

American National Standard for

# Pumps – General Guidelines

for Types, Definitions, Application, Sound Measurement and Decontamination

ANSI/HI 9.1-9.5-2000



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First Floor North  
Parsippany, New Jersey  
07054-4406  
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**Pumps – General Guidelines**  
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Decontamination

Secretariat  
**Hydraulic Institute**  
[www.Pumps.org](http://www.Pumps.org)

Approved March 10, 2000  
**American National Standards Institute, Inc.**

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Published By

**Hydraulic Institute**  
**6 Campus Drive, First Floor North**  
**Parsippany, NJ 07054-4406**

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Printed in the United States of America

ISBN 1-880952-43-2



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## Contents

	Page
Foreword .....	v
<b>9 Pumps – general guidelines</b>	
9.0 Scope .....	1
9.1 Types of pumps .....	1
9.1.1 Positive displacement pumps .....	1
9.1.2 Kinetic pumps .....	1
9.2 Definitions .....	3
9.2.1 Hardware terms .....	3
9.2.2 Slurry application terms .....	5
9.3 Design and application .....	7
9.3.1 Preferred measurement units and conversion factors .....	7
9.3.2 Materials .....	11
9.3.3 Common polymer materials of construction for various liquids. ....	37
9.4 Measurement of airborne sound .....	50
9.4.1 Instrumentation .....	50
9.4.2 Operation of pumping equipment .....	50
9.4.3 Test environment .....	50
9.4.4 Microphone locations .....	50
9.4.5 Measurement technique .....	51
9.4.6 Measurements to be taken .....	51
9.4.7 Calculation and interpretation of readings .....	52
9.4.8 Presentation of data .....	52
9.4.9 Airborne sound level test report .....	53
9.5 Decontamination of returned products procedure .....	61
Appendix A Bibliography .....	62
Appendix B Index .....	63
<b>Figures</b>	
9.1 — Types of pumps .....	2
9.2 — General ranking of cavitation erosion resistance of common cast metals when pumping clear water at ambient temperature .....	28
9.3 — Correction for background sound .....	54
9.4 — Horizontal end suction centrifugal pump .....	54
9.5 — Axially split case centrifugal pump .....	55

9.6 — Vertical in-line centrifugal pump . . . . .	55
9.7 — Double case centrifugal pump . . . . .	56
9.8 — Axially split case multistage centrifugal pump . . . . .	57
9.9 — Horizontal reciprocating pump . . . . .	57
9.10 — Vertical reciprocating pump . . . . .	58
9.11 — Horizontal rotary gear pump . . . . .	59
9.12 — Horizontal rotary screw pump . . . . .	59
9.13 — Vertical rotary pump . . . . .	60

Tables

9.1 — Examples of rounded equivalents . . . . .	7
9.2 — Hydraulic Institute – Preferred measurement units and conversion factors . . . . .	8
9.3 — Materials of construction for pumping various liquids . . . . .	29
9.4 — Polymers used in pump construction . . . . .	38
9.5 — Guide for maximum continuous temperature (°C) liquid vs. material selection for polymer pumps . . . . .	40
9.6 — Guide for maximum continuous temperature (°F) liquid vs. material selection for polymer pumps . . . . .	45

## 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 Hydraulic Institute. It will direct all such questions to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of an Institute publication or an answer provided by the Institute to a question such as indicated above, the point in question shall be referred to the Executive Committee of the Hydraulic Institute, which then shall act as a Board of Appeals.

## 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.

## Units of Measurement

Metric units of measurement are used; corresponding US units appear in brackets. Charts, graphs and sample calculations are also shown in both metric and US units.

Since values given in metric units are not exact equivalents to values given in US 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 centrifugal pumps were contacted prior to the approval of this revision of the standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

A.R. Wilfley & Sons, Inc.	Fluid Sealing Association
ANSIMAG Incorporated	Franklin Electric
Arizona Chemicals	Graco, Inc.
Bal Seal Engineering	Grundfos Pumps Corporation
Bechtel Corporation	Haskel International, Inc.
Black & Veatch LLP	Illinois Department of Transportation
Bran & Luebbe	IMO Pump Industries, Inc.
Brown & Caldwell	Ingersoll-Dresser Pump Company
Camp Dresser & McKee, Inc.	Ingersoll-Rand/ARO Fluid Products Div.
Carver Pump Company	ITT Commercial Products Group
Cascade Pump Co.	ITT Flygt Corporation
Chas. S. Lewis & Company, Inc.	ITT Industrial Pump Group
Cheng Fluid Systems, Inc.	Iwaki Walchem Corporation
Crane Company, Chempump Division	J.P. Messina Pump and Hydr. Cons.
Crane Pumps & Systems, Inc.	Jim Walters Resources
Cuma S.A.	John Crane, Inc.
David Brown Union Pumps	Krebs Consulting Service
Dean Pump Division, Metpro Corp.	KSB, Inc.
DeWante & Stowell	Lawrence Pumps, Inc.
Dow Chemical	M.W. Kellogg Company
Englehard Corp.	Malcolm Pirnie, Inc.
EnviroTech Pumpsystems	Marine Machinery Association
Equistar LP	Marshall Eng. Prod. Co. (MEPCO)
Essco Pumps	McFarland Pump Company L.L.C.
Exeter Energy Limited Partnership	Milton Roy Flow Control
Fairbanks Morse Pump Corp.	Montana State University Dept. Civil Engineering
Ferris State Univ. Const. and Facilities Dept.	Moving Water Industries (MWI)
Flow Products, Inc.	Moyno Industrial Products
Floway Pumps	Neptune Chemical Pump Company
Flowserve Corporation	

Ortev Enterprises Inc.  
Pacer Pumps  
Patterson Pump Company  
Pinellas County, Gen. Serv. Dept.  
The Process Group, LLC  
Product Consulting, Inc.  
Raytheon Engineers & Constructors  
Red Jacket  
Reddy-Buffaloes Pump, Inc.  
Scot Process Equipment Corp.  
Settler Supply Company  
Skidmore Pump Co.  
South Florida Water Mgmt. Dist.  
Sta-Rite Industries, Inc.

Sterling Fluid Systems (USA) Inc.  
Stone & Webster Eng. Corp.  
Sulzer Pumps (USA) Inc.  
Summers Engineering, Inc.  
Systecon, Inc.  
Tuthill Pump Group  
Val-Matic Valve & Manufacturing Corp.  
Versa-Matic Pump Co.  
Viking Pump, Inc.  
Warren Rupp, Inc.  
Wilden Pump & Engineering Co.  
Williams Instrument Co., Inc.  
Yeomans Chicago Corporation  
Zoeller Engineered Products

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# 9 Pumps – general guidelines

## 9.0 Scope

This Standard applies to all industrial/commercial pumps, including centrifugal, vertical, rotary and reciprocating types. It includes: types; definitions; design and application; airborne sound measurement and decontamination.

## 9.1 Types of pumps

Industrial/commercial pumps are used in an infinite variety of applications, and many different configurations of design are used to satisfy these requirements.

The different designs can be typified diagrammatically, as shown in Figure 9.1 on the following page. The first distinction is the manner in which the machine adds energy and moves the liquid.

### 9.1.1 Positive displacement pumps

Positive displacement pumps add energy by trapping liquid in a confined space and forcibly moving it out of the pump and into the discharge pipe. This pumping action is done by one of three methods:

- 1) Reciprocating action of plungers, pistons, bellows or diaphragms;
- 2) Rotary action of mechanical devices such as gears, screws, vanes, etc.;
- 3) Blow case arrangements using pressurized air to displace liquid.

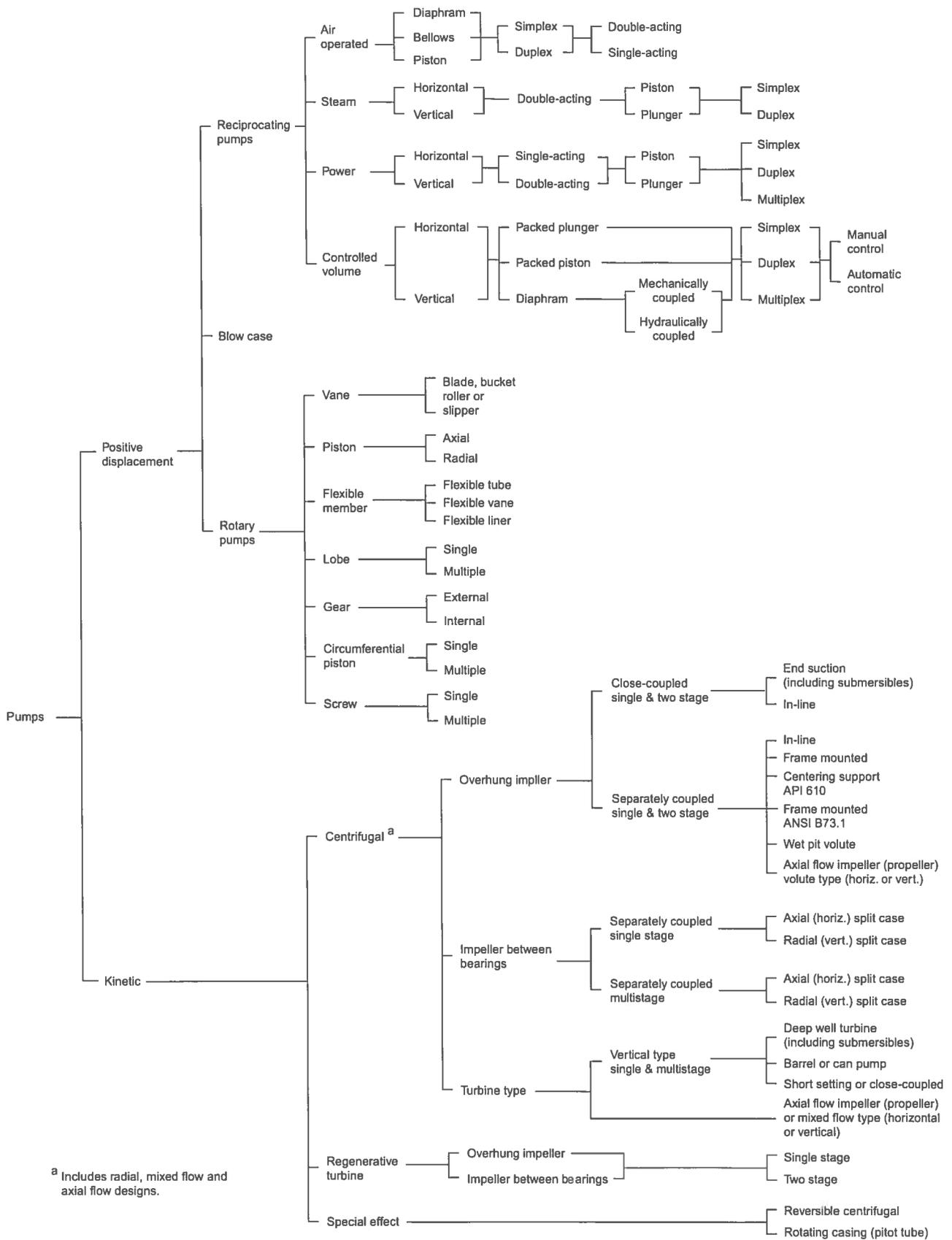
### 9.1.2 Kinetic pumps

Kinetic pumps add energy by high-speed rotating wheels or impellers and fall into the following categories:

- Centrifugal, both horizontal and vertical turbine types;
- Regenerative turbine;
- Rotating casing with pitot tube.

Each of the above pump types are described further in one of the sections of this series of standards as follows:

Standard	Pump type
HI 1.1-1.5	Centrifugal pumps
HI 2.2-2.5	Vertical pumps
HI 3.1-3.5	Rotary pumps
HI 4.1-4.6	Sealless rotary pumps
HI 5.1-5.6	Sealless centrifugal pumps
HI 6.1-6.5	Reciprocating power pumps
HI 7.1 -7.5	Reciprocating controlled volume metering pumps
HI 8.1-8.5	Reciprocating direct acting pumps
HI 10.1-10.6	Air operated pumps



<sup>a</sup> Includes radial, mixed flow and axial flow designs.

Figure 9.1 — Types of pumps

## 9.2 Definitions

### 9.2.1 Hardware terms

**9.2.1.1 accumulator:** A mechanical device which stores pressure energy of any noncompressible liquid held under pressure by an external source against some dynamic force.

**9.2.1.2 alleviator:** A device, usually a pressure vessel with a liquid-gas interface used to absorb or reduce the hydraulic “shock” or “water hammer” caused by rapidly closing valves.

**9.2.1.3 bearing:** A device which supports or positions the pump shaft. It may be either a rolling element bearing (ball or roller) or fluid film type (sleeve and journal), and it may be internal (wetted by the pumped liquid) or external.

**9.2.1.4 body:** An external part which surrounds the periphery of the pumping chamber. It is sometimes called a casing or a housing.

**9.2.1.5 burst disc (rupture):** A thin membrane or diaphragm, usually of metal, fitted in a suitable holder in the wall of a pressure vessel. Physical proportions of the disc are selected so that it will rupture at a predetermined pressure, thus providing virtually unobstructed passage for pressure relief.

**9.2.1.6 bypass piping:** Alternate conduit through which liquid may be made to flow around any component(s) in a liquid handling system.

**9.2.1.7 check valve:** A valve which permits flow in one direction only.

**9.2.1.8 column, piping:** A vertical pipe by which the pump is suspended.

**9.2.1.9 compound gauge:** A gauge capable of measuring vacuum and pressure.

**9.2.1.10 dead weight tester:** An instrument used for calibrating gauges. Known hydraulic pressures are generated by means of weights loaded on a calibrated piston.

**9.2.1.11 dynamometer (see transmission dynamometer):** A device used to determine pump input power.

**9.2.1.12 eddy current drive coupling:** A device in which drive coupling excitation of a coil sets up a magnetic drag that controls the output speed.

**9.2.1.13 end plate:** An external part that closes an end of the body to form the pumping chamber. One or more are used, depending on the construction of the pump. It is sometimes called a head or cover.

**9.2.1.14 flexible coupling:** A device for connecting two rotating shafts that is designed to accept limited, varying amounts of misalignment between shafts.

**9.2.1.15 fluid drive:** A drive in which hydraulic fluid serves as a means of transmitting power from one part of the system to another.

**9.2.1.16 foot valve:** A check valve installed at the foot of the suction line.

**9.2.1.17 gland, packing:** An adjustable follower that compresses packing in a stuffing box.

**9.2.1.18 heat exchanger:** A device that transfers heat from one fluid to another.

**9.2.1.19 inlet or suction port:** One or more openings in the pump through which the pumped liquid may enter the pumping chamber.

**9.2.1.20 jacketed pump:** A pump in which the body and/or end plates incorporate passageways through which steam, oil, water or other fluids can be circulated, typically to control the temperature of the pump and/or the pumped liquid.

**9.2.1.21 lantern ring:** Sometimes referred to as seal cage and used in the stuffing box between packing rings to provide a means of introducing lubrication or sealing mediums in the packed stuffing box.

**9.2.1.22 lip seal:** A device that normally statically seals on its outside diameter by means of an interference fit and also dynamically seals to a rotating or reciprocating shaft by means of a flexible, radial-loaded lip.

**9.2.1.23 mechanical seal:** A mechanical device for sealing the shaft as opposed to packing. Mechanical seals generally consist of a rotating element, stationary element and, sometimes, a gland plate.

**9.2.1.24 mechanical seal chamber:** The space inside the pump casing that houses the mechanical seal.

**9.2.1.25 mechanical seal gland:** A plate or cover that closes the end of the mechanical seal chamber. It usually contains the stationary part of the mechanical seal.

**9.2.1.26 mud (slush) pump:** A pump used to circulate drilling mud.

**9.2.1.27 nozzle:** A device used to convert liquid pressure to velocity.

**9.2.1.28 oil seal:** A contact seal or cover used to retain oil.

**9.2.1.29 orifice:** A pressure breakdown device consisting of one or more sudden contractions and sudden enlargements in series, sometimes used for measuring rate of flow.

**9.2.1.30 outlet or discharge port:** One or more openings in the pump through which the pumped liquid may leave the pumping chamber.

**9.2.1.31 packing:** A deformable substance used to provide sealing between shafts, rods or plungers and the pressure containing housings.

**9.2.1.32 packing box:** The portion of the casing or cover through which the shaft extends and in which packing or a mechanical seal is placed to limit leakage. (See stuffing box and seal chamber.)

**9.2.1.33 packing gland:** An adjustable follower which compresses packing in a stuffing box.

**9.2.1.34 pilot-operated relief valve:** A power actuated relief valve installed in a pump system which prevents build up of pressure beyond a preselected limit.

**9.2.1.35 pulsation dampener:** A device to reduce liquid pulsation on the suction or discharge side of the pump. It is also referred to by the following names:

- Suction chamber;
- Surge chamber;
- Cushion chamber;
- Discharge chamber;

- Suction stabilizer;
- Desurger;
- Alleviator.

**9.2.1.36 pump:** A device that adds energy to liquids in one or more of the following ways: increase pressure, increase velocity and/or increase elevation. The net effect is usually to facilitate the movement of the liquid.

**9.2.1.37 radial seal:** A device that seals on its outside diameter through an interference fit with its mating bore and on a rotating shaft with flexible, radially loaded surface. Radial seals include lip type seals, "O" rings, "V" cups, "U" cups, etc., and may or may not be spring-loaded.

**9.2.1.38 receiver-pulsation dampener:** A device that reduces liquid pulsations.

**9.2.1.39 relief valve:** A mechanism designed to limit or control pressure by the opening of an auxiliary liquid passage at a predetermined or set pressure.

**9.2.1.40 revolution counter:** A device to measure the number of revolutions of a pump or motor shaft.

**9.2.1.41 rotor:** A part that rotates in the pumping chamber. One or more are used per pump. It is sometimes referred to by a specific name such as gear, screw, impeller, etc.

**9.2.1.42 seal chamber:** A cavity through which a shaft extends and in which leakage at the shaft is controlled by means of a mechanical seal or radial seal.

**9.2.1.43 seal piping:** The pipe or tube used to convey the sealing medium to the lantern ring.

**9.2.1.44 sealless:** A generic industrial word used for pumps not employing packing or mechanical shaft seals as the prime method of sealing liquid or vapor from the atmosphere. It is understood that static seals may be used in pumps that are designated sealless.

**9.2.1.45 shear pin relief valve:** A relief valve that depends upon shearing of a pin for actuation.

**9.2.1.46 sleeve bearing:** A stationary cylindrical component which supports the rotating pump shaft through a lubricating interface.

**9.2.1.47 smothering gland:** A gland that has provision for introducing liquids at lower temperature than the liquid being pumped, to condense vapors that may escape through the stuffing box packing or mechanical seal.

**9.2.1.48 steam jacket:** A passageway through which steam can be circulated to control the temperature of the pumped liquid without coming in contact with the pumped liquid.

**9.2.1.49 stop valve:** A valve used to stop the flow in a fluid-handling system.

**9.2.1.50 stuffing box:** The portion of the casing or cover through which the shaft extends and in which packing or seal is placed to limit leakage.

**9.2.1.51 stuffing box bushing:** A replaceable sleeve or ring placed in the end of the stuffing box opposite the gland.

**9.2.1.52 suction nozzle:** A portion of the pump casing that serves as an adapter or connection between the pump and suction piping.

**9.2.1.53 tachometer:** An instrument that measures the revolutions per minute of a rotating shaft.

**9.2.1.54 timing gear:** A part used to transmit torque from one rotor shaft to another and to maintain the proper angular relationship of the rotors. It may be outside or inside the pumping chamber and is sometimes called a pilot gear.

**9.2.1.55 torsional dynamometer:** A measuring device used to determine the torque being transmitted in a power train.

**9.2.1.56 transmission dynamometer:** A device used to determine pump input power.

**9.2.1.57 universal joint:** A device used to connect shafts that are not necessarily aligned.

**9.2.1.58 vacuum breaker piping:** A pipe connecting the vacuum breaker valve to the pump.

**9.2.1.59 vent piping:** A device that releases or "vents" air out of the pump or piping system.

**9.2.1.60 venturi meter:** A form of flow measuring device that contains no moving parts and operates on the principle of pressure to velocity conversion.

## 9.2.2 Slurry application terms

**9.2.2.1 apparent viscosity:** The viscosity of a non-Newtonian slurry at a particular rate of shear, expressed in terms applicable to Newtonian liquids.

**9.2.2.2 critical carrying velocity:** The mean velocity of the specific slurry in a particular conduit, above which the solids phase remains in suspension, and below which solid-liquid separation occurs.

**9.2.2.3 effective particle diameter:** Single size particle used to represent the behavior of a mixture of various sizes of particles in a slurry. This designation is used by some engineers to calculate system requirements and pump performance.

**9.2.2.4 friction characteristic:** A term used to describe the resistance to flow that is exhibited by solid-liquid mixtures at various rates of flow.

**9.2.2.5 heterogeneous mixture:** A mixture of solids and a liquid in which the solids are not uniformly distributed.

**9.2.2.6 homogeneous flow (fully suspended solids):** A type of slurry flow in which the solids are thoroughly mixed in the flowing stream and a negligible amount of the solids are sliding along the conduit wall.

**9.2.2.7 homogeneous mixture:** A mixture of solids and a liquid in which the solids are uniformly distributed.

**9.2.2.8 non-homogeneous flow (partially suspended solids):** A type of slurry flow in which the solids are stratified, with a portion of the solids sliding along the conduit wall. Sometimes called "heterogeneous flow" or "flow with partially suspended solids."

**9.2.2.9 non-settling slurry:** A slurry in which the solids will not settle to the bottom of the containing vessel or conduit but will remain in suspension, without agitation, for long periods of time.

**9.2.2.10 percent solids by volume:** The actual volume of the solid material in a given volume of slurry divided by the given volume of slurry multiplied by 100.

**9.2.2.11 percent solids by weight:** Weight of dry solids in a given volume of slurry, divided by the total weight of that volume of slurry, multiplied by 100.

**9.2.2.12 saltation:** A condition that exists in a moving stream of slurry when solids settle in the bottom of the stream in random agglomerations, which build up and wash away with irregular frequency.

**9.2.2.13 settling slurry:** A slurry in which the solids will move to the bottom of the containing vessel or conduit at a discernible rate but which will remain in suspension if the slurry is agitated constantly.

**9.2.2.14 settling velocity:** The rate at which the solids in a slurry will move to the bottom of a container of liquid that is not in motion. (Not to be confused with the velocity of a slurry, which is less than the critical carrying velocity as defined above.)

**9.2.2.15 slurry:** A mixture consisting of solid particles dispersed in a liquid.

**9.2.2.16 square root law:** A rule used to calculate the approximate increase in critical carrying velocity for a given slurry when pipe size is increased. It states:

$$V_L = V_S \times \sqrt{\frac{D_L}{D_S}}$$

Where:

$V_L$  = Critical carrying velocity in larger pipe;

$D_L$  = Diameter of larger pipe;

$V_S$  = Critical carrying velocity in smaller pipe;

$D_S$  = Diameter of smaller pipe.

NOTE: This rule should not be used when pipe size is decreased.

**9.2.2.17 yield value (stress):** The stress at which many non-Newtonian slurries will start to deform and below which there will be no relative motion between adjacent particles in the slurry.

### 9.3 Design and application

#### 9.3.1 Preferred measurement units and conversion factors

Table 9.2 has been prepared by the Hydraulic Institute to aid those wishing to convert US Customary units to metric units.

Neither the quantities nor the applications are intended to be exhaustive but are selected as those most commonly and frequently used or those where a question could exist in selection of the metric unit. It is assumed that, by comparing similar applications with those listed, one can determine the recommended metric unit to use for most applications.

The multiples of the metric units shown have been selected from the best available information as to what will eventually be industry usage for the indicated applications. To reduce the volume of data, some quantities defined by derived units have been omitted from the list.

Some of the column headings require an explanation — as follows:

##### 9.3.1.1 Quantity

The five categories and the sequence of items are the same as in ISO-1000 (and its parent document ISO-R31), because a list arranged in alphabetical order would have suffered from the variety of names used for a single quantity. For example, moment of force is also called torque or bending moment. The American National Metric Council has recently requested each of its Sector Committees to follow this same sequence

to facilitate comparison and coordination. Compound units not appearing in ISO-1000 are inserted immediately after the appearance of all of its component units — for example, unbalance (g·mm) is immediately after gram (g).

##### 9.3.1.2 US Customary unit

This is the system of measurements most commonly used in the USA. The symbols are per *ANSI/IEEE 260.1-1993, Letter Symbols for SI Units of Measurement*.

##### 9.3.1.3 Metric unit

These are not all SI units. For example, angles in degrees or any unit based on minute or hour are not in conformance with SI guidelines.

The factors are based on conversion tables which contain seven significant figures; but they have been rounded to the nearest fourth significant figure, which is adequate for practically all pumping applications.

Never retain more than four significant figures after making a conversion with these factors (except those that are exact) and only then when necessary. In most cases (except for linear measurements), two or three will be enough, as can be seen from the following examples in Table 9.1, in which the values entitled "conversion" result have been calculated from the conversion factors on the following pages. If four significant figures are retained, the fourth figure will often differ from the value that would have been shown by using a conversion factor having seven significant figures. Even if the result is rounded to three significant figures, the last one may occasionally differ by 1, but such results are adequate for most engineering.

