Chapter 9
Lined Piping Systems

9-1. General

When properly utilized, a lined piping system is an effective means by which to protect metallic piping from internal corrosion while maintaining system strength and external impact resistance. Cathodic protection is still required for buried applications to address external corrosion. Manufacturing standard options for the outer piping material are usually Schedule 40 or 80 carbon steel. Lined piping systems are not double containment piping systems.

a. Design Parameters

Design factors that must be taken into account for the engineering of lined piping systems include: pressure, temperature and flow considerations; liner selection factors of permeation, absorption, and stress cracking; and heat tracing, venting and other installation requirements.

b. Operating Pressures and Temperatures

The requirements for addressing pressure and temperature conditions for lined piping systems are summarized in the following paragraphs.

Lined piping systems are used primarily for handling corrosive fluids in applications where the operating pressures and temperatures require the mechanical strength of metallic pipe. Therefore, the determination of maximum steady state design pressure is based on the same procedure and requirements as metallic pipe shell, and the design temperature is based on similar procedures and requirements as thermoplastic pipe.

Table 9-1 lists recommended temperature limits of thermoplastic used as liners. The temperature limits are based on material tests and do not necessarily reflect evidence of successful use as piping component linings in specific fluid serviced at the temperatures listed. The manufacturer is consulted for specific application limitations.

c. Liner Selection

Liner selection for piping systems must consider the materials being carried (chemical types and concentrations, abrasives, flow rates), the operating conditions (flow, temperature, pressure), and external situations (high temperature potential).

For the material compatibility of metallic lined piping system with various chemicals, see Appendix B. As discussed in Chapter 4, metallic material compatibility should consider the type and concentration of chemicals

Table 9-1
Thermoplastic Liner Temperature Limits (Continuous Duty)

	Recommended Temperature Limits			
	Minimum		**Maximum**	
Materials	**EF**	**EC**	**EF**	**EC**
ECTFE	-325	-198	340	171
ETFE	-325	-198	300	149
FEP	-325	-198	400	204
PFA	-325	-198	500	260
PP	0	-18	225	107
PTFE	-325	-198	500	260
PVDC	0	-18	175	79
PFDF	0	-18	275	135

Note: Temperature compatibility should be confirmed with manufacturers before use is specified.
Source: ASME B31.3, p. 96, Reprinted by permission of ASME.

in the liquid, liquid temperature and total stress of the piping system. The selection of materials of construction should be made by an engineer experienced in corrosion or similar applications. See Appendix A, Paragraph A-4, for additional sources of corrosion data.

As discussed in Chapter 5, thermoplastic materials do not display corrosion rates and are, therefore, either completely resistant to a chemical or will rapidly deteriorate. Plastic lined piping system material failure occurs primarily by the following mechanisms: absorption, permeation, environmental-stress cracking, and combinations of the above mechanisms.

Permeation of chemicals may not affect the liner but may cause corrosion of the outer metallic piping. The main design factors that affect the rate of permeation include absorption, temperature, pressure, concentration, and liner density and thickness. As temperature, pressure, and concentration of the chemical in the liquid increase, the rate of permeation is likely to increase. On the other hand, as liner material density and thickness increase, permeation rates tend to decrease[1].

For plastic material compatibility with various chemicals, see Appendix B. See Appendix A, Paragraph A-4, for additional sources of corrosion data. For the material compatibility of elastomeric and rubber as well as other nonmetallic material lined piping systems with various chemicals, see appendix B.

Liners should not be affected by erosion with liquid velocities of less than or equal to 3.66 m/s (12 ft/s) when abrasives are not present. If slurries are to be handled, lined piping is best used with a 50% or greater solids content and liquid velocities in the range of 0.61 to 1.22 m/s (2 to 4 ft/s). Particle size also has an effect on erosion. Significant erosion occurs at >100 mesh; some erosion occurs at >250 but <100 mesh; and little erosion occurs at <250 mesh. Recommended liners for slurry applications are PVDF and PTFE, and soft rubber; by comparison, in a corrosive slurry application, PP erodes 2 times as fast and carbon steel erodes 6.5 times as fast[2].

d. Joining

Two available methods for joining lined pipe are flanged joints and mechanical couplings (in conjunction with heat fusion of the thermoplastic liners).

