SECTION 9.6

CHEMICAL INDUSTRY

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SOLUTION CHARACTERISTICS

Chemical industries can be broadly defined as those that make, use, or dispose of chemicals. The pumps used in these industries are different from those used in other industries primarily in the materials from which they are made. Although cast iron, ductile iron, carbon steel, and aluminum- or copper-base alloys will handle a few chemical solutions, most chemical pumps are made of stainless steel, Hastelloy, the nickel-base alloys, or the more exotic metals, such as titanium and zirconium. Pumps are also available in carbon, glass, porcelain, rubber, lead, and whole families of engineering polymers, including the thermoplastics, thermosets, epoxies, and fluorocarbons. Each of these materials has been incorporated into pump design for just one reason—to eliminate or reduce the destructive effect of the chemical liquid on the pump parts.

Because the type of corrosive liquid to be pumped determines which of these materials is most suitable, a careful analysis of the chemical solution to be handled is the first step in selecting the proper materials for pump construction.

Major and Minor Constituents Foremost in importance in a study of the characteristics of any solution are the constituents of the solution. This means not only the major constituents but the minor ones as well, for in many instances the minor constituents will be the more important. They can drastically alter corrosion rates, and therefore a full and detailed analysis is most critical.

Concentration Closely allied to what the constituents are is the concentration of each. Merely stating "concentrated," "dilute," or "trace quantities" is basically meaningless because of the broad scope of interpretation of these terms. For instance, some interpret *concentrated* as meaning any constituent having a concentration of greater than 50% by weight, whereas others interpret any concentration above 5% in a like manner. Hence it is always desirable to cite the percentage by weight of each and every constituent in a given solution. This eliminates multiple interpretations and permits a more accurate evaluation. It is also recommended that the percentage by weight of any trace quantities be cited, even if this involves only parts per million. For example, high-silicon iron might be completely suitable in a given environment in the absence of fluorides. If, however, the same environment contained even a few parts per million of fluorides, the high-silicon iron would suffer a catastrophic corrosion failure.

Temperature Generalized terms such as *hot, cold,* or even *ambient* are ambiguous. The preferred terminology would be the maximum, minimum, and normal operating temperature. In general, the rate of a chemical reaction increases approximately two to three times with each 18°F (10°C) increase in temperature. Because corrosion can be considered a chemical reaction, the importance of temperature or temperature range is obvious.

A weather-exposed pump installation is a good illustration of the ambiguity of the term *ambient.* There could be as much as a 150°F (83°C) difference between an extremely cold climate and an extremely warm climate. If temperature cannot be cited accurately, the ambient temperature should be qualified by stating the geographic location of the pump. This is particularly important for materials that are subject to thermal shock in addition to increased corrosion rate at higher temperatures.

Acidity and Alkalinity More often than not, little consideration is given to the pH of process solutions. This may be a critical and well-controlled factor during production processing, and it can be equally revealing in evaluating solution characteristics for material selection. One reason the pH may be overlooked is that it generally is obvious whether the corrosive substance is acidic or alkaline. However, this is not always true, particularly with process solutions in which the pH is adjusted so the solutions will always be either alkaline or acidic. When this situation exists, the precise details should be known so a more thorough evaluation can be made. It is also quite important to know when a solution alternates between acidic and alkaline conditions because this can have a pronounced effect on materials selection. Some materials, although entirely suitable for handling a given alkaline or acidic solution, may not be suitable for handling a solution whose pH is changing.

Solids in Suspension Erosion-corrosion, velocity, and solids in suspension are closely allied in chemical industry pump services. Pump design is a very critical factor when the solution to be pumped contains solids. It is not uncommon for a given alloy to range from satisfactory to completely unsatisfactory in a given chemical application when hydraulic design is the only variable. Failure to cite the presence of solids on a solution data sheet is not an uncommon occurrence. The concentration of solids should be referred to as percent by volume or weight. This undoubtedly is the reason for many catastrophic erosion-corrosion failures.

Aerated or Nonaerated The presence of air in a solution can be quite significant. In some instances, it is the difference between success and failure in that it can conceivably render a reducing solution oxidizing and require an altogether different material for pump construction. A good example of this would be a self-priming nickel-molybdenum-alloy pump for handling commercially pure hydrochloric acid. This alloy is excellent for the commercially pure form of this acid, but any condition that can induce even slightly oxidizing tendencies renders this same alloy completely unsuitable. The very fact that the pump is a self-primer means that aeration is a factor to contend with, and extreme caution must be exercised in using an alloy that is not suitable for an oxidizing environment. The presence of air will not only affect the head-flow rate performance, but also the *NPSHR*. The maximum amount of air a conventional centrifugal pump can handle is approximately five percent by volume.

Transferring or Recirculating This item is important because of the possible buildup of corrosion product or contaminants, which can influence the service life of the pump.

Such a buildup of contaminants can have a beneficial or deleterious effect, and for this reason it should be an integral part of evaluating solution characteristics.

Inhibitors or Accelerators Both inhibitors and accelerators can be intentionally or unintentionally added to the solution. Inhibitors reduce corrosivity, whereas accelerators increase corrosivity. Obviously, no one would add an accelerator to increase the corrosion rate on a piece of equipment, but a minor constituent added as a necessary part of a process may serve as an accelerator; thus the importance of knowing the presence of such constituents.

Purity of Product Where purity of product is of absolute importance, particular note should be made of any element that may cause contamination problems, whether it be discoloration of product or solution breakdown. In some environments, pickup of only a few parts per billion of certain elements can create severe problems. This effect is particularly important in pump applications where velocity effects and the presence of solids can alter the end result, as contrasted with other types of process equipment where the velocity or solids may have little or no effect.

When a material is basically suitable for a given environment, purity of product should not be a problem. However, this cannot be an ironclad rule, particularly with chemical pumps.

Continuous or Intermittent Duty Depending upon the solution, continuous or intermittent contact can have a bearing on service life. Intermittent duty in some environments can be more destructive than continuous duty if the pump remains half full of corrosive during periods of downtime and accelerated corrosion occurs at the air-liquid interface. Perhaps of equal importance is whether the pump is flushed or drained when not in service.

