CHAPTER B12

PLASTIC-LINED PIPING FOR CORROSION RESISTANCE

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INTRODUCTION

Plastic-lined piping and fittings consist of a metal housing lined with chemically resistant plastic. The combination of a chemical-resistant engineered plastic liner inside a relatively inexpensive but mechanically strong pipe or fitting housing allows for the safe and economical conveyance of corrosive and dangerous chemicals. For this reason, plastic-lined pipe finds widespread use in such industries as the chemical process, pulp and paper, and metal finishing industries. It is also the desired choice when product purity is of concern, particularly when metal corrosion by-products cannot be tolerated in the process fluid. Industries requiring such purity are pharmaceuticals, food, power generation, and electronics, to name a few. When service conditions are within the capabilities of a plastic-lined piping system, it is often an economical alternative to expensive alloy piping. The methods of lining vary, but all achieve the same goal: to ensure that the liner and housing expand and contract as one unit, even though plastic and metal have greatly differing rates of expansion and contraction.

History

Plastic-lined pipe was first manufactured in the early 1940s and sold commercially in 1948.[1] The first piping system was made by mechanically reducing or swaging a steel tube housing down onto an extruded polyvinylidene chloride (PVDC) resin liner. Initially, plastic-lined pipe was not widely accepted by the chemical processing industries because the PVDC liner could only be used for acids and caustics to a maximum service temperature of 175°F (79°C). As new high-performance resins and different manufacturing techniques were developed, plastic-lined pipe was taken more seriously as a cost-efficient method of fighting corrosion.

Thanks to high standards developed by the various manufacturers in the plastic-lined pipe industry and more than 50 years of success in very aggressive applications, plastic-lined pipe is a proven and accepted piping product wherever corrosive chemicals must be conveyed.

METHODS OF MANUFACTURE

The plastic-lined pipe industry uses both extrusion techniques for melt-extrudable type resins or sintering methods for processing polytetrafluoroethylene[2] (PTFE) powder resins into their final forms. Sintering can be defined as forming a coherent bonded mass by heating a powder without melting it. The following sections provides a brief description of the type of processing used by the various manufacturers of plastic-lined piping products.

Liner Manufacturing Processes for PTFE Liners

Although PTFE fluorocarbon resins are thermoplastic materials, they do not flow readily as do most thermoplastics. Instead when PTFE melts at 647°F (342°C), it changes from a white solid to a transparent rubbery gel. Because of the extremely high viscosity of the melted PTFE, special techniques have been developed for converting granular PTFE resins to finished products. The basics steps common to all of these techniques are

- Compaction of the granular resin at a relatively low temperature into a compressed form so that it can be handled
- Heating of the compacted resin above its melting temperature (commonly called sintering) so that the polymer particles can coalesce into a strong homogeneous structure
- Cooling of the sintered product at a controlled rate to room temperature to achieve the desired degree of crystallinity development

Voids caused by insufficient consolidation of PTFE resin particles during preforming may appear in the finished articles. With reference to a temperature, for example 73°F (23°C), PTFE-liner specific gravities below 2.11 indicate a high-void content. The minimum accepted standard specific gravity as defined in ASTM F 1545 for PTFE-lined pipe is 2.14. Although void content is determined largely by particle characteristics and preforming conditions, sintering conditions can also have an effect. Sintering at too high or too low a temperature can increase void content.[3,4]

A number of processes are used to produce PTFE pipe and fittings liners. These are described below:

Paste Extrusion: This is the original method of producing cold-formed tubing from PTFE resin. PTFE resin is mixed with a lubricant, such as naptha, and is compressed into a dense billet. The billet is loaded into an extrusion chamber and is extruded under great pressure through a die-and-core pin combination. The resultant shape is a tube with a tightly controlled inside and outside diameter. The tube is then heated to drive off the lubricant and then sintered in an oven in a controlled time-and-temperature cycle. The tube may be used as a pipe liner or as a liner for elbows.

Isostatic Molding: This method is analogous to powder-metal sintering, in that the PTFE resin is compressed in special precision molds under great pressure to form a near-net shape. For lined piping products, the shape is either a tube, which will be used as a pipe liner, or a fitting shape, which will be used as a fitting liner. Pipe liners must be produced using special molds that consist of precision-machined cylinders and mandrels. After the PTFE is compressed, it is sintered in an oven in a controlled time-and-temperature cycle. The PTFE liners shrink approximately 3 to 5 percent during the sintering process, so the manufacturer must compensate for this shrinkage in the mold design.

Ram Extrusion: Ram extrusion is a continuous process in which the specially formulated granular PTFE resin is first fed to the charging unit, compacted at room temperature, then heated above its melting point (commonly called sintering) and then cooled back to room temperature. The above sequence of events is carried out in a single piece of equipment (vertical or horizontal) rather than in several operations as is common with other PTFE-forming methods. Succeeding ram cycles cause the compacted resin charges to advance, step by step, through the heated extruder die where sintering takes place. The process allows for the continuous production of extruded PTFE tubing of very controlled wall thickness.[5]

Tape Wrapping: PTFE resin is compressed into a billet from which a continuous narrow thin tape is *skived,* resulting in a tape very nearly identical to pipe thread sealant (plumber's tape). This tape is then wound crossways around a long mandrel in many layers, building a thickness that will eventually be the liner thickness. The tape-wrapped mandrel is put into a sintering oven, and a time-temperature cycle sinters the PTFE into a continuous tube.

Thermoplastic Liner Manufacturing

The other widely used thermoplastic liners such as polypropylene (PP), polyvinylidene fluoride (PVDF), and perfluoroalkoxy (PFA) are melt processed and are either extruded in tube form for piping or injection or transfer-molded for fittings, spacers, and valves.

Pipe and Fitting Lining Techniques

Pipe Lining. The key to successfully manufacturing lined pipe is to combine the plastic liner with a metal housing such that the two will expand and contract as one, particularly when subjected to thermal changes common to the chemical process industry. There are a number of methods for inserting the liner within the steel pipe, used by various manufacturers. Each has its benefit as well as its limitations. They are as follows:

The first patent for lined pipe was granted in 1962[6] for a process by which an oversized liner is first drawn through a sizing die directly into a flanged pipe housing. The liner is allowed to expand against the housing by heating the pipe and liner in an oven that is programmed to provide a carefully controlled time-and-temperature cycle. This method first induces stresses into the liner, then relaxes those same stresses in the oven. The result is a liner which is locked into the housing, providing thermal stability and vacuum resistance. A modified oven cycle for pipe that can be field fabricated results in a moveable liner that exhibits the same thermal stability and vacuum characteristics as the locked-in liner.

Another method involves inserting an oversized plastic liner into an oversized steel tube and then mechanically reducing (swaging) the steel down onto the liner to lock it in place, thus imparting a compressive force on it. The interior of the steel tube is roughened (picked) for the thermoplastic liners and grooved for PTFE. The picking helps anchor the liner and the grooves create an internal venting system for the PTFE lined product.

This manufacturing technique literally grips the liner and facilitates the plastic and steel to act as a single unit during thermal cycles. The amount of compression imparted to the plastic liner is easily demonstrated by measuring the liner push-out resistance of a swaged spool versus that manufactured by other techniques.

The last method is by simply placing a loose liner into a steel pipe housing. Although this method may serve the function of having a liner within the pipe, practice has shown that such lined systems do not perform well under thermal cycle conditions and can lead to premature failures.

Lined Fittings and Valves. PTFE fitting liners may be isostatically molded one of two ways:

- Outside the housing in special molds, which allows for quality assurance checks on the liner after molding
- By using the actual fitting as the mold, which eliminates the need for special molds.

The thermoplastic liners such as PP, PVDF, FEP, (perfluoroethylene propylene) and PFA are lined by traditional extrusion, injection molding, or transfer-molding techniques. The casting or fabricated-steel fitting is fitted with an internal mold that creates an annular space between itself and the metal housing. The melted plastic is injected into the annular space to form the actual lining. Unlike pipe, the sealing plastic face is molded in place as the fitting is being lined. The result is a seamless plastic with uniform wall thickness.

Spacers. Thermoplastic spacers are used as transition pieces when mating plastic-lined pipe or fittings next to other types of pipe equipment such as alloy piping, tanks, or pumps. Their purpose is to provide a firm surface against which the plastic-lined pipe end forms a positive seal. The bore of the spacer is equal to the inside (ID) diameter of the plastic-lined pipe with which it is used. The spacer also protects the plastic-lined pipe end (flared face) from damage which may be caused by imperfections in the surface of the dissimilar material. Often a gasket is added between the spacer and the dissimilar material to assist in providing a good seal and to protect the surface of the spacer. Spacers are generally first injection molded into 0.5-in-(12.7 mm) thick panels, and then separate panels are pressure formed to each other to form a solid plastic block of a desired thickness. The solid plastic block can now be machined to create a specific spacer type. PTFE spacers are available in solid plastic form in a ring or full-face configuration, or with a steel or ductile-iron housing. Solid PTFE spacers are machined from sintered cylindrical billets. For extra mechanical strength, solid PTFE spacers made with glass-filled resins are also available.

When connecting lined pipe to an unlined flat-faced flange, use a minimum 0.5-in-(12.7 mm) thick plastic spacer of the same material as the plastic liner for NPS 1 (DN 25) through NPS 8 (DN 200) pipe sizes and at least a 0.75-in-(19 mm) thick spacer for NPS 10 and 12 (DN 250 and 300) pipe. For installing butterfly valves, use tapered bore spacers with the larger bore adjacent to the valve side. Use blind spacers when blanking off lined pipe, fittings, or valves. For small-angle direction changes, use a tapered face spacer. If in doubt about the spacer material, one can always use a reinforced PTFE spacer, as it will handle all temperatures and all but a few chemical systems.

For a full listing of the types of spacers available, consult the manufacturer. Also, spacers may be used only in accordance with the applicable piping code requirements.

Finished Pipe Fabrication

Flange-end options for lined pipe are dependent on the type of method used to fit the liner into the steel housing. For lined pipe that is swaged, a threaded-chamfered flange or a threaded-chamfered stub end fitted with a rotatable flange is screwed onto the pipe end. Although threaded flanges can also be used with all other pipe housings, a rotatable flange is typically used on other fabrication methods, and the steel pipe end is then flared. Other pipe end options can include lap-joint stub ends with rotatable flanges, or welded flanges.

