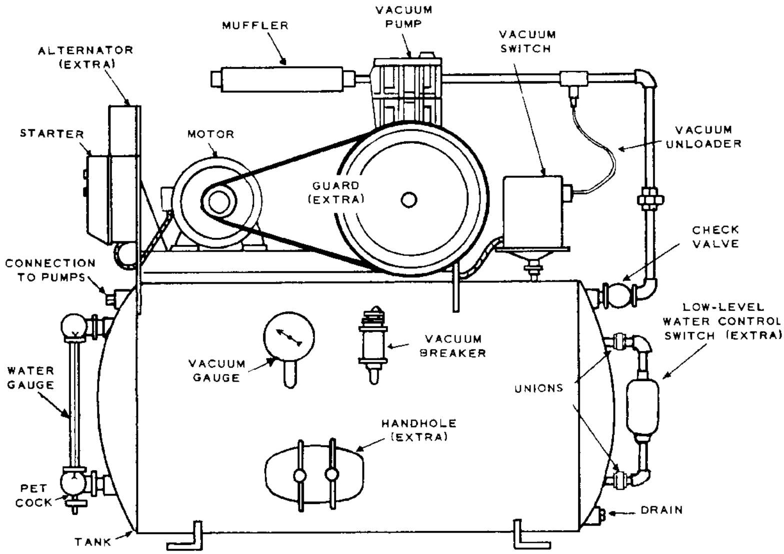


FIGURE 9 Combination dry reciprocating-type vacuum pump and vacuum tank (Apco/Valve and Primer)

An automatically primed motor-driven pump uses a wet vacuum pump either directly connected to the pump or driven by a separate motor. In a directly connected unit, as soon as the centrifugal pump is primed, a pressure-operated control opens the vacuum pump suction to atmosphere so it operates unloaded. With a separately driven vacuum pump, the controls stop the vacuum pump when the centrifugal pump is primed.

SELF-PRIMING PUMPS

The basic requirement for a self-priming centrifugal pump is that the pumped liquid must be able to entrain air in the form of bubbles so the air will be removed from the suction side of the pump. This air must be allowed to separate from the liquid after the mixture of the two has been discharged by the impeller, and the separated air must be allowed to escape or to be swept out through the pump discharge. Such a self-priming pump therefore requires, on its discharge side, an air-separator, which is a relatively large stilling chamber, or reservoir, either attached to or built into the pump casing. Alternatively, a small air bleed line can be installed from the discharge pipe between the pump and the discharge check valve back to the suction source.

There are two basic variations of the manner in which the liquid from the discharge reservoir makes the pump self-priming: (1) recirculation from the reservoir back to the suction and (2) recirculation within the discharge and the impeller itself.

Recirculation to Suction In such a pump, a recirculating port is provided in the discharge reservoir, communicating with the suction side of the impeller. Before the first time the pump is started, the reservoir is filled. As the pump is started, the impeller handles whatever liquid comes to it through the recirculating port plus a certain amount of air from the suction line. This mixture of air and liquid is discharged to the reservoir, where the two elements are separated, the air passing out of the pump discharge and the liquid returning to the suction of the impeller through the recirculation port. This operation continues until all the air has been exhausted from the suction line.

The vacuum thus produced draws the liquid from the suction supply up the suction piping and into the impeller. After all the air has been exhausted and liquid is drawn into the pump, the pressure difference between the pump body and the inlet causes the priming valve, which permits communication between discharge and suction passages, to close. It is essential that the reservoir in the suction side remain filled with liquid when the pump is stopped, so the pump is ready to restart. This is accomplished by incorporating either a valve or some sort of trap between the suction line and the impeller.

Pumps with recirculation to suction are seldom used today, and by far the most common arrangement is that with recirculation at the discharge.

Recirculation at Discharge This form of priming is distinguished from the preceding method by the fact that the priming liquid is not returned to the suction of the pump but mixes with the air either in the impeller or at its periphery. The principal advantage of this method, therefore, is that it eliminates the complexity of internal valve mechanisms.

One such self-priming pump is illustrated in Figure 10. An open impeller (A) rotates in a volute casing (B), discharging the pumped liquid through passage C into the reservoir (D). When the pump starts, the trapped liquid carries entrained air bubbles from the suction to the discharge chamber. There, the air separates from the liquid and escapes,

