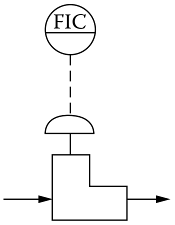
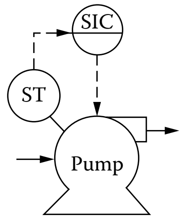
7.4 Pumps as Control Elements

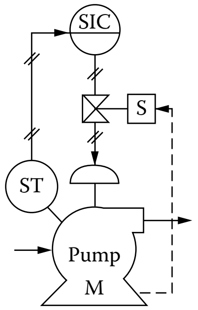
A. BRODGESELL (1970) **R. D. BUCHANAN** (1985)
B. G. LIPTÁK (1995) **I. H. GIBSON** (2005)



Metering pump



Electric speed control



Mechanical speed control

Flow sheet symbols

Types of Pumps:	A. Radial-flow pumps B. Axial- and mixed-flow pumps C. Peripheral or regenerative turbine pumps D. Pitot or jet pumps E. Progressing cavity pumps F. Flexible-rotor pumps G. Peristaltic pumps H. Gear pumps I. Plunger and piston pumps J. Diaphragm pumps K. Eductors L. Blow-egg and air lifts *Note:* Types A, B, and E are available in both conventional and submersible designs.
Rangeability:	*Variable-speed drives*: From 4:1 to 40:1 (electrical types), from 4:1 to 10:1 (mechanical designs), up to 40:1 (hydraulic types).
Metering pumps:	Can exceed 100:1 combining variable speed and variable stroke.
Efficiencies:	Pump efficiencies range from 85% for large-capacity centrifugals (types A and B) to below 50% for many of the smaller units. For types I and J, the efficiency ranges from 30% and up, depending on power and number of heads. For type J the efficiency is at most 30%, and for other types as low as 25%.
Materials of Construction:	For water using type A or B pumps: normally bronze impellers, bronze or steel bearings, stainless or carbon steel shafts, cast iron housing. For industrial process services, stainless steel and cast steel. For corrosive services, engineering plastic materials are common.

Costs:

Varies with size and horsepower. For example, type A pumps cost from $650 to more than $34,000. Typically, a type A 10 hp (7.5 kW) sewage pump might cost $5000 for a horizontal and $4000 for a vertical model. A 10 hp (7.5 kW) type F ejector costs about $24,000, but to do the same work as the type A pump, a 30 hp (22 kW) $47,000 ejector is needed. A 10 hp (7.5 kW) type I, J, or K sludge pump costs about $12,000. Prefabricated stations (including pump) range from $13,000 to $100,000. The cost is $2700 for a pneumatic metering pump and $5400 for type K metering pump with positioner. The cost of stainless steel pumps is three to four times that of cast iron or bronze-fitted pumps. The purchase cost of a submersible pump is higher than that of one of the "dry pit" types, but the total installed cost is lower because there is no need for both a dry and a wet well (Figure 7.4k).

Partial List of Suppliers:

There are a multitude of pump manufacturers throughout the world, many of whom make a variety of types. For a survey of pump manufacturers, with access to catalogs and mechanical details, the Web offers several excellent sources, such as GlobalSpec, http://flow-control.globalspec.com/ProductFinder/Flow_Transfer_Control/Pumps; and Thomas Global Register, http://www.thomasglobal.com/us/products18/pumps_suppliers.htm.

Allweiler Pump, down:

Allweiler Pump (A, B, E, G, I) (www.allweiler.de)
American Lewa (J, K) (www.amlewa.com)
American Turbine Pump Co. (B) (americanturbine.net)
Ashbrook-Simon-Hartley (I)
ASF Thomas Inc. (G) (www.thomaspumps.com)
Aurora Pump (A, C) (www.aurorapump.com)
Blackmer Pump (A, H, I) (www.blackmer.com)
Bran+Luebbe Inc. (J, K) (www.branluebbe.com)
BW/IP International Inc. (A), now Flowserve
Cat Pumps (J) (www.catpumps.com)
Clark-Cooper Div. of Magnetrol (J) (www.clarkcooper.com)
Cole-Parmer Instrument Co. (G) (www.coleparmer.com)
Cornell Pump Co. (A, B) (www.cornellpump.com)
Crane Pumps and Systems–Barnes Pumps (A, J, K) (www.cranepumps.com/barnes)
Dean Pump Div. Metpro Corp. (A) (www.deanpump.com)
Duriron Div. of Flowserve (A, C, D, H) (www.flowserve.com/pumps)
Eaton Corp. (H) (hydraulics.eaton.com)
Edson International (G, K) (www.edsonpumps.com)
Edwards High Vacuum International, now BOC Edwards (E) (www.bocedwards.com)
Edwards Inc. & Jones Inc./Willet (J) (www.edwardsandjones.com)
EMU Unterwasserpumpen Gmbh (A) (www.emu.de/english)
Fairbanks Morse Pump (A, B) (www.fmpump.com)
Flowserve (A, B–J, K) (www.flowserve.com/pumps/ index.htm)
FMI—Fluid Metering Inc. (J) (www.fmipump.com)
GE Osmonics (A, K) (www.gewater.com/equipment/pumps/index.jsp)
GE Ruska (J) (www.ruska.com)
Geho Pumps–Div. Weir Netherlands b.r. (J, K) (www.geho.nl/minerals/home.nsf)
Gorman-Rupp Industries Div. (A, C, D, E, H) (www.gormanrupp.com)
Goulds Pumps (A, J) (www.goulds.com)
Hale Fire Pump Co. (A) (www.haleproducts.com)
Hydroflo Pumps (A, B) (www.hydroflo pumps.com)
IMO Industries Inc. (I, J) (www.imo-pump.com)
Ingersoll Dresser Pump Div. of Flowserve (A, C) (www.idpump.com)
IR ARO Fluid Products (K) (www.arozone.com/Index.html)
ITT A-C Pump (A, K) (www.gouldspumps.com/ac_files)
ITT Bell & Gossett (A) (www.bellgossett.com)
ITT Jabsco Products (A, F) (www.jabsco.com)
ITT Marlow Pumps (AB) (www.marlowpumpsonline.net)
Jaeco Fluid Systems Inc. (J, K) (www.jaecofs.com/metering_pumps.html)
KNF Neuberger Inc. (J, K) (www.knf.com/usa.htm)
Komline-Sanderson (J) (www.komline.com/index.html)
LaBour– Taber Div. of Peerless Pump Co. (A) (216.37.51.16/labourtaber)
Lakeside Equipment Corp. (I) (www.lakeside-equipment.com)

Lear Romec Div. of Crane Co. (H) (www.learromec.com)
Linc Milton Roy (J) (www.lincpumps.com)
Liquiflo Equipment Co. (A, H) (www.liquiflo.com)
Lutz Pumps Inc. (A, K) (www.lutzpumps.com)
McFarland Pump Co. (J, K) (www.mcfarlandpump.com)
Micropump Corp. (A, G, J, K) (www.micropump.com)
Mono Pumps Ltd. (Monoflo in North America) (E) (www.mono-pumps.com)
MP Pumps Inc. (K) (www.mppumps.com)
Nagle Pumps (A) (www.naglepumps.com)
Netzch Mohnopumpe Gmbh (A)
Oberdorfer Pumps Inc. (E, H) (www.thomaspumps.com/pumpsprofile.htm)
Pacer Pumps (A) (www.pacerpumps.com)
Patterson Pump Co. (A, B) (www.pattersonpumps.com)
PCM Moineau (E) (www.pcmpompes.com)
Peerless Pump (A, B) (www.peerlesspump.com)
Plenty Mirrlees Pumps Div. of SPX Process Equipment (H, I) (www.plenty.co.uk/pumps)
Price Pump Co. (A, K) (www.pricepump.com)
Pulsafeeder Div. of IDEX Corp. (J, K) (www.pulsa.com)
QED Environmental Systems Inc. (L) (www.qedenv.com)
Robbins & Myers Inc. —Moyno (A, E, J) (www.robn.com)
Roper Pump Co. (H) (www.roperpumps.com)
Tuthill Corp.(H) (pump.tuthill.com)
Valcor Engineering Corp. (J) (www.valcor.com)
Vanton Pump & Equipment Co. (A, G) (www.vanton.com)
Viking Pump Div. of IDEX Corp. (C, H) (www.vikingpump.com)
Wallace & Tiernan (K) (www.wallace-tiernan.com)
Wanner Engineering Inc. (A, G, K) (www.wannereng.com)
Warman Pump Group (A, G, K) (www.warman.co.za)
Warren Pumps Inc. (H) (www.warrenpumps.com)
Waukesha Cherry Burrell Div. of SPX Process Equipment (H) (www.gowcb.com)
Weir Minerals Division (A, J, K) (www.weirminerals.com)
WEMCO Div. of Weir Clearliquid (A) (www.weirclearliquid.com)
Wright Pump Div. of IDEX Corp. (H) (www.idexcorp.com/groups/wright.asp)
Zenith Div. of Parker Hannifin Corp. (H, J) (www.zenithpumps.com)
Zimpro/Passavant Inc. (I) (www.usfilter.com)