**Table 9.1 — Examples of rounded equivalents**

	US unit	Conversion result	Rounded equivalent
Volume	8.6 gal	0.032 55	0.033 m <sup>3</sup>
Weight	8340 lb	3 783.024	3780 kg
Bending moment	22 500 lbf·in	2 542.5	2540 N·m
Beam stress	18 500 lbf/in <sup>2</sup>	127.557 5	128 MPa
Fluid pressure	1750 psi	12 066.25	12 100 kPa
Unbalance	0.3 oz·in	216.03	200 g·mm

Table 9.2 — Hydraulic Institute — Preferred measurement units and conversion factors

Quantity <sup>a</sup>	Typical applications	Metric unit	Abbreviation	US Customary unit	Abbreviation	Conversion factors — multiply by	
						Metric to US unit	US unit to Metric
<b>1. Space and time</b>							
plane angle	fluid flow angle	degree	°	degree	°	1	1
	dimensions of sumps and pits	meter	m	foot and inch	ft or'	3.281	0.3048 <sup>b</sup>
		meter	m		in or "	39.37 <sup>b</sup>	0.0254 <sup>b</sup>
length	mechanical engineering drawings	millimeter	mm	inch	in or "	.03937	25.4 <sup>b</sup>
		micrometer	μ m	thousandths of inch	mil	.03937	25.4 <sup>b</sup>
		micrometer	μ m	microinch	μ in	39.37	0.0254 <sup>b</sup>
area	surface area, flow area	micrometer	μ m	micron	μ m	1 <sup>b</sup>	1 <sup>b</sup>
		square meter	m <sup>2</sup>	square foot	ft <sup>2</sup>	10.76	0.092 90
		square centimeter	cm <sup>2</sup>	square inch	in <sup>2</sup>	0.155	6.452
volume	fluid volume rate of flow	milliliter (cm <sup>3</sup> ) <sup>c</sup>	mL <sup>d</sup>	cubic inch	in <sup>3</sup>	0.061 02	16.39
		cubic meter	m <sup>3</sup>	cubic foot	ft <sup>3</sup>	35.31	0.028 32
		cubic meter	m <sup>3</sup>	gallon	gal	264.2	0.003785
		liter	L	quart	qt	1.057	0.9464
time	time interval	hour	h	hour	h	1 <sup>b</sup>	1 <sup>b</sup>
		minute	min	minute	min	1 <sup>b</sup>	1 <sup>b</sup>
volume per unit time	flow rate of fluids	second	s	second	s	1 <sup>b</sup>	1 <sup>b</sup>
		cubic meter per hour	m <sup>3</sup> /h	gallon per minute	gpm	4.403	0.2271
velocity, linear	fluid velocity	liter per minute	L/min	gallon per minute	gpm	0.2642	3.785
		meter per second	m/s	foot per second	fps	3.281	0.3048 <sup>b</sup>
acceleration	gravity	meter per second — squared	m/s <sup>2</sup>	foot per second — squared	ft/s <sup>2</sup>	3.281	0.3048 <sup>b</sup>
<b>2. Periodic and related phenomena</b>							
frequency	system vibration, sound, alternating current	hertz	Hz	hertz	Hz	1 <sup>b</sup>	1 <sup>b</sup>
speed of rotation	speed of rotation	revolution per minute	rpm	revolution per minute	rpm	1 <sup>b</sup>	1 <sup>b</sup>

Table 9.2 — Hydraulic Institute — Preferred measurement units and conversion factors (continued)

Quantity <sup>a</sup>	Typical applications	Metric unit	Abbreviation	US Customary unit	Abbreviation	Conversion factors — multiply by	
						Metric to US	US to Metric
<b>3. Mechanics</b>							
mass	equipment mass	kilogram	kg	pound (decimalized)	lb or #	2.205	0.4536
		gram	g	ounce	oz	0.035 27	28.35
unbalance	impeller, rotor	gram-millimeter	g•mm	ounce-inch	oz•in	0.001 389	720.1
density (mass density)	density of solids and fluids	kilogram per cubic meter	kg/m <sup>3</sup>	pound per cubic foot	lb/ft <sup>3</sup>	0.062 43	16.02
specific weight (force)	solids and fluids			pound force per cubic foot	lbf/ft <sup>3</sup>	6.366	
moment of inertia (dynamic)	rotor inertia		kg•m <sup>2</sup>	pound foot-squared	lb•ft <sup>2</sup>	23.73	0.042 14
			Newton	pound-force	lbf	0.2248	4.448
force	applied load		N				
	head of fluid	meter	m	foot	ft	3.281	0.3048 <sup>a</sup>
moment of force, torque and bending moment	bolt tightening, shaft torque, beam stress and deflection calculations		N•m	pound-force foot	lbf•ft	0.7376	1.356
			Newton-meter	pound-force inch	lbf•in	8.851	0.1130
pressure	fluid pressure or vacuum		kPa	pound-force per square inch	psi	0.1450	6.895
			kilopascal [kN/m <sup>2</sup> ]	inch of mercury [60°F]	in Hg	0.2961	3.377
			kilopascal	inch of water [60°F]	in H <sub>2</sub> O	4.019	0.2488
stress	sound pressure level	mikropascal [20 μPa]	μPa	decibel	dB	0.000 01	100 000
	unit force	megapascal	MPa <sup>e</sup>	pound-force per square inch	psi	145.0	0.006 895
specific speed	centrifugal pump impeller	$\left[ \frac{N(Q)^{.5}}{h^{.75}} \right]$	dimensionless	$\frac{\text{rpm (gpm)}^{.5}}{\text{ft}^{.75}}$	dimensionless	0.8608	1.162
viscosity, dynamic	liquid characteristic	millipascal-second	mPa•s				
viscosity, kinematic	liquid characteristic	square-millimeter per second	mm <sup>2</sup> /s	Seconds Saybolt Universal	SSU	4.55	0.22
energy, work (see also heat & electricity)	force times distance	joule [N•m] <sup>9</sup>	J	foot-pound-force	ft•lbf	0.7376	1.356
power (see also heat & electricity)	mechanical power	kilowatt [kJ/s] <sup>9</sup>	kW	horsepower	hp	1.341	0.7457

Table 9.2 — Hydraulic Institute — Preferred measurement units and conversion factors (continued)

Quantity <sup>a</sup>	Typical applications	Metric unit	Abbr- viation	US Customary unit	Abbr- viation	Conversion factors — multiply by	
						Metric to US	US to Metric
<b>4. Heat</b>							
temperature	temperature	degree Celsius <sup>h</sup>	°C	degree Fahrenheit	°F	(°C x 1.8) + 32 <sup>b</sup>	(°F - 32) x 5/9 <sup>b</sup>
	absolute temperature	degree Kelvin	°K	degree Rankin	°R	1.8 <sup>b</sup>	5/9 <sup>b</sup>
heat (energy)	heat input	kilojoule	kJ	British Thermal Unit	Btu <sup>i</sup>	0.9478	1.055
heat flow rate (power)	heat rejection rate, air conditioning power	watt [(J/s)] <sup>g</sup>	W	British Thermal Unit per minute	Btu/min	0.05687	17.58
<b>5. Electricity</b>							
electric current	electricity flow	ampere	A	ampere	A	1 <sup>b</sup>	1 <sup>b</sup>
electromotive force	battery potential	Volt	V	volt	V	1 <sup>b</sup>	1 <sup>b</sup>
electric resistance	resistors, conductors	ohm	Ω	ohm	ohm	1 <sup>b</sup>	1 <sup>b</sup>
electric conductance	conductors	Siemens	S	Mho	Mho	1 <sup>b</sup>	1 <sup>b</sup>
electric energy	electric consumption	kilowatt-hour <sup>j</sup>	kW·h	kilowatt-hour	kW·h	1 <sup>b</sup>	1 <sup>b</sup>
electric power	motors	kilowatt	kW	kilowatt	kW	1 <sup>b</sup>	1 <sup>b</sup>

<sup>a</sup> As used in ISO-31 and ISO-1000, "quantity" means "measurable property".

<sup>b</sup> Exact

<sup>c</sup> Symbols in brackets [ ] are explanatory only.

<sup>d</sup> The U.S. Department of Commerce, National Bureau of Standards, has established the capital letter "L" as the preferred unit symbol for liter for the U.S.

<sup>e</sup> Except in very weak materials (for which kPa may be more convenient), or for modulus of elasticity (for which GPa will usually be more convenient).

<sup>f</sup> Conversion from Saybolt Universal Seconds to centistokes can be done from a table.

<sup>g</sup> By using J instead of N·m, the distinction from N·m for moment of force is made apparent.

<sup>h</sup> Conversion requires a formula, wherein the Fahrenheit temperature is indicated by °F and the Celsius temperature by °C.

<sup>i</sup> All factors in this table are based on Btu-International Table.

<sup>j</sup> The SI unit for electric energy is watt·second (W·s), which is equal to joule (J). (1 kW·h = 3.6 MJ).

## 9.3.2 Materials

### 9.3.2.1 Introduction

This tabulation of materials (see Table 9.3 at the end of this section) for wetted parts for pumps, applied to various liquids, is a compilation of types of materials that have been specified or purchased by users. These are not to be considered as recommendations of materials to be used for the liquids listed, because this tabulation is not based on the selection of material for maximum corrosion resistance. Also, the order of listing does not necessarily indicate relative superiority, as certain factors predominating in one instance may be sufficiently over-shadowed in others to reverse the arrangement. The Hydraulic Institute is offering this only as a guide for the user's consideration.

The factors which must be considered in the selection of materials for wetted pump parts are: user's experience, expected pump life such as temporary or long-term use, intermittent or continuous duty, pumping hazardous or toxic liquids and condition of the liquid. The corrosive properties of liquids may vary with one or more of the following liquid conditions: temperature, concentration, purity, velocity and entrained solids or gases.

### 9.3.2.2 Data on liquids

#### 9.3.2.2.1 General characteristics

The liquids are assumed to be of commercial quality and of the degree of purity usually encountered. However, one must recognize that the presence of a foreign substance, even in small percentages, may, and frequently does, have a profound effect upon the corrosiveness of the solution and, hence, upon the choice of materials. Various liquid conditions and characteristics are listed in columns 2 to 4 of Table 9.3.

#### 9.3.2.2.2 Effects of temperature and concentration

In some cases, the satisfactory use of a particular material is restricted to a definite temperature and/or concentration range, and, where this is known to occur, the limitations are so noted in the tabulation.

#### 9.3.2.2.3 Handling high- or low-temperature liquids

The handling of liquids at temperatures below 0°C (32°F) or above 120°C (250°F) usually requires careful selection of the materials and corresponding attention

to construction details. For material selections, applicable codes and practices of the industry in which the pump is to be used should be consulted.

### 9.3.2.2.4 Specific gravity

These data are given where accurate information is available. Unless otherwise specified, they apply at room temperature.

### 9.3.2.2.5 Chemical symbols

The chemical symbols have been included, where available, both as a matter for information and as a means of identification in the event the name of the liquid is not fully descriptive.

### 9.3.2.3 Factors affecting material selection

The materials listed for the various liquids are those which have been specified by the pump users for the principal parts of the pump such as casing, cylinders, pumping chambers, impellers, rotors or other wetted parts. Where applicable, the American Society for Testing and Materials (ASTM) designations are used. Refer to the ASTM standards or other materials handbooks for the chemical and physical properties of materials.

The use of higher-alloyed materials is required where the conditions of corrosion and/or abrasion are severe. They are also required in those cases where contamination of the liquid by metallic salts, through corrosive attack on the pump material, may adversely affect the color and characteristics of the product or develop toxicity (as in the case of foodstuffs). The use of such alloys may become increasingly important when the pump is operated intermittently and is not washed out after each run.

The presence of a small percentage of soluble chloride or other halide in many of the liquids included in the table may greatly intensify their corrosive properties. Conversely, certain substances, such as the chromates and dichromates, may inhibit the corrosive action of many solutions on ferrous metals. Further, some liquids, noticeably the vegetable oils, while relatively inactive when fresh, may, upon exposure to heat and/or the atmosphere, turn rancid and become quite corrosive. While cast iron might be used safely with such oils when they are sweet, it would not necessarily be satisfactory after they had soured. In the latter case, other more resistant materials would probably be required.

Where reliable performance data are not available, test specimens of likely materials suitably exposed to the liquid to be handled may assist in the selection of those most resistant to corrosive attack. When possible, a plant test, using actual flow and temperature condition, is preferable to a laboratory test. However, the practical limitations of such tests must be recognized. The difficulty of subjecting a single test specimen to the many variables which may exist in a system such as velocity impingement, abrasion, aeration and galvanic action, any of which may have an important effect on the result, is considerable. Nevertheless, helpful information may be obtained through such tests despite their limitations.

#### **9.3.2.3.1 Optimize life cost**

The cost of the material utilized is normally the number one consideration. Operational costs, replacement costs, longevity of service and repair costs will determine the selection of materials. Standard pump part materials such as cast iron housings and bronze impellers are the least expensive materials and most readily available items for replacement. Depending on the service, increased corrosion resistance dictates upgrading of materials to levels where the cost of the equipment is still acceptable to the user.

#### **9.3.2.3.2 General design of pumps**

The general design of pumps selected for a given service may be any of those shown in the other sections of the Hydraulic Institute Standards, and each design has its own standard materials of construction. It is important to be well-guided on the proper design for the service intended, and the materials must be selected accordingly.

#### **9.3.2.3.3 Properties - chemical and physical**

The chemical and physical properties of the material selected have to be considered. It is not uncommon to use materials that are not quite up to the corrosion resistance and/or wear-resistance required for long-term service. If this is the case, the user must be prepared to replace or repair components at more frequent intervals. On the other hand, when designing the equipment, physical properties such as the tensile strength and yield strength of the material must be such that failure of the material is not a risk when operating.

The chemical and physical properties of the materials listed are substantially in agreement with the current standards of the American Society for Testing Materials, and the inspection of testing requirements set

forth in their specification are, in general, applicable. However, the Hydraulic Institute recognizes that many casting defects may be corrected by welding without impairing the strength or quality of the piece, provided suitable techniques are used. This assumes that any welding or the elimination of major defects is done prior to final heat treatment. The latter is particularly important in the case of the more highly alloyed steels intended for use with the more corrosive liquids. Also, the Hydraulic Institute recognizes that, for certain materials, slight leakage through a porous spot, when under hydrostatic test, in an otherwise structurally sound casting, may be sealed by impregnation with a sealing medium which, after processing, is not degraded by the liquid to be handled.

When the liquid to be handled is an electrolyte, combinations of dissimilar metals which may promote galvanic reactions should, where practical, be avoided. The rate of corrosion, where metals widely separated in the galvanic series are used, will depend upon such things as the nature of the electrolyte, temperature, velocity, and, particularly, the relative cathode-anode surface area. Although bronze fittings in an iron pump handling sea water may initially accelerate the corrosion of the surface of the iron, the overall rate is sometimes sufficiently low to make the use of large pumps, so fitted, economically sound.

#### **9.3.2.3.4 Temperature of liquid pumped**

Many materials are of the nature where high or low temperatures will affect the corrosion-resistance and/or the physical properties of these materials. Therefore, it is important that the temperature of the liquid pumped be considered.

The handling of liquids at temperatures higher than 120°C (250°F) usually requires careful selection of the materials and corresponding attention to construction details. For material selections acceptable in the temperature range involved, the applicable codes and practices of the industry in which the pump is to be used should be consulted.

Selection of materials for pumps operating at low temperature should be made only after each component and its function has been considered. Many materials change from tough to brittle behavior with a decrease in temperature. Although a considerable amount of research has been completed and many varieties of tests have been developed to evaluate the toughness of metals and the conditions under which this transition takes place, these tests have not yet been able to

predict all the variables significant to the problems of embrittlement.

The following generalities may serve as a starting point in the selection of a suitable ferritic steel for low-temperature service.

A heat-treated, fine-grain, low-carbon alloy steel with low phosphorus, with nickel and molybdenum, and of moderate hardness, usually offers better notch toughness at low temperatures than do other ferritic steels.

Consideration should also be given to the austenitic stainless steels and to bronzes for possible use in low-temperature pumping applications. Austenitic stainless steels, fully annealed, show improving toughness with decreasing temperature and exhibit no transition point. Most bronzes and all aluminum alloys are not embrittled at low temperatures and may also serve for this type of service, if otherwise suitable for the application.

Other considerations, such as cost, corrosion-resistance, availability, erosion-resistance, hardness, toughness and fatigue strength must be carefully considered before the final selection of materials for high- or low-temperature services is made.

### 9.3.2.3.5 Galvanic corrosion

Galvanic corrosion may be defined as the accelerated electro-chemical corrosion produced when one metal is in electrical contact with another more noble metal, both being immersed in the same corroding medium, which is called the electrolyte. Corrosion of this type usually results in an accelerated degradation for one member of the couple and protection for the other. The protected member, the one that does not corrode, is called the more noble metal. Note that as galvanic corrosion is generally understood, it consists of the total corrosion, which comprises the normal corrosion that would occur on a metal exposed alone, plus the additional amount that is due to contact with the more noble material.

#### 9.3.2.3.5.1 Galvanic series

With a knowledge of the galvanic corrosion behavior of metals and alloys, it is possible to arrange them in a series which will indicate their general tendencies to form galvanic cells and then to predict the probable direction of the galvanic effects. The relative positions of the metals will vary to some extent depending upon the electrolyte. Such a series for seawater is provided in the list below.

This series should not be confused with the familiar *Electromotive Series*, which is found in many textbooks and is of value in physical chemistry and thermodynamic studies.

It will be noticed that some of the metals in the list below are grouped together. These group members have no strong tendency to produce galvanic corrosion on each other. From a practical standpoint, they are relatively safe to use in contact with each other, but the coupling of two metals from different groups and distant from each other in the list will result in galvanic, or accelerated, corrosion of the one higher in the list. The farther apart the metals stand, the greater will be the galvanic action.

Galvanic series of metals and alloys beginning with the corroded end (anodic, or least noble):

- magnesium;
- magnesium alloys;
- zinc;
- aluminum;
- cadmium;
- steel or iron;
- cast iron;
- chromium stainless steel, 400 series (active);
- austenitic nickel or nickel-copper cast iron alloy;
- 18-8 chromium-nickel stainless steel; type 304 (active);
- 18-8-3 chromium-nickel-molybdenum stainless steel, type 316 (active);
- lead-tin solders;
- lead;
- tin;
- nickel (active);
- nickel-base alloy (active);
- nickel-molybdenum-chromium-iron alloy (active);

- brasses;
- copper;
- bronzes;
- copper-nickel alloy;
- nickel-copper alloy;
- silver solder;
- nickel (passive);
- nickel-base alloy (passive);
- 18-8 chromium-nickel stainless steel, type 304 (passive);
- chromium stainless steel, 400 series (passive);
- 18-8-3 chromium-nickel-molybdenum stainless steel, type 316 (passive);
- nickel-molybdenum-chromium-iron alloy (passive);
- titanium
- silver;
- graphite;
- gold;
- platinum.

Protected end (cathodic, or most noble)

NOTE: Reprinted by courtesy of The International Nickel Company Inc.

This may be determined by measurement of the electrical potential difference between them, and this is often done; but it is not practical to tabulate these differences, because the voltage values for combinations of the metals will vary with every different corrosive condition. What actually determines galvanic effect is the quantity of current generated rather than the potential difference.

The relative position of a metal within a group sometimes changes with external conditions, but only rarely do changes occur from group to group. It will be seen that the chromium stainless steel and chromium-nickel stainless steel alloys are in two places on the list. They

frequently change positions as indicated, depending upon the corrosive media and stability of the oxide film. The most important reasons for this are the oxidizing power and acidity of the solutions, and the presence of activating ions, such as halides. Inconel and nickel also occasionally behave in a similar manner, though the variations of their position are less frequent and less extensive. In environments where these alloys ordinarily demonstrate good resistance to corrosion, they will now be in their passive condition and behave accordingly in galvanic couples.

#### 9.3.2.3.5.2 To minimize galvanic corrosion

Select combinations of metals as close together as possible in the galvanic series.

Avoid making combinations where the area of the less noble materials is relatively small.

Insulate dissimilar metals wherever practical, including use of plastic washers and sleeves at flanged joints. If complete insulation cannot be achieved, anything such as a paint or plastic coating at joints will help to increase the resistance of the circuit.

Apply coatings with caution. For example, do not paint the less noble material without also coating the more noble; otherwise, greatly accelerated attack may be concentrated at imperfections in coatings on the less noble metal. Keep such coatings in good repair.

In cases where the metals cannot be painted and are connected by a conductor external to the liquid, the electrical resistance of the liquid path may be increased by designing the equipment to keep the metals as far apart as possible.

If practical, and dependent on velocity, add suitable chemical inhibitors to the corrosive solution.

If you must use dissimilar materials well apart in the series, avoid joining them by threaded connections, as the threads will probably deteriorate excessively. Welded or brazed joints are preferred. Use a brazing alloy more noble than at least one of the metals to be joined.

If possible, install relatively small replaceable sections of the less noble materials at joints, and increase its thickness in such regions. For example, extra heavy wall nipples can often be used in piping, or replaceable pieces of the less noble material can be attached in the vicinity of the galvanic contact.

Install pieces of bare zinc, magnesium, or steel so as to provide a counteracting effect that will suppress galvanic corrosion.

#### 9.3.2.3.6 Microstructure of metals

Cast irons all contain an appreciable volume of free carbon as graphite, either as flakes or spheroids (ductile irons). The metal matrix of gray irons is typically pearlite, and the ductile iron matrix can be ferrite (lower strength) or pearlite (high strength). The ductile irons are produced with a treatment to change the graphite form and thus obtain ductility.

Steels have all of the carbon in the combined form as iron carbide. Typical structure is a ferrite matrix with pearlite (a lamellar arrangement of ferrite and iron carbide).

Hardenable chromium steels, such as A217-C5 and CA 15, can have a pearlite structure or one of tempered martensite. Hardness of CA 15 can be varied over a considerable range, depending upon the heat treatment process used.

The non-hardenable chromium steels, A743-CB30 and CC 50, are inherently nonductile and have a fully ferrite matrix.

The austenitic stainless steels have an austenitic matrix with limited amounts of ferrite, except A743-CN7M which is wholly austenitic.

The austenitic cast irons have a structure of austenite and graphite: flake graphite in the ordinary grades, spheroidal graphite in the ductile grades.

#### 9.3.2.3.7 Galling resistance

Galling resistance of metals is not known precisely. Most knowledge is based on experience and limited empirical data. Ranking of classes of material in galling resistance would be as follows:

Most resistant at the top - least resistant at the bottom.

- 1) Bronzes;
- 2) Cobalt-base hard-surfacing alloys;
- 3) Type 1, Type 2 of austenitic gray irons;
- 4) Unalloyed irons - gray and ductile;
- 5) Nickel-base hard-surfacing alloys;

- 6) Hardened steels above 325 BHN;
- 7) Nickel-copper alloy;
- 8) Low-hardness steels below 240 BHN;
- 9) Austenitic cast irons - "other types";
- 10) Austenitic stainless steels.

Various hard surface coatings such as carbide, ceramic, etc., are not included in the ranking. In general, these would be good in galling resistance if high in hardness.

In general, higher hardness gives better galling resistance, but there are many exceptions. Two parts to run together are often made with a hardness differential of 50 BHN or more between them.

#### 9.3.2.3.8 Corrosion/erosion

Conditions involving severe corrosion or abrasion often require the use of higher-alloyed materials. These are also included in cases where contamination of the liquid by metallic salts, through corrosive attack on the pump materials, may adversely affect the color and characteristics of the product or develop toxicity (as in the case of food-stuffs). The use of such alloys may become increasingly important where the pump is operated intermittently and is not washed out after each run.

Where contamination of the product is not a factor, some users prefer the less costly materials, accepting the more frequent replacements. Occasionally, the less resistant materials are used during a process development period, while the more resistant materials are installed after the conditions have become standardized and the corrosion or erosion problems are known.

#### 9.3.2.3.9 Mechanical situation in pumping

There are various mechanical situations in pumping which have special effects on materials not typically duplicated in laboratory, chemical or physical analyses. These effects include the following:

##### 9.3.2.3.9.1 Crevice corrosion

Stainless steels and some other alloys rely on an oxide coating to generate a corrosive-resistant film. Pump designs which have tight crevices, or fits, do not permit the continued replenishment of this oxide film

and may, therefore, corrode in these areas even though the material is basically compatible with the liquid being pumped. Certain liquids, such as sea water and halide salt solutions, are more likely to promote crevice corrosion.

#### 9.3.2.3.9.2 Velocity effects

Most wetted surfaces in a pump are subject to relatively high liquid velocities, such as internal impeller and diffuser passages and wearing ring, balancing drum and balancing disc clearances. This velocity and its scouring effect on corrosion deposits, soft-base metals and oxide films can, and often does, adversely affect corrosion rates. Therefore, laboratory static submergence tests for determining corrosion rates of specific liquid/material combinations can, at best, only be considered as a general guide to material selection.

#### 9.3.2.3.9.3 Thermal or hydraulic shock

Certain pumping situations may subject the pump to thermal or hydraulic shock, which may preclude the use of brittle materials such as cast iron. Such shock may occur in startup on high-temperature applications; when pumps are handling flammable liquids that could leak, catch fire and be hosed down with cold water; or when water hammer shock results from sudden valve closure.

Based on the above and other situations unique to the pumping environment, it becomes evident that the best determining factor for pump material selection is actual experience of similar pumps in the same or similar applications.

### 9.3.2.4 Pump - material - general designation

#### 9.3.2.4.1 Centrifugal pumps - introduction

The following are the most frequently used material designations for centrifugal pumps:

- bronze fitted pump (material B);
- all bronze pump (material A);
- specific composition bronze pump;
- all iron pump (material C);
- stainless steel fitted pump;
- all stainless steel pump;

- rigid polymers/composites.

#### 9.3.2.4.1.1 Bronze fitted pump

The casing is made of cast iron, and the impeller and impeller rings are made of bronze.

#### 9.3.2.4.1.2 All bronze pump

All parts of the pump in direct contact with the liquid pumped are made of manufacturer's standard bronze.

#### 9.3.2.4.1.3 Specific composition bronze pump

All parts of the pump in direct contact with the liquid pumped are made of bronze composition of suitable properties for the specific application.

#### 9.3.2.4.1.4 All iron pump

All parts of the pump in direct contact with the liquid pumped are made of ferrous metal (cast iron/ductile iron, carbon steel, or low-alloy steel).

#### 9.3.2.4.1.5 Stainless steel fitted pump

The casing is made of material suitable for the service. The impellers, impeller rings and shaft sleeves (if used) are made of a corrosion-resistant steel with suitable properties for the specific application.

#### 9.3.2.4.1.6 All stainless steel pump

All parts of the pump in direct contact with the liquid pumped are made of corrosion-resistant steel with suitable properties for the specific application.

#### 9.3.2.4.1.7 Rigid polymers/composites

All parts of the pump in direct contact with the liquid are made of rigid polymers or composites (plastics), either as coatings or as structural material.

### 9.3.2.4.2 Vertical pumps - introduction

The following are the most frequently used material designations for vertical pumps:

- bronze fitted pump (material B);
- all bronze pump (material A);
- specific composition bronze pump;
- all iron pump (material C);

- all stainless steel pump.