The plastic flared face is now simply made by heating the exposed plastic stub and then flaring or molding it against the flange or flared-steel pipe end. For swaged lined pipe, the steel housing is cut through to just where the plastic shows and the steel collar removed to expose the plastic-liner stub end. For flared pipe, a longer liner is inserted into the steel pipe housing and then cut to the desired length. For pipe lined with thermal-expansion methods, the pipe is already flanged, and enough liner extends beyond the flange ends to make the flares.

Quality Control

Each plastic-lined pipe and fitting is subjected to a 10,000-volt minimum electrostatic test prior to shipping so as to ensure that the liners do not contain any defects. A visible or audible spark that occurs at the probe when an electrical contact is made with the housing indicates the presence of a defect in the liner and is cause for rejection. A 425-psig (2930 kPa) hydrostatic test is an acceptable alternative to the electrostatic test. The sealing surface of the liner is also to be free of any defects that would impair sealing effectiveness. Other quality checks such as metal-and-plastic traceability, mil certs, length, liner type, and pipe size are noted to make sure that the part being shipped meets with the requirements as listed on the order. Special requirements such as on-site inspections, X-ray inspection of welds, and hydrostatic tests are also accommodated. All pressure-containing welds in the steel housings are made by welders certified to the ASME Boiler and Pressure Vessel Code, Section IX, and subject to the provisions therein.

LINER MATERIALS

Plastic lining materials fall into two main categories: fluorinated plastics and nonfluorinated plastics. Fluorinated plastics are either fully fluorinated, as in the case of polytetrafluoroethylene (PTFE), perfluoroalkoxy, and perfluoroethylenepropylene, or partially fluorinated, as in the case of ethylenetetrafluoroethylene (ETFE) and polyvinylidenefluoride. It is the fluorine-carbon bonding of these materials that provides the outstanding resistance to chemical attack. In fact, the fully fluorinated plastics exhibit better chemical resistance than virtually any other material, including other metals, plastics, or composites. They also possess[7]

- High thermal stability
- Resistance to sunlight degradation
- Low smoke and flame characteristics
- Resistance to fungus and bacteria build-up

They generally have

- Low permeability to most gases and liquids
- High purity in the virgin form
- Processibility, formability, and moldability
- Cold weather impact strength
- High abrasion resistance
- Low coefficients of friction
- Approval for food contact use

The nonfluorinated plastics, polypropylene (PP) and polyvinylidene chloride (PVDC), are more general purpose materials that provide good overall chemical resistance. They have lower temperature and chemical resistance than the fluoropolymers and are generally less expensive.

Liner Types

Polytetrafluoroethylene (PTFE). PTFE was originally developed by DuPont in 1938, and was first utilized as a hose and pipe liner in the 1950s. (DuPont markets PTFE under the Teflon tradename, but other manufacturers use their own trade names such as Fluon, Hostaflon, Algoflon, and Polyflon.) PTFE is fully fluorinated and thus virtually inert to most chemicals.

Fluorinated Ethylene Propylene (FEP). FEP was introduced in 1960 as the first melt-processible resin that matched the chemical resistance of PTFE. FEP is marketed under the DuPont trade name of Teflon FEP, and by others such as Hostaflon and Algoflon. The temperature handling capability of FEP, however, is less than PTFE or PFA. It can be used from −20°F (−29°C) to 300°F (149°C). With the advent of PFA in 1972, FEP found fewer applications in the lined-pipe industry. FEP lined piping is offered by a few manufacturers on special order. FEP is still widely used, however, in other product forms, including solid tubing, corrosion-resistant film, and cable and wire insulation.

Perfluoroalkoxy (PFA). PFA is a chemically modified polymer of PTFE that exhibits the same chemical resistance and temperature-handling capabilities as PTFE. It was developed by DuPont in 1972 as a melt-processible high-temperature fully fluorinated plastic. PFA is also marketed by DuPont under the trade name of Teflon PFA, and by others as Hostaflon PFA and Neoflon. Although the cost of PFA resin compared to PTFE is appreciably higher, it still finds utility as both a pipe and fitting liner. PFA has found broader acceptance in other related product forms, including corrosion-resistant plastic-lined pumps, valves, and solid plastic tubing. As with PTFE, PFA can be used in cryogenic services when the housings and flanges are stainless steel. PFA costs 3 to 4 times that of PTFE.

Ethylenetetrafluoroethylene (ETFE). ETFE is a partially fluorinated plastic copolymer of ethylene and PTFE and is marketed by DuPont under the trade name Tefzel. Other tradenames are Hostaflon ET, Aflon COP and Neoflon. ETFE exhibits better chemical resistance and temperature-handling capability than any other plastics except PTFE, PFA, and FEP. ETFE is offered as a liner for both pipe and fittings, and has a service-temperature range of −20°F (−29°C) to 300°F (149°C). ETFE can be specified for lower service temperatures in conjunction with stainless steel housings. For the chemical resistance of ETFE to various chemicals, please see Table B12.1. ETFE has about the same cost as PFA.

Polyvinylidene Fluoride (PVDF).[8] Homopolymer PVDF is a partially fluorinated polymer that is marketed by Elf Atochem North America and Ausimont under the names KYNAR and Hylar, respectively. Other manufacturer's, tradenames are Solef, Neoflon, and KF. Elf Atochem also markets a copolymer of polyvinylidene fluoride and hexafluoropropylene (PVDF/HFP) under the tradename of KYNAR Flex. PVDF exhibits excellent chemical resistance to many chemicals and has a service-temperature range of −20°F (−29°C)(regardless of housing material) to 275°F (135°C). Homopolymer PVDF is widely used for piping conveying halogenated compounds but should not be used in any service where the pH is above 11. The PVDF/HFP copolymer has a higher mole percent fluorine and, as a result, can tolerate solutions of pH up to near 13. For the chemical resistance of PVDF to various chemicals, please see Table B12.1. PVDF also cannot tolerate esters, ketones, or aldehydes.

Polypropylene (PP). Polypropylene is a good general purpose lining material that exhibits good chemical resistance to a wide variety of chemicals in the temperature range of 0°F (−18°C) (regardless of housing material) to 225°F (107°C). PP is generally used to convey inorganic acids such as hydrochloric and sulfuric as well as caustics such as sodium hydroxide. PP is readily attacked by free chlorine and should not be used in this service or other services where free chlorine may be generated in an upset condition. Chlorinated hydrocarbons can cause swelling and softening at elevated temperatures. Another sometimes observed attack is thermal oxidative degradation of PP, as caused by 93% and greater sulfuric acid concentrations. For the chemical resistance of PP to various chemicals, please see Table B12.1.

Polyvinylidene Chloride (PVDC). PVDC has the lowest temperature limit of the standard lining materials and is known by the trade name SARAN. Its use as a lining was discontinued at the end of 1996. PVDC found widespread use in the water treatment and pulp and paper industries, as it had particularly good chemical resistance towards chlorine. Although the service temperature range for PVDC is 0°F to 175°F (−18°C to 79°C), it required special handling when the shipping, handling, and storage temperatures dropped to below 40°F (4°C). For the chemical resistance of PVDC to various chemicals, please see Table B12.1.

TABLE B12.1 Chemical Resistance of Liner Material

Liners made from PTFE and PFA are resistant to the following chemicals to 450°F (232°C).
Liners made from FEP are resistant to the following chemicals to 300°F (149°C).

Liner material maximum-use temperature (°F)				
Chemical	ETFE	PVDF	PP	PVDC
Acetic acid (glacial)	230	NR	70	125
Acetone (10%)	150	75	120	75
Ammonia (dry gas)	300	NR	140	—
Ammonia aqua (30%)	230	175	150	—
Amyl acetate	250	125	NR	125
Benzene	212	170	NR	75
Bromine liquid	150	150	NR	NR
Chlorine liquid	212	200	NR	NR
Chlorine gas	212	175	NR	75
Chlorine dioxide (15%)	250	150	NR	125
Chlorosulfonic acid	75	NR	NR	NR
Cyclohexane	300	275	NR	125
Diethylamine	230	70	120	NR
Ethyl acrylate	212	70	NR	—
Formaldehyde (37%)	230	120	140	125
Formic acid	275	250	140	150
Hydrochloric acid (10%)	300	275	185	175
Hydrochloric acid (20%)	300	275	175	175
Hydrochloric acid (36%)	300	275	150	—
Hydrofluoric acid (35%)	275	250	200	175
Hydrofluoric acid (100%)	230	212	70	NR
Hydrogen peroxide (30%)	250	212	70	125
Hydrogen peroxide (90%)	150	75	70	125
Methyl ethyl ketone	230	NR	70	NR
Methylene chloride	212	70	70	NR
Nitric acid (10%)	212	225	150	150
Nitric acid (50%)	150	120	70	125
Nitric acid (90%)	NR	NR	NR	NR
Phenol	212	120	140	75
Phosgene (gas or liquid)	212	120	NR	—
Phosphoric acid	275	250	225	125
Propyl alcohol	212	120	140	150
Sodium hydroxide (10%)	230	NR	225	150
Sodium hydroxide (50%)	230	NR	225	75
Sodium hypochlorite	300	125	150	125
Sulfuric acid (30%)	300	230	200	75
Sulfuric acid (50%)	300	230	125	NR
Sulfuric acid (93%)	300	200	NR	NR
Sulfuric acid (98%)	200	120	NR	NR
Sulfuric acid—fuming	120	NR	NR	NR
Toluene	250	170	NR	75
Trisodium phosphate	275	275	150	150

To convert from °F to °C, subtract 32 and multiply by 5/9.

Polyethylene (PE). Polyethylene is not truly used by the plastic-lined pipe industry as such but is offered as a retrofit liner as a low cost option for refurbishing already installed carbon steel piping. The polyethylene liner is drawn into the steel pipe in a buckled form and then expanded out to the steel shell with heat and or pressure. Polyethylene has <180°F (82°C) temperature capability but has reasonable chemical resistance.

Selection Criteria

The piping-design engineer should specify the most economical liner material that is suitable for the given service conditions. The specifier must know the major and minor chemical(s) to be piped, as well as the concentration and operating temperature, in order to select the proper liner. By consulting published data for chemical resistance of plastics, the end user can choose an appropriate liner material. See Table B12.1. All lined-piping manufacturers publish chemical resistance charts for their plastic-lined piping products. Other factors, such as vacuum-handling capability, liner thickness, and reputation of the manufacturer, often influence purchasing decisions.

Liner Identification

Liners are color coded per the standards set by the APFA (American Pipe and Fittings Association) to allow for easy identification by the end user. See Table B12.2 for colors used.

