POLYMER COMPOSITE INDUSTRIAL CHEMICAL PUMPS

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ABSTRACT

Polymers are important materials in the design and application of pumps and piping in many chemical processing systems today. The ability of polymer composites to resist chemical attack is the primary reason for use in industrial equipment, creating an economical alternative to high alloy metals and other exotic materials.

Discussion includes the principles of corrosion, construction of polymer composites pumps, and the use of composites in chemical process applications. Discussion on pump construction includes the design and manufacture of thermosets, thermoplastics, and lined pumps. A user perspective includes pump cost comparisons, equipment selection, application guidelines, sealed versus sealless pumps, piping, and examples of field experiences.

INTRODUCTION

Nonmetallic components have been used for the past 20 or more years in corrosion services for sea water applications, electrical systems, chemical laboratories, structural corrosive environments, hydrocarbon tanks, and the automotive industry. The main reason for using them is excellent resistance to corrosion.

The initial development of industrial nonmetallic component pumps with flanges and high pressure did not always have favorable results. However, the development of polymers with reinforcements has resulted in products that are pressure competitive to metals. Metallic storage tanks for highly corrosive liquids are replaced by lined tanks of reinforced polymer. Underground metal gasoline storage tanks are being replaced by reinforced polymer tanks.

Basically, metals corrode and nonmetallics do not. With the continuous improvement of polymers, users should consider the application of nonmetallic pumps for corrosion, concerns of application, and cost.

PRINCIPLES OF CORROSION OF MATERIALS

Corrosion is discussed to help understand the corrosion performance difference between metals and composites as used in pumping applications. In corrosion, metals are always losing material to electrochemical reactions, while composite materials last indefinitely or individual components of the composite degrade (i.e., either the composite works or it does not). The goal is to select a metal that has a very low material loss, less than 0.002 in per year of surface corrosion, or to select a composite that will last indefinitely.

Corrosion in Metals

Corrosion in metals is caused by electrochemical reactions between the metal and the electrolyte. The electrolyte in the case of pumps is the process fluid. For corrosion to occur, an anode and a cathode must be established. Direct current flows from the anode to the cathode through the electrolyte. The amount of corrosion in the metal is directly proportional to the amount of current flowing between the anode and cathode.

The level of acidity or alkalinity of a fluid is important when applying metal pumps. The method used for measuring acidity and alkalinity is the pH system. A neutral solution such as water has a pH of 7.0. The pH is on a logarithmic scale. A solution with a pH above 7.0 is an alkaline, and a pH below 7.0 is an acid.

The general types of corrosion in metals are as follows:

- *Uniform attack,* the most common form of corrosion, is characterized by electrochemical reactions proceeding uniformly over the entire exposed surface. This type of corrosion can be managed easily, since equipment can be selected with a known corrosion rate.

- *Galvanic corrosion* occurs when two dissimilar metals are in contact and exposed to an electrolyte and set up a galvanic cell. The further apart the two materials are in the galvanic series, the more chance there is for corrosion.

- *Intergranular corrosion* involves the localized attack at metal-grain boundaries. Damage can be severe, even though total weight loss is minimal. Welding on 303 and 304 stainless steel can create this type of corrosion. The high temperatures of the welding process cause the chromium to precipitate out, depleting the corrosion resistance in the weld area. Heat treatment after welding will redissolve chromium back into the metal, restoring its corrosion resistance.

- *Pitting* is the trickiest form of corrosion, causing equipment to fail by local perforation, without exhibiting any weight loss. The pits or holes are easily recognized on the surface of the metal. In general, chlorides and other halogens foster pitting.

- *Concentration-cell corrosion/crevice corrosion* occurs when a metal is in contact with different electrolyte concentrations in the process environment. This localized corrosion is usually a result of crevices, scale, and deposits in the metal that create stagnant areas in the corrosive medium.

- *Stress corrosion* occurs from a combination of stresses in the metal and the corrosive environment. The stresses cause a breakdown of the corrosion resistant elements resulting in intergranular corrosion.

After understanding the type of corrosion in metals, it is important to realize that the rate of corrosion can be drastically affected by the temperature, pH (acidity), formation/removal of an oxide corrosion barrier (erosion corrosion), and the velocity of the solution.

Corrosion in Fiber Reinforced Polymer

The corrosion or material degradation, as it is referred to in fiber reinforced composites, is completely different from the corrosion process of metals. Since the fiber reinforced composite material (fiber and polymer) is nonconductive, an electrochemical reaction does not take place. The material degradation occurs in the resin, the reinforcing fiber, the interface between the two, or in any of the components in the composite. If the material is going to be attacked, it will occur rather rapidly and a simple coupon test in the process solution, over several days to a few months, will indicate whether or not the material is corrosion resistant.

Temperature and fluid concentration are the only two process properties required to successfully select a fiber reinforced composite. The pH and the formation and removal of an oxide barrier are usually irrelevant. However, "cor-brasion," which is the softening of the surface by action of alkaline salt slurries, can cause problems.

When selecting composites, there is no such thing as a corrosion rate. The material either is or is not corrosion resistant! A simple coupon test or published corrosion guides indicate the suitability of a material on a given application. The exception is chlorine and oxidizing material can cause attack similar to metals at 180°F to 200°F, resulting in a corrosion rate.

COMPOSITE MATERIALS USED FOR INDUSTRIAL PUMPS

The family of nonmetallic composites include a large variety of various polymers. Used in virtually every type pump part, either as a coating or as structural materials of construction, nonmetallics offer designers, manufacturers, and ultimate end-users a broad array of benefits. Proper selection of nonmetallic materials offers many combinations of *improved corrosion resistance, lighter weight, lower costs, magnetic transparency, and complexity of unitized part designs.* As nonmetallic materials with higher modulus of elasticity and higher allowable temperatures become commercially available, so will more replacement of metal parts.

Proper material selection for a particular application has allowed nonmetallic substitutions in otherwise traditional metallic parts, such as *shafts, pull rods, valve seats, pump casings, impellers, bushings, wear rings, ball bearings, and many more.* Benefits, other than cost alone, direct design engineers to consider nonmetallic alternatives for longer life and higher quality.

Polymer Processing

Polymers are formed by the resin/chemical companies in a process called polymerization. The polymer is formed under the reaction of a catalyst, pressure, and heat inside vessels or reactor tubes. The polymer is then shipped to the processor in pelletized, granulated, powdered, or liquid form. At this stage, the polymer is referred to as resin. The processor typically combines other materials with the resin, to form a compound. These other materials include colorants, flame retardants, heat or light stabilizers, lubricants, glass or carbon fibers, minerals, hollow glass spheres, and/or other polymers. The composite is designed to have properties superior to the component materials by themselves. Adding fillers or reinforcements to resins increases the overall performance of the composite. A common reinforcing technique is adding glass fiber to resin that, when molded, leaves the composite with higher strength properties than the resin alone. This reinforcement is similar to the way steel reinforcing bars strengthen concrete.

