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LIQUID PROCESS PIPING - VOL 2 OF 2

Main Category:	Mechanical Engineering
Sub Category:	Process Design
Course #:	MEC-117
Course Content:	170 pgs
PDH/CE Hours:	6

OFFICIAL COURSE/EXAM

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MEC-117 EXAM PREVIEW

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Exam Preview:

1. Thermoplastic piping systems, commonly referred to as plastic piping systems, are composed of various additives to a base resin or composition. Thermoplastics are characterized by their ability to be softened and reshaped repeatedly by the application of pressure.
    a. True
    b. False
2. Unlike metallic piping, thermoplastic materials do not display corrosion rates.
    a. True
    b. False
3. CPVC stands for Cold Poly Vinyl Chloride.
    a. True
    b. False
4. When designing a piping system where thermal expansion of the piping is ___ at supports, anchors, equipment nozzles and penetrations, large thermal stresses and loads must be analyzed and accounted for within the design.
    a. Restrained
    b. Located
    c. Coupled
    d. Flexible

5. CPVC is commonly used for chemical or corrosive services and hot water in the temperature range of:
    a. 140-210F
    b. 120-210F
    c. 110-250F
    d. 250-300F
6. High Density (HDPE) has a specific gravity (SG) of 0.91 to 0.925.
    a. True
    b. False
7. The design of double containment piping systems includes the provision for pressure testing both the primary and secondary systems. Testing is specified in the same manner as other process piping systems.
    a. True
    b. False
8. For liquid piping systems, ___ are the controlling element.
    a. pressure design
    b. containment
    c. supports
    d. valves
9. Valve seats are an integral part of a valve. The materials for valve seats are specified under valve trim for each valve. As such, valve seats are manufacturer specific and should not be interchanged.
    a. True
    b. False
10. In buried installations, leaks due to corrosion in metallic piping systems can cause environmental damage. Furthermore, certain types of processes pose safety problems if cathodic protection is not properly installed and maintained. The design and installation of the piping system without consideration of cathodic protection is not acceptable.
    a. True
    b. False

COURSE DETAILS

This course outlines the fundamentals of design for liquid process piping. The course content is primarily focused towards Mechanical, Chemical & Industrial Engineers.

COURSE OBJECTIVES

The objective of this educational course is to review the fundamentals of the design of Liquid Process Piping. This course is vol 2 of 2. This course can be taken individually, and it is not required that vol 1 of 2 be taken. This course covers Plastic Piping Systems; Rubber and Elastomer Piping Systems; Thermoset Piping Systems; Double Containment Piping Systems; Lined Piping Systems; Valves; Ancillary Equipment; & Corrosion Protection.

EXAM/COMPLETION CERTIFICATES

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Chapter 5
Plastic Piping Systems

5-1. General

Thermoplastic piping systems, commonly referred to as plastic piping systems, are composed of various additives to a base resin or composition. Thermoplastics are characterized by their ability to be softened and reshaped repeatedly by the application of heat. Table 5-1 lists the chemical names and abbreviations for a number of thermoplastic piping materials. Because of the slightly different formulations, properties of plastic piping materials (for example, polyvinyl chloride - PVC) may vary from manufacturer to manufacturer[1]. Therefore, designs and specifications need to address specific material requirements on a type or grade basis, which may have to be investigated and confirmed with manufacturers.

a. Corrosion

Unlike metallic piping, thermoplastic materials do not display corrosion rates[2]. That is, the corrosion of thermoplastic materials is dependent totally on the material's chemical resistance rather than an oxide layer, so the material is either completely resistant to a chemical or it deteriorates. This deterioration may be either rapid or slow. Plastic piping system corrosion is indicated by material softening, discoloration, charring, embrittlement, stress cracking (also referred to as crazing), blistering, swelling, dissolving, and other effects. Corrosion of plastics occurs by the following mechanisms:

- absorption;
- solvation;
- chemical reactions such as oxidation (affects chemical bonds), hydrolysis (affects ester linkages), radiation, dehydration, alkylation, reduction, and halogenation (chlorination);

Table 5-1
Abbreviations for Thermoplastic Materials

Abbreviation	Chemical Name
ABS	Acrylonitrile-Butadiene-Styrene
CPVC	Chlorinated Poly(Vinyl Chloride)
ECTFE	Ethylene-Chlorotrifluoroethylene
ETFE	Ethylene-Tetrafluoroethylene
FEP	Perfluoro(Ethylene-Propylene) Copolymer
PE	Polyethylene
PFA	Perfluoro(Alkoxyalkane) Copolymer
PP	Polypropylene
PTFE	Polytetrafluoroethylene
PVC	Poly(Vinyl Chloride)
PVDC	Poly(Vinylidene Chloride)
PVDF	Poly(Vinylidene Fluoride)

Sources: ASTM D 1600.
ASME B31.3 (Used by permission of ASME).

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[1] Schweitzer, Corrosion-Resistant Piping Systems, p. 17.
[2] Ibid., p. 18.

- thermal degradation which may result in either depolymerization or plasticization;
- environmental-stress cracking (ESC) which is essentially the same as stress-corrosion cracking in metals;
- UV degradation; and
- combinations of the above mechanisms.

For plastic material compatibility with various chemicals, see Appendix B. If reinforcing is used as part of the piping system, the reinforcement is also a material that is resistant to the fluid being transported. Material selection and compatibility review should consider the type and concentration of chemicals in the liquid, liquid temperature, duration of contact, total stress of the piping system, and the contact surface quality of the piping system. See Appendix A, paragraph A-4 - Other Sources of Information, for additional sources of corrosion data.

b. Operating Pressures and Temperatures

The determination of maximum steady state design pressure and temperature is similar to that described for metallic piping systems. However, a key issue that must be addressed relative to plastic piping systems is the impact of both minimum and maximum temperature limits of the materials of construction.

c. Sizing

The sizing for plastic piping systems is performed consistent with the procedures of Paragraph 3-3. However, one of the basic principles of designing and specifying thermoplastic piping systems for liquid process piping pressure applications is that the short and long term strength of thermoplastic pipe decreases as the temperature of the pipe material increases.

Thermoplastic pipe is pressure rated by using the International Standards Organization (ISO) rating equation using the Hydrostatic Design Basis (HDB) as contained in ASTM standards and Design Factors (DFs). The use of DFs is based on the specific material being used and specific application requirements such as temperature and pressure surges. The following is the basic equation for internal hydraulic pressure rating of thermoplastic piping:

$$P_R = 2(HDS)(t/D_m)$$

where:
P_R = pipe pressure rating, MPa (psi)
t = minimum wall thickness, mm (in)
D_m = mean diameter, mm (in)
HDS = (HDB)(DF)

The minimum pipe wall thickness can also be determined using the requirements of ASME B31.3 as described in Paragraph 3-3b. This procedure is not directly applicable to thermoplastic pipe fittings, particularly in cyclic pressure operations due to material fatigue. Therefore, it should not be assumed that thermoplastic fittings labeled with a pipe schedule designation will have the same pressure rating as pipe of the same designation. A good example of this is contained in ASTM D 2466 and D 2467 which specify pressure ratings for PVC schedule 40 and 80 fittings. These ratings are significantly lower than the rating for PVC pipe of the same designation. For thermoplastic pipe fittings that do not have published pressure ratings information similar to ASTM standards, the fitting manufacturer shall be consulted for fitting pressure rating recommendations.

d. Joining

Common methods for the joining of thermoplastic pipe for liquid process waste treatment and storage systems are contained in Table 5-2. In selecting a joining method for liquid process piping systems, the advantages and disadvantages of each method are evaluated and the manner by which the joining is accomplished for each liquid service is specified. Recommended procedures and specification for these joining methods are found in codes, standards and manufacturer procedures for joining thermoplastic pipe. Table 5-3 lists applicable references for joining thermoplastic pipe.

e. Thermal Expansion

When designing a piping system where thermal expansion of the piping is restrained at supports, anchors, equipment nozzles and penetrations, large thermal stresses and loads must be analyzed and accounted for within the design. The system PFDs and P&IDs are analyzed to determine the thermal conditions or modes to

Table 5-2
Thermoplastic Joining Methods

Joining Method	ABS	PVC	CPVC	PE	PP	PVDF
Solvent Cementing	X	X	X			
Heat Fusion				X	X	X
Threading*	X	X	X	X	X	X
Flanged Connectors**	X	X	X	X	X	X
Grooved Joints***	X	X	X	X	X	X
Mechanical Compression****	X	X	X	X	X	X
Elastomeric seal	X	X	X	X	X	X
Flaring				X		

Notes:
X = applicable method
* Threading requires a minimum pipe wall thickness (Schedule 80).
** Flanged adapters are fastened to pipe by heat fusion, solvent cementing, or threading.
*** Grooving requires a minimum pipe wall thickness (material dependent).
**** Internal stiffeners are required.
Source: Compiled by SAIC, 1998.

Table 5-3
Thermoplastic Joining Standards

Reference	Key Aspects of Reference
ASTM D 2657	Recommended practice for heat fusion.
ASTM D 2855	Standard practice for solvent cementing PVC pipe and fittings.
ASTM D 3139	Elastomeric gasketed connections for pressure applications.
ASTM F 1290	Recommended practice for electrofusion.

Source: Compiled by SAIC, 1998.

which the piping system will be subjected during operation. Based on this analysis, the design and material specification requirements from an applicable standard or design reference are followed in the design.

A basic approach to assess the need for additional thermal stress analysis for piping systems includes identifying operating conditions that will expose the piping to the most severe thermal loading conditions. Once these conditions have been established, a free or unrestrained thermal analysis of the piping can be performed to establish location, sizing, and arrangement of expansion loops, or expansion joints (generally, bellows or slip types).

If the application requires the use of a bellow or piston joint, the manufacturer of the joint shall be consulted to determine design and installation requirements.

When expansion loops are used, the effects of bending on the fittings used to install the expansion loop are considered. Installation of the loop should be performed in consultation with the fitting manufacturer to ensure that specified fittings are capable of withstanding the anticipated loading conditions, constant and cyclic, at the design temperatures of the system. Terminal loadings on equipment determined from this analysis can then be used to assess the equipment capabilities for withstanding the loading from the piping system. It should also be noted that this termination analysis at equipment and anchor terminations should consider the movement and stress impacts of the "cold" condition.

No rigid or restraining supports or connections should be made within the developed length of an expansion loop, offset, bend or brand. Concentrated loads such as valves should not be installed in the developed length. Piping support guides should restrict lateral movement and should direct axial movement into the compensating configurations. Calculated support guide spacing distances for offsets and bends should not exceed recommended hanging support spacing for the maximum temperature. If that occurs, distance between anchors will have to be decreased until the support guide spacing distance equals or is less than the recommended support spacing. Use of the rule of thumb method or calculated method is not recommended for threaded Schedule 80 connections. Properly cemented socket cement joints should be utilized.

Expansion loops, offsets and bends should be installed as nearly as possible at the mid point between anchors.

Values for expansion joints, offsets, bends and branches can be obtained by calculating the developed length from the following equation.

$$L = n_1 \left(\frac{3\ E\ D_o\ e}{S} \right)^{1/2}$$

where:

L = developed length, m (ft)
n_1 = conversion factor, 10^{-3} m/mm (1/12 ft/in)
E = tensile modulus of elasticity, MPa (psi)
D_o = pipe outer diameter, mm (in)
e = elongation due to temperature rise, mm (in)
S = maximum allowable stress, MPa (psi)

In determining the elongation due to temperature rise information from the manufacturer on the material to be used should be consulted. For example, the coefficient of expansion is 6.3 x 10^{-5} mm/mm/°C (3.4 x 10^{-5} in/in/°F) for Type IV Grade I CPVC and 5.4 x 10^{-5} mm/mm/°C (2.9 x 10^{-5} in/in/°F) for Type I Grade I PVC. Other sources of information on thermal expansion coefficients are available from plastic pipe manufacturers.