CORROSIVES AND MATERIALS

Metallic or Nonmetallic Materials for chemical industry pump applications can, in general, be divided into two very broad categories: metallic and nonmetallic. The metallic category can be further divided into ferrous and nonferrous alloys, both of which have extensive application in the chemical industry. The nonmetallic category can be further divided into natural and synthetic rubbers, polymers, ceramics and glass, carbon and graphite, and wood. Of these nonmetallic materials, wood, of course, has little or no application for pump services. The other materials have definite application in the handling of heavy corrosives. In particular, polymers in recent years have gained widespread acclaim for their ability to handle chemicals. For a given application, a thorough evaluation of not only the solution characteristics but also the materials available should be made to ensure the most economical selection.

Source of Data To evaluate material for chemical pump services, various sources of data are available. The best source is previous practical experience within one's own organization. It is not unusual, particularly in large organizations, to have a materials group or corrosion group whose basic responsibility is to collect and compile corrosion data pertaining to process equipment in service. These sources should be consulted whenever a materials evaluation program is being conducted. A second source of data is laboratory and pilot-plant experience. Though the information from this source cannot be as valuable and detailed as plant experience, it certainly can be very indicative and serve as an important guide. The experience of suppliers can be a third source of information. Though suppliers cannot hope to provide data on the specific details of a given process and the constituents involved, they normally can provide assistance and materials for test to facilitate a decision. Technical journals and periodicals are a fourth source of information. A wealth of information is contained in these publications, but if an excellent information retrieval system is not available, it can be very difficult to locate the information desired.

Reams of information have been published in books, tables, charts, periodicals, bulletins, and reports pertaining to materials selection for various environments. It is not the intent of this section of the handbook to make materials recommendations. However, it is deemed advisable to provide some general comments and to point out a few applications having unusual characteristics. The Hydraulic Institute Standards present a very comprehensive guide for polymer material selection.

Sulfuric Acid This is the most widely used chemical in industrial applications today, and much time is spent in evaluating and selecting materials for applications involving sulfuric acid with and without constituents. The following are some of the applications that merit special consideration.

DILUTION OF COMMERCIALLY PURE SULFURIC ACID When sulfuric acid is diluted with water, there is considerable evolution of heat. At times, the mixing of the acid and water takes place not in the mixing tank but in the pump transferring the acid. This means that heat is evolved as the solution is passing through the pump. Temperatures of 200°F (93°C) or higher are reached, depending upon the degree of dilution and the amount of mixing taking place in the pump. Thus, the heat evolved in the dilution would restrict material selection. Very few metallics or nonmetallics are resistant to 70% sulfuric acid at temperatures approaching 200°F (93°C). Refer to Section 5.2 for material guidelines for sulfuric acid.

SULFURIC ACID SATURATED WITH CHLORINE It is a well-known fact that any solution involving wet chlorine is extremely corrosive. In a solution containing sulfuric acid and chlorine, the specific weight percentage of sulfuric acid determines whether the solution will accelerate corrosion. Because of the hygroscopic nature of concentrated sulfuric acid, it will absorb moisture from the chlorine. Thus, when a sulfuric acid-chlorine solution contains at least 80% sulfuric acid, there need be little concern for the chlorine because dry chlorine is essentially noncorrosive. In such a case, a material selection can be made as if sulfuric acid were the only constituent. If the solution is saturated with chlorine but contains less than approximately 80% sulfuric acid; however, the material selection must be based not only on the sulfuric acid but also on the wet chlorine. This, of course, is a very corrosive solution, and extreme caution must be exercised in selecting the material to be used.

SULFURIC ACID CONTAINING SODIUM CHLORIDE It is quite apparent that the addition of sodium chloride to sulfuric acid will result in the formation of hydrochloric acid and thus necessitate a material that will resist the corrosive action of hydrochloric acid also. Though this may seem obvious, it is amazing how often it is ignored. This is particularly true in 10 to 15% sulfuric acid pickling solutions to which sodium chloride has been added to increase the rate of pickling, with little or no consideration being given to the destructive effect of the salt on the process equipment handling the pickling solution.

PIGMENT MANUFACTURE A slurry of titanium dioxide in sulfuric acid is one of the processing stations in the manufacture of pigment. A variety of metallics and nonmetallics would be suitable for this application in the absence of the titanium dioxide solids, but the presence of the solids circulating in a pump renders practically all of the normal sulfuric acid-resistant pump materials unsuitable. Special consideration must be given to materials that will resist the severe erosion-corrosion encountered in this type of service.

SULFURIC ACID CONTAINING NITRIC ACID, FERRIC SULFATE, OR CUPRIC SULFATE The presence of these compounds in sulfuric acid solutions will drastically alter the suitability of materials that can be used. Their presence in quantities of 1% or less can make a sulfuric acid solution oxidizing, whereas it would normally be reducing. Their presence, singly or in combination, could serve as a corrosion inhibitor, thus in certain instances allowing a stainless steel, such as type 316, to be used. On the other hand, the same compounds could serve as a corrosion accelerator for a non-chromium bearing alloy, such as nickel-molybdenum alloys, and thus render it completely unsuitable.

Nitric Acid In the concentrations normally encountered in chemical applications, nitric acid presents fewer problems than sulfuric acid. The choice of metallic materials for various nitric applications is somewhat broader than the choice of nonmetallic materials. Nitric acid, being a strongly oxidizing acid, permits the use of stainless steel quite extensively, but its oxidizing characteristics restrict the application of nonmetallics in general and plastics in particular. Requiring special evaluation are such aggressive solutions as fuming nitric acid; nitric-hydrofluoric; nitrichydrochloric (some of which fall into the aqua regia category); nitric-adipic combinations; and practically any environment consisting of nitric acid in combination with other constituents. Invariably, additional constituents in nitric acid result in more aggressive corrosion; hence material selection becomes quite critical.

Hydrochloric Acid Both commercially pure and contaminated hydrochloric acid present difficult situations in selecting pump materials. The most common contaminant that creates problems is ferric chloride, the presence of which can render this otherwise reducing solution oxidizing and thus completely change the material of construction that can be used. Addition of a very few parts per million of iron to commercially pure hydrochloric acid can result in the formation of enough ferric chloride to cause materials such as nickel-molybdenum, nickel-copper, and zirconium to be completely unsuitable. Conversely, the presence of ferric chloride can make titanium completely suitable. Nonmetallics find extensive application in many hydrochloric acid environments. Often the limiting factors for the nonmetallics are temperature, mechanical properties, and suitability for producing pump parts in the design desired. With the nonmetallics, the near-complete immunity from corrosion in such environments subordinates corrosion resistance to other factors. Refer to Section 5.2 for material guidelines for hydrochloric acid.

