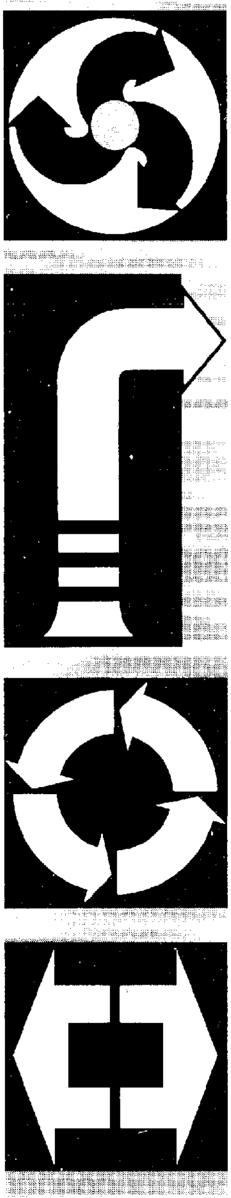

ANSI/HI 9.1-9.5-1994

American National Standard for

Pumps – General Guidelines

for Types, Definitions, Application and Sound Measurement

Hydraulic
INSTITUTE
9 Sylvan Way
Parsippany, New Jersey
07054-3802

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Pumps – General Guidelines

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Sponsor
Hydraulic Institute

Approved June 3, 1994
American National Standards Institute, Inc.

American National Standard

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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

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

a. To develop and publish standards for pumps;

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

c. To represent its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;

d. To expand and 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 which will, in turn, 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 review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art.

Scope

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

Units of Measurement

US Customary units of measurement are predominantly used, and, where appropriate, Metric unit equivalents appear in brackets following the US units. Sample calculations are shown with US units only.

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

The following organizations, recognized as having an interest in the standardization of 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.

Agrico Chemical Corporation
American Petroleum Institute
Amer. Society of Heating, Refrigerating & Air-Conditioning Engineers
Amer. Society of Mechanical Engineers
Amoco Oil Company
Aurora Industries
Black & Veatch
BP America
Brown & Caldwell
Camp dresser & McKee, Inc.
CH2M Hill
Chiyoda International Corporation
Commonwealth Edison
DeWanti & Stowell
Dexter Corporation
DuPont Engineering
Durametallic Corporation
Edison Electrical Institute
Electric Power Research Institute
Florida Power Corporation
Florida Power & Light
Fluor Daniel
Freese and Nichols, Inc.
G.E. Motors
HDR Engineering
Holabird & Root
Hydraulic Institute
Institute of Paper Science & Tech.
John Carollo Engineers
John Crane, Inc.
Marine Spill Response Corporation
Min Proc Eng., Inc.
Mobil Research & Development Corp.
Monsanto Chemical Company
Montana State University
Montgomery Watson
M. W. Kellogg Company
Naval Sea Systems
Naval Surface Warfare Center
Newport News Shipbuilding
Pacific Gas & Electric
Raytheon Engineers & Constructors
Riverwood International Georgia, Inc.
San Francisco Bureau of Engineering
Siemens Energy & Automation
Simons-Eastern Consultants
Sordoni-Skanska Construction Co.
Star Enterprises
State Farm Mutual Automobile Ins. Co.
State of California Dept. of Water Res.
Stone & Webster
Summers Engineering, Inc.
T. Hopkins - Consultant
Tennessee Eastman
Union Carbide Chemicals & Plastics Co.
US Bureau of Reclamation

9 Pumps – general guidelines

9.1 Types of pumps

Industrial 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 classified 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 accomplish this action 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 or plungers;

2) Rotary action of mechanical devices such as gears, screws, vanes, etc.;

3) Blow case arrangements using pressurized air to displace liquid.

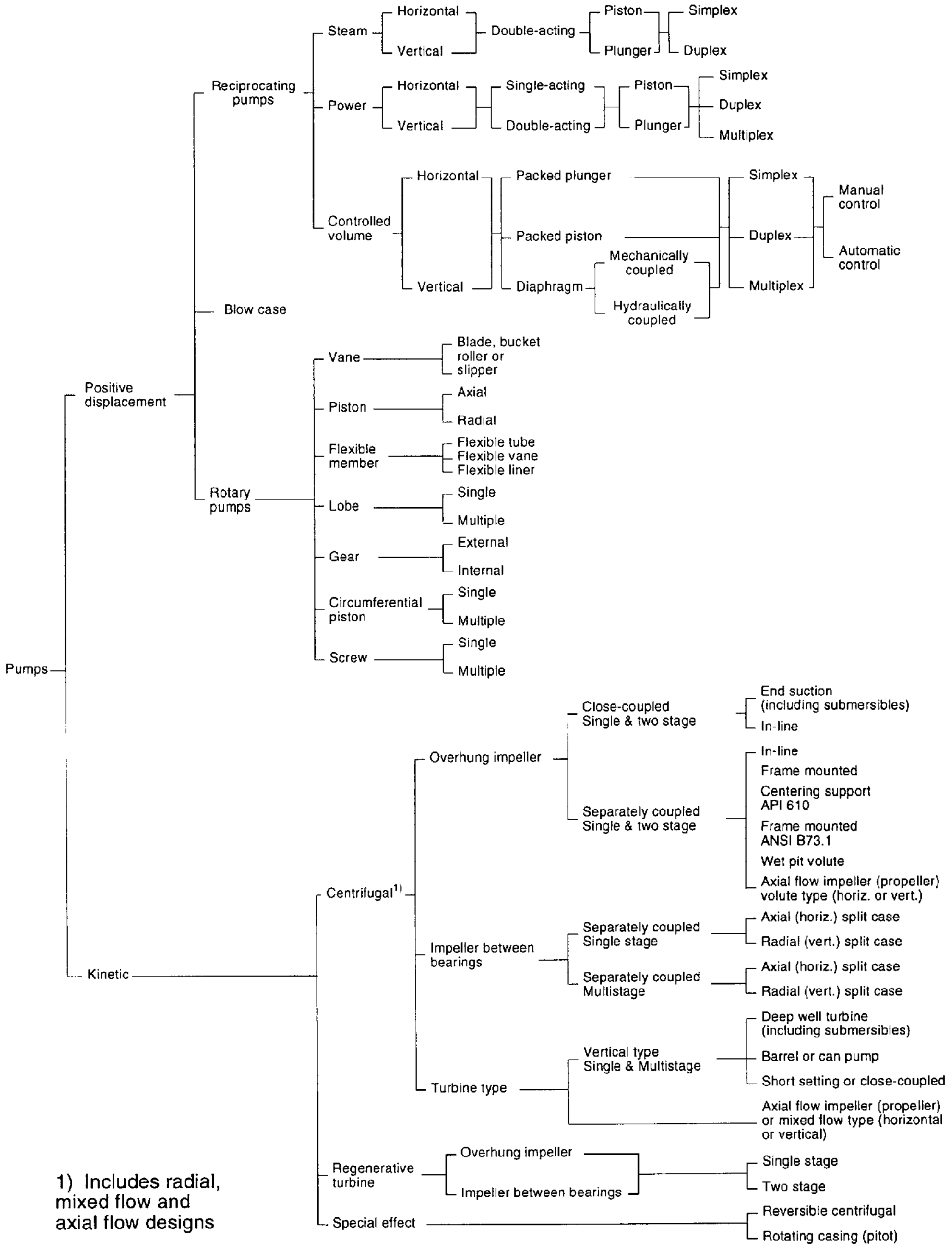
9.1.2 Kinetic pumps

Kinetic pumps accomplish this action 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 pumps
HI 8.1-8.5	Reciprocating direct acting pumps



1) 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 potential energy of any noncompressible fluid 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 auto-transformer: A single winding linking a magnetic circuit.