The term "composite polymers" generally includes two large groups of organic compounds that differ considerably in their makeup.

- *Thermoplastics* are made from long-chain organic materials that melt at some specific elevated temperature, depending on the material. They can be amorphous or crystalline in structure. Thermoplastics do not undergo a chemical change in their processing and, therefore, will become "pliable" upon reheating above their yield temperature. For improved physical properties, various reinforcements may be utilized, such as glass, carbon fiber, or mica.

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

- *Thermosetting polymers*, generally reinforced with fiberglass or carbon (graphite) fibers, are mixing groups of chemical chains polymerized into a solid matrix. During the molding cycle, these materials undergo a *chemical change* (molecular), which is irreversible. These thermosetting materials will not soften or become flowable by reheating the parts.

Thermoset composite pumps are made from a cross-linked unsaturated polymer resin, such as epoxy, unsaturated polyester, or vinyl ester resin reinforced with glass fibers. Other reinforcements are sometimes utilized, such as carbon fibers. However, glass fibers remain the major reinforcement medium. Thermoset plastics have good high temperature characteristics. They exhibit good resistance to creep; as application temperatures increase, they eventually char. Thermoset composite pumps are typically manufactured by one of several methods. They may be compression molded, resin transfer molded, or cast. A listing is shown in Table 1 of various thermosets used in pumps.

Table 1. Thermoset Materials.

Composite Material	Common Trade Name Chemical
Vinyl ester GL	Vinyl ester
Vinyl ester CL	Vinyl ester
Epoxy	Epoxy

GL = Glass Reinforced
CL = Carbon Reinforced

A comparison of the corrosion capabilities with temperatures of these materials is shown in Table 2. This table should only be used as a rough guide when determining the suitability of polymers in the mentioned fluids. This guide does not take into consideration the ability of the materials to contain pressure. Pump parts made from these materials require reinforcement to handle higher pressures. The effect on modulus of elasticity with temperature is shown in Figure 1.

TYPES OF COMPOSITE PUMP CONSTRUCTION

Thermoset Composite Pumps

Nonmetallic pump technology has been referred to as fiber reinforced plastics (FRP), but today is more commonly referred to as engineered composites. Pumps using these reinforced thermoset compounds have strengths similar to metallic pumps and exhibit excellent corrosion resistance. These pumps successfully handle

Table 2. Maximum Temperatures of Polymers in Various Fluids.

CORROSION RESISTANCE OF COMMON POLYMERS
DIFFICULT PROCESS FLUIDS

MAXIMUM RECOMMENDED TEMPERATURE (DEG. F)

Type	Fluid		Concen.	Vinyl Ester	CPVC	PVC	PVDF	PTFE
Acids	Hydrochloric Acid	HC1	37%	180	185	70	250	260
	Sulfuric Acid	H2SO4	75%	120	140	70	200	500
	Nitric Acid	HNO3	20%	150	185	140	140	250
Alkalies (Caustics)	Potassium Hydroxide	KOH	45%	180	200	185	165	300
	Sodium Hydroxide	NaOH	50%	210	200	NR	200	300
	Ammonium Hydroxide	NH3OH	29%	100	200	150	250	300
	Sodium Chloride	NaC1	Sat'd	210	200	150	250	400
Oxidizers	Sodium Hypochlorite	NaOC1	18%	180	200	100	200	300
	Hydrogen Peroxide	H2O2	30%	150	140	70	200	480
Organics (Solvents)	Benzene	C8H6	100%	100	NR	NR	170	390
	Styrene	C8H5CH: CH2	100%	120	NR	NR	180	200
	Ethyl Alcohol	C2H5OH	95%	100	140	70	210	390

Type	Fluid		Concen.	ETFE	PPS	POLYPRO PYLENE	EPOXY	PEEK
Acids	Hydrochloric Acid	HC1	37%	250	200	70	140	250
	Sulfuric Acid	H2SO4	75%	250	80	125	NR	NR
	Nitric Acid	HNO3	20%	200	150	140	70	NR
Alkalies (Caustics)	Potassium Hydroxide	KOH	45%	200	200	185	185	150
	Sodium Hydroxide	NaOH	50%	225	160	185	70	150
	Ammonium Hydroxide	NH3OH	29%	250	200	225	100	250
	Sodium Chloride	NaC1	Sat'd	250	200	225	210	250
Oxidizers	Sodium Hypochlorite	NaOC1	18%	250	200	140	NR	250
	Hydrogen Peroxide	H2O2	30%	250	150	70	70	250
Organics (Solvents)	Benzene	C6H6	100%	200	200	NR	NR	250
	Styrene	C6H5CH: CH2	100%	200	120	NR	140	250
	Ethyl Alcohol	C2H5OH	95%	250	200	140	70	250

NR = Not Recommended

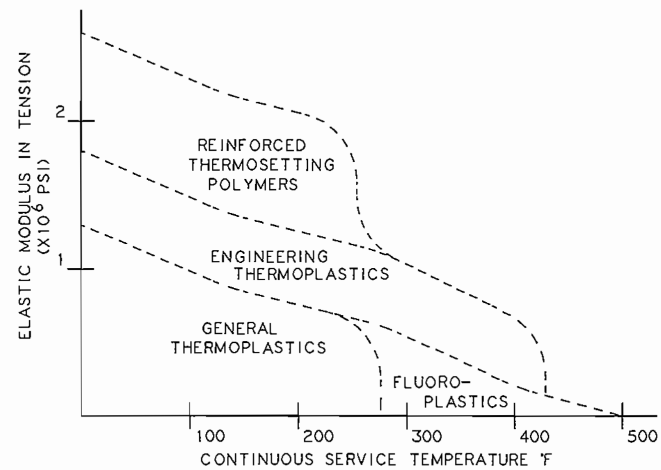

Figure 1. Modulus of Elasticity Versus Temperature.

acids, alkalis, oxidizing agents, solvents, and salts, at normal operating temperatures to 250°F. While exhibiting similar mechanical properties and superior corrosion resistance, these pumps are even more attractive.

