ANSI/HI 10.1–10.5-2010

Approved American National Standard

ANSI

American National Standard for

Air-Operated Pumps

for Nomenclature, Definitions, Application, and Operation

ANSI/HI 10.1–10.5-2010

Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
07054-4406
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Sponsor
Hydraulic Institute, Inc.
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Approved July 13, 2010
American National Standards Institute, Inc.

American National Standard

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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Institute are to promote the continued growth and well-being of pump manufacturers and further the interests of the public in such matters as are involved in manufacturing, engineering, distribution, safety, transportation and other problems of the industry, and to this end, among other things:

a) To develop and publish standards for pumps;

b) To collect and disseminate information of value to its members and to the public;

c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;

d) To increase the amount and to improve the quality of pump service to the public;

e) To support educational and research activities;

f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of Standards

1) Hydraulic Institute Standards are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.

2) Use of Hydraulic Institute Standards is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the standards.

Definition of a Standard of the Hydraulic Institute

Quoting from Article XV, Standards, of the By-Laws of the Institute, Section B:

"An Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and service for which designed."

Comments from users

Comments from users of this standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this standard may be directed to the Technical Director of the Hydraulic Institute. The inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of an Institute standard or an answer provided by the Institute to a question such as indicated above, the point in question shall be sent in writing to the Technical Director of the Hydraulic Institute, who shall initiate the appeals process.

Revisions

The Standards of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards are reaffirmed using the ANSI canvass procedure.

Scope

This standard applies to air-operated diaphragm and bellows pumps.

Units of measurement

Metric units of measurement are used; corresponding US customary units appear in brackets. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Refer to Table 10.2a for metric and US customary units.

Because values given in metric units are not exact equivalents to values given in US customary units, it is important that the selected units of measure to be applied be stated in reference to this standard. If no such statement is provided, metric units shall govern.

Consensus for this standard was achieved by use of the Canvass Method

The following organizations, recognized as having an interest in the standardization of air-operated pumps were contacted prior to the approval of this standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

A.W. Chesterton
ekwestrel corp
Hutchinson, Frank - Consultant
John Anspach Consulting
Patterson Pump Company
Pentair Engineered Flow - Fairbanks Morse
Pump Design, Development & Diagnostics
Weir Floway, Inc.
Weir Minerals North America
Wild, Alan - Consultant

Committee List

Although this standard was processed and approved for submittal to ANSI by the Canvass Method, a working committee met many times to facilitate its development. At the time it was developed, the committee had the following members:

Chair – Gary Cornell, Blacoh Fluid Controls, Inc
Vice-chair – Gregory Duncan, Wilden Pump & Engineering LLC

Committee Members	Company
Robert Piazza	Price Pump Company
David Roseberry	Warren Rupp, Inc.
Jonathan Wiechers	ARO/Ingersoll Rand

Alternates	Company
John Armitage	Price Pump Company
Pawel Bankowski	Price Pump Company
Nick Kozumplik	ARO/Ingersoll Rand
Michael Medaska	ARO/Ingersoll Rand
Oakley Roberts	ARO/Ingersoll Rand

10 Air-operated pumps

10.1 Types and nomenclature

An air-operated pump is a positive-displacement reciprocating pump used for general liquid transfer. It is driven by means of a compressed gas (usually air) from an outside source. Where "air" is used throughout this document, it should be taken to mean any compressed gas, but usually air.

Air-operated rotodynamic and rotary pumps are not included in this standard.

10.1.1 Types of air-operated pumps

Air-operated pumps fall into the basic types shown in Figure 10.1.1 and described below.

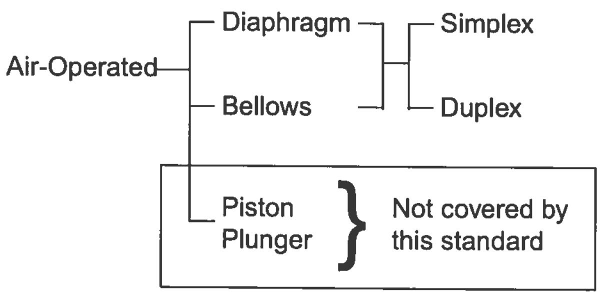


Figure 10.1.1 — Types of air-operated pumps

10.1.1.1 Air-operated diaphragm pump

An air-operated diaphragm pump contains a single diaphragm or double diaphragms connected to a reciprocating shaft in which one side of the diaphragm is in contact with the liquid being pumped and the other side is in contact with the compressed air. A typical air-operated double diaphragm (AODD) pump configuration is shown in Figure 10.1.1.1.

10.1.1.2 Air-operated bellows pump

An air-operated bellows pump contains two bellows connected to a reciprocating shaft in which one side of the bellows is in contact with the liquid being pumped and the other side is in contact with the compressed air. A typical configuration is shown in Figure 10.1.1.2.

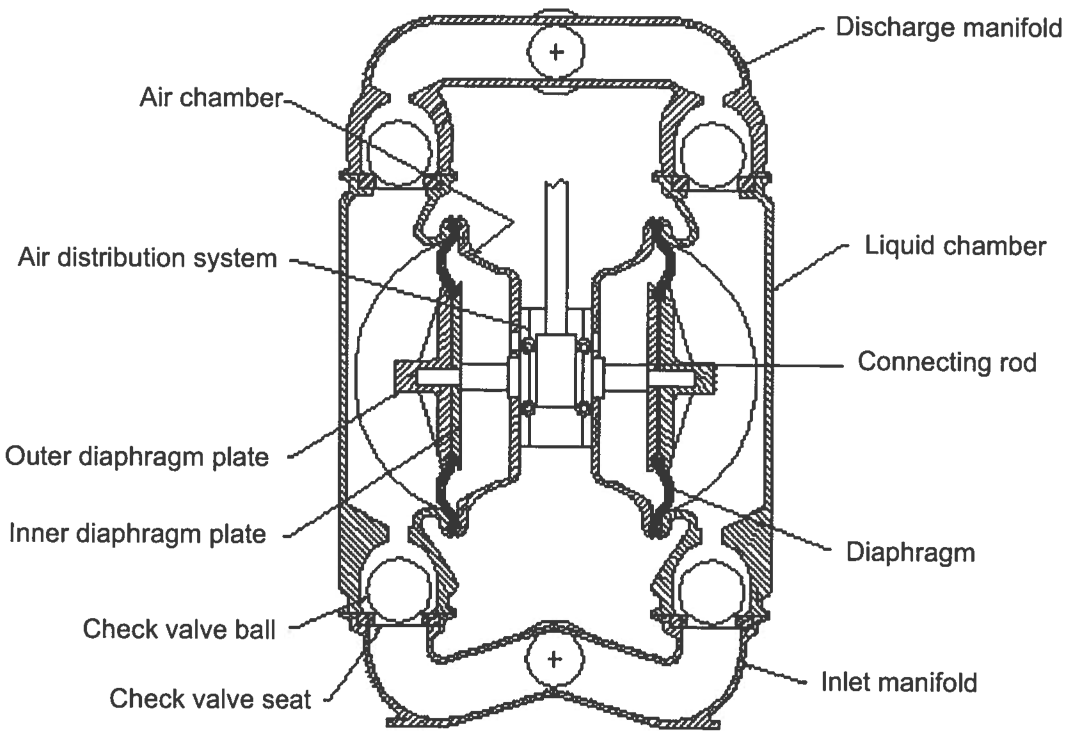


Figure 10.1.1.1 — Air-operated double diaphragm pump configuration

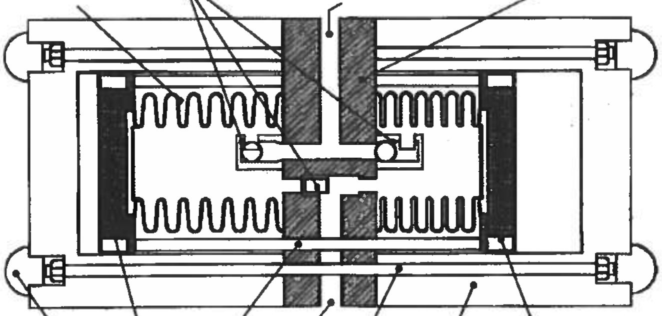


Figure 10.1.1.2 — Air-operated bellows pump configuration

10.1.2 Configuration of pumping devices

10.1.2.1 Simplex, single-acting

Contains one diaphragm or bellows.