Phosphoric Acid The increasing use and demand for all types of fertilizers have made phosphoric acid a very important commodity. In the wet process of producing phosphoric acid, the phosphate rock normally contains fluorides. In addition, at various stages of the operation the solution will also contain sulfuric, hydrofluoric, fluosilicic, and phosphoric acids as well as solids. In some instances, the water used in these solutions may have an exceptionally high chloride content, which can result in the formation of hydrochloric acid, which further aggravates the corrosion problem. It is also common for certain of these solutions to contain solids, which of course create an erosion-corrosion problem. Pure phosphoric and superphosphoric acids are relatively easy to cope with from a material standpoint, but when the solution contains all or some of the aforementioned constituents, a very careful materials evaluation must be conducted. Such environments are severely corrosive in the absence of solids and cause severe erosion-corrosion and a drastically reduced service life when solids are present. This is particularly significant with any type of chemical pump.

Chlorine Little need be said about the corrosivity of chlorine. Wet chlorine, in addition to being extremely hazardous, is among the most corrosive environments known. Dry chlorine is not corrosive, but there are those who contend that dry chlorine does not exist. Chlorine vapor combined with the moisture in the atmosphere, for instance, can create severe corrosion problems. In any case, selecting the most suitable material for any type of chlorine environment requires very careful evaluation.

Alkaline Solutions With some exceptions, alkaline solutions, such as sodium hydroxide or potassium hydroxide, do not present serious corrosion problems at temperatures below 200°F (93°C). However, in certain applications, purity of product is of utmost concern, necessitating selection of a material that will have essentially no corrosion rate. Among the exceptions to the rule that alkaline solutions are relatively noncorrosive are bleaches, alkaline brines, and other solutions containing chlorine in some form.

Organic Acids Organic acids are much less corrosive than inorganic acids. This does not mean, however, that they can be taken lightly. For instance, acetic, lactic, formic, and maleic acids all have their corrosive characteristics and must be treated accordingly when evaluating metallics and nonmetallics.

Salt Solutions Normally considered neutral, salt solutions do not present a serious corrosion problem. In some instances, process streams adjust pH to maintain a slightly alkaline environment, and such solutions are even less corrosive than when they are neutral. On the other hand, when a process stream has a pH adjustment to maintain a slightly acidic environment, the liquid becomes considerably more corrosive than neutral salt solutions. This condition requires that more effort be expended in evaluating the solution before making a material selection.

Organic Compounds Most organic compounds do not present corrosion problems of the same magnitude as inorganic compounds. This does not mean that any material arbitrarily selected will be a suitable choice. It does mean that there will be more materials available to choose from, but each application should be considered on its own merits. Of particular concern in this area are chlorinated organic compounds and those that will produce hydrochloric acid when moisture is present. Plastics, categorically, possess excellent corrosion resistance to inorganic compounds within their temperature limitations, but they do exhibit some weaknesses in their corrosion resistance to organic compounds.

Water Water is less corrosive than most of the other mediums encountered in the chemical and allied industries. For the term *water* to be meaningful, however, it is extremely important to know the specific kind of water: demineralized, fresh, brackish, salt, boiler feed, mine. These waters and the various constituents in them can demand a variety of materials, indicated, for example, by the spectrum of materials being studied and used in desalination programs. Because they are likely to have a very pronounced effect on our total economy, precise materials evaluation and selection are integral parts of these programs.

TYPES OF PUMP CORROSION

The types of corrosion encountered in chemical pumps may at first appear to be unusual compared with those found in other process equipment. Nevertheless pumps, like any other type of chemical process equipment, experience basically only eight forms of corrosion, of which some are more predominant in pumps than in other types of equipment. It is not the intent here to describe in detail these eight forms of corrosion, but it is desirable to enumerate them and provide a brief description of each so they can be recognized when they occur.

General, or Uniform, Corrosion This is the most common type, and it is characterized by essentially the same rate of deterioration over the entire wetted or exposed surface. General corrosion may be very slow or very rapid, but it is of less concern than the other forms of corrosion because of its predictability. However, predicting the general corrosion rate in a pump can be a difficult task because of the varying velocities of the solution in the pump.

Concentration Cell, or Crevice, Corrosion This is a localized form of corrosion resulting from small quantities of stagnant solution in areas such as threads, gasket surfaces, holes, crevices, surface deposits, and the underside of bolt and rivet heads. When concentration cell corrosion occurs, the concentration of metal ions or oxygen in the stagnant area is different from the concentration in the main body of the liquid. This causes electric current to flow between the two areas, resulting in severe localized attack in the stagnant area.

Pitting Corrosion This is the most insidious form of corrosion, and it is very difficult to predict. It is extremely localized and manifested by small holes, and the weight loss due to the pits will be only a small percentage of the total weight of the equipment. Chlorides in particular are notorious for inducing pitting. Pitting is common in areas other than stagnant areas, whereas concentration cell corrosion is basically confined to areas of stagnation.

Stress Corrosion Cracking This is localized failure caused by a combination of tensile stresses in a medium. Fortunately, castings, because of their basic overdesign, seldom experience stress corrosion cracking. Corrosion fatigue, which can be classified as stress corrosion cracking, is of concern in chemical pump shafts because of the repeated cyclic stressing. Failures of this type occur at stress levels below the yield point as a result of the cyclic application of the stress.

Intergranular Corrosion This is a selective form of corrosion at and adjacent to grain boundaries. It is associated primarily with stainless steels but can also occur with other alloy systems. In stainless steels, it occurs when the material is subjected to heat in the 800 to 1600°F (427 to 871°C) temperature range. Unless other alloy adjustments are made, this form of corrosion can be prevented only by heat-treating. It is easily detectable in castings because the grains are quite large relative to those in wrought material of equivalent composition. In some instances, uniform corrosion is misinterpreted as intergranular corrosion because of the etched appearance of the surfaces exposed to the environment. Even in ideally heat-treated stainless steels, very slight accelerated attack can be noticed at the grain boundaries because these areas are more reactive than the grains themselves. Care should be taken to avoid confusing general and intergranular corrosion. Stainless steel castings will never encounter intergranular corrosion if they are properly heat-treated after being exposed to temperatures in the 800 to 1600°F range (427 to 871°C).