Thermoset composite pumps (Figures 2 and 3) are currently produced in ASME/ANSI B73.5M, with 6.0 in through 15 in impeller sizes. They may be applied to pumpages with temperatures as high as 250°F and pressures to 250 psi. (Individual manufacturers have specifications that may vary from this general guide.) They demonstrate good resistance to acids, bases, and oxidizing agents. Typical applications are in CPI markets, oil patch applications, pulp and paper industries, and other applications where corrosion resistance is of concern.

Impeller

A concern with nonmetallic pumps is the attachment of the impeller (Figure 4) to the shaft. Depending upon the speed and horsepower, most impellers cannot use a single key for attachment, due to the stress levels of the material. Many impellers are,

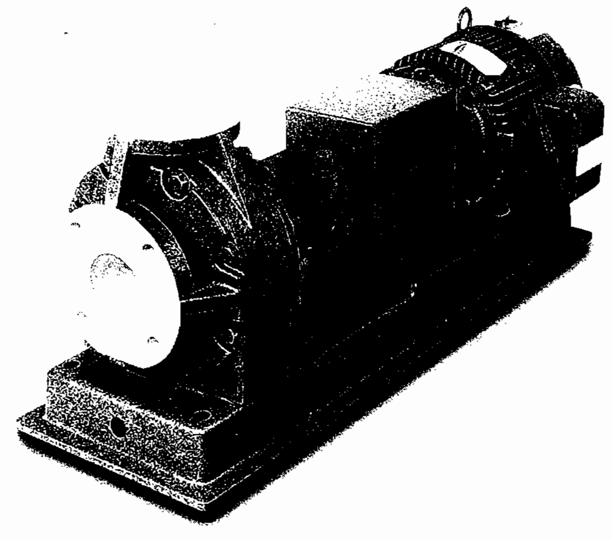

Figure 2. Picture of a Mounted Thermoset Pump.

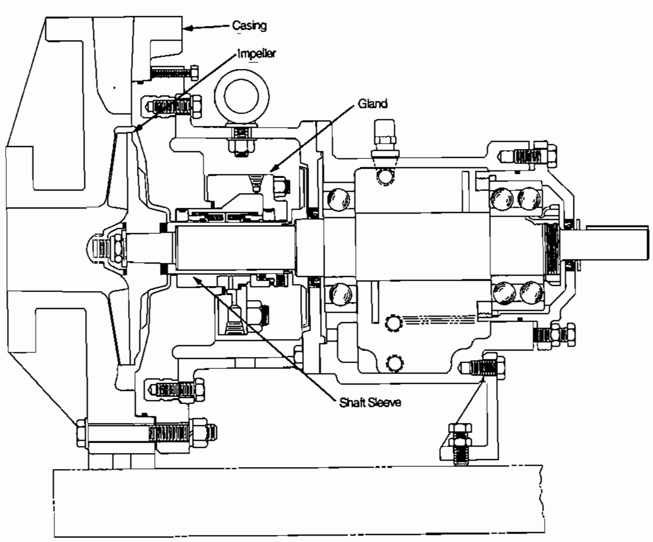

Figure 3. Cross Section of Reinforced Thermoset Pump.

therefore, attached by using threaded inserts molded within the impeller. An alternate method of attachment is a multikeyed or polygon shape, which does not require an internal insert because the stresses of the material are distributed throughout the circumference.

Casings

Unlike metallic pumps, there are no standards for the pressure-temperature ratings of the flanges; the rating changes from one manufacturer to another and from material to material. Good engineering design practices have shown that the reinforced vinyl ester and epoxy flanges (Figure 4) have the capability, at ambient temperature, to be equivalent to that of the same size metal 150 lb flanges. The pressure- temperature gradient is a linear factor and degrades above 100°F. Heavy wall vinyl ester is a good insulator that makes the temperature gradient from the liquid side of the pump case to atmosphere about 100°F. This allows for higher pumpage temperatures without causing excess bearing temperatures; it is also good for the user, since there will be little loss of heat from the fluid while passing through the pump. To obtain additional strength, some manufacturers employ metal

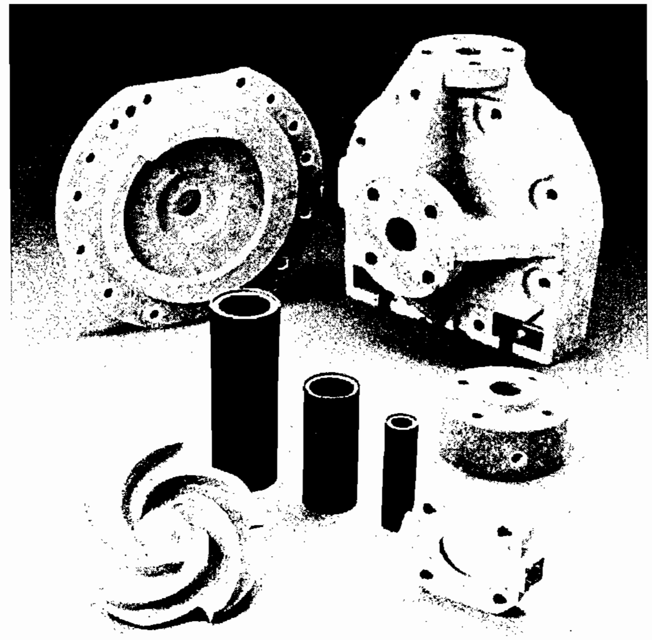

Figure 4. Components Made of Thermoset.

backup rings, which are either separate pieces bolted to the support head or the support head is integral with the backup ring.

Gasketing

In nonmetallic pumps, most of the main gaskets are confined O-rings. This reduces the stress on the main bolts. If the gasket surface requires final machining, it is advisable to coat the surfaces with the base resin, to prevent wicking of the pump fluid. To reduce the area stress from the bolt heads or nut loading, it is recommended that when washers are used, their diameter should be at least three times that of the bolt. The normal gasketing material used in nonmetallic chemical pumps is Viton®-A.

Bolting and Metallic Insert

Threaded studs into the casing will impose tension in the composite casing during assembly, so it is preferable to use through bolting; this leaves the casing in compression rather than tension. All bolting and inserts used on the nonmetallic pumps are made of 303 stainless steel, as a minimum. Nonmetallic studs are used on some pumps.

Shaft

A high strength AISI 4140 carbon steel can be used effectively in corrosive services, if it is designed to be completely unwetted, even in the event of a seal failure. Stainless steel shafts are also available, and are used in corrosive atmospheric conditions.

