SECTION 5.2
MATERIALS OF CONSTRUCTION FOR NONMETALLIC (COMPOSITE) PUMPS

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The use of composite materials is playing an increasing role in the manufacture of industrial pumps due to the cost savings they offer in manufacturing, installation, and operation. Composite parts can be molded to near "net shape." This eliminates the cost of secondary machining to attain the final part. Because one composite material can replace two or three different grades of metal part, the combining of several parts into one assembly is possible. This parts integration reduces assembly time, reduces inventory, and ultimately reduces manufacturing costs.

Because composite pumps weigh less than metal pumps, they are easier to handle during installation and maintenance. Further, because composites naturally dampen vibration, a composite pump operates more quietly than a comparable metallic pump.

The corrosion resistance of composites is superior to metals. For this reason, a composite pump's life can be significantly greater than a metallic pump. When the amortization costs of both composite and metallic pumps are calculated, the composite pump has the cost advantage.

FACTORS TO CONSIDER

Factors to consider in using composite materials for pump parts are mechanical properties, abrasion and corrosion resistance, temperature, costs, weight and insulating properties, exposure to sun, fire resistance, and chemical resistance.

Mechanical Properties The composite pump or parts must be designed to withstand the loads/stresses of the operating conditions. If the existing metal part design were simply replicated in a composite, the composite part could fail. Excessive stresses for a composite pump at the nozzle area or at the bearing housing can cause the pump housing to creep. The result is part distortion or bending and shaft misalignment.

A solution to this problem is to calculate the stress levels in the composite part and design within the composite's elastic limit. These complex stress calculations are now done on a routine basis with the aid of a computer and non-linear FEA (finite element analysis) programs.

Abrasion and Corrosion Resistance The abrasive wear on 316 stainless steel is caused by the continuing removal of the metal's protective oxidation layer on the metal's surface. Composites do not need a protective layer and therefore have better resistance to mild abrasives. However, some composites are subject to corrosion by caustic liquids.

As background, metallic materials deteriorate from any one or combination of the following electrochemical reactions: galvanic action, pitting, corrosive attack, crevice corrosion, intergranular corrosion, and stress corrosion. The temperature, pH, formation, removal of an oxide corrosion barrier, or the velocity of the solution affects the rate of corrosion in a metal's surface.

Temperature Most composite pump materials are limited to operating temperatures below 300°F (150°C) for non-corrosive liquids and under 250°F (120°C) for corrosive liquids. Like metals, there is a reduction of mechanical properties for composites with increasing temperature.

Costs There are three areas of cost to consider when evaluating a composite part: development costs, initial capital costs, and cost savings.

Developing costs would include the following:

- Designing the part for composites
- Evaluating and testing alternative composite materials
- Prototype molding the parts

Initial capital costs are in the cost of the molds to produce the parts. Cost savings in manufacture and use include the following:

- Little or no corrosion increases the time between maintenance and extends the useful life of the pump.
- Reduced secondary machining cost at manufacture (the parts are near "net shape")
- Integrating several parts into one assembly results in a less expensive part, lower inventories, and less assembly time.
- Quality control cost is reduced as part tolerance is primarily determined by the mold.

The initial cost of a composite pump versus a metallic pump is typically as follows:

- equal or slightly more expensive than an all 316 stainless steel pump
- 80% the cost of an Alloy 20 pump
- 50% the cost of a Hastelloy C pump

Weight and Insulation Properties With a significant reduction in weight compared to metal, the composite pump is easier to handle during installation and maintenance removal. As an example, an immersion sump pump that is usually 3–10 ft long weighs only 10–30% of a comparable metal pump.

Added insulation on the pump to conserve high temperature process heat is usually not needed on a composite pump, as the composite is a natural insulator when compared to metal. This saves the cost to fabricate an insulation cover over the pump and provides easier access for maintenance.

Exposure to the Sun Some composites are susceptible to the UV (ultraviolet) rays of the sun. 2% carbon black in the resin is an effective UV blocker. HALS (hindered amine light stabilizers) can also be added to the composite to effectively prevent damage by the UV rays of the sun.

Fire Resistance In a severe fire, thermoplastic composites will melt and burn and thermoset composites will char and ash. If the composite reaches 400–500°F (204–260°C), there will be distortion of the pump and the pump will be lost. Because of the insulating properties of a composite pump housing, however, the liquids inside the pump will be cooler than if the pump were metal.