#### 9.3.2.4.2.1 Bronze fitted pump

All cast stationary, pressure containing, components are made of cast iron, with the internal bowl waterways generally coated with vitreous enamelling for sizes below approximately 500 mm (20 inches) diameter. The wrought stationary components, such as the column pipe, are made of carbon steel. The impellers, wear rings (if used) and bearings are made of bronze, with the exception of open/product-lubricated column sections, which typically have rubber bearings running on stainless steel sleeves. Shafting is made of carbon steel, except in the bowl assembly where martensitic stainless steel is normally used.

#### 9.3.2.4.2.2 All bronze pump

All parts of the bowl assembly are made of the manufacturer's standard bronze, with the exception of the bowl shaft, which is made of stainless steel.

#### 9.3.2.4.2.3 Specific composition bronze pump

All parts of the bowl assembly are made of a bronze composition with suitable properties for the specific application, with a stainless steel or monel bowl shaft suitable for the application.

#### 9.3.2.4.2.4 All iron pump

All parts of the bowl assembly are made of ferrous metal (cast iron, ductile iron, or high-nickel iron/Ni-resist). The bowl bearings are normally bronze, rubber, or cast iron, with stainless steel bowl shafting.

#### 9.3.2.4.2.5 All stainless steel pump

All parts of the bowl assembly are made of corrosion-resistant steel with suitable properties for the specific application. The shafting is made of corrosion-resistant steel or monel of a grade equal to that of the other parts of the bowl assembly. The bearings are normally metal-filled graphite, filled teflon, glass-filled epoxy, rubber or zincless bronze, depending on the application. Wrought column and discharge head parts are normally made of coated steel or stainless steel.

#### 9.3.2.4.3 Rotary pumps

Because rotary pumps are individually manufactured in many different types, and because the materials used for the parts may be varied almost infinitely, it is difficult to use general terms to designate the various

materials of construction which may be employed. Some rotary pumps incorporate the use of composite and elastomeric materials as critical parts of construction in contact with the liquid being pumped. In such cases, this non-metallic material may well be the controlling factor in material compatibility with the liquid being handled.

All materials must be chosen for their physical properties in relation to the liquid being pumped, the environmental conditions of the pump, and the stresses in the materials due to the operating conditions of the pump. Also, the materials must be mechanically compatible; that is, if they bear on each other, they must not gall. This may prevent the use of a single corrosion-resistant material for both the rotating and stationary parts if the material will not run in bearing contact with itself as, for example, many stainless steels.

Consideration of the corrosive nature of the liquids to be pumped is particularly important in applying rotary pumps. Proper functioning of the pumps depends on maintenance of close clearances. It is important, therefore, that the exact natures of the materials of construction be specified, as only certain grades of bronze or stainless steel may be suitable.

Galvanic corrosion rates acceptable in large clearance pumps may be catastrophic to some rotary pumps, and dissimilar metal combinations need to be selected carefully. If the liquid is an electrolyte so that galvanic corrosion is possible, only metals near each other in the galvanic series should be used.

The following are commonly used designations. Each is a description of the materials of construction for the major parts of the pump. These materials represent the minimum requirements of the respective category. These designations should always be used with discretion. Each new application should be reviewed with the pump manufacturer:

- all iron pumps have all wetted parts made of iron or carbon steel;
- bronze fitted pumps also have major wetted parts of iron or carbon steel, but have some internal parts of bronze;
- all bronze pumps have all wetted parts made of bronzes selected for compatibility with each other and the liquid pumped;
- all stainless pumps have all wetted parts made of stainless steels with particular attention to

materials compatibility and limitations. Coatings and/or other alloys may be added in critical parts.

### 9.3.2.5 Reciprocating pumps

#### 9.3.2.5.1 Power pumps

The following are the most frequently used material designations for power pumps:

- all iron pumps have all parts in direct contact with the liquid pumped made of iron or carbon steel - including alloys;
- bronze fitted pumps have liquid cylinder and piston or plunger made of iron or steel and piston rods, valves, cylinder liners and trim of bronze. Fully bronze fitted would additionally have bronze pistons or plungers.

#### 9.3.2.5.1.1 Controlled volume pumps

Controlled volume pumps are used to accurately inject measured volumes of liquids into process systems, and, therefore, the materials in contact with the liquids must be selected to provide adequate chemical resistance. Each manufacturer will select from the many available materials a composition to satisfy the chemical resistance requirements. Therefore, these standards for materials of construction do not specify the type of material for each component but, instead, designate the different general levels of chemical resistance required by describing the types of liquid which are included for the different levels of chemical corrosive characteristics.

General purpose pumps for non-corrosive liquids would be made of ferrous and non-ferrous materials with corrosion resistance equivalent to or better than iron, low carbon steel, or bronze.

Corrosive chemical pumps for high purity liquids are made of 316 stainless steel or higher alloy.

Severe corrosive chemical pumps for highly corrosive or hazardous chemicals are made of higher-alloy materials, ceramics, and composites.

#### 9.3.2.5.1.2 Direct acting (steam) pumps

The following are the most frequently used material designations for direct acting pumps:

- all iron pumps have all parts coming in contact with the liquid pumped made of ferrous metal;

- bronze fitted pumps have iron or carbon steel liquid cylinders, pistons or plungers and bronze piston rods, valves, cylinder liners and trim. Fully bronze fitted pumps have bronze pistons or plungers;

- all bronze pumps have all parts in contact with the liquid pumped made of bronze.

### 9.3.2.6 Materials of construction

#### 9.3.2.6.1 Gray cast iron

Gray cast iron has useful corrosive- and wear-resistant properties, making it widely used throughout the pump industry. It may be obtained in a wide range of tensile strengths, which are listed under ASTM specification A 48. This specification provides for tensile strengths from 138,000 kPa (20,000 psi) through 415,000 kPa (60,000 psi) designated as Class 20 through Class 60. Gray cast irons may be modified to improve certain characteristics by means of various additives. Nickel and molybdenum are often used to attain higher tensile strengths at machineable hardnesses. Nickel is also used for additional corrosive resistance; and nickel or ferro-chrome for added wear-resistance.

#### 9.3.2.6.2 Ductile iron

Ductile (nodular) irons have increased strength and ductility and are suitable for applications where strength and resistance to mechanical and/or thermal shock is required. Ductile irons are covered by the ASTM specifications A395 and A536 and include strengths from 415,000 to 830,000 kPa (60,000 to 120,000 psi).

#### 9.3.2.6.3 Malleable cast iron

Malleable irons are available as ferritic (grades 32510 and 35018) and pearlitic (grades 45006, 45008, 60004, and 80002). The grade designates the minimum yield strength and elongation, e.g., grade 32510 has a minimum yield strength of 225,000 kPa (32,500 psi) and a minimum elongation of 10%. Malleable iron can be thoroughly hardened by heating and quenching. By alloying with copper, atmospheric corrosion resistance is increased. ASTM specification is A47 for the ferritic grades and A220 for the pearlitic grades.

#### 9.3.2.6.4 Austenitic gray cast iron (high-nickel or nickel-copper alloys)

For increased corrosion resistance, austenitic gray cast irons are often used. These materials are covered

by ASTM specification A436, types 1, 2, 4, and 5. Some types are known for their ability to handle salt slurries; other types are able to handle caustic solutions; while still others are noted for high-temperature services. Certain types of austenitic gray irons should be used with caution where thermal shock is encountered, since they do have a comparatively high coefficient of thermal expansion.

#### 9.3.2.6.5 Austenitic ductile iron

Austenitic ductile irons may be used where increased strength and ductility, as well as greater corrosion-resistance is required. Types D-2 through D-5S are covered in ASTM specification A439. They have tensile strengths in the 380,000 to 450,000 kPa (55,000 psi to 65,000 psi) range and elongations of 6% to 20%. ASTM specification A571, type D-2M, provides an austenitic ductile iron material suitable for low-temperature service.

#### 9.3.2.6.6 High silicon cast irons

High silicon cast iron is a corrosion-resistant metal that is hard, brittle and susceptible to thermal shock. Conventional cutting tools are not suitable for machining this material. It is covered by ASTM specification A518.

#### 9.3.2.6.7 Abrasion resistant cast irons

This series of irons is referred to as white irons. The carbon content is present in the form of carbides or complex carbides, and these irons are free from flake graphite. ASTM specification is A532. Most of these alloys are considered to be unmachineable, though certain grades can be annealed for improved toughness or machinability and then heat treated, if desired, to obtain higher hardness. Brinell hardness varies from 350 to over 700. The white irons are commonly alloyed with nickel, chromium and molybdenum to increase their abrasion resistance. These materials are brittle and have poor resistance to thermal shock.

#### 9.3.2.6.8 Carbon and low alloy steels

##### 9.3.2.6.8.1 Carbon steel

Carbon steel is widely used in the manufacture of pump components for its advantageous combination of strength, toughness, low cost and weldability. As castings (A216), carbon steel is used in various grades produced to enhance the high-or-low-temperature properties or the strength. Bar steels provide a range of available strengths, and the resulphurized

and rephosphorized grades are used for their free machineability. In plates and sheets, formability and weldability permit the construction of a wide range of components. Other forms, such as forgings, flanges, fittings, pipe and tubing, supply the properties of steel in a variety of useful configurations.

##### 9.3.2.6.8.2 Low alloy steels

The low alloy steels are used in place of carbon steel where special properties are needed, such as greater hardenability, yield, tensile, or fatigue strength, improved toughness or enhanced wear, abrasion, or corrosion-resistance.

##### 9.3.2.6.9 High alloy steels

Steel alloyed with relatively high amounts of chromium or chromium and nickel is designated as high alloy steel. Other alloying elements may be used to enhance the properties of certain of these materials. Molybdenum is used to increase resistance to pitting corrosion; silicon is used for resistance to scaling and oxidation at elevated temperatures; and sulphur and selenium are used to improve machineability and reduce galling. The stabilizing elements columbium or titanium may be added to reduce susceptibility to carbide precipitation during welding. Lower carbon is used to enhance corrosion-resistance.

##### 9.3.2.6.9.1 Chromium-nickel (austenitic) stainless steel

Alloys with chromium and nickel (austenitic steels) in the wrought form are the 300 series stainless steels. Most of these in equivalent or similar compositions can be secured as castings.

Cast forms are covered by ASTM specifications A743 and A744 for general applications. ASTM specification A297 covers heat-resistant materials and ASTM A351 covers materials for high-temperature service. The wrought forms are covered by ASTM specification A276, A479, A582, and B473 for bars and A167, A176, A240 and B463 for plates.

Chromium-nickel (austenitic) stainless steels have corrosion-resistant properties superior to the straight chromium stainless steels in most instances. In general, their corrosion resistance increases with the amount of nickel included in the alloy.

An additional group of iron-chromium-nickel alloys are the precipitation or age-hardening stainless steels, which when heat-treated achieve increased hardness

and strength, making them better suited for services where abrasion is encountered. These alloys are covered by ASTM specification A564.

#### **9.3.2.6.9.2 Chromium (ferric) stainless steel**

Those alloyed with chromium only (ferritic steels) in the wrought form are the 400 series steels. The 12% chromium alloys have excellent resistance to all fresh water and solutions of mild acid corrosives such as carbonic acid. The 28% chromium alloys are suitable for handling oxidizing solutions such as high concentrations of nitric acid.

#### **9.3.2.6.9.3 Duplex stainless steels**

Duplex stainless steels are partly austenitic and partly ferritic. In general, these stainless steels have higher tensile and yield strengths and more resistance to chloride stress corrosion cracking than austenitic stainless steels.

Corrosion-resistance and intergranular corrosion-resistance of duplex steels are generally higher than those of the austenitic stainless steels. Consequently, duplex stainless steel has found increased usage in pumps handling seawater.

#### **9.3.2.6.10 Copper and copper alloys**

There are hundreds of commercial copper alloy compositions. The precise composition and heat treatment requirements are defined by the relevant standard specification for each composition, issued by the American Society for Testing Materials.

Copper and copper alloys are available as rod, plate, tube shapes, forgings and castings. These alloys are grouped according to composition into several general categories: coppers, high copper alloys, brasses, leaded brasses, bronzes, manganese bronze and copper-nickel alloys.

Most alloys resist corrosion by water and steam. Copper nickels and aluminum brasses and bronzes provide superior resistance to saltwater corrosion. Copper alloys have high resistance to alkalis and organic acids, but alloys containing zinc have poor resistance to inorganic acids.

##### **9.3.2.6.10.1 High copper alloys**

For wrought products, these are alloys with copper content more than 96.0% and those that do not fall into any other copper alloy group. The cast high copper

alloys have a copper content in excess of 94% to which silver or other elements may be added for special properties.

##### **9.3.2.6.10.2 Leaded red brass**

Because of their good casting and machining characteristics, these general utility alloys of copper, tin, lead and zinc are used for a wide variety of pump parts such as impellers, shaft sleeves, bushings, wear rings and pump cases subject to moderate pressures. These alloys have moderate corrosion-resistance and good hydrostatic tightness. Welding of these alloys is not recommended.

##### **9.3.2.6.10.3 Yellow brass**

Copper-zinc alloys, usually the so-called manganese bronze materials, have good castability, afford a sound structure, offer a broad selection regarding strength-to-weight ratios and a machineability rating varying from fair to very good. These materials have the advantages of lower metallic content cost, but they have the disadvantage of being difficult to repair, weld or join and, under several corrosive environments, can be subject to attack known as dezincification.

##### **9.3.2.6.10.4 Silicon bronze**

These copper-silicon alloys contain some zinc and in some instances are alloyed with tin or lead. While these alloys have higher strengths than the red metal alloys, they are used more for their resistance to corrosion. These alloys have good casting characteristics, their machineability rating is fair, and they can be welded. Typical uses are impellers, pump and valve components, bearings, gears and shafts.

##### **9.3.2.6.10.5 Tin bronze**

Copper-tin alloys often contain some zinc and, in many instances, lead. They are moderate strength materials with good machineability. Depending upon lead and tin content, they have excellent bearing and wearing characteristics under moderate loads. Because of a wide liquidus-solidus freezing range, it is very difficult to obtain a complex casting free of microshrinkage. Such defects are usually corrected by impregnation with non-metallics. Salvage repair welding is difficult. These materials, especially the zinc-free types, are very satisfactory for mildly corrosive conditions. The copper-tin-lead alloy is very good for many mine water service requirements.

#### 9.3.2.6.10.6 Aluminum bronze

Copper-aluminum alloys offer the greatest flexibility of all of the copper-base materials regarding strength-to-weight ratios. Unlike many of the copper alloys, they respond to thermal treatments. Corrosion-resistance is equal to or better than any of the other copper-base materials. Resistance to corrosion and erosion at high liquid velocity is excellent. Metallurgically, the alloys have a very narrow liquidus-solidus freezing range, which results in a structure free of micro-porosity and is, therefore, good for high fluid pressure containing components. These alloys offer fair-to-good machineability. Welding characteristics are excellent. Because of their high strength, the materials can be very heavily loaded; however, adequate lubrication is mandatory.

#### 9.3.2.6.10.7 Copper-nickel alloys

These alloys are moderately high strength-to-weight ratio materials that offer excellent corrosion and liquid velocity resistance. Machineability is fair. Weldability varies from poor for the 10% nickel material to good for the 30% nickel material. The liquidus-solidus range is moderately wide, which can result in micro-shrinkage and resultant leakage in heavy castings that are slowly cooled.

#### 9.3.2.6.10.8 Leaded nickel bronze (nickel silvers)

Copper, tin, lead, nickel, zinc alloys are used for pumps, valves, marine castings and sanitary fittings. They have moderate strengths and machinability ratings. Welding of these alloys is not recommended.

#### 9.3.2.6.11 Nickel and nickel alloys

##### 9.3.2.6.11.1 Nickel alloys (95% min. nickel)

The relatively pure nickel alloys described in ASTM specifications A743, A744, A494, B160, and B162 are noteworthy for their resistance to hot concentrated caustic soda, chlorine and fluorine at temperatures up to 535°C (1000°F). They are frequently used in the soap and fat industries where a pure white product is desired. The modulus of elasticity and thermal expansion of nickel are comparable to those of steel, with tensile strengths generally in the 380,000 to 900,000 kPa (55,000 to 130,000 psi) range, depending on the mechanical working and annealing history of the material form. Pure nickel is not easily cast, but commercial castings are available.

##### 9.3.2.6.11.2 Nickel-chromium-iron alloys

These alloys contain 60 to 79% nickel and 13 to 18% chromium, with the remainder principally iron. They are described in ASTM specifications A743, A744, A494, B163, and B168. They have excellent mechanical properties and are used for handling hydrochloric acid solutions, acid chlorides and solutions containing free chlorine. The overall corrosion-resistance of these alloys is excellent.

##### 9.3.2.6.11.3 Nickel-molybdenum and nickel-molybdenum-chromium alloys (Hastelloys B and C)

These alloys, described in ASTM specifications A743, A744, A494, B335, and B622, have good mechanical properties and are used to handle hydrochloric, sulfuric and phosphoric acid in both dilute and hot concentrated form. Not all alloys in the group handle all acids in all forms, and selection of the particular alloy should be based on the specific application.

##### 9.3.2.6.11.4 Nickel copper alloys (monel types)

These alloys, described in ASTM specification A743, A744, A494, B127, B164 and B165, contain about two-thirds nickel and one-third copper.

They have high strength, good ductility and good corrosion-resistance to flowing saltwater, dilute mineral acids, hydrofluoric, hydrochloric, sulfuric, phosphoric, and most organic acids, and also strong caustic soda. They are not resistant to strongly oxidizing solutions such as nitric acid, ferric chloride and most acid mine waters. This group is widely used in the chemical and marine industries, and some forms of the alloy have good resistance to galling, erosion and abrasion. In its various compositions and forms, it has tensile strength ranging from 480,000 to 1,200,000 kPa (70,000 to 170,000 psi).

##### 9.3.2.6.11.5 Miscellaneous nickel alloys

A number of cast alloys developed by various foundries for good corrosion-resistance, wear-resistance and excellent resistance to galling are available. Typical of nickel alloys in this group are Stainless Foundry and Engineering Co. Illium alloys G, R and PD, and Waukesha Foundry Co. Waukesha alloys 23 and 88. With corrosion-resistance equal to or exceeding that of stainless steel, these alloys are widely used in the food, dairy, beverage and chemical industries where they offer good corrosion-resistance and ability to maintain smooth cleanable surfaces.

### 9.3.2.6.12 Aluminum and aluminum alloys

Aluminum was discovered as an element in 1825 and has been in great commercial use since around 1900. Except for magnesium and beryllium, aluminum is the lightest of the structurally useful metals. Commercially pure aluminum has a specific gravity of 2.71. It has a highly anodic electrode potential, causing it to be dissolved sacrificially when in contact with most other metals in a corrosive environment.

Aluminum and aluminum alloys are dependent for their corrosion-resistance on an oxide film that forms on the surface. Handling of abrasive materials that would wear away the protective oxide film would adversely affect the corrosion resistance.

Aluminum equipment is an established standard for the storage and transfer of the highest purity distilled water. It has seen many years of usage in the processing of foods, fruit juices and other beverages.

Aluminum and aluminum alloys are generally not satisfactory in contact with sulphur and sulphur compounds but are satisfactorily used for a number of organic amines. They are not generally satisfactory for inorganic acid solutions but have rather wide usage in the handling of organic solutions; the exceptions being formic and oxalic acid solutions which attack aluminum at an appreciably high rate.

Aluminum alloy 319 is used in applications where good casting characteristics, good weldability, pressure tightness and moderate strength are required. It is useful in the handling of motor oils, vegetable oils and in some food processing.

Aluminum alloy 355 has excellent castability, weldability and pressure tightness. It generally is used in the heat-treated form and is useful in the handling of fuel oils, motor oils and water.

Aluminum alloy C-355-T6 has the same characteristics as alloy 355 but has a greater elongation.

Aluminum alloy 356 has good castability, weldability, pressure tightness and resistance to corrosion. It has wide usage as a construction material for aircraft pumps and oil pumps. It is commonly used for pumps handling hydrogen peroxide rocket fuel where compatibility of materials is most critical. In the handling of high-strength hydrogen peroxide, the effect of the liquid on the pump material is by far less critical than the effect that the pump material might have on the peroxide.

Aluminum alloy TP-220-T4 has excellent machineability and corrosion-resistance with the highest strength and elongation of any aluminum sand castings.

Tenzalloy (Al/Zn) alloys are generally used where a good combination of mechanical properties are required without heat-treating. They have good shock- and corrosion-resistance.

Aluminum alloy B750 is used primarily for bearings, as it has good resistance to the corrosion that takes place with engine oils.

Aluminum alloy ASTM B211, alloy 2011 (wrought) has high resistance to rural atmospheres and is fairly good in industrial atmospheres and sea water.

Aluminum copper (Al/Cu) SAE AA2017 (wrought) alloy is similar to alloy 2011 except that it has greater strength.

Aluminum alloy ASTM B211, alloy 6061 is good in the handling of beverages, some chemicals and marine uses.

Aluminum alloy 7075 (Al-Zn-Mg-Cu-Cr) has good shock-resistance, corrosion-resistance and mechanical properties.

### 9.3.2.6.13 Other metals and coating systems

These encompass the less common metallic materials that come in contact with the liquid pumped and cannot be classified under the other main metal selections.

Coatings to resist wear and corrosion have become of increasing importance and are extensively used for parts requiring greater wear- and corrosion-resistance than can be obtained from an economic base material. Corrosion protection can be obtained only when the coating is free of porosity. One of the problems in applying various types of coating, where the process heats the substrate, is the tendency to cause chromium carbide precipitation in austenitic stainless steels. Low or extra-low carbide grades or stabilized grades of austenitic metals will minimize the tendency for carbide precipitation. Coating processes such as plasma arc, metallic oxide spraying, metal spraying and detonation spraying, properly applied, do not heat austenitic stainless steels into the carbide precipitation range. Also, where fusion type coatings are used, careful consideration should be given to the coefficient of thermal expansion for the coating and the base material. Wide deviations in expansion rates could

result in cracking of the coating that, in turn, may precipitate fatigue failure of the part.

#### 9.3.2.6.13.1 Zinc and zinc alloys

Zinc and zinc alloys are useful in the pH range from 6 to 12.5. They exhibit a high corrosion rate in acid and strong acid solutions.

#### 9.3.2.6.13.2 Tin-base bearing metals

Tin-base bearing metals (or babbitt) are substantially alloys of tin, antimony and copper and have better corrosion resistance than lead-base bearing alloys.

#### 9.3.2.6.13.3 Lead and lead alloys

Lead and lead alloys found early use in the sulfuric acid industry where they are still most widely used; however, they are also being used commercially for sulfurous, chromic and phosphoric acids. The corrosion-resistance of lead and lead alloys is based on the ability of the metal to form a protective sulfate, oxide, carbonate, chromate or chemical complex coating.

#### 9.3.2.6.13.4 Cobalt alloys

Cobalt alloys retain their hardness and strength at elevated temperatures and were first used for gas-turbine blades. They are generally classified by hardness — soft, medium and hard — with the softer (and tougher) grades being used for high-temperature service and the harder grades for wear-resistance.

#### 9.3.2.6.13.5 Titanium alloys

Titanium alloys exhibit resistance to oxidization up to 535°C (1000°F) and have good corrosion-resistance to strong oxidizing acids, chloride solutions, chlorine gas, sodium hypochlorite, seawater and brines. The three metallurgical types are classified as alpha, alpha-beta, and beta, which pertain to their microstructure phase. The alpha is a hexagonal crystal structure and the beta is a body cubic structure. Various alloys are used to bring out the type desired. The alpha group exhibits good weldability and high strength retention at elevated temperatures. The alpha-beta are stronger than the alpha, and the beta class can be strengthened by heat treatment.

#### 9.3.2.6.13.6 Zirconium

Zirconium has been used primarily for the basis of alloys used in nuclear reactor core structures which are at elevated temperature. Common acids and

bases do not attack zirconium except hydrofluoric, concentrated sulfuric, hydrochloric, phosphoric and mixed sulfuric and nitric acids.

#### 9.3.2.6.13.7 Cobalt-chromium-tungsten alloy

This material is one of the first wear and corrosion-resistant coatings to be widely used for pump parts subject to wear, such as sleeves, wearing rings, plungers, piston rods and valves. These coatings usually provide excellent wear-resistance, galling-resistance and corrosion-resistance to most products.

The coatings are usually applied to carbon steel or stainless steel base metals. Special attention should be paid to ensure that all areas of the part exposed to corrosion or wear are properly coated with the protective materials. Carbide precipitation created in the application process can cause a loss of corrosion-resistance in austenitic type stainless steels. These factors should be considered in the selection of the stainless steel and in the application of the part to any corrosion media, so that both the coating and any coated areas will have adequate resistance.

#### 9.3.2.6.13.8 Nickel or cobalt-chromium boron alloy

This coating material is available in a number of alloys having different wear and corrosion resisting characteristics. Some of these may be applied by spray welding, while others require oxyacetylene or arc welding and are successfully employed on such parts as wearing rings, sleeves, shafts, piston rods and plungers.

The same precautionary statements relative to carbon content of the base materials, indicated above, apply to these types of coatings as well. Free machining types of steels should not be used.

#### 9.3.2.6.13.9 Chromium coatings

Chromium coatings are normally applied by electroplating. This process tends to produce porosity in the coating. It is preferable to use a base metal which is resistant to the liquid being pumped.

Chromium coatings have excellent corrosion-resistance to many media, including caustics and compounds of nitrogen. They are usually not suitable for compounds of sulphur and chlorine. This plating provides a very hard, wear-resisting and low-friction surface. For reciprocating or rotating parts, these are favorable factors both from the standpoint of wear of the plated parts and service life of the packing. Pump parts most generally

chrome-plated are plungers, liners, piston rods, sleeves and shafts.

**9.3.2.6.13.10 Other coatings**

Ceramic coatings have been employed for special services; however, these coatings are usually quite porous, which limits their application on sliding surfaces in pump applications even though a sealer may be employed to seal the porosity. Further development may permit more general use of these coatings. It is preferable to use a base metal which is resistant to corrosion by the liquid being pumped.

Flame-sprayed carbide or oxide coatings provide high wear-resistance but are relatively expensive.