PVC and CPVC pipe does not have the rigidity of metal pipe and can flex during expansion, especially with smaller diameters. If expansion joints are used, axial guides should be installed to ensure straight entrance into the expansion joint, especially when maximum movement of the joint is anticipated. Leakage at the seals can occur if the pipe is cocked. Independent anchoring of the joint is also recommended for positive movement of expansion joints.

f. Piping Support and Burial

Support for thermoplastic pipe follows the same basic principles as metallic piping. Spacing of supports is crucial for plastic pipe. Plastic pipe will deflect under load more than metallic pipe. Excessive deflection will lead to structural failure. Therefore, spacing for plastic pipe is closer than for metallic pipe. Valves, meters, and fittings should be supported independently in plastic pipe systems, as in metallic systems.

In addition, plastic pipe systems are not located near sources of excessive heat. The nature of thermoplastic pipe is that it is capable of being repeatedly softened by increasing temperature, and hardened by decreasing temperature. If the pipe is exposed to higher than design value ambient temperatures, the integrity of the system could be compromised.

Contact with supports should be such that the plastic pipe material is not damaged or excessively stressed. Point contact or sharp surfaces are avoided as they may impose excessive stress on the pipe or otherwise damage it.

Support hangers are designed to minimize stress concentrations in plastic pipe systems. Spacing of supports should be such that clusters of fittings or concentrated loads are adequately supported. Valves, meters, and other miscellaneous fittings should be supported exclusive of pipe sections.

Supports for plastic pipe and various valves, meters, and fittings, should allow for axial movement caused by thermal expansion and contraction. In addition, external stresses should not be transferred to the pipe system through the support members. Supports should allow for axial movement, but not lateral movement. When a pipeline changes direction, such as through a 90° elbow, the plastic pipe should be rigidly anchored near the elbow.

Plastic pipe systems should be isolated from sources of vibration, such as pumps and motors. Vibrations can negatively influence the integrity of the piping system, particularly at joints.

Support spacing for several types of plastic pipe are found in Tables 5-4 through 5-6. Spacing is dependent upon the temperature of the fluid being carried by the pipe.

The determining factor to consider in designing buried thermoplastic piping is the maximum allowable deflection in the pipe. The deflection is a function of the bedding conditions and the load on the pipe. The procedure for determining deflection is as follows[3]:

$$\%\ deflection = \frac{100\ \Delta Y}{D_o}$$

where:

ΔY = calculated deflection
D_o = outer pipe diameter, mm (in)

$$\Delta Y = \frac{(K_x)(d_e)(\omega)}{[0.149(PS) + 0.061(E')]}$$

where:

ΔY = calculated deflection
K_x = bedding factor, see Table 5-7
d_e = deflection lag factor, see Table 5-8
ω = weight per length of overburden, N/m (lb/in)
PS = pipe stiffness, MPa (psi)
E′ = soil modulus, MPa (psi), see Table 5-9

$$\omega = \frac{(H)(D_o)(\gamma)}{144} = (\sigma)(D_o)$$

where:

ω = weight per length of overburden, N/m (lb/in)
H = height of cover, m (ft)
D_o = outer pipe diameter, mm (in)
γ = density of soil N/m^3 (lb/ft^3)
σ = soil overburden pressure, MPa (psi)

$$PS = \frac{(E)(I_a)}{0.149\ (R)^3}$$

where:

PS = pipe stiffness, MPa (psi)
E = modulus of elasticity of pipe, MPa (psi)
I_a = area moment of inertia per unit length of pipe, mm^4/mm (in^4/in)
R = mean radii of pipe, MPa (psi)

$$R = \frac{(D_o - t)}{2}$$

where:

R = mean radii of pipe, MPa (psi)
D_o = outer pipe diameter, mm (in)
t = average wall thickness, mm (in)

$$I_a = \frac{t^3}{12}$$

where:

I_a = area moment of inertia per unit length of pipe, mm^4/mm (in^4/in)
t = average wall thickness, mm (in)

Proper excavation, placement, and backfill of buried plastic pipe is crucial to the structural integrity of the system. It is also the riskiest operation, as a leak in the system may not be detected before contamination has occurred. A proper bed, or trench, for the pipe is the initial step in the process. In cold weather areas, underground pipelines should be placed no less than one

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[3] ASTM D 2412, Appendices.

Table 5-4
Support Spacing for Schedule 80 PVC Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft) at Various Temperatures				
	16EC (60EF)	27EC (80EF)	38EC (100EF)	49EC (120EF)	60EC (140EF)*
25 (1)	1.83 (6.0)	1.68 (5.5)	1.52 (5.0)	1.07 (3.5)	0.91 (3.0)
40 (1.5)	1.98 (6.5)	1.83 (6.0)	1.68 (5.5)	1.07 (3.5)	1.07 (3.5)
50 (2)	2.13 (7.0)	1.98 (6.5)	1.83 (6.0)	1.22 (4.0)	1.07 (3.5)
80 (3)	2.44 (8.0)	2.29 (7.5)	2.13 (7.0)	1.37 (4.5)	1.22 (4.0)
100 (4)	2.74 (9.0)	2.59 (8.5)	2.29 (7.5)	1.52 (5.0)	1.37 (4.5)
150 (6)	3.05 (10.0)	2.90 (9.5)	2.74 (9.0)	1.83 (6.0)	1.52 (5.0)
200 (8)	3.35 (11.0)	3.2 (10.5)	2.90 (9.5)	1.98 (6.5)	1.68 (5.5)
250 (10)	3.66 (12.0)	3.35 (11.0)	3.05 (10.0)	2.13 (7.0)	1.83 (6.0)
300 (12)	3.96 (13.0)	3.66 (12.0)	3.2 (10.5)	2.29 (7.5)	1.98 (6.5)
350 (14)	4.11 (13.5)	3.96 (13.0)	3.35 (11.0)	2.44 (8.0)	2.13 (7.0)

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.
* The use of continuous supports or a change of material (e.g., to CPVC) is recommended at 60°C (140°F).
Source: Harvel Plastics, Product Bulletin 112/401 (rev. 10/1/95), p. 63.

Table 5-5
Support Spacing for Schedule 80 PVDF Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft) at Various Temperatures			
	20EC (68EF)	40EC (104EF)	60EC (140EF)	80EC (176EF)
25 (1)	1.07 (3.5)	0.91 (3.0)	0.91 (3.0)	0.76 (2.5)
40 (1.5)	1.22 (4.0)	0.91 (3.0)	0.91 (3.0)	0.91 (3.0)
50 (2)	1.37 (4.5)	1.22 (4.0)	0.91 (3.0)	0.91 (3.0)
80 (3)	1.68 (5.5)	1.22 (4.0)	1.22 (4.0)	1.07 (3.5)
100 (4)	1.83 (6.0)	1.52 (5.0)	1.22 (4.0)	1.22 (4.0)
150 (6)	2.13 (7.0)	1.83 (6.0)	1.52 (5.0)	1.37 (4.5)

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.
Source: Asahi/America, Piping Systems Product Bulletin P-97/A, p. 24.

Table 5-6
Support Spacing for Schedule 80 CPVC Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft) at Various Temperatures					
	23EC (73EF)	38EC (100EF)	49EC (120EF)	60EC (140EF)	71EC (160EF)	82EC (180EF)
25 (1)	1.83 (6.0)	1.83 (6.0)	1.68 (5.5)	1.52 (5.0)	1.07 (3.5)	0.91 (3.0)
40 (1.5)	2.13 (7.0)	1.98 (6.5)	1.83 (6.0)	1.68 (5.5)	1.07 (3.5)	0.91 (3.0)
50 (2)	2.13 (7.0)	2.13 (7.0)	1.98 (6.5)	1.83 (6.0)	1.22 (4.0)	1.07 (3.5)
80 (3)	2.44 (8.0)	2.44 (8.0)	2.29 (7.5)	2.13 (7.0)	1.37 (4.5)	1.22 (4.0)
100 (4)	2 59 (8.5)	2 59 (8.5)	2 59 (8.5)	2.29 (7.5)	1.52 (5.0)	1.37 (4.5)
150 (6)	3.05 (10.0)	2.90 (9.5)	2.74 (9.0)	2.44 (8.0)	1.68 (5.5)	1.52 (5.0)
200 (8)	3.35 (11.0)	3.20 (10.5)	3.05 (10.0)	2.74 (9.0)	1.83 (6.0)	1.68 (5.5)
250 (10)	3.51 (11.5)	3.35 (11.0)	3.20 (10.5)	2.90 (9.5)	1.98 (6.5)	1.83 (6.0)
300 (12)	3.81 (12.5)	3.66 (12.0)	3.51 (11.5)	3.20 (10.5)	2.29 (7.5)	1.98 (6.5)

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.

Source: Harvel Plastics, Product Bulletin 112/401 (rev. 10/1/95), p. 63.

Table 5-7
Bedding Factor, K_x

Type of Installation	K_x
Shaped bottom with tamped backfill material placed at the sides of the pipe, 95% Proctor density or greater	0.083
Compacted coarse-grained bedding and backfill material placed at the side of the pipe, 70-100% relative density	0.083
Shaped bottom, moderately compacted backfill material placed at the sides of the pipe, 85-95% Proctor density	0.103
Coarse-grained bedding, lightly compacted backfill material placed at the sides of the pipe, 40-70% relative density	0.103
Flat bottom, loose material placed at the sides of the pipe (not recommended); <35% Proctor density, <40% relative density	0.110

Source: Reprinted from Schweitzer, Corrosion-Resistant Piping Systems, p. 49, by courtesy of Marcel Dekker, Inc.

Table 5-8
Deflection Lag Factor, d_e

Installation Condition	d_e
Burial depth <5 ft. with moderate to high degree of compaction (85% or greater Proctor, ASTM D 698 or 50% or greater relative density ASTM D-2049)	2.0
Burial depth <5 ft. with dumped or slight degree of compaction (Proctor > 85%, relative density > 40%)	1.5
Burial depth >5 ft. with moderate to high degree of compaction	1.5
Burial depth > 5 ft. with dumped or slight degree of compaction	1.25

Source: Reprinted from Schweitzer, Corrosion-Resistant Piping Systems, p. 49, by courtesy of Marcel Dekker, Inc.