Fire retardant additives can be used with composite materials, but they may affect optimum mechanical properties. Most thermoset composites are self-extinguishing in a fire, but the pump manufacturer should be consulted to determine if there is a potential for toxic fumes if the composite is burned.

CHEMICAL RESISTANCE OF COMPOSITES

Composites do not corrode because they are non-conductive. Therefore, an electrochemical reaction does not take place. (An exception to this may be when electrically conductive long carbon fibers are used in the wrapping of a pressure vessel or a pump housing.) Their lack of resistance to different chemical fluids can degrade composite materials. This degrading can be in the resin, the reinforcing fiber, or in the coupling agent between the resin and fiber. If a composite material is going to be degraded, it will usually be immediate. Fluid temperature and concentrations are vital when selecting the appropriate composite material. With some composites, such as nylon, the pH can be a factor when selecting the best composite material for the application.

As an initial test, a sample coupon of the composite can be immersed in the process liquid and the results noted. A more definitive method is to review the composite manufacturer's informational database on chemical resistance. Many composite manufacturers have run extensive chemical resistance studies of their materials in a variety of liquids at set temperatures over time. The composite's physical properties are measured before and after the test period and the percentage deterioration versus time is documented in the manufacturer's literature.

The Hydraulic Institute, discussed later, has a polymer material selection guide that recommends specific composites for various liquids.

TYPES OF COMPOSITES

Composites can be divided into two general groups of organic compounds: thermoplastic and thermoset.

Thermoplastic Thermoplastic materials can be repeatedly melted and solidified. They do not go through an irreversible chemical process when heated. Amorphous thermoplastics resins have a broad softening range and are suitable for processes that require good melting strength like thermoforming. They can be transparent in color but do have limited chemical resistance.

Crystalline thermoplastic resins have a sharp melt point and are better suited to molding processes like injection molding where melt strength is not required. They have excellent chemical resistance. Their physical properties can be modified and improved with the addition of glass or carbon fiber, tougheners, or mica. Chart 1 shows the effect of various reinforcement materials on selected polymers.

Some of the thermoplastic processes that are used to form pump parts are injection molding, vacuum forming, extrusion, and blow molding. Thermoplastic resins suitable for pump applications include floropolymers, acrylics, polyethylene, polypropylene, polyvinyl chloride, and others. The allowable temperature range for these materials is from

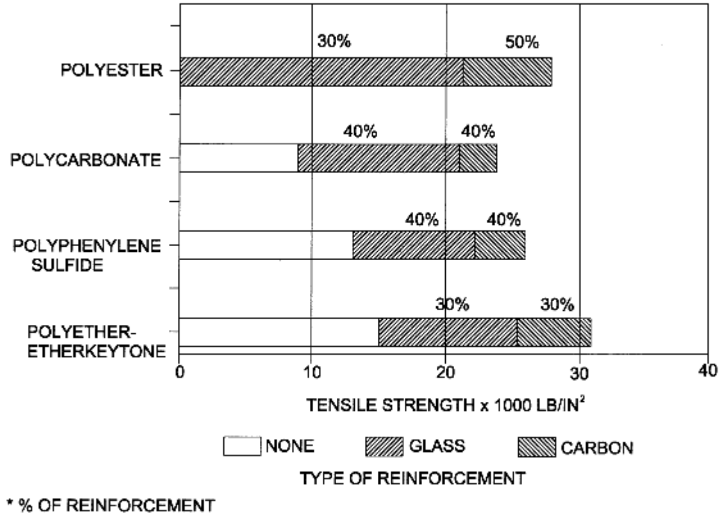

CHART 1 Thermoplastics strength versus reinforcement

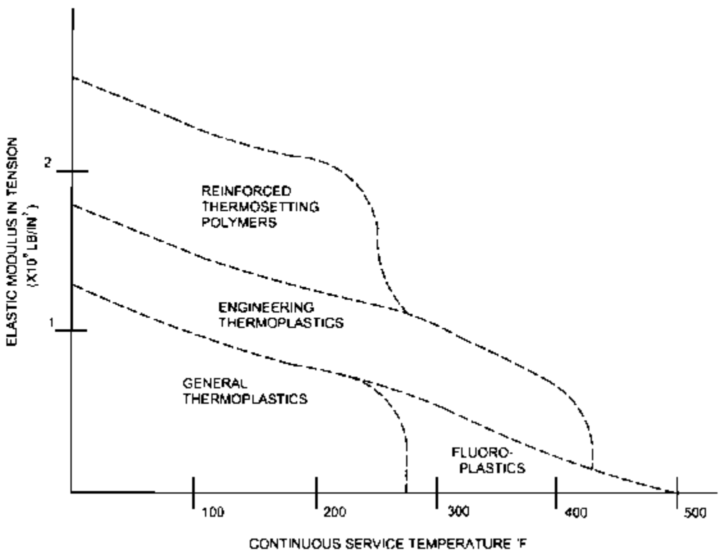

FIGURE 1 The effect of temperature on modules of elasticity

130–300°F (54–150°C), depending on the material. Figure 1 shows the elastic modulus versus service temperature for various polymers.

