

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/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 ²⁾	Typical applications	US Customary unit	Abbreviation	Metric unit	Abbre- viation	Conversion factors – multiply by	
						US unit to Metric	Metric to US unit
1. Space and time							
plane angle length area volume time volume per unit time velocity, linear acceleration	fluid flow angle	degree	°	degree	o	1	1
	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
				micrometer	µ m	25.4 ¹⁾	.03937
				micrometer	µ m	0.0254 ¹⁾	39.37
	coating thickness, surface finish, filter particle size	microinch	µ in	micrometer	m m	1 ¹⁾	1 ¹⁾
				micrometer	m m	1 ¹⁾	1 ¹⁾
				micrometer	m m	1 ¹⁾	1 ¹⁾
	surface area, flow area	square foot	ft²	square meter	m²	0.092 90	10.76
square meter				m²	645.2	0.001 550	
square millimeter				mm²	16.39	0.061 02	
fluid volume capacity	cubic inch	in³	milliliter (cm³) ³⁾	mL ⁴⁾	0.028 32	35.31	
			cubic meter	m³	0.003785	264.2	
			cubic meter	m³	0.003785	264.2	
			liter	L	0.9464	1.057	
			hour	h	1 ¹⁾	1 ¹⁾	
			minute	min	1 ¹⁾	1 ¹⁾	
time interval	second	s	second	s	1 ¹⁾	1 ¹⁾	
			second	s	1 ¹⁾	1 ¹⁾	
			second	s	1 ¹⁾	1 ¹⁾	
flow rate of fluids	gallon per minute	gpm	cubic meter per hour	m³/h	0.2271	4.403	
			liter per minute	L/min	3.785	0.2642	
			meter per minute	m/min	0.3048 ¹⁾	3.281	
fluid velocity	foot per minute	fpm	meter per minute	m/min	0.3048 ¹⁾	3.281	
			meter per second	m/s	0.3048 ¹⁾	3.281	
			meter per second – squared	m/s²	0.3048 ¹⁾	3.281	
gravity	foot per second – squared	ft/s²	meter per second – squared	m/s²	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
unbalance	impeller, rotor	ounce	oz	gram	g	28.35	0.035 27
density (mass density)	density of solids and fluids	ounce-inch	oz-in	gram-millimeter	g-mm	720.1	0.001 389
specific weight (force)	solids and fluids	pound per cubic foot	lb/ft ³	kilogram per cubic meter	kg/m ³	16.02	0.062 43
moment of inertia (dynamic)		pound force per cubic foot	lbf/ft ³	kiloNewton per cubic meter	kN/m ³	0.1571	6.366
force	rotor inertia	pound foot-squared	lb•ft ²	kilogram meter-squared	kg-m ²	0.042 14	23.73
fluid energy	applied load	pound-force foot	lbf	Newton	N	4.448	0.2248
moment of force, torque and bending moment	head of fluid	foot	ft	meter	m	0.3048 ¹⁾	3.281
	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 O	kilopascal	kPa	0.2488	4.019
stress	sound pressure level	decibel	dB	micropascal [20 µPa]	µPa	100 000	0.000 01
	unit force	pound-force per square inch	psi	megapascal	MPa ⁵⁾	0.006 895	145.0
specific speed	centrifugal pump impeller	$\frac{\text{rpm}(\text{gpm})^{.5}}{\text{ft}^{.75}}$	dimensionless	$\frac{\text{rpm}(\text{m}^3/\text{hr})^{.5}}{\text{m}^{.75}}$	dimensionless	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⁾	(°C x 1.8) + 32 ¹⁾
	absolute temperature	degree Rankin	°R	degree Kelvin	°K	5⁄9 ¹⁾	1.81)
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 centistokes 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).

¹⁾ Exact²⁾ 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 centistokes 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 Celsius 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 re-

quires 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 ar-

range 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. In-

conel 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 food-stuffs). The use of such alloys may become increasingly important where the pump is operated intermittently and is not washed out after each run.

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

9.3.2.3.9 Mechanical situation in pumping

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

9.3.2.3.9.1 Crevice corrosion

Stainless steels and some other alloys rely on an oxide coating to generate a corrosive-resistant film. Pump designs which have tight crevices, or fits, do not permit the continued replenishment of this oxide film and may, therefore, corrode in these areas even though the material is basically compatible with the liquid being pumped. Certain liquids, such as sea water and halide salt solutions, are more likely to promote crevice corrosion.