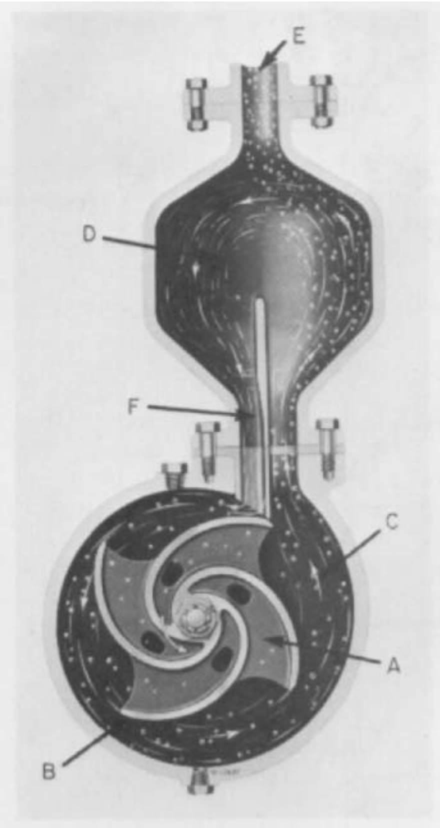


FIGURE 10 Self-priming pump with recirculation at discharge (Flowserve Corporation)

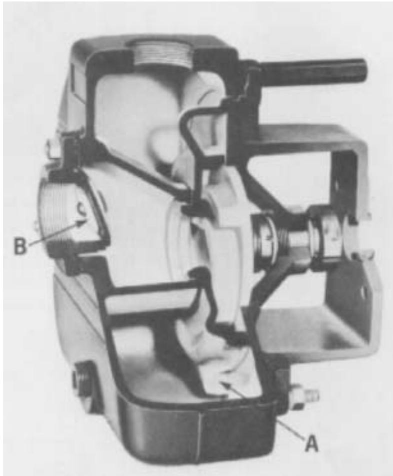


FIGURE 11 Self-priming pump with recirculation at discharge (Peabody Barnes)

whereas the liquid in the reservoir returns to the impeller through the recirculation port (F), reenters the impeller and, after mixing once more with air bubbles, is discharged through passage C. This operation is repeated continuously until all the air in the suction line has been expelled. After the pump is primed, a uniform pressure distribution is established around the impeller, preventing further recirculation. From this moment on, the liquid is discharged into the reservoir bath at C and at F.

Figure 11 illustrates another form of self-priming pump with recirculation at the discharge. In this arrangement, the return of the liquid to the impeller periphery takes place through a communicating passage (A) located at the bottom of the pump casing. After the pump is primed, liquid is delivered into the reservoir at the discharge both through its normal volute discharge and through port A. In the pump illustrated in Figure 11, a check valve at the pump suction (B) acts to prevent the draining of the pump after it has been stopped.

Regenerative Turbine Pumps Because these pumps can handle relatively large amounts of gas, they are inherently self-priming as long as sufficient liquid remains in the pump to seal the clearance between the suction and discharge passages. This condition is usually met by building a trap in the pump suction.

SPECIAL APPLICATIONS

Systems for Sewage Pumps A pump handling sewage or similar liquids containing stringy material can be equipped with automatic priming, but special precautions must be used to prevent carry-over of the liquid into the vacuum-producing device.

One approach is to use a tee on the suction line immediately adjacent to the pump suction nozzle, with a vertical riser mounted on the top outlet of the tee. This riser is blanked at the top, thus forming a small tank. The top of the tank is vented to a vacuum system through a solenoid valve. The solenoid valve in turn is controlled electrically through electrodes located at different levels in the tank. The solenoid valve closes if the liquid reaches the top electrode and opens if the liquid level falls below the level of the lower electrode.

Another solution permits the use of an automatic priming system with a separate motor-driven vacuum pump controlled by a discharge-pressure-actuated pressure switch. An inverted vertical loop is incorporated in the vacuum pump suction line to the pump

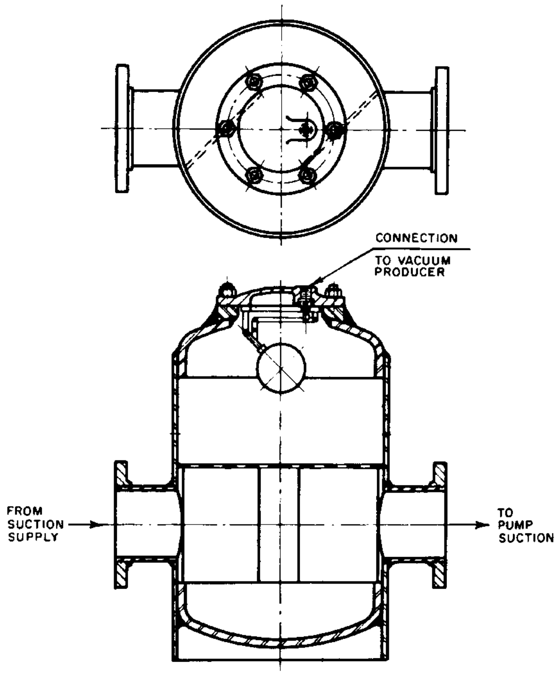


FIGURE 12 Air-separating chamber

being primed. This prevents the sewage from being carried over into the vacuum pump because this pump shuts down before the liquid reaches the top of the loop.