10.1.2.2 Duplex, single-acting

Contains two diaphragms or bellows.

10.1.3 Nomenclature

The nomenclature and definitions in these standards were prepared to (1) provide a means for identifying the various pump components covered by these standards, and (2) to serve as a common language for all who deal with this type of equipment.

The following definitions and drawings illustrate typical constructions of air-operated pump components, but do not necessarily represent recommended designs. Variations in design may exist without violating the intent of these standards.

10.1.3.1 Air distribution system

The air distribution system consists of all parts within the pump required to operate the pump from the air inlet to the air exhaust. Various air distribution system designs exist, but all perform the same basic function.

10.1.3.2 Air chamber

The air chamber houses the pressurized air that causes the diaphragm or bellows to be displaced.

10.1.3.3 Diaphragm assembly

10.1.3.3.1 Diaphragm

The diaphragm provides for separation of the process liquid and the compressed-air power source. To perform adequately, the diaphragm should be of sufficient thickness and of appropriate material to prevent degradation or permeation in specified process liquid. Various diaphragm materials and configurations exist, but all perform the same basic function.

10.1.3.3.2 Inner and outer diaphragm plates

The inner and outer diaphragm plates provide means to support and to connect the diaphragm to the reciprocating shaft and aid in sealing the liquid side from the air side of the diaphragm.

Some manufacturers offer a diaphragm with an outer plate that is integrated and molded inside the diaphragm. This eliminates the requirement to achieve a seal between the diaphragm and the outer diaphragm plate. See Figure 10.1.3.3.2.

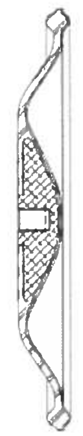


Figure 10.1.3.3.2 — Diaphragm with integral outer piston plate

10.1.3.4 Bellows assembly

10.1.3.4.1 Bellows

The bellows provide for separation of the process liquid and the compressed-air power source. Various bellows materials and configurations exist, but all perform the same basic function.

10.1.3.4.2 Bellows end caps and connecting rods

The bellows end caps and connecting rods provide a means to connect the bellows to the center block.

10.1.3.5 Wetted path housings

10.1.3.5.1 Liquid chamber

The liquid chamber is filled with the liquid being pumped during the suction stroke and empties during the discharge stroke. It is separated from the compressed gas by the diaphragm or bellows.

10.1.3.5.2 Inlet manifold

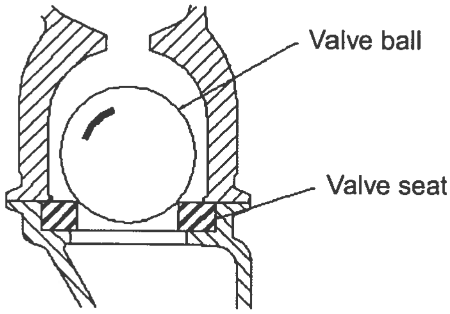
The inlet manifold contains the suction passageways of the pump. The inlet manifold for an air-operated reciprocating pump is typically at the bottom of the pump for configurations with ball check valves, but can be at the top for some configurations containing check valves other than ball check valves.

10.1.3.5.3 Discharge manifold

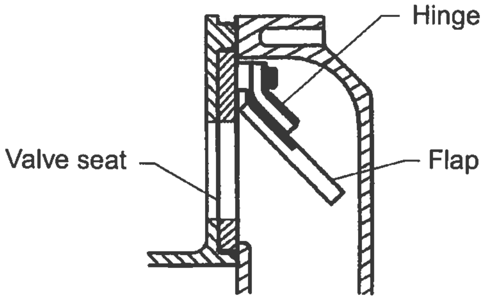
The discharge manifold contains the discharge passageways of the pump. The discharge manifold for an air-operated reciprocating pump is typically at the top of the pump for configurations with ball check valves, but can be at the bottom for some configurations containing check valves other than ball check valves.

10.1.3.6 Check valves

An air-operated pump uses suction and discharge check valves to produce directional flow of process liquid in the liquid chamber assembly. Various configurations of check valves are available for specific applications. The most common types are shown in Figure 10.1.3.6.



Ball Check Valve



Flap Check Valve

Figure 10.1.3.6 — Types of check valves

10.2 Definitions

The purpose of this section is to define terms used in air-operated pump applications. Symbols, terms, and units are shown in Table 10.2a and subscripts in Table 10.2b.

10.2.1 Rate of flow

10.2.1.1 Rate of flow (capacity) (*Q*)

The volume of liquid delivered per unit of time defined at suction conditions. It assumes no entrained gases at the stated operating conditions.

10.2.1.2 Stroke length (*L*)

The distance traveled in one complete unidirectional motion of a diaphragm or bellows and connecting rod.

10.2.1.3 Cycle

One complete motion of the diaphragms or bellows. Two strokes equal one cycle.

10.2.1.4 Cycle rate (*n*)

The number of cycles in a given unit of time, usually one minute.

10.2.1.5 Maximum cycle rate

The highest cycle rate achieved at maximum operating conditions.

10.2.1.6 Effective diaphragm area (A_{EFF})

An approximation of the actual working area of a diaphragm due to the flexibility of the diaphragm. It is determined by averaging the diameter at the outermost flex point of the diaphragm and the outside diameter of the outer diaphragm plate, and calculating the area from resultant diameter. (See Figure 10.2.1.6.)

$$A_{EFF} = \frac{\pi \times \left(\frac{(d_d + d_{DP})}{2}\right)^2}{4}$$

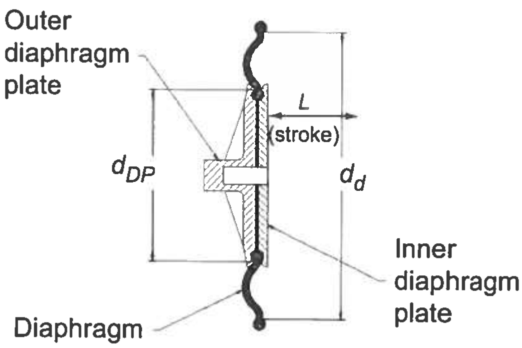


Figure 10.2.1.6 — Effective diaphragm area

Table 10.2a — Symbols

Symbol	Term	Metric unit	Abbreviation	US Customary Unit	Abbreviation	Conversion factor[a]
A	Area	square millimeters	mm^2	square inches	in^2	0.00155
D	Displacement per stroke	cubic meters	m^3	US gallons	gal	264.17
d	Diameter	millimeters	mm	inches	in	0.0394
g	Gravitational acceleration	meters/second/second	m/s^2	feet/second/second	ft/s^2	3.281
γ (gamma)	Specific weight	kilonewtons/cubic meter	kN/m^3	pounds/cubic foot	lb/ft^3	6.365
L	Stroke length	millimeters	mm	inches	in	0.0394
n	Cycle rate	cycles/minute	cpm	cycles/minute	cpm	1
NPIPA	Net positive inlet pressure available	kilopascals	kPa	pounds/square inch	psi	0.145
NPIPR	Net positive inlet pressure required	kilopascals	kPa	pounds/square inch	psi	0.145
NPSHA	Net positive suction head available	meters	m	feet	ft	3.281
NPSHR	Net positive suction head required	meters	m	feet	ft	3.281
π	pi = 3.1416	dimensionless	—	dimensionless	—	1
p	Pressure	kilopascals	kPa	pounds/square inch	psi	0.145
Q	Rate of flow (capacity)	cubic meters/hour	m^3/h	US gallons/minute	gpm	4.403
s	Specific gravity	dimensionless	—	dimensionless	—	1
t	Temperature	degrees Celsius	°C	degrees Fahrenheit	°F	$\left(°C \times \frac{9}{5}\right) + 32$
v	Velocity	meters/second	m/s	feet/second	ft/s	3.281
Z	Elevation gauge distance above or below datum	meters	m	feet	ft	3.281

[a] Conversion factor x metric units = US customary units.