Thermoplastic spacers are used for making connections between lined steel pipe and other types of pipe and equipment. The spacer provides a positive seal. The bore of the spacer is the same as the internal diameter (D_i) of the lined pipe. Often, a gasket is added between the spacer and a dissimilar material to assist in providing a good seal and to protect the spacer.

When connecting lined pipe to an unlined flat face flange, a 12.7 mm (½ in) thick plastic spacer of the same material as the pipe liner is used. A gasket and a spacer will connect to an unlined raised face flange. Both a gasket and a spacer is recommended to connect to glass-lined equipment nozzles. Install a 12.7 mm (½ in) thick spacer between lined pipe or fittings and other plastic-lined components, particularly valves, if the diameters of the raised plastic faces are different.

For small angle direction changes, tapered face spacers may be used[3]. It is not recommended to exceed a five degree directional change using a tapered face spacer. For directional changes greater than five degrees, precision-bent fabricated pipe sections are available from lined pipe manufacturers.

Gaskets are not necessary to attain a good seal between sections of thermoplastic lined pipe, if recommended fabrication and installation practices are followed. Often, leaks result from using insufficient torque when trying to seal a joint. The addition of a gasket provides a softer material which seals under the lesser stress developed by low torque. When gaskets or any dissimilar materials are used in the pipe joint, the lowest recommended torque for the materials in the joint is always used.

Gaskets are put in when previously used lined pipe is reinstalled following maintenance. Gaskets are also used between plastic spacers and non-plastic-lined pipe, valves, or fittings.

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[1] Schweitzer, Corrosion-Resistant Piping Systems, pp.149-151.
[2] Ibid., p. 153.
[3] Crane/Resistoflex, "Plastic Lined Piping Products Engineering Manual," p. 41.

The recommended bolt torque values for thermoplastic lined piping systems are shown on Tables 9-2 through 9-5. Excessive torque causes damage to the plastic sealing surfaces. When bolting together dissimilar materials, the lowest recommended torque of the components in the joint is used.

Bolting torque is rechecked approximately 24 hours after the initial installation or after the first thermal cycle. This is required to reseat the plastic and allow for relaxation of the bolts. Bolting is performed only on the system in the ambient, cooled state, and never while the process is at elevated temperature or excessive force could result upon cooling.

e. Thermal Expansion

Thermal expansion design for lined piping systems can be handled in a similar manner as metallic piping. Expansion joints have been used to compensate for thermal expansion. However, expansion joints are usually considered the weakest component in a piping system and are usually eliminated through good engineering practices. Due to the bonding between the liner and the metallic pipe casing, pre-manufactured sections of pipe designed to allow for changes in movement of the piping system are available from manufacturers.

On long straight pipe runs, lined pipe is treated similarly to carbon steel piping. Changes in direction in pipe runs are introduced wherever possible to allow thermal expansion.

A common problem is the installation of lined piping between a pump and another piece of equipment. On new installations, equipment can be laid out such that there are no direct piping runs. Where a constricted layout is required or a piping loop would not be practical, the solution is to allow the pump to "float." The pump-motor base assemblies are mounted on a platform with legs. These bases are available from several manufacturers or can be constructed. These bases allow movement in order to relieve the stresses in the piping system.

f. Heat Tracing and Insulation

Heat tracing, insulation, and cladding can be installed on lined piping systems when required. The key for the design is to not exceed the maximum allowable temperature of the lining. Manufacturers recommendations on electrical heat tracing design should be followed to avoid localized hot spots. Steam heat tracing should not be used with most plastic lined piping systems due to the high temperature potential. Venting is required on many lined piping systems to allow for permeating vapor release. If insulation or cladding is to be mounted on the piping system, vent extenders should be specified to extend past the potential blockage.

g. Piping Support and Burial

Design of support systems for lined piping systems follows the same guidelines as for the outer piping material. Spans for systems consisting of the material used in the outer pipe may be used. Supports should permit the pipe to move freely with thermal expansion and contraction. The design requirements for buried lined piping systems are the same as those for the outer piping material. That is, a buried plastic lined carbon steel pipe should be treated the same way as a carbon steel pipe without a liner.

