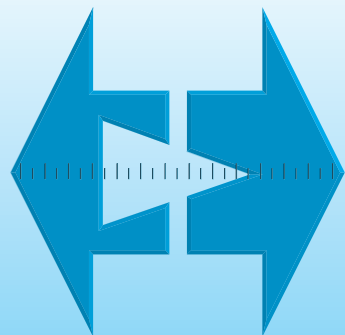
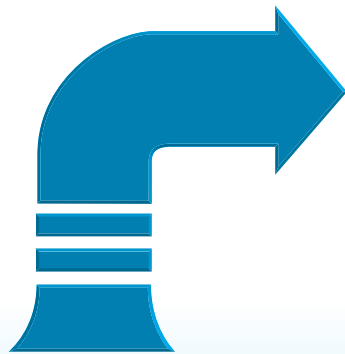
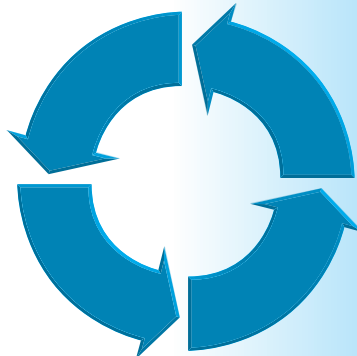




American National Standard for
Pumps – General Guidelines

*for Types, Definitions,
Application, Sound
Measurement and
Decontamination*

 **Hydraulic**
INSTITUTE

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American National Standard for

Pumps – General Guidelines

for Types, Definitions, Application,
Sound Measurement and
Decontamination

Secretariat
Hydraulic Institute
www.pumps.org

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



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Contents

Page

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

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

Tables

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

Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

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

- a) To develop and publish standards for pumps;
- b) To collect and disseminate information of value to its members and to the public;
- c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;
- d) To increase the amount and to improve the quality of pump service to the public;
- e) To support educational and research activities;
- f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of Standards

- 1) Hydraulic Institute Standards are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.
- 2) Use of Hydraulic Institute Standards is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the Standards.

Definition of a Standard of the Hydraulic Institute

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

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

Comments from users

Comments from users of this Standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this Standard may be directed to the Hydraulic Institute. It will direct all such questions to the appropriate technical committee for provision of a suitable answer.

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

Revisions

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

Units of Measurement

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

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

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

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

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

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

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

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9 Pumps – general guidelines