Because pumping is the primary means of liquid transportation in most processes, pumps are important parts of control systems. The various pump control systems will be discussed in Chapter 8; the features and designs of variable-speed drives are covered in Section 7.10; and metering pumps have been discussed in Section 2.14 of the *Process Measurement and Analysis* volume of this fourth edition of the handbook. Therefore, the main emphasis of this chapter will be to describe the features and selection of conventional (centrifugal, reciprocating, screw) pumps and their applications. In addition, this section will also briefly discuss metering pumps for the benefit of those who do not have access to *Process Measurement and Analysis.*

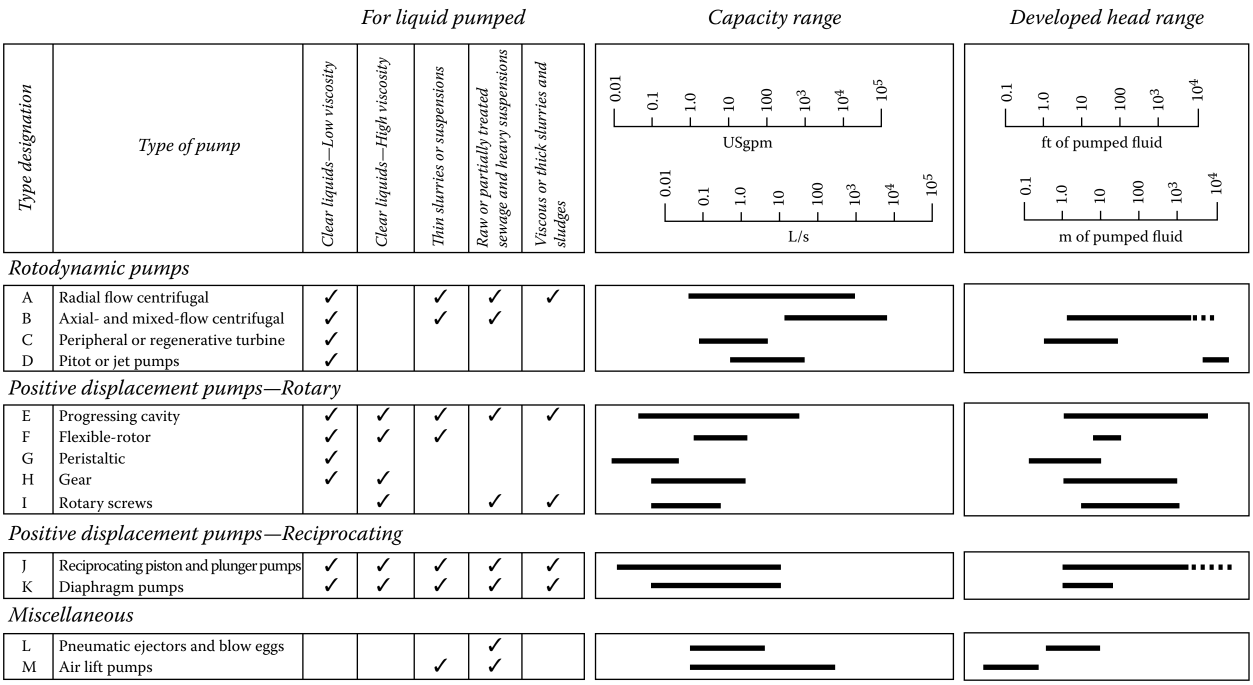
ROTODYNAMIC OR CENTRIFUGAL PUMPS

Types A, B, C, and D of the feature summary (Table 7.4a) fall within this classification, which is the most common type of pump. In the form of tall, slender, deep well submersibles, they pump clear water from depths greater than 2000 ft (600 m). Horizontal centrifugals with volutes almost the size of a man can pump 9000 gpm (0.57 m^3/s) of raw sewage through municipal treatment plants. Few applications are beyond their range, including flow rates of 1–100,000 gpm (3.78 lpm to 6.3 m^3/s) and process fluids from liquefied gases through clear water to all but the densest sludge.

Radial-Flow

Radial-flow pumps are designed to throw the liquid entering the center of the impeller or diffuser out into a spiral volute or bowl. The impellers may be closed, semi-open, or open, depending on the application (Figure 7.4b). Closed impellers have higher efficiencies and are more popular than the other two types. They can readily be designed with nonclogging features. By using more than one impeller the discharge head characteristics can be increased, in proportion to the number of impellers. These pumps may be of horizontal or vertical design. Multiple stage designs with up to 99 impeller/volute assemblies on a single shaft are available, though not common. Flow can be throttled, but many pumps have a minimum

TABLE 7.4a
Pump Feature Summary



Type designation	Type of pump	Clear liquids—Low viscosity	Clear liquids—High viscosity	Thin slurries or suspensions	Raw or partially treated sewage and heavy suspensions	Viscous or thick slurries and sludges
Rotodynamic pumps						
A	Radial flow centrifugal	✓		✓	✓	✓
B	Axial- and mixed-flow centrifugal	✓		✓	✓	
C	Peripheral or regenerative turbine	✓				
D	Pitot or jet pumps	✓				
Positive displacement pumps—Rotary						
E	Progressing cavity	✓	✓	✓	✓	✓
F	Flexible-rotor	✓	✓	✓		
G	Peristaltic	✓				
H	Gear	✓	✓			
I	Rotary screws		✓		✓	✓
Positive displacement pumps—Reciprocating						
J	Reciprocating piston and plunger pumps	✓	✓	✓	✓	✓
K	Diaphragm pumps	✓	✓	✓	✓	✓
Miscellaneous						
L	Pneumatic ejectors and blow eggs				✓	
M	Air lift pumps			✓	✓	

flow below which they become bistable, flipping between zero and a much higher flow. In some cases, this may be as high as 75–80% of design rate.

Axial- and Mixed-Flow

Axial-flow (propeller) pumps, although classed as centrifugals, do not truly belong in this category because the propeller thrusts axially rather than throwing the liquid outward. Impeller vanes for mixed-flow centrifugals are shaped so as to provide partial throw, partial push of the liquid outward and upward. Axial-flow and mixed-flow designs can handle huge capacities but only at the expense of a reduction in discharge heads. They are constructed vertically. The head/flow characteristic is such that throttling the flow is usually undesirable, and bypassing or speed control is a better control strategy.

Peripheral or Regenerative Turbine

Peripheral turbine pumps (Figure 7.4c) are low-flow/high-head devices that require very little positive suction head. The fluid enters an annular space near the periphery of the rotor, which has a large number of slots. The fluid is carried around by the rotor, gaining pressure as it circulates in the rotor slots, and is discharged after traveling about 300° around the casing. A small single-stage impeller can provide up to 500 ft (150 m) head.

Pitot or Jet Pumps Pitot pumps (Figure 7.4d) provide extremely high head, up to 5000 ft (1500 m), at relatively low flow rate. The pump has an internal cylindrical casing that rotates at high speed, with a fixed pitot pickup inside. The discharge

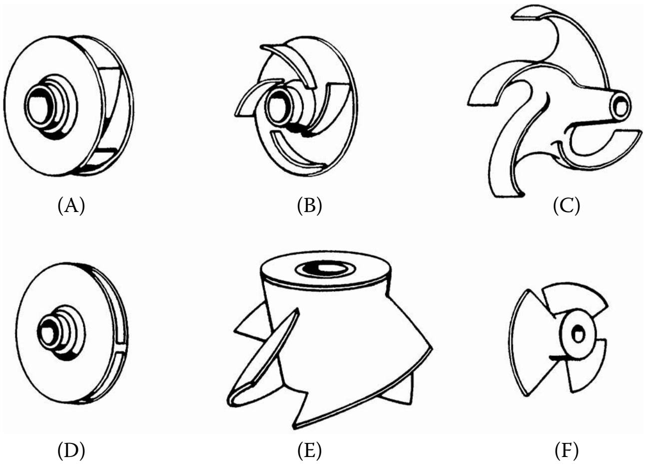


FIG. 7.4b
Types of centrifugal pump impellers: (A) closed impeller, (B) semi-open impeller, (C) open impeller, (D) diffuser, (E) mixed-flow impeller, (F) axial-flow impeller.