TABLE B12.2 Polymer Standard Specifications*

Lining material—resin type	Standard resin specification	Allowable resin classification	Standard liner color	Maximum filler material (by weight)
Polypropylene	ASTM D 4101	Type I and II	Orange	<30% glass fiber
Poly (vinylidene chloride) (PVDC)	ASTM D 729		Gray	<20% glass fiber
Poly (vinylidene fluoride) (PVDF)	ASTM D 3222		Black	
Poly (vinylidene fluoride) Copolymer (PVDF)	ASTM D 5575		Black	
Polytetrafluoroethylene (PTFE)	ASTM D 1457 ASTM D 4894 ASTM D 4895		White	
Perfluoro (ethylene-propylene) Copolymer (FEP)	ASTM D 2116	Type III	Green	
Perfluoro (alkoxyalkane) Copolymer (PFA)	ASTM D 3307	Type II	Natural	
Ethylyene tetrafluoroethylene copolymer (ETFE)	ASTM D 3159	Type I	Natural	

* A maximum of 1% by weight of additives or colorants, or both, is permissible. Colorants, if used, shall be identified in the manufacturer's specification.

Clean reworked resins may be used, provided all mechanical property requirements are maintained. Only virgin PTFE resin may be used.

DESIGN CONSIDERATIONS

Installed Cost Comparisons

Specification of a corrosion-resistant piping system is a complex assignment, if for no other reason than the large number of available materials that vary both in cost and performance. The materials-selection phase usually yields a number of piping candidates that will perform adequately from a technical standpoint. Then a choice is made from the candidates on an economic basis. Three types of cost comparisons are common:

Material cost

Initial installed cost

Long-term life-cycle cost.

Many specifiers limit their economic analysis to materials costs only because they are relatively simple to estimate. Yet this approach poses a very real danger because it ignores what is often well over half of the true required investment for a piping system, that is, the in-place cost of the system, including fabrication and installation costs.

Many types of corrosion-resistant piping have relatively high material costs because they are supplied from the manufacturer in the form of prefabricated components. This, however, makes these materials relatively less expensive to install. Conversely, many piping systems with low material costs often require the additional expense of fabrication at the job site prior to installation.

A widely used formatted study[9] presents a comparison of initial installed costs for a broad variety of corrosion-resistant piping systems. It provides the engineer with a screening tool to help narrow the field of candidates for a piping project so that a final detailed economic study can be made on the specific piping arrangement under consideration. Factors considered in the study are: type of piping used, material costs, complexity of the piping system, fabrication and erection techniques, and labor rates and productivity in installation. Table B12.3 summarizes the installed cost ratios from the most recent publication for a NPS 2 (DN 50) complex piping system. The report list cost ratios are for NPS 2, 4, and 6 (DN 50, 100, and 150) piping layouts for both straight-run and complex arrangements.

A plastic-lined metallic piping system offers clear advantages over both metal and solid-plastic piping systems. Compared to a piping system consisting of corrosion-resistant metal, plastic-lined pipe provides equal or better resistance to chemical attack, depending on liner material. When comparing the installed cost of a flanged plastic-lined metallic piping system to a welded metallic piping system, the plastic lined system is often lower. See Table 12.3. This is especially true when comparing plastic-lined pipe to metal systems of higher alloy materials.

Compared to a plastic system made from the same material as the plastic liner, plastic-lined pipe provides higher service capabilities as well as higher mechanical strength. Plastic-lined piping systems are also available in a wider range of line sizes, with a broader selection of fittings, when compared to solid thermoplastic or thermosetting systems.

Plastic-lined pipe is not only used where chemical attack is a concern, it is also used where media contact with metal is detrimental, as in the case of ultra-pure chemicals and deionized water used in various processes in the electronics industry.

TABLE B12.3

Installed cost ratio (carbon steel as 1.00) of plastic-lined piping and other selected piping materials. Cost ratios based on a shop-fabricated complex system NPS 2 (DN 50) and 400 ft (102 m).

PIPING MATERIAL COST RATIOS			
PVC (sch 80)	0.56	PTFE-lined FRP	3.20
CPVC (sch 80)	0.63	Monel (Sch 40)	3.24
		Alloy 20 (Sch 40)	3.32
Carbon steel (Sch. 40)	1.00	Nickel (Sch 10)	3.34
304L S.S. (Sch. 10)	1.13	Hastelloy C-276 (Sch 10)	3.52
Rubber-lined steel (Sch 40)	1.16		
316L S.S. (Sch. 10)	1.20	PTFE-lined 304L SS (Sch 10)	4.12
304L S.S. (Sch. 40)	1.31	Nickel (Sch 40)	4.27
316L S.S. (Sch. 40)	1.45	Titanium (Sch 10)	4.46
		Hastelloy C-276 (Sch 40)	4.46
FRP/vinyl ester	1.78		
FRP/epoxy	1.86	Hastelloy B (Sch 40)	5.71
FRP/polyester	1.86	Zirconium (Sch 10)	5.95
Polypropylene lined steel (Sch 40)	1.90		
Saran lined steel (Sch 40)	1.91	Zirconium (Sch 40)	7.04
PVDF-lined steel (Sch 40)	2.47		
Alloy 20 (Sch. 10)	2.60		
Monel (Sch 10)	2.61		
Glass-lined steel (Sch 40)	2.69		
PVDF (Sch 80)	2.71		
PTFE-lined steel (Sch 40)	2.94		
Titanium (Sch 10)	2.99		
FEP-lined steel (Sch 40)	2.99		

Available Pipe Sizes

Corrosion-resistant lined pipe is widely available in NPS 1 to 12 (DN 25 to 300), with larger diameters up to NPS 24 (DN 600) available, but with limited liner-material selections. Except as otherwise noted, this discussion will focus on sizes NPS 1 to 12 (DN 25 to 300). Straight sections of pipe are available as standard and custom-length pipe spools. Standard spool lengths are 20 ft (6m), with 40-ft (12m) sections available when flange minimization is desired. A complete selection of plastic-lined metal fittings is available to include elbows, tees, reducing tees, instrument tees, crosses, 45-degree laterals, concentric and eccentric reducers, reducing flanges, and blind flanges. For examples of lined-pipe and fittings, see Figs. B12.1 and B12.2.

Metallurgy and Pressure Capabilities

FIGURE B12.1 Small photo of lined pipe flanged end. (*Courtesy of Crane Resistoflex*)

Plastic-lined pipe and fittings are available in cast iron, ductile-iron and steel housings, and ANSI or ASME Class 125, 150, and 300 ratings respectively. The pressure-temperature ratings for ASME B16.5 Class 300 housings are down-rated to account for the safe-working pressure limit of the flared plastic. The pressure and temperature ratings for these housings are as listed in Fig. B12.3.

Plastic-lined piping systems are rated for ASME Class 150 service. ASME Class 300 flanged systems are available, but they do not carry the true ASME Class 300 rating. This is because the sealing pressure required to meet ASME Class 300 requirements are beyond the mechanical capabilities of the plastic flared faces. Consult the manufacturer's literature for pressure and temperature limitations.

Temperature Limitation

All plastic-lined piping systems have a minimum- and maximum-use temperature that must not be exceeded. These use-temperature limits are derived from the various resin manufacturer's testing and are found in Table B12.4. These temperature limitations are always well below the melt temperature of the liner material. In the cases of PTFE, PFA, and FEP, the maximum-use temperatures apply to virtually all chemicals. In fact only a few chemicals attack these plastics, namely, molten alkali metals, elemental fluorine, and chlorine trifluoride, all at high pressures and temperatures above 500°F (260°C).

FIGURE B12.2 Concentric reducer, elbow, and tee. (*Courtesy of Crane Resistoflex*)

In the case of all other plastic-lining materials, resin manufacturers have gathered test data that indicates above which temperature limit various chemicals will either swell, react with, or degrade the lining materials. These temperatures are referred to as *rated* temperatures for use with particular chemicals. Below these recommended

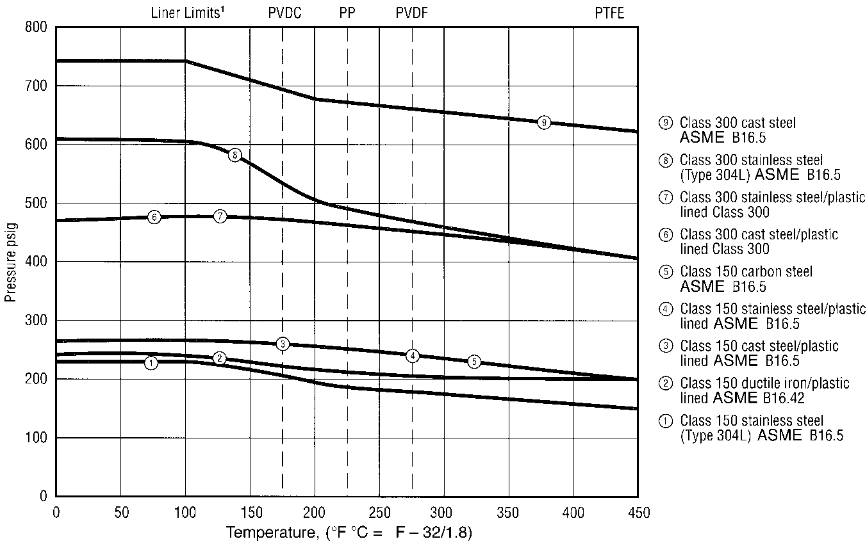


FIGURE B12.3 Working pressures for ASME Class 150 and 300 plastic-lined pipe and fitting. (*Courtesy of Crane Resistoflex*)

limits, the chemical media will not swell, react with, or degrade the liner, and thus the liners can be safely specified for use. Just as there are high temperature limits, liners should not be used below the recommended minimum operating temperatures, as plastics can become brittle and be subject to mechanical rather than chemical failure.

Where a plastic-lining material is rated for less than its overall maximum use temperature, the end user must make certain that the rated temperature will not be exceeded. These situations can occur as a result of upset conditions, unusual ambient conditions, and unplanned exothermic reactions. If the possibility exists that the rated temperature could be exceeded, the end user should specify a different plastic-liner material with a sufficiently high-temperature rating for that chemical service.