Table 10.2b — Subscripts

Subscript	Term	Subscript	Term
a	absolute	H	total head
b	barometric	i	inlet
d	discharge	max	maximum
D	diaphragm	min	minimum
DP	diaphragm plate	s	suction
EFF	effective	v	velocity
f	friction	vp	vapor pressure
g	gauge	z	elevation

10.2.1.7 Displacement per stroke (D)

The volume swept by the bellows or diaphragm in one stroke.

The displacement per stroke can be approximated with the following formula:

$$D \approx A_{EFF} \times L$$

It should be noted that the actual displacement per stroke will vary to some degree with diaphragm construction and flow rate during operation due to the flexibility of the diaphragm. The effective area A_{EFF} for a bellows pump depends on the bellows geometry. Refer to the pump manufacturer for the effective bellows area.

10.2.1.8 Datum

The datum is the centerline of the pump inlet from which all elevations are measured. For example, the elevation pressure (p_z) to the datum is positive when the gauge is above datum and negative when the gauge is below datum.

10.2.2 Pressures

Pressure is the expression of the energy content of the liquid in units of force per unit area.

10.2.2.1 Inlet air pressure (p_i)

The gauge pressure of the compressed air or gas at the inlet port of the air distribution system.

10.2.2.1.1 Maximum allowable air inlet pressure ($p_{d\ max}$)

The maximum allowable gauge pressure at the pump air inlet that will not result in damage to the pump during operation as specified by the manufacturer.

10.2.2.2 Discharge pressure (p_d)

The liquid gauge pressure at the centerline of the pump discharge port.

10.2.2.2.1 Maximum allowable discharge pressure

The maximum allowable gauge pressure at the pump discharge that will not result in damage to the pump during operation.

10.2.2.3 Suction pressure (p_s)

The liquid gauge pressure at the centerline of the pump suction port.

10.2.2.4 Maximum allowable suction pressure ($p_{s\ max}$)

The maximum allowable gauge pressure at the pump inlet that will not result in damage to the pump during operation.

10.2.2.5 Total differential pressure (p_H)

The measure of the pressure increase imparted to the liquid by the pump, and is, therefore, the difference between the total discharge pressure and the total suction pressure:

$$p_H = p_d - p_s$$

NOTE: Air-operated pumps will produce a maximum discharge pressure that is established by the operating air pressure. Discharge pressure, rather than differential head, is often stated on performance curves.

10.2.2.6 Cavitation

Cavitation is defined as the phenomenon of vapor bubble formation in a liquid, in a region where the pressure falls below the liquid's vapor pressure, followed by sudden collapse of bubbles due to an increase in pressure in the same region, or downstream.

10.2.2.7 Friction loss pressure (p_f)

The loss of pressure in a liquid due to friction as it flows through pipe(s) and fittings.

10.2.3 Suction conditions

10.2.3.1 Submerged suction

A submerged suction exists when the pump inlet port is below the level of the liquid in the supply tank (Figure 10.4.1.6).

10.2.3.2 Flooded suction

Air-operated diaphragm pumps and air-operated pumps of the bellows type work most effectively with a flooded suction. A pump installation is considered to have a flooded suction when the surface of the pumping liquid is above the datum of the pump (Figure 10.4.1.3a).

10.2.3.3 Suction lift (priming)

When the pump datum is located above the surface of the supply liquid, it is considered a suction lift installation (Figure 10.4.1.3b). When a pump is installed in a suction lift system, be sure to consult the pump manufacturer's operating manual for suction lift capabilities of a given pump.

Pump priming is commonly referred to as *suction lift* for air-operated pumps. Suction lift is defined as the vertical elevation in meters (feet) of water that can be lifted through a column by the pump at sea level and room temperature. There are two types of priming: dry suction lift and wet suction lift.

10.2.3.3.1 Dry suction lift

Dry suction lift is defined as the vertical elevation in meters (feet) of water that can be lifted through an air column by the pump with the pump in an unprimed (dry) condition.

10.2.3.3.2 Wet suction lift

With the pump and suction piping full of fluid, the wet suction lift is defined as the vertical elevation in meters (feet) of water that can be lifted by the pump.

10.2.3.4 Net positive inlet pressure (NPIP)/Net positive suction head (NPSH)

10.2.3.4.1 Net positive inlet pressure available (NPIPA)/Net positive suction head available (NPSHA)

NPIPA is the total absolute suction pressure available from the system, determined at the pump suction nozzle, less the absolute vapor pressure of the liquid at pumping temperature.

NPIPA = $p_{sa} - p_{vp}$, in kPa (psi)

Where:

p_{sa} = total suction pressure + barometric pressure = $p_s + p_b$, in kPa (psi)

p_{vp} = vapor pressure of the liquid at the temperature being pumped, in kPa (psi)

or

NPIPA = $p_s + p_b - p_{vp}$, in kPa (psi)

Where:

(Metric units) $p_s = p_{gs} + p_v + Z_s/0.102$, in kPa

(US customary units) $p_s = p_{gs} + p_v + Z_s/2.31$, in psi

NPIPA is determined at the centerline of the pump suction nozzle.

NPSHA is the same concept expressed in units of meters (feet) of process fluid.

10.2.3.4.2 Net positive inlet pressure required (NPIPR)/Net positive suction head required (NPSHR)

NPIPR is the amount of suction pressure required by the pump to obtain satisfactory volumetric efficiency and minimize damage from cavitation. This is usually when there is no more than 3% reduction in flow rate (capacity) from the pump at any air inlet pressure and total head condition on the pump curve.

The pump manufacturer determines by test the net positive inlet pressure required by the pump at the specified operating conditions.

NPIPR is related to losses in the suction valves of the pump and frictional losses in the pump suction manifold and pumping chambers. NPIPR does not include system acceleration pressure, which is a system-related factor and can be a significant problem as explained in ANSI/HI 10.1-10.5, Section 10.2.3.6.

NPSHR is the same concept expressed in units of meters (feet) of process fluid.

10.2.3.5 Total suction lift

Total suction lift is the difference between the absolute operating inlet pressure at the pump inlet port centerline and atmospheric pressure. It is also the sum of suction system frictional losses and the static suction lift.

10.2.3.6 Acceleration head (h_{acc})/Acceleration pressure (p_{acc})

Total suction lift, as defined in the preceding paragraphs, represents the average, without reference to the fluctuation above and below this average, due to the inertia effect of the fluid mass in the suction line. This pressure fluctuation or acceleration pressure must be taken into account if the pump is to fill properly without separation and pounding or vibration of the suction line.

Acceleration head is the head required to accelerate the liquid column on each suction stroke so that there may be no separation of this column in the pump or suction line. If adequate acceleration head is not provided, then the pump may experience cavitation.

If there is insufficient head to meet the minimum acceleration requirement of NPIP/NPSH, then the pump may experience cavitation resulting in loss of volumetric efficiency. Damage may also occur due to the forces in collapsing the gas or vapor bubbles.

NOTE: The equation below was developed for reciprocating pumps. Characteristics of air-operated diaphragm pumps vary slightly from reciprocating pumps, so acceleration head or pressure losses in piping lengths up to 15.24 m (50 ft) calculated using the equation below will be a conservative value and need to be considered as a reference value only.