Shaft Sleeves

The shaft sleeve is used to protect the shaft from the process fluid and mechanical seal wear. The shaft sleeve (Figure 4) can be made of injection molded glass reinforced polyphenylene sulfide (PPS) or compression molded vinyl ester. The shaft sleeve can be a separate piece or can be made integral with the impeller. When nonmetallic sleeves are used, mechanical seals with Teflon® wedges should not be employed, because of the excess fretting. The designer also has to consider the extrusion from the holding force of the set screws on soft nonmetallic sleeves. Split clamping rings, using a radial type of set screw, are sometimes used to prevent damage to the shaft sleeve. The shaft sleeves are usually of the hook type variety, to allow for axial thermal expansion.

Other components

Other components are support columns, bearing holders, and mounting plates for vertical wet pit pumps (Figure 5).

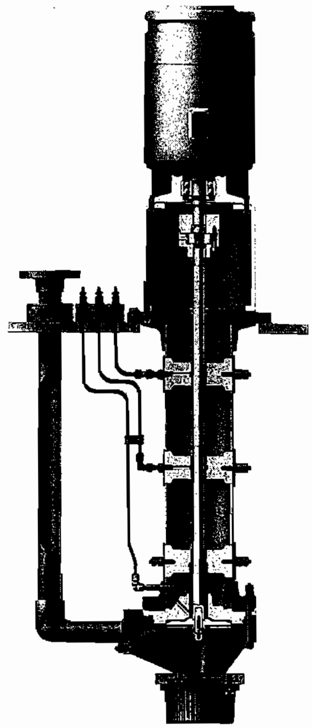

Figure 5. Vertical Immersion Pump.

Solid Thermoplastic Composite Pumps

Many solid thermoplastic pumps are smaller in size, designed with application temperatures of less than 200°F. These pumps are typically used in lighter duty services and have threaded connections for suction and discharge piping, although may be offered with flange type connections (Figure 6). Casing wall thickness is typically thinner (.06 in to .19 in) than thermoset pump casing walls. Thus, mechanical loading such as flange loading is limited. Typical chemical applications would be plating, tank circulation, fresh water, corrosion resistant sumps, and food handling. Magnetic drive designs (Figure 6) using reinforced thermoplastic components have grown in use, due to the elimination of the mechanical seal and associated problems on some services.

Metal Pumps Lined with Thermoplastic

This class of pumps typically uses a chemical resistant fluoropolymer such as PFA, PTFE, ETFE, or PVDF as a lining inside a metal casing. This combination provides the excellent corrosion resistance along with the mechanical strength of a metal pump.

These products typically fall into two classes:

- Heavy duty pumps lined with PFA or PTFE—these pumps typically have temperature capabilities to 350°F, operating pressure to 275 psi, and universal corrosion resistance. The properties of PFA and PTFE require a specialized molding process and mechanical locking of the lining to the metal pump casing. These types of pumps are offered in either mechanically sealed or sealless designs, as shown in Figures 7 and 8. The impeller usually has some type of metal insert to provide structural support. This can limit the ability to trim impellers.

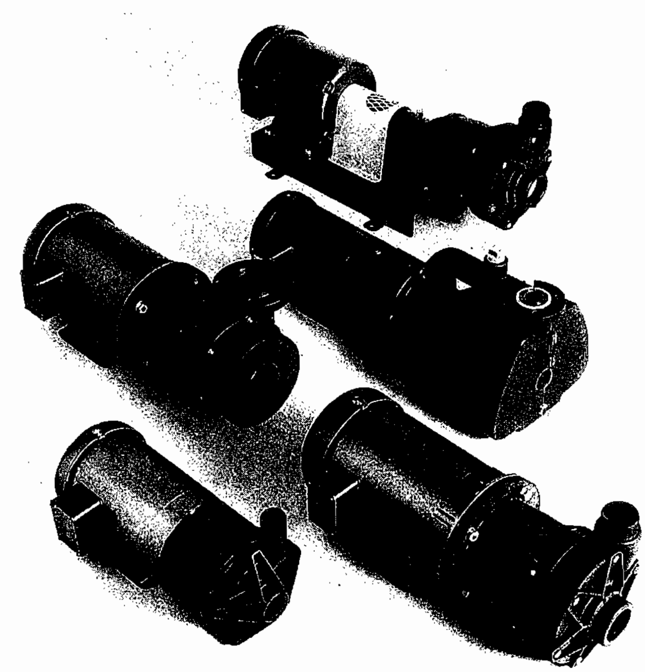

Figure 6. Solid Thermoplastic Pumps.

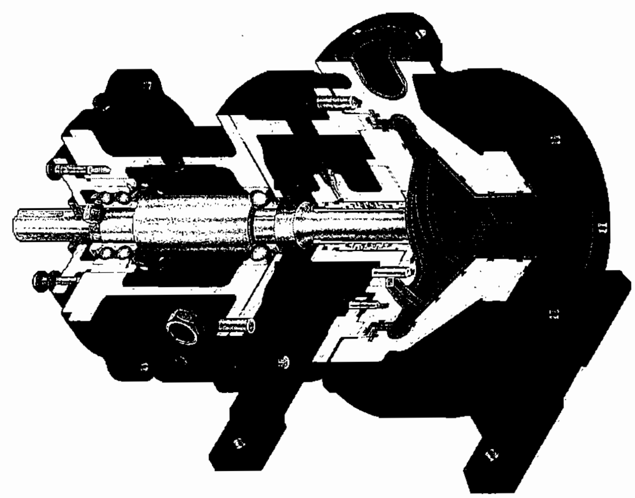

Figure 7. Heavy Duty Mechanically Sealed Pumps Lined with PFA or PTFE.

- Medium duty pumps lined with ETFE or PVDF—these pumps typically have temperature capabilities to 250°F, operating pressure in the range of 150 psi to 225 psi, and near universal corrosion resistance. The properties of ETFE or PVDF allow the use of conventional injection molding equipment. The conventional manufacturing process generally results in a lower cost design. These types of pumps are offered in either mechanically sealed or sealless designs. Sealless medium duty plastic lined designs have become very popular, due to their attractive price, simple design, and elimination of mechanical seal problems. A typical design is shown in Figure 9.

Armored Pumps

In this product, the pump casing and cover is molded from suitable polymer materials, generally a very corrosion resistant

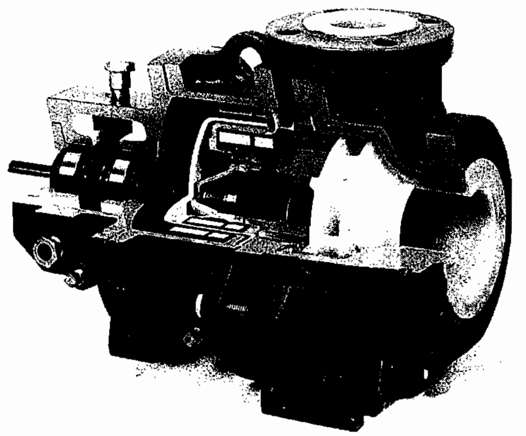

Figure 8. Heavy Duty Sealless Pumps Lined with PFA or PTFE.