Table 5-9
Values of ENModulus of Soil Reaction for Various Soils

Soil Type and Pipe Bedding Material	EN for Degree of Compaction of Bedding, MPa (lb/ft^2)			
	Dumped	Slight <85% Proctor >40% rel. den.	Moderate 85-95% Proctor 40-70% rel. den.	High >90% Proctor >70% rel. den.
Fine-grained soils (LL >50) with medium to high plasticity CH, MH, CH-MH	No data available - consult a soil engineer or use E′ = 0			
Fine-grained soils (LL <50) with medium to no plasticity CL, ML, ML-CL, with <25% coarse-grained particles	0.35 (50)	1.38 (200)	2.76 (400)	6.90 (1000)
Fine-grained soils (LL <50) with no plasticity CL, ML, ML-CL, with >25% coarse-grained particles.	0.69 (100)	2.76 (400)	6.90 (1000)	13.8 (2000)
Coarse-grained soils with fines GM, GC, SM, SC contains >12% fines.	0.69 (100)	2.76 (400)	6.90 (1000)	13.8 (2000)
Coarse-grained soils with little or no fines GW, SW, GP, SP contains <12% fines (or any borderline soil beginning with GM-GC or GC-SC)	1.38 (200)	6.90 (1000)	13.8 (2000)	20.7 (3000)
Crushed rock	6.90 (1000)	20.7 (3000)	20.7 (3000)	20.7 (3000)

Notes: LL = liquid limit
Sources: AWWA C900, Table A.4., p.17.
Schweitzer, Corrosion-Resistant Piping Systems, p. 48, (by courtesy of Marcel Dekker, Inc.).

foot below the frost line. The trench bottom should be relatively flat, and smooth, with no sharp rocks that could damage the pipe material. The pipe should be bedded with a uniformly graded material that will protect the pipe during backfill. Typical installations use an American Association of State Highway Transportation Officials (AASHTO) #8 aggregate, or pea-gravel for six inches below and above the pipe. These materials can be dumped in the trench at approximately 90-95% Proctor without mechanical compaction. The remainder of the trench should be backfilled with earth, or other material appropriate for surface construction, and compacted according to the design specifications.

5-2. Polyvinyl Chloride (PVC)

Polyvinyl chloride (PVC) is the most widely used thermoplastic piping system. PVC is stronger and more rigid than the other thermoplastic materials. When specifying PVC thermoplastic piping systems particular attention must be paid to the high coefficient of expansion-contraction for these materials in addition to effects of temperature extremes on pressure rating, viscoelasticity, tensile creep, ductility, and brittleness.

a. PVC Specifications

PVC pipe is available in sizes ranging from 8 to 400 mm (1/4 to 16 in), in Schedules 40 and 80. Piping shall conform to ASTM D 2464 for Schedule 80 threaded type; ASTM D 2466 for Schedule 40 socket type; or ASTM D 2467 for Schedule 80 socket type.

Maximum allowable pressure ratings decrease with increasing diameter size. To maintain pressures ratings at standard temperatures, PVC is also available in Standard Dimension Ratio (SDR). SDR changes the dimensions of the piping in order to maintain the maximum allowable pressure rating.

b. PVC Installation

For piping larger than 100 mm (4 in) in diameter, threaded fittings should not be used. Instead socket welded or flanged fittings should be specified. If a threaded PVC piping system is used, two choices are available, either use all Schedule 80 piping and fittings, or use Schedule 40 pipe and Schedule 80 threaded fittings. Schedule 40 pipe will not be threaded. Schedule 80 pipe would be specified typically for larger diameter pipes, elevated temperatures, or longer support span spacing. The system is selected based upon the application and design calculations.

The ranking of PVC piping systems from highest to lowest maximum operating pressure is as follows: Schedule 80 pipe socket-welded; Schedule 40 pipe with Schedule 80 fittings, socket-welded; and Schedule 80 pipe threaded. Schedule 40 pipe provides equal pressure rating to threaded Schedule 80, making Schedule 80 threaded uneconomical. In addition, the maximum allowable working pressure of PVC valves is lower than a Schedule 80 threaded piping system.

5-3. Polytetrafluoroethylene (PTFE)

Polytetrafluoroethylene (PTFE) is a very common thermoplastic material used in many other applications in addition to piping systems. PTFE is chemically resistant and has a relatively wide allowable temperature range of -260°C (-436°F) to 260°C (500°F). Furthermore, PTFE has a high impact resistance and a low coefficient of friction and is often considered “self-lubricating.” The most common trade name for PTFE is Teflon, registered trademark of E.I Dupont Company.

5-4. Acrylonitrile-Butadiene-Styrene (ABS)

Acrylonitrile-Butadiene-Styrene (ABS) is a thermoplastic material made with virgin ABS compounds meeting the ASTM requirements of Cell Classification 4-2-2-2-2 (pipe) and 3-2-2-2-2 (fittings). Pipe is available in both solid wall and cellular core wall, which can be used interchangeably. Pipe and fittings are available in size 32 mm (1-1/4 in) through 300 mm (12 in) in diameter. The pipe can be installed above or below grade.

a. ABS Standards

ASTM D 2282 specifies requirements for solid wall ABS pipe. ASTM D 2661 specifies requirements for solid wall pipe for drain, waste, and vents. ASTM F 628 specifies requirements for drain, waste, and vent pipe and fittings with a cellular core. Solid wall ABS fittings conform to ASTM D 2661. The drainage pattern for fittings is specified by ASTM D 3311.

ABS compounds have many different formulations that vary by manufacturer. The properties of the different formulations also vary extensively. ABS shall be specified very carefully and thoroughly because the acceptable use of one compound does not mean that all ABS piping systems are acceptable. Similarly, ABS compositions that are designed for air or gas handling may not be acceptable for liquids handling.

b. ABS Limitations

Pigments are added to the ABS to make pipe and fittings resistant to ultraviolet (UV) radiation degradation. Pipe and fittings specified for buried installations may be exposed to sunlight during construction, however, and prolonged exposure is not advised.

ABS pipe and fittings are combustible materials; however, they may be installed in noncombustible buildings. Most building codes have determined that ABS must be protected at penetrations of walls, floors, ceilings, and fire resistance rated assemblies. The method of protecting the pipe penetration is using a through-penetration protection assembly that has been tested and rated in accordance with ASTM E 814. The important rating is the "F" rating for the through penetration protection assembly. The "F" rating must be a minimum of the hourly rating of the fire resistance rated assembly that the ABS plastic pipe penetrates. Local code interpretations related to through penetrations are verified with the jurisdiction having authority.

5-5. Chlorinated Polyvinyl Chloride (CPVC)

Chlorinated polyvinyl chloride (CPVC) is more highly chlorinated than PVC. CPVC is commonly used for chemical or corrosive services and hot water above 60°C (140°F) and up to 99°C (210°F). CPVC is commercially available in sizes of 8 to 300 mm (1/4 to 12 in) for Schedule 40 and Schedule 80. Exposed CPVC piping should not be pneumatically tested, at any pressure, due to the possibility of personal injury from fragments in the event of pipe failure; see Paragraph 3-8d for further information.

ASTM specifications for CPVC include: ASTM F 437 for Schedule 80 threaded type; ASTM F 439 for Schedule 80 socket type; and ASTM F 438 for Schedule 40 socket type. However, note that Schedule 40 socket may be difficult to procure.

5-6. Polyethylene (PE)

Polyethylene (PE) piping material properties vary as a result of manufacturing processes. Table 5-10 lists the common types of PE, although an ultra high molecular weight type also exists. PE should be protected from ultraviolet radiation by the addition of carbon black as a stabilizer; other types of stabilizers do not protect adequately[4]. PE piping systems are available in sizes ranging from 15 to 750 mm (½ to 30 in). Like PVC, PE piping is available in SDR dimensions to maintain maximum allowable pressure ratings.

5-7. Polypropylene (PP)

Polypropylene (PP) piping materials are similar to PE, containing no chlorine or fluorine. PP piping systems are available in Schedule 40, Schedule 80, and SDR dimensions. With a specific gravity of 0.91, PP piping systems are one of the lightest thermoplastic piping systems.

5-8. Polyvinylidene Fluoride (PVDF)

Polyvinylidene fluoride (PVDF) pipe is available in a diameter range of 15 to 150 mm (½ to 6 in); Schedules 40 and 80; and pressure ratings of 1.03 MPa (150 psig) and 1.59 MPa (230 psig). Use of PVDF with liquids above 49°C (120°F) requires continuous support. Care must be taken in using PVDF piping under suction. PVDF does not degrade in sunlight; therefore, PVDF does not require UV stabilizers or antioxidants. PVDF pipe is chemically resistant to most acids; bases and organics; and can transport liquid or powdered halogens such as chlorine or bromine. PVDF should not be used with strong alkalies, fuming acids, polar solvents, amines, ketones or esters[5]. Trade names for PVDF pipe include Kynar by Elf Atochem, Solef by Solvay, Hylar by Ausimont USA, and Super Pro 230 by Asahi America.

Fusion welding is the preferred method for joining PVDF pipe. Threading can only be accomplished on Schedule 80 pipe.

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[4] Schweitzer, Corrosion-Resistant Piping System, p. 39.

[5] Ibid., p. 43.

Table 5-10
Polyethylene Designations

Type	Standard	Specific Gravity
Low Density (LDPE)	ASTM D 3350, Type I	0.91 to 0.925
Medium Density (MDPE)	ASTM D 3350, Type II	0.926 to 0.940
High Density (HDPE)	ASTM D 3350, Type III and ASTM D 1248 Type IV	0.941 to 0.959

Source: Compiled by SAIC, 1998

Chapter 6
Rubber and Elastomer Piping Systems

6-1. General

The diverse nature of the chemical and physical characteristics of rubber and elastomeric materials makes these material suited for many chemical handling and waste treatment applications. The most common elastomeric piping systems are comprised of hoses. These hoses are constructed of three components: the tube, the reinforcement, and the cover. The tube is most commonly an elastomer and must be suitable for the chemical, temperature, and pressure conditions that a particular application involves. Table 6-1 lists several elastomers used in piping systems and the chemical identifications of the polymers. Physical and chemical characteristics of elastomers used in hose manufacturing are specified in ASTM D 2000. Hose reinforcement is designed to provide protection from internal forces, external forces, or both. Reinforcement usually consists of a layer of textile, plastic, metal, or a combination of these materials. Hose covers are designed to provide hoses with protection from negative impacts resulting from the environment in which the hose is used. Covers are also typically composed of textile, plastic, metal, or a combination of these materials.

6-2. Design Factors

In selecting and sizing a rubber or elastomeric piping system, four factors must be considered: service conditions, (pressure and temperature); operating conditions (indoor/outdoor use, vibration resistance, intermittent of continu ous service, etc.); end connections; and environment requirements (flame resistance, material conductivity, labeling requirements, etc.).

a. Service Conditions

For applications requiring pressure or vacuum service reinforcement can improve the mechanical properties of the hose. The maximum recommended operating pressure in industrial applications utilizing Society of Automotive Engineers (SAE) standards hose designations is approximately 25% of the rated bursting pressure of the specific hose. Table 6-2 lists common SAE hose standards.

In determining the maximum operating conditions, special consideration must be given to the operating temperatures. Rubber and elastomer materials are temperature sensitive, and both the mechanical qualities and chemical resistance properties of the materials are effected by temperature. Appendix B provides information regarding the effects of temperature on chemical resistance, and Table 6-1 provides information

Table 6-1
Common Materials Used in Rubber/Elastomer Piping Systems

Elastomer	ASTM D 1418 Class	Common or Trade Name	Minimum Service Temperature - Continuous Operations	Maximum Service Temperature - Continuous Operations
Fluoroelastomer	FKM	FKM, Viton, Fluorel	-23°C (-10°F)	260°C (500°F)
Isobutylene Isoprene	IIR	Butyl	-46°C (-50°F)	148°C (300°F)
Acrylonitrile Butadiene	NBR	Buna-N, Nitrile	-51°C (-60°F)	148°C (300°F)
Polychloroprene	CR	Neoprene	-40°C (-40°F)	115°C (240°F)
Natural Rubber or Styrene Butadiene	NR or SBR	Gum Rubber; Buna-S	-51°C (-60°F)	82°C (180°F)

Source: Compiled by SAIC, 1998.