The pressure required to accelerate the fluid column is a function of the length of the suction line, the average velocity in this line, the cycle speed, the type of pump, and the relative elasticity of the fluid and the pipe and may be calculated as follows:

$h_{acc} = lvnC/Kg$ (metric and US customary units)

$p_{acc} = lvnCs/0.1Kg$ (metric units)

$p_{acc} = lvnCs/2.31Kg$ (US customary units)

Where:

h_{acc} = Acceleration head, in meters (feet) of process fluid

p_{acc} = Acceleration pressure, in kilopascals (pounds per square inch)

l = Length of suction line, in meters (feet)

v = Velocity in suction line, in meters per second (feet per second)

n = Pump speed, in cycles per minute

s = Specific gravity (dimensionless)

C = Coefficient as follows:

	Single-acting
Simplex	0.628
Duplex	0.200

K = A factor representing the relative compressibility of the liquid (K = 1.0 for urea and liquids with minimal entrained air; K = 1.4 for deareated water; K = 1.5 for amine, glycol, water; K = 2.0 for most hydrocarbons; K = 2.5 for hot oil)

g = Gravitational constant, 9.81 m/s^2 (32.2 ft/s^2)

A pulsation dampener properly installed near the pump inlet with a short, full-size connection to the pump or suction pipe can absorb the cyclical flow variation and reduce the pressure fluctuation in the suction pipe to that corresponding to a length of 5 to 15 pipe diameters, if properly adjusted.

There is a similar pressure fluctuation on the discharge side of every AODD pump, but it cannot be analyzed as readily because of the pressure influence on liquid and piping elasticity plus the smaller diameter and much greater length of the discharge line in most applications. However, a pulsation dampener can be just as effective in absorbing the flow variation on the discharge side of the pump as on the suction side, and should be used if pressure fluctuation or piping vibration is a problem.

10.2.4 Air consumption

The average volume of inlet air required at a specified operating condition of a pump.

10.2.4.1 Standard cubic feet per minute (SCFM)

A volumetric flow rate corrected to a set of "standardized" conditions of pressure, temperature, and relative humidity. The standard conditions are often defined as pressure of 14.7 psia, temperature of 60 °F, and relative humidity of 0%. But the conditions may vary depending on the "standard" used.

In countries using the metric system, the term *normal cubic meter per minute* (Nm^3/min) is often used to denote gas volumes at a normalized or standard condition.

10.2.5 Temperatures

10.2.5.1 Maximum operating temperature (t_{max})

The maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the liquid.

10.2.5.2 Minimum operating temperature (t_{min})

The minimum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the liquid.

10.2.6 Compressed-air properties

10.2.6.1 Condensation

The process of cooling air below its dew point and turning entrained water vapor into its liquid state.

10.2.6.2 Dew point

The temperature at which water vapor begins to condense at a given pressure.

10.2.6.3 Relative humidity

The ratio of the partial pressure of the vapor to the saturation vapor pressure at any given temperature.

10.2.6.4 Saturation vapor pressure

The pressure at which, at a given temperature, vaporization of the liquid takes place.

10.2.7 Liquid properties

10.2.7.1 Viscosity

A measure of a liquid's internal resistance to flow. Viscosity influences the amount of pressure a pump must generate to cause the liquid to flow.

10.2.7.2 Newtonian liquids

A liquid that exhibits no change in viscosity due to shearing or flowing of the liquid.

10.2.7.3 Thixotropic liquids

A liquid that exhibits a reduction in viscosity due to shearing or flowing of the liquid. Thixotropic liquids recover their original viscosity after some period of rest.

10.2.7.4 Dilatant liquids

A liquid that exhibits an increase in viscosity due to shearing or flowing of the liquid.

10.2.7.5 Colloidal liquids

A liquid that acts like a thixotropic liquid, but does not recover its original viscosity once the shear or flow is stopped.

10.3 Design and application

The purpose of this section is to provide general guidelines for the application of air-operated diaphragm and bellows pumps.

However, the general guidelines cannot guarantee successful operation in all given situations. The user is encouraged to obtain assistance from the manufacturer or its representative for specific applications.

10.3.1 Typical services

General: Air-operated diaphragm pumps are ideally suited for handling many kinds of liquids, including abrasive slurries, viscous liquids, and liquids containing high solids content. The liquid velocity through the check valves and pumping chambers usually does not exceed pipeline velocity and there is minimal scouring and abrasion from the pumped media. These pumps can be used for liquids with viscosity up to approximately 10,000 centipoise in small pumps (25 mm [1 in] and smaller) and up to 100,000 centipoise in larger pumps. Viscosity limit will vary from application to application. Because there is minimum turbulence and mixing, they are ideally suited for shear-sensitive materials, such as latex and polymers. Liquid pressures up to 8.6 bar (125 psi) and temperature range of –18 – 100 °C (0 – 212 °F) are typical.

Air-operated bellows pumps are typically suited for pumping clean liquids, low viscosity, and handling materials with a temperature range of 21 – 176 °C (70 – 350 °F) and liquid pressures up to 8.6 bar (125 psi).

Hazardous: When properly configured through the use of chemically resistant materials, secondary containment designs, and leak detection and spill prevention techniques, air-operated diaphragm pumps are ideally suited for handling hazardous liquids, including corrosive chemicals, neurotoxins, and carcinogens.

Liquids handled/applications: A variety of liquids can be handled by air-operated diaphragm pumps. Liquids and slurries handled by these pumps include ceramic slurry, paint, cement grout, chemicals, glue, resins, petroleum products, driller's mud, mill scale, ore concentrates, printer's ink, sewage, filter aids, latex, waste oils, wood preservatives, core washes, asphaltic coatings, bilge waste, radioactive waste, lapping compounds, porcelain frit, mine tailings, volatile solvents, coolant with metal fines, varnish, acids, coatings, soapstone slurries, explosives, lime slurries, yeast, chocolate, and wine. Typical applications include tank and container loading and unloading, liquid filtration, spray painting, adhesive application, process mixing and batching, cutting oil, machine coolant, lubrication, sump pumping, dewatering, and wastewater treatment. Consult the manufacturer to determine the liquid compatibility for the pump.

Bellows pumps are typically constructed for handling hot liquid, such as acids and bases used in the manufacture of semiconductor components.

Pumping dry powders: Diaphragm pumps can pump air as well as liquids, and have successfully pumped dry powders. Fluidized dry powder acts as a fluid medium with the powders in suspension, and the pump moves the gas containing the suspended powder. Sometimes it is necessary to inject gas into the powder to lower the apparent specific gravity and to get the powder into suspension. Consult with the manufacturer or its representative concerning safety precautions required when handling dry powders.

10.3.2 Diaphragm and bellows type pumps – design and operating features

10.3.2.1 Diaphragm type pumps

Air-operated pumps are a class of displacement pump featuring flexible membranes in combination with check valves used to move liquids into and out of pumping chambers. These pumps are used extensively in transfer and metering applications requiring flows up to about 1150 L/min (300 gpm). They are quite versatile, handling a wide variety of liquids including, but not limited to: chemicals, dry powders, food additives, glues, paints, pharmaceutical products, slurries, tailings, and wastewater.

Air-operated pumps have unique operating characteristics. They are sealless pumps, have no dynamic seals or packing, are self-priming, can run dry indefinitely, and can operate at infinitely variable rates of flow and pressure within the pressure and rate of flow range for the pump. The liquid discharge can be throttled to zero flow indefinitely. With the pump discharge valve closed, there is no power consumption. Air consumption is approximately proportional to flow rate: zero air consumption at zero flow rate and maximum air consumption at maximum flow rate. This feature allows air-operated diaphragm pumps to be used in applications requiring the flow rate to be varied from 0% to 100% of full flow.