Systems for Air-Charged Liquids Some types of liquid have considerable dissolved gas that is liberated when the pump handles a suction lift. In such installations, an air-separating tank (also called a *priming tank* or an air *eliminator)* should be used in the suction line. One type (Figure 12) uses a float-operated vent valve to permit the withdrawal of air or other gas. Another common arrangement uses a float valve mounted on the side of the tank to directly control the starting and stopping of the vacuum pump. Unless the air-separating tank is relatively large and the vacuum pump is not oversized, there is danger of frequent starting and stopping of the vacuum pump in such a system. When sand is present as an impurity in the liquid, the air-separating tank can be made to also function as a sand trap.

Systems for Units Driven by Gasoline or Diesel Engines An automatic priming system using motor-driven vacuum pumps can be used for centrifugal pumps driven by diesel engines if a reliable source of electric power is available in the station. An auxiliary vacuum pump driven by a gasoline engine might be desirable for emergency use in case of electric power failure. Alternatively, a direct-connected wet vacuum pump with controls similar to those used in motor-driven automatically primed units is very satisfactory.

The choice of the priming device for a gasoline-engine centrifugal pump depends on the size of the pump, the required frequency of priming, and the portability of the unit. Most portable units are used for relatively low heads and small capacities, for use in pumping out excavations and ditches, for example. Self-priming pumps of various types are most satisfactory for this service and are preferable to regular centrifugal pumps.

It is possible to utilize the vacuum in the intake manifold of a gasoline engine as a means of priming or keeping the pump primed. The rate at which the air can be drawn from the pump in this manner is relatively low, so many of these units use foot valves. They are initially primed by filling the pump manually. Provision must be made to prevent liquid from being drawn over into the manifold.

TIME REQUIRED FOR PRIMING

The time required to prime a pump with a vacuum-producing device depends on (1) the total volume to be exhausted, (2) the initial and final vacuums, and (3) the capacity of the vacuum-producing device over the range of vacuums that will exist during the priming cycle. The calculations for determining the time necessary to prime a pump are complicated. To permit close approximations, jet primers are usually rated in net capacity for various lifts. It is necessary to divide the volume to be exhausted by the rating to obtain the approximate priming time. Unless such a simplified method is available, the selection of the size of a primer is best left to the vendor of the equipment.

Central automatic priming systems are usually rated for the total volume to be kept primed. The time initially required to prime each unit served by the central system is not usually considered, as the basic function of the system is to keep the pumps primed and in operating condition at all times.

PREVENTION OF UNPRIMED OPERATION

Various controls may be used to prevent the operation of a pump when it is unprimed. These controls depend upon the type of priming system used. For many installations, a form of float switch in a chamber connected with the suction line is used. If the level in the chamber is above the impeller eye of the pump, the float switch control allows the pump to operate. If the liquid falls below a safe level, the float switch acts through the control to stop the pump, to prevent its being started, to sound an alarm, or to light a warning lamp. Such a valve and switch are illustrated in Figure 13.

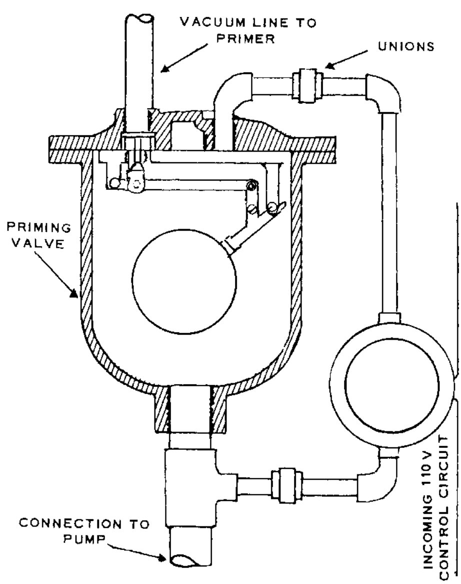


FIGURE 13 Priming valve with liquid level control switch (Apco/Valve and Primer)

GENERAL

Because a great number of automatic priming devices and systems are available, care should be taken to use the type or variation best suited to the application. The discussion of priming in this section does not, of course, cover all makes and modifications available for every specific application.

An automatic priming system will often allow units to be operated with excessive air leakage into the suction lines. This is poor practice because it requires the operation of the vacuum producer for greater periods of time than normally necessary.

FURTHER READING

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Karassik, I. J., and Carter, R. Chap. 21 in *Centrifugal Pumps: Selection, Operation, and Maintenance.* McGraw-Hill: New York, 1960.