Thermoset Thermoset materials, when heated, go through an irreversible chemical change with the result that the material will not soften when reheated. Thermoset resins are generally reinforced with glass fiber, linen, carbon fiber, graphite, minerals and so on.

TABLE 1 Differences between Thermoset and Thermoplastic

Process	Thermoset	Thermoplastic
Average range of molded thickness	.030 to 2.00 in (0.75 to 50 mm)	.06 to .50 in (1.5 to 13 mm)
Weight range of piece	1 to 500 lb (0.5 to 225 kg)	0.5 to 5.0 lb (0.22 to 2.26 kg)
Glass content by volume	50 to 60%	30 to 40%
Length of glass fiber	0.25 in (6 mm) to several inches (mm)	0.06 in (1.5 mm)
Strength	Not uniform throughout	Uniform
Minimum annual quantities	Less than 1000	10,000
Obtain strength from ribs	Not necessarily	Yes
Tooling	Depends on complexity and size	Generally 20 to 30% higher than compression molding
Process	Compression or resin transfer	Injection, cannot use compression molding.

They have an allowable application temperature range of 180–250°F (82–120°C), depending on the material. Examples of thermosets are epoxies and vinyl esters. They can be stronger than thermoplastics but are usually more brittle. Thermosets are processed by comparison molding or transfer molding. They have good chemical resistance to acids, bases, and oxidizing agents.

Table 1 outlines the differences between thermoset and thermoplastic polymers.

LINED PUMPS

To provide chemical resistance for a metallic pump, it is possible to install a flexible, rigid, or sprayed-on liner inside the pump housing. With a flexible lined pump, a metal casing is made to the design shape and pressure. Then a loose liner is fitted inside the pump housing and bonded to the metal casing with an adhesive. This type of liner can come loose under vacuum conditions. There also can be problems at the termination of the liner to the mating pipe flanges.

A resin used in some lined pumps is PTFE (polytetrafluoroethylene). By itself, PTFE does not have the physical properties needed for a pump housing. When it is supported by a metal housing, however, it provides an excellent lining material due to its outstanding range of chemical resistance at high temperatures.

Rigid pump liners are machined out of plastic stock shapes or molded into a near net shape. The liner is then mechanically compressed between bolted steel plates to provide the support. Such pumps are usually small in size.

A sprayed-on composite lining is made by taking a metal casing of the required pressure rating, heating it, and then spraying the composite material inside the housing and flanges. At 0.030 in (0.76 mm) thickness, the lining will not have pinholes and is suitable for pump applications. This lining process is usually limited to pumps that require up to 100 horsepower (75 kW) drives.

Table 2 gives an overview of the comparative advantages and disadvantages of the different styles of pumps.

CERAMIC AND CARBON PUMPS

Solid ceramic or carbon pumps are used for very hostile liquids such as concentrated hydrofluoric acid. Ceramic and carbon pumps are much more expensive than non-metallic pump materials, but do have the chemical resistance required for extremely aggressive chemicals.

TECHNIQUES FOR MOLDING PUMP COMPONENTS

Injection molding is a process for high volume forming of high quality thermoplastic parts. The part cost is low, but the initial mold costs can be high. The reinforcing materials for injection molding are short strand fibers (0.06 to 0.50 in or 1.5 to 13 mm long) and are glass, graphite, mica, and so on.

Compression or transfer molding uses thermoset resins and can make small quantities of larger parts. The mold costs are less, but the part price is usually more due to trimming and secondary machining steps. The reinforcing materials for these processes can be continuous or chopped mat strands, as well as woven mats and blankets. These long strand fibers give exceptional physical properties to the final part.

MECHANICAL PROPERTIES OF COMPOSITES

Composites in general have far lower physical properties when compared to steel and lower physical properties than aluminum or brass. Composites can, however, be designed to withstand the operating pressures of a pump by increasing the section modulus of the part; that is, increasing the wall thickness. Table 3 shows some unreinforced composite properties versus steel. Figure 2 illustrates where the various composites and metallic are positioned and applied on a grid of developed pressure versus flow.