Table 6-2
Rubber and Elastomer Hose Standards

SAE Designation	Tube	Reinforcement	Cover
100R1A		one-wire-braid	synthetic-rubber
100RIT		one-wire-braid	thin, nonskive
100R2A		two-wire-braid	synthetic rubber
100R2B		two spiral wire plus one wire-braid	synthetic rubber
100R2AT		two-wire-braid	thin, nonskive
100R2BT		two spiral wire plus one wire-braid	thin, nonskive
100R3		two rayon-braided	synthetic rubber
100R5		one textile braid plus one wire-braid	textile braid
100R7	thermoplastic	synthetic-fiber	thermoplastic
100R8	thermoplastic	synthetic-fiber	thermoplastic
100R9		four-ply, light-spiral-wire	synthetic-rubber
100R9T		four-ply, light-spiral-wire	thin, nonskive

Source: Compiled by SAIC, 1998.

on the temperature limitations of the mechanical properties of rubber and elastomeric materials. As the operating temperature increases, the use of jacketed or reinforced hose should be considered to accommodate lower pressure ratings of the elastomeric materials.

Like plastic piping systems, rubber and elastomer systems do not display corrosion rates, as corrosion is totally dependent on the material's resistance to environmental factors rather than on the formation of an oxide layer. The corrosion of rubbers and elastomers is indicated by material softening, discoloring, charring, embrittlement, stress cracking (also referred to as crazing), blistering, swelling, and dissolving. Corrosion of rubber and elastomers occurs through one or more of the following mechanisms: absorption, solvation, chemical reactions, thermal degradation, and environmental stress cracking.

General compatibility information for common elastomer is listed in Table 6-3. Information regarding the compatibility of various elastomers with specific chemicals can be found in Appendix B. In addition, standards for resistance to oil and gasoline exposure have been developed by the Rubber Manufacturer's Association (RMA). These standards are related to the effects of oil or gasoline exposure for 70 hours at 100 °C (ASTM D 471) on the physical/mechanical properties of the material. Table 6-4 summarizes the requirements of the RMA oil and gasoline resistance classes.

b. Operating Conditions

In most cases, the flexible nature of elastomers will compensate for vibration and thermal expansion and contraction in extreme cases. However, designs should incorporate a sufficient length of hose to compensate for the mechanical effects of vibration and temperature.

Table 6-3
General Chemical Compatibility Characteristics of Common Elastomers

Material	Good Resistance	Poor Resistance
Fluoroelastomer	Oxidizing acids and oxidizers, fuels containing <30% aromatics	Aromatics; fuels containing >30% aromatics
Isobutylene Isoprene	Dilute mineral acids, alkalies, some concentrated acids, oxygenated solvents	Hydrocarbons and oils, most solvents, concentrated nitric and sulfuric acids
Acrylonitrile Butadiene	Oils, water, and solvents	Strong oxidizing agents, polar solvents, chlorinated hydrocarbons
Polychloroprene	Aliphatic solvents, dilute mineral acids, salts, alkalies	Strong oxidizing acids, chlorinated and aromatic hydrocarbons
Natural Rubber or Styrene Butadiene	Non-oxidizing acids, alkalies, and salts	Hydrocarbons, oils, and oxidizing agents

Notes: See Appendix B for more chemical resistance information.
Source: Compiled by SAIC, 1998.

Table 6-4
RMA Oil and Gasoline Resistance Classifications

RMA Designation	Maximum Volume Change	Tensile Strength Retained
Class A (High oil resistance)	+25%	80%
Class B (Medium-High oil resistance)	+65%	50%
Class C (Medium oil resistance)	+100%	40%

Source: RMA, "The 1996 Hose Handbook," IP-2, p. 52.

c. End Connections

Hose couplings are used to connect hoses to a process discharge or input point. Methods for joining elastomeric hose include banding/clamping, flanged joints, and threaded and mechanical coupling systems. These methods are typically divided into reusable and non-reusable couplings. Table 6-5 lists common types of couplings for hoses. Selection of the proper coupling should take into account the operating conditions and procedures that will be employed.

d. Environmental Requirements

Hose is also manufactured with conductive, non-conductive, and uncontrolled electrical properties. Critical applications such as transferring aircraft hose or transferring liquids around high-voltage lines, require the electrical properties of hose to be controlled. Unless the hose is designated as conducting or nonconducting, the electrical properties are uncontrolled. Standards do not currently exist for the prevention and safe dissipation of static charge from hoses. Methods used to control electrical properties include designing contact between a body reinforcing wire and a metal coupling to provide electrical continuity for the hose or using a conductive hose cover. ASTM D 380 describes standard test methods for the conductivity of elastomeric hoses. For a hose to be considered non-conductive, it should be tested using these methods.

6-3. Sizing

The primary considerations in determining the minimum acceptable diameter of any elastomeric hose are design flow rate and pressure drop. The design flow rate is based on system demands that are normally established in the process design phase of a project and which should be

Table 6-5
Typical Hose Couplings

Class	Description
Reusable with clamps	1. Short Shank Coupling 2. Long Shank Coupling 3. Interlocking Type 4. Compression Ring Type
Reusable without clamps	1. Screw Type 2. Push-on Type
Non-reusable couplings	1. Swaged-on 2. Crimped-on 3. Internally Expanded Full Flow Type 4. Built-in Fittings
Specialty couplings	1. Sand Blast Sleeves 2. Radiator and Heater Clamps 3. Gasoline Pump Hose Couplings 4. Coaxial Gasoline Pump Couplings 5. Welding Hose Couplings 6. Fire Hose Couplings

Source: Compiled by SAIC, 1998.

fully defined by this stage of the system design. Pressure drop through the elastomeric hose must be designed to provide an optimum balance between installed costs and operating costs. Primary factors that will impact these costs and system operating performance are internal diameter (and the resulting fluid velocity), materials of construction and length of hose.

6-4. Piping Support and Burial

Support for rubber and elastomer piping systems should follow similar principles as metallic and plastic pipe. However, continuous piping support is recommended for most applications due to the flexible nature of these materials. Also due to its flexible nature, elastomer piping is not used in buried service because the piping is unable to support the loads required for buried service.

When routing elastomer hose, change in piping direction can be achieved through bending the hose rather than using fittings. When designing a rubber or elastomer piping system, it is important to make sure that the bend radius used does not exceed the maximum bend radius for the hose used. If the maximum bend radius is exceeded, the hose may collapse and constricted flow or material failure could occur. As a rule of thumb, the bend radius should be six times the diameter of a hard wall hose or twelve times the diameter of a soft wall hose.

6-5. Fluoroelastomer

Fluoroelastomer (FKM) is a class of materials which includes several fluoropolymers used for hose products. Trade names of these materials include Viton and Fluorel. Fluoroelastomers provide excellent high temperature resistance, with the maximum allowable operating temperatures for fluoroelastomer varying from 232 to 315°C (450 to 600°F), depending upon the manufacturer. Fluoroelastomers also provide very good chemical resistance to a wide variety of chemical classes.

6-6. Isobutylene Isoprene

Isobutylene isoprene (Butyl or II R) has excellent abrasion resistance and excellent flexing properties. These characteristics combine to give isobutylene isoprene very good weathering and aging resistance. Isobutylene isoprene is impermeable to most gases, but provides poor resistance to petroleum based fluids. Isobutylene isoprene is also not flame resistant.

6-7. Acrylonitrile Butadiene

Acrylonitrile butadiene (nitrile, Buna-N or NBR) offers excellent resistance to petroleum oils, aromatic hydrocarbons and many acids. NBR also has good elongation properties. However, NBR does not provide good resistance to weathering.

6-8. Polychloroprene

Polychloroprene (neoprene or CR) is one of the oldest synthetic rubbers. It is a good all-purpose elastomer that is resistant to ozone, ultraviolet radiation, and oxidation. Neoprene is also heat and flame resistant. These characteristics give neoprene excellent resistance to aging and weathering. Neoprene also provides good chemical resistance to many petroleum based products and aliphatic hydrocarbons. However, neoprene is vulnerable to chlorinated solvents, polar solvents, and strong mineral acids.

6-9. Natural Rubber

Natural rubber (styrene butadiene, gum rubber, Buna-S, NR, or SBR) has high resilience, good tear resistance, and good tensile strength. It also exhibits wear resistance and is flexible at low temperatures. These characteristics make natural rubber suitable for general service outdoor use. However, natural rubber is not flame resistant and does not provide resistance to petroleum based fluids.

Chapter 7
Thermoset Piping Systems

7-1. General

Thermoset piping systems are composed of plastic materials and are identified by being permanently set, cured or hardened into shape during the manufacturing process. Thermoset piping system materials are a combination of resins and reinforcing. The four primary thermoset resins are epoxies, vinyl esters, polyesters, and furans. Other resins are available.

a. Thermoset Piping Characteristics

Advantages of thermoset piping systems are a high strength-to-weight ratio; low installation costs; ease of repair and maintenance; hydraulic smoothness with a typical surface roughness of 0.005 mm (0.0002 in); flexibility, since low axial modulus of elasticity allows lightweight restraints and reduces the need for expansion loops; and low thermal and electrical conductivity. Disadvantages of thermoset piping systems are low temperature limits; vulnerability to impact failure; increased support requirements, a drawback of the low modulus of elasticity; lack of dimensional standards including joints since pipe, fittings, joints and adhesives are generally not interchangeable between manufacturers; and susceptibility to movement with pressure surges, such as water hammer. Table 7-1 lists applicable standards for thermoset piping systems.

b. Corrosion Resistance

Like other plastic materials, thermoset piping systems provide both internal and external corrosion resistance. For compatibility of thermoset plastic material with various chemicals, see Appendix B. Due to the different formulations of the resin groups, manufacturers are contacted to confirm material compatibility. For applications that have limited data relating liquid services and resins, ASTM C 581 provides a procedure to evaluate the chemical resistance of thermosetting resins.

c. Materials of Construction

Fiberglass is the most common reinforcing material used in thermoset piping systems because of its low cost, high tensile strength, light weight and good corrosion resistance. Other types of commercially available reinforcement include graphite fibers for use with fluorinated chemicals such as hydrofluoric acid; aramid; polyester; and polyethylene. The types of fiberglass used are E-glass; S-glass for higher temperature and tensile strength requirements; and C-glass for extremely corrosive applications.

Most thermoset piping systems are manufactured using a filament winding process for adding reinforcement. This process accurately orients and uniformly places tension on the reinforcing fibers for use in pressure applications. It also provides the best strength-to-weight ratio as compared to other production methods. The other main method of manufacturing is centrifugal casting, particularly using the more reactive resins.

Thermoset piping can be provided with a resin-rich layer (liner) to protect the reinforcing fibers. The use of liners is recommended for chemical and corrosive applications. Liners for filament wound pipe generally range in thickness from 0.25 to 1.25 mm (0.01 to 0.05 in), but can be custom fabricated as thick as 2.8 mm (0.110 in) and are often reinforced. Liner thickness for centrifugally cast thermoset piping generally ranges from 1.25 to 2.0 mm (0.05 to 0.08 in); these liners are not reinforced. If not reinforced, liners may become brittle when exposed to low temperatures. Impacts or harsh abrasion may cause failure under these conditions.

Fittings are manufactured using compression molding, filament winding, spray-up, contact molding and mitered processes. Compression molding is typically used for smaller diameter fittings, and filament winding is used for larger, 200 to 400 mm (8 to 16 in), fittings. The spray-up, contact molding and mitered processes are used for complex or custom fittings. The mitered process is typically used for on-site modifications.

d. Operating Pressures and Temperatures

Loads; service conditions; materials; design codes and standards; and system operational pressures and temperatures are established as described in Chapters 2 and 3 for plastic piping systems. Table 7-2 lists recommended temperature limits for reinforced thermosetting resin pipe.