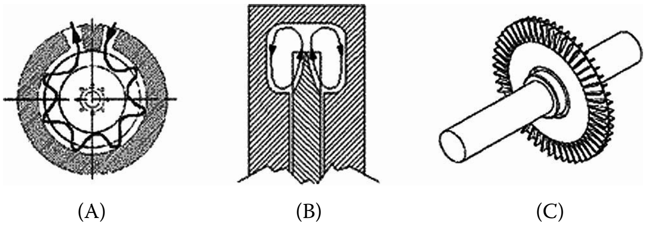


FIG. 7.4c
Peripheral turbine pump impeller: (A) view on shaft end, showing fluid path, (B) view of impeller and housing, showing fluid internal circulation, (C) impeller and shaft assembly. (Courtesy of Dynaflo Engineering Inc.)

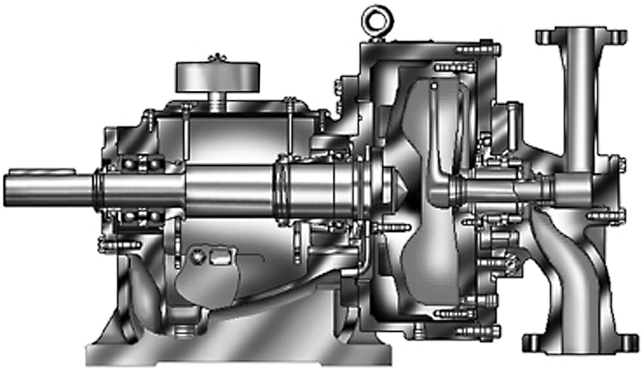


FIG. 7.4d
Roto-jet pitot pump sectional drawing. (Courtesy of Weir Clear Liquid Division.)

from the pitot exits on the impeller axis, coaxial with the suction connection.

Applications Most liquids and wastes can be pumped with centrifugal pumps. It is easier to list the applications for which they are not suited than the ones for which they are. They should not be used for pumping (1) very viscous industrial liquids or sludges (the efficiencies of centrifugal pumps drop to zero, and therefore various positive displacement pumps are used), (2) low flows against very high heads (except for deep well applications, the large number of impellers needed put the centrifugal design at a competitive disadvantage), and (3) low to moderate flows of liquids with high solids contents (except for the recessed impeller type, rags and large particles will clog the smaller centrifugals). For low flow and high head, the turbine and the jet pump designs may be competitive with positive-displacement types up to 400 hp (300 kW).

POSITIVE-DISPLACEMENT PUMPS

Rotary Pumps

Progressing Cavity Pumps Invented by R. Moineau in 1930, progressing cavity pumps have a helical metal rotor within a (usually) elastomer stator with a bihelical bore; the rotor is connected to the rotating drive through a sealed universal joint set or a flexible shaft enabling the rotor to nutate as it rotates. The resulting motion causes a series of trapped cavities to progress axially through the pump. Such pumps offer unusual capabilities in handling fragile products (small live fish can pass through them) and can be classed as semipositive displacement; the capacity is largely proportional to rotational speed; though slippage increases above a value depending on the tightness of fit of the rotor in the stator. The pumps must not be run dry, as this will rapidly damage the stator, but will act as vacuum pumps provided there is enough liquid to lubricate the system. They are therefore capable of suction lift equivalent to about 90% of the vapor pressure of the liquid. They find application in paste and slurry handling service, as well as small high-lift submersible and down-hole pumps. Variants with hopper/auger feed will handle filtercake and similar extremely high viscosity products. Multistage variants utilize a single, long rotor and a series of standard stator units. Other variants exist with an n-start helical rotor and $n + 1$-start stator, which have even less pulsation than the standard design. The progressive cavity pump with VSD can be one of the most useful tools for a control system engineer, offering a simple alternative to centrifugal pump, control valve, and check valve in a single package. A single-stage pump is capable of producing a differential of up to about 62 psid (430 kPa).

Flexible-Rotor Pumps A cylindrical metallic housing with diametric suction and discharge connections contains a multivaned elastomer rotor, eccentrically mounted (Figure 7.4e). As the rotor turns, the volume between the vanes increases to a maximum as the set of vanes pass the suction connection, trapping a volume of liquid, and then diminishes to a minimum as the trapped volume passes the discharge connection. The pump is reversible.

Peristaltic Pumps Widely used in laboratory applications, the peristaltic pump has an elastomer tube. held inside a cylindrical retainer and a set of spring-loaded rollers that trap a series of volumes of fluid in the tube as they rotate, transferring liquid from the suction to the discharge (Figure 7.4f). These commonly have multiple heads on a single variable-speed drive mechanism and will accept a variety of different bore tubes, enabling a variety of reagents and samples to be fed proportionately to analytical equipment. They are also used for industrial purposes, handling material such as nitric and hydrofluoric acids. Pumps will handle both liquids and gases,

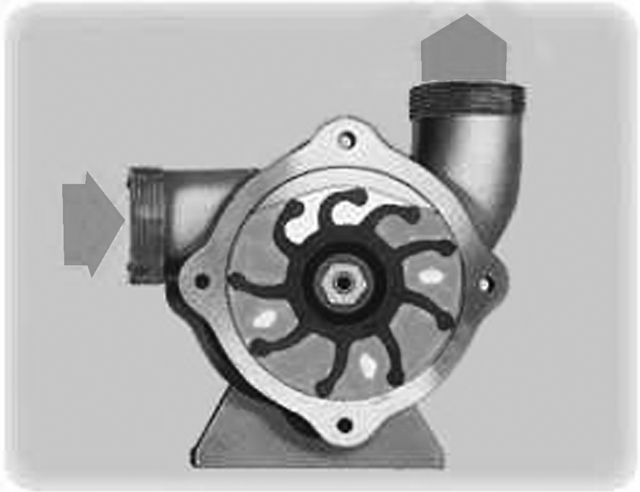
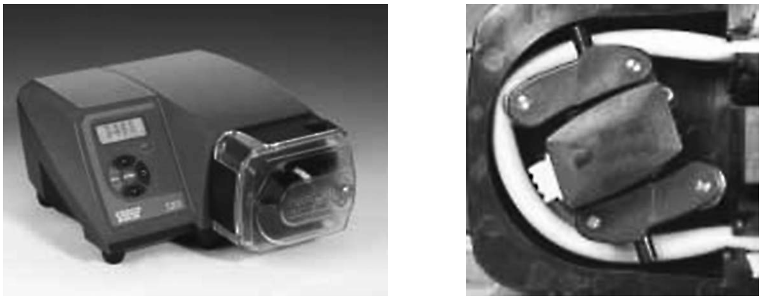


FIG. 7.4e
Flexible rotor pump section. (Courtesy of Bombas Trief.)



(A) Laboratory peristaltic pump

(B) Industrial peristaltic pump

FIG. 7.4f

Peristaltic pumps: (A) laboratory, (B) industrial. (Courtesy of Watson-Marlow Bredel.)

and available capacities vary from fractions of a milliliter/minute to 1400 gph (90 lpm).

Gear Pumps

Gear pumps are available in a multitude of variations. Most designs have a pumping chamber with a pair of meshed gears; as the gears rotate, liquid is trapped between the housing and the gear teeth, being carried from the suction chamber to the discharge chamber. As the gear teeth engage, the liquid is forced out of the discharge port. Another common design is the "star and moon" with a planetary gear and a quarter-moon-shaped stationary component inside a driven ring-gear.

Reciprocating Pumps

Almost all reciprocating pumps are either metering or power pumps. The steam-driven pump is historically interesting but rarely used. Most frequently a piston or plunger is utilized in a cylinder, which is driven forward and backward by a crankshaft connected to an outside drive. Metering pump flows can readily be adjusted by changing the length and frequency of strokes of the piston. The diaphragm pump is similar to the piston type, except that instead of a piston, it contains a flexible diaphragm that oscillates as the crankshaft rotates. Diaphragm pumps commonly have a buffer hydraulic fluid to transfer the force to the diaphragm.

Smaller units may be solenoid driven or use pneumatic power.

Plunger and diaphragm pumps can feed metered amounts of chemicals (acids or alkalis for pH adjustment) or can also pump sludge and slurries. Plunger pumps commonly come as simplex (one head), duplex (two head) or triplex (three head). The triplex design, with the piston throws operating at 120° to each other, minimize pulsation in suction and discharge, and acceleration losses in the suction lines. Pulsation dampers are commonly fitted to further reduce these effects.