9-2. Plastic Lined Piping Systems

Thermoplastic lined piping systems are commonly used and widely available commercially under a variety of trade names. Table 9-6 presents a summary of some of the material properties for plastic liners, and Table 9-7 lists some of the liner thicknesses used for the protection of oil production equipment when applied as a liquid coating. Standard liner thicknesses are 3.3 to 8.6 mm (0.130 to 0.340 inches).

a. Common Plastic Liners

Most thermoplastics can be used as liner material. However, the more common and commercially available plastic liners include polyvinylidene chloride, perfluoroalkoxyl, polypropylene, polytetrafluoroethylene, and polyvinylidene fluoride.

Table 9-2
ANSI Class 125 and Class 150 Systems
(Lightly Oiled Bolting)

Pipe Size, mm (in)	Number of Bolts	Bolt Diameter mm (in)	Bolt Torque, N-m (ft-lb)			
			PVDC	PP	PVDF	PTFE
25 (1)	4	14 (½)	41 (30)	37 (35)	75 (55)	34 (25)
40 (1½)	4	14 (½)	54 (40)	102 (75)	81 (60)	75 (55)
50 (2)	4	16 (5/8)	61 (45)	149 (110)	169 (125)	102 (75)
65 (2½)	4	16 (5/8)	75 (55)	169 (125)	N.A.	N.A.
80 (3)	4	16 (5/8)	95 (70)	169 (125)	169 (125)	149 (110)
100 (4)	8	16 (5/8)	68 (50)	190 (140)	169 (125)	129 (95)
150 (6)	8	20 (3/4)	129 (95)	305 (225)	305 (225)	169 (125)
200 (8)	8	20 (3/4)	217 (160)	305 (225)	305 (225)	258 (190)
250 (10)	12	24 (7/8)	N.A.	468 (345)	N.A.	271 (200)

Notes: These torques are only valid for lightly oiled ASTM A 193 bolts and nuts. Lightly oiled is considered WD-40 (WD-40 is a registered trademark of WD-40 Company, San Diego, CA) or equivalent.
N.A. = Part is not available from source.

Source: Crane/Resistoflex, "Plastic Lined Piping Products Engineering Manual," p. 54.

TABLE 9-3
ANSI Class 300 Systems
(Lightly Oiled Bolting)

Pipe Size mm (in)	Number of Bolts	Bolt Diameter mm (in)	Bolt Torque, N-m (ft-lb)			
			PVDC	PP	PVDF	PTFE
25 (1)	4	16 (5/8)	37 (35)	61 (45)	95 (70)	41 (30)
40 (1½)	4	16 (5/8)	81 (60)	149 (110)	230 (170)	108 (80)
50 (2)	8	16 (5/8)	34 (25)	75 (55)	115 (85)	54 (40)
80 (3)	8	20 (3/4)	54 (40)	136 (100)	210 (155)	88 (65)
100 (4)	8	20 (3/4)	81 (60)	230 (170)	305 (225)	149 (110)
150 (6)	12	20 (3/4)	88 (65)	224 (165)	305 (225)	115 (85)
200 (8)	12	24 (7/8)	169 (125)	441 (325)	495 (365)	203 (150)

Note: These torques are only valid for lightly oiled ASTM A 193, B7 bolts and ASTM A 194, 2H nuts. Lightly oiled is considered WD-40 (WD-40 is a registered trademark of WD-40 Company, San Diego, CA) or equivalent.

Source: Crane/Resistoflex, "Plastic Lined Piping Products Engineering Manual," p. 54.

Table 9-4
ANSI Class 125 and Class 150 Systems
(Teflon - Coated Bolting)

Pipe Size, mm (in)	Number of Bolts	Bolt Diameter mm (in)	Bolt Torque N-m (ft-lb)			
			PVDC	PP	PVDF	PTFE
25 (1)	4	14 (½)	27 (20)	34 (25)	54 (40)	20 (15)
40 (1½)	4	14 (½)	41 (30)	75 (55)	61 (45)	54 (40)
50 (2)	4	16 (5/8)	41 (30)	95 (70)	122 (90)	68 (50)
65 (2½)	4	16 (5/8)	37 (35)	122 (90)	N.A.	N.A.
80 (3)	4	16 (5/8)	68 (50)	122 (90)	122 (90)	95 (70)
100 (4)	8	16 (5/8)	37 (35)	122 (90)	122 (90)	81 (60)
150 (6)	8	20 (3/4)	41 (30)	102 (75)	102 (75)	68 (50)
200 (8)	8	20 (3/4)	75 (55)	102 (75)	102 (75)	102 (75)
250 (10)	12	24 (7/8)	N.A.	339 (250)	N.A.	203 (150)
300 (12)	12	24 (7/8)	N.A.	339 (250)	N.A.	271 (200)

Notes: These torques are valid only for Teflon-coated ASTM A 193, B7 bolts and ASTM A 194, 2H nuts.
N.A. = Part is not available from source.