Thermoplastics PVC and CPVC pumps are low-cost and suitable for the lower temperature ranges. PVC can be used up to 140°F (60°C) and CPVC, with greater abrasion resistance, is suitable for temperatures up to 210°F (100°C). PVC and CPVC can be solvent-bonded together to attain the best attributes of each resin in a single pump.

Polypropylene (PP) has excellent corrosion resistance and is used in hydrocarbon service up to 185°F (85°C). It is not suitable for strong acids or chlorinated hydrocarbons. The material can be ultrasonic, vibration, and spin welded in assembly.

PVDF (Kynar) is very corrosion- and abrasive-resistant and suitable for temperatures up to 300°F (150°C). It is also relatively expensive.

PTFE (Teflon) is extremely corrosion resistant, but its low physical properties require it to have a metal reinforcement backing to withstand high pump pressures. Table 4 is a partial list of thermoplastics used for pump parts.

Thermosets Vinyl esters and epoxies are the strongest of the thermoset composites and usually do not require external metal reinforcement. Vinyl esters are resistant to corrosion, whereas the epoxy composites are resistant to solvents. Table 5 is a list of thermosets used for pump parts.

CANDIDATE FLUIDS FOR COMPOSITE PUMPS

This section discusses some of the more general liquids that are suitable for use in composite pumps.

Chlorine and Caustics Chlorine is used in the production of organic chemicals such as vinyl chloride, chlorinated solvents, pesticides, and fluorocarbons. Chlorine is also used in the pulp and paper industry, municipal water purification, sewage treatment plants, and in the electrolysis of sodium chloride to produce sodium hydroxide. Additional fluids in this category are as follows:

- Potassium hydroxide
- Sodium chloride solutions
- Seawater, brine

TABLE 2 Comparative advantages and disadvantages of the different styles of pumps

Feature	Thermoset	Thermo-plastic	Flex-lined	Sprayed-lined	Rigid-lined
Cut impellers available	Yes	Yes	Yes & No	Yes	Yes
Potential for damage to liner in operation or repair	Low	Low	High	High	Low
Integral casing flanges	Yes	Yes	Yes	Yes	No
Efficiency	High	Med	Med	Yes	Med/Low
CPI Hydraulic Coverage	Yes	No	Yes	Yes	No
Conforms to ASME/ANSI B73.1M dimensions	Yes	No	Yes	Yes	No
Cost	Med	Low	Yes	Yes	Med/High
Pressure Capability	Med	Low	High	High	High
Vacuum Capability	Good	Fair	Low	Good	Good
Temperature Capability	Med	Med/Low	High	High	High

TABLE 3 Mechanical properties of some unreinforced composites

Property/Material	Steel	Glass	Vinyl Ester	PVC	PVDF	PTFE	PPS	PP	PEEK	Epoxy
Modules of Elasticity 1×10^6 lb/in^2	29	5	3.5	0.4	0.16	0.8	0.6	0.2	0.6	3.5
Tensile strength 1×10^3 lb/in^2	60	300	11	7	7	4	14	6	16	16
Specific gravity	7.8	2.6	1.2	1.3	1.8	2.2	1.3	0.9	1.31	2.2
Coefficient of Thermal Expansion 1×10^5 in/in/°F	0.6	0.3	2.0	2.8	8.5	10.0	2.8	8.0	4.0	2.2

Lb/in^2 $\times$ 6.894757 = kPa
In/in/°F $\times$ 1.8 = cm/cm/°C

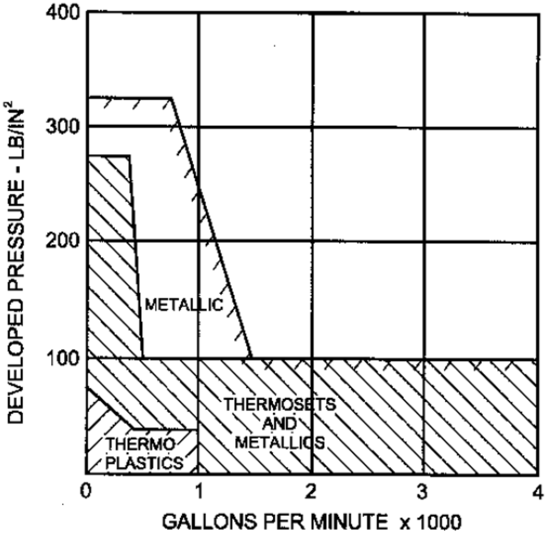

FIGURE 2 Developed pressure versus flow for composite pumps (lb/in² × 0.0689 = bar; gpm × 0.227 = m³/h)