Table 7-1
Thermoset Piping Systems Standards (As of Nov. 1997)

Standard	Application
ASTM D 2310	Machine-made reinforced thermosetting pipe.
ASTM D 2996	Filament wound fiberglass reinforced thermoset pipe.
ASTM D 2997	Centrifugally cast reinforced thermoset pipe.
ASTM D 3517	Fiberglass reinforced thermoset pipe conveying water.
ASTM D 3754	Fiberglass reinforced thermoset pipe conveying industrial process liquids and wastes.
ASTM D 4024	Reinforced thermoset flanges.
ASTM D 4161	Fiberglass reinforced thermoset pipe joints using elastomeric seals.
ASTM F 1173	Epoxy thermoset pipe conveying seawater and chemicals in a marine environment.
AWWA C950	Fiberglass reinforced thermoset pipe conveying water.
API 15LR	Low pressure fiberglass reinforced thermoset pipe.

Source: Compiled by SAIC, 1998.

Table 7-2
Recommended Temperature Limits for Reinforced Thermosetting Resin Pipe

Materials		Recommended Temperature Limits			
Resin	Reinforcing	Minimum		Maximum	
		°F	°C	°F	°C
Epoxy	Glass Fiber	-20	-29	300	149
Furan	Carbon	-20	-29	200	93
Furan	Glass Fiber	-20	-29	200	93
Phenolic	Glass Fiber	-20	-29	300	149
Polyester	Glass Fiber	-20	-29	200	93
Vinyl Ester	Glass Fiber	-20	-29	200	93

Source: ASME B31.3, p. 96, Reprinted by permission of ASME.

e. Thermoset Piping Support

Support for thermoset piping systems follow similar principles as thermoplastic piping systems. Physical properties of the materials are similar enough that the same general recommendations apply. Spacing of supports is crucial to the structural integrity of the piping system. Valves, meters, and other miscellaneous fittings are supported independently of pipe sections. Separate supports are provided on either side of flanged connections. Additionally, anchor points, such as where the pipeline changes direction, are built-up with a rubber sleeve at least the thickness of the pipe wall. This provides protection for the pipe material on either side of the anchor.

Reinforced polyester pipe requires a wide support surface on the hanger. It also calls for a rubber or elastomeric cushion between the hanger and the pipe to isolate the pipe from point loads. This cushion is approximately 3 mm ($^{1}/_{8}$ in) thick. Table 7-3 summarizes the maximum support spacing at various system pressures for reinforced epoxy pipe.

Table 7-3
Support Spacing for Reinforced Epoxy Pipe

Nominal Pipe Size, mm (in)	**Maximum Support Spacing, m (ft) at Various Temperatures**					
	24EC (75EF)	**66EC (150EF)**	**79EC (175EF)**	**93EC (200EF)**	**107EC (225EF)**	**121EC (250EF)**
25 (1)	3.20 (9.9)	2.99 (9.8)	2.96 (9.7)	2.87 (9.4)	2.83 (9.3)	2.65 (8.7)
40 (1.5)	3.54 (11.6)	3.47 (11.4)	3.44 (11.3)	3.35 (11.0)	3.29 (10.8)	3.08 (10.1)
50 (2)	3.99 (13.1)	3.93 (12.9)	3.90 (12.8)	3.78 (12.4)	3.72 (12.2)	3.47 (11.4)
80 (3)	4.57 (15.0)	4.51 (14.8)	4.45 (14.6)	4.33 (14.2)	4.27 (14.0)	3.96 (13.0)
100 (4)	5.09 (16.7)	5.03 (16.5)	4.97 (16.3)	4.82 (15.8)	4.75 (15.6)	4.42 (14.5)
150 (6)	5.76 (18.9)	5.67 (18.6)	5.61 (18.4)	5.46 (17.9)	5.36 (17.6)	5.00 (16.4)
200 (8)	6.10 (20.0)	6.10 (20.0)	6.04 (19.8)	5.88 (19.3)	5.79 (19.0)	5.39 (17.7)
250 (10)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	5.73 (18.8)
300 (12)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.00 (19.7)
350 (14)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)	6.10 (20.0)

Note: The above spacing values are based on long-term elevated temperature test data developed by the manufacturer for the specific product. The above spacing is based on a 3-span continuous beam with maximum rated pressure and 12.7 mm (0.5 in) deflection. The piping is assumed to be centrifugally cast and is full of liquid that has a specific gravity of 1.00.
Source: Fibercast, Centricast Plus RB-2530, p. 2.

The same principles for pipe support for reinforced polyester apply to reinforced vinyl ester and reinforced epoxy thermoset pipe. Span distances for supports vary from manufacturer to manufacturer. The design of piping systems utilizing reinforced vinyl ester or reinforced epoxy pipe reference the manufacturer's recommendations for support spacing.

Each section of thermoset piping has at least one support. Additionally, valves, meters, flanges, expansion joints, and other miscellaneous fittings are supported independently. Supports are not attached to flanges or expansion joints. Supports allow axial movement of the pipe.

f. Thermoset Piping Burial

Reinforced polyester, vinyl ester, and epoxy pipe may be buried. The same basic principles which apply to burying plastic pipe also apply for thermoset pipe regarding frost line, trench excavation, pipe installation, and backfill. For operating pressures greater than 689 kPa (100 psi), the internal pressure determines the required wall thickness. For operating pressures less than 689 kPa (100 psi), the vertical pressure on the pipe from ground cover and wheel load dictates the required wall thickness of the pipe.

g. Joining

Common methods for the joining of thermoset pipe for liquid process waste treatment and storage systems include the use of adhesive bonded joints, over wrapped joints, and mechanical joining systems. The application requirements and material specification for these fittings are found in various codes, standards, and manufacturer procedures and specifications, including:

- ASME B31.3 Chapter VII;
- ASME B31.1 Power Piping Code;
- The Piping Handbook, 6th Edition; and
- Fibercast Company Piping Design Manual.

h. Thermal Expansion

When designing a piping system in which thermal expansion of the piping is restrained at supports, anchors, equipment nozzles, and penetrations, thermal stresses and loads must be analyzed and accounted for within the design. The system PFDs and P&IDs are analyzed to determine the thermal conditions or modes to which the piping system will be subjected during operation. Based on this analysis, the design and material specification requirements are determined from an applicable standard or design reference.

The primary objective of the analysis is to identify operating conditions that will expose the piping to the most severe thermal loading conditions. Once these conditions have been established, a free or unrestrained thermal analysis of the piping can be performed to establish location, sizing, and arrangement of expansion joints or loops. Due to the cost of thermoset piping, the use of loops is not normally cost-effective.

The following procedure can be used to design expansion joints in fiberglass piping systems. The expansion joint must be selected and installed to accommodate the maximum axial motion in both expansion and contraction. This typically requires that some amount of preset compression be provided in the expansion joint to accommodate for all operating conditions. In addition, suitable anchors must be provided to restrain the expansion joint; guides must be installed to assure that the pipe will move directly into the expansion joint in accordance with manufacturer requirements; and pipe supports, which allow axial movement, prevent lateral movement, and provide sufficient support to prevent buckling, must be included in the design.

Step 1: Determine Required Preset

$$Length\ of\ Preset = \frac{R(T_i - T_{\mathrm{min}})}{T_{\mathrm{max}} - T_{\mathrm{min}}}$$

where:

R = rated movement of expansion joint, mm (in)
T_i = installation temperature, °C (°F)
T_{min} = minimum system temperature, °C (°F)
T_{max} = maximum system temperature, °C (°F)

Step 2: Design expansion loops using the equation provided in Paragraph 4-6, or consult with the piping manufacturer; for example, see Table 7-4.

Table 7-4
Loop Leg Sizing Chart for Fibercast RB-2530 Pipe

D_o mm (in)	Thermal Expansion, mm (in), versus Minimum Leg Length, m (ft)					
	25.4 mm (1 in)	**50.8 mm (2 in)**	**76.2 mm (3 in)**	**127 mm (5 in)**	**178 mm (7 in)**	**229 mm (9 in)**
33.40 (1.315)	1.22 m (4 ft)	1.52 m (5 ft)	1.83 m (6 ft)	2.44 m (8 ft)	2.74 m (9 ft)	3.05 m (10 ft)
48.26 (1.900)	1.83 m (6 ft)	2.44 m (8 ft)	2.74 m (9 ft)	3.66 m (12 ft)	4.27 m (14 ft)	4.88 m (16 ft)
60.33 (2.375)	2.13 m (7 ft)	3.05 m (10 ft)	3.66 m (12 ft)	4.88 m (16 ft)	5.79 m (19 ft)	6.40 m (21 ft)
88.90 (3.500)	2.74 m (9 ft)	3.96 m (13 ft)	4.88 m (16 ft)	6.10 m (20 ft)	7.32 m (24 ft)	8.23 m (27 ft)
114.3 (4.500)	3.66 m (12 ft)	4.88 m (16 ft)	6.10 m (20 ft)	7.62 m (25 ft)	9.14 m (30 ft)	10.4 m (34 ft)
168.3 (6.625)	4.57 m (15 ft)	6.40 m (21 ft)	7.62 m (25 ft)	9.75 m (32 ft)	11.6 m (38 ft)	13.1 m (43 ft)
219.1 (8.625)	5.18 m (17 ft)	7.01 m (23 ft)	8.84 m (29 ft)	11.3 m (37 ft)	13.1 m (43 ft)	14.9 m (49 ft)
273.1 (10.75)	5.79 m (19 ft)	7.92 m (26 ft)	9.75 m (32 ft)	12.5 m (41 ft)	14.6 m (48 ft)	16.8 m (55 ft)
323.9 (12.75)	6.10 m (20 ft)	8.53 m (28 ft)	10.4 m (34 ft)	13.4 m (44 ft)	15.8 m (52 ft)	18.0 m (59 ft)
355.6 (14.00)	5.79 m (19 ft)	7.92 m (26 ft)	9.75 m (32 ft)	12.5 m (41 ft)	14.9 m (49 ft)	16.8 m (55 ft)

Notes: D_o = outside diameter of standard Fibercast pipe. D_o may be different for other manufacturers.
Thermal expansion characteristics and required loop lengths will vary between manufacturers.
Source: Fibercast, Piping Design Manual, FC-680, p. 6.

7-2. Reinforced Epoxies

Although epoxies cure without the need for additional heat, almost all pipe is manufactured with heat-cure. Reinforced epoxy piping systems are not manufactured to dimensional or pressure standards. Therefore, considerable variation between manufacturers exist in regard to available size, maximum pressure rating and maximum temperature rating. Performance requirements, including manufacturing, conforms to ASTM standards in order to not sole-source the piping system.

7-3. Reinforced Polyesters

Reinforced polyester thermoset piping systems are the most widely used due to affordability and versatility. The maximum continuous operating temperature for optimum chemical resistance is 71°C (160°F). Like the epoxies, reinforced polyester piping systems are not manufactured to dimensional or pressure standards. Variation of available piping sizes, maximum pressure rating, and maximum temperature ratings exist between manufacturers. Performance requirements, including manufacturing, conform to ASTM standards in order to not sole-source the piping system.

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[1] Schweitzer, Corrosion-Resistant Piping Systems, p. 102.

7-4. Reinforced Vinyl Esters

The vinyl ester generally used for chemical process piping systems is bisphenol-A fumarate due to good corrosion resistance[1]. Reinforced vinyl ester piping systems vary by manufacturer for allowable pressures and temperatures. Performance requirements, including manufacturing, conforms to ASTM standards in order to not sole-source the piping system.

7-5. Reinforced Furans

The advantage of furan resins is their resistance to solvents in combination with acids or bases[2]. Furans are difficult to work with and should not be used for oxidizing applications. Maximum operating temperatures for furan resins can be 189°C (300°F). Furan resin piping is commercially available in sizes ranging from 15 to 300 mm (½ to 12 in) standard.