9.2.1.4 bearing: A device which supports or positions the pump shaft. It may be either an anti-friction (ball or roller bearing) or fluid film (sleeve and journal) type, and it may be internal (wetted by the pumped fluid) or external.

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

9.2.1.6 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.

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

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

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

9.2.1.10 compound gauge: A gauge capable of indicating vacuum and pressure.

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

9.2.1.12 dynamometer (see transmission dynamometer): A device used to determine pump input horsepower.

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

9.2.1.14 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.

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

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

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

9.2.1.18 gland (follower): An adjustable follower that compresses packing in a stuffing box.

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

9.2.1.20 inlet or suction port: One or more openings in the pump through which the pumped fluid may enter the pumping chamber.

9.2.1.21 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 fluid.

9.2.1.22 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.

9.2.1.23 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.

9.2.1.24 liquid end: The liquid end of a reciprocating pump consists of the liquid cylinder, valves and manifolds where the liquid develops the pressure induced by the plunger.

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

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

9.2.1.27 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.

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

9.2.1.29 nozzle: A device used to convert fluid pressure to velocity.

9.2.1.30 oil seal: A contact seal or cover used to retain oil.

9.2.1.31 orifice: A pressure breakdown device consisting of one or more sudden contractions and sudden enlargements in series often used for measuring rate of flow.

9.2.1.32 outlet or discharge port: One or more openings in the pump through which the pumped fluid may leave the pumping chamber.

9.2.1.33 packing: A deformable substance used to provide sealing between locations at which fluids are present under different conditions, usually where relative motion occurs at the boundary between the fluids.

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

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

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

9.2.1.37 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.

9.2.1.38 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.

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

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

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

9.2.1.42 rolling contact: A term used to describe ball and roller bearings because of their rolling elements.

9.2.1.43 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.

9.2.1.44 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.

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

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

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

9.2.1.48 smothering gland: A gland that has provision for introducing liquids at lower temperature than the fluid being pumped, to condense vapors that may escape through the stuffing box packing.

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

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

9.2.1.51 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.

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

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

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

9.2.1.55 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.

9.2.1.56 torsional dynamometers: A measuring device used to determine the torque being transmitted in a power train.

9.2.1.57 transmission dynamometer: A device used to determine pump input horsepower.

9.2.1.58 universal joint: A device used to connect shafts that are not aligned.

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

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

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

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 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:

$$V_L = V_S \text{ x } \sqrt{\frac{D_L}{D_S}}$$

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 Std. 260 — 1978, 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 in *ASTM E-380 (ANSI Z210.1)* 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^3
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/in2	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[2]	Typical applications	US Customary unit	Abbreviation	Metric unit	Abbreviation	Conversion factors – multiply by	
						US unit to Metric	Metric to US unit
1. Space and time							
plane angle	fluid flow angle	degree	°	degree	o	1	1
length	dimensions of sumps and pits	foot and inch	ft or ′	meter	m	0.3048[1]	3.281
			in or “	meter	m	0.0254[1]	39.37[1]
	mechanical engineering drawings	inch	in or “	millimeter	mm	25.4[1]	.03937
	coating thickness, surface finish, filter particle size	thousandths of inch	mil	micrometer	μ m	25.4[1]	.03937
		microinch	μin	micrometer	μ m	0.0254[1]	39.37
		micron	μm	micrometer	m m	1[1]	1[1]
area	surface area, flow area	square foot	ft^2	square meter	m^2	0.092 90	10.76
		square inch	in^2	square millimeter	mm^2	645.2	0.001 550
volume	fluid volume capacity	cubic inch	in^3	milliliter (cm^3)[3]	mL[4]	16.39	0.061 02
		cubic foot	ft^3	cubic meter	m^3	0.028 32	35.31
		gallon	gal	cubic meter	m^3	0.003785	264.2
		quart	qt	liter	L	0.9464	1.057
time	time interval	hour	h	hour	h	1[1]	1[1]
		minute	min	minute	min	1[1]	1[1]
		second	s	second	s	1[1]	1[1]
volume per unit time	flow rate of fluids	gallon per minute	gpm	cubic meter per hour	m^3/h	0.2271	4.403
		gallon per minute	gpm	liter per minute	L/min	3.785	0.2642
velocity, linear	fluid velocity	foot per minute	fpm	meter per minute	m/min	0.3048[1]	3.281
		foot per second	fps	meter per second	m/s	0.3048[1]	3.281
acceleration	gravity	foot per second – squared	ft/s^2	meter per second – squared	m/s^2	0.3048[1]	3.281
2. Periodic and related phenomena							
frequency	system vibration, sound, alternating current	hertz	Hz	hertz	Hz	1[1]	1[1]
speed of rotation	speed of rotation	revolution per minute	rpm	revolution per minute	rpm	1[1]	1[1]

3. Mechanics

mass	equipment mass	pound (decimalized)	lb or #	kilogram	kg	0.4536	2.205
		ounce	oz	gram	g	28.35	0.035 27
unbalance	impeller, rotor	ounce-inch	oz•in	gram-millimeter	g•mm	720.1	0.001 389
density (mass density)	density of solids and fluids	pound per cubic foot	lb/ft^3	kilogram per cubic meter	kg/m^3	16.02	0.062 43
specific weight (force)	solids and fluids	pound force per cubic foot	lbf/ft^3	kiloNewton per cubic meter	kN/m^3	0.1571	6.366
moment of inertia (dynamic)	rotor inertia	pound foot-squared	lb•ft^2	kilogram meter-squared	kg•m^2	0.042 14	23.73
force	applied load	pound-force	lbf	Newton	N	4.448	0.2248
fluid energy	head of fluid	foot	ft	meter	m	0.3048 1)	3.281
moment of force, torque and bending moment	bolt tightening, shaft torque, beam stress and deflection calculations	pound-force foot	lbf•ft	Newton-meter	N•m	1.356	0.7376
		pound-force inch	lbf•in	Newton-meter	N•m	0.1130	8.851
pressure	fluid pressure or vacuum	pound-force per square inch	psi	kilopascal [kN/m^2]	kPa	6.895	0.1450
		inch of mercury [60°F]	inHg	kilopascal	kPa	3.377	0.2961
		inch of water [60°F]	inH$_2$0	kilopascal	kPa	0.2488	4.019
	sound pressure level	decibel	dB	micropascal [20 µPa]	µPa	100 000	0.000 01
stress	unit force	pound-force per square inch	psi	megapascal	MPa 5)	0.006 895	145.0
specific speed	centrifugal pump impeller $\left[\frac{N(Q)^{.5}}{h^{.75}}\right]$	$\frac{rpm(gpm)^{.5}}{ft^{.75}}$	dimensionless	$\frac{rpm(m^3/hr)^{.5}}{m^{.75}}$	dimen-sionless	1.162	0.8608
viscosity, dynamic	liquid characteristic	centipoise	cP	millipascal-second	mPa•s	1 1)	11)
viscosity, kinematic	liquid characteristic	centistokes 6)	cSt	square-millimeter per second	mm^2/s	1 1)	11)
energy, work (see also heat & electricity)	force times distance	foot-pound-force	ft•lbf	joule [N•m] 7)	J	1.356	0.7376
power (see also heat & electricity	mechanical power	horsepower	hp	kilowatt [kJ/s] 7)	kW	0.7457	1.341

Footnotes shown on page 10.