TABLE B12.4 Temperature Specifications

Material	Temperature range, °F (°C)
PTFE	−20 to 500 (−29 to 260)
PFA	−20 to 500 (−29 to 260)
FEP	−20 to 300 (−29 to 149)
ETFE	−20 to 300 (−29 to 149)
PVDF*	−20 to 275 (−29 to 135)
PP	0 to 225 (−18 to 107)
PVDC	0 to 175 (−18 to 79)

* Homopolymer and copolymer

Vacuum Capabilities

Vacuum-rating capability in lined-piping products depends on liner thickness, liner-manufacturing process, and pipe-lining process. Typically, most manufacturer's NPS 1 to 8 (DN 25 to 200) material is rated for full vacuum at the liner material's maximum-use temperature. The vacuum capability of different manufacturers NPS 10 and 12 (DN150 and 300) lined piping varies from just-pressure service (no vacuum) to full vacuum capability. Since there is no industry standard for vacuum ratings, it is critical that the end-user consult the manufacturer's literature when considering lined pipe for vacuum service or services which may experience vacuum.

An added precaution regarding vacuum ratings: Piping not rated or designed for vacuum service when installed in vacuum service can lead to liner collapse and failure.

The unplanned or upset condition that induces vacuum can cause failure in nonvacuum-rated piping. Block valves, positive displacement pumps, unexpected rapid cooling, and other conditions can produce inadvertent vacuum conditions in process lines. The design engineer should decide if these scenarios are likely and select lined piping with the appropriate vacuum-handling capability.

Dimensional Compatibility with Other Flanged Systems

Finished lined pipe spools and fittings are measured from plastic-sealing face to plastic-sealing face. Plastic-lined fittings conform to the nominal overall length and center-to-face dimensions as specified in ASME B16.1, Standard for Cast Iron Flanges and Flanged Fittings; ASME B16.42 Standard for Ductile Iron Pipe Flanges and Flanged Fittings; or ASME B16.5 Standard for Flanges and Flanged Fittings. However, it is always a good idea to check with the manufacturer for the applicable dimensions, as some special shapes and systems may have other dimensions.

Joining Techniques

Traditionally, plastic-lined pipe, elbows, branched fittings, reducers, and instrument connections have the plastic liner flared over the flange in order to make connections that seal without exposing the metal housing to the service media. Sealing is accomplished by flaring or molding the liner material out over the metal flange face to form a *formed or flared in place* gasket-sealing surface. See Figs. B12.1 and B12.2. The purpose of this design is to ensure that the service media contacts only the plastic and never the metal. Flanges conform to ASME Class 150 or Class 300 ratings. For pipe spools and fabricated fittings, many types of flanges are available, including lap-joint rotating, slip-on, socket weld, welding neck, and threaded. In the case of a cast fitting, the flange is integral to the casting. The plastic-flared face serves as its own gasket and therefore a gasket is not required. When mating plastic-lined components to other nonlined components, such as carbon steel or alloy piping, fittings, valves, pumps, or vessels, it is recommended that a plastic spacer be used as a transition piece. See Fig. B12.4. However, flanged connections are a potential source of leaks, and new technologies now allow for their significant reductions. See the later section on Flange Reduction Techniques.

Permeation and Venting

Permeation is the migration of small amounts of flow media through the liner wall, in the absence of cracks or continuous voids. It is the product of two functions: the diffusion between molecular chains, and solubility of the permeant in the polymer. If the permeant is as polar as the polymer, or has similar chemically functional groups, it will be more soluble in the polymer.[10] All plastics are subject to permeation, with some plastics exhibiting higher permeation rates than others.[11]

Permeation data relative to chemical handling are very limited because there is no universal laboratory protocol for measuring permeation that generates data applicable to all situations. Care must be exercised in extrapolating the thin-film data frequently found in the literature to the liners used in chemical-process equipment and piping.[12] In general, all other things being equal, pressure and temperature predominantly will drive permeation from a process perspective, and liner thickness and polymer crystallinity from a material viewpoint. Insulation has been determined to help decrease the thermal gradient across the liner and hence decrease the magnitude of permeation.

ASTM F1545 requires components lined with PTFE, FEP, and PFA to be vented (venting is not required for other liner materials) to prevent permeant vapors from collecting between the PTFE liner and the pipe housing. Depending on the manufacturer, venting is achieved by directing the permeant vapors to the pipe ends behind the plastic flare faces, and out at the flanges (Fig. B12.5), or out vent holes drilled through the pipe housing, back from the flanges. All PTFE-lined fittings regardless of manufacturer contain vent holes in the housing. Testing shows that both methods adequately vent permeant vapors in piping lined with PTFE. For piping that will be insulated, the vent hole or flange face must not be blocked. Vent extensions or vented flange covers are available for pipe and fittings that can be insulated.

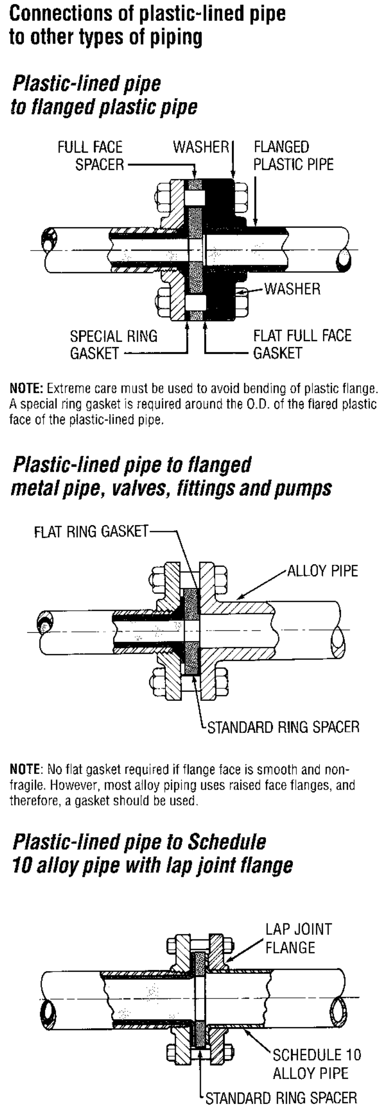
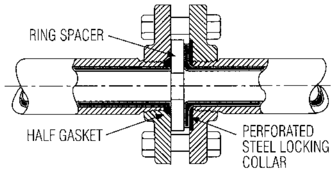


FIGURE B12.4 Recommended installation of plastic-lined pipe to carbon-steel, alloy and non-metallic piping systems. (*Courtesy of Crane Resistoflex*)

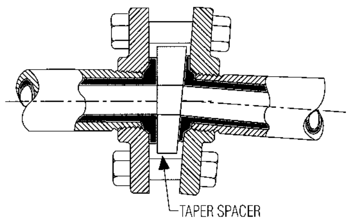
Another situation associated with permeation is the tendency of some permeants

Pipe-to-pipe connections between different joint types

Connection of reinforced flared face to gasketed plastic-lined pipe



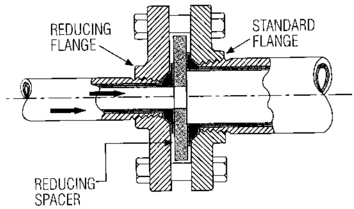
Providing low-angle bend using tapered face spacer



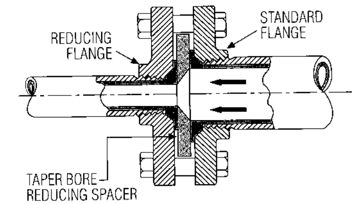
NOTE: Avoid axial forces on this joint. Such forces will tend to push the spacer outward. Consider bent pipe for an alternative to tapered spacers.

Pipe-to-pipe reducing connections

With standard reducing spacer



With taper reducing spacer



With reducing filler flange

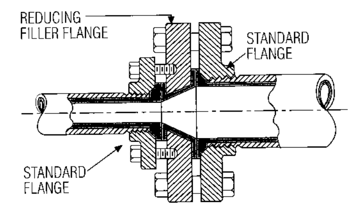
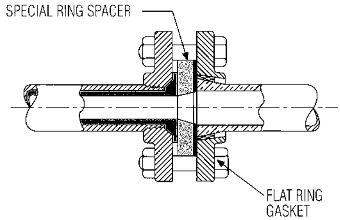


FIGURE B12.4 (*Continued*)

to form corrosive acids at the interface of the vent because of atmospheric humidity. These acids can attack the area where the vent is located. In systems where permeants are known to corrode the area of the vent location, vents located on the pipe housing can be fitted with a half-coupling with a replaceable sacrificial nipple. This nipple can be periodically replaced.

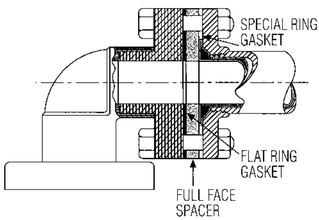
All other things being equal, a thick liner will reduce the permeation rate when compared to a thin liner. Liner thickness varies by manufacturer, ranging from .100-in (2.5 mm) to .130-in (3.3mm) in NPS 1 (DN 25), to .200-in (5 mm) to .425-in (10.8 mm) in NPS 12 (DN 300). Table B12.5 lists the ranges of PTFE liner thickness that are available. Specific thickness data is shown in each manufacturer's literature.

***Plastic-lined pipe to porcelain, glass or carbon pipe*[1]**



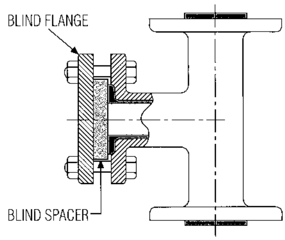
[1] In order to ensure that the special ring spacer supplied has the correct I.D., the I.D. of the porcelain, glass or carbon pipe should be specified on the order or inquiry.

Plastic-lined pipe to glass fiber-reinforced plastic (FRP) flanged fitting or pipe



NOTE: Extreme care must be used to avoid bending of FRP flange. Special spacer may be required. A special ring gasket is required around the O.D. of the flared plastic face of the plastic-lined pipe.

Blanking one outlet of fitting



Valve connections

Plastic-lined pipe to butterfly valve

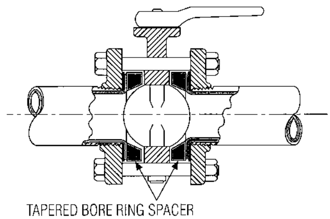


FIGURE B12.4 (*Continued*) (*Courtesy of Crane Resistoflex*)

Pressure Drop Calculations[13,14]

In order to calculate pressure drop through lined pipe, the variables of importance regarding the lined pipe are the true inside diameter and the friction factor. The true ID can usually be determined from the metal pipe and liner thickness data in the manufacturer's literature. The friction factor, which is necessary to calculate the pressure drop using the Darcy equation, can be obtained if the Reynolds number and roughness factors are known. Moody diagrams contain many curves for roughness factors. See Fig. B12.6. For lined pipe, use the curve labeled smooth pipes to arrive at the friction factor. It should be noted that flow rates in plastic-lined piping have been kept less than 12 ft/sec (3.7 m/sec), which in turn limit the pressure drop of the system. It has been also suggested to keep gas velocities in lined piping to less than 35 ft/sec (10.7 m/sec). Typical pressure-drop curves for PP, PVDF, and PTFE are shown in (Fig. B12.7).