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[2] Schweitzer, Corrosion-Resistant Piping Systems, p. 96.

Chapter 8
Double Containment Piping Systems

8-1. General

To date, the double containment piping system design has not been standardized. If possible, the use of double containment piping should be deferred until design and construction standards are published by a national standards organization, such as ASTM. An alternative to the factory designed secondary containment piping may be the use of single wall piping inside a sealed, watertight, 360-degree secondary containment barrier; refer to CEGS 11145, Aviation Fueling Systems. Due to the nature of the liquids transported in double containment piping systems, the primary standard for the design of these systems is the ASME B31.3, Chemical Plant and Petroleum Refinery Piping Code.

a. Regulatory Basis

Secondary containment is a means by which to prevent and detect releases to the environment. Therefore, when dealing with regulated substances in underground storage tank systems or when managing hazardous wastes, regulations typically require secondary containment of piping systems for new construction. Double wall piping systems are available to provide secondary containment. The double containment piping system is composed of an outer pipe that completely encloses an inner carrier pipe in order to detect and contain any leaks that may occur and to allow detection of such leaks.

Under storage tank regulation 40 CFR 280, secondary containment is required for tanks containing hazardous substances (as defined by CERCLA 101-14) or petroleum products. The requirement applies whenever 10% or more of the volume of the tank is underground. Tank standards in hazardous waste regulations in 40 CFR 264 and 40 CFR 265 also require secondary containment of piping systems. These requirements are not only applicable to RCRA Part B permitted treatment storage and disposal facilities, but also apply to interim status facilities and to generators accumulating waste in tanks with ancillary piping.

b. Design Requirements

Many options seem to exist for the combination of different primary (carrier) and secondary (containment) piping systems based on physical dimensions. However, the commercial availability of components must be carefully reviewed for the selected materials of construction. Availability of piping sizes, both diameter and wall thickness; joining methods; and pressure ratings may preclude the combination of certain primary and secondary piping system materials.

In addition, some manufacturers offer “pre-engineered” double containment piping systems. Some of these systems may have been conceptualized without detailed engineering of system components. If specified for use, the detailed engineering of the “pre-engineered” system must be performed, including any required customizing, details, and code review.

c. Material Selection

For piping system material compatibility with various chemicals, see Appendix B. Material compatibility should consider the type and concentration of chemicals 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 - Other Sources of Information, for additional sources of corrosion data.

Corrosion of metallic and thermoplastic piping systems was addressed in Paragraphs 4-2 and 5-1. However, it must be remembered that cracking, such as stress-corrosion cracking and environmental stress cracking, is a potentially significant failure mechanism in double containment piping systems. Differential expansion of inner and outer piping can cause reaction loads at interconnecting components. These loads can produce tensile stresses that approach yield strengths and induce stress cracking at the interconnection areas.

Material combinations may be classified into three main categories:

(1) the primary and secondary piping materials are identical except for size, for example, ASTM A 53 carbon steel and A 53 carbon steel, respectively;
(2) the primary and secondary piping are the same type of materials but not identical, for example, 316L stainless steel and A 53 carbon steel; and
(3) different types of materials are used, for example,

PVDF as primary and A 53 carbon steel as secondary. Table 8-1 provides a further breakdown and description of these three groups.

d. Thermal Expansion

As discussed in the previous chapters, when a piping system is subjected to a temperature change, it expands or contracts accordingly. Double containment piping systems have additional considerations, including expansion-contraction forces occurring between two potentially different, interconnected piping systems. Thermal stresses can be significant when flexibility is not taken into account in the design. For a double containment piping system, the primary and secondary piping systems must be analyzed both as individual systems and as parts of the whole. The basic correlations between the systems are: (1) the primary piping system has a greater temperature change; and (2) the secondary piping system has a greater temperature change.

Because of the insulating effect of the secondary piping system, the primary piping system usually only exhibits a larger temperature induced change when the process dictates, for example, when a hot liquid enters the piping system. In both above grade and buried systems, secondary piping system expansions are typically compensated for with expansion loops, changes in direction, or a totally restrained system. Expansion joints are not recommended for this use due to potential leaks, replacement and maintenance, unless they can be located in a tank or vault.

To accommodate the dimensional changes of the primary piping system in expansion loops and change of direction elbows, secondary piping systems are often increased in size. Another alternative is to fully restrain the primary piping system. Figure 8-1 demonstrates the result of differential movement between the piping systems without full restraint, and Figure 8-2 depicts an expansion loop with an increase to the secondary piping diameter.

Totally restrained systems are complex. Stresses are induced at points of interconnection, at interstitial supports, and at other areas of contact. For rigid piping systems, restraints are placed at the ends of straight pipe lengths and before and after complex fittings to relieve thermal stress and prevent fitting failure[1]. Plastic piping systems relieve themselves through deformation and wall relaxation, potentially leading to failure. Totally restrained systems should undergo a stress analysis and a flexibility analysis as part of the design.

The combined stress on the secondary piping system is the result of bending, as well as torsional, internal hydrostatic, and thermal expansion induced axial stresses. The following method, which assumes that internal hydrostatic and thermal expansion induced axial stresses approximate the total stress, can be used to determine whether a totally restrained design is suitable[2]:

$$S_c = \sqrt{(\sigma_{at})^2 + (\sigma_p)^2}$$

where:
S_c = combined stress, MPa (psi)
σ_{at} = thermal induced axial stress, MPa (psi)
σ_p = internal hydrostatic stress, MPa (psi)

$$\sigma_{at} = E \, \alpha \, \Delta T$$

where:
σ_{at} = thermal induced axial stress, MPa (psi)
E = modulus of elasticity, MPa (psi)
α = coefficient of thermal expansion, mm/mm/°C (in/in/°F)
ΔT = differential between maximum operating and installation temperature, °C (°F)

$$\sigma_p = \frac{P \, (D_o - t)}{2 \, t}$$

where:
σ_p = internal hydrostatic stress, MPa (psi)
P = liquid pressure, MPa (psi)
D_o = outside pipe diameter, mm (in)
t = pipe wall thickness, mm (in)

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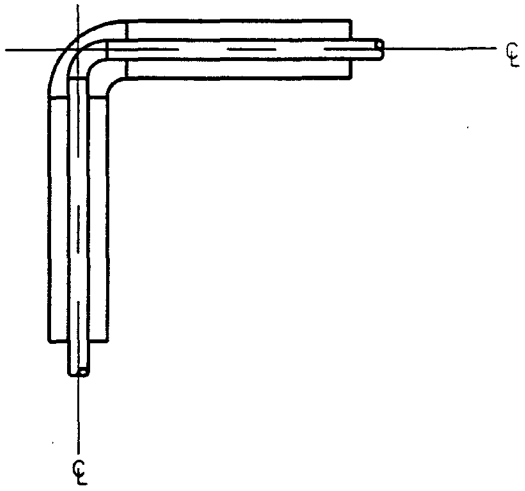
[1] Schweitzer, Corrosion-Resistant Piping Systems, p. 417.
[2] Ibid., pp. 418-420.

Table 8-1
Double Containment Piping Material Combinations

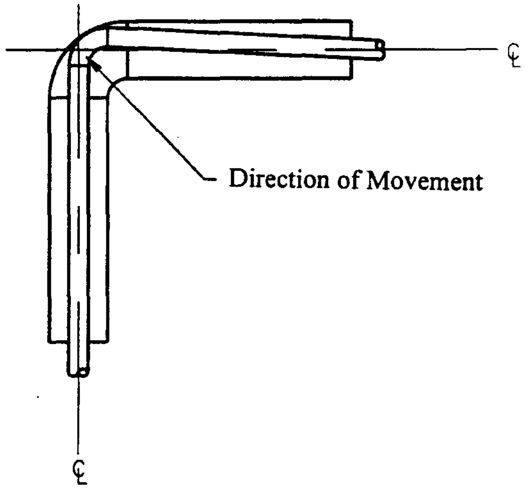
Catagory	Primary	Secondary	Comments	Common Materials
1	M	M	Used with elevated temperatures and/or pressures. Good structural strength and impact resistant. May be required by fire or building codes. Cathodic protection required if buried.	CS, 304 SS, 304L SS, 316 SS, 316L SS, 410 SS, Ni 200, Ni 201, Cu/Ni alloys
1	TS	TS	Common for above grade and buried use for organic, inorganic, and acid wastes/chemicals. Good chemical resistance and structural strength. Conductive to field fabrication.	polyester resin, epoxy resin, vinyl ester resin, furan resin
1	TP	TP	Easily joined and fabricated. Resistant to soil corrosion and many chemicals. May be restricted by fire/building codes. Impact safety may require safeguards.	PVC, CPVC, HDPE, PP, PVDF, ECTFE, ETFE, PFA
2	M	M	May be required by fire codes or mechanical properties. Galvanic actions must be controlled at crevices and interconnections. Cathodic protection required if buried.	CS-SS, Cu/Ni alloy - CS, CS-Ni, CS-410 SS
2	TS	TS	Not advisable to combine resin grades. Epoxy and polyester resins are most economical.	polyester-epoxy, vinyl ester-epoxy, vinyl ester-polyester
2	TP	TP	Common for above grade and buried acid/caustic use. Economical - many commercial systems are available.	Many - PVDF-PP, PVDF-HDPE, PP-HDPE
3	M	TS	Common and economical. Practical - interconnections have been developed. Good for buried use, may eliminate cathodic protection requirements.	epoxy-M (CS, SS, Ni, Cu), polyester-M (CS, SS, Ni, Cu)
3	M	TP	Common and economical. Good for buried use, may eliminate cathodic protection requirements. May be limited by fire or building codes.	HDPE - M (CS, SS), PVDF- M (CS, SS), PP-M (CS, SS)
3	M	O	Limited practical use except for concrete trench. Ability for leak detection is a concern.	concrete trench - M
3	TS	M	Common for above grade systems requiring thermoset chemical resistance and metallic mechanical properties. Can meet category "M" service per ASME code.	many
3	TS	TP	Economical. Good for buried applications.	epoxy-TP (HDPE, PVC, PP), polyester-TP (HDPE, PVC, PP)
3	TS	O	Limited practical use except for concrete trench. Ability for leak detection is a concern.	concrete trench - TS
3	TP	M	Common for above grade systems requiring thermoset chemical resistance and metallic mechanical properties. Can meet category "M" service per ASME code.	many
3	TP	TS	Limited in use - thermoplastic chemical resistance needed with thermoset mechanical properties. May not meet UL acceptance standards.	limited
3	TP	O	Limited practical use except for concrete trench or pipe. Ability for leak detection is a concern.	concrete trench - TP, concrete pipe - PVC
3	O	M	Interconnections may be difficult. Good for protection of brittle materials.	CS-glass, CS-clay

Notes: The primary piping material is listed first on primary-secondary combinations.
Material designations are: M - metallic materials; TS - thermoset materials; TP - thermoplastic materials; and O - other nonmetallic materials

Source: Compiled by SAIC, 1998.



a. Before Thermal Expansion



b. After Thermal Expansion

Figure 8-1.Primary Piping Thermal Expansion
(Source: SAIC, 1998)

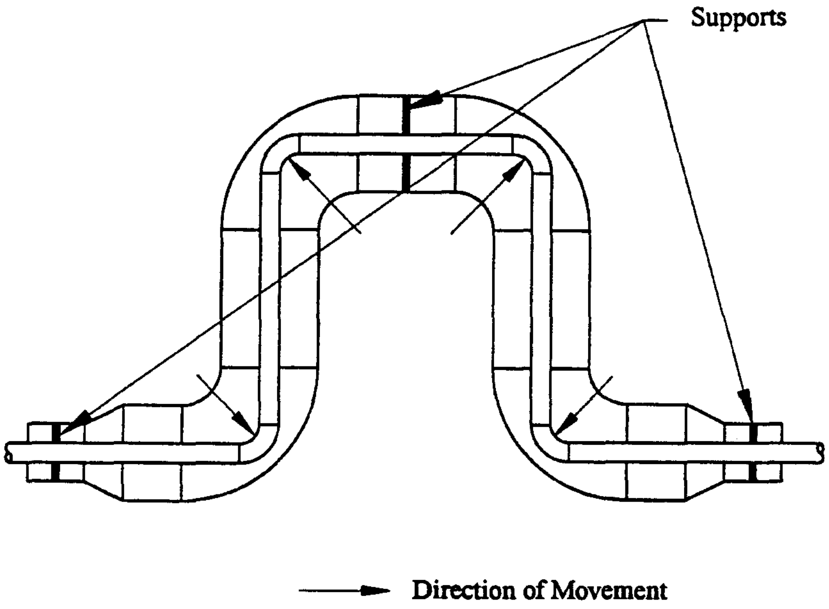


Figure 8-2. Double Containment Piping Expansion Loop Configuration
(Source: SAIC, 1998)

If the value of the combined stress, S_c, is less than the design stress rating of the secondary piping material, then the totally restrained design can be used.