(continued)

Table 9.2 *(concluded)*

Quantity[2]	Typical applications	US Customary unit	Abbreviation	Metric unit	Abbreviation	Conversion factors – multiply by	
						US unit to Metric	Metric to US unit
4. Heat							
temperature	temperature	degree Fahrenheit	°F	degree Celcius[8]	°C	(°F – 32) x 5/9[1]	(oC x 1.8) + 32[1]
	absolute temperature	degree Rankin	oR	degree Kelvin	°K	5/9[1]	1.8[1]
heat (energy)	heat input	British Thermal Unit	Btu[9]	kilojoule	kJ	1.055	0.9478
heat flow rate (power)	heat rejection rate, air conditioning power	British Thermal Unit per minute	Btu/min	watt [(J/s)][7]	W	17.58	0.05687
5. Electricity							
electric current	electricity flow	ampere	A	ampere	A	1[1]	1[1]
electromotive force	battery potential	volt	V	Volt	V	1[1]	1[1]
electric resistance	resistors, conductors	ohm	ohm	ohm	Ω	1[1]	1[1]
electric conductance	conductors	Mho	Mho	Siemens	S	1[1]	1[1]
electric energy	electric consumption	kilowatt-hour	kW•h	kilowatt-hour[10]	kW•h	1[1]	1[1]
electric power	motors	kilowatt	kW	kilowatt	kW	1[1]	1[1]

[1] Exact

[2] As used in ISO–31 and ISO–1000, "quantity" means "measurable property".

[3] Symbols in brackets [ ] are explanatory only.

[4] 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.

[5] 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).

[6] Conversion from Saybolt Universal Seconds to centistrokes can be done from a table.

[7] By using J instead of N•m, the distinction from N•m for moment of force is made apparent.

[8] Conversion requires a formula, wherein the Fahrenheit temperature is indicated by °F and the Celcius temperature by °C.

[9] All factors in this table are based on Btu-International Table.

[10] 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 32°F (0°C) or above 250°F (120°C) 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

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

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 250°F (120°C) 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 protection, area/voltage effect

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);
- 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

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 Compatibility (galling)

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 foodstuffs). 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 20" (500 mm) 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 - introduction

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 fluid being pumped. In such cases, this non-metallic material may well be the controlling factor in material compatibility with the fluid being handled.

All materials must be chosen for their physical properties in relation to the fluid 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 fluids 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 fluid 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 iron castings

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 20,000 psi through 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 castings

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 60,000 to 120,000 psi.

9.3.2.6.3 Malleable cast iron castings

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 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 iron castings (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 castings

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 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

Iron 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 Iron chromium-nickel alloys

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 Iron chromium alloys

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 - introduction

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 alkalies and organic acids, but alloys containing zinc have poor resistance to inorganic acids.

9.3.2.6.10.1 Copper and 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 brasses

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 bronzes

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 micro-shrinkage. 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 bronzes

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 fluid 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 1000°F (535°C). 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 55,000 psi 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 70,000 psi 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 1000°F (535°C) 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 insure 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 electro-plating. 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:

	R Class	
Name	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.

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

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

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

NOTE – The A class rubbers are the silicon rubbers.

	U Class	
Name	Polymer name	Sym
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. Non-metallic 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 non-metallic 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 antigalling 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 Standard 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 180°F (85°C) 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, alkalies 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.

9.3.2.7 Common 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 Paragraphs 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

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		$H_3AsO_4. \frac{1}{2}H_2O$	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. 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, hydrofluosilcic		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	$C_2H_2O_4. 2H_2O$	1.65	8, 9, 10, 11, 12
Acid, oxalic	Hot	$C_2H_2O_4. 2H_2O$		10, 11, 12
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

(continued)

Table 9.3 *(continued)*

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	**Conditions of liquid**	**Chemical symbol**	**Specific gravity**	**Material selection**
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.	$C_4H_6O_6 . H_2O$		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)			
Bleach solutions	(See type)			
Blood				A, B
Boiler feedwater	(See water, boiler feed)			
Brine, calcium chloride	pH>8	$CaCl_2$		C
Brine, calcium chloride	pH<8			A, 10, 11, 13, 14
Brine, calcium and magnesium chlorides	Aqueous sol.			A, 10, 11, 13, 14
Brine, calcium and sodium chloride	Aqueous sol.			A, 10, 11, 13, 14
Brine, sodium chloride	Under 3% salt, cold	$NaCl$		A, C, 13
Brine, sodium chloride	Over 3% salt, cold		1.02-1.20	A, 8, 9, 10, 11, 13, 14
Brine, sodium chloride	Over 3% salt, hot			9, 10, 11, 12, 14
Brine, seawater			1.03	A, B, C
Butane		C_4H_{10}	0.60 @ 32°F	B, C, 3

(continued)

Table 9.3 *(continued)*

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	**Conditions of liquid**	**Chemical symbol**	**Specific gravity**	**Material selection**
Calcium bisulfite	Paper mill	$Ca(HSO_3)_2$	1.06	9, 10, 11
Calcium chlorate	Aqueous sol.	$Ca(ClO_3)_2 2H_2O$		10, 11, 12
Calcium hyposchlorite		$Ca(OCl)_2$		C, 10, 11, 12
Calcium magnesium chloride	(See brines)			
Cane juice				A, B, 13
Carbon bisulfide		CS_2	1.26	C
Carbonate of soda	(See soda ash)			
Carbon tetrachloride	Anhydrous	CCl_4	1.50	B, C
Carbon tetrachloride	Plus water			A, 8
Catsup				A, 8, 9, 10, 11
Caustic potash	(See potassium hydroxide)			
Caustic soda	(See sodium hydroxide)			
Cellulose acetate				9, 10, 11
Chlorate of lime	(See calcium chlorate)			
Chloride of lime	(See calcium hypochlorite)			
Chlorine water	(Depending on conc.)			9, 10, 11, 12
Chlorobenzene		C_6H_5Cl	1.1	A, B, 8
Chloroform		$CHCl_3$	1.5	A, 8, 9, 10, 11, 14
Chrome alum	Aqueous sol.	$CrK(SO_4)_2. 12H_2O$		10, 11, 12
Condensate	(See water, distilled)			
Copperas, green	(See ferrous sulfate)			
Copper ammonium acetate	Aqueous sol.			C, 8, 9, 10, 11
Copper chloride (cupric)	Aqueous sol.	$CuCl_2$		11, 12
Copper nitrate		$Cu(NO_3)_2$		8, 9, 10, 11
Copper sulfate, blue vitriol	Aqueous sol.	$CuSO_4$		8, 9, 10, 11, 12
Creosote	(See oil, creosote)			
Cresol, meta		C_7H_8O	1.03	C, 5
Cyanide	(See sodium cyanide and potassium cyanide)			
Cyanogen	In water	$(CN)_2$ gas		C
Diphenyl		$C_6H_5. C_6H_5$	.99	C, 3
Enamel				C
Ethanol	(See alcohols)			
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