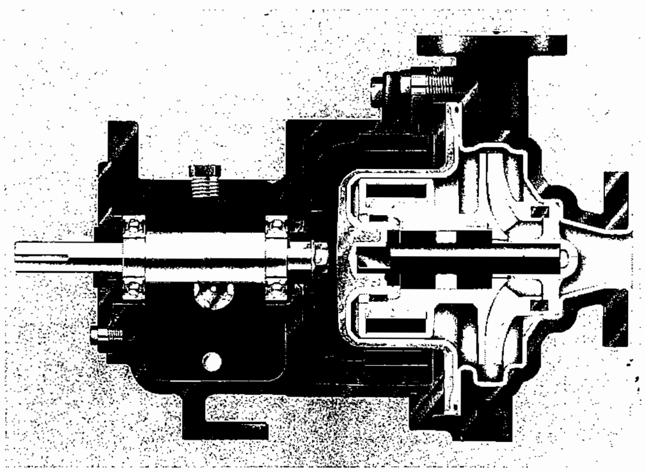

Figure 9. Medium Duty Pumps Lined with ETFE.

material. The wetted components are molded out of materials such as carbon, PTFE, CPVC, or PVDF. The pressure rating of the molded pump parts by themselves is low. In order to increase the structural rigidity and pressure containing capability of the pump, the molded nonmetallic parts are held in compression between plates. These plates are considered the pump "armor."

Ceramic/Carbon Pumps

Solid ceramic and carbon pumps are much more expensive than comparable pumps in the market. These pumps are designed for specialty applications where metal and polymer pumps cannot be used. For example, the carbon pumps can handle high concentrations of hydrofluoric acid (HF). Ceramic pumps are used for pumping mixtures of corrosive liquids and abrasive particles.

A range chart is shown in Figure 10 of developed pressure versus gallons per minute for application of thermoplastics, thermosets, and metal chemical pumps.

TECHNIQUES FOR MOLDING POLYMER COMPOSITE PUMP COMPONENTS

Reinforcement

Composite pumps are made from thermoplastics and thermosets, many of which have molded in reinforcement. Glass or carbon fibers are used as reinforcing members in the composite material. The combination of fibers and a resin compound results in a material with properties superior to those found in either

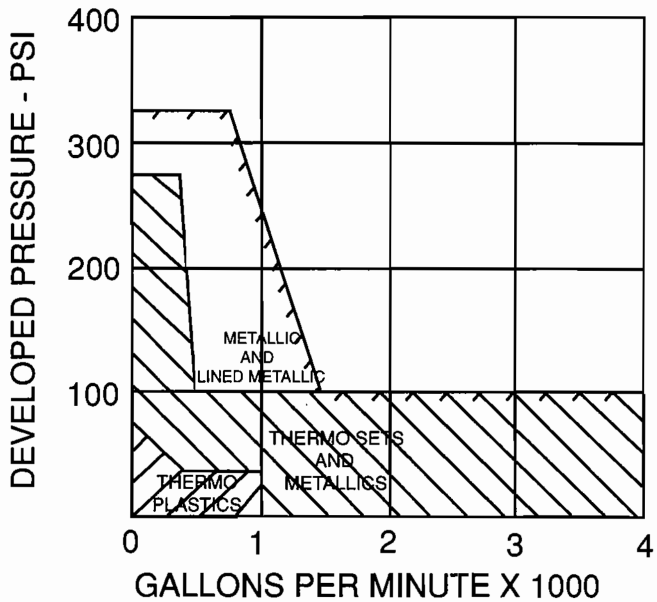

Figure 10. Pressure Versus Flow for Composite Pumps.

component. Fibers have several inherent qualities that are critical to the resolution of structural problems in plastics: high strength to weight ratio, dimensional stability, resistance to temperature extremes, resistance to corrosion, and ease of fabrication. There are several commercially available forms of glass fibers. Chopped strand is supplied as bulk-cut strands 1/16 to 1/2 inch in length. The chopped strands of glass are mixed into a molding compound that is used in compression molding and injection molding. Continuous or chopped strand mats are used in resin transfer molding. Carbon fiber comes in similar forms.

Thermoset—Resin Transfer Molding (RTM)

The process to make a casing begins by molding a volute out of a removable core material. The volute is wrapped in several layers of glass reinforcement. The glass reinforcement is oriented to optimize the overall strength of the finished composite part. Cutting patterns similar to cutting cloth are used to ensure the shape consistency of the glass mats. The wrapped core is placed into the cavity of the mold, which is laden with reinforcing glass. The mold is then closed and prepared for the transfer of resin. The resin is thoroughly mixed with a catalyst and maintained at an exact temperature to ensure proper curing, once inside the mold. The resin and catalyst mixture is forced into the mold under pressure. The pressure is used to ensure that the resin permeates all voids between the glass. The casing is removed from the mold after curing. The core is then removed by heat or chemical dissolving. Once the entire molding process is performed, the casing is machined as required.

- *Advantage:* Lower initial cost for tooling than compression molding; structural strength can be increased with properly placed reinforcement.

- *Disadvantage:* More hand labor involved; much higher per piece cost than compression molded pieces; less dimensional accuracy and more post mold machining required than with compression molded pieces; structural strength decreased with improperly placed reinforcement.

Thermoset—Compression Molding

The exact amount of molding compound is measured out and placed into the lower half of the precision steel mold. The mold is closed under high pressure. The temperature of the mold is closely controlled. The high pressure and temperature allow the part to cure in a matter of minutes. After curing, the part is removed with ejector pins built into the mold.

- *Advantage:* Lower per piece cost; very precise components requiring little or no machining; yields a very dense void-free material.
- *Disadvantage:* High cost of mold and press machinery due to the higher temperatures and pressures involved.

Thermoplastic—Injection Molding

An injection molding machine is used to inject the polymer composite into a heated mold at high pressure. After the plastic solidifies, the mold halves move apart and ejector pins push the part out of the mold. Mold materials vary from aluminum to tool steel to stainless steel, depending upon the polymer processed and expected part volume.

- *Advantage:* Parts can be produced economically in large quantities; availability of a wide variety of molding materials.
- *Disadvantage:* Mold tooling is relatively expensive; generally limited to smaller parts.