Abrasion Considerations

In general, plastic-lined piping is not the first choice to solve problems associated with abrasion. Some slurries, however, due to their aggressive chemical nature,

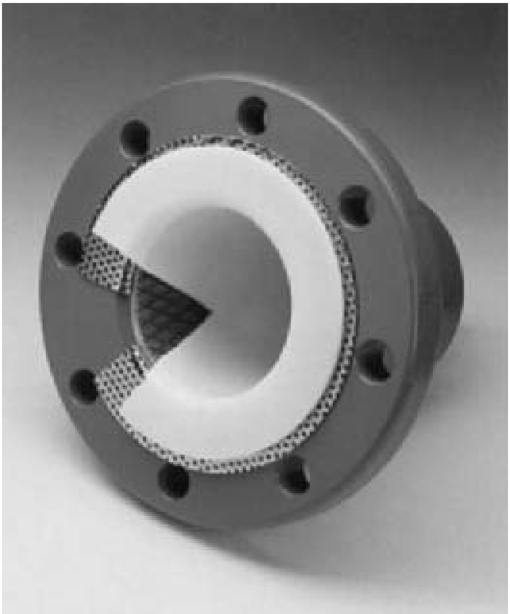


FIGURE B12.5 Swaged pipe and PTFE venting collar system. (*Courtesy of Crane Resistoflex*)

TABLE B12.5 Published PTFE-Liner Thickness Versus Pipe Size

Pipe size NPS (DN)	PTFE-Liner thickness range inches (mm)
1 (25)	0.125 (3.2) − .138 (3.5)
1.5 (40)	0.125 (3.2) − .150 (3.8)
2 (50)	0.125 (3.2) − .160 (4.1)
3 (80)	0.125 (3.2) − .185 (4.7)
4 (100)	0.125 (3.2) − .187 (4.7)
6 (150)	0.145 (3.7) − .275 (7.0)
8 (200)	0.150 (3.8) − 0.315 (8.0)
10 (250)	0.190 (4.8) − 0.325 (8.2)
12 (300)	0.200 (5.1) − 0.425 (10.8)

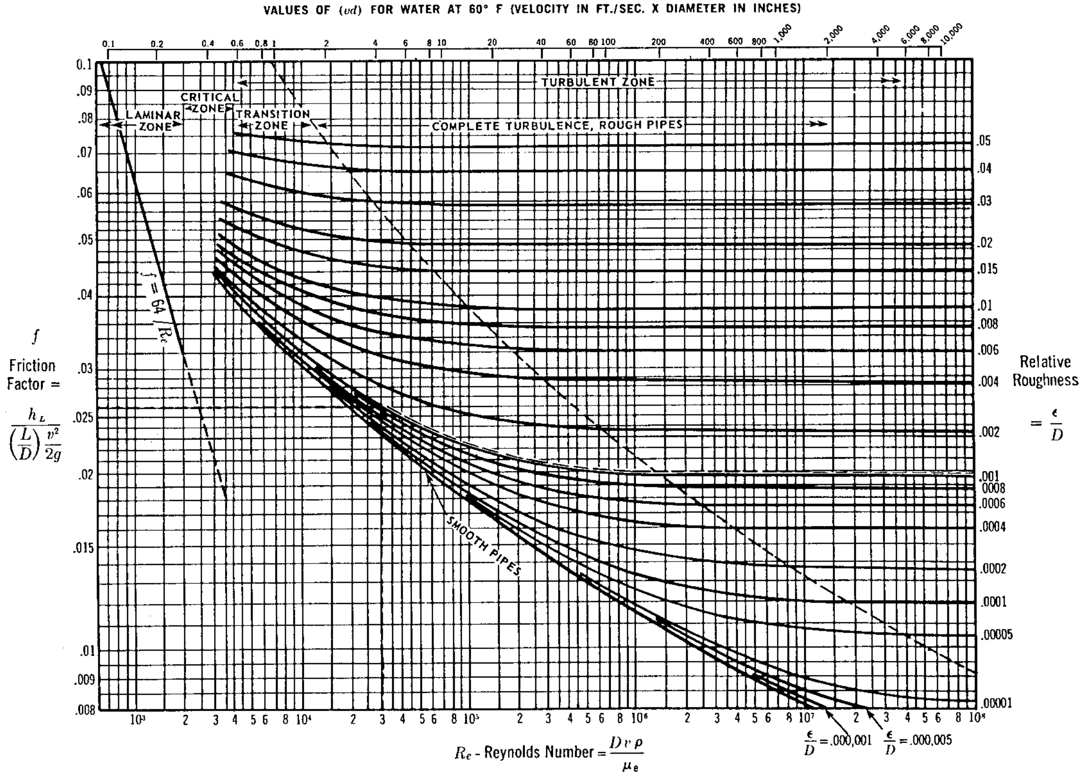
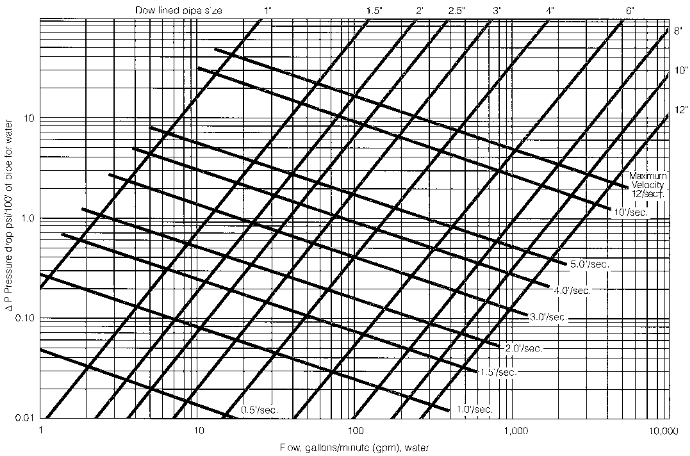


FIGURE B12.6 Friction factors for any type of commercial pipe. (*Reprinted with permission from Crane Valve Group, Long Beach, Calif.*)



These graphs have been prepared for rapid determination of approximate pressure drop through Dow plastic-lined pipe. These figures plot pressure drop versus water flow rate for the plastic-lined pipe. Pressure drops for liquids with densities other than 1.0 (for water) may be determined by multiplying by the density of the liquid.

Δ P for any liquid = Δ P water x specific gravity

†At greater velocities, higher turbulence significantly reduces pump efficiency and can cause excessive wear of system components.

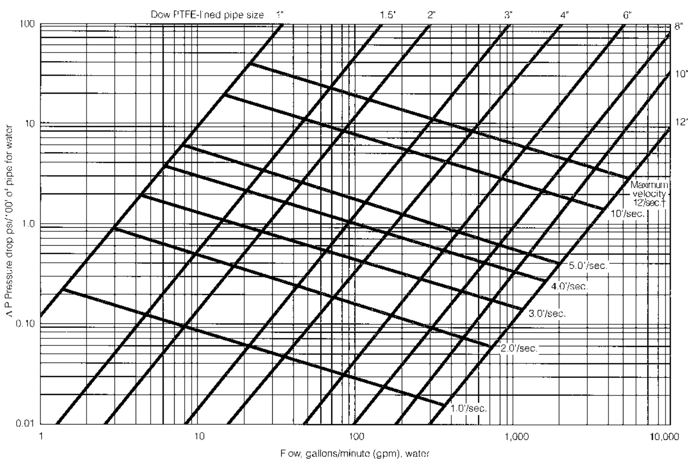


FIGURE B12.7 Pressure-drop curves for PP, PVDF, and PTFE-lined pipe. (*Courtesy of Crane Resistoflex*).

require lined pipe. In these cases, it is advisable to design the system so as to minimize the slurry velocity (less than 2 to 4 ft/sec or 0.6 to 1.2 m/s), and the number of changes in direction. Some have found that installing a tee in the place of a 90-degree elbow can minimize liner wear by having the material wear on itself. Other factors such as solids loading, particulate size, and particulate hardness also determine the amount of abrasion that will result from piping a slurry. Since slurries can erode the plastic liner to the point of failure, and the time required to do so depends on many variables, there is no accurate way to predict lined-pipe service life in a slurry situation. If practical, it is advisable to install a test piece in the actual service to determine if lined pipe will be suitable in a given slurry service.

Nonstandard Fittings Configurations

When faced with the need for a plastic-lined component that does not conform to ASME B16.5, B16.42, or B16.1 dimensional requirements, the end user should consider rotationally lined piping products. Components can be rotationally lined with ETFE or polypropylene.

Rotational lining is a process that is not dependent on the fitting or component geometry for a satisfactory lining job. Therefore, an unlimited number of custom fittings, such as two-and three-branch instrument tees, manifolds, reducing elbows, branch elbows, and other complex configurations can be lined with a thick seamless, mechanically bonded liner. See Fig. B12.8.

FIGURE B12.8 Rotationally lined custom fittings. (*Courtesy of Crane Resistoflex*)

Powder resin is placed inside the housing, and the flanges are capped with special tooling. The housing is bolted to a spindle that rotates on two axes simultaneously. The spindle rotates in an oven that is heated to the resin's melt temperature, and the resin coats the interior evenly. After the fitting is allowed to cool, the tooling is removed, the flares finished, and the components are hydrostatically or electrostatically tested.

Underground Installations

Direct burial of unprotected plastic-lined steel pipe is not recommended without additional surface preparation. Various systems are available for this purpose, including tar coating and wrapping with a pressure-sensitive PVC tape. The tape should be wrapped with at least a ½-in (12.7 mm) overlay down and back the length of the pipe.

The user should recognize that all manufacturers of flanged plastic-lined piping systems recommend that the flange bolts be checked for tightness on an annual basis. Consequently, for obvious reasons, this is difficult to do if the pipe is buried. However, the flangeless technology option as described later in this chapter does allow for plastic-lined pipe to be considered for burial because of the virtual elimination of flanged connections.