Galvanic Corrosion This occurs when dissimilar metals are in contact or are otherwise electrically connected in a corrosive medium. Corrosion of the less noble metal is accelerated, and corrosion of the more corrosion-resistant metal is decreased. The farther apart the metals or alloys are in the electromotive series, the greater the possibility of galvanic corrosion. When it is necessary to have two dissimilar metals in contact, the total surface area of the less resistant metal should far exceed that of the more resistant material. This tends to prevent premature failure by simply providing a substantially greater area of the more corrosion-prone material. This form of corrosion is not common in chemical pumps but may be of some concern with accessory items in contact with pump parts and exposed to the environment.

Erosion-Corrosion This type of failure is characterized by accelerated attack resulting from the combination of corrosion and mechanical wear. It may involve solids in suspension or high velocity. It is quite common with pumps where the erosive effects prevent the formation of a passive surface on alloys that require passivity to be corrosion-resistant. The ideal material for avoiding erosion-corrosion in pumps would possess the characteristics of corrosion resistance, strength, ductility, and extreme hardness. Few materials possess such a combination of properties.

Selective Leaching Corrosion This, in essence, involves removal of one element from a solid alloy in a corrosive medium. Specifically, it is typified by dezincification, dealuminumification, and graphitization. This form of attack is not common in chemical pump applications because the alloys in which it occurs are not commonly used in heavy chemical applications.

TYPES OF CHEMICAL PUMPS

The second step in selecting a chemical pump is to determine which type of pump is required, based on the characteristics of the liquid and on the desired head and flow rate.

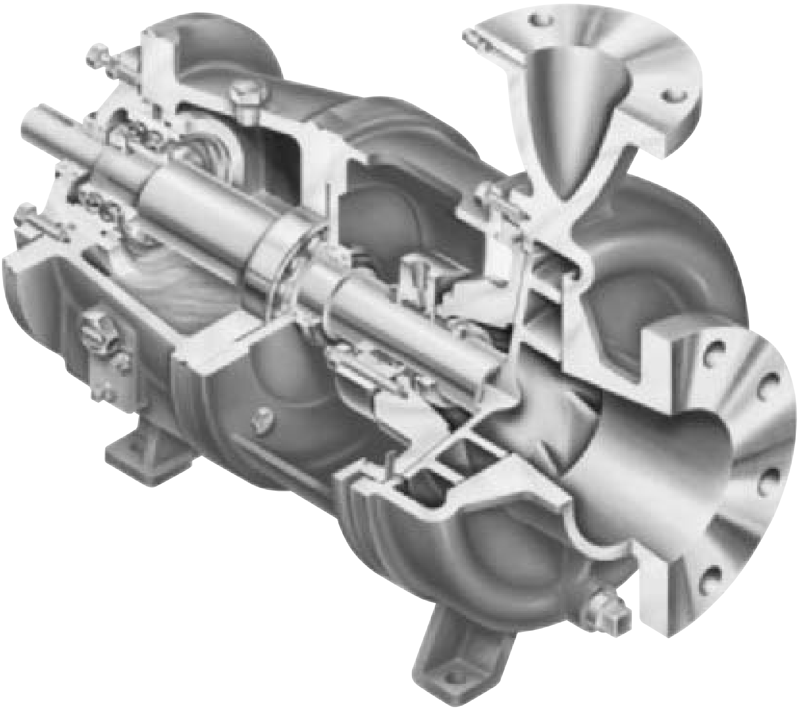

FIGURE 1 Cutaway of a typical centrifugal chemical pump (Flowserve Corporation)

It should also be noted that not all types are available in every material of construction, and the final selection of pump type may depend on the availability of designs in the proper material.

Centrifugal Pumps Centrifugal pumps (Figure 1) are used extensively in the chemical industry because of their suitability in practically any service. They are available in an almost unending array of corrosion-resistant materials. Although not built in extremely large sizes, pumps with capacity ranges of 5000 to 6000 gpm (1100 to 1400 m^3/h) are commonplace. Heads range as high as 500 to 600 ft (150 to 180 m) at standard electric motor speeds. Centrifugal pumps are normally mounted in the horizontal position, but they may also be installed vertically, suspended in a tank, or hung in a pipeline similar to a valve. They are simple, economical, dependable, and efficient. Disadvantages include reduced performance when handling liquids of more than 500 SSU (108 cSt) viscosity and the tendency to lose prime when comparatively small amounts of air or vapor (3 to 5 percent) are present in the liquid.

Rotary Pumps The gear, screw, deforming-vane, sliding-vane, axial-piston, and cam types are used for high-pressure service. They are particularly adept at pumping liquids of high viscosity or low vapor pressure. Their constant displacement at a set speed makes them ideal for use in metering small quantities of liquid. Because they operate on the positive displacement principle, they are inherently self-priming. When built of materials that tend to gall or seize on rubbing contact, the clearances between mating parts must be increased, with the result of decreased efficiency. The gear, sliding-vane, and cam units are generally limited to use on clear, nonabrasive liquids.

Diaphragm Pumps These units are also classed as positive displacement sealless pumps because the diaphragm acts as a limited displacement piston. Pumping action is obtained when the diaphragm is forced into reciprocating motion by mechanical linkage, compressed air, or oil from a pulsating external source. This type of construction eliminates any connection between the liquid being pumped and the source of energy and thereby eliminates the possibility of leakage. This characteristic is of great importance when toxic or very expensive liquids are being handled. Disadvantages include a limited selection of corrosion-resistant materials, limited head and capacity range, and the necessity of using check valves in the suction and discharge nozzles. Although air-operated diaphragm pumps are displacement pumps, they are not positive displacement pumps. The maximum pumping pressure cannot exceed the pressure of the compressed air powering the pump. Refer to Section 3.6 for more details on diaphragm pumps.