When double containment piping systems are buried, and the secondary piping system has a larger temperature change than the primary system, the ground will generally provide enough friction to prevent movement of the outer pipe. However, if extreme temperature differentials are expected, it may be necessary to install vaults or trenches to accommodate expansion joints and loops.

For double containment systems located above grade, with secondary piping systems that have a larger temperature differential than primary systems, two common solutions are used. First, expansion joints in the outer piping can accommodate the movement. Second, the secondary piping can be insulated and heat traced to reduce the potential expansion-contraction changes. The latter would be particularly effective with processes that produce constant temperature liquids; therefore, the primary piping is relatively constant.

e. Piping Support

Support design for double containment piping systems heeds the same guidelines as for the piping material used to construct the containment system. The support design is also based on the outside (containment) pipe size. Spans for single piping systems of the same material as the outer pipe may be used. The same recommendations may be applied for burial of double containment piping systems as for the outer containment pipe material.

The following equation approximates the maximum spacing of the secondary piping system guides, or interstitial supports. The maximum guide spacing should be compared to the maximum hanger spacing (at maximum operating temperature) and the lesser distance used. However, the flexibility of the system should still be analyzed using piping stress calculations to demonstrate that elastic parameters are satisfied[3].

$$l_g = \left(\frac{48\ f\ E\ I}{4\ Z\ S_c} \right)^{0.5}$$

where:

l_g = maximum span between guides, mm (in)
f = allowable sag, mm (in)
E = modulus of elasticity, MPa (psi)
I = moment of inertia, mm^4 (in^4)
Z = section modulus, mm^3 (in^3)
S_c = combined stress, MPa (psi)

8-2. Piping System Sizing

The method for sizing of the carrier pipe is identical to the methods required for single wall piping systems; see previous chapters.

a. Secondary Pipe

Secondary piping systems have more factors that must be considered during sizing. These factors include secondary piping function (drain or holding), pressurized or non-pressurized requirements, fabrication requirements, and type of leak detection system. The assumption has to be made that at some point the primary piping system will leak and have to be repaired, thus requiring the capability to drain and vent the secondary piping system. Most systems drain material collected by the secondary piping system into a collection vessel. Pressurized systems, if used, are generally only used with continuous leak detection methods, due to the required compartmentalization of the other leak detection systems.

Friction loss due to liquid flow in pressurized secondary piping systems is determined using the standard equations for flow in pipes with the exception that the hydraulic diameter is used, and friction losses due to the primary piping system supports have to be estimated. The hydraulic diameter may be determined from:

$$D_h = d_i - D_o$$

where:

D_h = hydraulic diameter, mm (in)
d_i = secondary pipe inside diameter, mm (in)
D_o = primary pipe outside diameter, mm (in)

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[3] Schweitzer, Corrosion-Resistant Piping Systems, p. 420.

In addition, for double containment piping systems that have multiple primary pipes inside of a single secondary piping system, pressurized flow parameters can be calculated using shell and tube heat exchanger approximations (for more information, refer to the additional references listed in Paragraph A-4 of Appendix A).

8-3. Double Containment Piping System Testing

The design of double containment piping systems includes the provision for pressure testing both the primary and secondary systems. Testing is specified in the same manner as other process piping systems. The design of each piping system contains the necessary devices required for safe and proper operation including pressure relief, air vents, and drains.

Pressurized secondary piping systems are equipped with pressure relief devices, one per compartment, as appropriate. Care should be taken with the placement of these devices to avoid spills to the environment or hazards to operators.

Low points of the secondary piping system should be equipped with drains, and high points should be equipped with vents. If compartmentalized, each compartment must be equipped with at least one drain and one vent. Drains and vents need to be sized to allow total drainage of liquid from the annular space that may result from leaks or flushing. The following equations can be used for sizing[4]:

Step 1. Drainage Flow through Drain.

$$t \; ' \; \int \frac{A_a}{C_d \; A_D \; \sqrt{2 \; g \; h}} \; dh, \; for \; h_1 \; \& \; h_2$$

where:

t = time, s
A_a = annular area, m^2 (ft^2)
$C_d = C_c C_v$
C_c = coefficient of contraction, see Table 8-2
C_v = coefficient of velocity, see Table 8-2
A_D = area of drain opening, m^2 (ft^2)
g = gravitational acceleration, 9.81 m/s^2 (32.2 ft/s^2)
h = fluid head, m (ft)

Step 2. Flushing Flow through Drain.

$$t \; ' \; \int \frac{A_a}{[(C_d \; A_D \; \sqrt{2 \; g \; h}) \; \& \; Q_{fl}]} \; dh, \; for \; h_1 \; \& \; h_2$$

where:

Q_{fl} = flushing liquid flow rate, m^3/s (ft^3/s)
t = time, s
A_a = annular area, m^2 (ft^2)
$C_d = C_c C_v$
C_c = coefficient of contraction, see Table 8-2
C_v = coefficient of velocity, see Table 8-2
A_D = area of drain opening, m^2 (ft^2)
g = gravitational acceleration, 9.81 m/s^2 (32.2 ft/s^2)
h = fluid head, m (ft)

Table 8-2
Common Orifice Coefficients

Condition	**C_v**	**C_c**
Short tube with no separation of fluid flow from walls	0.82	1.00
Short tube with rounded entrance	0.98	0.99

Source: Reprinted from Schweitzer, Corrosion-Resistant Piping Systems, p. 414, by courtesy of Marcel Dekker, Inc.

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[4] Schweitzer, Corrosion-Resistant Piping Systems, pp. 414-415.

8-4. Leak Detection Systems

Leak detection is one of the main principles of double containment piping systems. Any fluid leakage is to be contained by the secondary piping until the secondary piping can be drained, flushed, and cleaned; and the primary piping system failure can be repaired. Without leak detection, the potential exists to compromise the secondary piping system and release a hazardous substance into the environment. Early in the design of a double containment piping system, the objectives of leak detection are established in order to determine the best methods to achieve the objectives. Objectives include:

- need to locate leaks;
- required response time;
- system reliability demands; and
- operation and maintenance requirements.

a. Cable Leak Detection Systems

Cable detection systems are a continuous monitoring method. The purpose of this method is to measure the electrical properties (conductance or impedance) of a cable; when properties change, a leak has occurred. These systems are relatively expensive compared to the other methods of leak detection. Many of the commercially available systems can determine when a leak has occurred, and can also define the location of the leak. Conductance cable systems can detect the immediate presence of small leaks, and impedance systems can detect multiple leaks. However, it must be remembered that these types of systems are sophisticated electronic systems and that there may be problems with false alarms, power outages, and corroded cables[5]. Design requirements for these systems include: access, control panel uninterruptible power supply (UPS), and installation requirements.

Access ports should be provided in the secondary piping system for installation and maintenance purposes. The ports should be spaced similar to any other electrical wiring:

- at the cable entry into and exit from each pipe run;
- after every two changes in direction;
- at tee branches and lateral connections;
- at splices or cable branch connections; and
- after every 30.5 m (100 feet) of straight run.

Power surges or temporary outages will set off alarms. To avoid such occurrences, consideration should be given to UPS.

Installation requirements for a cable system include the completing of testing and thorough cleaning and drying of the secondary piping system prior to installation to avoid false alarms. In addition, a minimum annular clearance of 18 mm (3/4 in) for conductance cables and 38 to 50 mm (1-1/2 to 2 inches) for impedance cables is required to allow installation. These values may vary between manufacturers.

b. Probe Systems

Probes that measure the presence of liquids through conductivity, pH, liquid level, moisture, specific ion concentrations, pressure, and other methods are used as sensing elements in leak detection systems. The double containment piping systems are separated into compartments with each compartment containing a probe with probe systems. Leaks can only be located to the extent to which the compartment senses liquid in the secondary containment piping.

c. Visual Systems

Visual systems include the use of sumps and traps; installation of sight glasses into the secondary piping system; equipping the secondary piping system with clear traps; and use of a clear secondary piping material. Some manufacturers offer clear PVC. Visual systems are often used in addition to other leak detection methods.

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[5] Schweitzer, Corrosion-Resistant Piping Systems, p. 412.

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)

Materials	Recommended Temperature Limits			
	Minimum		Maximum	
	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, °C (°F)
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

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[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, <u>Corrosion-Resistant Piping Systems</u>, p. 198.

[9] Ibid., p. 199.

Chapter 10
Valves

10-1. General

For liquid piping systems, valves are the controlling element. Valves are used to isolate equipment and piping systems, regulate flow, prevent backflow, and regulate and relieve pressure. The most suitable valve must be carefully selected for the piping system. The minimum design or selection parameters for the valve most suitable for an application are the following: size, material of construction, pressure and temperature ratings, and end connections. In addition, if the valve is to be used for control purposes, additional parameters must be defined. These parameters include: method of operation, maximum and minimum flow capacity requirement, pressure drop during normal flowing conditions, pressure drop at shutoff, and maximum and minimum inlet pressure at the valve. These parameters are met by selecting body styles, material of construction, seats, packing, end connections, operators and supports.

a. Body Styles

The control valve body type selection requires a combination of valve body style, material, and trim considerations to allow for the best application for the intended service.

Valve body styles have different flow characteristics as they open from 0 to 100%. The flow rate through each type or body style will vary according to different curves with constant pressure drops. This is referred to as the valve flow characteristics. A quick opening flow characteristic produces a large flow rate change with minimal valve travel until the valve plug nears a wide open position. At that point, the flow rate change is minimal with valve travel. A linear flow characteristic is one that has a flow rate directly proportional to valve travel. An equal percentage flow characteristic is one in which a flow rate change is proportional to the flow rate just prior to the change in valve position. Equal increments of valve travel result in equal percentage changes to the existing flow rate. That is, with a valve nearly closed (existing flow rate is small), a large valve travel will result in a small flow rate change, and a large flow rate change will occur when the valve is almost completely open, regardless of the amount of valve travel.

The purpose of characterizing control valves is to allow for relatively uniform control stability over the expected operating range of the piping system. A design goal is to match a control valve flow characteristic to the specific system. Figure 10-1 illustrates some typical flow characteristic curves for control valves.