The most common type is the double diaphragm pump (duplex pump), which has two pumping chambers and two flexible diaphragms. The diaphragms are connected to each other through a connecting rod and are clamped at the outer edges of the diaphragm. Continuous reciprocating motion, along with internal check valves, creates an alternating intake and discharge of pumped liquid into and out of each chamber that results in a nearly continuous pumping action from the combined chambers. See Section 10.4.2 and Figure 10.4.2.1 for details and an explanation of pump operation.

Simplex pumps use compressed air/gas directed to the back side of the diaphragm to expel liquid from a single pumping chamber. Spring return is typically used to return the diaphragm and provide energy for the suction stroke. The intake and discharge valves direct flow into and out of the pumping chamber.

10.3.2.2 Air-operated bellows pump

Air-operated bellows pumps are designed to handle some of the harshest chemicals in the world. The air-operated pump is a safe and easy pump to install and maintain. Most bellows pumps are made out of fluororesin to withstand the chemicals that are pumped and there are no exposed metal parts. This particular design, pictured in Figure 10.1.1.2, provides a high-purity pump that is a front-runner in the semiconductor industry in wet process tools. Bellows pump products are mainly used in cleaning, chemical-mechanical polishing (CMP) slurry, and chemical feed applications for wet benches.

The design of the bellows usually incorporates the latest materials and processes using flouropolymers, which provide ultimate life due to the shape and special material characteristics. A benefit of a bellows pump is that it distributes the stress over a number of convolutions to extend the life. The pump operates on externally supplied compressed air. The air is chambered from left to right in this particular product to create a chambering action that produces suction and discharge of the chemical, through the use of internal check valves. The amount of air pressure and volume supplied to the pump directly relates to the liquid discharge pressure.

Typically, air-operated bellows pumps need to be externally controlled. This can be done via proximity sensors and a controller or external air valves attached to each chamber of the pump. The use of proximity sensors maximizes the full stroke length of the bellows. They also allow the pump's discharge speed and the volume dispensed to be measured. Because there are no electronics or motors needed to operate a bellows pump, the temperature of the liquid can be extremely high.

10.3.3 Rate of flow

The rate of flow of an air-operated diaphragm pump is a function of three design values: effective diaphragm area (A_{EFF}), stroke length, and stroke speed. Effective diaphragm area (A_{EFF}) is a fixed value determined by the manufacturer's design. The stroke length is normally fixed by design, and along with A_{EFF}, is the other parameter that determines volumetric displacement per stroke. Variable stroke length may be optional from some manufacturers. Stroke speed is determined by the operating air pressure, the operating air volume, and the liquid backpressure at the discharge port of the pump.

10.3.4 Accuracy

These values are expressed in percent as deviations from the specified flow rate. Each application has its own requirement for accuracy. With proper pump selection, along with the system analysis, the accuracy can be greater or equal to the application requirements. Accuracy of ancillary devices must be evaluated and added to the pump deviation value.

10.3.5 Pump controls

An air-pressure regulator or valve in the compressed-gas supply line can be used to control the pumping pressure. An in-line throttling valve at the discharge port of the diaphragm pump can be used to control the pumping rate. Thus, the pressure and capacity are easily controlled.

Air-operated diaphragm pumps are displacement pumps, but due to diaphragm flexibility, their displacement will vary slightly with changes to air pressure, liquid pressure, and cycle rate.

10.3.6 Wetted parts selection

Many combinations of pump case and diaphragm materials are possible to cover a wide range of pumped products.

10.3.6.1 Pump case materials

Pump case materials include cast and ductile iron, aluminum, stainless steel, other metal alloys and nonmetallic materials. The nonmetallic materials include polypropylene, polyvinylidene fluoride (PVDF), PFA, polytetrafluoroethylene (PTFE), acetal reinforced with glass or metal fibers, and others.

10.3.6.2 Diaphragm/bellows selection and materials

Diaphragms are customarily made of fabric-reinforced synthetic rubber, fluoroelastomers, thermoplastic elastomers (TPEs), or PTFE. Bellows are typically made of PTFE or PFA.

Diaphragm materials include most of the synthetic rubbers, such as neoprene, nitrile, EPR/EPDM, and others. Fluoroelastomers, thermoplastic elastomers, and PTFE are also used for diaphragm materials. For some solvents and aggressive acids or alkalis, PTFE diaphragms can be used either directly or as an overlay on the conventional diaphragm.

10.3.6.3 Check valve selection and materials

Check valve components for diaphragm pumps are typically of three types: ball, flap, and poppet.

Ball checks are simply a ball on a round seat. They are the most common type and their advantages are high suction lift, compact size, and economical construction. Pumps with ball checks typically have a bottom inlet and top discharge. This arrangement allows air or vapor to be easily expelled from the pumping chambers. Trapped air or vapor can reduce the volumetric displacement of the pump because it is compressible. This may be a concern in low-flow, high-pressure applications, or when pumping viscous liquids. With high flows there is sufficient turbulence and mixing, however, usually there is sufficient mixing to purge the pumping chambers of the gases.

Flap checks have the advantage of being able to handle large, solid objects suspended in the liquid. Flap valves often hang vertically and use elastomeric hinges. Discharge is from the bottom of the pumping chambers, which is ideal for pumping suspended solids that may settle out, particularly at low flow or when the pump is idle.

Poppet-type check valves are usually guided by a valve stem and are spring loaded. This type of valve is not position sensitive and can operate in any orientation. They are typically used on smaller pumps and on low-viscosity, nonabrasive liquids.

Typically, check valve components are available in materials that match the diaphragm material or the pump case material. Materials commonly used are aluminum; stainless steel, both hard and soft grades; thermoplastics, such as polypropylene, PVDF, and others; and PTFE. For diaphragm pumps used to pump abrasive slurries, the valves usually have elastomeric faces or elastomeric balls. Large ball check valves may have metal cores covered by a thick wall of synthetic rubber or may be manufactured from solid rubber.

10.3.7 Effect of viscosity and specific gravity on pump performance

The manufacturer's published data are normally based on testing with water. The supplied air pressure, pump flow rate and NPIP/NPSH, and the pumping system determine the discharge pressure for a given air-operated diaphragm/bellows pump.

Liquids with viscosity below 500 centipoise do not usually affect manufacturers' published pump performance data. As viscosity increases above this value, the possibility of liquid cavitation increases, and pressure drops across pump components, particularly the suction check valve(s), raise NPIP/NPSH significantly.

Specific gravity can affect the pump suction performance. A liquid with a high specific gravity will reduce the manufacturer's published data on suction lift capabilities.

Viscous liquids tend to impede efficient check valve operation, which can result in a reduction of flow rate. This condition is caused by delayed check seating and reverse liquid flow.

Care should be taken to determine the nature of the liquid being pumped. Non-Newtonian or shear-sensitive liquids may have pumping characteristics unrelated to those observed with Newtonian liquids of similar quiescent viscosity. Apparent viscosity for an application using a non-Newtonian liquid can be adjusted based on flow rate conditions for the application by consulting the material manufacturer's shear rate versus shear stress diagram for the specific material.

10.4 Installation, operation, and maintenance

10.4.1 Installation

Air-operated pumps, when properly installed and given good care and regular maintenance, will operate satisfactorily for a long period of time. The following paragraphs discuss the general principles that must be considered to ensure trouble-free operation.

Air-operated pumps are built in a wide variety of designs for many different services. The manufacturer's instruction book, furnished with each pump, should be carefully studied and followed as there may be specific requirements of a particular pump or application that cannot be covered in a general discussion.

Inspect the pump before installation to avoid operational difficulties and ensure trouble-free start-up. Be sure to check all connections, especially clamp bands and bolts, as these may come loose during shipping. Retighten any connections as required.

To prevent undue stress and strain on the pump, use flexible connections near the pump on the suction and discharge piping. It is also recommended that flexible connections be used on the air inlet piping. Secure the pump to a mounting pad using appropriate diameter bolts. Rubber vibration insulators can be used between the pump mounting feet and the mounting pad to reduce vibrations and stresses.