Thermoplastic—Rotolining

The rotolining process is used to create a permanently bonded liner on the interior of pump casing or seal chamber. Granular resin is placed inside the component to be lined. Tooling is used to cover openings such as suction and discharge flanges. The component is placed in an oven with precise temperature controls on an arm that rotates in two directions. As the part is slowly rotated, the plastic resin tumbles around the inside and melts to the interior surfaces, producing an even coating that is typically .1 to .2 in thick. After processing, the interior surfaces may be machined using conventional machining equipment.

- *Advantage:* Tooling is lower in cost due to low processing pressure; excellent adhesion to metal casing and stressfree lining.
- *Disadvantage:* Limited to uniform lining thickness; long processing times can lead to higher costs, unless high volume tooling is used to process many parts at a time.

Thermoplastic—Transfer Molding

Very similar to injection molding, but more of a batch melting type process. The polymer is melted in a "pot" and then injected at high pressure into the component to be lined. The equipment and molding techniques are a specialty business with very limited availability.

- *Advantage:* Thick linings and variable lining thickness are possible; large plastic volumes may be injected.
- *Disadvantage:* Special machinery is required to process polymers; dovetail grooves are required in metal component to mechanically lock liner into the metal; careful design is required to avoid stress concentration in the liner at the dovetail grooves.

STANDARDS FOR COMPOSITE PUMPS

To enable the users to purchase flanged composite pumps to a standard similar to ASME/ANSI B73.1M there is now an ASME/ANSI B73.5M for composite pumps. It has the following same specifications as B73.1M:

- Envelope dimensional interchangeability
- Shaft deflection requirements
- Bearing life requirements
- Seal chamber requirements
- Same balance

It differs from B73.1M by:

- The basic working pressure will be from 100 to 275 psi, depending on the size of the pump.
- The nozzle flanges will be to 150 lb dimensions, but not rating.
- The hydrostatic pressure factor above working pressure will depend on the size, speed, and manufacturing process.
- The limiting temperature will be 250°F with mild corrosive liquids. The pressure-temperature limit will be based on a manufacturer-user agreement for the liquid and its concentration.
- The specification can be applied to thermoplastics or thermosets.
- The casing, cover, and gland will have a minimum corrosion allowance of two years.

A USER'S PERSPECTIVE

A chemical process industry plant owner/operator has a need to move liquids around in order to make his end product. To do this, he needs pumps and pipes. One of the forever issues he must deal with in construction and maintenance of his plant is what to make it out of—the materials of construction. There are two approaches to the materials of construction question: one is the corrosion of the equipment by the chemicals being pumped, and the other is the purity requirements of the process, i.e., the effect of corrosion products on the purity of the final product.

The traditional material for pump construction is cast metal. As the process corrosiveness increases and/or the purity requirement increases, the cost of the required metallurgy increases. At some point the logical question is: what about plastics? Many of them are chemically resistant. Some of them are strong enough to build a pump from directly. Others can be strengthened by reinforcements, i.e., composites. For the purposes of this tutorial, the term "composites" also includes lined pumps. Metal versus composites—how to decide?

One consideration is cost. Table 3 is a comparison of the cost of two sizes of ANSI pumps in two composite materials of construction. These are list prices of bare pumps with double seals (no supply tanks), except the magnetic drive pump, which is a long coupled model. First cost alone, however, is not sufficient information to make a decision. The process requirements frequently override just cost.

Table 3. Typical Polymer Composite Pump Costs.

Pump Size	Teflon® lined		Bare Metal		Fiberglass Reinforced
	sealed	mag-drive	stainless steel	Hastalloy C	
1.5 × 1-6	$5300	$5700	$4900	$10000	$2500
4 × 3-10	$10500	$13000	$8500	$11800	$4500

Process Considerations

Process considerations are probably more important than price when deciding which material of construction to use. There are some processes where there are essentially no acceptable metals. A good example of this are those that use or produce hydrochloric acid, especially hot hydrochloric acid. In fact, most chloride chemistry processes are big users of nonmetallic pumps and piping. Another example is ferric chloride, which is used in water purification.

Metal plating solutions are good examples of both concerns: corrosive and corrosion products from the pumps or piping would have an adverse effect on their performance. Some agricultural chemicals are the same way, especially during their manufacture. The intermediates are very corrosive and heavy metal corrosion products in the finished product are very undesirable. Another process stream where composite pumps and piping should get careful consideration is deionized water. The corrosiveness of deionized water is frequently underestimated.

Considerations When Using Composite Pumps

Once the issue of materials of construction has been resolved, it falls to the mechanical designer to work out the details of proper application and installation. Composite pumps have mechanical limits that are more restrictive than metal pumps. Some of them are:

- *Structural loads*—the nozzles on fiberglass reinforced pumps are not as strong as those on metal pumps. They cannot support pipe weight, especially metal pipe. The pipe weight must be completely supported by proper pipe anchors. The nozzles also will not tolerate excessive stresses from pipe misalignment. Expansion joints are usually recommended on the suction and discharge flanges to eliminate alignment stresses. This does not remove the need to do careful pipe fabrication, because if the expansion joints are too badly distorted by faulty pipe alignment, the expansion joints will fail prematurely. Another reason for removing pipe weight loads and misalignment loads from a fiberglass reinforced pump is that the casing feet are not as strong as those on a metal pump. The nozzles on lined pumps are as strong as those on bare metal pumps, because the metal armor of the pump makes it essentially the same as a bare metal pump.

- *Temperature limits*—the polymers in composite pumps have lower temperature limits than metal pumps. The highest temperature polymer is PFA Teflon®, which has a limit of 450°F; next is Tefzel® fluoropolymer with a limit of 250°F. Fiberglass reinforced plastic (FRP) pumps have a maximum temperature limit of 200°F; although the limit for some chemicals is lower, because the severity of attack increases with increasing temperature. For thermoplastics, the temperature limit may be well below 200°F, due to a combination of chemical attack and simple loss of structural strength with increasing temperature. Composite pumps and piping require more attention to temperature limits than bare metal pumps and piping.

- *Internal metal parts*—most composite pumps have some internal metal parts to provide structural strength. Most commonly they are cores in the shafts and inserts in the impeller. At the joints where these metal parts connect to other parts, gaskets or other secondary seals are used to protect the metal from the process chemicals. The user must recognize that these gaskets or secondary seals are used in places where they may not exist in metal pumps, and check that those gasket materials are compatible with the process.