**9.3.2.6.14 Elastomeric polymers**

Elastomers are defined as rubber-like materials that can be or already are modified to a state exhibiting little plastic flow and quick and nearly complete recovery from a deformation. When tested at room temperature, a material must meet the following requirements in order to be called an elastomer:

- a) Is capable of being stretched 100%;
- b) After being stretched 100%, held for five (5) minutes and then released, it is capable of retracting to within 10% of its original length within five (5) minutes after release.

Elastomers are used in pumps as coatings, linings and homogenous parts to protect against abrasion or corrosion, as component parts of face type and lip type seals, as slingers or baffles, as impellers or rotors, and for many other uses. Like the plastics, they are much more limited in their temperature range than the metals.

With the wide range of elastomers commercially available, it is important to specify material performance requirements. The industry standard recommended for specifying materials is *ASTM D2000, A Classification System for Elastomeric Materials for Automotive Applications*. The industry-adopted standard for common terminology is *ASTM D1418, The Recommended Practice for Nomenclature for Rubber and Rubber Lattices*.

Following by rubber class are common names, polymer name and ASTM symbols:

Name	R Class	
	Polymer name	Sym
Natural rubber		NR
Synthetic rubber	Polyisoprene	IR
Buna S	Styrene-butadiene	SBR
Butyl	Isobutene-isoprene	IIR
Nitrile	Acrylonitrile-butadiene	NBR
Buna N	Acrylonitrile-butadiene	NBR
Hycar Nitril	Acrylonitrile-butadiene	NBR
Neoprene	Chloroprene	CR

NOTE: The R class rubbers have an unsaturated carbon chain.

Name	M Class	
	Polymer name	Sym
Ethylene-propylene	Ethylene-propylene	EPM
Nordel	Ethylene-propylene terpolymer	EPDM
Hypalon	Chlorosulfonated polyethylene	CSM
Fluoro elastomers	Vinylidene fluoride/teravinton fluoropropylene	FKM
Kalrez	Perfluoroelastomer	FFKM

NOTE: The M class rubbers have a saturated chain of polymethylene type.

Name	A Class	
	Polymer name	Sym
Fluorosilicone	Methyl vinyl siloxane	VMQ
	Phenyl vinyl methyl siloxane	PVMQ
	Trifluoropropyl siloxane	FMQ

NOTE: The A class rubbers are the silicon rubbers.

Name	U Class	Sym
	Polymer name	
Urethanes	Polyester urethane	AU
Adiprene	Polyester urethane	EU

NOTE: The U class rubbers have carbon, oxygen and nitrogen in the polymer chain.

Similar to the rapid introduction of new non-metallic structural materials is the growth in the alternatives for elastomers over the last several years. Fluoro elastomers, silicone rubbers, urethanes, neoprene, and Buna N rubbers are among the most widely used.

**9.3.2.6.15 Rigid polymers and composites**

Rigid polymers and composites include a large variety of polymers and plastics — plain and reinforced. Rigid polymers are used in virtually every type pump part, either as coatings or as structural materials. Rigid polymers offer designers, manufacturers and ultimate end users a broad array of benefits.

Proper selection of polymer, filler and process offer many combinations of improved corrosion-resistance, longer fatigue life, lighter weight, flame retardance, lower costs, magnetic transparency, higher strength-to-weight ratios and complexity of unitized part designs. Nonmetallic materials with higher modulus of elasticity and higher use temperatures are becoming commercially available, making the state-of-the-art a dynamic study.

The term “plastics” generally includes two large groups of organic compounds, thermosetting polymers and thermoplastics, which differ considerably in their make-up. Proper material selection for a particular application has allowed nonmetallic substitutions of otherwise traditional metallic parts such as shafts, pull rods, valve seats, pump casings, impellers, bushings, wear rings, ball bearings, and many more. Benefits other than cost alone direct design engineers to consider non-metallic alternatives for longer life and higher quality.

**9.3.2.6.16 Thermosetting polymers**

Thermosetting polymers, generally reinforced with fiberglass or carbon (graphite) fibers, are repeating groups of chemical chains polymerized into a solid matrix. During the molding cycle, these materials undergo a chemical (molecular) change which is irreversible. In other words, these thermosetting materials

will not soften or become pliable by reheating the parts.

Thermoset polymers have four basic chemistries; they are polyesters (alkyds), phenolics, vinyl esters and epoxies. Each has its own particular set of advantages and manufacturing processes, as well as peculiarities. Generally, thermosets are reinforced with either continuous or short fibers of glass or carbon. These reinforcements are key in developing the design strengths, while the particular thermoset matrix determines the useful temperature range and general corrosion-resistance of the final part.

Manufacturing processes for thermosets are numerous and often are every bit as critical to the final part performance as the selection of the proper matrix/reinforcement combination. Compression molding (wet lay-up, SMC, BMC), transfer molding, pultrusion, resin transfer molding, cold molding, spray up and extrusion are among the most commonly used commercial processes.

**9.3.2.6.17 Thermoplastics**

Thermoplastics, on the other hand, do not undergo a chemical change in their processing and, therefore, will become “pliable” upon reheating above their yield temperatures.

Thermoplastic materials are available in a wide range of strengths and application envelopes. In general terms, thermoplastics can be divided into fluoropolymers (i.e., PFA, PTFE), engineering plastics (i.e., LCP, PPS and PEEK), and general (ABS, acrylics, polyethylene, PVC, and polypropylene), just to mention a few. Thermoplastic processes, such as injection molding, vacuum forming, extrusion and blow molding, offer the design engineer many selections for optimizing cost. Considering the large number of reinforced variations of thermoplastics, a designer is likely to have more applicable non-metallic alternatives than metallic alloy choices for a particular application.

Selection of a suitable non-metallic material requires a complete understanding of the end use application (strength requirements, environment, life cycle requirements, etc.), as well as a familiarity with the polymer’s physical, chemical and processing properties.

Although direct replacements without design changes can be achieved, more often the use of non-metallics is optimized by well-informed specialists.

### 9.3.2.6.18 Ceramics

There is an increasing use of ceramics in pump construction, primarily in the area of oxides.

Ceramics are primarily used because of their abrasion-resistant, corrosion-resistant, and anti-galling properties. They can be applied as coatings, or in some cases the entire part can be made from them.

The oxides are generally coatings applied by the thermospray or the plasma flame process. They are porous, and sealers are sometimes used to fill the pores. These can be either air drying or baking type sealers. Because of the porosity, even though sealers are used, the metal under the coating should be resistant to chemical attack by the liquid pumped. If properly machined after application, the coatings have a smooth, hard, abrasion-resistant surface with a low coefficient of friction.

The carbides are usually metallic, such as tungsten carbide, with a binder or matrix of either cobalt or high nickel alloy. The material is extremely hard and abrasion-resistant. It is corrosion-resistant but not to the extent of the more noble metals.

### 9.3.2.6.19 Other non-metals

Other non-metallic materials, covered by the subclassifications following, are used in a variety of ways, and usually are proprietary materials which are procured to specification of the manufacturer of the material. These materials are always selected for their specific properties in relation to the mechanical requirements of the application and the liquid being pumped.

#### 9.3.2.6.19.1 Fabrics

Felt is available in a variety of grades, each with varying chemical and physical requirements. SAE Standard J 314a covers types and qualities of felt for general automotive use. Specific properties obtained by special sizing, adhesives and impregnating materials must be agreed upon by the supplier and the purchaser.

#### 9.3.2.6.19.2 Reinforced fibers

This classification covers materials composed of inorganic fibers, organic fibers, cork or cellulose alone or in combination with various binders or coatings. Properties of these materials vary markedly and, therefore, must be selected judiciously. ASTM Stan-

dard F-104 covers these materials in relation to their use as gaskets.

#### 9.3.2.6.19.3 Leather

Leather has excellent pliable strength, toughness and abrasion characteristics, and a particular ability to hold lubricating liquids in its fibers. It is, however, not suitable for use above 85°C (180°F) or where it comes in contact with acid or strong alkaline chemicals. It is available in four general categories:

- 1) Rawhide (untanned);
- 2) Vegetable tanned;
- 3) Mineral tanned;
- 4) A combination of the foregoing tannages.

For some applications, leathers need impregnation with another material in addition to being tanned. Waxes, resins, and synthetic liquid polymers and molybdenum disulfide are typical of impregnants used.

#### 9.3.2.6.19.4 Adhesives and sealants

This category covers liquid, time curing type adhesives and sealants. They are generally available from manufacturers in various types for bonding different materials and in various grades or different strengths and cure times. Generally, these materials are unaffected by most liquids and maintain their strength at elevated temperatures.

#### 9.3.2.6.19.5 Carbon and graphite

Carbon and graphite are used because of their low friction properties, corrosion-resistance to most acids, alkalis and solvents, and dimensional stability over a wide temperature range. Numerous formulations of carbon and graphite materials are commercially available with varying physical properties. Metal filled formulations enhance physical properties and, when properly applied, provide the best features of both materials.

#### 9.3.2.6.20 Cavitation erosion resistance of materials

Satisfactory hydraulic performance of centrifugal pumps with no detectable signs of excessive noise or vibration does not guarantee that cavitation erosion will not be occurring at some point in the operating range as a result of insufficient NPSH, liquid recirculation and

separation. Under such conditions, the potential damage caused by cavitation erosion can be significantly reduced by the selection of suitable materials for the construction of the impellers.

The wear mechanism associated with cavitation damage is very complex and not fully understood and there is no single identifiable property in a material that clearly quantifies its resistance to cavitation erosion. It is known, however, that materials should have high resilience, hardness, tensile strength, impact and fatigue resistance. Brittle materials should be avoided.

A general ranking of the relative cavitation erosion resistance for metal castings that are commonly used in the construction of centrifugal pumps when pumping clear water at ambient temperature is presented as a guide for impeller material selection (Figure 9.2). The severity of cavitation damage will be lessened if noncondensable gas or air is present in the liquid.

When pumping corrosive liquids in a cavitating environment, the relative erosion rates should be judged as to which condition is likely to predominate and the material selected accordingly.

Corrosion is likely to be more severe in a cavitating condition because the cavitation destroys the protective corrosion film and constantly exposes fresh metal surfaces.

#### *Engineered plastics:*

The physical properties of engineered plastics are inferior to those of most common metals and consequently the damage caused by cavitation erosion will be greater. If the pump has to be applied to a service where cavitation erosion may be anticipated, engineered plastics as a material of construction should be avoided.

#### *Elastomers:*

Elastomer materials such as natural rubber, which are soft and have high resilience, perform well when subjected to cavitation. However, these materials can fail prematurely if the elastomer-to-metal adhesion is inadequate. The thickness of the coating is also significant and should not be less than 3 mm (.125 inches).

#### *Hard-faced materials:*

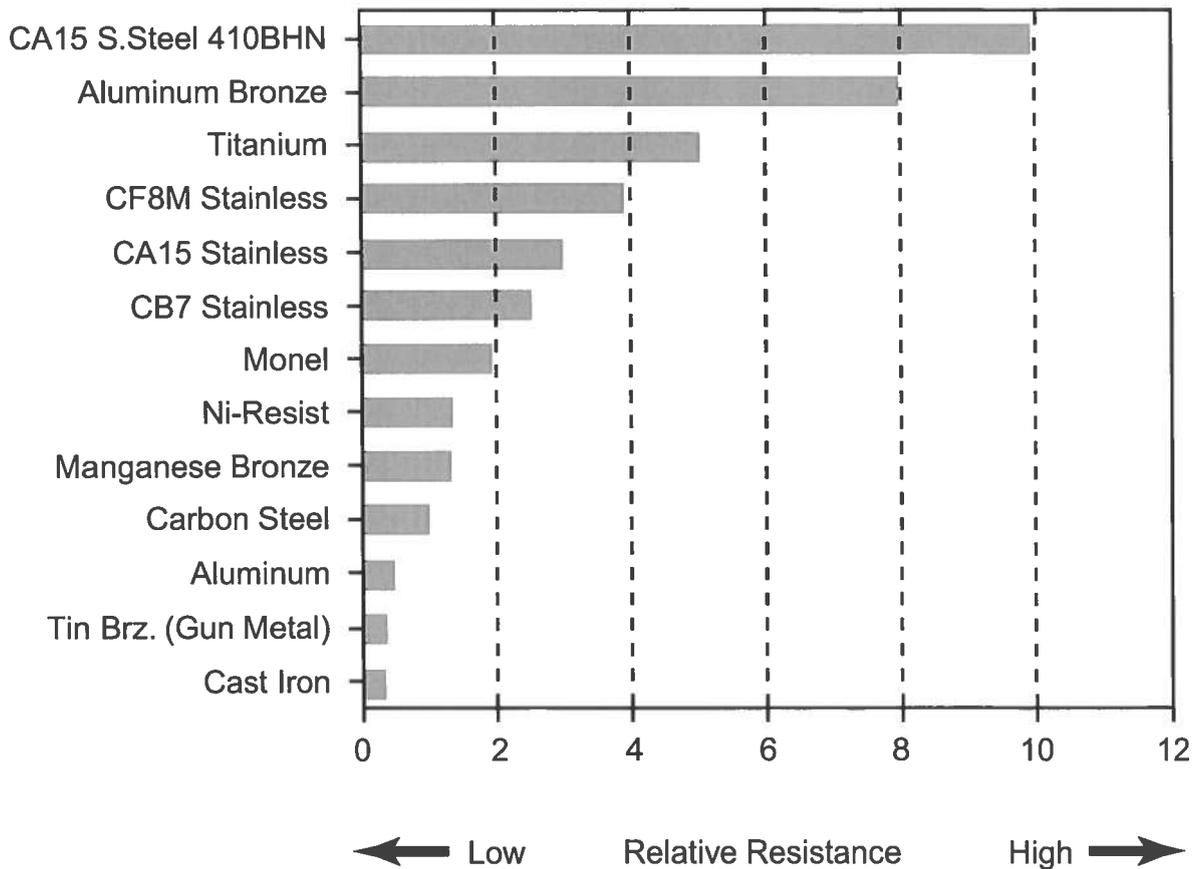
Hard materials can withstand cavitation erosion attack much better than other metals by a factor of six to one.

However, they can fail prematurely due to cracking caused by poor adhesion.

#### **9.3.2.7 Common metallic materials of construction for various liquids**

Table 9.3 shows the materials commonly used for pumping various liquids. The material selection codes shown in column 5 are described below. Although specifically not listed in the table, many non-metallic materials as described in Sections 9.3.2.6.14 through 9.3.2.6.19.5, are also commonly used for various liquids. Refer to pump manufacturers for recommendations.

Material selection	ASTM number	Remarks
A		All bronze construction
B		Bronze fitted construction
C		All iron construction
3	A216-WCB	Carbon steel
4	A217-C5	5% chromium steel
5	A743-CA15	12% chromium steel
6	A743-CB30	20% chromium steel
7	A743-CC50	28% chromium steel
8	A743-CF-8	19-9 austenitic steel
9	A743-CF-8M	19-10 molybdenum austenitic steel
10	A743-CN-7M	20-29 chromium nickel austenitic steel with copper & molybdenum
11		A series of nickel-base alloys
12	A518	Corrosion-resistant high-silicon cast iron
13	A436	Austenitic cast iron – 2 types
13(a)	A439	Ductile austenitic cast iron
14		Nickel-copper alloy
15		Nickel



Note: Rate of wear due to cavitation erosion increases with increased temperature.

**Figure 9.2 — General ranking of cavitation erosion resistance of common cast metals when pumping clear water at ambient temperature**

**Table 9.3 — Materials of construction for pumping various liquids**

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Acetaldehyde		$C_2H_4O$	0.78	C
Acetate solvents				A, B, C, 8, 9, 10, 11
Acetone		$C_3H_6O$	0.79	B, C
Acetic anhydride		$C_2H_6O_3$	1.08	8, 9, 10, 11, 12
Acid, acetic	Conc. cold	$C_2H_4O_2$	1.05	8, 9, 10, 11, 12
Acid, acetic	Dil. cold			A, 8, 9, 10, 11, 12
Acid, acetic	Conc. boiling			9, 10, 11, 12
Acid, acetic	Dil. boiling			9, 10, 11, 12
Acid, arsenic, ortho		$H_3AsO_4 \cdot \frac{1}{2}H_2O$	2.0-2.5	8, 9, 10, 11, 12
Acid, benzoic		$C_7H_6O_2$	1.27	8, 9, 10, 11
Acid, boric	Aqueous sol.	$H_3BO_3$		A, 8, 9, 10, 11, 12
Acid, butyric	Conc.	$C_4H_8O_2$	0.96	8, 9, 10, 11
Acid, carbolic	Conc. (M.P. 41°C [106°F])	$C_6H_6O$	1.07	C, 8, 9, 10, 11
Acid, carbolic	(See phenol)			B, 8, 9, 10, 11
Acid, carbonic	Aqueous sol.	$CO_2 + H_2O$		A
Acid, chromic	Aqueous sol.	$Cr_2O_3 + H_2O$		A, 8, 9, 10, 11, 12
Acid, citric	Aqueous sol.	$C_6H_8O_7 + H_2O$		A, 8, 9, 10, 11, 12
Acids, fatty (oleic, palmitic, stearic, etc.)				A, 8, 9, 10, 11
Acid, formic		$CH_2O_2$	1.22	9, 10, 11
Acid, fruit				A, 8, 9, 10, 11, 14
Acid, hydrochloric	Coml conc.	HCl	1,19 (38%)	11, 12
Acid, hydrochloric	Dil. cold			10, 11, 12, 14, 15
Acid, hydrochloric	Dil. hot			11, 12
Acid, hydrocyanic		HCN	0.70	C, 8, 9, 10, 11
Acid, hydrofluoric	Anhydrous, with hydro carbon	$HF + H_xC_x$		3, 14
Acid, hydrofluoric	Aqueous sol.	HF		A, 14
Acid, hydrofluosilicic		$H_2SiF_6$	1.30	A, 14
Acid, lactic		$C_3H_6O_3$	1.25	A, 8, 9, 10, 11, 12
Acid, mine water				A, 8, 9, 10, 11
Acid, mixed	Sulfuric + nitric			C, 3, 8, 9, 10, 11, 12
Acid, muriatic	(See acid, hydrochloric)			—
Acid, naphthenic				C, 5, 8, 9, 10, 11
Acid, nitric	Conc. boiling	$HNO_3$	1.50	6, 7, 10, 12
Acid, nitric	Dilute			5, 6, 7, 8, 9, 10, 12
Acid, oxalic	Cold	$C_2H_2O_4 \cdot 2H_2O$	1.65	8, 9, 10, 11, 12
Acid, oxalic	Hot	$C_2H_2O_4 \cdot 2H_2O$		10, 11, 12

**Table 9.3 — Materials of construction for pumping various liquids (continued)**

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Acid, ortho-phosphoric		$H_3PO_4$	1.87	9, 10, 11
Acid, picric		$C_6H_3N_3O_7$	1.76	8, 9, 10, 11, 12
Acid, pyrogallic		$C_6H_6O_3$	1.45	8, 9, 10, 11
Acid, pyroligneous				A, 8, 9, 10, 11
Acid, sulfuric	> 77% cold	$H_2SO_4$	1.69-1.84	C, 10, 11, 12
Acid, sulfuric	65/93% > 175°F			11, 12
Acid, sulfuric	65/93% < 175°F			10, 11, 12
Acid, sulfuric	10-65%			10, 11, 12
Acid, sulfuric	10%			A, 10, 11, 12, 14
Acid, sulfuric (Oleum)	Fuming	$H_2SO_4 + SO_3$	1.92-1.94	3, 10, 11
Acid sulfurous		$H_2SO_3$		A, 8, 9, 10, 11
Acid, tannic		$C_{14}H_{10}O_9$		A, 8, 9, 10, 11, 14
Acid, tartaric	Aqueous sol.	$C_4H_6O_6 \cdot H_2O$		A, 8, 9, 10, 11, 14
Alcohols				A, B
Alum	(See aluminum sulphate and potash alum)			
Aluminum sulphate	Aqueous sol.	$Al_2(SO_4)_3$		10, 11, 12, 14
Ammonia, aqua		$NH_4OH$		C
Ammonium bicarbonate	Aqueous sol.	$NH_4HCO_3$		C
Ammonium chloride	Aqueous sol.	$NH_4Cl$		9, 10, 11, 12, 14
Ammonium nitrate	Aqueous sol.	$NH_4NO_3$		C, 8, 9, 10, 11, 14
Ammonium phosphate, dibasic	Aqueous sol.	$(NH_4)_2HPO_4$		C, 8, 9, 10, 11, 14
Ammonium sulfate	Aqueous sol.	$(NH_4)_2SO_4$		C, 8, 9, 10, 11
Ammonium sulfate	With sulfuric acid			A, 9, 10, 11, 12
Aniline		$C_6H_7N$	1.02	B, C
Aniline hydrochloride	Aqueous sol.	$C_6H_5NH_2HCl$		11, 12
Asphalt	Hot		0.98-1.4	C, 5
Barium chloride	Aqueous sol.	$BaCl_2$		C, 8, 9, 10, 11
Barium nitrate	Aqueous sol.	$Ba(NO_3)_2$		C, 8, 9, 10, 11
Beer				A, 8
Beer wort				A, 8
Beet juice				A, 8
Beet pulp				A, B, 8, 9, 10, 11
Benzene		$C_6H_6$	0.88	
Benzine	(See petroleum ether)			
Benzol	(See benzene)			B, C
Bichloride of mercury	(See mercuric chloride)			
Black liquor	(See liquor, pulp mill)			

Table 9.3 — Materials of construction for pumping various liquids (*continued*)

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Bleach solutions Blood Boiler feedwater	(See type)  (See water, boiler feed)			A, B
Brine, calcium chloride Brine, calcium chloride Brine, calcium and magnesium chlorides	pH>8 pH<8 Aqueous sol.	CaCl <sub>2</sub>		C A, 10, 11, 13, 14 A, 10, 11, 13, 14
Brine, calcium and sodium chloride Brine, sodium chloride Brine, sodium chloride	Aqueous sol. Under 3% salt, cold Over 3% salt, cold	NaCl	1.02-1.20	A, 10, 11, 13, 14 A, C, 13 A, 8, 9, 10, 11, 13, 14
Brine, sodium chloride Brine, seawater Butane	Over 3% salt, hot	C <sub>4</sub> H <sub>10</sub>	1.03 0.60 @ 0°C (32°F)	9, 10, 11, 12, 14 A, B, C B, C, 3
Calcium bisulfite Calcium chlorate Calcium hypochlorite	Paper mill Aqueous sol.	Ca(HSO <sub>3</sub> ) <sub>2</sub> Ca(ClO <sub>3</sub> ) <sub>2</sub> ·2H <sub>2</sub> O Ca(OCl) <sub>2</sub>	1.06	9, 10, 11 10, 11, 12 C, 10, 11, 12
Calcium magnesium chloride Cane juice	(See brines)			A, B, 13
Carbon bisulfide Carbonate of soda Carbon tetrachloride	(See soda ash) Anhydrous	CS <sub>2</sub> CCl <sub>4</sub>	1.26 1.50	C B, C
Carbon tetrachloride Catsup Caustic potash	Plus water  (See potassium hydroxide)			A, 8 A, 8, 9, 10, 11
Caustic soda Cellulose acetate Chlorate of lime	(See sodium hydroxide)  (See calcium chlorate)			9, 10, 11
Chloride of lime Chlorine water Chlorobenzene	(See calcium hypochlorite) (Depending on conc.)	C <sub>6</sub> H <sub>5</sub> Cl	1.1	9, 10, 11, 12 A, B, 8
Chloroform Chrome alum Condensate	Aqueous sol. (See water, distilled)	CHCl <sub>3</sub> CrK(SO <sub>4</sub> ) <sub>2</sub> ·12H <sub>2</sub> O	1.5	A, 8, 9, 10, 11, 14 10, 11, 12
Copperas, green Copper ammonium acetate Copper chloride (cupric)	(See ferrous sulfate) Aqueous sol. Aqueous sol.	CuCl <sub>2</sub>		C, 8, 9, 10, 11 11, 12

**Table 9.3 — Materials of construction for pumping various liquids (continued)**

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Copper nitrate	Aqueous sol. (See oil, creosote)	$Cu(NO_3)_2$		8, 9, 10, 11
Copper sulfate, blue vitriol		$CuSO_4$		8, 9, 10, 11, 12
Creosote				
Cresol, meta	(See sodium cyanide and potassium cyanide) In water	$C_7H_8O$	1.03	C, 5
Cyanide				
Cyanogen		$(CN)_2$ gas		C
Diphenyl Enamel Ethanol	(See alcohols)	$C_6H_5. C_6H_5$	.99	C, 3 C
Ethylene chloride (di-chloride)	Cold	$C_2H_4Cl_2$	1.28	A, 8, 9, 10, 11, 14
Ferric chloride	Aqueous sol.	$FeCl_3$		11, 12
Ferric sulphate	Aqueous sol.	$Fe_2(SO_4)_3$		8, 9, 10, 11, 12
Ferrous chloride	Cold, aqueous	$FeCl_2$		11, 12
Ferrous sulphate (green copperas)	Aqueous sol.	$FeSO_4$		9, 10, 11, 12, 14
Formaldehyde		$CH_2O$	1.08	A, 8, 9, 10, 11
Fruit juices				A, 8, 9, 10, 11, 14
Furfural		$C_5H_4O_2$	1.16	A, C, 8, 9, 10, 11
Gasoline	(See sodium sulfate)		0.68-0.75	B, C
Gaubes salt				
Glucose				A, B
Glue	Hot			B, C
Glue sizing				A
Glycerol (glycerin)		$C_3H_8O_3$	1.26	A, B, C
Green liquor	(See liquor, pulp mill)			
Heptane	Aqueous sol.	$C_7H_{16}$	0.69	B, C
Hydrogen peroxide		$H_2O_2$		8, 9, 10, 11
Hydrogen sulfide		$H_2S$		8, 9, 10, 11
Hydrosulfite of soda	(See sodium hydrosulfite)			
Hyposulfite of soda	(See sodium thiosulfate)			
Kaolin slip	Suspension in water			C, 3
Kaolin slip	Suspension in acid			10, 11, 12
Kerosene	(See oil kerosene)			
Lard	Hot			B, C
Lead acetate (sugar of lead)	Aqueous sol.	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$		9, 10, 11, 14
Lead	Molten			C, 3

Table 9.3 — Materials of construction for pumping various liquids (*continued*)