(continued)

Table 9.3 *(continued)*

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	**Conditions of liquid**	**Chemical symbol**	**Specific gravity**	**Material selection**
Gasoline			0.68-0.75	B, C
Gaubes salt	(See sodium sulfate)			
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		C_7H_{16}	0.69	B, C
Hydrogen peroxide	Aqueous sol.	H_2O_2		8, 9, 10, 11
Hydrogen sulfide	Aqueous sol.	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.	$Pb(C_2H_3O_2)_2. 3H_2O$		9, 10, 11, 14
Lead	Molten			C, 3
Lime water (milk of lime)		$Ca(OH)_2$		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.	$MgCl_2$		10, 11, 12
Magnesium sulfate (epsom salts)	Aqueous sol.	$MgSo_4$		C, 8, 9, 10, 11
Manganese chloride	Aqueous Sol.	$MnCl_2. 4H_2O$		A, 8, 9, 10, 11, 12
Manganous sulfate	Aqueous Sol.	$MnSO_4. 4H_2O$		A, C, 8, 9, 10, 11
Mash				A, B, 8
Mercuric chloride	Very dilute aqueous sol.	$HgCl_2$		9, 10, 11, 12
Mercuric chloride	Coml. conc. aqueous sol.	$HgCl_2$		11, 12
Mercuric sulfate	In sulfuric acid	$HgSO_4 + H_2SO_4$		10, 11, 12
Mercurous sulfate	In sulfuric acid	$Hg_2SO_4 + H_2SO_4$		10, 11, 12
Methyl chloride		CH_3Cl	0.52	C
Methylene chloride		CH_2Cl_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

(continued)

Table 9.3 *(continued)*

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	**Conditions of liquid**	**Chemical symbol**	**Specific gravity**	**Material selection**
Mustard				A, 8, 9, 10, 11, 12
Naphtha			0.78-0.88	B, C
Naphtha, crude			0.92-0.95	B, C
Nicotine sulfate		$(C_{10}H_{14}N_2)_2H_2SO_4$		10, 11, 12, 14
Nitre	(See potassium nitrate)			
Nitre cake	(See sodium bisulphate)			
Nitro ethane		$C_2H_5NO_2$	1.04	B, C
Nitro methane		CH_3NO_2	1.14	B, C
Oil, coal tar				B, C, 8, 9, 10, 11
Oil, coconut			0.91	A, B, C, 8, 9, 10, 11, 14
Oil, creosote			1.04-1.10	B, C
Oil, crude	Cold			B, C
Oil, crude	Hot			3
Oil, essential				A, B, C
Oil, fuel				B, C
Oil, kerosene				B, C
Oil, linseed			0.94	A, B, C, 8, 9, 10, 11, 14
Oil, lubricating				B, C
Oil, mineral				B, C
Oil, olive			0.90	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			0.87	B, C
Paraffin	Hot			B, C
Perhydrol	(See hydrogen peroxide)			
Peroxide of hydrogen	(See hydrogen peroxide)			
Petroleum ether				B, C
Phenol		C_6H_6O	1.07	
Pink liquor	(See liquor, pulp mill)			
Photographic developers				8, 9, 10, 11
Plating solutions	(Varied and complicated, consult pump mfrs.)			
Potash	Plant liquor			A, 8, 9, 10, 11, 13, 14
Potash Alum	Aqueous sol.	$Al_2(SO_4)_3K_2SO_4 \cdot 24H_2O$		A, 9, 10, 11, 12, 13, 14
Potassium bichromate	Aqueous sol.	$K_2Cr_2O_7$		C
Potassium carbonate	Aqueous sol.	K_2CO_3		C
Potassium chlorate	Aqueous sol.	$KClO_3$		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_3		C, 5, 8, 9, 10, 11
Potassium sulfate	Aqueous sol.	K_2SO_4		A, 8, 9, 10, 11
Propane		C_3H_8	0.59 @ 48°F	B, C, 3

(continued)

Table 9.3 *(continued)*

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	**Conditions of liquid**	**Chemical symbol**	**Specific gravity**	**Material selection**
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.	$Na_2S_2O_4$, $2H_2O$		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,H_2O		A, 8, 9, 10, 11
Sodium phosphate: dibasic	Aqueous sol.	Na_2HPO_4. $7H_2O$		A, C, 8, 9, 10, 11
Sodium phosphate: tribasic	Aqueous sol.	Na_3PO_4. $12H_2O$		C
Sodium phosphate: meta	Aqueous sol.	$Na_4P_4O_{12}$		A, 8, 9, 10, 11
Sodium phosphate: hexameta	Aqueous sol.	$(NaPo_3)_6$		8, 9, 10, 11
Sodium plumbite	Aqueous sol.			C
Sodium sulfate	Aqueous sol.	Na_2SO_4		A, 8, 9, 10, 11
Sodium sulfide	Aqueous sol.	Na_2S		C, 8, 9, 10, 11
Sodium sulfite	Aqueous sol.	Na_2SO_3		A, 8, 9, 10, 11
Sodium thiosulfate	Aqueous sol.	$Na_2S_2O_3$. $5H_2O$		8, 9, 10, 11
Stannic chloride	Aqueous sol.	$SnCl_4$		11, 12
Stannous chloride	Aqueous sol.	$SnCl_2$		11, 12
Starch		$(C_6H_{10}O_5)x$		A, B

(continued)

Table 9.3 *(concluded)*

Column 1	Column 2	Column 3	Column 4	Column 5
Liquid	**Conditions of liquid**	**Chemical symbol**	**Specific gravity**	**Material selection**
Strontium nitrate	Aqueous sol.	$Sr(NO_3)_2$		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	S_2Cl_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		$Pb(C_2H_5)_4$	1.66	B, C
Toluene (toluol)		C_7H_8	0.87	B, C
Trichloroethylene		C_2HCl_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
Water, boiler feed	High makeup pH<8.5			B
Water, boiler feed	Low makeup Evaporated, any pH		1.00	4, 5, 8, 14
Water, distilled	High purity		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_8H_{10}	0.87	B, C, 8, 9, 10, 11
Yeast				A, B
Zinc chloride	Aqueous sol.	$ZnCl_2$		9, 10, 11, 12
Zinc sulfate	Aqueous sol.	$ZnSO_4$		A, 9, 10, 11

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 µpascals (.0002µBAR) 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 six 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 algebraically 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 algebraically 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 one meter above the reflecting plane.

9.4.4 Microphone locations

A preliminary survey shall be taken around the machine at a distance of one meter from the nearest major surface of the machine, and at a height of 1.5 meters, 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 one meter from the outermost major surface of the machine, and at a height of 1.5 meters above the floor or above the walk level.