Variable-capacity hydraulic pumps utilize a variable-angle swashplate to alter the stroke of a set of pistons (commonly five) in a common assembly. Fitted with an integrated hydraulic servomechanism, these can be set up to provide constant discharge pressure/variable flow, or constant power (flow × pressure). This design can also be used as a reversible variable-speed hydraulic motor.

AIR PUMPS AND AIR LIFTS

This method of pumping (type L) employs a receiver pot, into which the wastes flow by gravity, and an air pressure system that transports the liquid to a treatment process at a higher elevation. A controller is usually included, which keeps the tank vented while it is filling. The level controller energizes a three-way solenoid valve when it is full to close the vent and open the air supply to pressurize the vapor space in the tank.

The air system may use plant air (or steam), a pneumatic pressure tank, or an air compressor directly. With large compressors, a capacity of 600 gpm (2.28 m^3/min) with lifts of 50 ft (15 m) may be obtained. The advantage of this system is that it has no moving parts in contact with the waste and thus no impellers to clog. Ejectors are normally more maintenance free and longer lived than pumps.

Condensate Pumps

A related device can be used to transfer steam condensate at subatmospheric pressure to a condensate return system, by injecting live steam above the condensate surface. When the vessel is empty, the vapor space is connected to the steam space of the heater to equalize pressure and allow the condensate to refill the vessel (Figure 7.4g).

Air Lifts

Air lifts consist of an updraft tube, an air line, and an air compressor or blower. Air is blown into the bottom of the submerged updraft tube, and as the air bubbles travel upward, they expand (reducing density and pressure within the tube), inducing the surrounding liquid to enter. Flows as great as 1500 gpm (5.7 m^3/min) may be lifted short distances in this way. Air lifts are of great value in waste treatment to transfer mixed liquors or slurries from one process to another.

DESIGN OF PUMPING SYSTEMS

In order to choose the proper pump, the conditions that must be known include capacity, head requirements, and liquid characteristics. To compute capacity, one should first determine the average flow rate for the system and then decide if adjustments are necessary. For example, when pumping wastes from a community sewage system, the pump must handle peak flows that are roughly two to five times the average flow, depending on the size of the community. Summer and winter flows and future needs may also dictate capacity, and the population trends and past flow rates should be considered in this evaluation.

Head Requirements

Head describes pressure in terms of height of fluid. It is calculated by the expression:

$$\text{head in feet} = \frac{\text{pressure (psi)} \times 2.31}{\text{specific gravity}} \qquad \textbf{7.4(1)}$$

The discharge head on a pump is a summation of several contributing factors: static head, friction head, velocity head, and suction head.

Static head (h_d) is the vertical distance through which the liquid must be lifted (Figure 7.4h).

Friction head (h_f) is the resistance to flow caused by the friction in pipes. Entrance and transition losses may also be

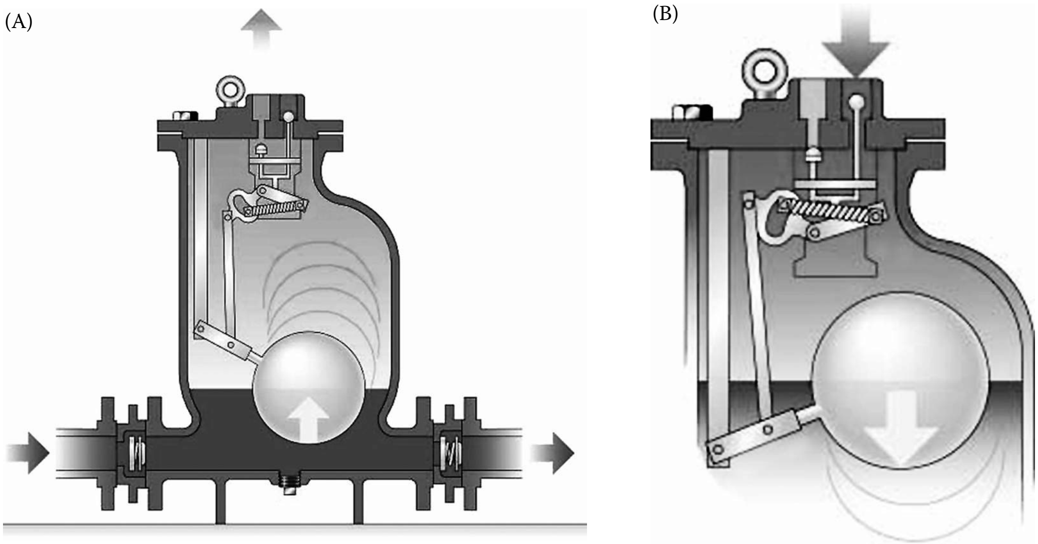


FIG. 7.4g
Automatic condensate pump operation: (A) filling, (B) emptying. (Courtesy of Spirax Sarco.)

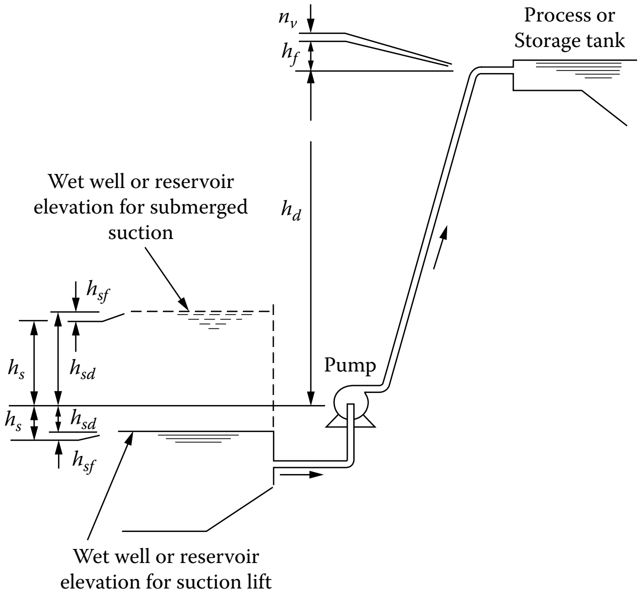


FIG. 7.4h

Determination of pump discharge head requirements. Legend: h_v *= velocity head;* h_f *= friction head;* h_d *= static head;* h_s *= suction head;* h_{sd} *= suction side static head;* h_{sf} *= suction side friction head.*

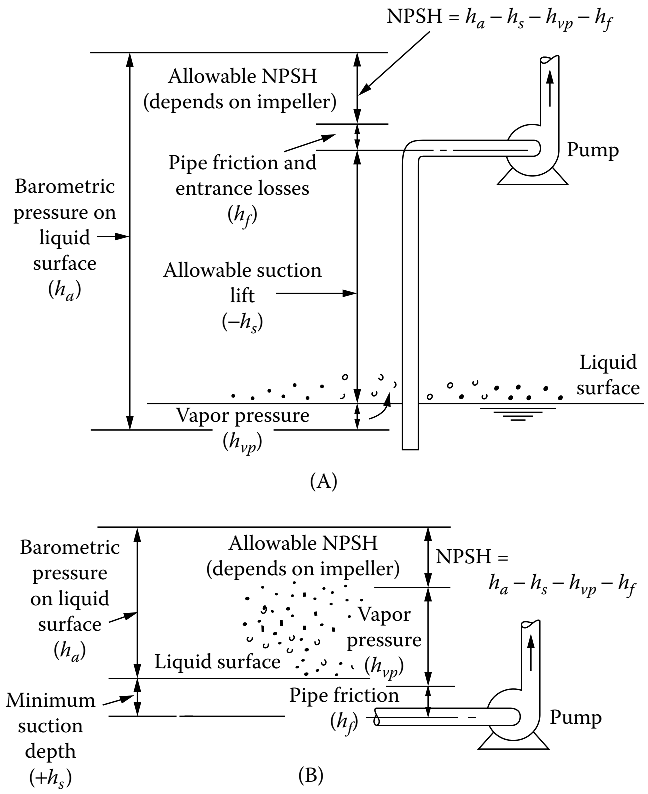


FIG. 7.4i

Role played by NPSH in determining allowable suction lift: (A) pump with suction lift, (B) pump with submerged suction but high vapor pressure (possibly hot water).

included. Because the nature of the fluid (density, viscosity, and temperature) and the nature of the pipe (roughness or straightness) affect the friction losses, a careful analysis is needed for most pumping systems, although for smaller systems, tables can be used.

Velocity head (h_v) is the head required to impart energy into a fluid to induce velocity. Normally this is quite small and may be ignored unless the total head is low.

Suction head (h_s), if there is a positive head on the suction side (a submerged impeller), will reduce the pressure differential that the pump has to develop. If the liquid level is below the pump, the suction lift plus friction in the suction pipe must be added to the total pressure differential required.