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Lime water (milk of lime)		$\text{Ca(OH)}_2$		C
Liquor-pulp mill: black				C, 3, 9, 10, 11, 12, 14
Liquor-pulp mill: green				C, 3, 9, 10, 11, 12, 14
Liquor-pulp mill: white				C, 3, 9, 10, 11, 12, 14
Liquor-pulp mill: pink				C, 3, 9, 10, 11, 12, 14
Liquor-pulp mill: sulfite				9, 10, 11
Lithium chloride	Aqueous sol.	LiCl		C
Lye, caustic	(See potassium and sodium hydroxide)			
Magnesium chloride	Aqueous sol.	$\text{MgCl}_2$		10, 11, 12
Magnesium sulfate (epsom salts)	Aqueous sol.	$\text{MgSO}_4$		C, 8, 9, 10, 11
Manganese chloride	Aqueous sol.	$\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$		A, 8, 9, 10, 11, 12
Manganous sulfate	Aqueous sol.	$\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$		A, C, 8, 9, 10, 11
Mash				A, B, 8
Mercuric chloride	Very dilute aqueous sol.	$\text{HgCl}_2$		9, 10, 11, 12
Mercuric chloride	Compl. conc. aqueous sol.	$\text{HgCl}_2$		11, 12
Mercuric sulfate	In sulfuric acid	$\text{HgSO}_4 + \text{H}_2\text{SO}_4$		10, 11, 12
Mercurous sulfate	In sulfuric acid	$\text{Hg}_2\text{SO}_4 + \text{H}_2\text{SO}_4$		10, 11, 12
Methyl chloride		$\text{CH}_3\text{Cl}$	0.52	C
Methylene chloride		$\text{CH}_2\text{Cl}_2$	1.34	C, 8
Milk			1.03-1.04	8
Milk of lime	(See lime water)			
Mine water	(See acid, mine water)			
Miscella	(20% soybean oil & solvent)		0.75	C
Molasses				A, B
Mustard				A, 8, 9, 10, 11, 12
Naphtha			0.78-0.88	B, C
Naphtha, crude			0.92-0.95	B, C
Nicotine sulfate		$(\text{C}_{10}\text{H}_{14}\text{N}_2)_2\text{H}_2\text{SO}_4$		10, 11, 12, 14
Nitre	(See potassium nitrate)			
Nitre cake	(See sodium bisulphate)			
Nitro ethane		$\text{C}_2\text{H}_5\text{NO}_2$	1.04	B, C
Nitro methane		$\text{CH}_3\text{NO}_2$	1.14	B, C
Oil, coal tar				B, C, 8, 9, 10, 11

**Table 9.3 — Materials of construction for pumping various liquids (continued)**

Column 1	Column 2	Column 3	Column 4	Column 5	
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection	
Oil, coconut	Cold		0.91	A, B, C, 8, 9, 10, 11, 14	
Oil, creosote			1.04-1.10	B, C	
Oil, crude				B, C	
Oil, crude	Hot			3	
Oil, essential				A, B, C	
Oil, fuel				B, C	
Oil, kerosene			0.94	B, C	
Oil, linseed				A, B, C, 8, 9, 10, 11, 14	
Oil, lubricating				B, C	
Oil, mineral			0.90	B, C	
Oil, olive				B, C	
Oil, palm				0.90	A, B, C, 8, 9, 10, 11, 14
Oil, quenching			0.91	B, C	
Oil, rapeseed			0.92	A, 8, 9, 10, 11, 14	
Oil, soya bean				A, B, C, 8, 9, 10, 11, 14	
Oil, turpentine	Hot (See hydrogen peroxide)		0.87	B, C	
Paraffin				B, C	
Perhydrol					
Peroxide of hydrogen	(See hydrogen peroxide)			B, C	
Petroleum ether					
Phenol					C <sub>6</sub> H <sub>6</sub> O
Pink liquor	(See liquor, pulp mill)			8, 9, 10, 11	
Photographic developers					
Plating solutions					(Varied and complicated, consult pump mfrs.)
Potash	Plant liquor			A, 8, 9, 10, 11, 13, 14	
Potash alum	Aqueous sol.			Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> K <sub>2</sub> SO <sub>4</sub> ·24H <sub>2</sub> O	A, 9, 10, 11, 12, 13, 14
Potassium bichromate	Aqueous sol.			K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	C
Potassium carbonate	Aqueous sol.	K <sub>2</sub> CO <sub>3</sub>		C	
Potassium chlorate	Aqueous sol.	KClO <sub>3</sub>		8, 9, 10, 11, 12	
Potassium chloride	Aqueous sol.	KCl		A, 8, 9, 10, 11, 14	
Potassium cyanide	Aqueous sol.	KCN		C	
Potassium hydroxide	Aqueous sol.	KOH		C, 5, 8, 9, 10, 11, 13, 14, 15	
Potassium nitrate	Aqueous sol.	KNO <sub>3</sub>		C, 5, 8, 9, 10, 11	

**Table 9.3 — Materials of construction for pumping various liquids (continued)**

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Potassium sulfate	Aqueous sol.	$K_2SO_4$		A, 8, 9, 10, 11
Propane		$C_3H_8$	0.59 @ 9°C (48°F)	B, C, 3
Pyridine		$C_5H_5N$	0.98	C
Pyridine sulfate				10, 12
Rhidolene				B
Rosin (colophony)	Paper mill			C
Sal ammoniac	(See ammonium chloride)			
Salt lake	Aqueous sol.	$Na_2SO_4$ + impurities		A, 8, 9, 10, 11, 12
Salt water	(See brines)			
Sea water	(See brines)			
Sewage				A, B, C
Shellac				A
Silver nitrate	Aqueous sol.	$AgNO_3$		8, 9, 10, 11, 12
Slop, brewery				A, B, C
Slop, distillers				A, 8, 9, 10, 11
Soap liquor				C
Soda ash	Cold	$Na_2CO_3$		C
Soda ash	Hot			8, 9, 10, 11, 13, 14
Sodium bicarbonate	Aqueous sol.	$NaHCO_3$		C, 8, 9, 10, 11, 13
Sodium bisulfate	Aqueous sol.	$NaHSO_4$		10, 11, 12
Sodium carbonate	(See soda ash)			
Sodium chlorate	Aqueous sol.	$NaClO_3$		8, 9, 10, 11, 12
Sodium chloride	(See brines)			
Sodium cyanide	Aqueous sol.	$NaCN$		C
Sodium hydroxide	Aqueous sol.	$NaOH$		C, 5, 8, 9, 10, 11, 13, 14, 15
Sodium hydrosulfite	Aqueous sol.	$Na_2S_2O_4 \cdot 2H_2O$		8, 9, 10, 11
Sodium hypochlorite		$NaOCl$		10, 11, 12
Sodium hyposulfite	(See sodium thiosulfate)			
Sodium meta silicate				C
Sodium nitrate	Aqueous sol.	$NaNO_3$		C, 5, 8, 9, 10, 11
Sodium phosphate: monobasic	Aqueous sol.	$NaH_2PO_4 \cdot H_2O$		A, 8, 9, 10, 11
Sodium phosphate: dibasic	Aqueous sol.	$Na_2HPO_4 \cdot 7H_2O$		A, C, 8, 9, 10, 11

**Table 9.3 — Materials of construction for pumping various liquids (continued)**

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Sodium phosphate: tribasic	Aqueous sol.	$\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$		C
Sodium phosphate: meta	Aqueous sol.	$\text{Na}_4\text{P}_4\text{O}_{12}$		A, 8, 9, 10, 11
Sodium phosphate: hexameta	Aqueous sol.	$(\text{NaPO}_3)_6$		8, 9, 10, 11
Sodium plumbite	Aqueous sol.			C
Sodium sulfate	Aqueous sol.	$\text{Na}_2\text{SO}_4$		A, 8, 9, 10, 11
Sodium sulfide	Aqueous sol.	$\text{Na}_2\text{S}$		C, 8, 9, 10, 11
Sodium sulfite	Aqueous sol.	$\text{Na}_2\text{SO}_3$		A, 8, 9, 10, 11
Sodium thiosulfate	Aqueous sol.	$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$		8, 9, 10, 11
Stannic chloride	Aqueous sol.	$\text{SnCl}_4$		11, 12
Stannous chloride	Aqueous sol.	$\text{SnCl}_2$		11, 12
Starch		$(\text{C}_6\text{H}_{10}\text{O}_5)_x$		A, B
Strontium nitrate	Aqueous sol.	$\text{Sr}(\text{NO}_3)_2$		C, 8
Sugar	Aqueous sol.			A, 8, 9, 10, 11, 13
Sulfite liquor	(See liquor, pulp mill)			
Sulfur	In water	S		A, C, 8, 9, 10, 11
Sulfur	Molten	S		C
Sulfur chloride	Cold	$\text{S}_2\text{Cl}_2$		C
Syrup	(See sugar)			
Tallow	Hot		0.99	C
Tanning liquors				A, B, 9, 10, 11, 12, 14
Tar	Hot			C, 3
Tar and ammonia	In water			C
Tetrachloride of tin	(See stannic chloride)			
Tetraethyl lead		$\text{Pb}(\text{C}_2\text{H}_5)_4$	1.66	B, C
Toluene (toluol)		$\text{C}_7\text{H}_8$	0.87	B, C
Trichloroethylene		$\text{C}_2\text{HCl}_3$	1.47	A, B, C, 8
Urine				A, 8, 9, 10, 11
Varnish				A, B, C, 8, 14
Vegetable juices				A, 8, 9, 10, 11, 14
Vinegar				A, 8, 9, 10, 11, 12
Vitriol, blue	(See copper sulfate)			
Vitriol, green	(See ferrous sulfate)			
Vitriol, oil of	(See acid, sulfuric)			
Vitriol, white	(See zinc sulfate)			
Water, boiler feed	Not evaporated pH > 8.5		1.00	C

**Table 9.3 — Materials of construction for pumping various liquids (continued)**

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	Conditions of liquid	Chemical symbol	Specific gravity	Material selection
Water, boiler feed	High makeup pH < 8.5			B
Water, boiler feed	Low makeup		1.00	4, 5, 8, 14
Water, distilled	Evaporated, any pH		1.00	A, 8
Water, distilled	Condensate			A, B
Water, fresh			1.00	B
Water, mine	(See acid, mine water)			
Water, salt and sea	(See brines)			
Whiskey				A, 8
White liquor	(See liquor, pulp mill)			
White water	Paper mill			A, B, C
Wine				A, 8
Wood pulp (stock)				A, B, C
Wood vinegar	(See acid pyroligneous)			
Wort	(See beer wort)			
Xylol (Xylene)		C <sub>8</sub> H <sub>10</sub>	0.87	B, C, 8, 9, 10, 11
Yeast				A, B
Zinc chloride	Aqueous sol.	ZnCl <sub>2</sub>		9, 10, 11, 12
Zinc sulfate	Aqueous sol.	ZnSO <sub>4</sub>		A, 9, 10, 11

### 9.3.3 Common polymer materials of construction for various liquids

#### 9.3.3.1 Introduction

Table 9.4 is a guide for the selection of polymers, both thermoplastic and thermoset, suitable for exposure to various liquids. The continuous temperature rating shown should result in no attack on the polymer by the liquids. For temperatures exceeding these ratings, even for a short period, consult the manufacturer.

The tensile strength and modulus of elasticity of polymers decrease significantly with increasing temperature and are the primary limitations for application. The other application criteria is the resistance to corrosion by the liquid. This resistance depends on the concentration of corrosive chemicals and the temperature of the liquid.

Two types of polymer materials — thermoplastics (TP) and thermosets (TS) — are used in polymer pumps. Thermoplastics are usually thin-wall members with lower allowable temperatures, and pressures. They are lower-weight pieces and melt when excessive heat

is applied to them. Thermosets can be heavy-wall, high-pressure, large components and char when excessive heat is applied.

Typical characteristics of pump construction of two polymer types are as follows. These characteristics are for a preliminary guide only. Depending on design, these values may be higher.

	Thermoplastics	Thermoset
Wall thickness range of components:		
mm	1.5 to 50	.8 to 50
inches	.06 to 2.0	.03 to 2.0
Maximum continuous temperature rating: <sup>a</sup>		
°C	93 <sup>b</sup>	120
°F	200 <sup>b</sup>	250

<sup>a</sup> Consult manufacturer for minimum temperature limits.

<sup>b</sup> Not externally reinforced. Also depends on liquid handled.

	Thermoplastics	Thermoset
Casing pressure range at maximum continuous temperature:		
kPa	175 to 1750 <sup>a</sup>	700 to 1750
psi	25 to 250 <sup>a</sup>	100 to 250

<sup>a</sup> Not externally reinforced. Also depends on liquid handled.

	Thermoplastics	Thermoset
Capacity range for pumps:		
m <sup>3</sup> /h	up to 225	up to 900
gpm	up to 1000	up to 4000

Both thermoplastics and thermosets are usually internally reinforced by the addition of glass or carbon fibers. The addition of the reinforcement can double the tensile strength in many of the polymers. When selecting materials for a liquid, the limiting criteria may be the attack of the liquid on the reinforcement — not the polymer. Table 9.4 assumes the addition of glass or carbon fiber reinforcement.

Since this guide is for a pump (pressure boundary parts), the limiting temperature is shown only for continuous applications. This guide does not apply to lined pumps. If a polymer is not recommended, it is identified as NR. When no data was available a dash (–) is indicated.

Polymers are also used for non-pressure parts such as wear rings and bushings, and may have higher temperature ratings than shown.

**9.3.3.2 Polymers used**

Table 9.4 identifies 11 different polymers which are used in pump construction.

The recommendations for these material applications are based on information received from the references shown in Section 9.3.3.4, and the experience of pump manufacturers and users. Because of the many combinations of liquid conditions, temperature effects, pressure and processing limits, this guide is intended to narrow the selection of polymer materials for a particular application but should not be used as the final recommendation. The Hydraulic Institute is offering this only as a guide for the user's consideration.

**Table 9.4 — Polymers used in pump construction**

Material	Abbrev.	Trade Name	Made By	Type
1. Phenylene oxide	PPO	Noryl <sup>®</sup>	GE	TP
2. Polycarbonate	PC	Lexan <sup>®</sup>	GE	TP
3. Poly-etheretherketone	PEEK	—	—	TP
4. Poly-phenylene Sulfide	PPS	Ryton <sup>®</sup>	Phillips	TP
5. Polypropylene	PP	—	—	TP
6. Polytetra Fluoroethylene	PTFE	Teflon <sup>®</sup>	DuPont	TP
7. Tetrafluoroethylene Perfluoroalkoxy Copolymer	PFA	Teflon <sup>®</sup>	Dupont	TP
8. Polyvinylfluoride	PVDF	Kynar <sup>®</sup>	Agochem	TP
9. Biphenol A Resin with Anhydride Hardener	Epoxy A		—	TS
10. Novolac Resin w/Aromatic Amine Hardener	Epoxy N		—	TS
11. Vinyl Ester (Bisphenol Epoxy)	Vin,Est		—	TS

### 9.3.3.3 Liquids

About 150 different liquids are shown in Table 9.5. Different conditions and concentrations are shown for the liquids. Concentrations are the percent by weight of the liquid in the solution. If the solution is saturated, concentration is shown as "SAT". Concentrated aqueous liquids are shown as "Conc".

### 9.3.3.4 Reference and source material

- 1) *Corrosion Resistance Guide*  
Phillips Petroleum Company  
Bartlesville, Oklahoma 74004
- 2) *Plastics Engineering Design Guide*  
Plastics Manufacturing, Inc.  
P.O. Box 579  
5685 Highway 49 South  
Harrisburg, NC 28075-0579
- 3) *Chemical Resistance of Victrex PEEK*  
Victrex Peek  
601 Willowbrook Lane  
West Chester, PA 19382
- 4) *Kynar Chemical Resistance Chart*  
Pennwalt Corporation  
Plastics Department  
Three Parkway  
Philadelphia, PA 19102
- 5) *Derakane Chemical Resistance and Engineering Guide*  
Dow Chemical Company  
2040 Dow Center  
Midland, MI 48674
- 6) *Teflon® PTFE Fluorocarbon Resin Properties Handbook*  
DuPont Fluoroproducts  
Chestnut Run 711  
Wilmington, DE 19880
- 7) *Teflon® PFA Fluorocarbon Resin Properties Handbook*  
DuPont Fluoroproducts  
Chestnut Run 711  
Wilmington, DE 19880
- 8) *Atlac and Dion Corrosion Resin Selection & Design Guide*  
Reichhold Chemical  
P.O. Box 13582  
Research Triangle Park, NC 27709

Table 9.5 — Guide for maximum continuous temperature (°C) liquid vs. material selection for polymer pumps

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFA/PTFE	PVDF	Epoxy A	Epoxy N	VIn Est
Acetaldehyde		40	20	0	100	95	60	95	60	NR	30	NR
Acetone		—	NR	NR	100	95	40	95	NR	—	—	82
Acetic anhydride		100	NR	NR	—	95	20	95	20	NR	60	NR
Acid, acetic		10-25	95	NR	100	95	85	95	95	60	60	80
Acid, acetic		50	20	NR	100	95	85	95	95	60	60	65
Acid, arsenic		—	20	—	—	95	85	95	95	—	—	25
Acid, benzoic		SAT	20	20	20	95	60	95	95	25	25	95
Acid, boric		10	20	—	20	100	95	95	95	25	25	100
Acid, butyric		20	20	—	—	95	NR	95	60	—	—	100
Acid, butyric		CONC	—	—	100	50	NR	—	—	—	—	50
Acid, borax		—	20	—	20	95	85	95	95	25	25	95
Acid, carbolic		10	—	—	20	—	20	20	0	—	—	—
Acid, carbonic		10	20	—	100	95	60	95	95	—	—	25
Acid, chromic		10	20	20	20	85	80	80	80	NR	NR	65
Acid, chromic		30	NR	—	20	85	85	95	60	NR	NR	NR
Acid, chromic		50	NR	—	20	NR	40	80	60	NR	NR	NR
Acid, citric		10	20	20	100	95	95	95	95	25	25	80
Acids, fatty		—	95	—	—	120	20	95	95	—	—	120
Acid, formic		3	95	NR	—	95	20	95	95	30	NR	65
Acid, hydrochloric		10	95	20	20	110	50	95	95	75	65	110
Acid, hydrochloric		20	95	20	20	110	85	95	95	75	65	110
Acid, hydrochloric		37	95	NR	20	NR	20	95	95	20	30	80
Acid, hydrofluoric		10	NR	—	NR	60 <sup>a</sup>	85	95	95	NR	NR	NR
Acid, hydrofluoric		30	NR	—	—	60 <sup>a</sup>	85	95	95	NR	NR	NR
Acid, hydrofluoric		50	NR	—	—	60 <sup>a</sup>	NR	95	95	NR	NR	NR
Acid, lactic		10	95	20	100	95	20	95	NR	25	25	65
Acid, mine water		—	—	—	—	20	—	20	—	—	—	—
Acid, nitric		10	95	20	100	NR	60	95	60	NR	NR	80
Acid, nitric		30	60	20	NR	NR	60	95	85	NR	NR	65
Acid, nitric		50	60	—	NR	NR	85	95	85	—	NR	NR
Acid, oxalic		10	20	—	20	95	60	95	60	NR	NR	80
Acid, phosphoric		10	95	—	100	95	85	95	95	60	60	80
Acid, phosphoric		50	95	—	100	95	85	95	95	60	60	80
Acid, phosphoric		80	95	—	100	95	85	95	95	NR	NR	80
Acid, sulfuric		0-10	95	20	100	95 <sup>a</sup>	95	95	85	60	65	80
Acid, sulfuric		11-70	95	20	NR	—	20	95	85	75	NR	50

Table 9.5 — Guide for maximum continuous temperature (°C) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFAPTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Acid, sulfuric		Conc	NR	—	NR	NR	NR	95	—	NR	NR	NR
Acid, sulfurous		10	95	—	—	95	85	95	95	25	25	50
Acid, tannic		10	20	NR	100	95	85	95	95	25	25	80
Acid, tartaric	Aqueous sol.	—	20	NR	100	95	60	95	60	25	25	80
Alcohols	Beverages	—	—	20	—	—	20	20	20	—	—	20
Aluminum chloride	Aqueous sol.	10	95	—	100	95	85	95	95	25	25	95
Aluminum sulphate	Aqueous sol.	10	95	20	100	95	85	95	95	25	25	95
Ammonia	Anhydrous	10	20	NR	100	95	—	95	95	25	25	NR
Ammonium carbonate	Aqueous sol.	—	60	—	—	95	85	95	95	—	—	65
Ammonium chloride	Aqueous sol.	10	95	20	100	95	85	95	95	25	25	95
Ammonium nitrate	Aqueous sol.	—	95	20	100	95	85	95	95	25	25	120
Ammonium phosphate	Aqueous sol.	65	20	—	—	95	85	95	95	25	25	95
Ammonium sulfate	Aqueous sol.	—	95	—	20	95	85	95	95	25	25	95
Aniline		—	NR	NR	—	95	85	95	20	NR	60	NR
Barium chloride	Aqueous sol.	10	95	20	—	95	85	95	95	25	25	95
Benzene		—	85	NR	120	95	NR	95	20	NR	NR	50
Benzol		—	85	NR	120	95	NR	95	85	—	—	—
Brine, calcium, chloride		10	95	NR	95	120	85	95	95	60	60	120
Calcium bisulfate	Aqueous sol.	—	20	—	—	95	95	95	95	25	25	65
Calcium hypochlorite	Aqueous sol.	—	20	NR	100	95	60	80	80	—	—	80
Carbon disulfide		—	20	—	—	85	60	95	95	—	—	NR
Carbon tetrachloride		—	NR	NR	100	NR	NR	95	95	25	25	80
Chlorine water	Aqueous sol.	10	20	NR	—	NR	NR	95	95	—	—	80
Chlorobenzene		—	NR	NR	20	95	NR	95	75	NR	NR	40
Chloroform		—	NR	NR	100	NR	NR	95	50	NR	NR	NR
Copper chloride (cupric)	Aqueous sol.	10	20	—	—	95	85	95	95	25	25	95
Copper nitrate	Aqueous sol.	—	20	—	—	95	80	95	95	25	25	80
Copper sulfate	Aqueous sol.	—	20	—	—	95	85	95	95	25	25	95
Cresol		—	85	NR	—	95	85	95	60	NR	—	—
Detergents		—	20	—	—	95	85	95	85	—	—	25
Dow Therm "A"		100	NR	NR	120	95	NR	95	85	25	25	50
Ethanol	Aqueous sol.	96	—	—	20	—	—	20	—	20	60	25
Ether		—	NR	NR	100	95	NR	95	NR	—	—	—
Ethylene chloride		—	NR	NR	—	60	NR	95	95	—	—	NR
Ethyl alcohol		95	—	—	95	60	60	95	95	—	—	40
Ferric chloride	Aqueous sol.	5	85	20	—	95	95	95	95	60	60	95

Table 9.5 — Guide for maximum continuous temperature (°C) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFA/PTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Ferric sulphate	Aqueous sol.	—	20	—	—	95	85	95	95	25	25	95
Ferrous chloride	Aqueous sol.	5	20	—	—	95	85	95	95	25	25	95
Ferrous sulphate	Aqueous sol.	—	20	—	20	95	85	95	95	25	25	95
Formaldehyde		40	95	NR	20	95	95	95	40	—	25	50
Furfural		—	NR	NR	—	95	NR	95	NR	25	25	NR
Gasoline		—	NR	20	20	95	NR	95	95	60	60	65
Glucose		—	—	—	—	95	—	—	—	25	25	95
Glycerol (glycerin)		—	—	—	—	95	95	20	95	75	25	95
Heptane		—	NR	20	20	95	20	95	95	—	—	80
Hydrogen sulfide	Aqueous sol.	30	—	20	—	NR	—	95	95	—	—	80
Hydrogen, sulfide	Aqueous sol.	50	NR	20	—	20	NR	95	95	25	25	80
Hydrogen peroxide	Aqueous sol.	30	60	20	95	NR	20	95	95	NR	NR	65
Hydrogen peroxide		50	NR	70	20	NR	NR	95	—	NR	NR	—
Kerosene		—	NR	0	20	95	20	95	95	60	60	80
Lead acetate	Aqueous sol.	10	20	—	—	95	85	95	95	25	25	80
Magnesium chloride	Aqueous sol.	10	95	20	NR	120	85	95	95	25	25	120
Magnesium sulfate (Epsom Salts)	Aqueous sol.	10	20	20	NR	120	85	95	95	30	30	120
Manganous sulfate	Aqueous sol.	10	—	—	—	—	—	95	95	25	25	—
Mercuric chloride	dilute aqueous	6	—	—	20	85	60	60	—	25	25	80
Methyl chloride		—	NR	NR	—	20	NR	95	95	—	25	—
Methylene chloride		—	NR	—	20	20	NR	95	NR	NR	—	NR
Naphtha		—	NR	—	100	95	NR	95	95	25	25	80
Nicotine sulfate		10	20	20	—	95	85	95	95	—	—	—
Oil, coconut		—	—	—	—	—	NR	95	95	—	—	60
Oil, creosote		—	—	—	—	—	—	—	—	—	—	—
Oil, vegetable		—	85	—	—	95	60	95	95	—	—	—
Oil, crude		—	NR	—	20	120	20	95	95	—	—	120
Oil, diesel		—	NR	20	20	95	20	95	95	—	—	95
Oil, fuel		—	—	—	20	115	20	95	95	60	60	115
Oil, kerosene		—	—	—	20	80	85	95	95	60	60	80
Oil, linseed		—	—	20	—	95	85	95	95	—	—	95
Oil, lubricating		—	NR	20	100	120	—	95	95	60	60	120
Oil, mineral		—	20	20	20	120	—	95	95	70	—	120
Oil, olive		—	—	100	100	250	—	95	95	—	—	120
Oil, JP-4		—	—	—	—	80	—	95	95	—	—	80
Oil, hydraulic		—	—	20	—	—	—	—	—	—	—	—