TABLE 4 Thermoplastics used for pump parts

Chemical name	Common reference	Temperature limit °F	°C
Polycarbonate	Lexon®	250	120
Phenylene Oxide	Noryl®	194	90
Polyphenylene	Ryton®-PPS	250	120
Polyphenylene	PP	150–180	65–82
Chlorinated Polyvinyl Chloride	CPVC	230	110
Polyvinylidene Chloride	PVDC	160	70
Polyvinyl Chloride	PVC	140	60
Polyetherether Keytone	PEEK	250	120
Polytetrafluoroethylene	Teflon®-PTFE	460	238
Chlorotrifluoroethylene	Teflon®	500	260
Polyvinylidenefluoride	Kynar®-PVDF	300	150

TABLE 5 Thermostats used for pump parts

Name	Common Reference	Temperature °F	°C
Vinyl Ester GL	VE-Gl	250	120
Vinyl Ester C	VE-C	250	120
Epoxy	Epoxy	250	120

GL—glass reinforced (should not be applied to hydrochloric acid or caustics)
C—carbon reinforced

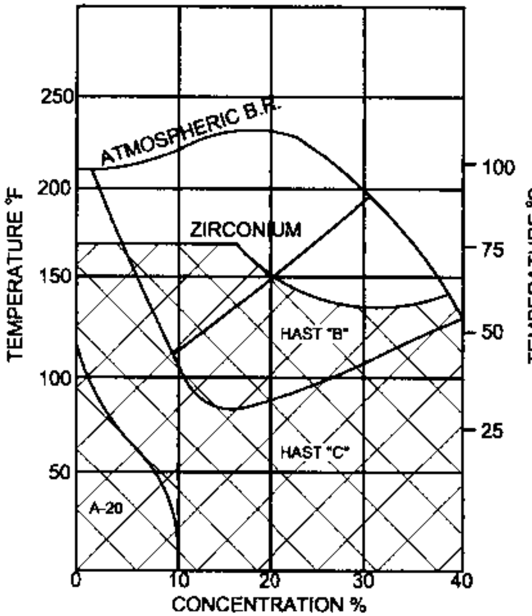

FIGURE 3 Material selection for hydrochloric acid

- Sulfuric acid diluted up to 70%
- Hydrochloric acid
- Sodium hydrochloride
- Nitric acid up to 5%

Figure 3 shows that a composite pump can handle up to a 40% concentration of hydrochloric acid at 175°F (80°C).

Sulfuric Acid Figure 4 shows the operating range of a composite pump, pumping sulfuric acid.

Ferrous and Ferric Chloride Ferric chloride is used as an etching reagent in the production of printed circuit boards. It is also used as a coagulant in wastewater treatment. In metal pickling operations, ferric is produced when hydrochloric acid reacts with iron and steel. In all of these applications, composite pumps have replaced the more costly titanium pumps.

Ethylene and Propylene Candidate applications for composites of ethylene and propylene are

- Propylene glycol
- Ethylene glycol
- Diethylene glycol
- Proplene chlorhydrin

Dyes Acid, sulfur, and Diazo dyes can be used in composite pumps.

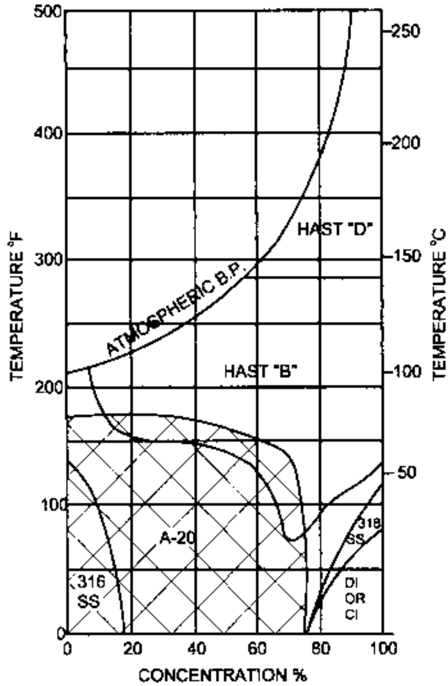

FIGURE 4 Material selection for sulfuric acid

Agriculture Chemicals Pesticides comprised of insecticides, herbicides, fungicides, and fertilizers can be severely corrosive to a composite pump. The chemical supplier should be contacted for their recommendations of materials suitable for use with their products.