If the pipe is to be buried, proper trench preparation is a must. This is to include depth, width, foundation, bedding, backfill, and earth cover. Backfill should only be done with clean sand containing no rocks or foreign material that could point load onto the pipe surface. Refer to ASTM D2321 for typical guidelines.

INSTALLATION AND MAINTENANCE PRACTICES

Shipping and Handling

Plastic-lined pipe and fittings are shipped with protective end covers made of wood or plastic and are designed to prevent damage to the plastic flared faces. The covers should be left on the pipe and fittings until just before installation time. Plastic caps are also used on plain (not flanged) pipe that is to be fabricated in the field. When moving pipe and fittings with a forklift, never put the forks inside a pipe or fitting, as permanent damage to the plastic liner will likely occur. Either secure the fittings to a pallet, or use a sling arrangement to move lined piping products with a forklift.

Installation

The installation of plastic-lined pipe is similar to that of flanged carbon-steel pipe, but some special precautions must be employed.[15,16,17] The flared plastic ends must be protected until the pipe or fitting is installed.

Bolt Torques. Bolts should be tightened to the manufacturer's published recommended torque values. If lubricants other than those listed by the manufacturer are to be used, a new torque value should be determined or calculated. Lubricants such as copper-based antiseize and nickel-based never-seize have nut factors[18] similar to that of fluoropolymer-coated bolts. Bolting or stud material should be ASTM A193 Grade B7, and nuts should be ASTM A194 Grade 2H. The reason for this is that it is possible to have bolt stress in the 50–70,000-psi (345–483,000 kPa) range which can be above the yield strength of low-and medium-grade bolting materials. The bolt must be able to stretch in its elastic zone in order to properly function at the flanged connection. If a bolt stress exceeds the material yield strength, the bolt will be deformed and result in decreased load being applied to the plastic gasket surface. A calibrated torque wrench should be used to avoid excess torque, which can also permanently damage the plastic flare faces. Bolt threads should be clean and lubricated. Bolting should be tightened in a *star* pattern to ensure even tightening of the flanges. When the initial torque value has been reached for all bolts on the flange connection, continue tightening, using the star pattern, until the bolt torques are at 80 percent of maximum torque value recommended by the manufacturer. After the first thermal cycle, all bolts should be checked and retorqued if necessary. This practice should also be followed on an annual basis and more frequently if the process has frequent thermal cycle swings. Fluoropolymer-coated bolts and nuts are typically used with PTFE-lined stainless-steel piping as many stainless-steel bolting materials are of low- to medium-strength quality.

Gaskets and Spacers. Gaskets are not required for connections of lined pipe to other lined pipe, because the plastic liner is flared out over the face of the flange and serves as its own gasket. Gaskets are recommended, however, when bolting lined pipe up to an unlined raised-face flange or glass-lined or graphite equipment. (Please note that the gasket material must be compatible with the service media.) Again, the emphasis is on protecting the plastic flare face. Special gaskets or spacers may be required when bolting up to dissimilar materials. See Fig. B12.4.

Shop and Field Fabrication. Plastic-lined pipe can be fabricated either in the shop or in the field. Shop fabrication, being the most economical method, is recommended when equipment arrangement is firm and detailed piping drawings are available. In the shop, pipe is cut to exact length, flanges are attached, and the liner ends molded or flared. Each item can be *piece marked* to conform to piping drawings that show the location of each piece for field identification.

Field fabrication should be used when equipment locations and piping lengths may not be firm at the time the pipe is purchased. Procedures for field flaring are specified by each manufacturer.

A compromise is available that allows shop fabrication when equipment arrangement is not firm. The line is completely fabricated in the shop, with the exception of the closure piece, which is supplied for field fabrication to exact length.

Support Requirements. The following are additional items that need to be considered when installing plastic-lined piping:

- Hanger spacing for plastic-lined piping is essentially the same as recommended for carbon steel piping.
- Special attention should be given to the steel wall thickness (Schedule 40, 30, or 20) because this variable will determine the free span.
- Supports such as spring-loaded hangers, clevis-type hangers with adjustable rods, guided support shoes, adjustable pipe stanchions, and pipe-roll support may be considered and should allow freedom of movement resulting from temperature changes.
- In addition, for plastic-lined pipe, it is recommended that each spool be supported near the flange connection for maximum protection against excessive deflection.
- Additional support is recommended where flow changes direction and in areas of high load concentrations such as clusters of valves or fittings.

Thermal Expansion and Contraction. Consideration for thermal expansion must be given to the system and allowances made for expansion and contraction. Where deemed necessary by the engineer or designer, a stress analysis should be done in order to avoid overstressing of piping, fittings, and gasket faces.[19] Thermal expansion can be compensated for by using expansion loops or expansion joints.

Welding. Never weld on plastic-lined pipe or use it as ground for electric welders, as the heat generated could severely damage the liner. Do not flame-cut plastic-lined pipe.

Paint. Lined piping products are generally shipped with a protective primer on the external metallic housing, which is applied at the factory. In many cases, this primer is suitable for compatible topcoats, or it can be sandblasted off for application of paint by the end user. When sandblasting, the end caps protecting the molded or flared plastic face must not be removed, and sandblasting should be directed away from the these plastic pipe ends. If the pipe is to be vented with holes on the pipe or fitting housing, the vent holes must be cleared of any debris so that paint will not plug them. An alternative to the end user applying paint in the field is to have primer, midcoat, and final coat applied at the factory. Special paint capabilities vary by manufacturer due to local emissions limits on the volatile organic content of different paints. The end user should forward all available information regarding the paint, including the end user's internal paint specifications, paint data sheets, and paint-material-safety data sheets. Special paint application by lined pipe manufacturers will generally result in an additional charge to the end user.

Heat Tracing. Handling materials that have high freezing points or high viscosity often requires the use of a pipe tracing system. Four systems that have been successfully used in tracing plastic-lined pipe are:

- Hot water
- Heat-transfer fluids such as Dowtherm
- Electrical resistance
- Steam

Any heat-tracing system used with plastic-lined pipe must be applied in accordance with the manufacturer's written recommendation.

Among the factors to be considered in the selection of tracing methods are the temperature rating of the plastic liner for the intended chemical, service, climate, length of heating season, temperature range to be maintained, length of tracer run, initial costs, operating costs, and need for future expansion

Steam tracing of polypropylene-lined pipe is not recommended, because it requires much more care in design and maintenance. However, the tracing of PVDF, FEP, PFA, and PTFE-lined pipe with steam may be done successfully, keeping in mind the maximum temperature limitations for these liners.

Tracing lined pipe with electrical heating tape has been successful in many applications, particularly those in which continuous heating is not needed. Such tracing is available in strip or cable form. In electrical tracing systems, it is especially important that the temperature-controller sensing device be placed in direct contact with the heating strip or cable to ensure that the maximum operating temperature of the pipe lining is not exceeded. As with the fluid tracing systems, flanges, fittings, valves, et cetera, should be protected from excessive heat losses. Refer to manufacturer's literature for specific recommendations.

As with both steam and electrical systems, it is important that standoff strips or heat transfer cement be used to prevent direct contact and hence hot spots on the pipe. Some installers have found that taping electrical heat tape to the pipe with 2-in-(50.8 mm) wide aluminum tape helps spread the heat.

Hot water and heat-transfer fluids are generally preferred when there is a need for closer control of operating temperatures or to hold them within the temperature limitations of plastic liners. The choice of heat-transfer fluids will depend on the temperature range.

Jacketed-Lined Pipe. Straight-pipe sections are also available with an exterior jacket made from pipe that is typically one size larger than the lined pipe. The jacket is contained with pipe caps the same size as the jacket that are bored out to fit the O.D. of the lined pipe. Inlet and outlet ports are generally half-couplings welded to the jacket. All jacket fabrication and welding on the pipe is done prior to lining of the pipe spool. The heating fluid can be water, steam, or heat transfer fluid. Fittings are generally not jacketed, but separate clamp-on jackets over the standard fitting housings are commercially available.

Insulation. The techniques used in insulating steel pipe can also be used with plastic-lined steel pipe. But, care should be exercised to ensure the integrity of the venting system. For PTFE lined pipe and fittings that are vented via small vent holes, the end-user must specify that vent couplings be welded over the vent holes prior to lining. The end-user then threads a pipe nipple into the vent coupling. The nipple must be long enough to extend beyond the insulation to prevent the blockage of the venting system.

Grounding. Grounding of piping systems is required if a possibility exists for spark generation through the buildup of a static electrical charge.[20] This typically occurs when nonconductive fluids such as xylene, toluene, or hexane are piped in plastic-lined piping. Although metallic or alloy systems may be better suited for this kind of fluid, lined pipe is selected if product purity is of concern or the process fluid has intermittent corrosive contaminants present. Several techniques are used by the chemical process industry to ensure that adequate grounding is achieved. First, it is important toassure that the metallic pipe shell is properly grounded. Two techniques are used to assure continuity to a ground connection. One is to carefully weld stud bolts to the pipe shell and electrically connect separate spools with braided-wire cable. The other is simply to use the flange bolts as an electrical connection[21]. These two techniques simply ensure that a path to ground is assured. However, the process fluid that has potential to build a static charge is on the inside of the piping, and therefore any charge buildup here must be dissipated. This is typically accomplished by inserting a grounding paddle (exotic metal such as hastelloy or tantalum) between flange connections. The handle of the paddle is then connected via a braided cable to the grounded pipe shell such that bleedoff of any internally generated charges can occur. Some European manufacturers offer carbon-filled PTFE-lined piping systems in which the liner resistivity is such that electrical charge dissipation can occur through the liner to the grounded steel shell. Ultimately, the design of the exterior/interior grounding system is the responsibility of the end-user.

Corrosion Allowance

Metals generally corrode due to electrochemical reactions, which gradually return the metal from a higher energy level (alloy) to a lower energy level (element or ore). In most cases this ongoing process can only be slowed by specifying a metal wall thickness that will deliver a predictable length of useful service life.

Plastics on the other hand, do not corrode. Instead, they are susceptible to attack from solvation, where the media reacts with the plastic, causing swelling or cracking, and failure. A plastic is either completely resistant to a chemical at a given temperature, or it will react with a chemical at, or above, a certain temperature. This process is usually rapid but can be avoided by following lined-pipe manufacturer's guidelines for their various liner material's resistance to different chemicals. When these guidelines are followed, and the system is installed and maintained in accordance with the manufacturer's guidelines, a plastic-lined piping system will provide a long, reliable service life.