Table 9.5 — Guide for maximum continuous temperature (°C) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFA/PTEE	PVDF	Epoxy A	Epoxy N	Vin Est
Oil, transformer		—	—	—	100	120	—	—	—	—	—	120
Oil, soya bean		—	—	—	—	80	—	95	95	—	—	80
Oil, turpentine		—	NR	20	20	95	NR	95	20	25	25	25
Paraffin		—	—	100	—	—	—	95	95	—	—	—
Phenol		6	NR	20	20	20	NR	95	NR	45	45	NR
Plating solutions		—	—	—	—	—	—	95	95	40	40	—
Potassium bichromate	Aqueous sol.	50	—	—	—	20	—	95	95	—	—	65
Potassium carbonate	Aqueous sol.	50	20	—	—	95	85	95	95	25	25	65
Potassium chlorate	Aqueous sol.	—	20	—	—	95	85	95	95	25	25	—
Potassium chloride	Aqueous sol.	90	20	20	20	95	85	95	95	—	—	95
Potassium cyanide	Aqueous sol.	—	20	—	—	95	85	95	95	—	—	NR
Potassium hydroxide	Aqueous sol.	10	20	—	20	95	85	95	60	—	25	50
Potassium hydroxide	Aqueous sol.	50	20	20	65	95	85	95	75	100	—	65
Potassium nitrate	Aqueous sol.	10	20	20	—	95	60	95	60	25	25	95
Potassium sulfate	Aqueous sol.	CONC	20	20	20	95	85	95	95	25	25	95
Potassium dichromate	Aqueous sol.	5	95	—	—	95	85	95	95	NR	25	80
Pyridine		—	NR	—	—	20	—	20	NR	NR	NR	—
Silver nitrate	Aqueous sol.	—	20	—	—	95	85	95	95	60	25	95
Soap liquor		—	95	—	100	95	85	95	95	—	—	—
Sodium bicarbonate	Aqueous sol.	50	95	20	—	95	85	95	95	25	25	60
Sodium bisulfate	Aqueous sol.	10	20	20	120	95	85	95	95	25	25	80
Sodium carbonate	Aqueous sol.	20	95	20	20	95	85	95	95	NR	60	55
Sodium chlorate	Aqueous (brine)	10	20	—	—	95	85	95	95	25	25	80
Sodium chloride	Aqueous (brine)	10	—	20	—	95	85	95	95	95	95	100
Sodium cyanide	Aqueous sol.	10	20	—	—	95	85	95	95	—	—	80
Sodium hydroxide	Aqueous sol.	20	95	NR	100	95 <sup>b</sup>	85	95	95	NR	50	60
Sodium hydroxide	Aqueous sol.	50	95	—	65	70 <sup>b</sup>	95	95	95	NR	50	70
Sodium hypochlorite		18	95	20	95	NR	60	95	95	NR	NR	80
Sodium silicate		—	20	—	—	95	85	95	95	NR	75	95
Sodium nitrate	Aqueous sol.	50	20	—	—	95	85	95	95	25	25	95
Sodium phosphate	Aqueous sol.	90	—	—	—	—	85	95	95	25	25	—
Sodium sulfate	Aqueous sol.	90	95	95	—	95	85	95	95	25	25	95
Sodium sulfide	Aqueous sol.	90	95	95	—	95	85	95	95	NR	25	95
Sodium sulfite	Aqueous sol.	—	—	—	—	—	—	—	95	—	—	95
Sodium thiosulfate	Aqueous sol.	10	20	—	—	95	—	95	—	25	25	65
Stannic chloride	Aqueous sol.	10	20	—	—	95	85	95	95	25	25	95

Table 9.5 — Guide for maximum continuous temperature (°C) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
Stannous chloride	Aqueous sol.	All	—	—	—	—	—	95	95	60	60	95
Styrene		100	—	—	—	95	NR	95	50	NR	60	40
Toluene (toluol)		—	NR	NR	—	95	20	95	95	NR	60	50
Trichloroethylene		—	NR	—	100	NR	NR	95	60	25	25	NR
Vinegar		—	20	—	100	95	20	95	95	25	25	80
Water, deionized		—	95	—	—	95	60	95	95	—	—	80
Water, fresh		—	95	20	95	95	60	95	95	60	60	95
Water, salt & sea		—	95	20	95	95	85	95	95	60	60	80
Whiskey		—	—	20	—	—	—	95	95	—	—	—
Xylol (xylene)		—	NR	NR	20	95	NR	95	85	NR	25	50
Zinc chloride	Aqueous sol.	10	20	NR	20	120	85	95	95	60	60	120
Zinc sulfate	Aqueous sol.	10	20	NR	20	120	85	95	95	25	25	120

a PPS contains glass

b Contains glass

Table 9.6 — Guide for maximum continuous temperature (°F) liquid vs. material selection for polymer pumps

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PPA/PTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Acetaldehyde		40	70	0	212	200	140	200	140	NR	86	NR
Acetone		—	NR	NR	212	200	100	200	NR	—	—	180
Acetic anhydride		100	NR	NR	—	200	70	200	70	NR	140	NR
Acid, acetic		10-25	200	NR	212	200	185	200	200	140	140	180
Acid, acetic		50	70	NR	212	200	185	200	200	140	140	150
Acid, arsenic		—	70	—	—	200	185	200	200	—	—	80
Acid, benzoic		SAT	70	70	70	200	140	200	200	75	75	200
Acid, boric		10	70	—	70	210	200	200	200	75	75	210
Acid, butyric		20	70	—	—	200	NR	200	140	—	—	210
Acid, butyric		CONC	—	—	212	120	NR	—	—	—	—	120
Acid, borax		—	70	—	70	200	185	200	200	75	75	200
Acid, carbolic		10	—	—	70	—	70	70	0	—	—	—
Acid, carbonic		10	70	—	212	200	140	200	200	—	—	75
Acid, chromic		10	70	70	70	185	175	175	175	NR	NR	150
Acid, chromic		30	NR	—	70	185	185	200	140	NR	NR	NR
Acid, chromic		50	NR	—	70	NR	100	175	140	NR	NR	NR
Acid, citric		10	70	70	212	200	200	200	200	75	75	180
Acids, fatty		—	200	—	—	250	70	200	200	—	—	250
Acid, formic		3	200	NR	—	200	70	200	200	85	NR	150
Acid, hydrochloric		10	200	70	70	230	120	200	200	165	150	230
Acid, hydrochloric		20	200	70	70	230	185	200	200	165	150	230
Acid, hydrochloric		37	200	NR	70	NR	70	200	200	70	85	180
Acid, hydrofluoric	Anhydrous	10	NR	—	NR	140 <sup>a</sup>	185	200	200	NR	NR	NR
Acid, hydrofluoric		30	NR	—	—	140 <sup>a</sup>	185	200	200	NR	NR	NR
Acid, hydrofluoric		50	NR	—	—	140 <sup>a</sup>	NR	200	200	NR	NR	NR
Acid, lactic		10	200	70	212	200	70	200	NR	75	75	150
Acid, mine water		—	—	—	—	70	—	70	—	—	—	—
Acid, nitric		10	200	70	212	NR	140	200	140	NR	NR	180
Acid, nitric		30	140	70	NR	NR	140	200	185	NR	NR	150
Acid, nitric		50	140	—	NR	NR	185	200	185	NR	NR	NR
Acid, oxalic		10	70	—	70	200	140	200	140	NR	NR	180
Acid, phosphoric		10	200	—	212	200	185	200	200	140	140	180
Acid, phosphoric		50	200	—	212	200	185	200	200	140	140	180
Acid, phosphoric		80	200	—	212	200	185	200	200	NR	NR	180
Acid, sulfuric		0-10	200	70	212	200 <sup>a</sup>	200	200	185	140	150	180
Acid, sulfuric		11-70	200	70	NR	—	70	200	185	166	NR	120

Table 9.6 — Guide for maximum continuous temperature (°F) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFAPTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Acid, sulfuric		Conc	NR	—	NR	NR	NR	200	—	NR	NR	NR
Acid, sulfurous		10	200	—	—	200	185	200	200	75	75	120
Acid, tannic		10	70	NR	212	200	185	200	200	75	75	180
Acid, tartaric	Aqueous sol.	—	70	NR	212	200	140	200	140	75	75	180
Alcohols	Beverages	—	—	70	—	—	200	200	70	—	—	70
Aluminum chloride	Aqueous sol.	10	200	—	212	200	185	200	200	75	75	200
Aluminum sulphate	Aqueous sol.	10	200	70	212	200	185	200	200	75	75	200
Ammonia	Anhydrous	10	70	NR	212	200	—	200	200	75	75	NR
Ammonium carbonate	Aqueous sol.	—	140	—	—	200	185	200	200	—	—	150
Ammonium chloride	Aqueous sol.	10	200	70	212	200	185	200	200	75	75	200
Ammonium nitrate	Aqueous sol.	—	200	70	212	200	185	200	200	75	75	250
Ammonium phosphate	Aqueous sol.	65	70	—	—	200	185	200	200	75	75	200
Ammonium sulfate	Aqueous sol.	—	200	—	70	200	185	200	200	75	75	200
Aniline		—	NR	NR	—	200	185	200	70	NR	140	NR
Barium chloride	Aqueous sol.	10	200	70	—	200	185	200	200	75	75	200
Benzene		—	185	NR	250	200	NR	200	70	NR	NR	120
Benzol		—	185	NR	250	200	NR	200	185	—	—	—
Brine, calcium, chloride		10	200	NR	200	250	185	200	200	140	140	250
Calcium bisulfate	Aqueous sol.	—	70	—	—	200	200	200	200	75	75	150
Calcium hypochlorite	Aqueous sol.	—	70	NR	212	200	140	175	175	—	—	180
Carbon disulfide		—	70	—	—	185	140	200	200	—	—	NR
Carbon tetrachloride		—	NR	NR	212	NR	NR	200	200	75	75	180
Chlorine water		10	70	NR	—	NR	NR	200	200	—	—	180
Chlorobenzene	Aqueous sol.	—	NR	NR	70	200	NR	200	170	NR	NR	100
Chloroform		—	NR	NR	212	NR	NR	200	125	NR	NR	NR
Copper chloride (cupric)	Aqueous sol.	10	70	—	—	200	185	200	200	75	75	200
Copper nitrate	Aqueous sol.	—	70	—	—	200	175	200	200	75	75	180
Copper sulfate	Aqueous sol.	—	70	—	—	200	185	200	200	75	75	200
Cresol		—	185	NR	—	200	185	200	140	NR	—	—
Detergents		—	70	—	—	200	185	200	185	—	—	75
Dow Therm "A"		100	NR	NR	250	200	NR	200	185	75	75	120
Ethanol	Aqueous sol.	96	—	—	70	—	—	70	—	65	140	75
Ether		—	NR	NR	212	200	NR	200	NR	—	—	—
Ethylene chloride		—	NR	NR	—	140	NR	200	200	—	—	NR
Ethyl alcohol		95	—	—	—	200	140	200	200	—	—	100
Ferric chloride	Aqueous sol.	5	185	70	—	200	200	200	200	140	140	200

Table 9.6 — Guide for maximum continuous temperature (°F) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFA/PTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Ferric sulphate	Aqueous sol.	—	70	—	—	200	185	200	200	75	75	200
Ferrous chloride	Aqueous sol.	5	70	—	—	200	185	200	200	75	75	200
Ferrous sulphate	Aqueous sol.	—	70	—	70	200	185	200	200	75	75	200
Formaldehyde		40	200	NR	70	200	200	200	100	—	75	120
Furfural		—	NR	NR	—	200	NR	200	NR	75	75	NR
Gasoline		—	NR	70	70	200	NR	200	200	140	140	150
Glucose		—	—	—	—	200	—	—	—	75	75	200
Glycerol (glycerin)		—	—	—	—	200	200	70	200	167	75	200
Heptane		—	NR	70	70	200	70	200	200	—	—	180
Hydrogen sulfide	Aqueous sol.	30	—	70	—	NR	—	200	200	—	—	180
Hydrogen, sulfide	Aqueous sol.	50	NR	70	—	70	NR	200	200	75	75	180
Hydrogen peroxide	Aqueous sol.	30	140	70	200	NR	70	200	200	NR	NR	150
Hydrogen peroxide		50	NR	70	70	NR	NR	200	—	NR	NR	—
Kerosene		—	NR	—	70	200	70	200	200	140	140	180
Lead acetate		10	70	—	—	200	185	200	200	75	75	180
Magnesium chloride	Aqueous sol.	10	200	70	NR	250	185	200	200	75	75	250
Magnesium sulfate (Epsom salts)	Aqueous sol.	10	70	70	NR	250	185	200	200	86	86	250
Manganous sulfate	Aqueous sol.	10	—	—	—	—	—	200	200	75	75	—
Mercuric chloride	dilute aqueous	6	—	—	70	185	140	140	—	75	75	180
Methyl chloride		—	NR	NR	—	70	NR	200	200	—	75	—
Methylene chloride		—	NR	—	70	70	NR	200	NR	NR	—	NR
Naphtha		—	NR	—	212	200	NR	200	200	75	75	180
Nicotine sulfate		10	70	70	—	200	185	200	200	—	—	—
Oil, coconut		—	—	—	—	—	NR	200	200	—	—	140
Oil, creosote		—	—	—	—	—	—	—	—	—	—	—
Oil, vegetable		—	185	—	—	200	140	200	200	—	—	—
Oil, crude		—	NR	—	70	250	70	200	200	—	—	250
Oil, diesel		—	NR	70	70	200	70	200	200	—	—	200
Oil, fuel		—	—	—	70	240	70	200	200	140	140	240
Oil, kerosene		—	—	—	70	180	185	200	200	140	140	180
Oil, linseed		—	—	—	—	200	185	200	200	—	—	200
Oil, lubricating		—	NR	70	212	250	—	200	200	140	140	250
Oil, mineral		—	70	70	70	250	—	200	200	158	—	250
Oil, olive		—	—	212	212	250	—	200	200	—	—	250
Oil, JP-4		—	—	—	—	180	—	200	200	—	—	180
Oil, hydraulic		—	—	70	—	—	—	—	—	—	—	—

Table 9.6 — Guide for maximum continuous temperature (°F) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFAPTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Oil, transformer		—	—	—	212	250	—	—	—	—	—	250
Oil, soya bean		—	—	—	—	180	—	200	200	—	—	180
Oil, turpentine		—	70	NR	70	200	NR	200	70	75	75	75
Paraffin		—	—	—	212	—	—	200	200	—	—	—
Phenol		6	NR	NR	70	70	NR	200	NR	NR	113	NR
Plating solutions		—	—	—	—	—	—	200	200	NR	100	—
Potassium bichromate	Aqueous sol.	50	—	—	—	70	—	200	200	—	—	150
Potassium carbonate	Aqueous sol.	50	70	—	—	200	185	200	200	NR	75	150
Potassium chlorate	Aqueous sol.	—	70	—	—	200	185	200	200	75	75	—
Potassium chloride	Aqueous sol.	90	70	70	70	200	185	200	200	—	—	200
Potassium cyanide	Aqueous sol.	—	70	—	—	200	185	200	200	—	—	NR
Potassium hydroxide	Aqueous sol.	10	70	—	70	200	185	200	140	—	75	120
Potassium hydroxide	Aqueous sol.	50	70	70	150	200	185	200	165	210	—	150
Potassium nitrate	Aqueous sol.	10	70	70	—	200	140	200	140	75	75	200
Potassium sulfate	Aqueous sol.	CONC	70	70	70	200	185	200	200	75	75	200
Potassium dichromate	Aqueous sol.	5	200	—	—	200	185	200	200	NR	75	180
Pyridine	Aqueous sol.	—	NR	NR	—	70	—	70	NR	NR	NR	—
Silver nitrate	Aqueous sol.	—	70	—	—	200	185	200	200	140	75	200
Soap liquor		—	200	—	212	200	185	200	200	—	—	—
Sodium bicarbonate	Aqueous sol.	50	200	70	—	200	185	200	200	75	75	140
Sodium bisulfate	Aqueous sol.	10	70	70	250	200	185	200	200	75	75	180
Sodium carbonate	Aqueous sol.	20	200	70	70	200	185	200	200	NR	140	130
Sodium chlorate	Aqueous (brine)	10	70	—	—	200	185	200	200	75	75	180
Sodium chloride	Aqueous (brine)	10	—	70	250	200	185	200	200	200	200	210
Sodium cyanide	Aqueous sol.	10	70	—	—	200	185	200	200	—	—	180
Sodium hydroxide	Aqueous sol.	20	200	NR	212	200 <sup>b</sup>	185	200	200	NR	120	140
Sodium hydroxide	Aqueous sol.	50	200	—	150	160 <sup>b</sup>	200	200	200	NR	120	160
Sodium hypochlorite		18	200	70	200	NR	140	200	200	NR	NR	180
Sodium silicate		—	70	—	—	200	185	200	200	NR	167	200
Sodium nitrate	Aqueous sol.	50	70	—	—	200	185	200	200	75	75	200
Sodium phosphate	Aqueous sol.	90	—	—	—	—	185	200	200	75	75	—
Sodium sulfate	Aqueous sol.	90	200	200	—	200	185	200	200	75	75	200
Sodium sulfide	Aqueous sol.	90	200	200	—	200	185	200	200	NR	75	200
Sodium sulfite	Aqueous sol.	—	—	—	—	—	—	—	—	—	—	200
Sodium thiosulfate	Aqueous sol.	10	70	70	—	200	—	200	—	75	75	150
Stannic chloride	Aqueous sol.	10	70	—	—	200	185	200	200	75	75	200

Table 9.6 — Guide for maximum continuous temperature (°F) liquid vs. material selection for polymer pumps (continued)

Liquid	Conditions	Conc	1	2	3	4	5	6	7	8	9	10
			PPO	PC	PEEK	PPS	PP	PFAPTFE	PVDF	Epoxy A	Epoxy N	Vin Est
Stannous chloride	Aqueous sol.	All	—	—	—	—	—	200	200	140	140	200
Styrene		100	—	—	—	200	NR	200	125	NR	140	100
Toluene (toluol)		—	NR	NR	—	200	70	200	200	NR	140	120
Trichloroethylene		—	NR	—	212	NR	NR	200	140	75	75	NR
Vinegar		—	70	—	212	200	70	200	200	75	75	180
Water, deionized		—	200	—	—	200	140	200	200	—	—	180
Water, fresh		—	200	70	200	200	140	200	200	140	140	200
Water, salt & sea		—	200	70	200	200	185	200	200	140	140	180
Whiskey		—	—	70	—	—	—	200	200	—	—	—
Xylol (xylene)		—	NR	NR	70	200	NR	200	185	NR	75	120
Zinc chloride	Aqueous sol.	10	70	NR	70	250	185	200	200	140	140	250
Zinc sulfate	Aqueous sol.	10	70	NR	70	250	185	200	200	75	75	250

a PPS contains glass

b Contains glass

## 9.4 Measurement of airborne sound

The purpose of this standard is to provide uniform test procedures for the measurement of airborne sound from pumping equipment.

This standard applies to centrifugal, rotary, and reciprocating pumping equipment and specifies procedures and operating conditions acceptable and expedient for use by non-specialists as well as by acoustic engineers. This standard does not apply to vertical submerged wet pit pumps.

In this standard, a sound pressure level of 20  $\mu$ pascals (.0002 $\mu$ BAR) is used as reference.

### 9.4.1 Instrumentation

The instrumentation required for carrying out the tests herein is as follows:

#### 9.4.1.1 Sound level meter and microphone system

The sound level meter and microphone system shall meet the requirements of IEC 179 or shall be calibrated to meet the requirements of IEC 179 or ANSI S1.4, type 1.

#### 9.4.1.2 Octave-band analyzer

The octave-band analyzer shall meet the requirements of ANSI S1.11.

#### 9.4.1.3 Acoustical calibration

The entire instrumentation system including the microphone and cable shall be calibrated at a convenient frequency before and after each test series using a suitable calibrator. Annually, the frequency response of the system should be checked to verify its accuracy at all frequencies in the range of interest. This calibration should be traceable to the NIST.

#### 9.4.1.4 Recorders

If a tape recorder or graphic level recorder is used, its stability and frequency response shall at least equal those of the sound level meter and microphone system over the frequency range of interest.

### 9.4.2 Operation of pumping equipment

Whenever possible, sound tests shall be made with the pump operating at rated application conditions. If

this operating condition cannot be obtained, then sound tests may be made at some other condition mutually agreed upon by the parties concerned. The test conditions shall be clearly described in the test report.

### 9.4.3 Test environment

It is desirable to conduct tests in a free field above a reflecting plane and not influenced by reflections from walls and nearby objects. A six (6) dB drop-off in sound pressure level in each octave band of interest in all directions around the machine, regardless of distance, indicates approximate free-field conditions and gives sufficient accuracy for the purposes of this test standard.

If a 6 dB drop-off cannot be obtained, the room can often be modified to meet this objective by covering the walls and other large surfaces near the measuring points with a sound absorptive material. Otherwise, room correction factors must be developed. The substitution method, using a calibrated reference sound source, is recommended for determining these factors.

The reference sound source should have "white noise" characteristics and its free-field sound pressure levels must be known. (A commonly used sound source is one manufactured by ILG Industries, Chicago, IL.)

By the substitution method, the reference sound source is placed in the test area, in lieu of the test pump, with its acoustic center located at the same point in the room as that of the pump. While the reference sound source is operating, octave-band sound pressure levels and the A-weighted sound level are measured at exactly the same microphone locations that are used for measuring the pump's sound levels. These measured levels, corrected for the background noise, are subtracted from the known free-field levels (for the particular source-to-microphone distance) of the reference sound source. The results are the room correction factors and are added to the pump's sound levels to develop its free-field values.

In mounting small machines for test purposes, the geometric center of the machine shall be approximately, 1 meter (3 feet) above the reflecting plane.

### 9.4.4 Microphone locations

A preliminary survey shall be taken around the machine at a distance of 1 meter (3 feet) from the nearest major surface of the machine, and at a height of 1.5 meters (5 feet), to locate the point of maximum

overall sound level (A-weighted). This is the *primary microphone location*.

Additional microphone locations shall be established at each end of the unit and at the center of the sides of each casing. All these microphone locations shall be at a horizontal distance of 1 meter (3 feet) from the outermost major surface of the machine, and at a height of 1.5 meters (5 feet) above the floor or above the walk level.

Typical microphone locations are shown in the following figures:

Figure	Title
9.4	Horizontal end suction centrifugal pump
9.5	Horizontally split centrifugal pump
9.6	Vertical in-line centrifugal pump
9.7	Double case centrifugal pump
9.8	Horizontally split multistage centrifugal pump
9.9	Horizontal reciprocating pump
9.10	Vertical reciprocating pump
9.11	Horizontal rotary gear pump
9.12	Horizontal rotary screw pump
9.13	Vertical rotary pump

#### 9.4.5 Measurement technique

The period of time during which the measurements are made shall be long enough to allow an average reading to be taken with the slow response setting of the meter.

No reflecting surfaces shall be near the microphone. Observers and measuring instruments shall be at a distance of not less than 1 meter (3 feet) from the microphone and the machine under test, and no observer or obstruction of any kind (unless part of the equipment) should be between the microphone and the machine under test.

Because of the interference between direct sound waves and those reflected from the floor, large errors may occur when strong discrete frequency components are present. When such components are present, tests shall be made by moving the microphone slowly in a vertical direction, approximately  $\pm 0.3$  meter (1 foot) from each location. The microphone shall be held in the position, grazing incidence or perpendicular incidence, in which it was calibrated for flat response.

#### 9.4.6 Measurements to be taken

The following measurements are to be taken at each of the microphone locations, with the machine operating under the conditions stated in Section 9.4.2:

- Overall sound level using the “A” weighing network;
- Octave band sound pressure levels using the flat response network.

In addition, with the equipment under test shut down, the above measurements are to be obtained at the Primary Microphone Location to obtain the background noise level.

The background noise should be at least 10 dB below the equipment operating levels. Otherwise, the readings must be corrected as described in Section 9.4.7.1.

##### 9.4.6.1 Caution

Corrections for background sound levels do not eliminate the effects of extraneous sound from components associated with the system, but not part of the equipment to be tested; i.e., piping, valves, drivers, gears, vibrating bases, etc.

Separation of the various sound sources may require special measurement techniques or may not be possible. Therefore, consideration must be given to reducing the level of extraneous noise. The following precautions in the test set-up should help accomplish this:

- a) Valves: select low-noise type valves. Use two or more throttling valves in series to reduce the differential pressure across the valve. Locate valves as remote from the pump as possible. Avoid putting them between the microphone and pump. Cover noisy valves with an acoustical barrier;
- b) Piping: use pipe and fittings, sized 1:1. Avoid situations which cause a change in velocity. Use straight runs of pipe from the pump to the supply tank. Cover noisy piping with an acoustical barrier material;
- c) Gears: avoid high ratio reducers and increasers. Cover test gears with an acoustical enclosure or barrier material;

- d) Test foundations/bases: use rigid foundations and bases to support the pump. Avoid using large, flat, thin material which can vibrate and radiate noise.

### 9.4.7 Calculation and interpretation of readings

#### 9.4.7.1 Corrections

Whenever there is less than 10 dB difference between the machinery operating and background sound levels, corrections should be applied per the graph in Figure 9.3.

If the difference is less than 3 dB, a valid measurement of the machinery noise cannot be made.

Only octave bands of interest should be considered for correction. These are defined as octave bands in which the levels are within 40 dB of the highest measured octave band level.

Sound pressure levels below 50 dB are not considered important.

In addition to the above, calibration corrections, if required, must be taken into account when recording the measured data.

#### 9.4.7.2 Averaging of readings

In general, the average of the corrected readings should not be calculated, since this can give misleading information. In the case of small, relatively non-directional sources, the average may be taken to give a convenient single number reading. When this is the case, the average of the corrected sound pressure level readings may be calculated to the following rules:

- Maximum variation 5 dB or less: average the sound pressure levels arithmetically;
- Maximum variation 5 dB to 10 dB: average the sound pressure levels arithmetically and add 1 dB;
- Maximum variation over 10 dB: average according to the equation below:

$$L = 10 \log_{10} \frac{1}{n} \left[ \text{antilog} \frac{L_1}{10} + \text{antilog} \frac{L_2}{10} + \dots + \text{antilog} \frac{L_n}{10} \right]$$

Where:

$[L]$  = Average sound level dB(A), or band average sound pressure level, in decibels;

$L_1$  = Sound level dB(A), or band sound pressure level, in decibels at location No. 1;

$L_n$  = Sound level dB(A), or band sound pressure level, in decibels at location No. n;

$n$  = Number of measurement locations.