Total head (H) is expressed by

$$H = h_d + h_f + h_v \pm h_s \qquad \textbf{7.4(2)}$$

NPSH Calculation

The suction lift that is possible to handle must be carefully computed. As shown in Figure 7.4i, it is limited by the barometric pressure (which in turn is dependent on elevation and temperature); the vapor pressure (also dependent on temperature); friction and entrance losses on the suction side; and the net positive suction head (NPSH)—a factor that depends on the shape of the impeller and is obtained from the pump manufacturer.

In order for the pump to be able to "pull in" the pumped fluid, the net positive suction head available (NPSHA) for the particular installation must be greater than the NPSH that the pump requires. The NPSH values for the particular pump are obtained from the pump curve (Figure 7.4j), while the available NPSH is calculated according to the following equation:

$$\text{NPSHA} = h_a(+\text{ or }-)h_s - h_{vp} - h_f \qquad \textbf{7.4(3)}$$

where

h_a = the absolute pressure (in feet) at the surface of the source of the pumped liquid. If the source is atmospheric, h_a = 33.96 ft.

h_s = the static head of the installation, which is the vertical distance between the pump inlet and the surface of the liquid on the supply side. It is positive if the liquid level is above the pump inlet, and it is negative if it is below.

h_{vp} = the vapor pressure of the pumped fluid (in feet) at the operating temperature. The h_{vp} rises with temperature, and $h_{vp} = h_a$ when the liquid reaches its boiling point.

h_f = the suction side friction head in feet. This term increases with the square of flow and reflects the pressure drop through all pipes, valves, and fittings

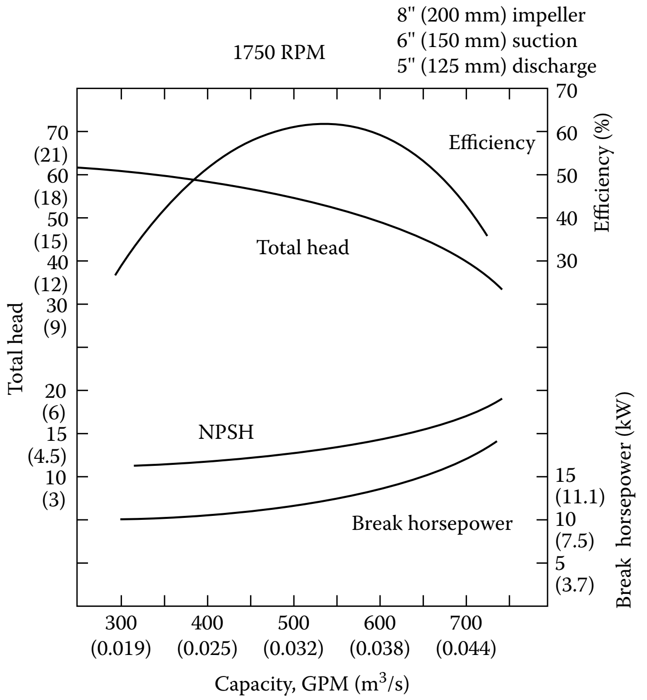


FIG. 7.4j
Typical pump curve for a single impeller.

on the suction side of the pump. When dealing with reciprocating pumps, the suction column is accelerated and decelerated with each stroke, and the head required to accelerate the suction column must be included.

If it is desired to convert NPSHA from feet to PSI, the NPSHA given in feet should be multiplied by the specific gravity of the fluid and should be divided by 2.31. (When converting to metric units, ft = 0.3048 m and PSI = 6.9 kPa.)

It is generally sufficient to calculate the available NPSH at maximum flow rate, because at that flow, the suction side friction head (h_f) is maximum and the NPSHA value is likely to be minimum. The NPSH required (NPSHR) of the pump rises with flow (Figure 7.4j). Therefore, if NPSHA exceeds NPSHR when the flow is maximum, it will exceed it by an even greater margin as the flow drops.

Specific Speed

The rotational speed of the impeller affects capacity, efficiency, and cavitation. Even if the suction lift is within permissible limits, cavitation can still occur, because additional static head is converted to velocity head as the fluid is accelerated in the pump.

The specific speed of the pump can be found using Equation 7.4(4).

$$\text{specific speed, } N_s = \frac{\text{RPM} \times \sqrt{\text{capacity (gpm)}}}{H^{3/4}} \qquad \textbf{7.4(4)}$$

Charts are available showing the upper limits of specific speed for various suction lifts. Caution: In metric units, specific speed values are NOT the same as in U.S. units, as the relationship is not dimensionally consistent.

Horsepower

The power required to drive the pump is called brake horsepower. It is found by solving Equation 7.4(5).

$$\text{BHP} = \frac{\text{capacity (gmp)} \times H\text{(ft)} \times \text{Sp. Gr.}}{3960 \times \text{pump efficiency}} \qquad \textbf{7.4(5a)}$$

In metric units,

$$\text{Power (kW)} = \frac{\text{capacity (m}^3\text{/h)} \times H\text{(Nm/kg)} \times \text{density (kg/m}^3\text{).}}{3.670 * 10^5 \times \text{pump efficiency}} \qquad \textbf{7.4(5b)}$$

or

$$\text{Power (kW)} = \frac{\text{capacity (m}^3\text{/h)} \times H\text{(kPa)}}{3600 \times \text{pump efficiency}} \qquad \textbf{7.4(5c)}$$

Installation Considerations for Wastewater Pumping Stations

The typical designs for wastewater pumping stations are shown in Figure 7.4k. In selecting the best design for a particular application, the following factors should be considered:

1. Many gases are formed by domestic wastes, including some that are flammable. When pumps or other equipment are located in rooms below grade, the possibility of explosion or the build-up of these gases exists, and ventilation is extremely important. Similarly, such gases may be toxic (hydrogen sulfide) and asphyxiant (methane, carbon dioxide).
2. When pumping at high velocities or through long lines, water hammer can be a problem. Valves and piping should be designed to withstand these pressure waves. Even for pumps that discharge to atmosphere, check valves should be chosen so as to cushion the surge.
3. Bar screens and comminutors are undesirable because they require maintenance, but they may be necessary for small centrifugal pump stations where the flow might get clogged.
4. Pump level controls are not fully reliable because rags can short electrodes and hang on floats. Purged air systems (air bubblers) require less maintenance but need an air compressor that must operate continuously. Therefore, it is important to provide maintenance-free instrumentation.