Air-operated pumps that use a diaphragm or bellows are typically self-priming. Consult the manufacturer's operating manual for suction lift capabilities. The suction side of the pump must be investigated for NPIP/NPSH against NPIP/NPSH. It is important for the end-user to verify that the NPIP/NPSH for the system is greater than the NPIP/NPSH of the pump being used.

Inspect the air line connected to the pump and make sure it is clean. The air line should be large enough to supply the volume of air necessary to achieve the required pumping rate. Verify that the air line pressure does not exceed the maximum inlet air pressure allowed by the pump. If it does, an air pressure regulator must be installed in the air line.

A shut-off valve and pressure gauge should be located in both the liquid suction and liquid discharge lines. The air supply line should be clear of debris before pump start-up. Excessive moisture, debris, and oil in the compressed air is not recommended for these types of pumps. Unless otherwise specified by the manufacturer, air-operated pumps will operate within the limits of air cleanliness and quality of industrial air compressors and drying equipment. When possible, the cleanest, driest compressed air should be used. An air-line filter, regulator, and lubricator may be added to the air supply line when necessary (Figure 10.4.1). Consult the manufacturer's operating manual to see if these components are necessary. A more accurate method of determining pump head rise may be obtained by using a differential pressure gauge across the pump.

10.4.1.1 Location of the pump

Locate the pump as close to the liquid supply as possible, either submerged or so that a short, direct suction pipe may be used. Not all air-operated reciprocating pumps are designed to be submerged. Consult the manufacturer's operating instructions before submerging a pump. When possible, the location should be a clean area with adequate clearance to facilitate any repair, maintenance, or inspection activity.

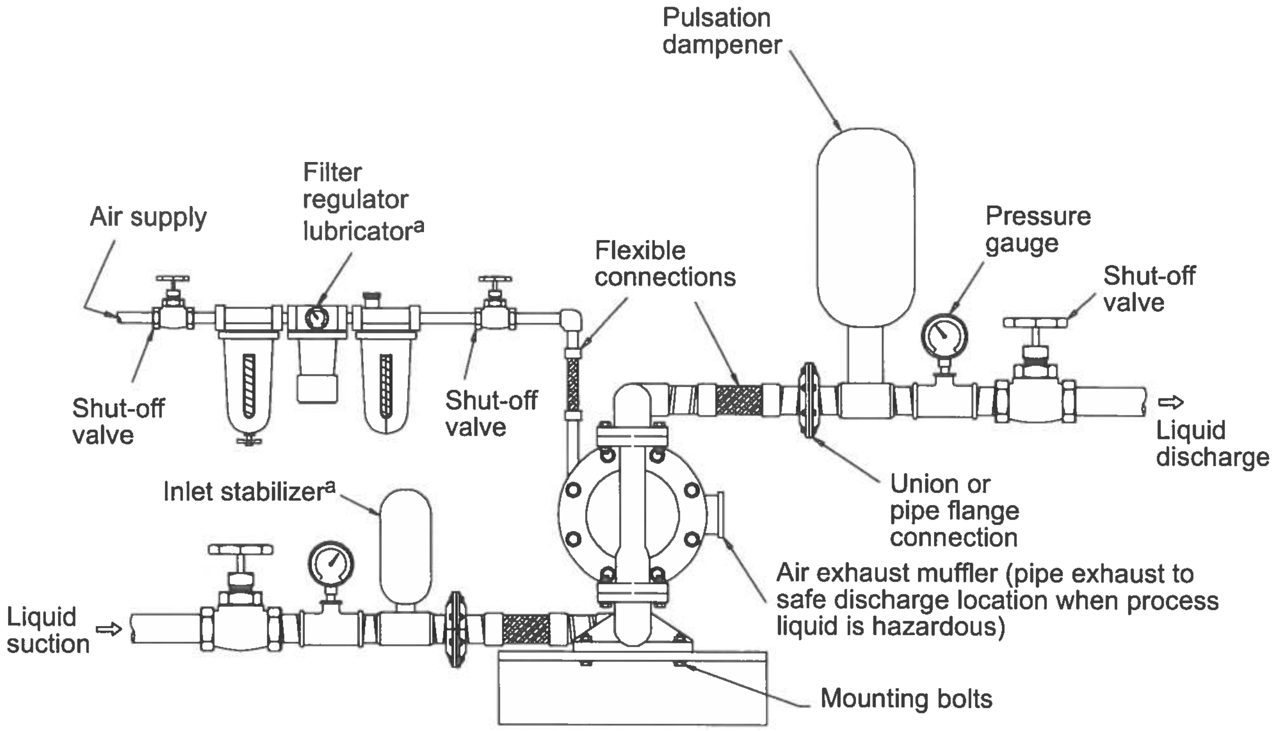
10.4.1.2 Piping

The liquid suction line should be as short and direct as possible to the liquid supply. Unnecessary bends shall be avoided. The recommended size of suction pipe to be used should be at least the size of the inlet port of the pump being used. The discharge piping should also be at least the size of the discharge port of the pump. In cases where the liquid suction line is long or the product being pumped has a high viscosity, a larger diameter pipe should be used. If suction hose is to be used, it must be of a reinforced, noncollapsible type as certain air-operated pumps are capable of generating a high vacuum.

The liquid suction line and the liquid discharge line must line up naturally with the pump. They must not be pulled into place, as this may force the pump out of alignment. Piping should be supported independently of the pump.

10.4.1.2.1 Forces and moments

Unless specified otherwise by the manufacturer, piping loads shall not be supported by pump connections.



[a] Denotes optional components.

Figure 10.4.1 — Suggested installation

10.4.1.3 Flooded and suction lift installations

Air-operated diaphragm pumps and air-operated pumps of the bellows type work most effectively with a flooded suction. A pump installation is considered to have a flooded suction when the surface of the pumping liquid is above the datum of the pump (Figure 10.4.1.3a). Inversely, when the pump datum is located above the surface of the supply liquid, it is considered a suction lift installation (Figure 10.4.1.3b).

When a pump is installed in a suction lift system, be sure to consult the pump manufacturer's operating manual for suction lift capabilities of a given pump.

10.4.1.4 Flanges and fittings

Flanged fittings, unions, and/or flexible connectors should be located close to the pump in all pipelines to facilitate removal of the pump. Flexible connections are recommended for the liquid suction and discharge lines along with the air inlet line. The flexible connections help absorb the vibration caused by air-operated pumps while in service. To further reduce pulsation and vibration in the system, a pulsation dampener next to the pump may be used.

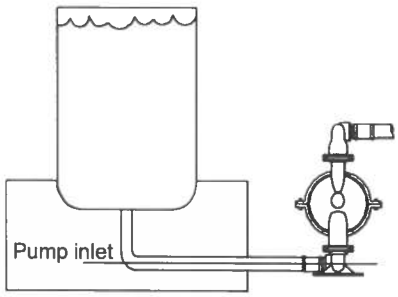


Figure 10.4.1.3a — Flooded suction installation

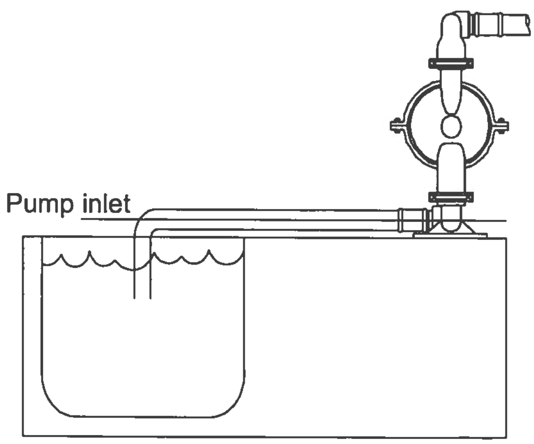


Figure 10.4.1.3b — Suction lift installation

A pulsation dampener installed at the pump discharge manifold can be used to minimize the pulsation and vibration in piping systems caused by the reciprocating action of the pump. The gas charge on one side of the dampener's diaphragm or bladder expands and contracts with the reciprocating action of the pump, which collects and releases liquid in the pipe and balances flow and pressure in the system. During pump operation mid-stroke, the pulsation dampener is recharged. An inlet stabilizer can be installed at the pump inlet to minimize the effect of acceleration head and cavitation.