Regenerative Turbine Pumps Flow rates up to 100 gpm (23 m^3/h) and heads up to 700 ft (210 m) are easily handled with this type of pump. When it is used for chemical service, the internal clearances must be increased to prevent rubbing contact, which results in decreased efficiency. These pumps are generally unsuitable for solid-liquid mixtures of any concentration.

CHEMICAL PUMP DESIGN CONSIDERATIONS

Casting Integrity Practically all the major components of chemical pumps are castings. There is probably more concern in chemical pump applications than in any other type of service because leakage, loss of product, and downtime can be extremely costly, as well as very dangerous.

Mechanical Properties There are several factors that determine whether a certain material can be utilized for a particular design. Materials may possess outstanding corrosion resistance but may be completely impossible to produce in the form of a chemical pump because of their limited mechanical properties. Accordingly, it is advisable to be aware of the mechanical properties of any material being considered in a corrosion evaluation program. Most materials are covered by ASTM or other specifications; such sources can be used for reference.

Weldments Welded construction should impose no limitation, provided the weldment is as good as or better than the base material. Materials requiring heat treatment to achieve maximum corrosion resistance must be treated after welding, or other adjustments must be made to make certain corrosion resistance is not sacrificed.

Section Thickness Pressure-containing parts are generally made thicker than required for handling a noncorrosive liquid so that full pumping capability will be maintained even after the loss of some material to the corrosive medium. Parts that are subject to corrosion from two or three sides, such as impellers, must be made considerably heavier than their counterparts in water or oil pumps. Pressure-containing parts are also made thicker so they will remain serviceable after a specified amount of corrosive deterioration. Areas subject to high velocities, such as the cutwater of a centrifugal pump casing, are reinforced to allow for the accelerated corrosion caused by the high velocities.

Threads Threaded construction of any type in the wetted parts must be avoided whenever possible. The thread form is subject to attack from two sides, and a small amount of corrosive deterioration can reduce the holding power of the threaded joint.

Gaskets Gasket materials must resist being corroded by the chemical being handled. Compressed synthetic fibers and elastomers have been used extensively for corrosion services. Fluorocarbon resins are used because of their almost complete corrosion resistance.

Power End This assembly, consisting of the bearing housing, bearings, oil or grease seals, and bearing lubrication system, is normally made of iron or steel components; thus it must be designed to withstand a severe chemical plant environment. For example, where venting of the bearing housing is required, special means of preventing the entrance of water, chemical fumes, or dirt must be incorporated into the vent design.

The bearing that controls axial shaft movement is usually selected to limit shaft movement to 0.002 in (0.051 mm) or less. Endplay values above this limit have been found detrimental to impeller and mechanical seal operation.

Water jacketing or fan cooling of the bearing housing may be necessary under certain conditions to maintain bearing temperatures below 180°F (82°C), the limit used in most applications.

Maintenance Maintenance of a chemical pump in a corrosive environment can be a very costly and time-consuming item. When evaluating materials and design factors, maintenance aspects should be high on the priority list. The ease and frequency of maintenance are critical items and should be considered part of a preventive maintenance program. Such a program can be the most effective way of eliminating emergency shutdowns caused by pump failure. Furthermore, the knowledge gained in a routine preventive maintenance program can be of unlimited value when a breakdown does occur because repair personnel will have acquired a thorough knowledge of the construction details of the pump.

SEALING

The area around the sealing chamber probably causes more chemical pump failures than all other parts combined. The problem of establishing a seal between a rotating shaft and the stationary pump parts is one of the most intricate and vexing problems facing the pump designer.

Packings Braided fluorocarbon resins, aluminum, graphite, and many other materials or combinations of materials have been used to establish a seal (discussed in more detail in Subsection 2.2.2). A small amount of liquid must be allowed to seep through the packing to lubricate the surface between packing and shaft. This leakage rate is hard to control, and usually the packing is overtightened and the leakage is stopped. The unfortunate results of this condition is rapid scoring of the sealing surface, making it much harder to adjust the packing.

Mechanical Seals Mechanical shaft seals as described in Subsection 2.2.3 are used extensively on chemical pumps. The majority of chemical pumps in service today do not use packing. The primary consideration is selection of the proper materials for the type of corrosive liquid being pumped. Stainless steels, ceramics, graphite, and fluorocarbon resins are used to make most seal parts. Many seals consist of separate rotating and stationary elements that are assembled into the pump. However, cartridge seals are becoming more common, where the seal and gland are arranged in a unitized fashion with the seal for ease of assembly and adjustment that improve seal installation and operating life.

Seal Chambers Most chemical pumps are available with traditional convertible sealing chambers that can accept packing or mechanical seals. These “stuffing boxes” require narrow cross-section mechanical seals that are prone to early failure because of excessive temperature rise and trapped air. Chemical pumps are now available with oversized bore sealing chambers with additional liquid for cooling the seal and tapered bore sealing chambers with excellent seal cooling from fluid exchange with the pump and no trapped air, as they are self-venting.

Temperature One of the most important factors affecting the sealing medium is their operating temperature. Increased temperatures can result from high process temperatures and from heat generated by the sealing device. High temperature can increase the corrosive attack on the sealing chamber, the packing or the mechanical seal. Seal parts not designed for high temperature can also distort or crack and fail.

One answer to the heat/temperature problem is to cool the sealing chamber with a water jacket that surrounds it and the seal gland. These jackets tend to be poor heat exchangers, however, and water can be expensive—or non-existent—in many locations. There is also the risk that the cooling water source will fail while the pump is running. These factors are contributing to the requirement that chemical pumps operating between 200° and 500°F (93° and 260°C) be selected with mechanical seals that can handle full process temperature. These pumps are then applied with oversized sealing chambers with product flush or tapered sealing chambers to maximize seal cooling and to avoid trapped air. In many cases, cooling water is no longer required.

Pressure Seal chamber pressure varies with suction or discharge pressure depending on its location in the pump and impeller design. Variations in impeller design include those using vertical or horizontal seal rings in combination with balance ports, or the use of back vanes, pump-out vanes, or pump-out slots. All impeller designs depend upon a close running clearance between the impeller and the stationary pump parts. This clearance must be kept as small as possible to prevent excessive recirculation of the liquid and the resulting loss of efficiency. Unfortunately, most chemical pump materials tend to seize when subjected to rubbing contact, and the running clearances must therefore be increased considerably above those used in pumps for other industries.