Source: Crane/Resistoflex, “Plastic Lined Piping Products Engineering Manual,” p. 55.

TABLE 9-5
ANSI Class 300 Systems
(Teflon - Coated Bolting)

Pipe Size mm (in)	Number of Bolts	Bolt Diameter mm (in)	Bolt Torque N-m (ft-lb)			
			PVDC	PP	PVDF	PTFE
25 (1)	4	16 (5/8)	41 (30)	37 (35)	61 (45)	27 (20)
40 (1½)	4	20 (3/4)	34 (25)	61 (45)	95 (70)	41 (30)
50 (2)	8	16 (5/8)	27 (20)	61 (45)	95 (70)	41 (30)
80 (3)	8	20 (3/4)	34 (25)	61 (45)	81 (60)	34 (25)
100 (4)	8	20 (3/4)	41 (30)	95 (70)	102 (75)	61 (45)
150 (6)	12	20 (3/4)	41 (30)	95 (70)	102 (75)	37 (35)
200 (8)	12	24 (7/8)	129 (95)	312 (230)	346 (255)	163 (120)

Notes: These torques are valid only for Teflon-coated ASTM A 193, B7 bolts and ASTM A 194, 2H nuts.

Source: Crane/Resistoflex, “Plastic Lined Piping Products Engineering Manual,” p. 55.

Table 9-6
Plastic Liner Material Properties

Liner Material	Shell Material	Specific Gravity	Tensile Strength, MPa (psi)	Available Size Range, mm (in)	Maximum Temperature, EC (EF)
PVC	- -	1.45	41.4 (6,000)	- -	82 (180)
PVDC	carbon steel	1.75	18.6 (2,700)	25 to 200 (1 to 8)	79 (175)
PE	carbon steel, aluminum	0.94	8.27 (1,200)	50 to 200 (2 to 8)	66 (150)
PP	carbon steel	0.91	31.0 (4,500)	25 to 300 (1 to 12)	107 (225)
PTFE	carbon steel, TP304L stainless steel	2.17	17.2 (2,500)	25 to 300 (1 to 12)	232 (450)
FEP	carbon steel	2.15	23.4 (3,400)	25 to 750 (1 to 30)	204 (400)
PFA	carbon steel	2.15	24.8 (3,600)	25 to 750 (1 to 30)	260 (500)
ETFE	carbon steel	1.7	44.8 (6,500)	as required*	150 (300)
PVDF	carbon steel	1.78	31.0 (4,500)	25 to 200 (1 to 8)	135 (275)
ECTFE	carbon steel, stainless steel	1.68	48.3 (7,000)	25 to 200 (1 to 8)	150 (300)

Note: *Typically liquid applied; availability based upon shell piping availability.
Source: Compiled by SAIC, 1998; note that confirmation is required from the specific vendor for a selected product.

Table 9-7
Liquid-Applied Coating Thickness

Material	Total Dry Film Thickness Range
Fluoropolymers (ETFE, ECTFE)	50 to 125 µm (2 to 5 mils)
PVDF	500 to 1,500 µm (20 to 60 mils)

Source: NACE, RP 0181-94, p. 3.

Polytetrafluoroethylene (PTFE) is a fully fluorinated polymer. Although PTFE is chemically inert to most materials, some chemicals will permeate through the liner. Therefore, venting of the joint area between the liner and outer casing is required[4]. PTFE materials are produced in accordance with ASTM D 1457 with material parameters specified by the designation of type (I through VIII) and class (specific to each type). The manufacture of PTFE lined pipe and materials are in accordance with ASTM F 423.