Field Hydrotest

Test the integrity of the installation per the applicable section of ASME B31 Piping Code, using a hydrostatic test. Sometimes it is more practical to *hydrotest* in sections, using spectacle blind flanges to block off portions of the piping. If a flange leak occurs during hydrotest, and that flange has been properly torqued, do not tighten further. Instead, the bolts on the opposite side of the leak should be loosened one-half turn, and the bolts on the leaking side should be tightened one-half turn.

If the leak continues, remove the bolts and inspect the flare faces for indications of damage. Do not remove the bolts if the system temperature is more than 30°F (17°C) above ambient temperature, or flare distortion may occur. Slight scratches or dents that do not exceed 20 percent of the liner thickness can be repaired by hand with sandpaper or emery cloth. Repeat the torquing process to 80 percent of final torque. If necessary, the bolts can be tightened to the maximum torque published in the manufacturer's literature. Exceeding this torque, however, may cause permanent damage to the plastic flare faces. Because of the nature of plastic-lined piping, it should not be assumed that the first hydrotest will always be successful. Installers and users should be prepared for the possible additional time and expense of retorquing that may be necessary for a successful hydrotest.

Maintenance Considerations

Maintenance requirements vary by application. A system that sees mostly ambient temperature may require little maintenance, such as a periodic spot check of bolt torques. A system that undergoes frequent thermal cycles may require a preventive maintenance program that entails a higher frequency of spot checks.

Field Fabrication of Lined Pipe

Field fabrication of pipe spools allows end users and authorized lined-pipe distributors to fabricate lined-pipe spools locally, a factor which expedites turnaround times when compared to factory-made finished pipe spools. Straight pieces of lined pipe without flanges are stored at the end user's or distributor's shop until a requirement for a pipe spool arises.

Using special field-fabrication tooling supplied by the manufacturer, the end user or distributor can fabricate custom-length flanged pipe spools. The tooling and procedures are not interchangeable for use on products from different manufacturers. Flange options for field-fabricated pipe spools vary by manufacturer. Consult manufacturers for field fabrication instructions.

FLANGE REDUCTION TECHNIQUES

Flanged connections have long been recognized as a potential leak source, and new technologies now allow for their significant reductions. This has been brought about in part by the realization that flanged connections are a significant contributor to fugitive emissions, which are regulated by the 1990 Clean Air Act amendments. Among these is a new butt-fusion—welded flangeless connection of the plastic liner,[22] extra long lengths of pipe spools up to 40 ft (12 m), and single and multiple bent pipe spools.[23,24] See Fig. B12.9.

A new and patented flangeless joining technique was formally introduced in 1995, which can virtually eliminate over 90 percent of the flange connections of a plastic-lined piping system. As a base, it utilizes the well known technology of butt-fusion-welding that is widely used by the solid-plastic pipe industry. In order to provide overall mechanical continuity, a low-profile steel mechanical coupling is

FIGURE B12.9 Illustration showing the flange-reduction possibilities of precision-bent plastic-lined pipe as compared with traditional flanged piping (*Courtesy of Crane Resistoflex*).

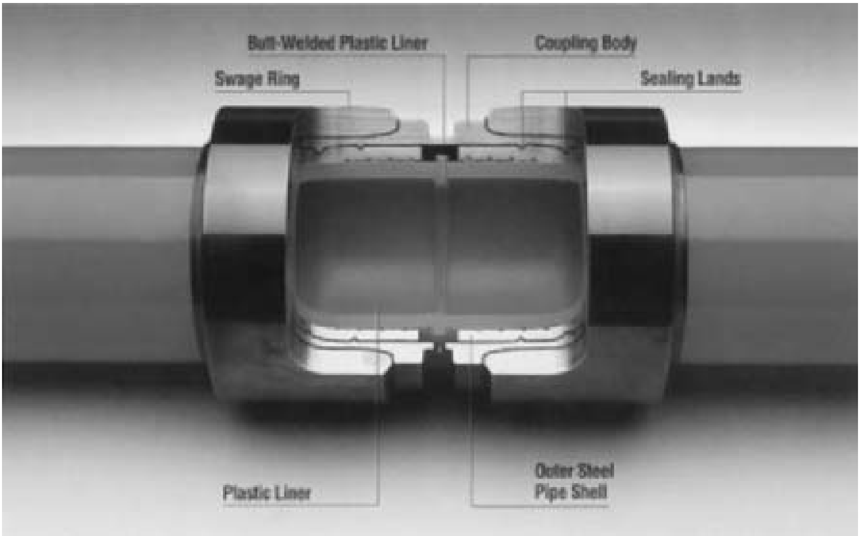


FIGURE B12.10 Sectioned view of a butt-fusion-welded polypropylene plastic liner connected with a mechanical coupling. (*Courtesy of Crane Resistoflex*)

engaged over the butt-fusion weld. See Fig B12.10. Other couplings and devices are available, but the user should determine which meet the code requirements of the applicable section of ASME B31, Pressure Piping Code.

The process is accomplished by butt-fusion welding two adjacent plastic-liner stub ends together to form a strong, leak-free joint. A special low-profile mechanical coupling is then installed over the welded connection to add structural integrity that is equivalent to a welded system. Coupling installation is accomplished with a hydraulic tool designed to seat the two swage rings positioned over the coupling sleeve. This technology allows the user to eliminate almost all flange connections for carbon-steel piping lined with polypropylene, polyvinylidene fluoride, perfluoroalkoxy and PTFE. A PFA- and PTFE-lined stainless steel option is available. Fittings are a low-profile construction with longer centerline to face dimensions so that the mechanical coupling can be slipped over the butt-fusion-welded joint prior to locking the coupling into place. Although the purchase price of the flangeless system may be initially more expensive, the user should look at the total life-cycle cost before making a final piping selection.[25]

The standard spool length for the plastic-lined pipe industry is 20 ft (6 m). Customers that now wish to further reduce the number of flange connections can also purchase 40 ft-(12m) long spools in NPS 1.5 (DN 40) through NPS 6 (DN 150) pipe sizes. These spools are an excellent complement when the flangeless system is being installed.

Lined pipe manufacturers also offer bent-lined-piping systems that can eliminate 50 to 70 percent of flange connections in a 20 ft-(6m) piping run with straight sections and elbows. Bends are done on a 3D pipe diameter bend radius to prevent collapse of the plastic liner. Available sizes are NPS 1 to 4 (DN 25 to 100) in both carbon-steel and stainless-steel pipe housings. Bent-pipe systems conform to the same ASTM F1545 testing requirements as conventional lined pipe. Although bent-

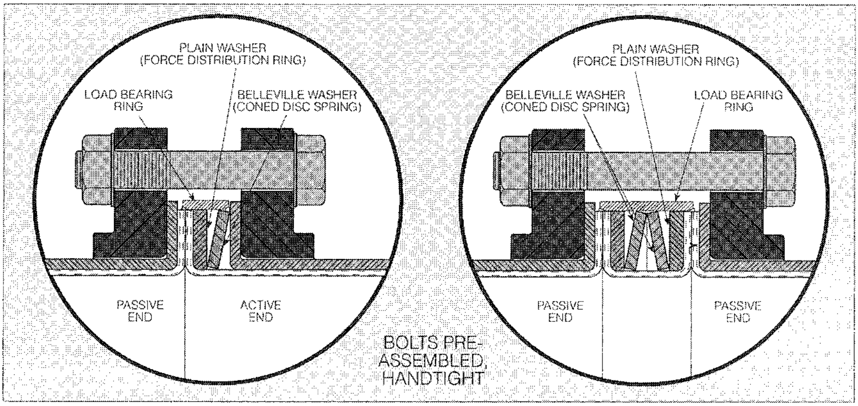


FIGURE B12.11 High integrity flange connection. (*Courtesy of Crane Resistoflex*)

pipe spools offer many obvious advantages, they require special manufacturing techniques and are generally made at the factory. Replacement spools are seldom stored on site and do require extra lead time for delivery. Consequently, it is a good idea to have a stock of replacement fittings nearby if an emergency replacement is required. Bent pipe can either be flanged or flangeless.

Modified Flange Connections

Where flange connections are necessary, there is a modified leakless flange connection that utilizes a dual-sealing action. The dual-sealing action is achieved through the use of belleville washers located behind the plastic flare and secondary sealing rings, also known as *load bearing rings* See Fig B12.11. When the user tightens the flange bolts, the belleville washers deflect enough to impart the necessary sealing pressure on the PTFE flare faces. Due to the interaction of the load-bearing ring and the belleville washers, the sealing pressure is optimized and not exceeded, even though this system calls for almost quadruple the bolt torque values of a standard lined-pipe connection. The result is a leakproof flange connection that allows practically zero emissions and is Factory Mutual Approved.

APPLICABLE INDUSTRY STANDARDS

Requirements for the materials, workmanship, dimensions, design, fabrication, working pressures and temperatures, test methods, qualification requirements, and markings are set forth in ASTM F 1545. This is the specification for metal pipe and fittings lined with PTFE, PFA, FEP, ETFE, PVDF, PVDC, and PP. ASTM F 1545 is the consolidation of the following six separate (but related) specifications:

ASTM F 423 Standard Specification for Polytetrafluoroethylene (PTFE) Plastic-Lined Ferrous Metal Pipe, Fittings and Flanges

ASTM F 491 Standard Specification for Poly (Vinylidene Fluoride) (PVDF) Plastic-Lined Ferrous Metal Pipe and Fittings

ASTM F 492 Standard Specification for Propylene and Polypropylene (PP) Plastic-Lined Ferrous Metal Pipe and Fittings

ASTM F 546 Standard Specification for Perfluoro (Ethylene-Propylene) Copolymer (FEP) Plastic-Lined Ferrous Metal Pipe and Fittings

ASTM F 599 Standard Specification for Poly (Vinylidene Chloride) (PVDC) Plastic-Lined Ferrous Metal Pipe and Fittings

ASTM F 781 Standard Specification for Perfluoro (Alkoxyalkane) Copolymer (PFA) Plastic-Lined Ferrous Metal Pipe and Fittings

ASTM F 1545 lists requirements for materials of construction, qualification testing, and inspection requirements for plastic-lined piping as follows:

ASTM F1545 Requirements for Plastic-Lining Materials

Plastic-lining materials shall be made from a resin that conforms to the appropriate specifications as shown in Table B12.2.