Typical microphone locations are shown in the following figures:

Figure	Title
9.3	Horizontal end suction centrifugal pump
9.4	Horizontally split centrifugal pump
9.5	Vertical in-line centrifugal pump
9.6	Double case centrifugal pump
9.7	Horizontally split multistage centrifugal pump
9.8	Horizontal reciprocating pump
9.9	Vertical reciprocating pump
9.10	Horizontal rotary gear pump
9.11	Horizontal rotary screw pump
9.12	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 one meter 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 ± 0.3 meter 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 Paragraph 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 Paragraph 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 9.2.

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:

a) Maximum variation 5 dB or less: average the sound pressure levels arithmetically;

b) Maximum variation 5 dB to 10 dB: average the sound pressure levels arithmetically and add one dB;

c) Maximum variation over 10 dB: average according to the equation below:

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

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 38 should be used for reporting the following data:

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

a) Statement that the test was conducted in accordance with the Hydraulic Institute Test Standard;

b) Description of the machine, operating conditions, and a sketch showing the test layout and microphone locations;

c) 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:

a) The corrected sound level measurements at each microphone location, dB(A), and corrected octave band sound pressure levels;

b) Background sound level at one location, dB(A), and octave band sound pressure levels;

c) 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:

a) 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: ______________ Capacity: ______________ 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, Capacity: ______________ gpm

Total head: ______________ Feet, 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)												
			Location 1)											
		Back-ground	(P) prim.	1	2	3	4	5	6	7	8	9	10	Av.
Midband freq.-Hz	dB A													
	63													
	125													
	250													
	500													
	1k													
	2k													
	4k													
	8k													