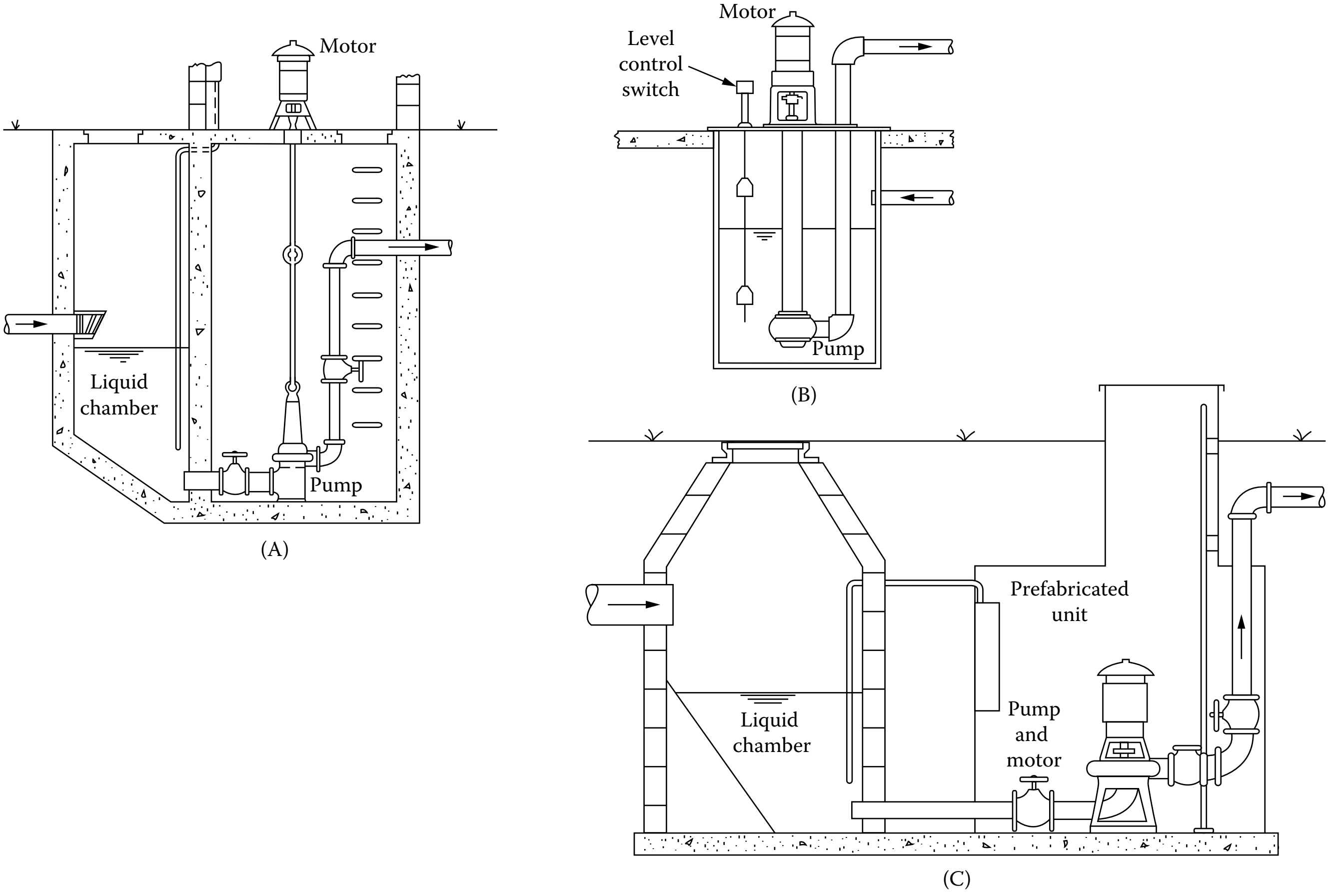


FIG. 7.4k
Pumping stations: (A) dry well design, (B) wet well design, (C) prefabricated pumping station.

5. Charts and formulas are available for sizing wet wells, but infiltration and runoff must also be taken into account.
6. Sump pumps, humidity control, a second pump with alternator, and a pump hoisting mechanism are desirable.
7. Most sewage utilities prefer the dry well designs for ease of maintenance.

METERING PUMPS

Flow control of liquids can be accomplished by means of pumps that incorporate the measurement and control element in a single unit. Metering pumps are designed to provide measurement and control of the process. For a measurement-oriented discussion of these pumps, refer to Section 2.14 in the *Process Measurement and Analysis* volume of this handbook.

Plunger Pumps

Plunger pumps are suitable for use on clean liquids at high pressures and low flow rates. A typical plunger pump is shown in Figure 7.4l. The pump consists of a plunger, cylinder, stuffing box, packing, and suction and discharge valves. Rotary motion of the driver is converted to linear motion by an eccentric. The plunger moves inside the cylinder with reciprocating motion, displacing a volume of fluid on each stroke.

Stroke length, and thus the volume delivered per stroke, is adjustable. The adjustment can be a manual indicator and dial, or for automatic control applications, a pneumatic actuator with positioner can be provided. Stroke adjustment alone offers operating flow ranges of 10:1 from maximum to minimum. Additional rangeability can be obtained by means of a variable-speed drive. A pneumatic stroke positioner used in conjunction with a variable-speed drive provides rangeability of at least 100:1. In the case of automatic stroke adjustment and variable speed, the pumping rate can be controlled by two independent variables, or the controller output can be "split-ranged" between stroke and speed adjustment.

The reciprocating action of the plunger results in a pulsating discharge flow, as represented in Figure 7.4m by the dotted simplex curve. For applications where these flow pulsations cannot be tolerated, particularly if a flow measurement is required, pumps can be run in duplex or triplex arrangements. With the duplex pump, two pump heads are

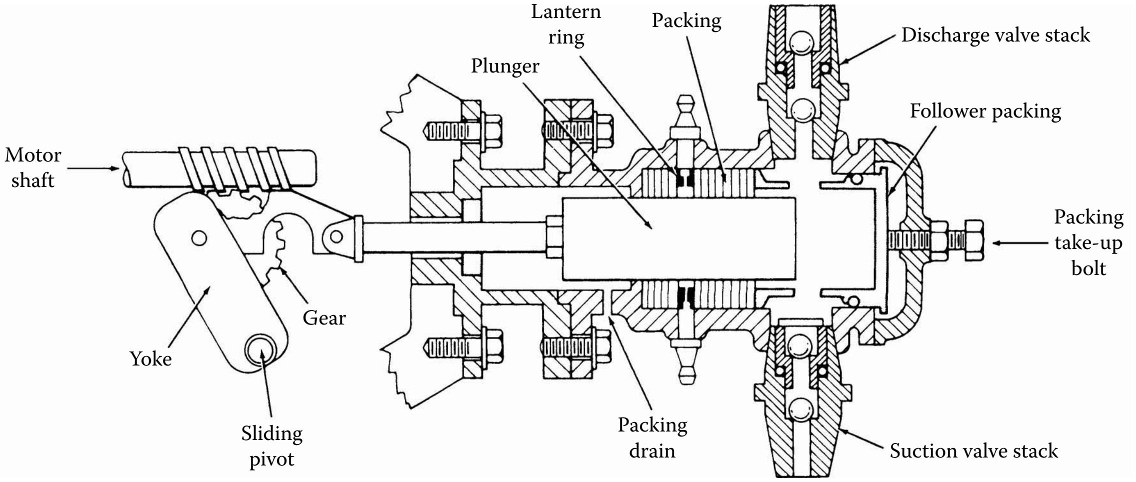


FIG. 7.4l
Plunger- or piston-type metering pump.

driven off the same motor, and the discharge strokes are phased 180° apart. With a triplex arrangement, three pump heads are driven by one motor and the discharge strokes are 120° apart. Both the duplex and triplex pumps provide a smoother flow than the single pump, as shown by the dashed and solid curves of Figure 7.4m.

For blending two or more streams, several pumps can be ganged to one motor. Stroke length adjustment can be used to control the blend ratio, and drive speed can control total flow. However, in this case rangeability is sacrificed for ratio control.

Pumping efficiency is affected by leakage at the suction and discharge valves. These pumps are therefore not recommended for fluids such as slurries, which will interfere with proper valve seating or settle out in pump cavities.

Diaphragm Pumps

Diaphragm pumps use a flexible diaphragm to achieve pumping action. The input shaft drives an eccentric through a worm and gear. Rotation of the eccentric moves the diaphragm on the discharge stroke by means of a push rod. A spring returns the push rod and diaphragm during the suction stroke. A typical pump is shown in Figure 7.4n.

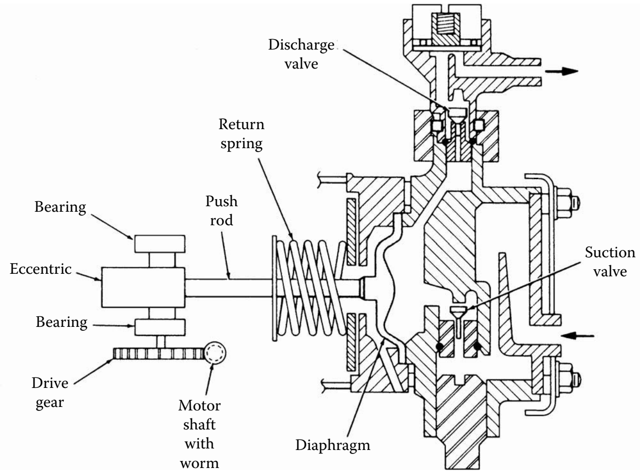


FIG. 7.4n
Diaphragm-type metering pump.

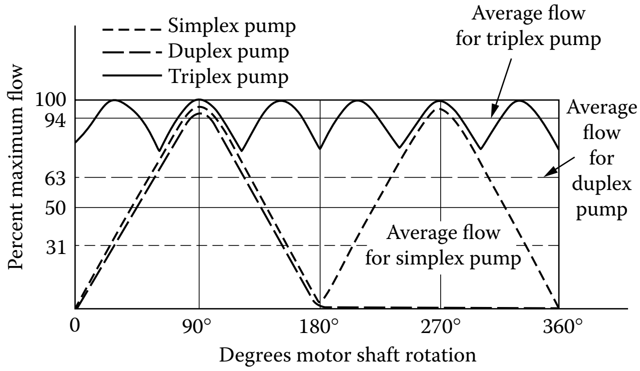


FIG. 7.4m
Flow characteristics of simplex and multiple plunger pumps.