Table 6 lists the maximum temperature and concentration of several liquids for various polymers.

INDUSTRIES USING COMPOSITE PUMPS

Pulp and Paper Composite pumps are used in bleaching and cooling of liquor preparation. The pumps can handle white, black, and green liquors. Other liquids suitable for composite pumps associated with this industry include

- Sulfuric acid
- Sodium chlorate
- Sodium hypochlorite
- Sulfur dioxide
- Chlorine
- Methanol
- Peroxide bleach
- Sodium chloride
- Chlorine dioxide

TABLE 6 Maximum temperatures of polymers in various liquids

Type	Fluid	Symbol	Concentration	Vinyl Ester	CPVC	PVC	PVDF	PTFE	ECTFE	PPS	Polypropylene	Epoxy	PEEK
Acids	Hydrochloric Acid	HCl	37	100 (38)	185 (85)	70 (21)	275 (135)	260 (127)	200 (93)	200 (93)	70 (21)	140 (60)	250 (121)
	Sulfuric Acid	H_2SO_4	75	120 (49)	140 (60)	70 (21)	200 (93)	500 (260)	300 (150)	80 (27)	125 (52)	NR	NR
	Nitric Acid	HNO_3	20	150 (65)	185 (85)	140 (60)	140 (60)	250 (121)	200 (93)	150 (65)	140 (60)	70 (21)	NR
Alkalies (Caustics)	Potassium Hydroxide	KOH	45	100 (38)	200 (93)	185 (85)	165 (74)	300 (150)	250 (121)	200 (93)	185 (85)	185 (85)	150 (65)
	Sodium Hydroxide	NaOH	50	210 (100)	200 (93)	NR	200 (93)	300 (150)	200 (93)	160 (71)	185 (85)	70 (21)	150 (65)
	Ammonium Hydroxide	NH_3OH	20	100 (38)	200 (93)	150 (65)	275 (135)	300 (150)	200 (93)	200 (93)	225 (107)	100 (38)	250 (121)
	Sodium Chloride	NaCl	Sat'd.	210 (100)	200 (93)	150 (65)	275 (135)	400 (204)	70 (21)	200 (93)	225 (107)	210 (100)	250 (121)
Oxidizers	Sodium Hypochlorite	NaOCl	10	180 (82)	200 (93)	100 (38)	100 (38)	300 (150)	200 (93)	200 (93)	140 (60)	NR	250 (121)
	Hydrogen Peroxide	H_2O_2	30	150 (65)	140 (60)	70 (21)	240 (115)	480 (250)	140 (60)	150 (65)	70 (21)	70 (21)	250 (121)
Organics (Solvents)	Benzene	C_6H_6	100	100 (38)	NR	NR	125 (52)	390 (200)	200 (93)	200 (93)	NR	NR	250 (121)
	Styrene	$CH_5CH{:}CH_2$	100	120 (49)	NR	NR	ND	200 (93)	ND	120 (49)	NR	140 (60)	250 (121)
	Ethyl Alcohol	C_2H_5OH	95	100 (38)	140 (60)	70 (21)	210 (100)	390 (200)	300 (150)	200 (93)	140 (60)	70 (21)	250 (121)

Corrosion resistance of common polymers in difficult process fluids. Max. recommended temperature—*deg. F (deg. C)*

NR = Not Recommended

ND = No Data Available

- Sodium hydroxide
- Hydrochloric acid

Metal Finishing Composite pumps are an excellent choice for use in this industry for two reasons:

- The chemicals used in electroplating, steel pickling, etching, anodizing, galvanizing, and plating do not chemically attack composites.
- Metal pumps can generate stray currents and could effect the plating process.

Composite pumps are natural electrical insulators, which makes them well suited for this industry.

Desalinization and Water Purification Composites can replace 316 stainless steel, duplex stainless steel and Alloy 20 on sea water distillation plants. On reverse osmosis equipment, composite pumps can be used for backwash, membrane blowdown, and intake screen wash.

Aqua Culture Composite pumps can be used for waste removal, seawater transfer, washdown, and filtering without adversely affecting sea life. This adverse reaction can occur with metal pumps. Metal pumps can have a chemical reaction with seawater and stray electrical currents generated by the pump can affect the pump's mechanical seal.