10.4.1.5 Gaskets, pipe dope, and pipe tape

The gaskets, thread sealant, and pipe tape used in the system piping are exposed to the same conditions as the pump parts. Careful selection will avoid joint failure and air and process liquid leakage at the connections to the pump.

10.4.1.6 Mounting

Pumps can be located on the floor, a supporting surface, or, if small enough, directly on the plumbing, provided that the supporting installation area is strong enough to support at least 150% of the total unit weight. In most cases, a pump with ball check valves should be installed upright within 10° of the vertical centerline.

Some air-operated pumps are designed to be submerged. Before submerging a pump, check the chemical compatibility of the material of the wetted and nonwetted parts of the pump with the liquid in which the pump is to be submerged. Check the manufacturer's operation manual for a particular pump before trying to use it in a submergible application.

When submerging a pump, a hose should be attached to the pump air exhaust with the exhaust piped above the liquid level to prevent the liquid from entering the pump (Figure 10.4.1.6).

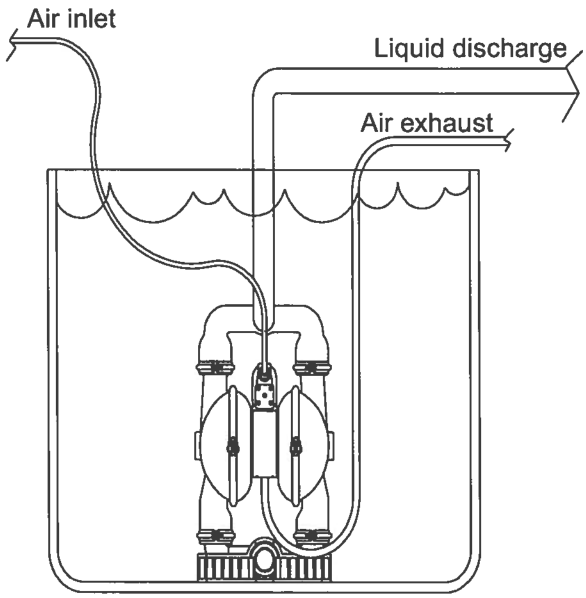


Figure 10.4.1.6 — Suggested submerged installation

10.4.2 Operation

10.4.2.1 General

Instructions for operation of an air-operated pump may vary by pump manufacturer. Therefore the following information should only be used as a general guide. Always follow the operating guidelines published by the manufacturer.

For a duplex pump, compressed air is directed into the pump air chamber via the air distribution system. The compressed air is separated from the liquid by a diaphragm. The diaphragm, in turn, applies pressure on the liquid and forces it out of the pump discharge. While this is occurring, the opposite-side air chamber is depressurized and exhausted to atmosphere and liquid is drawn into the pump suction. The cycle repeats, thus creating a constant reciprocating action, which maintains flow through the pump (Figure 10.4.2.1).

A simplex pump operates in much the same manner, however, no liquid is discharged during the recharge stroke of the diaphragm or bellows.

Pump rate of flow can be controlled by adjusting the pressure of the air supply to the pump. The use of an air-line regulator or flow control valve installed at the air inlet to the pump is suggested for this purpose. When operation is

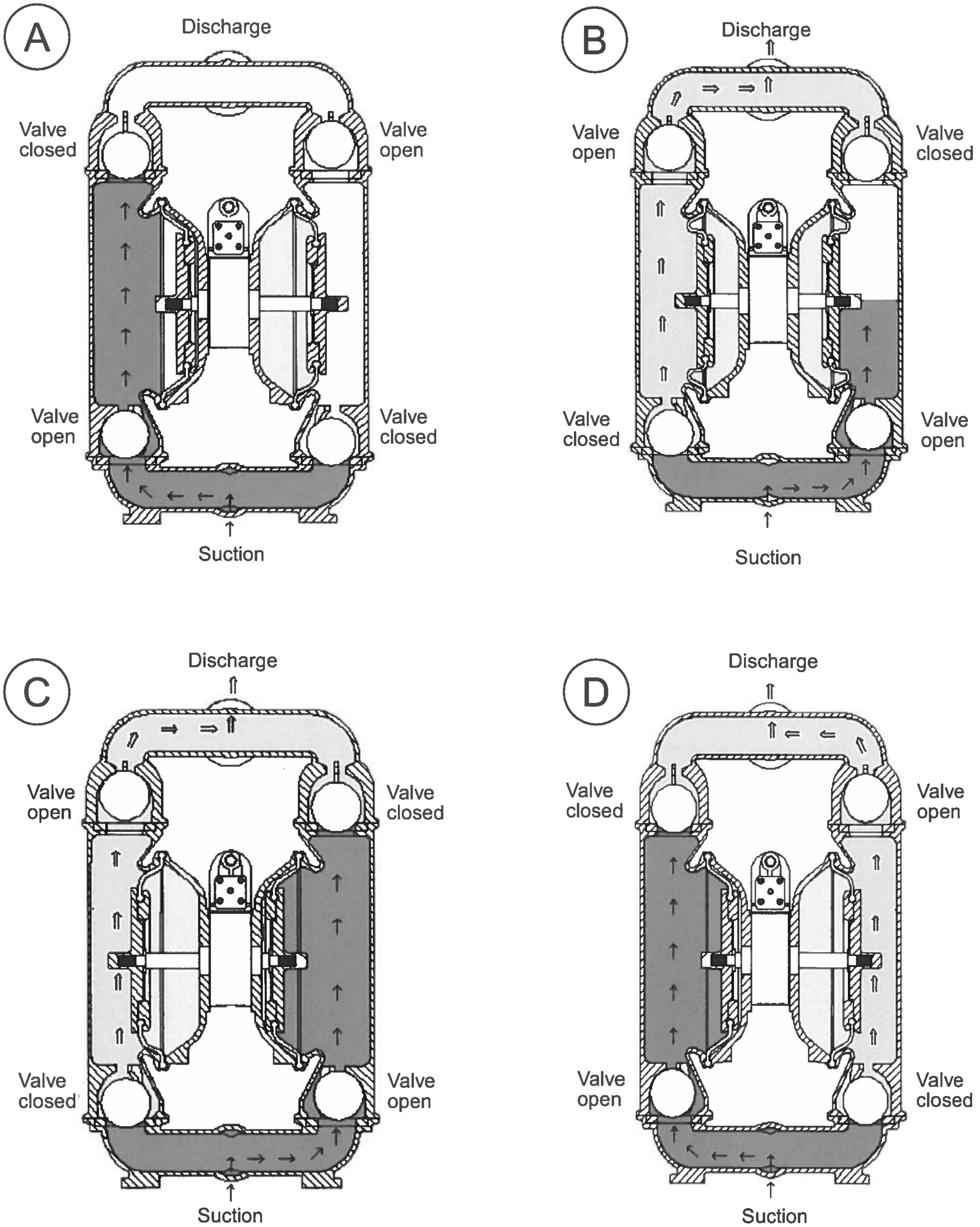


Figure 10.4.2.1 — Duplex pump operation

controlled by a solenoid valve in the air line, a three-way valve is suggested to relieve residual air pressure between the valve and pump.

Some diaphragm pumps and most bellows pumps are shifted by a solenoid valve and an electronic control system. One stroke occurs when the solenoid is energized and one when it is de-energized. These two strokes comprise a cycle. For these pumps, the rate of flow is controlled by varying the cycle speed.