ASTM F1545 Requirements for Lining-Material Mechanical Properties

For liner materials, the minimum tensile strength and minimum elongation at break when tested in accordance with the specifications shown in Table B12.2 shall conform to Table B12.6. Note that these are minimum requirements. Lined-piping manufacturers use various formulations of resins that may exceed the minimum values shown.

TABLE B12.6 Polymer Mechanical Properties

Lining material—resin type	Minimum tensile strength at break, psi (MPa)	Minimum elongation at break, %
Polypropylene (PP) Type I	4000 (27.6)*	10*
Polypropylene (PP) Type II	3000 (20.7)*	10*
Polypropylene (PP) 30% Glass Filled	2500 (17.3)*	2*
Poly (vinylidene chloride) (PVDC)	1500 (10.3)*	2*
Poly (vinylidene fluoride (PVDF)	4500 (31.0)	10
Poly (vinylidene fluoride) copolymer (PVDF)	4000 (27.6)	300
Polytetrafluoroethylene (PTFE)	3000 (20.7)	250
Perfluoro (ethylene-propylene) Copolymer (FEP)	3000 (20.7)	250
Perfluoro (alkoxyalkane) copolymer (PFA)	3800 (26.2)	300
Ethylyene tetrafluoroethylene copolymer (ETFE)	6500 (44.8)	275

* Minimum tensile strength and elongation at yield.

TABLE B12.7 Approved Ferrous-Metal Flange and Fitting Material Standards (ASTM)

Lining material	Pipe specifications	Flange specifications	Fitting specifications
PVDF, PTFE, FEP, ETFE, and PFA	A53	A105	A105
	A106	A181	A181
	A135	A182	A182
	A312	A216	A216
	A513	A395	A234
	A587	A536	A351
			A395
			A403
			A536 (60-40-18)
PP and PVDC	A53	A105	A48
	A106	A181	A105
	A135	A182	A126
	A312	A216	A181
	A513	A395	A182
	A587	A536	A216
			A234
			A278
			A351
			A395
			A403
			A536

ASTM F1545 Requirements for Ferrous-Metal Pipes, Flanges, and Fittings Materials

The mechanical properties of the ferrous metal pipes, flanges, and fittings shall conform to the appropriate specifications listed in Table B12.7, except as they are influenced by accepted methods of processing in the industry (for example, Van Stone flaring, bending, swaging, welding, and threading).

ASTM F1545 Requirements for Inspection Testing

ASTM F1545 provides for a final proof test of finished components prior to shipping. Each pipe spool and fitting, prior to shipment, shall be either hydrostatically or electrostatically tested in accordance with the following:

Hydrostatic Test. The internal test pressure shall be 425 psig (2930 kPa) for Class 150 and Class 300 components. Reach full test pressure within one minute and hold for a total of three minutes. Observe the pressure gage throughout the test for evidence of leakage, which shall be cause for rejection.

Electrostatic Test. Conduct the test with a nondestructive high-voltage tester at a minimum output voltage of 10 kV. A visible or audible spark, or both, that occurs at the probe when electrical contact is made with the housing because of a defect in the liner shall be cause for rejection.

TABLE B12.8 Test Temperatures, °F (°C)

PTFE	PFA	FEP	ETFE	PVDF	PP	PVDC
500 ± 5 (260 ± 3)	500 ± 5 (260 ± 3)	300 ± 5 (149 ± 3)	300 ± 5 (149 ± 3)	275 ± 5 (135 ± 3)	225 ± 5 (107 ± 3)	175 ± 5 (79 ± 3)

ASTM F1545 Requirements for Qualification Testing

ASTM F1545 also requires each lined-pipe manufacturer to perform qualification testing on representative pipe and fittings in each liner material being offered for sale. This is not meant to be an inspection test for customer orders but a verification that the methods and materials used by each manufacturer will result in a product that is capable of satisfactory performance in conditions found in a chemical plant environment. The representative pieces must pass the hydrostatic or electrostatic test following each of the tests in order to be in compliance with the specification for specific test designs. Refer to ASTM F1545.

High and Low-Temperature Aging Test. This test is to determine the ability of the lined component's to withstand extended exposure to the liner material's maximum and minimum temperature. Test temperatures for the high-temperature test are shown in Table B12.8, and the low-test temperature is 0°F (−18°C).

Steam-Cold–Water Cycling Test. This test is to determine the lined components ability to withstand rapid, repeated, and extreme temperature cycling. A representative pipe spool is blind flanged and then filled with steam at the pressure listed in Table B12.9. When the temperature stabilizes, the steam is shut off, and the pipe spool is filled with ambient water until the outside metal temperature reaches 122°F (50°C). This procedure is repeated for 100 cycles. At the completion of the test, the liner shall exhibit no buckling or cracking.

Vacuum Testing. ASTM 1545 does not require that lined-pipe manufacturers offer vacuum-rated piping products, but if manufacturers make claims of vacuum-handling capability, they must perform vacuum testing per ASTM F1545.

The above qualification tests, again, are not production-inspection tests but are designed to establish baseline levels of quality and performance for products that are regularly installed in the most demanding chemical services. Reputable plastic-lined piping manufacturers will provide certificates of compliance to ASTM F 1545 upon request.

TABLE B12.9 Steam Test Pressures, psig (kPa)

PTFE	PFA	FEP	ETFE	PVDF	PP	PVDC
125 ± 5 (862 ± 35)	125 ± 5 (862 ± 35)	50 ± 3 (345 ± 21)	50 ± 3 (345 ± 21)	30 ± 2 (207 ± 15)	4 ± 1 (28 ± 7)	* *

* The thermocycling test for PVDC-lined pipe and fittings should be run using water at 175 ± 5°F (79 + 3°C)

PROJECT SPECIFICATIONS

A piping specification is used by the process engineer to develop piping and instrumentation drawings by the designer to lay out the piping run and product-detailed drawings by the purchasing agent for procurement and by the field engineer to ensure proper installation.[26] Thus the specification must include: the maximum pressure and temperature ratings; a list of flow media; the complete description of pipe, fittings, valves-and other piping items; and installation details. To be certain that a complete specification is achieved, the following procedure has proven useful:

1. The process engineer specifies maximum operating pressure and temperature and the flow media. An *initial piping index* can be useful in supplying this information. At this point it is necessary to ascertain that all possible media are included, that the operating conditions (pressure, temperature, and vacuum) are not minimized or exaggerated, and that the size range is all inclusive and accurate.

2. Completely describe all pipe and components. Reference the applicable ASTM standards to which all material and tests must conform. Include the size range required. Note the limitations of individual components—e.g., does a valve, hose, expansion joint, or sight glass have a pressure or temperature rating lower than that of the specification?

3. To assist the designer in laying out the pipe and in preparing detailed drawings, provide information giving the maximum and minimum lengths available, the methods of making branch connections, and the connections to dissimilar piping materials. Include instructions regarding the use of reducing tees, instrument tees, gaskets, and spacers.

Most frequently, piping components fail because their design capabilities have been exceeded. Know what is required of the components you specify and do not expect more from them than what they have been designed for. Reliable manufacturers of plastic-lined piping will not recommend the use of their products for services and conditions not previously tested.

INSPECTION AND SERVICE LIFE ANALYSIS

Currently there is an increased interest and more activity focused on improving existing mechanical-integrity standards that will continue to improve the overall mechanical integrity of process piping in the process industry.[27] The objective here is to eliminate piping and equipment-related incidents caused by leaks and failures that result in unscheduled maintenance, downtime, and asset losses. This can be approached by analysis of existing piping systems, the historical-type failure modes, and the expected service life. A repeat pattern of failures or a prioritized listing can help the maintenance department implement a plan for reduction and elimination of reccurring patterns. A key to any good maintenance program is the proper documentation of when a piping system was installed and any maintenance replacements that may have occurred. This is particularly important in today's mobile employment environment, as the personnel that originally installed the piping may not be at the same location several years into the future.

Plastic-lined piping also does not lend itself to traditional methods of inspection common in metal or alloy systems. The difficulties lie with lined pipe itself, as there is no *corrosion rate* basis that can be applied, such as a steady loss of thickness, until failure occurs. Rather, the action of the corrosive, if it has any effect, will alter the structure of the plastic at varying rates. When such changes in properties occur, this can lead to the eventual mechanical failure of the plastic liner. The determinant of suitability then becomes the rate at which the property changes occur. Performance variability is due to the type of plastic used, grade, quality, manufacturing process, and the service condition.

The following procedures have been employed to minimize and identify piping problems:

1. Ultrasonic techniques have proven useful in locating liner collapse. Decreased flow or pressure drop may also preclude liner collapse due to vacuum or permeation.
2. Visual inspection is a time-tested method.
3. Excessive external corrosion or that around a vent port on fluoropolymer-lined piping may indicate a liner leak.
4. Destructive testing of spools taken from service of known length of time in a documented environment.
5. Excessive loading due to thermal stresses may result in flange leaks. Make sure that the piping has been properly supported. The Manufacturers Standardization Society (MSS) Standard Practice SP-69, Pipe Hangers and Supports-Selection and Application, provides good references for supports and hangers.
6. Excessive fluid loading such as water hammer or the thermal expansion of hydraulically full piping can cause liner failure. Other loads can be in the form of rapid decreases in temperature via the introduction of a liquified gas.
7. Infrared can be used in locating leaks if corrosion and or oxidation reactions are taking place. Inspection must be done at night, and the capabilities are dependent on the degree of access to the piping system.

For particularly aggressive chemical services, it may be advisable to install several test spools that can be removed at predetermined time intervals to ascertain the overall pipe condition. The user may elect to re-install them or perform destructive tests for determination of liner properties. Current practices vary from company to company and site to site. Issues of internal versus external inspection can depend on the severity of service. Generally the approach is to replace it when it fails.

Plastic-lined piping is a durable product, but it should be recognized that it does not last forever. Although, cases have been reported where service life has exceeded 25 years, 10 to 15 years is typical, particularly in aggressive services. However this range can be decreased with high-temperature operation or high numbers of thermal cycles.

AUXILIARY PRODUCTS

There is a variety of auxiliary lined products compatible with lined pipe and fittings. These products include PTFE-lined hose, PTFE expansion joints, lined valves, dip pipes and spargers, sight-flow indicators, and strainers. These items are offered by most lined-pipe manufacturers to supplement their standard lined-pipe offering. Other equipment such as lined pumps, vessels, valves, flowmeters, and other lined components are available from a wide variety of manufacturers, enabling the end user to design and install a complete corrosion-resistant plastic-lined system with no metal-wetted parts.

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*Trademark of the Dow Chemical Company

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