STANDARDS FOR COMPOSITE PUMPS

There are many composite pump designs for low-pressure and low-capacity use in the general-purpose market. For composite pumps in the "industrial chemical market," however, a separate standard ANSI/ASME B 73.5M has been written. This standard is similar to B73.1M for metal pumps in that it requires the same dimensional interchangeability, shaft deflection, and seal chamber requirements. The composite pump standard differs from the metallic pump standard in these areas:

- Basic working pressure is from 100 to 275 lb/in^2 (6.9 to 19 bar) depending on pump size.
- Nozzle flanges are Class 150 dimensions but not Class 150 rated.
- Hydrostatic pressure factor above working pressure will depend on size, rpm, and manufacturing process.
- Pressure-temperature limit will be based on a manufacturer-user agreement for the liquid and its concentration.
- The standard applies to both thermoplastic and thermoset composites.
- Casing, casing cover, and gland have a minimum corrosion allowance of two years.

Hydraulic Institute Material Selection Guide A material selection guide has been written with recommendations of what composite should be used with what type of liquid. This guide lists 150 liquids at various concentrations and temperatures and recommends suitable compostites for applications. See References and Further Reading at the end of this section.

PUMP CONSTRUCTION

The pump section views in Figures 5 to 8 illustrate the construction of some composite pumps.

Components Figure 9 shows various pump components made from both thermoplastic and thermoset polymers. The enclosed impellers are made of thermoplastic resins

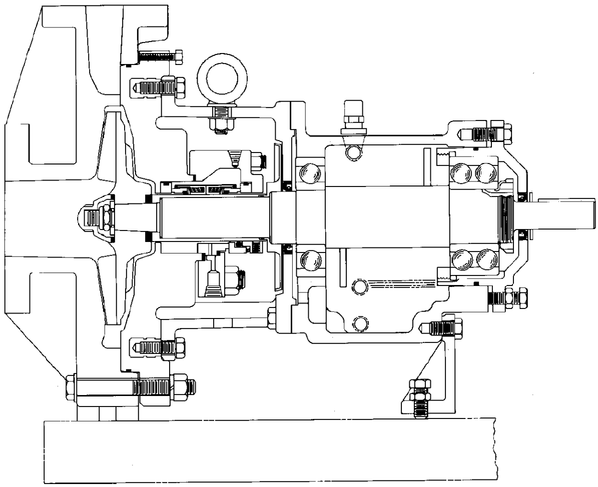

FIGURE 5 ANSI/ASME B73.5M pump (Flowserve Corporation)

because the front and back shroud can be ultrasonic- or vibration-welded together. Semi-open impellers can be made of either type of composite. On sizes greater than 6 in (152 mm) diameter, thermosets are usually used due to their superior strength over thermoplastics. When thermoplastics are used in larger impellers, a metal reinforcing skeleton is used for reinforcement. Casing and casing covers are made of either composite depending on the pump size and pressure rating.

The seal between the casing and cover is usually a shaped "O-ring" held by a groove running around the perimeter of the casing. The "O-ring" is compressed between the casing and cover with a ring of bolts around the casing's perimeter.

Shafts are made of AISI 4140 or 316 stainless steel with a thermoplastic shaft sleeve for corrosion protection. Mechanical seals are of "outside" construction to prevent liquid from contacting the metal portion (springs) of the seal.

Bedplates Composite materials have several advantages over metals and other materials when used for bedplates. Composites do not rust, rot, or deteriorate in adverse environments. The composite bedplate maintains its shape over time. This assures that the pump shafts will stay in alignment, and the pump's nozzle will not be stressed due to a sagging bedplate. The designed in features in a composite bedplate include an integral drip lip, slopping surface to collect drips, and ringed grout holes.

Disclaimer The data and notes included in this section are only for general guidance. No recommendations are intended as a guarantee by the author or other sources. Pump manufacturers and material suppliers can supply specific application information for their products when used with specific liquids in identified services and environments.