The pump rate of flow can also be controlled by throttling the pump discharge by installing a valve in the discharge line of the pump. When the pump discharge pressure equals or exceeds the air supply pressure, the pump will stop; no bypass or pressure relief valve is needed, and pump damage will not occur.

Pumping rate of flow can be estimated by counting the number of strokes per minute and then multiplying this number by the manufacturer's published displacement per stroke.

10.4.2.1.1 Simplex pump

Simplex pumps require a controller to cycle the compressed air/gas into the air chamber of the pump and to exhaust the air out. The controller can be mechanical or electrical, such as a repeat cycle timer and solenoid valve. The speed of the pump is set by the controller. Maximum speed is determined by the manufacturer.

10.4.2.1.2 Duplex pump

To determine the maximum pumping speed on a duplex pump, increase the air supply while the pump rate of flow increases. When the rate of flow no longer increases, throttle back the air supply until the pump rate of flow starts to decrease. This point is the optimum pump cycle rate achievable under these system conditions.

Priming bottom-suction, ball check type pumps is best accomplished using a slow cycle speed with an open discharge valve. Priming top-suction, flap check type pumps is best accomplished using a high cycle speed with an open discharge valve.

10.4.3 Safety

Be sure to comply with all warnings listed on the pump and/or defined in the manufacturer's operating manual. This listing is typical. Specific pumps may have additional requirements. Refer to the pump manufacturer's operating manual for a complete list of safety precautions.

- Do not exceed the maximum air inlet pressure as stated on the pump or in the operating literature. Be sure all hose, piping, fittings, etc. are rated for the same pressures as the pump.

- Static electricity is generated by liquid flow through a pump. If the pump is not properly grounded, static spark may occur. The pump and pumping system must be properly grounded per local and national codes.

- Secure pump, connections, and all contact points to avoid vibrations and generation of contact or static spark.

- Pipe exhaust away from the work area and personnel. In the event of a diaphragm or bellows rupture, material may be forced out of the air exhaust system. Pipe the exhaust to a safe location when pumping hazardous or flammable material.

- Verify the chemical compatibility of the pump's wetted parts with the substance being pumped, flushed, or circulated. Chemical compatibility may change with temperature and chemical concentration. Also, certain types of pumps are incapable of handling liquids that crystallize, liquids that contain slurry, solvent-type liquids, etc.

- Do not exceed maximum operating temperatures of pumping media as listed in the manufacturer's operating manual.

- Never operate a pump that is leaking, damaged, corroded, or otherwise unable to contain the internal liquid pressure.
- To avoid trapping liquid pressure when stopping an air-operated pump, it is important to first open the discharge side of the pump and then close the supply air pressure valve.
- If pump operation is to be stopped for a prolonged period, be sure to remove the remaining liquid from the pumping chamber.
- Do not supply air to both the right and left air supply ports of a bellows type pump when pump operation is suspended. This will pressurize the bellows and deform them.
- Care should be taken to dispose of toxic or flammable liquids or vapors properly.
- The work area should be kept clear and any unnecessary items removed.
- All lifting devices should be checked for condition and capacity limits before using.
- Before dismantling, assembling, or performing maintenance on the pump, the proper tools, correct parts, and manufacturer's operating manual should be available.

10.4.3.1 Storage

If an air-operated pump has been stored for six months or longer, check with the manufacturer for the shelf life of the elastomers used in the construction of the pump.

10.4.4 Maintenance

10.4.4.1 Inspection

A regular inspection schedule should be made and each inspection should be recorded. A proper log of maintenance problems and replacement parts may aid in preventing future pump or pump part failures. Most pump failures can be traced to improper suction conditions, poor maintenance, or to faulty conditions outside of the pump itself. There is no substitute for regular, thorough, preventive maintenance.

Wear parts should be inspected regularly. Check with the pump manufacturer for a list of the wear parts. Typical wear parts include diaphragms or bellows, check valve components, and seals. It is good practice to replace all wear parts at the same time during a maintenance checkup.

If in-line air filter and water/oil separator units are being used, proper and timely servicing of the these components will add longer life to the interior pump air distribution system.

10.4.4.2 Malfunctions, cause and remedy

In the event of a malfunction of the pump, after normal operation, refer to Table 10.4.4.2a for diaphragm pumps and Table 10.4.4.2b for bellows pumps for the most probable cause and remedy of malfunctions. For product-specific malfunctions, consult the manufacturer's operating manual for more causes and remedies.

Table 10.4.4.2a — Diaphragm pump malfunctions – cause and remedy

Malfunction	Probable Cause	Remedy
Pump will not cycle or cycles slowly	Ruptured diaphragm	Replace the diaphragm
	Suction and/or discharge blocked	Repair as required
	Insufficient air pressure and/or volume	Increase air pressure/volume
Unbalanced cycling	Ball (or flap) valve is not seating on one side	Inspect for wear or contamination on balls (or flaps) as required
	Ruptured diaphragm	Replace the diaphragm
Pump cycles but little or no product flows	Improper suction conditions (cavitation)	Move pump closer to pumped liquid and/or reduce suction line restriction
	NPSHR > NPSHA	Reduce pump speed to match viscosity of the material being pumped
	Air leak on suction side	Make sure that all suction connections are air-tight
	Improper seating of ball (or flap) checks	Check for (air) suction on suction port with gauge and/or disassemble ball (or flap) checks and look for proper seating between check and seat
		Make sure that the material being pumped is compatible with the pump elastomers
	Blockage of suction or discharge line	Repair as required
	Ruptured diaphragm	Replace the diaphragm
	Pump is not primed	Follow priming directions per Section 10.4.2.1.2
	Air distribution system problem	See manual
Pump air distribution system freezes	Excessive moisture in compressed air	Consult operating manual
		Install/set air dryer to the pump manufacturer's recommended dew point setting
		Reduce moisture in compressed air to the pump manufacturer's recommendation
	High head pressure	Reduce head pressure
Air bubbles in the pump discharge	Ruptured diaphragm	Replace the diaphragm
	Loose connections in suction line	Check the suction line connection and the tightness of clamp bands and bolts
Pumping liquid comes out of the air exhaust	Ruptured diaphragm	Replace the diaphragm

Table 10.4.4.2b — Bellows pump malfunctions – cause and remedy

Malfunction	Probable Cause	Remedy
Pump does not operate	Bellows is damaged	Replace the pump
	Supply air pressure is reduced	Set back to initial set value (RESET) or recheck capacity
	Compressor failure	Inspect and repair
	Pressure setting of reducing valve is not correct	Reset pressure
	Air filter is clogged or air leaks from pipe	Clean or repair if necessary
	Wrong wiring or disconnection	Inspect and rearrange the wiring normally
	Faulty selection of solenoid valve	Inspect and clean, or repair if necessary
	Galling or damage of connecting rod, central block, and/or seals	Inspect and replace if necessary
	Increased discharge pressure in liquid feeding pipe	Inspect filter and replace if necessary
Pump operates, but no liquid is discharged	Pump head (inside bellows) is clogged with foreign matter	Replace pump head
	Air suction through suction pipe	Tighten pipe couplings
Discharge volume is reduced	Supply air pressure or volume is reduced	Reset to initial value
	Compressor failure	Inspect and repair
	Pressure setting of reducing valve is not correct	Reset pressure
	Air filter is clogged or air leaks from pipe	Clean or repair if necessary
	Insufficient NPSHA	Inspect and improve suction condition
	Increased discharge pressure	Inspect and improve discharge condition
	Pump head (inside bellows) is clogged with foreign matter	Inspect suction conditions and take measures and, if necessary, replace pump head
Liquid leaks	Bellows is damaged	Replace pump head
Air consumption is excessive	Connecting rod seals are worn	Replace pump head

Appendix A

Index

This appendix is not part of this standard, but is presented to help the user in considering factors beyond this standard.

Note: an f. indicates a figure, and a t. indicates a table.

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