Polyvinylidene fluoride (PVDF) is similar to PTFE but is not fully fluorinated. PVDF liners can be produced with sufficient thickness to prevent permeation of gases (seeTable 9-8) so that liner venting is not required[5]. PVDF resins are produced in accordance with ASTM D 3222 with material parameters specified by the designation of either type 1 (class 1 or 2) or type 2. PVDF lined pipe and fittings are manufactured to conform to ASTM F 491.

Polyvinylidene chloride (PVDC) is a proprietary product of Dow Chemical (trade name Saran). PVDC is often used in applications where purity protection is critical. PFA resins are manufactured according to ASTM D 729, and lined piping and fittings are manufactured to conform to ASTM F 599.

Polypropylene (PP) lined pipe is typically inexpensive compared to other lined plastic piping systems. In addition, PP does not allow permeation; therefore, liner venting is not required[6]. Physical parameters (e.g., density, tensile strength, flexural modulus) of PP materials are specified by cell classification pursuant to ASTM D 4101. Additional material requirements may be added using the ASTM D 4000 suffixes; for example, W = weather resistant. The manufacture of PP lined pipe and materials are in accordance with ASTM F 492.

Perfluoroalkoxyl (PFA) is a fully fluorinated polymer that is not affected by chemicals commonly found in chemical processes. Depending upon process conditions PFA will absorb some liquids, however, including benzaldehyde, carbon tetrachloride, toluene, ferric chloride, hydrochloric acid, and other liquids. PFA lacks the physical strength of PTFE at higher temperatures and fails at 1/4 of the life of PTFE under flexibility tests[7]. PFA resins are manufactured according to ASTM D 3307, and lined piping and fittings are manufactured to conform to ASTM F 781.

Table 9-8
Typical PVDF Liner Thickness
Required to Prevent Permeation

Nominal Pipe Size, mm (in)	Liner Thickness, mm (in)
25 (1)	3.81 (0.150)
40 (1 ½)	4.07 (0.160)
50 (2)	4.37 (0.172)
80 (3)	4.45 (0.175)
100 (4)	5.26 (0.207)
150 (6)	5.54 (0.218)
200 (8)	5.54 (0.218)

Source: Reprinted from Schweitzer, Corrosion-Resistant Piping Systems, p. 182, by courtesy of Marcel Dekker, Inc.

b. Plastic Lined Piping Construction

As discussed in Paragraph 9-1d, plastic lined pipe piping is joined using flanges or mechanical couplings and fittings that are normally flanged. Some manufacturers can provide pre-bent pipe sections to avoid the use of flanged elbows. Use of pre-bent pipe sections requires

4 Schweitzer, Corrosion-Resistant Piping Systems, pp. 161-162.
5 Ibid., p. 165.
6 Ibid., p. 166.
7 Ibid., p. 164.

that the design take into account the manufacturer's standard bend radius which is often larger than the bend radius for conventional elbows.

9-3. Other Lined Piping Systems

The elastomer and rubber materials most commonly used as liner materials include natural rubber, neoprene, butyl, chlorobutyl, nitrile, and EPDM, which tend to be less expensive than other liners. Design criteria that need to be considered before selecting elastomeric and rubber lined piping systems include: corrosion resistance, abrasion resistance, maximum operating temperature, and potential contamination of conveyed material.

Elastomeric and rubber linings vary in thickness from 3.2 to 6.4 mm (1/8 to 1/4 in). Lined pipe is available from 40 to 250 mm (1½ to 10 in), standard, at ratings of 1.03 MPa (150 psi) or 2.06 MPa (300 psi). Joining is typically accomplished through the use of flanges.

Glass-lined piping systems are commercially available with carbon steel outer piping in sizes of 25 to 300 mm (1 to 12 in), standard. Joining is accomplished using class 150 split flanges, although class 300 split flanges are also available as options. A PTFE envelope gasket is recommended[8]. Stress is to be avoided; expansion joints should be used to isolate vibration and other stresses from the piping system. Sudden changes in process temperatures should also be avoided.

Nickel-lined piping systems are available in sizes from 40 to 600 mm (1½ to 24 in) with liner thickness of 0.0008 to 0.015 inches. Joining is accomplished either by welding or flanging, with welding the preferred method[9].

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[8] Schweitzer, Corrosion-Resistant Piping Systems, p. 198.
[9] Ibid., p. 199.