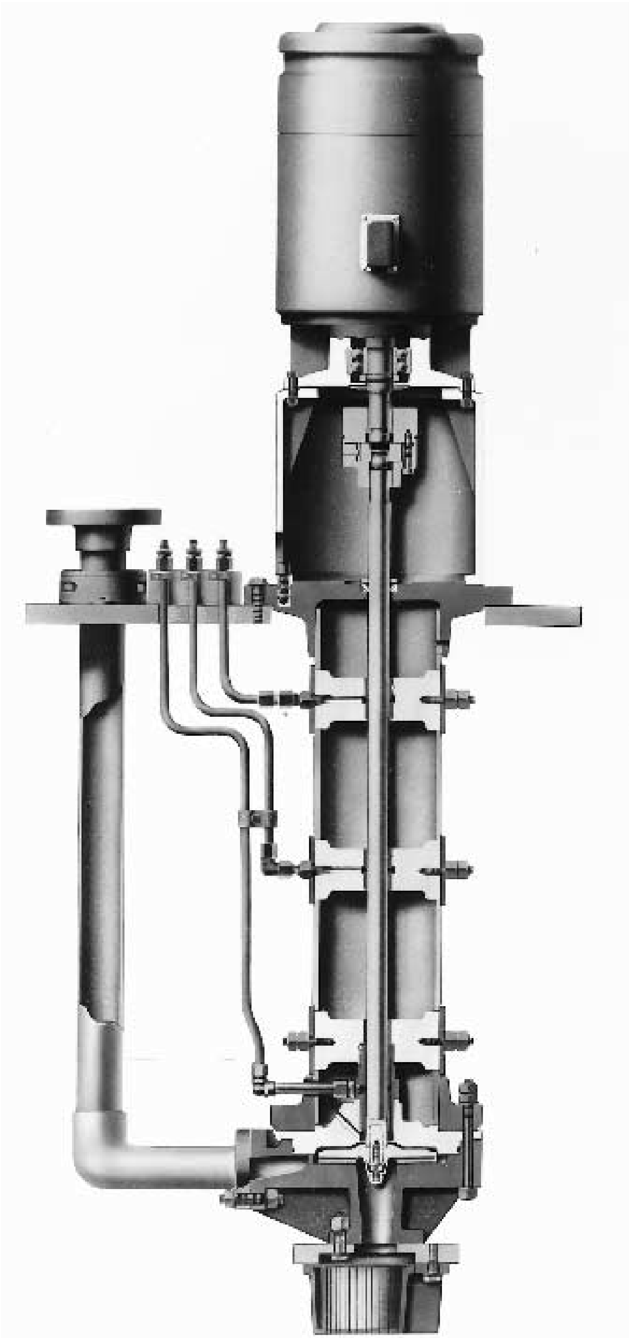

FIGURE 6 Vertical immersion pump (Flowserve Corporation)

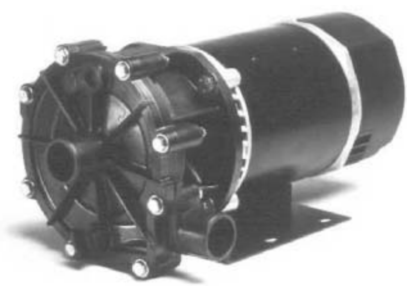

FIGURE 7 Thermoplastic coolant pump (Flowserve Corporation)

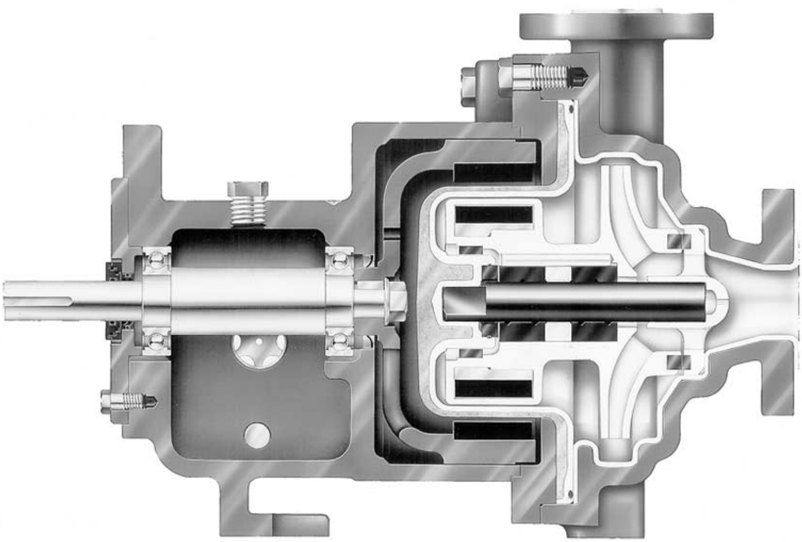

FIGURE 8 Fluoropolymer sprayed lined ANSI/ASME B73.3 pump (Goulds Pumps)

FIGURE 9 Components made of thermoset (Flowserve Corporation)

REFERENCES AND FURTHER READING

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Internet Resources

Injection Molding Magazine's listing of books: http://www.immbookclub.com

Plastic technology consulting source: http://www.rapra.net/intro.htm

Listing of plastic resources and issues: http://www.polysort.com