### 9.4.8 Presentation of data

A form such as illustrated on page 53 should be used for reporting the following data:

#### 9.4.8.1 A test report shall be supplied and shall give the following information

- Statement that the test was conducted in accordance with ANSI/HI 9.4-2000, *Measurement of Airborne Sound*;
- Description of the machine, operating conditions, and a sketch showing the test layout and microphone locations;
- Make, model and serial numbers of the instruments used, and the date of the last full calibration (traceable to NIST).

#### 9.4.8.2 A tabulation of the test data showing

- The corrected sound level measurements at each microphone location, dB(A), and corrected octave band sound pressure levels;
- Background sound level at one location, dB(A), and octave band sound pressure levels;
- When required in special cases, the average of the corrected dB(A) and octave band sound pressure levels.

#### 9.4.8.3 A graphic plot of

- Octave band data shall be made for the primary microphone location only (where the highest sound level dB(A) was measured). This graph should also include a plot of the background sound levels.

9.4.9 Airborne sound level test report

**Airborne sound level test report for pumping equipment**

**Report form**

**Subject:**

Model: \_\_\_\_\_ Manufacturer: \_\_\_\_\_ Serial: \_\_\_\_\_  
 Rated pump speed: \_\_\_\_\_ Rate of flow: \_\_\_\_\_ Total head: \_\_\_\_\_  
 Type of driver: \_\_\_\_\_ Speed: \_\_\_\_\_  
 Auxiliaries such as gears: \_\_\_\_\_  
 Applicable figure No: \_\_\_\_\_  
 Description: \_\_\_\_\_

**Test conditions:**

Distance from subject to microphone: 1 meter Height of microphone above reflecting plane: 1.5 meters  
 Operating speed as tested: \_\_\_\_\_ rpm, Rate of flow: \_\_\_\_\_  
 Total head: \_\_\_\_\_, Suction conditions: \_\_\_\_\_  
 Reflecting plane composition: \_\_\_\_\_  
 Remarks: \_\_\_\_\_

**Instrumentation:**

Microphone: \_\_\_\_\_ No. \_\_\_\_\_ Calibration date: \_\_\_\_\_  
 Sound level meter: \_\_\_\_\_ No. \_\_\_\_\_ Calibration date: \_\_\_\_\_  
 Octave band analyzer: \_\_\_\_\_ No. \_\_\_\_\_ Calibration date: \_\_\_\_\_  
 Calibrator: \_\_\_\_\_ No. \_\_\_\_\_ Calibration date: \_\_\_\_\_  
 Other: \_\_\_\_\_ No. \_\_\_\_\_ Calibration date: \_\_\_\_\_

**Data:**

		Level (1) — dB re 20μPa (.0002μBAR)												
		Background	Location <sup>a</sup>										Av.	
			(P) prim.	1	2	3	4	5	6	7	8	9		10
Midband freq.-Hz	dB A													
	63													
	125													
	250													
	500													
	1k													
	2k													
	4k													
	8k													

<sup>a</sup> Corrected for background sound. Readings having 3 dB corrections shall be reported in brackets. All measured levels shall be reported.

Tested by: \_\_\_\_\_ Date: \_\_\_\_\_  
 Reported by: \_\_\_\_\_ Date: \_\_\_\_\_