1) 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: ______________

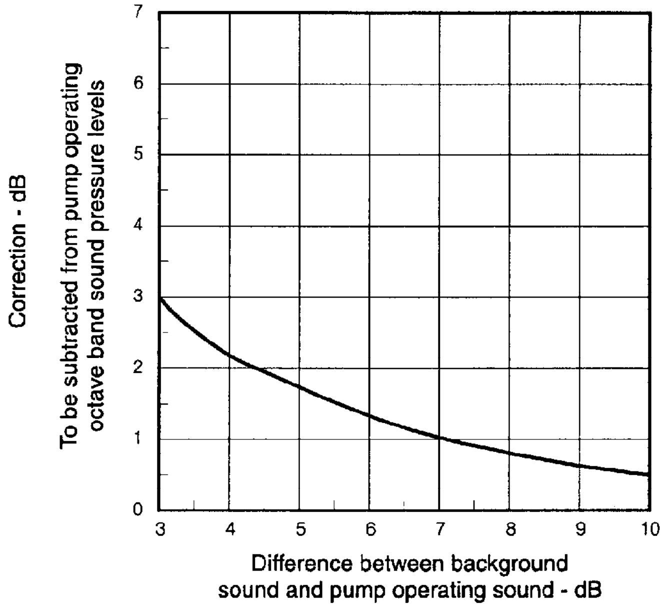


Figure 9.2 — Correction for background sound

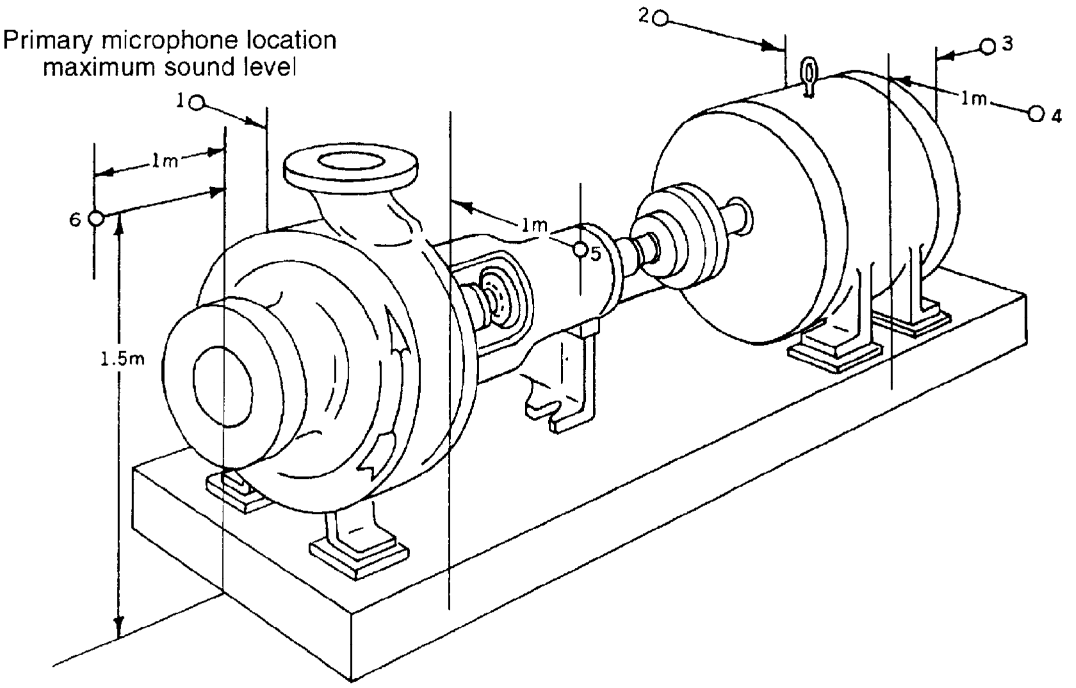


Figure 9.3 — Horizontal end suction centrifugal pump

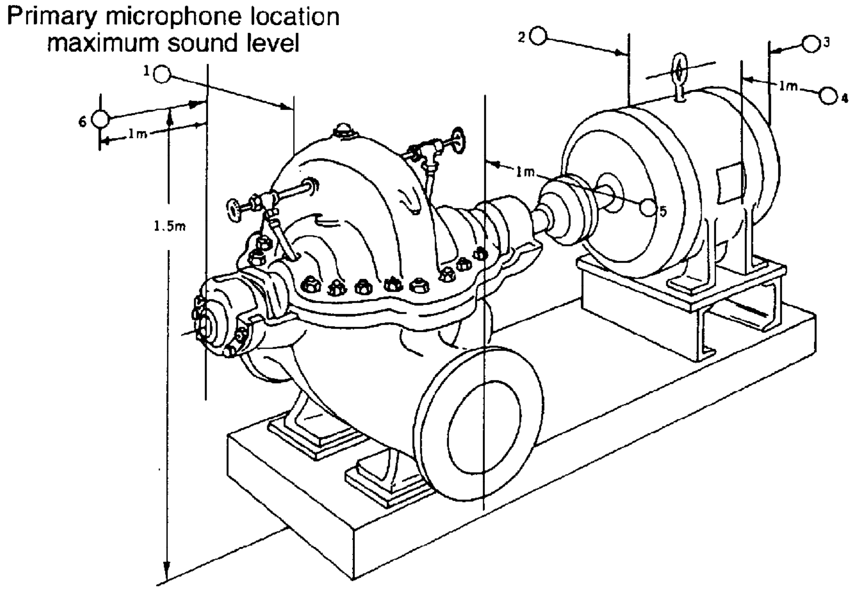


Figure 9.4 — Horizontally split centrifugal pump

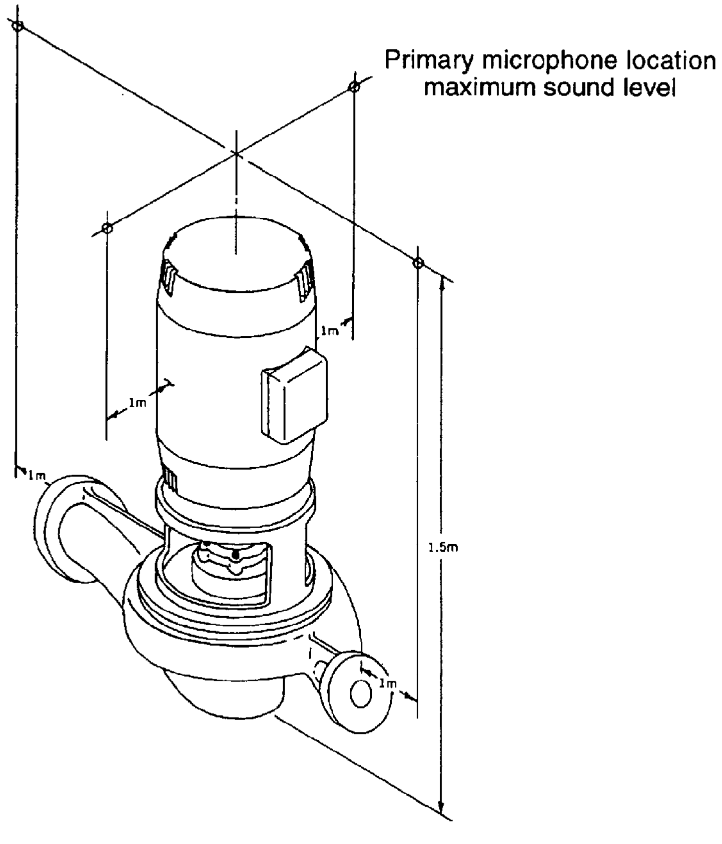


Figure 9.5 — Vertical in-line centrifugal pump

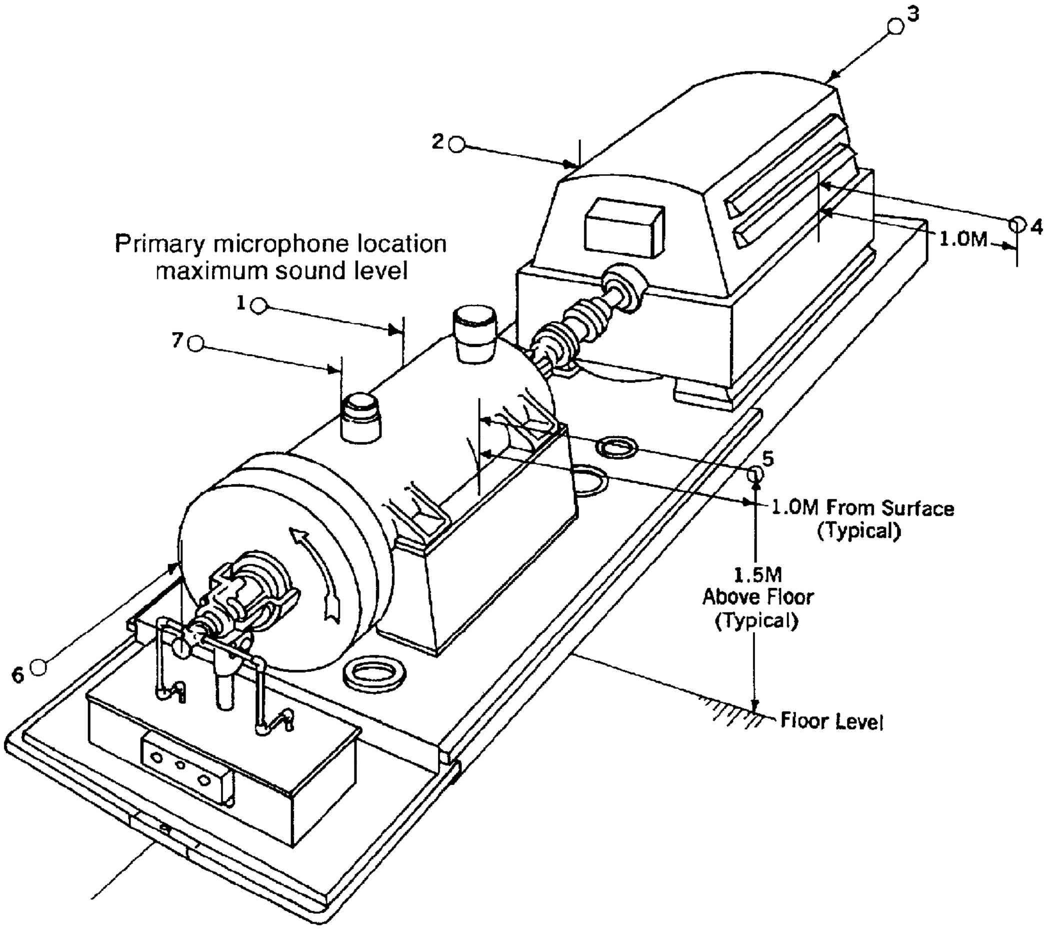


Figure 9.6 — Double case centrifugal pump

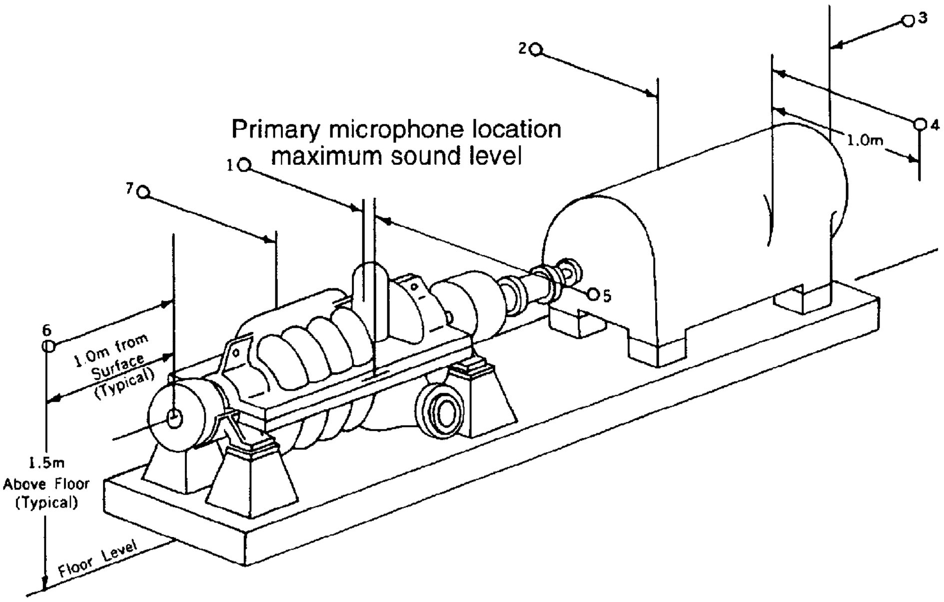


Figure 9.7 — Horizontally split multistage centrifugal pump

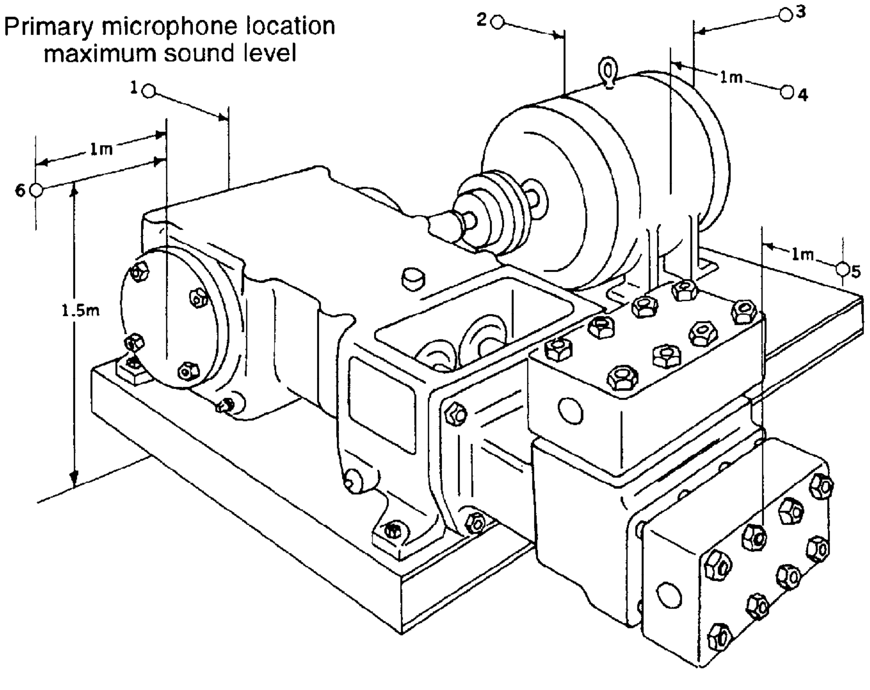


Figure 9.8 — Horizontal reciprocating pump

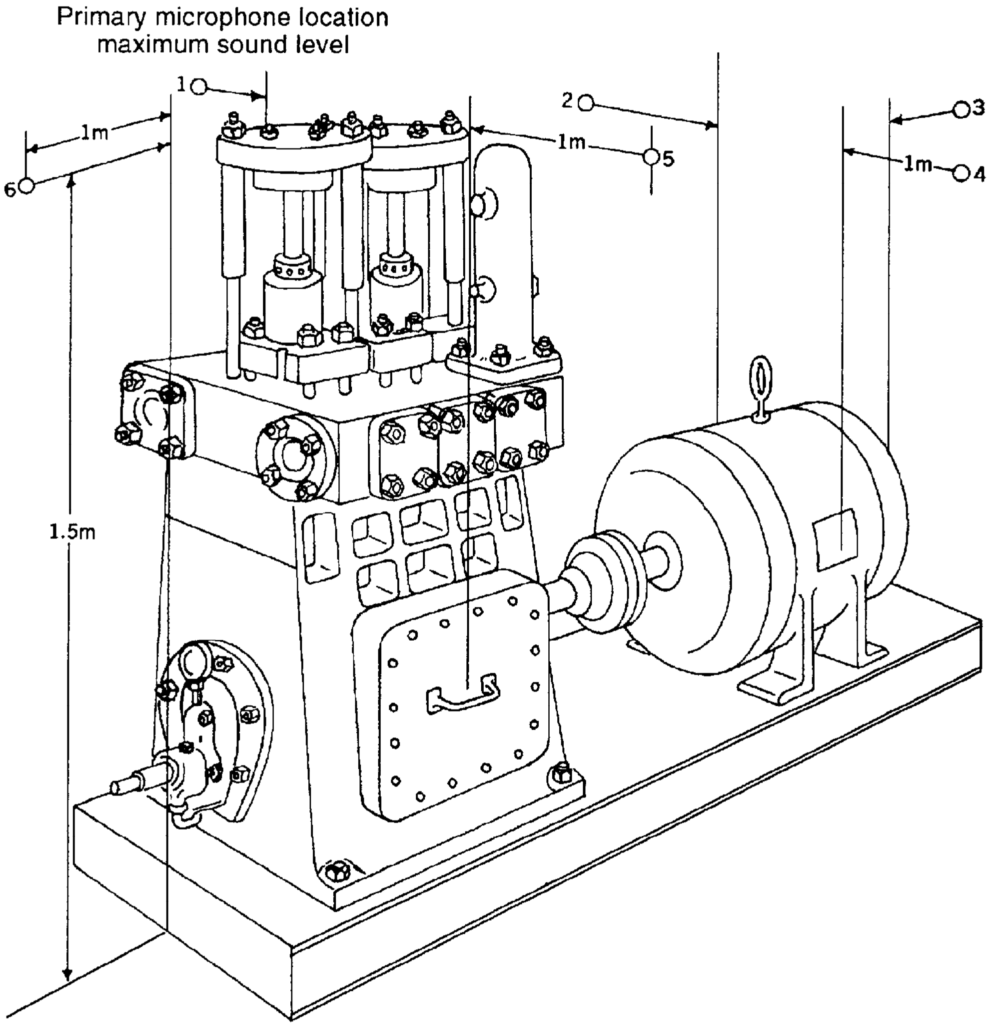


Figure 9.9 — Vertical reciprocating pump