9.0 Scope

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

9.1 Types of pumps

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

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

9.1.1 Positive displacement pumps

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

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

9.1.2 Kinetic pumps

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

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

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

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

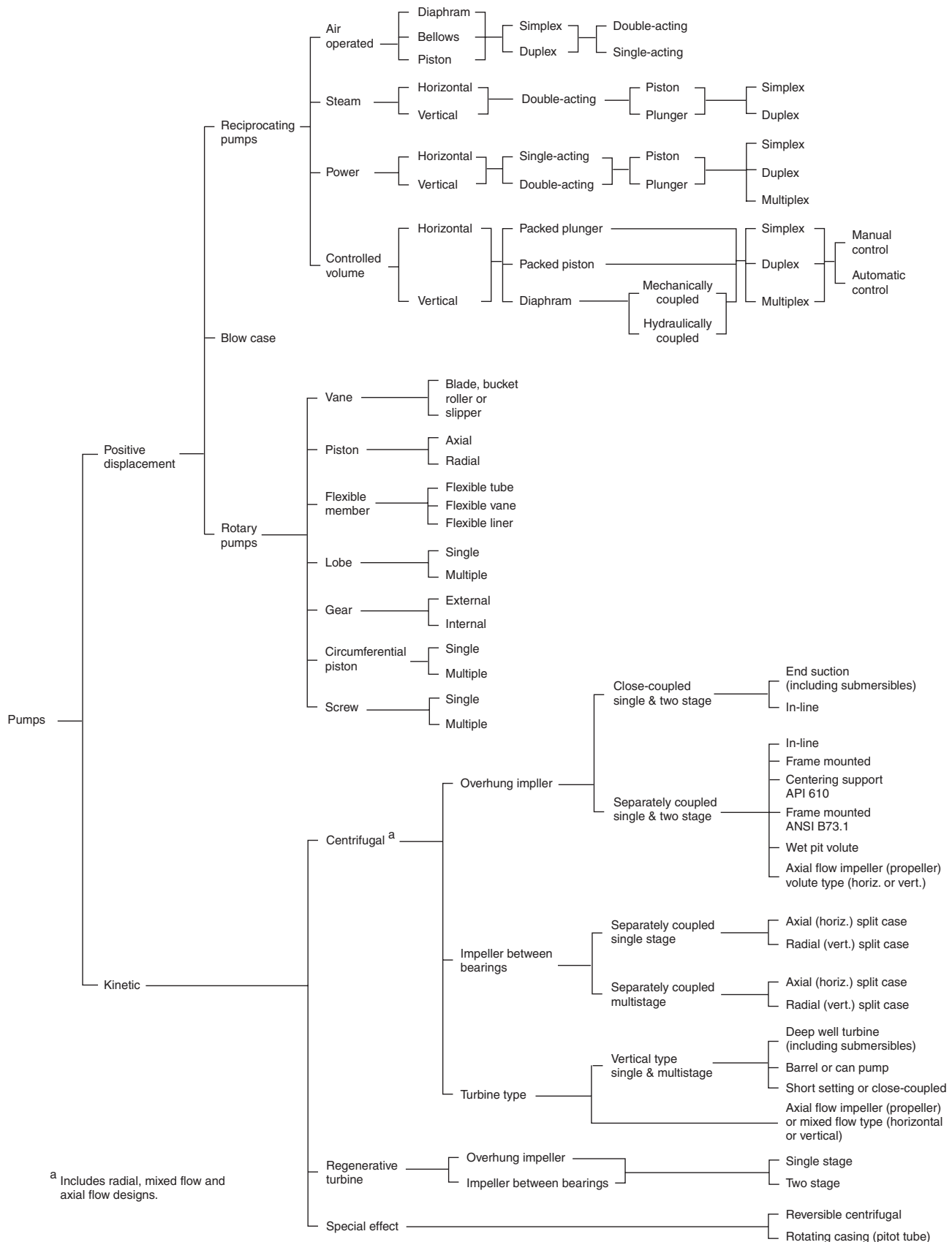


Figure 9.1 — Types of pumps

9.2 Definitions

9.2.1 Hardware terms

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- Suction stabilizer;
- Desurger;
- Alleviator.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

9.2.2 Slurry application terms

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Where:

V_L = Critical carrying velocity in larger pipe;

D_L = Diameter of larger pipe;

V_S = Critical carrying velocity in smaller pipe;

D_S = Diameter of smaller pipe.

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

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

9.3 Design and application

9.3.1 Preferred measurement units and conversion factors

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

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

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

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

9.3.1.1 Quantity

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

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

9.3.1.2 US Customary unit

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

9.3.1.3 Metric unit

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

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

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

Table 9.1 — Examples of rounded equivalents

	US unit	Conversion result	Rounded equivalent
Volume	8.6 gal	0.032 55	0.033 m 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/in ²	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 ^a	Typical applications	Metric unit	Abbreviation	US Customary unit	Abbreviation	Conversion factors – multiply by	
						Metric to US unit	US unit to Metric
1. Space and time							
plane angle	fluid flow angle	degree	°	degree	°	1	1
length	dimensions of sumps and pits	meter	m	foot and inch	ft or '	3.281	0.3048 ^b
		meter	m		in or "	39.37 ^b	0.0254 ^b
	mechanical engineering drawings	millimeter	mm	inch	in or "	.03937	25.4 ^b
	coating thickness, surface finish, filter particle size	micrometer	μ m	thousandths of inch	mil	.03937	25.4 ^b
		micrometer	μ m	microinch	μin	39.37	0.0254 ^b
		micrometer	μ m	micron	μm	1 ^b	1 ^b
area	surface area, flow area	square meter	m ²	square foot	ft ²	10.76	0.092 90
		square centimeter	cm ²	square inch	in ²	0.155	6.452
volume	fluid volume rate of flow	milliliter (cm ³) ^c	mL ^d	cubic inch	in ³	0.061 02	16.39
		cubic meter	m ³	cubic foot	ft ³	35.31	0.028 32
		cubic meter	m ³	gallon	gal	264.2	0.003785
		liter	L	quart	qt	1.057	0.9464
time	time interval	hour	h	hour	h	1 ^b	1 ^b
		minute	min	minute	min	1 ^b	1 ^b
		second	s	second	s	1 ^b	1 ^b
volume per unit time	flow rate of fluids	cubic meter per hour	m ³ /h	gallon per minute	gpm	4.403	0.2271
		liter per minute	L/min	gallon per minute	gpm	0.2642	3.785
velocity, linear	fluid velocity	meter per second	m/s	foot per second	fps	3.281	0.3048 ^b
acceleration	gravity	meter per second – squared	m/s ²	foot per second – squared	ft/s ²	3.281	0.3048 ^b
2. Periodic and related phenomena							
frequency	system vibration, sound, alternating current	hertz	Hz	hertz	Hz	1 ^b	1 ^b
speed of rotation	speed of rotation	revolution per minute	rpm	revolution per minute	rpm	1 ^b	1 ^b

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

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

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

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

^a As used in ISO–31 and ISO–1000, “quantity” means “measurable property”.

^b Exact

^c Symbols in brackets [] are explanatory only.

^d 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.

^e 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).

^f Conversion from Saybolt Universal Seconds to centistrokes can be done from a table.

^g By using J instead of N•m, the distinction from N•m for moment of force is made apparent.

^h Conversion requires a formula, wherein the Fahrenheit temperature is indicated by °F and the Celsius temperature by °C.

ⁱ All factors in this table are based on Btu-International Table.

^j The SI unit for electric energy is watt•second (W•s), which is equal to joule (J). (1 kW•h = 3.6 MJ).

9.3.2 Materials

9.3.2.1 Introduction

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

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

9.3.2.2 Data on liquids

9.3.2.2.1 General characteristics

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

9.3.2.2.2 Effects of temperature and concentration

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

9.3.2.2.3 Handling high- or low-temperature liquids

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

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

9.3.2.2.4 Specific gravity

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

9.3.2.2.5 Chemical symbols

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

9.3.2.3 Factors affecting material selection

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

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

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

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

9.3.2.3.1 Optimize life cost

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

9.3.2.3.2 General design of pumps

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

9.3.2.3.3 Properties - chemical and physical

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

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

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

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

9.3.2.3.4 Temperature of liquid pumped

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

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

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

predict all the variables significant to the problems of embrittlement.

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

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

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

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

9.3.2.3.5 Galvanic corrosion

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

9.3.2.3.5.1 Galvanic series

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

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

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

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

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

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

Protected end (cathodic, or most noble)

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

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

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

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

9.3.2.3.5.2 To minimize galvanic corrosion

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

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

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

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

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

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

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

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