- *Gaskets*—all pumps have internal gaskets between major components, for example, between the casing and the rear cover. Problems can arise because the overall configuration of composite and bare metal pumps may appear the same, but many times the torque required to seat these gaskets is significantly less than that required for metal pumps. Over tightening can damage the gasket, the gasket seat, even the whole part. Extra instruction of the mechanics and operators is frequently necessary to prevent structural damage and leaks.

Considerations When Using Composite Piping

Chemical processes that benefit from composite pumps frequently also benefit from composite piping. Composite piping can be either thermoplastic, fiberglass reinforced, or lined. In addition to the considerations around chemical compatibility and temperature already mentioned in regard to pumps, composite piping has its own considerations versus metal piping.

Lined pipe is the most metal-like, because it does have a metal pipe armor outside the lining. Span lengths are the same as bare metal pipe. Pipe supports and anchors can be the same as bare pipe. One significant difference is that some chemicals will permeate a polymer lining. The amount of vapor that permeates through depends on the chemical and temperature. All lined pipe has vents along its length and on the fittings. These vents must be left open. If they are plugged, the vapor will build up between the lining and the metal armor, collapsing the lining, which blocks the pipe. If the pipe is insulated, the vents should be extended beyond the insulation (Figure 11). Another troublesome situation is cold processes (below 0°F). Shrinkage of the lining and the gasket at a flanged connection can cause a loss of bolt preload and a leak. Belleville washers have been used successfully to overcome that problem (Figure 12).

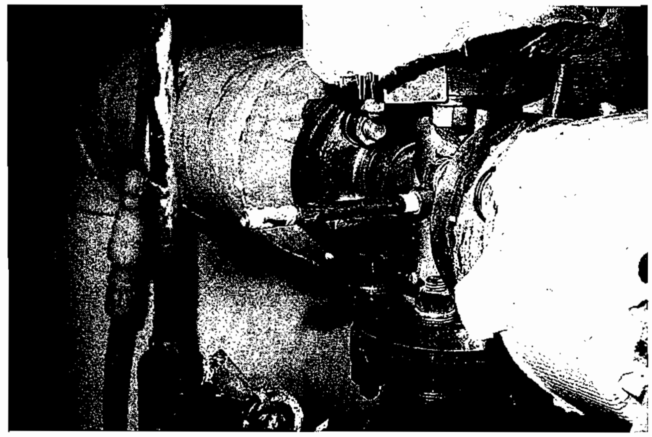

Figure 11. Lined Pipe Vent Extended Beyond Insulation. (Removed for Maintenance.)

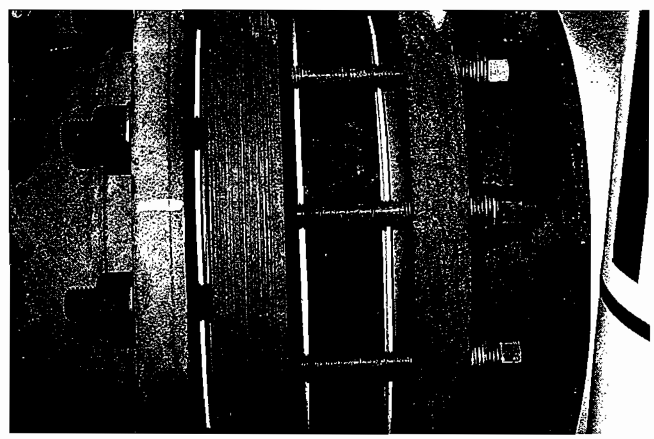

Figure 12. Flanged Joint with Belleville Washers under the Studs.

Thermoplastic and fiberglass reinforced pipe are significantly different from metal pipe. They are essentially brittle materials; they lack toughness. They should never be used for compressed gases. Water hammer should be avoided at all costs. Things like dashpot loaded check valves and soft start motor controllers are recommended in larger sizes to control water hammer. Span lengths for thermoplastic and fiberglass reinforced pipe are shorter than metal pipe. For two inch pipe size and less, cable trays are frequently used to support the pipe between stanchions.

The thermal coefficient of expansion of thermoplastic and fiberglass reinforced pipe is significantly more than metal pipe. For example, the coefficient for PVC pipe is 5× that of steel: 45 versus 8.5×10^{-6} /in/in/°F. The coefficient for fiberglass reinforced pipe is typically 2× that of steel. When there are long runs, the overall length change from ambient to operating temperature should be checked and accounted for. This is especially true for pipe laid in a cable tray.

As has already been mentioned around pumps, thermoplastic and fiberglass reinforced pipe needs to be fully supported by anchors at the ends where it connects to the pump. They should also be guided along their whole length to take up expansion by elastic compression, rather than bending and subsequent cracking. Expansion joints are recommended, both for thermal expansion reasons and to isolate the pipe from any pump vibrations. From a safety standpoint, it is advisable to put covers over the expansion joints to protect personnel from leaks spraying out (Figure 13). The weight of valves should not be supported by the pipe; it should be independently supported.

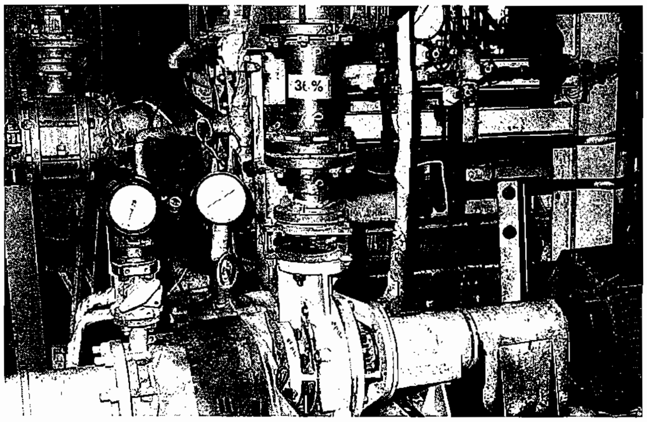

Figure 13. Fiberglass Reinforced Composite Pump with Expansion Joints on Suction and Discharge. (Discharge Cover Removed for Maintenance.)

Sealed and Sealless Pumps

Seals on composite pumps require extra attention because they contain metal parts, which is at odds with the reason for choosing composite construction in the first place. Sometimes outside seals are suggested to move the metal parts outside the process stream. Outside seals should be evaluated carefully because when they leak, they can spray the process chemicals several feet. Some manufacturers provide shields to direct the spray down toward the base, but it is too easy to leave the shield off after maintenance.