At pressures above 100 lb/in^2 (690 kPa), packing is generally unsatisfactory. Mechanical seals incorporating a balancing feature to relieve the high face pressure are the best means of sealing at pressures above 100 lb/in^2 (690 kPa).

Shaft Pump shaft bending—or deflection—can create additional sealing problems. Undersize shafts, or those made of materials that bend readily, will deflect from their true center in response to radial thrust on the impeller.

Mechanical seal operation is impaired when the shaft is bent or deflected during operation. Because the flexible member of the seal must adjust with each revolution of the shaft, excessive deflection results in shortened seal life. If the deflection is of more than nominal value, the flexible seal member will be unable to react with sufficient speed to keep the seal faces together, allowing leakage at the mating faces.

A limit of 0.002 in (0.05 mm) at the seal faces has been established as the maximum allowable shaft deflection consistent with good pump design and seal life. Operation of the pump outside the allowable operating flow region can also increase radial thrust and shaft deflection, shortening seal life.

Shaft Surface In the seal chamber region, the shaft surface must have corrosion resistance at least equal to and preferably better than that of the wetted parts of the pump. In addition, this surface must be hard enough to resist the tendency to wear under the packing or mechanical seal parts. Further, it must be capable of withstanding the sudden temperature changes often encountered in operation.

Often it is cost effective to make the shaft from high-strength carbon steel, and then add protective sleeve of stainless steel, plastic, carbon, glass, or a coating in the seal chamber area. Cylindrical sleeves are made so they can be removed and replaced when they become worn. Other designs utilize sleeves that are permanently bonded to the shaft. Where possible, shafts are increasingly being made from solid stainless steel to maximize the shaft diameter under the seal, reducing bending and increasing seal life. This is most effective when cartridge seals are used as they include their own sleeve.

Another method of obtaining a hard surface in this region is the welded overlay or spray coating of hard metals onto the base shaft. Ceramic materials applied by the plasma spray technique possess excellent corrosion resistance but cannot achieve the complete density required to protect the underlying shaft.

Composite shafts utilizing carbon steel for the power end and a higher alloy for the wet end have been used extensively where the high-alloy end has acceptable corrosion resistance. The two ends are joined by various welding techniques, and the combination of metals is therefore limited to those that can be easily welded together. On such assemblies, the weld joint and the heat-affected zone must be outside the wetted area of the shaft.

Sealless Pumps Elimination of the sealing chamber and its associated problems has been the objective of several pump designs. Refer to Subsection 2.2.7 for sealless canned motor pumps and magnetically driven pumps. Diaphragm pumps previously mentioned are sealless pumps.

Vertical immersion pumps utilize sleeve bearings in the area immediately above the impeller to limit the flow of liquid along the shaft. For chemical service, the problem of materials associated with this bearing and its lubrication has to be addressed on an application basis.

CONSTRUCTION OF NONMETALLIC PUMPS

A number of non-metallic materials have been used extensively in chemical pump construction (refer to Section 5.2). Their excellent chemical resistance makes them competitive with stronger metal alloys.

CHEMICAL PUMP STANDARDS

In 1962, a committee of the Manufacturing Chemists Association (MCA) reached agreement with a special committee of the Hydraulic Institute on a proposed American Standards Association (ASA) standard for chemical process pumps. This document was referred to as the American Voluntary Standard or the Manufacturing Chemists Association Standard. In 1971, it was accepted by the American National Standards Institute (ANSI) and issued as ANSI Standard B123.1. This ANSI standard was renumbered in 1974 to ANSI B73.1, then to ANSI B73.1M in 1984.

It is the intent of this standard that pumps of similar size from all sources of supply shall be dimensionally interchangeable with respect to mounting dimensions, size and location of suction and discharge nozzles, input shafts, base plates, and foundation bolts. Table 1A and B lists the pump dimensions that have been standardized, and a cross-sectional assembly of a pump meeting these criteria is shown in Figure 1.

It is also the intent of this standard to outline certain design features that will minimize maintenance problems. The standard states, for instance, that the pump shaft should be sized so the maximum shaft deflection, measured at the centerline of the impeller when the pump is operating under its most adverse allowable conditions, will not exceed 0.005 in (0.127 mm). It does not specify shaft diameter because impeller diameter, shaft length, and provision for operation with liquids of high specific gravity would determine the proper diameter.

The standard also states that the minimum bearing life, again under the most adverse operating conditions within the allowable operating region, should be not less than two years. Bearing size is not specified but is to be determined by the individual manufacturer and will be dependent upon the load to be carried.

Additional specifications in the standard include hydrostatic test pressure, shaft finish at rubbing points, packing space, and seal chamber space.

ANSI B73.2M covers vertical in-line centrifugal pumps for chemical process. Dimensional criteria are shown in Table 2A and B, and a pump meeting these requirements is shown in Figure 2.

ANSI B73.5M-1995 is the Specification for Thermoplastic and Thermoset Polymer Material Horizontal End Suction Centrifugal Pumps for Chemical Process. A typical composite pump meeting these requirements is shown in Figure 3. Codes for acceptance tests are given in the American National Standard for Centrifugal Pump Tests, ANSI/HI 1.6-2000 (see References and Further Reading at the end of the section).

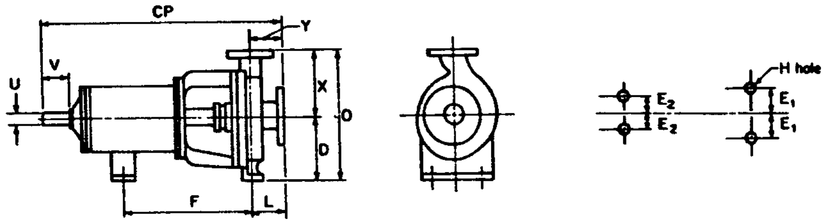

TABLE 1A Standard ANSI B73.1M dimensions in inches for horizontal pumps (Figure 1)