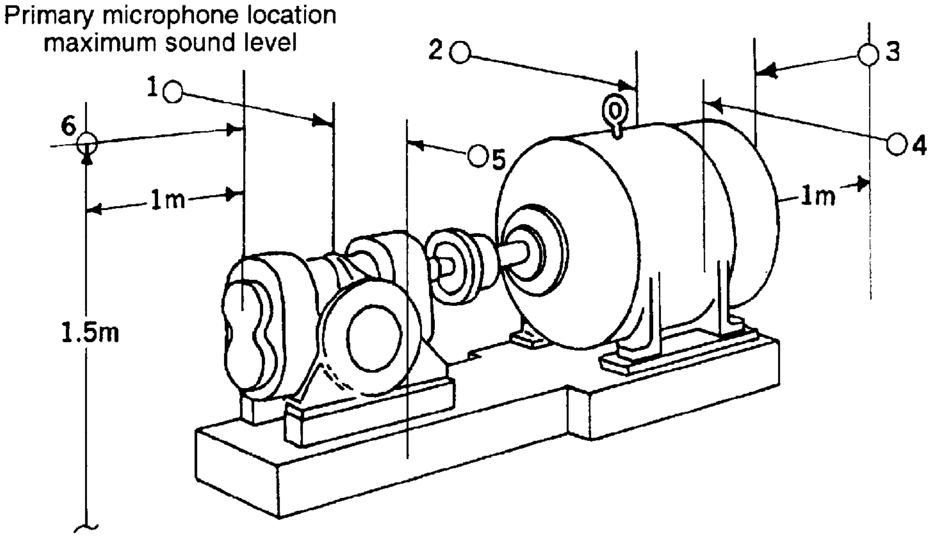


Figure 9.10 — Horizontal rotary gear pump

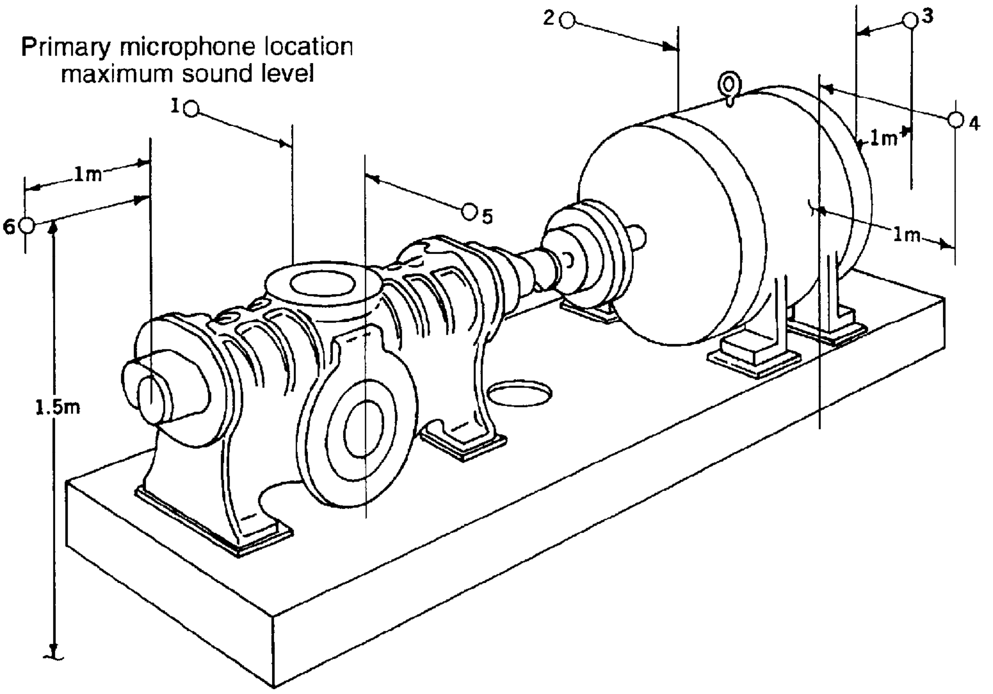


Figure 9.11 — Horizontal rotary screw pump

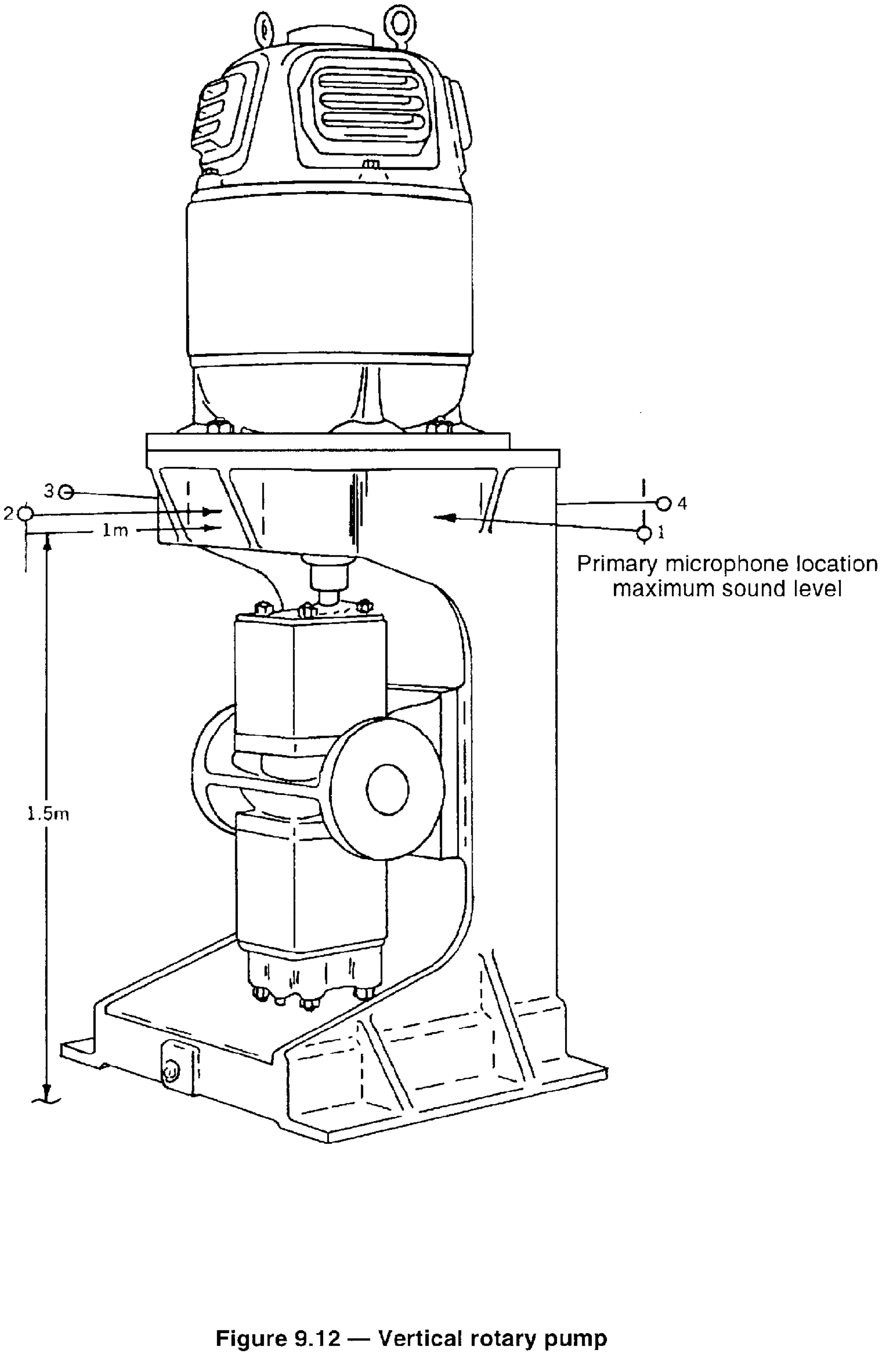


Figure 9.12 — Vertical rotary pump

9.5 Reference and source material

9.5.1 ASTM – American Society for Testing and Materials

"A" Series of Specifications – *Annual Book of ASTM Standards, Section 1 through 3*

D-1418, *The Recommended Practice for Nomenclature for Rubber and Rubber Lattices*

D-2000, *A Classification System for Electromeric Materials for Automotive Applications*

E-380, *Standard Practice for Use of the International System of Units*

F-104, *Classification System for Non-Metallic Gasket Materials*

ASTM
1916 Race Street
Philadelphia, PA 19103-1187

9.5.2 Hydraulic Institute

Hydraulic Institute
9 Sylvan Way
Parsippany, NJ 07054-3802

9.5.3 ANSI/IEC

IEC-179, *Specifications for Sound level Meters*

American National Standards Institute
11 West 42nd Street
New York, NY 10036

9.5.4 ANSI/ISO, International Organization for Standards

ISO-1000, *SI Units and Recommendations for the Use of Their Multiples and Certain Other Units*

American National Standards Institute
11 West 42nd Street
New York, NY 10036

9.5.5 IEEE, Institute of Electrical and Electronic Engineers

IEEE-260, *Letter Symbols for SI Units of Measurement*

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

9.5.6 SAE, Society of Automotive Engineers

SAE-J314A, *Felt, Wool and Part Wool*

Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096