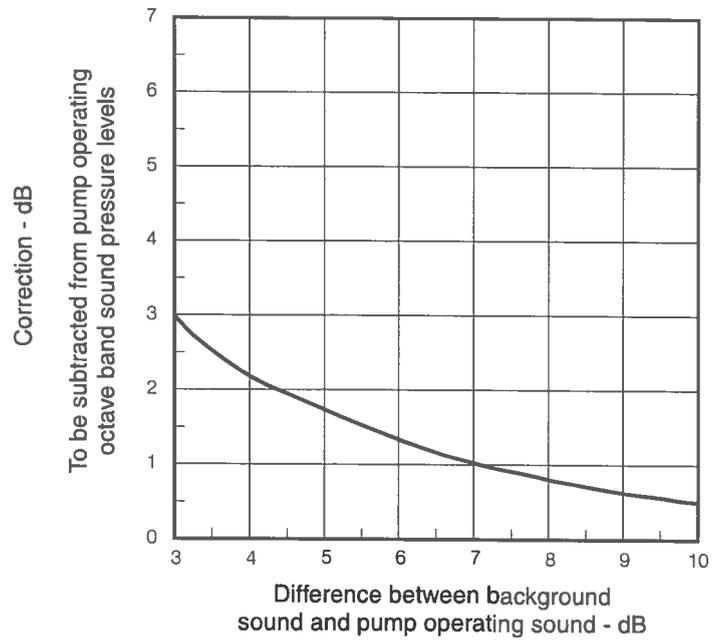


Figure 9.3 — Correction for background sound

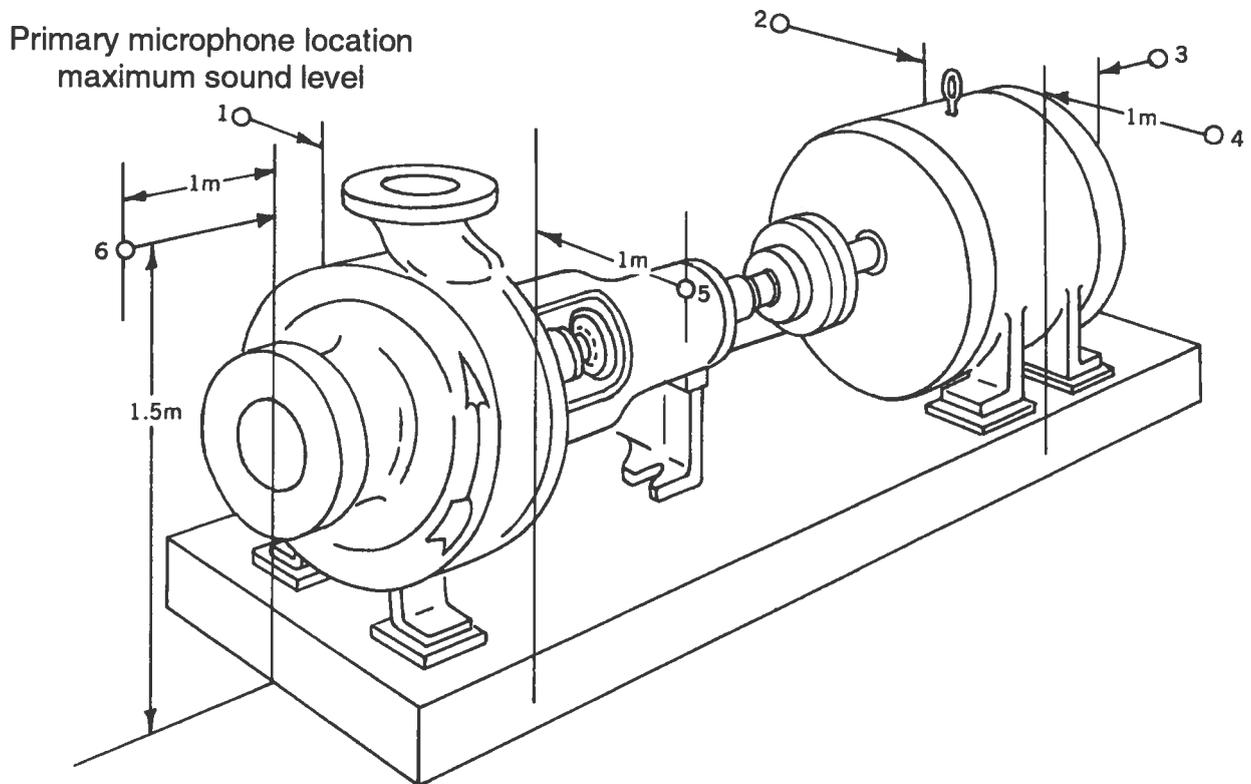


Figure 9.4 — Horizontal end suction centrifugal pump

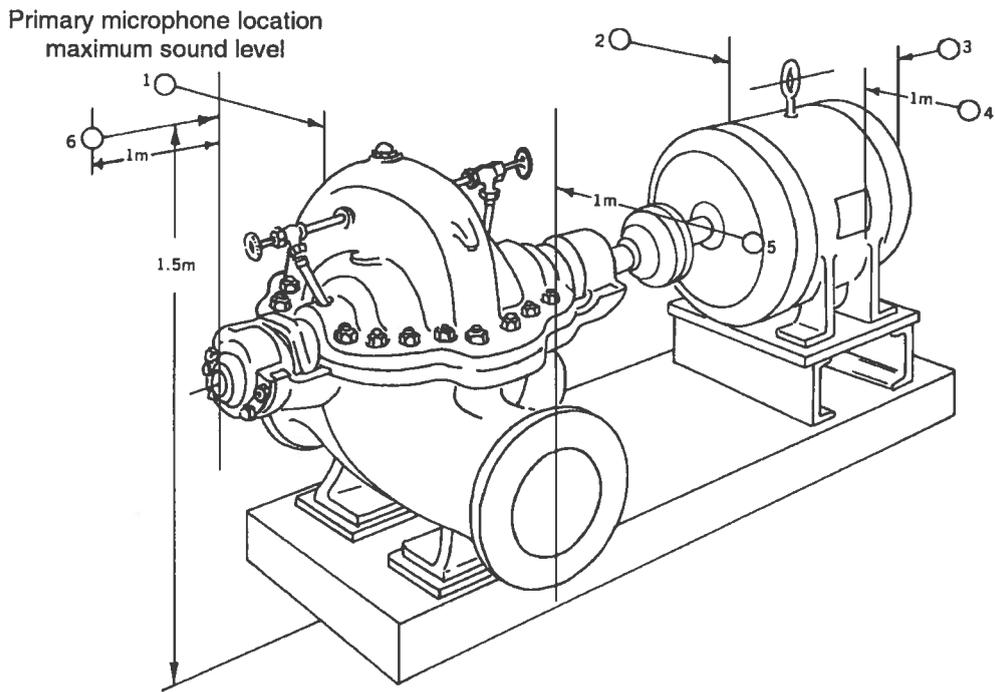


Figure 9.5 — Axially split case centrifugal pump

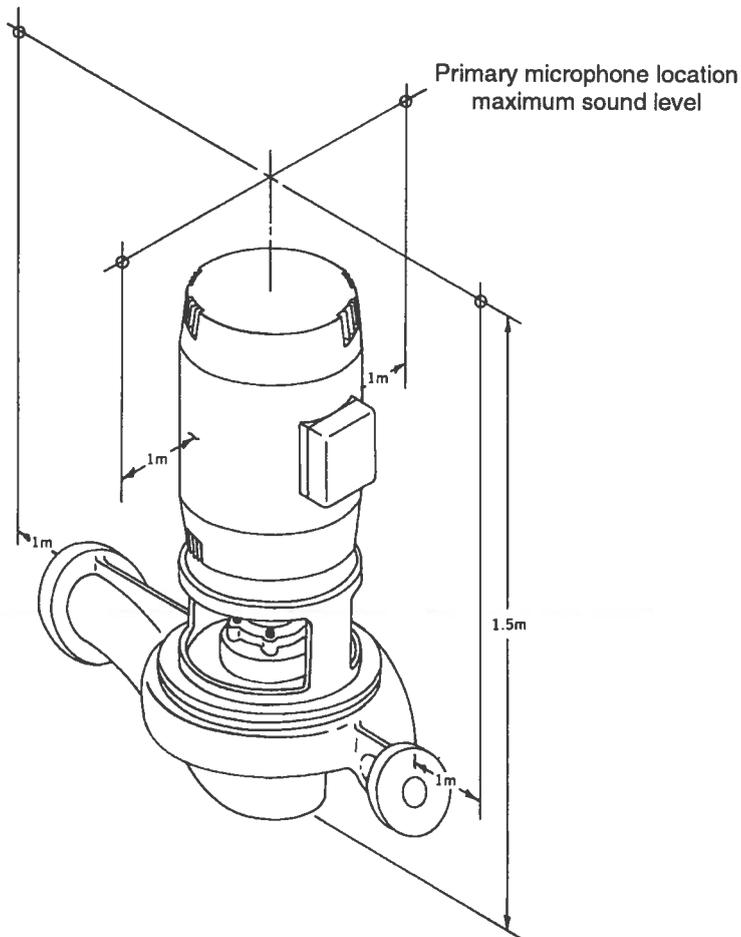


Figure 9.6 — Vertical in-line centrifugal pump

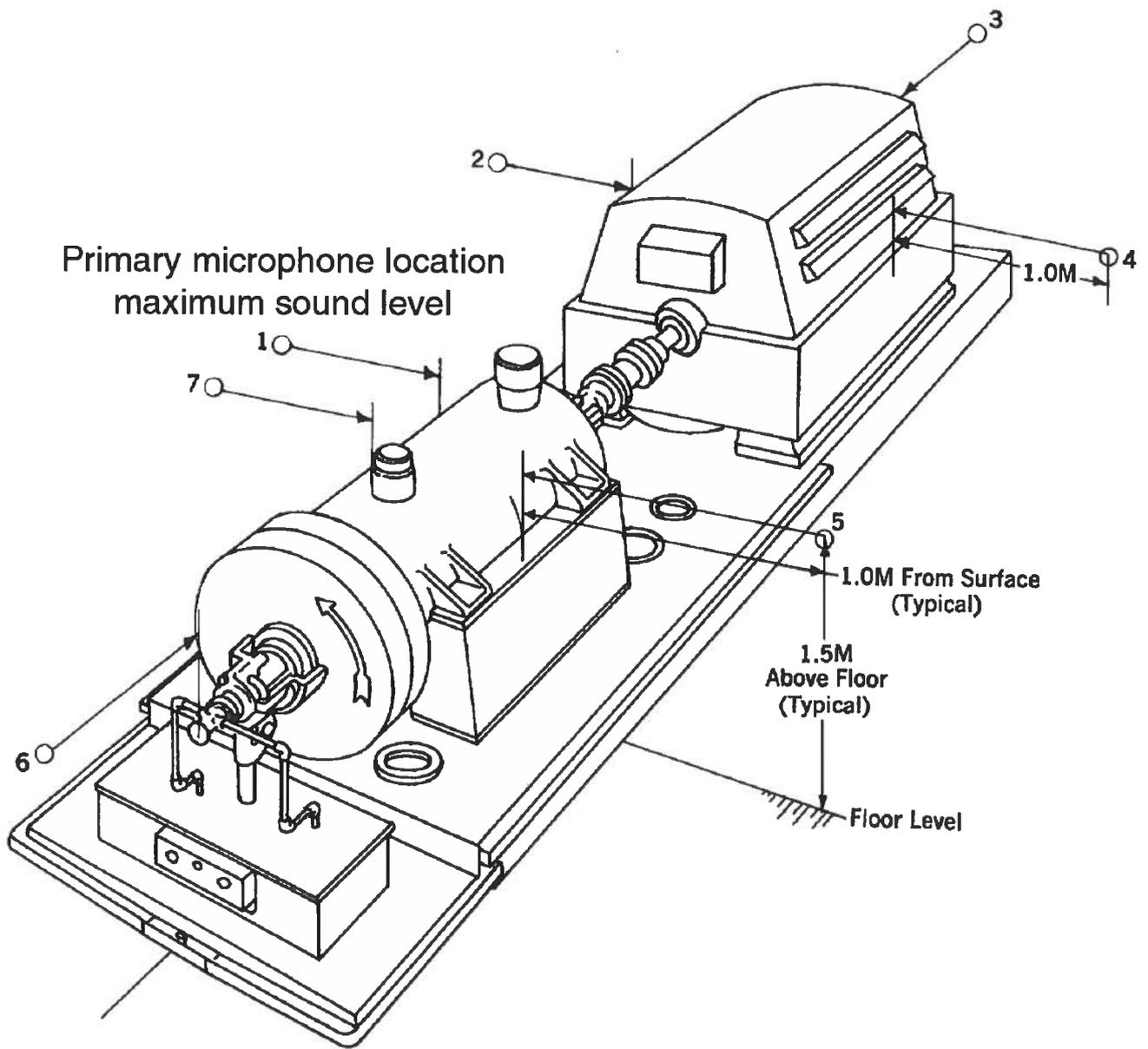


Figure 9.7 — Double case centrifugal pump

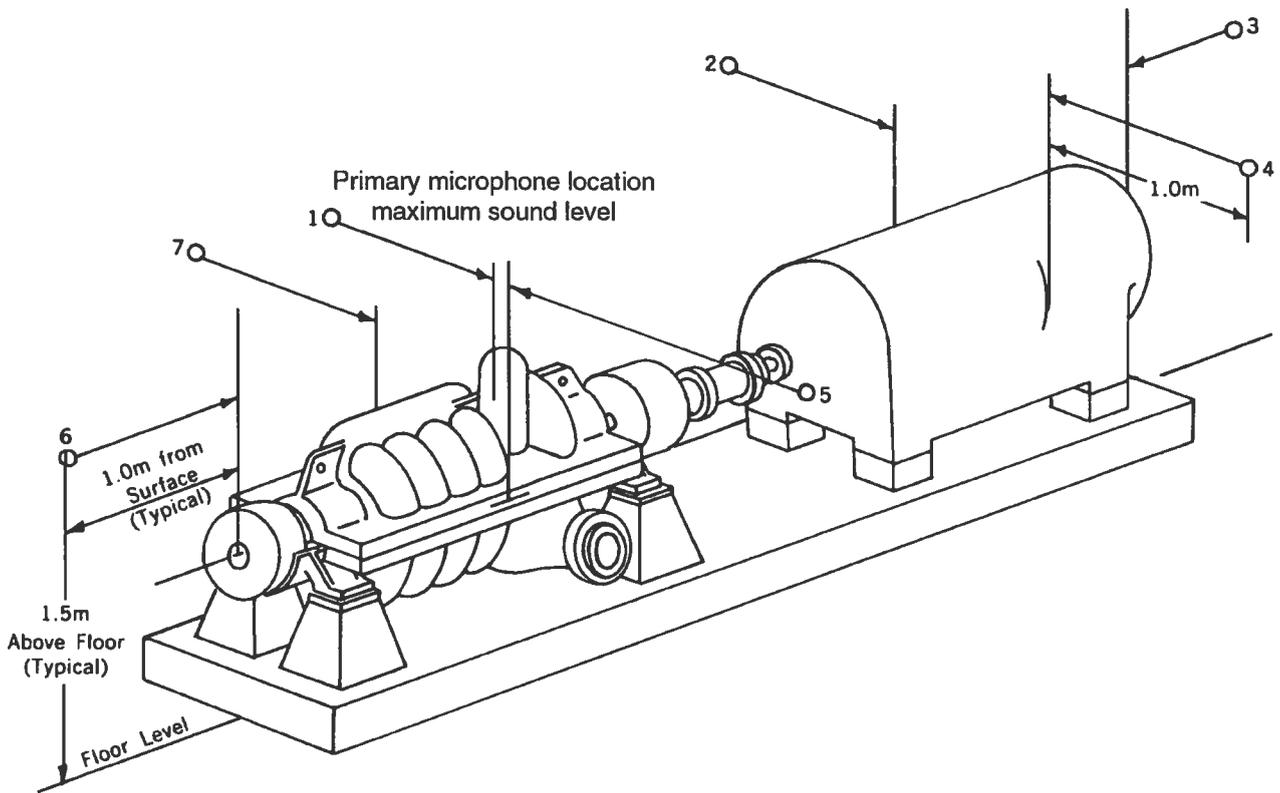


Figure 9.8 — Axially split case multistage centrifugal pump

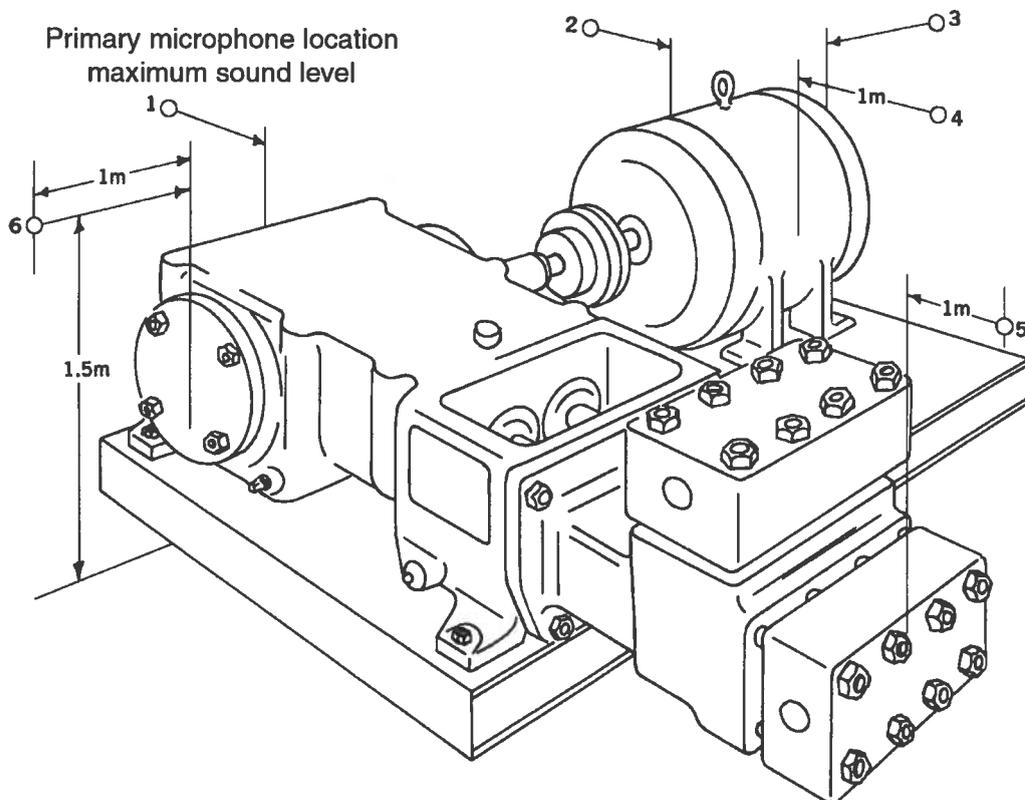


Figure 9.9 — Horizontal reciprocating pump

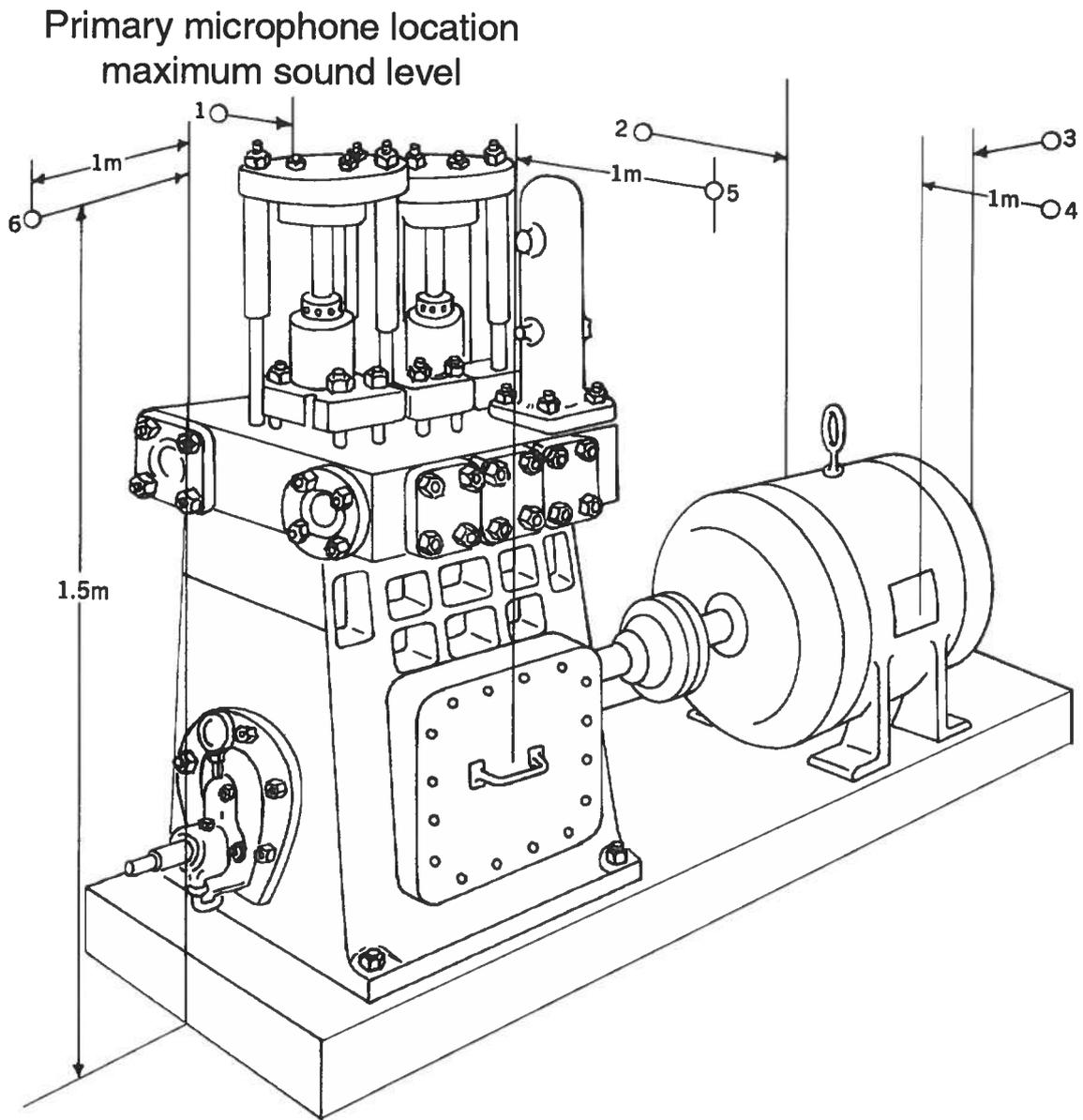


Figure 9.10 — Vertical reciprocating pump

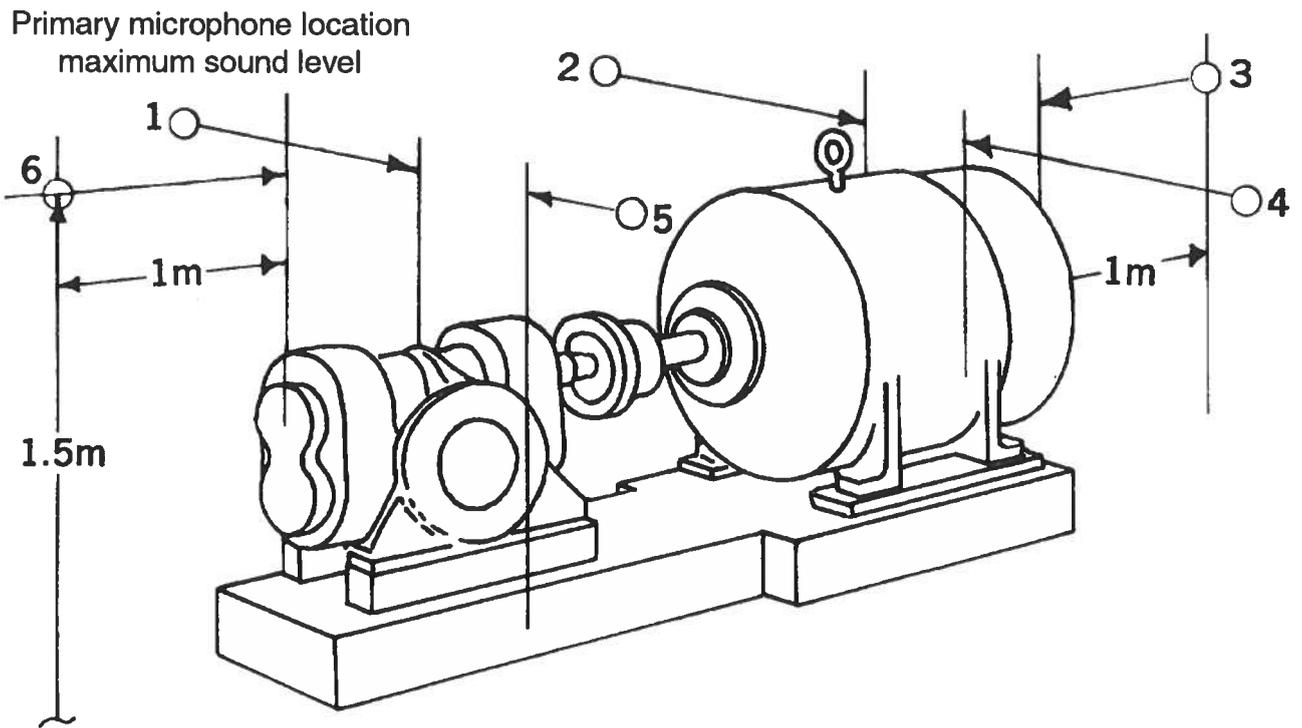


Figure 9.11 — Horizontal rotary gear pump

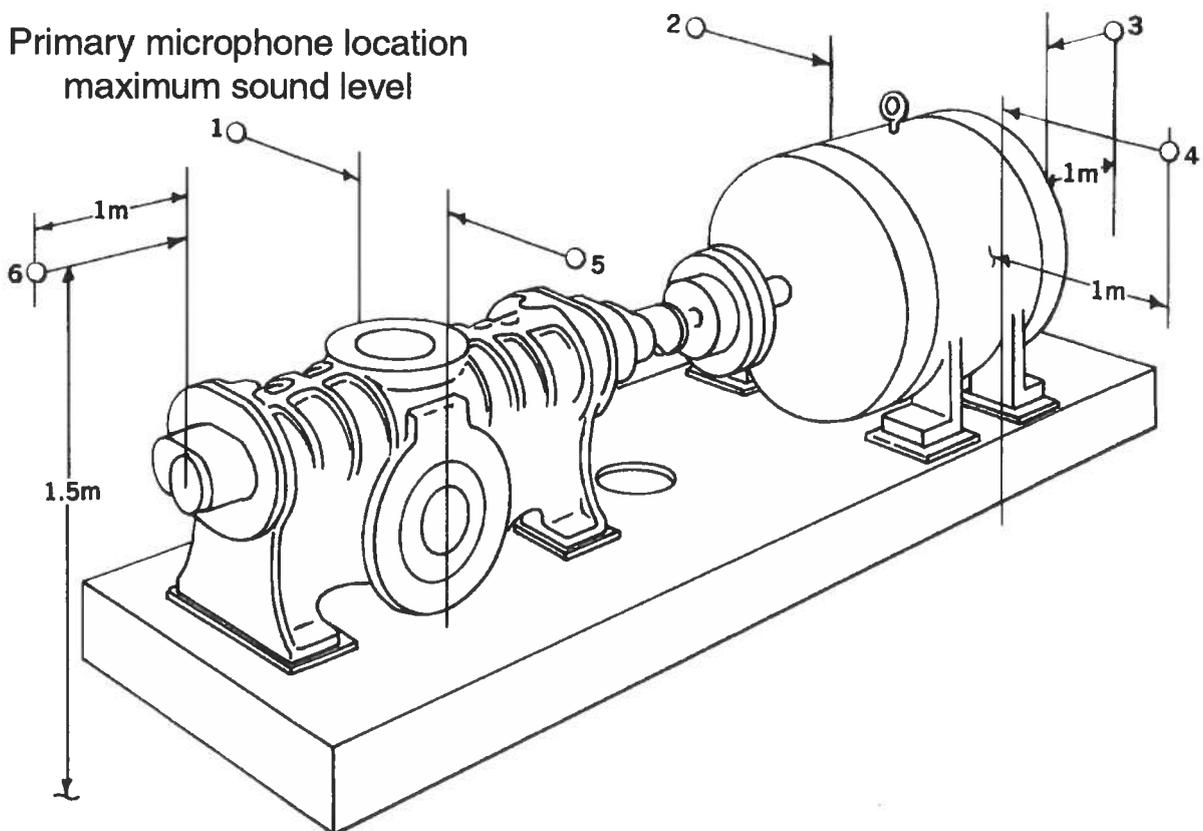


Figure 9.12 — Horizontal rotary screw pump

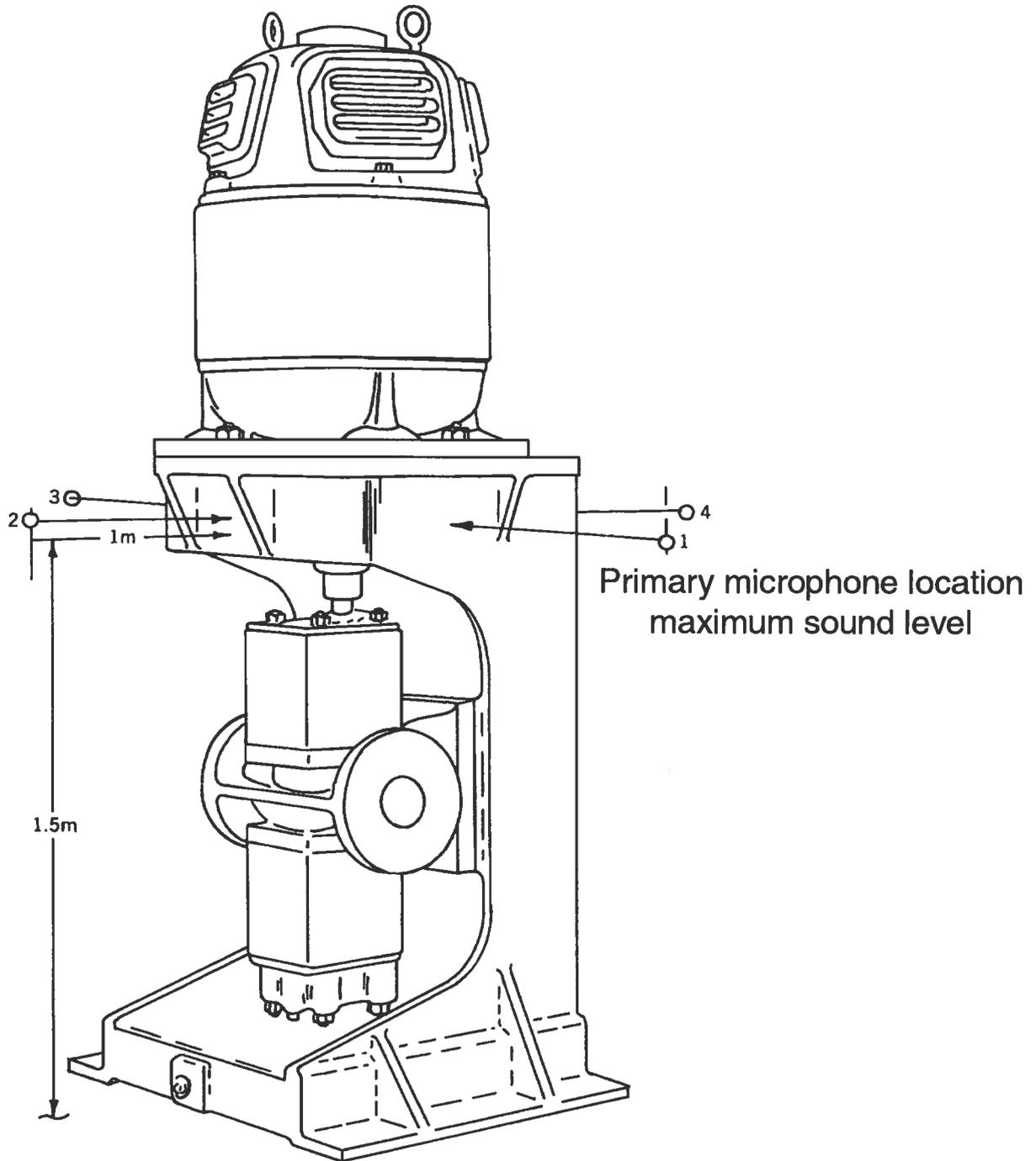


Figure 9.13 — Vertical rotary pump

## 9.5 Decontamination of returned products procedure

Products returned to the manufacturers that have the appearance of being in service, do not have a return materials authorization (RMA) number attached, or do not show signs of being decontaminated will not be accepted by the manufacturers or authorized service companies. These products will be returned to the point of origin freight collect. To avoid this situation, the procedures below shall be followed:

Pumps used in hazardous chemical or biological wastewater service shall be completely cleaned and decontaminated prior to shipping off site, regardless of destination.

- 1) Before any action is taken to return pumps or parts to a manufacturer or authorized service company, the company is to be contacted.
  - i) Inform the manufacturer why the product is being returned.
 

If the product is being returned for warranty inspection, the manufacturer may request that a specific process different from that used to send pumps back for general reconditioning be used for cleaning and disassembly.
  - ii) Describe those liquid(s) the product has been in contact with.
  - iii) Request any special procedures for cleaning or packaging the product prior to shipping it to the manufacturer.
- 2) The manufacturer will assign an RMA number to the product being returned.
- 3) Unless advised otherwise by the organization to which the product is being returned, the complete disassembly, cleaning and decontamination of the pump/parts must take place prior to shipping. If the product is to be returned in a disassembled condition, an itemized list of all of the parts shall accompany the shipment.
  - i) The product shall be drained and decontamination fluids flushed from the pump/parts.
    - ii) The pump/parts shall be dried and free of contaminants, liquid or particulates.
    - iii) Radioactive material will not be accepted even if decontaminated or cleaned.
- 4) Prior to shipment, attach a tag indicating the RMA number assigned by the manufacturer or service company.
- 5) Prepare two copies of a data pack that includes:
  - i) a statement that decontamination took place.
  - ii) a description of the decontamination procedure.
  - iii) a signature, with date, of the person certifying the decontamination was completed.
  - iv) a description of the installation and operation of the product.
  - v) description of the liquid characteristics (name, concentration, temperature, pressures, viscosity, particulate, etc.).
  - vi) the Material Safety Data Sheet (MSDS) for the liquid.
- 6) Attach a copy of the data pack to the pump/parts being shipped. Mail or fax the second copy to the manufacturer or service company for protection in the event that the one included with the product shipment is lost due to poor handling during shipping.
- 7) The pump/parts shall be shipped in a closed container. Inside shall be the pump/parts, the RMA tag attached to the product, and one copy of the data pack (item 5 above). Mark clearly on the outside of the container the RMA number assigned by the company.
- 8) If authorized by the company to ship a contaminated or partially decontaminated product, follow all DOT regulations for shipment of hazardous materials. Prepare a data pack that includes the contents of Sections iv through vi from above and include this with the shipment.

## Appendix A

### Bibliography

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

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1916 Race Street  
Philadelphia, PA 19103-1187

*Hydraulic Institute*

Hydraulic Institute  
9 Sylvan Way  
Parsippany, NJ 07054-3802

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New York, NY 10036

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11 West 42nd Street  
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Institute of Electrical and Electronic Engineers  
United Engineering Center  
345 East 47th Street  
New York, NY 10017

*SAE, Society of Automotive Engineers*

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Society of Automotive Engineers  
400 Commonwealth Drive  
Warrendale, PA 15096

## Appendix B

### 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.

- Abrasion, 11
  - severe, 15
- Abrasion resistant cast irons, 19
- Accumulator, 3
- Acoustical calibration, 50
- Adhesives, 26
- Airborne sound measurement, 50
  - 6 dB drop-off, 50
  - acoustical calibration, 50
  - averaging of readings, 52
  - A-weighted sound level, 50, 51, 52
  - background sound level and corrections, 52, 54*f.*
  - calculation and interpretation of readings, 52
  - caution (extraneous noise), 51
  - data presentation, 52
  - graphic plot, 52
  - instrumentation, 50
  - measurements and technique, 51
  - microphone locations, 50, 51, 54*f.*–60*f.*
  - microphone system, 50
  - octave-band analyzer, 50
  - octave-band sound pressure levels, 50, 51, 52
  - operation of pumping equipment, 50
  - primary microphone location, 51
  - recorders, 50
  - reference sound source, 50
  - sound level meter, 50
  - test data tabulation, 52
  - test environment, 50
  - test reports, 52, 53*f.*
- All bronze pumps, 16, 17
- All iron pumps, 16, 17
- All stainless steel pumps, 16, 17
- Alleviator, 3
- Aluminum and aluminum alloys, 22
- Aluminum bronze, 21
- American National Metric Council, 7
- American Society for Testing and Materials, 11
- Apparent viscosity, 5
- ASTM *See* American Society for Testing and Materials
- Austenitic ductile iron, 19
- Austenitic gray cast iron, 18
- A-weighted sound level, 50, 51, 52
- Bearing, 3
- Body, 3
- Brass
  - leaded red, 20
  - yellow, 20
- Bronze
  - all bronze pumps, 16, 17
  - aluminum, 21
  - leaded nickel bronze, 21
  - silicone, 20
  - specific composition bronze pumps, 16, 17
  - tin, 20
- Bronze fitted pumps, 16, 17
- Burst disc (rupture), 3
- Bypass piping, 3
- Carbon, 26
- Carbon and low alloy steels, 19
- Carbon steel, 19
- Cavitation erosion resistance of, 26, 28*f.*
- Centrifugal pump materials, 16
- Ceramics, 26
- Check valve, 3
- Chromates, 11
- Chromium coatings, 23
- Chromium (ferric) stainless steel, 20
- Chromium-nickel (austenitic) stainless steel, 19
- Coating systems, 22, 23–24
- Cobalt alloys, 23
- Cobalt-chromium boron alloy, 23
- Cobalt-chromium-tungsten alloy, 23
- Column, piping, 3
- Compound gauge, 3
- Controlled volume pump materials, 18
- Copper and copper alloys, 20
- Copper-nickel alloys, 21
- Corrosion, 11, 12
  - in crevices, 15
  - galvanic, 13, 14
  - severe, 15
- Critical carrying velocity, 5
- Data packs, 61

- Dead weight tester, 3
- Decontamination of returned products, 61
- Definitions, 3–6
- Dichromates, 11
- Direct acting (steam) pump materials, 18
- Discharge port, 4
- Ductile iron, 18
- Duplex stainless steels, 20
- Dynamometers, 3
  
- Eddy currents
  - drive coupling, 3
- Effective particle diameter, 5
- Elastomeric polymers, 24
- Electrolytes, 12
- End plate, 3
- Erosion, 15
  - cavitation erosion resistance of materials, 26, 28*f*.
  
- Fabrics, 26
- Flexible couplings, 3
- Fluid drive, 3
- Foot valves, 3
- Friction characteristic, 5
- Fully suspended solids, 5
  
- Galvanic corrosion, 13
  - minimizing, 14
- Galvanic series, 13
- Gland, packing, 3
- Graphic level recorders, 50
- Graphite, 26
- Gray cast iron, 18
  
- Halide, 11
- Hardware terms, 3
- Hazardous chemicals, 61
- Heat exchanger, 3
- Heterogeneous mixture, 5
- High alloy steels, 19
- High copper alloys, 20
- High silicon cast irons, 19
- Homogeneous flow, 5
- Homogeneous mixture, 5
  
- Inlet, 3
- Inlet port, 3
- Iron
  - abrasion resistant cast irons, 19
  - all iron pumps, 16, 17
  - austenitic gray cast iron, 18
  - ductile, 18
  - gray cast iron, 18
  - high silicon cast irons, 19
  - malleable cast iron, 18
  - nickel-chromium-iron alloys, 21
  
- Jacketed pump, 3
  
- Kinetic pumps, 1, 2*f*.
  
- Lantern ring, 3
- Lead and lead alloys, 23
- Leaded nickel bronze (nickel silvers), 21
- Leaded red brass, 20
- Leather, 26
- Lip seal, 3
- Liquids
  - chemical symbols, 11
  - common polymer materials for, 37, 38*t*.
  - effects of temperature and concentration, 11
  - high temperature, 11, 12
  - low temperature, 11, 12
  - material selection for maximum continuous temperature of various liquids, 39, 40*t*.–44*t*., 45*t*.–49*t*.
  - materials commonly used for pumping, 27, 29*f*.–37*t*.
  - specific gravity, 11
- Low alloy steels, 19
  
- Malleable cast iron, 18
- Material Safety Data Sheets, 61
- Materials
  - abrasion resistant cast irons, 19
  - adhesives, 26
  - aluminum and aluminum alloys, 22
  - aluminum bronze, 21
  - austenitic ductile iron, 19
  - austenitic gray cast iron, 18
  - carbon, 26
  - carbon and low alloy steels, 19
  - carbon steel, 19
  - cavitation erosion resistance of, 26, 28*f*.
  - centrifugal pumps, 16
  - ceramics, 26
  - chemical and physical properties, 12
  - chromium coatings, 23
  - chromium (ferric) stainless steel, 20
  - chromium-nickel (austenitic) stainless steel, 19
  - coating systems, 22, 23–24
  - cobalt alloys, 23
  - cobalt-chromium-tungsten alloy, 23
  - common polymer for various liquids, 37, 38*t*.
  - controlled volume pumps, 18
  - copper and copper alloys, 20
  - copper-nickel alloys, 21
  - and crevice corrosion, 15
  - direct acting (steam) pumps, 18

- ductile iron, 18
- duplex stainless steels, 20
- elastomeric polymers, 24
- fabrics, 26
- factors affecting selection, 11–16
- galling resistance, 15
  - and galvanic corrosion, 13, 14
  - and galvanic series, 13
  - and general design, 12
- general designations by pump type, 16–18
- graphite, 26
- gray cast iron, 18
- high alloy steels, 19
- high copper alloys, 20
- high silicon cast irons, 19
- lead and lead alloys, 23
- leaded nickel bronze (nickel silvers), 21
- leaded red brass, 20
- leather, 26
  - and liquid temperature, 12, 39, 40*t.*–44*t.*, 45*t.*–49*t.*
  - and liquids, 11
- low alloy steels, 19
- malleable cast iron, 18
  - and mechanical situation in pumping, 15
- microstructure of metals, 15
- nickel alloys, 21
- nickel copper alloys, 21
- nickel or cobalt-chromium boron alloy, 23
- nickel-chromium-iron alloys, 21
- nickel-molybdenum alloys, 21
- nickel-molybdenum-chromium alloys, 21
- non-metal, 24–26
- optimizing life cost, 12
- power pumps, 18
- reciprocating pumps, 18
- reinforced fibers, 26
- rigid polymers and composites, 25
- rotary pumps, 17
- sealants, 26
  - and severe corrosion or abrasion, 15
- silicon bronze, 20
  - and thermal or hydraulic shock, 16
- thermoplastics, 25
- thermosetting polymers, 25
- tin bronze, 20
- tin-base bearing metals, 23
- titanium alloys, 23
  - used for pumping various liquids, 27, 29*t.*–37*t.*
  - and velocity effects, 16
- vertical pumps, 16
  - for wetted pump parts, 11
- yellow brass, 20
- zinc and zinc alloys, 23
- zirconium, 23
- Measurement of airborne sound See Airborne sound measurement
- Mechanical seal chamber, 4
- Mechanical seal gland, 4
- Mechanical seals, 3
- Metals
  - galling resistance, 15
  - microstructure, 15
- Metric units, 7
  - conversion factors, 8*t.*–10*t.*
  - rounded equivalents, 7*t.*
- Microphone locations (airborne sound measurement), 50
  - axially split case centrifugal pump, 55*f.*
  - axially split case multistage centrifugal pump, 57*f.*
  - double case centrifugal pump, 56*f.*
  - horizontal end suction centrifugal pump, 54*f.*
  - horizontal reciprocating pump, 57*f.*
  - horizontal rotary gear pump, 59*f.*
  - horizontal rotary screw pump, 59*f.*
  - primary, 51
  - vertical in-line centrifugal pump, 55*f.*
  - vertical reciprocating pump, 58*f.*
  - vertical rotary pump, 60*f.*
- Microphone systems, 50
- MSDS See Material Safety Data Sheets
- Mud pump, 4
- Nickel alloys, 21
- Nickel copper alloys, 21
- Nickel or cobalt-chromium boron alloy, 23
- Nickel-chromium-iron alloys, 21
- Nickel-molybdenum alloys, 21
- Nickel-molybdenum-chromium alloys, 21
- NIST, 50
- Non-homogeneous flow, 5
- Non-settling slurry, 5
- Nozzles, 4
- Octave-band analyzers, 50
- Octave-band sound pressure levels, 50, 51, 52
- Oil seal, 4
- Orifice, 4
- Outlet, 4
- Outlet port, 4
- Packing, 4
- Packing box, 4
- Packing gland, 4
- Partially suspended solids, 5
- Percent solids by volume, 5
- Percent solids by weight, 5
- Pilot-operated relief valve, 4

Polymers

- composites, 16, 25
- elastomeric, 24
- material selection for maximum continuous temperature of various liquids, 39, 40*t.*–44*t.*, 45*t.*–49*t.*
- rigid, 16, 25
- thermosetting, 25
- used in pump construction, 38
- for various liquids, 37, 38*t.*

Positive displacement pumps, 1, 2*f.*

Power pump materials, 18

Preferred measurement units, 7

- conversion factors, 8*t.*–10*t.*
- rounded equivalents, 7*t.*

Pulsation dampener, 4

Pumps

- decontamination of returned products, 61
- defined, 4
- hardware terms, 3
- kinetic, 1, 2*f.*
- positive displacement, 1, 2*f.*
- slurry application terms, 5
- types of, 1, 2*f.*

Radial seal, 4

Receiver-pulsation dampener, 4

Reciprocating pump materials, 18

Reinforced fibers, 26

Relief valve, 4

Return materials authorization number, 61

Revolution counter, 4

Rigid polymers and composites, 25

- parts, 16

RMA See Return materials authorization number

Rotary pump materials, 17

Rotor, 4

Rupture, 3

Saltation, 6

Seal chamber, 4

Seal piping, 4

Sealants, 26

Sealing by impregnation, 12

Sealless (defined), 4

Settling slurry, 6

Settling velocity, 6

Shear pin relief valve, 4

Silicon bronze, 20

Sleeve bearings, 4

Slurry, 6

Slurry application terms, 5

Slush pump, 4

Smothering gland, 5

Soluble chloride, 11

Sound level meters, 50

Specific composition bronze pumps, 16, 17

Square root law, 6

Stainless steel fitted pumps, 16

Steam jacket, 5

Steel

- all stainless steel pumps, 16, 17
- carbon and low alloy steels, 19
- chromium (ferric) stainless steel, 20
- chromium-nickel (austenitic) stainless steel, 19
- duplex stainless steels, 20
- high alloy steels, 19
- stainless steel fitted pumps, 16

Stop valve, 5

Stuffing box, 5

- bushings, 5

Suction nozzle, 5

Suction port, 3

Tachometers, 5

Tape recorders, 50

Thermoplastics, 25

Thermosetting polymers, 25

Timing gear, 5

Tin bronze, 20

Tin-base bearing metals, 23

Titanium alloys, 23

Torsional dynamometer, 5

Transmission dynamometers, 5

Units of measure, 7

- conversion factors, 8*t.*–10*t.*
- rounded equivalents, 7*t.*

Universal joint, 5

US Customary units, 7

- conversion factors, 8*t.*–10*t.*
- rounded equivalents, 7*t.*

Vacuum breaker piping, 5

Vegetable oils, 11

Vent piping, 5

Venturi meter, 5

Vertical pump materials, 16

Wastewater, 61

Welding, 12

Yellow brass, 20

Yield value, 6

Zinc and zinc alloys, 23

Zirconium, 23

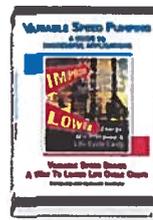
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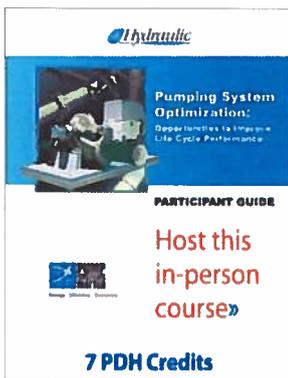
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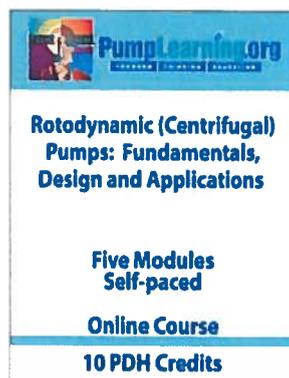
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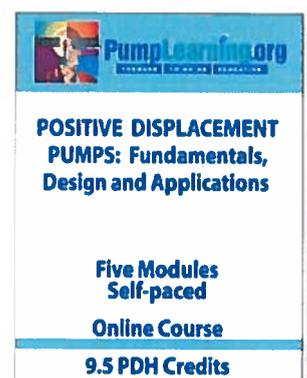
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