Dimension designation	Suction × discharge × nominal impeller diameter	*CP*	*D*	$2E_1$	$2E_2$	*F*	*H*	*O*	*U*		*V*, min.	*X*	*Y*
									Diameter	Keyway			
AA	$1\frac{1}{2} \times 1 \times 6$	$17\frac{1}{2}$	$5\frac{1}{4}$	6	0	$7\frac{1}{4}$	$\frac{5}{8}$	$11\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{32}$	2	$6\frac{1}{2}$	4
AB	$3 \times 2 \times 6$	$17\frac{1}{2}$	$5\frac{1}{4}$	6	0	$7\frac{1}{4}$	$\frac{5}{8}$	$11\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{32}$	2	$6\frac{1}{2}$	4
AC	$3 \times 2 \times 6$	$17\frac{1}{2}$	$5\frac{1}{4}$	6	0	$7\frac{1}{4}$	$\frac{5}{8}$	$11\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{32}$	2	$6\frac{1}{2}$	4
AB	$3 \times 1\frac{1}{2} \times 8$	$17\frac{1}{2}$	$5\frac{1}{4}$	6	0	$7\frac{1}{4}$	$\frac{5}{8}$	$11\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{32}$	2	$6\frac{1}{2}$	4
A10	$3 \times 2 \times 6$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$16\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$8\frac{1}{4}$	4
AA	$1\frac{1}{2} \times 1 \times 8$	$17\frac{1}{2}$	$5\frac{1}{4}$	6	0	$7\frac{1}{4}$	$\frac{5}{8}$	$11\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{32}$	2	$6\frac{1}{2}$	4
A50	$3 \times 1\frac{1}{2} \times 8$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$16\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$8\frac{1}{2}$	4
A60	$3 \times 2 \times 8$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$17\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$9\frac{1}{2}$	4
A70	$4 \times 3 \times 8$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$19\frac{1}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	11	4
A05	$2 \times 1 \times 10$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$16\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$8\frac{1}{2}$	4
A50	$3 \times 1\frac{1}{2} \times 10$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$16\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$8\frac{1}{2}$	4
A60	$3 \times 2 \times 10$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$17\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$9\frac{1}{2}$	4
A70	$4 \times 3 \times 10$	$23\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$19\frac{1}{4}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	11	4

(continues)

TABLE 1A Continued.

Dimension designation	Suction × discharge × nominal impeller diameter	CP	D	$2E_1$	$2E_2$	F	H	O	U		V, min.	X	Y
									Diameter	Keyway			
A40	$4 \times 3 \times 10$	$23\frac{1}{2}$	10	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$22\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$12\frac{1}{2}$	4
A20	$3 \times 1\frac{1}{2} \times 13$	$23\frac{1}{2}$	10	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$20\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$10\frac{1}{2}$	4
A30	$3 \times 2 \times 13$	$23\frac{1}{2}$	10	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$21\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$11\frac{1}{2}$	4
A40	$4 \times 3 \times 13$	$23\frac{1}{2}$	10	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$22\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$12\frac{1}{2}$	4
A80[a]	$6 \times 4 \times 13$	$23\frac{1}{2}$	10	$9\frac{3}{4}$	$7\frac{1}{4}$	$12\frac{1}{2}$	$\frac{5}{8}$	$23\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{8}$	$2\frac{5}{8}$	$13\frac{1}{2}$	4
A90[a]	$8 \times 6 \times 13$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$30\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	16	6
A100[a]	$10 \times 8 \times 13$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$32\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	18	6
A105	$6 \times 4 \times 15$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$30\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	16	6
A110[a]	$8 \times 6 \times 15$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$33\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	18	6
A120[a]	$10 \times 8 \times 15$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$33\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	19	6
A125	$6 \times 4 \times 17$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$30\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	16	6
A110	$8 \times 6 \times 17$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$32\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	18	6
A120	$10 \times 8 \times 17$	$33\frac{7}{8}$	$14\frac{1}{2}$	16	9	$18\frac{3}{4}$	$\frac{7}{8}$	$33\frac{1}{2}$	$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{16}$	4	19	6

[a] Suction connections may have tapped bolt holes.

TABLE 1B Standard ANSI B73.1M dimensions in millimeters for horizontal pumps (Figure 1)

Dimension designation	Suction × discharge × nominal impeller diameter	CP[b]	D	$2E_1$	$2E_2$	F	H	O	U		V, min.	X	Y
									Diameter	Keyway			
AA	40 × 25 × 150	445	133	152	0	184	16	298	22.23	4.76 × 2.38	51	165	102
AB	80 × 50 × 150	445	133	152	0	184	16	298	22.23	4.76 × 2.38	51	165	102
AC	80 × 50 × 150	445	133	152	0	184	16	298	22.23	4.76 × 2.38	51	165	102
AB	80 × 40 × 200	445	133	152	0	184	16	298	22.23	4.76 × 2.38	51	165	102
A10	80 × 50 × 150	597	210	248	184	318	16	420	28.58	6.35 × 3.18	67	210	102
AA	40 × 25 × 200	445	133	152	0	194	16	298	22.23	4.76 × 2.38	51	165	102
A50	80 × 40 × 200	597	210	248	184	318	16	425	28.58	6.35 × 3.18	67	216	102
A60	80 × 50 × 200	597	210	248	184	318	16	450	28.58	6.35 × 3.18	67	242	102
A70	100 × 80 × 200	597	210	248	184	318	16	490	28.58	6.35 × 3.18	67	280	102
A05	50 × 25 × 250	597	210	248	184	318	16	425	28.58	6.35 × 3.18	67	216	102
A50	80 × 40 × 250	597	210	248	184	318	16	425	28.58	6.35 × 3.18	67	216	102
A60	80 × 50 × 250	597	210	248	184	318	16	450	28.58	6.35 × 3.18	67	216	102
A70	100 × 80 × 250	597	210	248	184	318	16	490	28.58	6.35 × 3.18	67	280	102
A40	100 × 80 × 250	597	254	248	184	318	16	572	28.58	6.35 × 3.18	67	318	102
A20	80 × 40 × 330	597	254	248	184	318	16	520	28.58	6.35 × 3.18	67	266	102
A30	80 × 50 × 330	597	254	248	184	318	16	520	28.58	6.35 × 3.18	67	266	102
A40	100 × 80 × 330	597	254	248	184	318	16	572	28.58	6.35 × 3.18	67	318	102
A80[a]	150 × 100 × 330	597	254	248	184	318	16	597	28.58	6.35 × 3.18	67	343	102
A90[a]	200 × 150 × 330	860	368	406	229	476	22	775	60.33	15.88 × 7.94	102	406	152
A100[a]	250 × 200 × 330	860	368	406	229	476	22	826	60.33	15.88 × 7.94	102	457	152
A105	150 × 100 × 380	860	368	406	229	476	22	775	60.33	15.88 × 7.94	102	406	152
A110[a]	200 × 150 × 380	860	368	406	229	476	22	826	60.33	15.88 × 7.94	102	457	152
A120[a]	250 × 200 × 380	860	368	406	229	476	22	851	60.33	15.88 × 7.94	102	483	152
A125	150 × 100 × 425	860	368	406	229	476	22	775	60.33	15.88 × 7.94	102	406	152
A110	200 × 150 × 425	860	368	406	229	476	22	826	60.33	15.88 × 7.94	102	457	152
A120	250 × 200 × 425	860	368	406	229	476	22	851	60.33	15.88 × 7.94	102	483	152