Frequently, dual seals are selected because they can contain hazardous chemicals more positively than single seals. Dual seals bring with them the added cost of a barrier fluid supply tank and the supply tank instrumentation. Plus, a compatible barrier fluid must be chosen. The many details of dual seal systems are outside the scope of this tutorial.

One significant area where sealed composite pumps differ from their metal cousins is the details of the secondary seals. Secondary seals are those parts that seal the joint between the mechanical seal parts and the pump parts, for example, the seal between the stationary mating ring and the pump seal chamber. They are most typically elastomer O-rings, but they may be flat gaskets. The issue for thermoplastic pumps and lined pumps is that the pump surface is soft and indents over time, allowing a leak. A related problem is that these soft surfaces are supposed to locate the seal parts, keeping them square and concentric to the shaft. If (or when) they cold flow out of square, the seal will leak. In that case, there is little alternative to replacing the composite parts.

All sealless composite pumps are magnetic drives, as there are no composite canned motor pumps on the market. They are most frequently lined pumps, although there are a few thermoplastic magnetic drive pumps. Sealless composite pumps are mostly smaller pumps. There is only a limited selection available over eight inch impeller diameter. One real advantage they have versus metal magnetic drive pumps is that their nonmetallic rear containment shell does not suffer from eddy current heating. This eliminates the heat input to the process that occurs with a metal rear containment shell, which can be a real advantage when operating in the left portion of the pump curve or with liquids near their boiling point. This also gives them an efficiency advantage *vis-à-vis* a pump with a metal rear containment shell.

They do, however, have all the other application limits common to sealless pumps; i.e., they do not tolerate solids well, they do not tolerate entrained gas well, and running dry damages them quickly.

Operating Examples

Agricultural chemicals—An example of a chemical process that uses PFA lined pumps and piping is one that makes an agricultural chemical intermediate using hydrogen fluoride as one of the feedstocks. The entire reaction and purification process is so corrosive that every vessel, pipe, and pump is PFA lined. One step in the process is cooled to $-15°F$. All the pipe flanges used for that part of the process use Belleville washers to maintain gasket compression when the gaskets and liners contract during cooling (Figure 12). The lined pipe runs in the cold part of the process are insulated. The vents are brought out through the insulation (Figure 11). The magnetic drive circulating pump for this cold process stream has a nitrogen purge into the housing surrounding the rotating outer magnets to exclude atmospheric moisture, so it will not condense and freeze on the outside of the magnet containment shell. Without the purge, the condensed water and ice accumulation inside the housing and magnet rotor cause problems.

Due to the hazardous nature of the process chemicals, all but one of the pumps are magnetic drive. That one pump is double sealed with a barrier fluid tank and a pumping ring in the seal. The seal tank has a pressure switch and a level device. Both of them alarm in the control room. The sealed pump was chosen for that location because the process stream contains solids.

One unusual problem with the magnetic drive pumps was that after several years enough hydrogen fluoride permeated the PFA encapsulating the inner magnets to corrode the metal magnets. Those corrosion products caused enough swelling to the magnet capsule that it rubbed the inside of the containment shell. The only solution was to replace the entire inner rotor.

Waste recovery—Another process that relies exclusively on nonmetallic pumps and pipes is the recovery of hydrogen chloride. A process to produce a polymer intermediate makes weak hydrochloric acid as a waste stream. Rather than incur the expense to neutralize, then dispose of, that stream; the weak acid is first concentrated, then anhydrous hydrogen chloride gas is recovered for sale. Needless to say, the equipment to concentrate the acid and then strip off the hydrogen chloride gas must be very corrosion resistant. A significant part of the economic viability of the recovery process depends on long equipment life.

The pumps used for the first processing steps are 3×4 and 4×6 fiberglass reinforced composite pumps. All these pumps have double mechanical seals. The piping is also fiberglass reinforced composite with rubber elastomer expansion joints on the pump suction and discharge flanges (Figure 14).

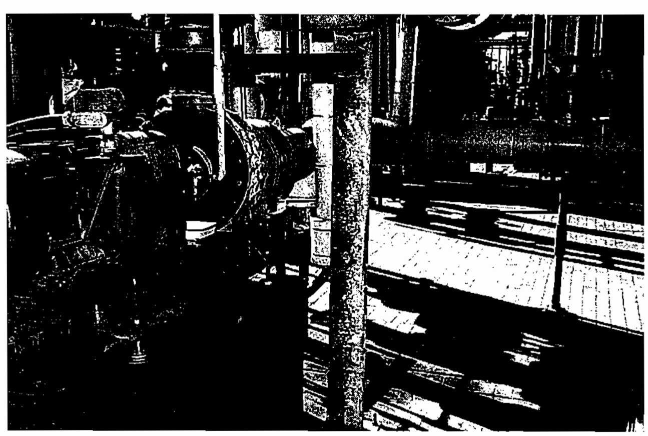

Figure 14. Fiberglass Reinforced Pipe with Expansion Joints and Pipe Supports.

At the end of the process train, where the vapor is stripped, the temperature approaches 200°F. Reinforced composite does not have sufficient chemical resistance for this temperature, so PFA lined pumps and pipes are used there. Fortunately, the flows are also less than at the front end of the process, so the size limitations of lined magnetic drive pumps are not a problem.

Both processes described have been in operation for several years. During that time, the composite pumps and piping have proved to be a sound investment.

CONCLUSION

The development of polymer composite pumps and piping has provided chemical plant owner/operators with equipment that has excellent corrosion resistance. Polymer composite equipment is most frequently used in applications where:

- The corrosion rate of metallic equipment is unreasonably high and/or the cost of metallic equipment exceeds that of polymer composite equipment.
- The purity requirements of the process stream are such that metallic corrosion products are not acceptable.

The physical properties of polymer composites are significantly different from metal and it is important to understand these differences when selecting and installing composite equipment. Some of the more important considerations are:

- Temperature limits are lower than metals.
- Thermal expansion is greater than metals. At bolted joints, this may cause leakage problems because of the differential between the composite and metal bolts. In piping runs, the increased growth in length must be accommodated.
- Composites have lower strength, which means bolting torque at bolted joints must be lower than at similar metallic joints. This requires reeducation and reminding. Lower strength means fiberglass reinforced pipe and thermoplastic pipe must have shorter span lengths than metallic pipe. Expansion joints should be used at pump flanges for vibration isolation.

To repeat, in closing, the principal advantage of polymer composite pumps and piping is the absence of corrosion and fouling from corrosion products in selected chemical processes.

DISCLAIMER

These data and notes are for use as general guidance. No recommendations are intended as a guarantee by the author or other sources. Pump manufacturers and material suppliers will or can supply application information.

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