Operation of the diaphragm pump is similar to that of the plunger pump; however, discharge pressure is much lower due to the strength limitation of the diaphragm. Their principal advantage over plunger pumps is lower cost. Designs with two pumps driven by one motor can be used to advantage for increased capacity or to smooth out flow pulsations. By combining automatic stroke length adjustment with a variable-speed drive, operating ranges can be as wide as 20:1. These pumps can be used only on relatively clean fluids, because solids will interfere with proper suction and discharge valve seating or may settle out in the pump cavities.

The weakness of the diaphragm pump design is in the diaphragm, which is operated directly by the push rod. The diaphragm has to be flexible for pumping and yet strong enough to deliver the pressure. The strength requirement can

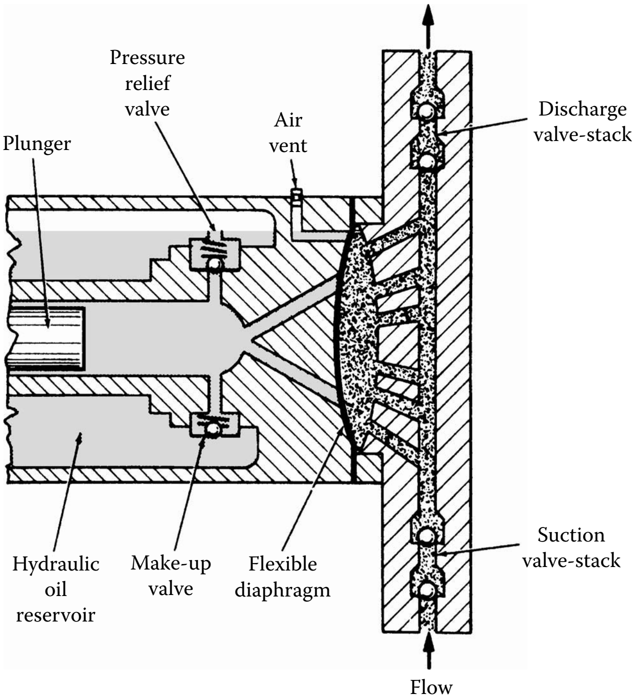


FIG. 7.4o
Diaphragm pump operated with hydraulic fluid.

be reduced by using a hydraulic fluid to move the diaphragm, thereby eliminating the high differential pressures across it. This design consists basically of a plunger pump to provide hydraulic fluid pressure for diaphragm operation and the diaphragm pumping head (Figure 7.4o). The forces on the diaphragm are balanced, and discharge pressures comparable to plunger pumps are possible. The volume pumped per stroke is equal to the hydraulic fluid displaced by the plunger, and this volume is controlled by the stroke length adjustment as in the plunger pump.

A pump design using a flexible tube to achieve pumping action is shown in Figure 7.4p. Motion of the plunger displaces the diaphragm, which in turn causes the flexible tube to constrict, forcing fluid in the tube to discharge (similar to the operation of a peristaltic pump). This design is better suited for use on viscous and slurry liquids than the previously discussed types because the flow path is straight with few obstructions and no cavities; however, seating of the valves can still be a problem.

Pneumatic Metering Pumps

Pneumatically operated plunger-type (Figure 7.4q) and bellows-type metering pumps are also available for use when liquids in small quantities need to be injected at high pressure. The pneumatic timer is adjustable between 4 and 60 strokes per min, while the stroke length is also adjustable from 1/4 –1 in. (6–25 mm). When at the end of the stroke, the pressurized air-operated plunger has displaced the process fluid through the discharge check valve, the piston trips the vent valve, which resets the timer and allows the spring to return the piston to the starting position.

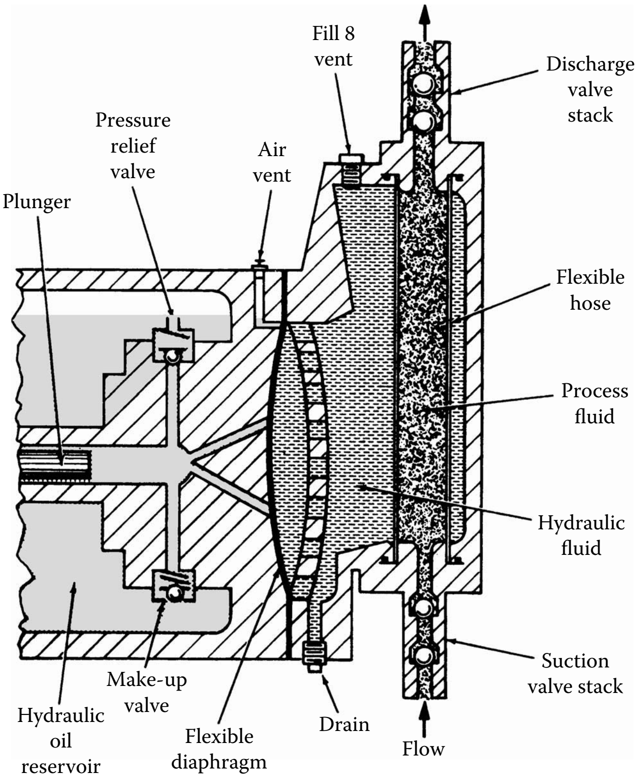


FIG. 7.4p
Diaphragm pump operated with hydraulic fluid and flexible hose element.

Pneumatic metering pumps are available in all stainless steel construction, require no lubrication, can be provided with plungers of 1/8 – 1/2 in. (3–12 mm) diameter, and can deliver flows from 0.1–60 gpd (0.4–225 lpd) at pressures up to 5000 PSIG (3.4 MPa). Until recently, natural gas was frequently used as the motive fluid for odorant injection pumps of this type. While this has the advantage that no other utilities are required, it releases methane to the atmosphere, and this is illegal in many places.

Installation Considerations

In order to ensure a properly working installation, a number of factors associated with the physical installation and with the properties of the fluid must be considered. Some factors that can contribute to a poor installation include:

1. Long inlet and outlet piping with many fittings and valves
2. Inlet pressure higher than outlet pressure
3. Pocketing of suction or discharge lines
4. Low suction head or suction lift

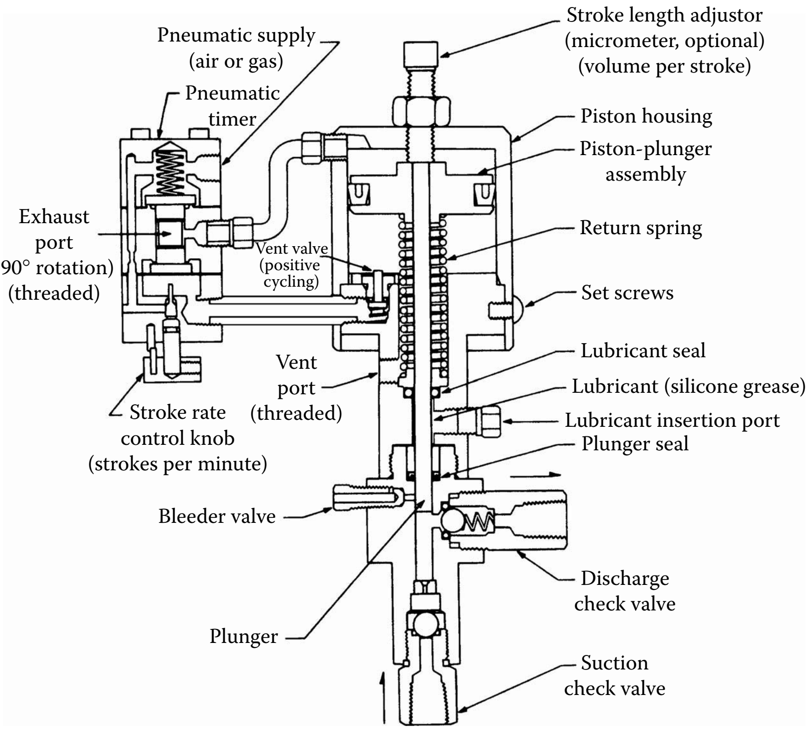


FIG. 7.4q

Pneumatically operated plunger-type metering pump. (Courtesy of Linc Mfg.)

A tortuous flow path in the pump suction or discharge can be troublesome when the fluid handled contains solids, is of high viscosity, or has a high vapor pressure, or if the suction head available is low. Generally, valves that offer a full flow path (such as ball valves) are preferred. Needle valves should be avoided. If the inlet pressure is higher than discharge, the fluid may flow unrestricted through the pump. Spring-loaded check valves at the pump are undesirable because the spring loading stops the ball check from rotating and from finding a new seating surface, for increased valve life. For such applications the installations shown in Figures 7.4r and 7.4s offer solutions.