[a] Suction connections may have tapped bolt holes.

[b] See Table 1A for dimensional symbols.

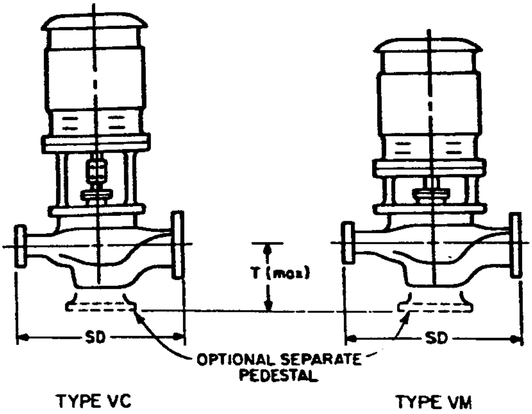

TABLE 2A Standard ANSI B73.2M dimensions for vertical inline pumps—USCS units

Pump designation *VC* (or *VM*)[a]	ANSI 125, 150, 250, or 300 flange size, in		*SD* (+10, −0.08), in	*T* (max), in
	Suction	Discharge		
2015/15	2	$1\frac{1}{2}$	14.96	6.89
2015/17	2	$1\frac{1}{2}$	16.93	
2015/19	2	$1\frac{1}{2}$	18.90	
3015/15	3	$1\frac{1}{2}$	14.96	7.87
3015/19	3	$1\frac{1}{2}$	18.90	
3015/24	3	$1\frac{1}{2}$	24.02	
3020/17	3	2	16.93	7.87
3020/20	3	2	20.08	
3020/24	3	2	24.02	
4030/22	4	3	22.05	8.86
4030/25	4	3	25.00	
4030/28	4	3	27.95	
6040/24	6	4	24.02	9.84
6040/28	6	4	27.95	
6040/30	6	4	29.92	

[a] Sequence defines design, suction flange size, discharge flange size and SD dimension

TABLE 2B Standard ANSI B73.2M dimensions for vertical inline pumps—SI units

Pump designation[a], *VC* (or *VM*)	Flange Size, mm		*SD*[b] (+2.5, −2.0), mm	*T* (max), mm
	Suction	Discharge		
50-40-380	50	40	380	175
50-40-430	50	40	430	175
50-40-480	50	40	480	175
80-40-380	80	40	380	200
80-40-480	80	40	480	200
80-40-610	80	40	610	200
80-50-430	80	50	430	200
80-50-510	80	50	510	200
80-50-610	80	50	610	200
100-80-560	100	80	560	225
100-80-635	100	80	635	225
100-80-710	100	80	710	225
150-100-610	150	100	610	250
150-100-710	150	100	710	250
150-100-760	150	100	760	250

[a] Sequence defines design, suction flange size, discharge flange size, and SD dimension

[b] See Table 2A for dimensional symbols.

Other global dimensional standards for both horizontal and vertical pumps are also used. In 1971, the International Organization for Standardization (ISO) reached agreement on a set of dimensional standards for horizontal end-suction centrifugal pumps. This document, ISO 2858, in SI units, describes a series of pumps of slightly lower capacity than described in ANSI B73.1. Technical specifications are covered in ISO 5199. Codes for acceptance tests are given in ISO 2548 and ISO 3555.

FIGURE 2 Vertical in-line centrifugal pump for chemical process applications (Flowserve Corporation)

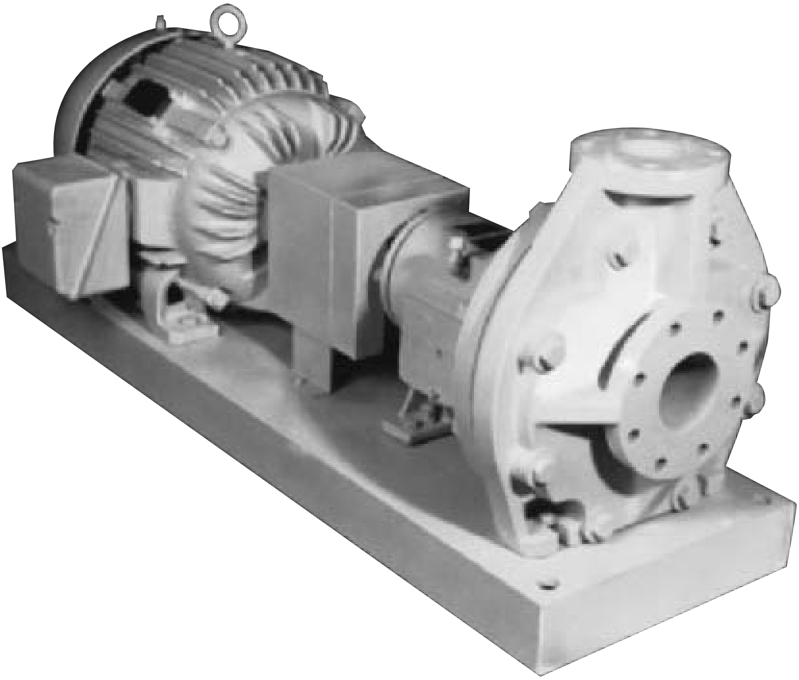

FIGURE 3 A typical composite pump (Flowserve Corporation)

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