In Figure 7.4r, the piping arrangement will supply the head to prevent through flow and siphoning. The height of the liquid should be varied depending on pump capacity and fluid velocity. This dimension varies between 2 and 10 ft (0.6 and 3 m) and increases with capacity and velocity. Figure 7.4s illustrates the use of a spring-loaded back-pressure valve to overcome the suction pressure. For this installation a volume chamber (gas-filled bladder) to dampen pulsations should be placed between the pump discharge and the valve.

Dissolved or entrained gases in the fluid can destroy metering accuracy, and in quite small volume they can stop pumping action entirely, as the gas volume is compressed before the fluid can exit through the discharge check valve. Figure 7.4t illustrates an installation design to vent entrained gases back to the fluid hold tank.

It is always desirable to locate the pump below and near the fluid hold tank. Under these conditions the fluid will flow by gravity into the pump suction and loss of prime is unlikely. If the pump cannot be located below the hold tank, other measures must be taken to prevent loss of prime.

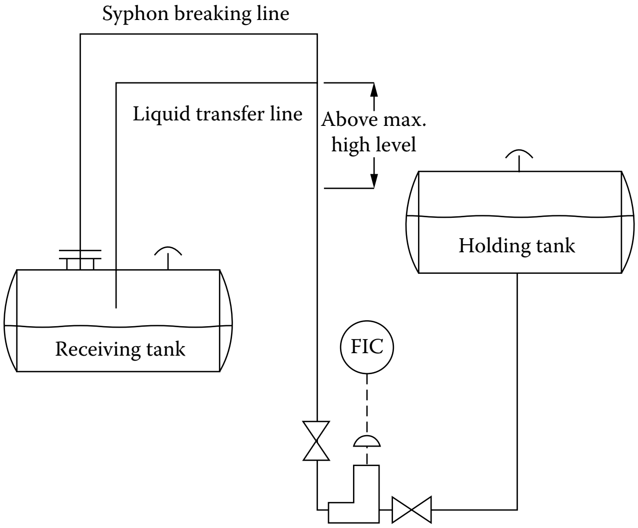


FIG. 7.4r

Piping arrangement to prevent through flow and siphoning.

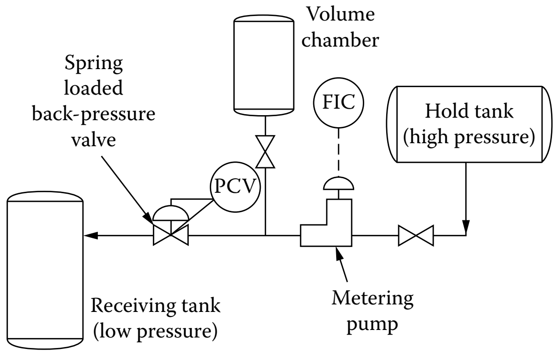


FIG. 7.4s
Metering pump with artificial head created by back-pressure valve.

NPSH and Pulsation Dampening

In order for the pump to operate properly, the net positive suction head must be above the minimum practical suction pressure of approximately 10 psia (69 kPa abs). The available net positive suction head is given by Equation 7.4(6).

$$\text{NPSHA} = P - P_v \pm P_h - \sqrt{\left(\frac{lvGN}{525}\right)^2 + \left(\frac{lvC}{980Gd^2}\right)^2} \qquad \textbf{7.4(6)}$$

where

P = feed tank pressure (psia)
P_v = liquid vapor pressure at pump inlet temperature (psia)
P_h = head of liquid above or below the pump centerline (psid)
l = actual length of suction pipe (ft)
v = liquid velocity (ft/s) at maximum piston speed (see Figure 7.4m)
G = Liquid specific gravity
N = number of pump strokes per minute
C = viscosity (centipoise)
d = inside diameter of pipe (in.)

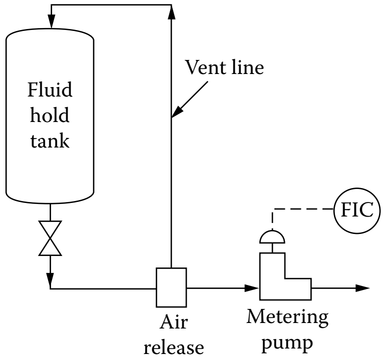


FIG. 7.4t
Elimination of entrained gases in metering pump installations.

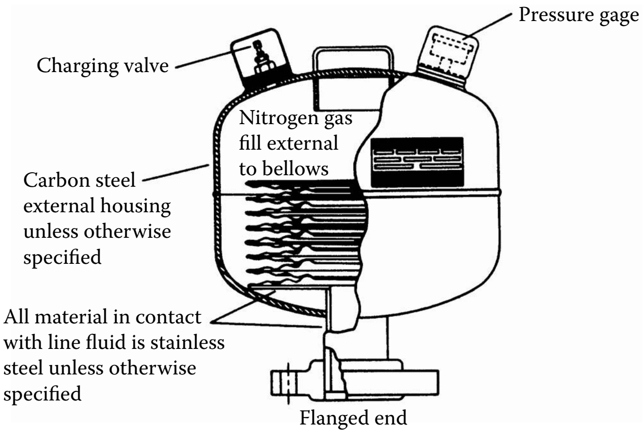


FIG. 7.4u
Pulsation dampener will suppress the pressure surges caused by positive displacement pumps. (Courtesy of the Meraflex Co.)

For liquids below approximately 50 centipoise (0.05 Pa·s), viscosity effects can be neglected, and Equation 7.4(6) reduces to

$$\text{NPSHA} = P - P_v \pm P_h - \frac{(lvGN)}{(525)} \qquad \textbf{7.4(7)}$$

The calculated value to NPSHA must be above the minimum suction pressure required by the selected pump.

In addition to multiple pumping heads, a pulsation dampener can be used on the pump discharge to smooth the discharge flow pulsations. The pulsation dampener is a pneumatically charged diaphragm chamber that stores energy on the pump discharge stroke and delivers energy on the suction stroke, thus helping to smooth the flow pulses. In order to be effective, however, the dampener volume must be equal to at least five times the volume displaced per stroke (Figure 7.4u), and the precharge pressure matched to the discharge pressure. Suction dampeners are also used to minimize the acceleration losses in the suction line if the NPSHA is close to the minimum, particularly for simplex and duplex designs; triplex designs are less sensitive. When handling flammable fluids, the piping code may call for the use of excess-flow valves in the suction line, to shut off the tank if the line ruptures. The use of these on a simplex or duplex reciprocating pump suction needs sizing for the maximum pump suction flow, not the average value.

OPPOSED CENTRIFUGAL PUMPS

The opposed centrifugal pump is not a control element but is an adaptation of a centrifugal pump to flow control. This method of control is particularly suitable for coarse, rapidly settling slurries at low flow rates. In such services the conflicting requirements of control at low flow and the need for a large free area to pass the solids may make it impossible

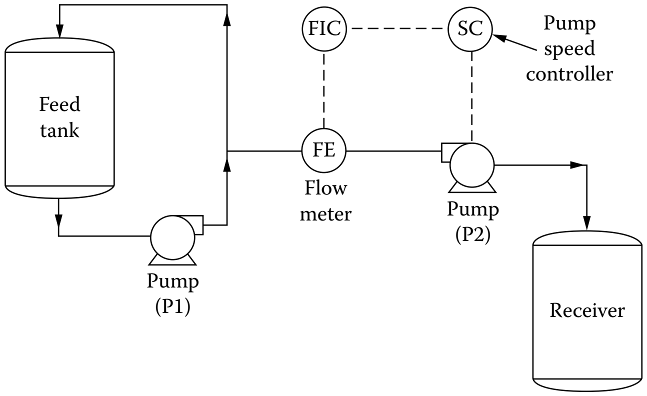


FIG. 7.4v
Opposed centrifugal pump as final control element.

to find a suitable control valve. A system that requires a small quantity of slurry to be fed to a receiving vessel under controlled conditions is depicted in Figure 7.4v. Pump P_1 continuously circulates the slurry from the feed tank at high velocity. A branch line from the discharge of P_1 is connected to the opposed centrifugal pump P_2. Pump P_2 is connected in opposition to the direction of slurry flow and provides a pressure drop to throttle flow. A variable-speed driver on pump P_2 throttles the pump pressure drop so as to keep the flow constant. At full speed the pressure difference across P_2 is sufficient to stop the branch line slurry flow completely. A magnetic flowmeter or some other suitable device can be used to measure the slurry flow. A VSD can be used to vary pump speed in response to the flow controller output signal.

A related approach utilizes a progressing-cavity pump as the restriction element, close-coupled to the circulating line and preferably discharging freely from the drive end. This does not need the flowmeter, as it is effectively positive displacement at low head, and flow is proportional to speed.

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