Table 10-1 provides guidelines for the selection of proper flow characteristics. There are exceptions to these guidelines, and a complete dynamic analysis is performed on the piping system to obtain a definite characteristic. Quick opening valves are primarily used for open/close applications (or on/off service) but may also be appropriate for applications requiring near linear flow. For processes that have highly varying pressure drop operating conditions, an equal percentage valve may be appropriate.

b. Material of Construction

The selection of valve body material and trim material is typically based on pressure, temperature, corrosive and erosive properties of the liquid. Table 10-2 provides basic information on typical castable materials used for control valve bodies. Certain service conditions require other alloys and metals to withstand corrosive and erosive properties of the liquid. The materials that can be used for these situations are similar to the piping materials; therefore, the material fluid matrix found in Appendix B can be used as a guide to select materials for these special conditions. The use of non-standard materials is much more expensive than the use of standard valve body materials.

c. Seats

Valve seats are an integral part of a valve. The materials for valve seats are specified under valve trim for each valve. As such, valve seats are manufacturer specific and should not be interchanged. Seat material is selected for compatibility with the fluid. Valve seats can be either metallic or non-metallic. The fluid/material matrix found in Appendix B may be used to assist in material selection. Table 10-3 provides a wear and galling resistance chart for different metallic valve plug and seat combinations. Table 10-4 provides general information for elastomers used in valve seats.

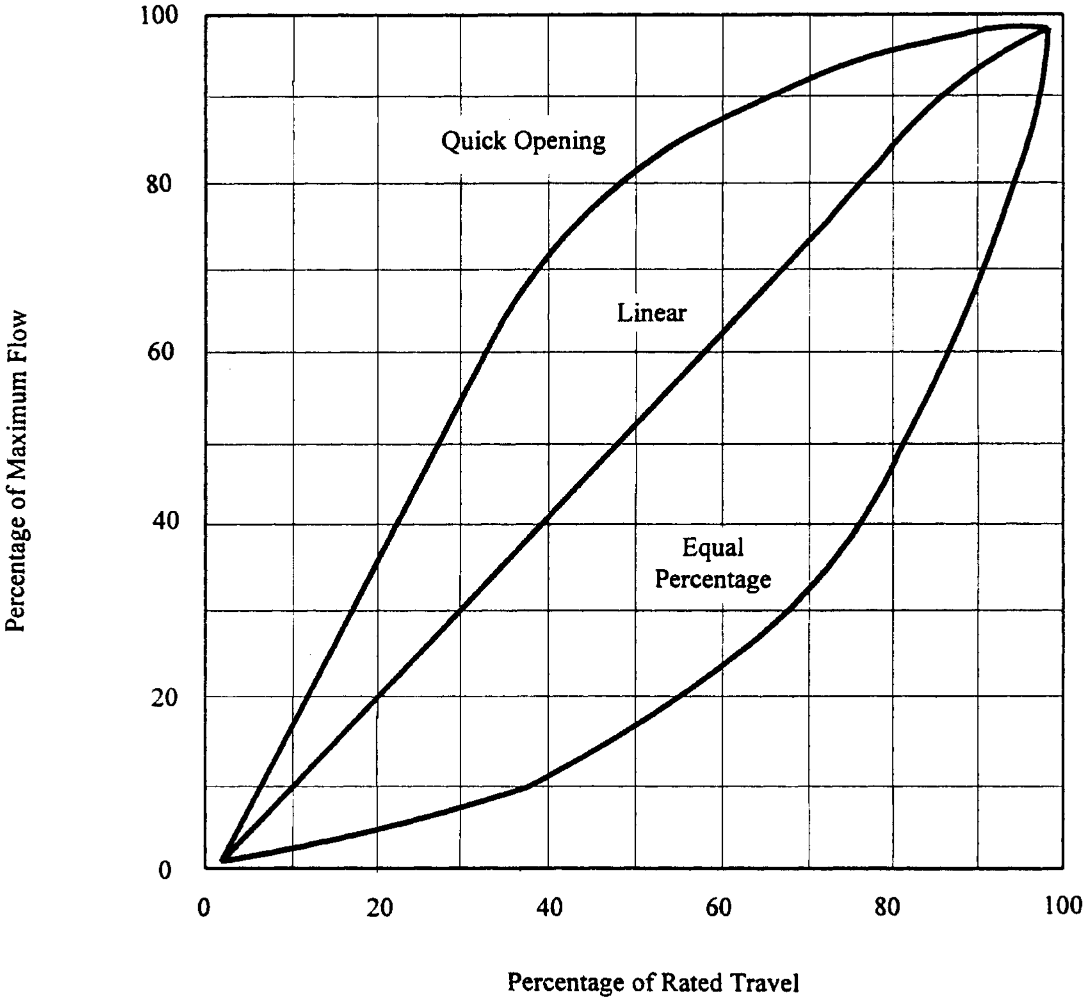

Figure 10-1. Valve Flow Characteristics
(Source: Fisher, Control Valve Handbook, 2nd Ed., p. 60.)

Table 10-1
Recommended Flow Characteristics

Control System	Application	Recommended Flow Characteristic
Liquid Level	Constant ΔP.	Linear
Liquid Level	Decreasing ΔP with increasing flow; $\Delta P_{min} > 20\% \Delta P_{max}$.	Linear
Liquid Level	Decreasing ΔP with increasing flow; $\Delta P_{min} < 20\% \Delta P_{max}$.	Equal Percentage
Liquid Level	Increasing ΔP with increasing flow; $\Delta P_{max} < 200\% \Delta P_{min}$.	Linear
Liquid Level	Increasing ΔP with increasing flow; $\Delta P_{max} > 200\% \Delta P_{min}$.	Quick Opening
Flow	Measurement signal proportional to flow; valve in series with measurement device; wide range of flow required.	Linear
Flow	Measurement signal proportional to flow; valve in series with measurement device; small range of flow required with large ΔP change for increasing flow.	Equal Percentage
Flow	Measurement signal proportional to flow; valve in parallel (bypass) with measurement device; wide range of flow required.	Linear
Flow	Measurement signal proportional to flow; valve in parallel (bypass) with measurement device; small range of flow required with large ΔP change for increasing flow.	Equal Percentage
Flow	Measurement signal proportional to flow squared; valve in series with measurement device; wide range of flow required.	Linear
Flow	Measurement signal proportional to flow squared; valve in series with measurement device; small range of flow required with large ΔP change for increasing flow.	Equal Percentage
Flow	Measurement signal proportional to flow squared; valve in parallel (bypass) with measurement device; wide range of flow required.	Equal Percentage
Flow	Measurement signal proportional to flow squared; valve in parallel (bypass) with measurement device; small range of flow required with large ΔP change for increasing flow.	Equal Percentage
Pressure	All.	Equal Percentage

Source: Control Valve Handbook, Fisher Controls Company, pp. 61-62.

Table 10-2
Standard Control Valve Body Materials

Cast Material	Standard	Comments
Carbon Steel	ASTM A 216 Gr. WCB	Moderate services such as non-corrosive liquids. Higher pressures and temperatures than cast iron. Check codes for suitability at extended high temperatures.
Chrome-Moly Steel	ASTM A 217, Gr. C5	Used for mildly corrosive fluids such as sea water, oils. Resistant to erosion and creep at high temperatures. Can be used to 595°C (1,100°F).
Type 304 Stainless Steel	ASTM A 351, Gr. CF8	Used for oxidizing or very corrosive fluids (see Appendix C). Can be used above 540°C (1,000°F).
Type 316 Stainless Steel	ASTM A 351, Gr. CF8M	Used for oxidizing or very corrosive fluids, resistant to corrosion pitting and creep (see Appendix C). Provides greater strength than 304 S.S.
Monel	ASTM A 494 Gr. M35-1	Resistant to nonoxidizing acids. Used with seawater and other mildly corrosive fluids at high temperatures. Expensive.
Hastelloy-C	ASTM A 494 Gr. CW2N	Used particularly with chlorine and chloride compounds. Expensive.
Iron	ASTM A 126 Class B	Inexpensive and non-ductile. Used for water and non-corrosive liquids.
Bronze	ASTM B 61 and B 62	ASTM B 61 typically used for trim. ASTM B 62 typically used for valve body. Can be used for water and dilute acid service (see Appendix B).

Note: Gr. = grade; grade designation pursuant to the referenced standard.
Source: Compiled by SAIC, 1998.

Table 10-3
Wear and Galling Resistance Chart of Material Combinations

	304 SS	316 SS	Bronze	Inconel	Monel	Hastelloy B	Hastelloy C	Titanium 75A	Nickel	Alloy 20	Type 416 Hard	Type 440 Hard	Alloy 6 (Co-Cr)	Cr-Plate	Al-Bronze
304 SS	P	P	F	P	P	P	F	P	P	P	F	F	F	F	F
316 SS	P	P	F	P	P	P	F	P	P	P	F	F	F	F	F
Bronze	F	F	S	S	S	S	S	S	S	S	F	F	F	F	F
Inconel	P	P	S	P	P	P	F	P	F	F	F	F	F	F	S
Monel	P	P	S	P	P	P	F	F	F	F	F	F	S	F	S
Hastelloy B	P	P	S	P	P	P	F	F	S	F	F	F	S	S	S
Hastelloy C	F	F	S	F	F	F	F	F	F	F	F	F	S	S	S
Titanium 75A	P	P	S	P	F	F	F	P	F	F	F	F	S	F	S
Nickel	P	P	S	F	F	S	F	F	P	P	F	F	S	F	S
Alloy 20	P	P	S	F	F	F	F	F	P	P	F	F	S	F	S
Type 416 Hard	F	F	F	F	F	F	F	F	F	F	F	F	S	S	S
Type 440 Hard	F	F	F	F	F	F	F	F	F	F	S	F	S	S	S
17-4 PH	F	F	F	F	F	F	F	F	F	F	F	S	S	S	S
Alloy 6 (Co-Cr)	F	F	F	F	S	S	S	S	S	S	S	S	F	S	S
ENC*	F	F	F	F	F	F	F	F	F	F	S	S	S	S	S
Cr Plate	F	F	F	F	F	S	S	F	F	F	S	S	S	P	S
Al Bronze	F	F	F	S	S	S	S	S	S	S	S	S	S	S	P

* Electroless nickel coating

S - Satisfactory

F - Fair

P - Poor

Source: Control Valve Handbook, Fisher Controls Company, p. 49.

Table 10-4
Elastomer General Properties

Property		Natural Rubber	Buna-S	Nitrile	Neoprene	Butyl	Thiokol	Silicone	Hypalon	Viton[2,3]	Polyurethane[3]	Ethylene Propylene[4]
Tensile Strength, psi (Bar)	PureGum	3000 (207)	400 (28)	600 (41)	3500 (241)	3000 (207)	300 (21)	200-450 (14-31)	4000 (276)	---	---	---
	Reinforced	4500 (310)	3000 (207)	4000 (276)	3500 (241)	3000 (207)	1500 (103)	1100 (76)	4400 (303)	2300 (159)	6500 (448)	2500 (172)
Tear Resistance		Excellent	Poor-Fair	Fair	Good	Good	Fair	Poor-Fair	Excellent	Good	Excellent	Poor
Abrasion Resistance		Excellent	Good	Good	Excellent	Fair	Poor	Poor	Excellent	Very Good	Excellent	Good
Aging:	Sunlight Oxidation	Poor Good	Poor Fair	Poor Fair	Excellent Good	Excellent Good	Good Good	Good, Very Good	Excellent, Very Good	Excellent Excellent	Excellent Excellent	Excellent Good
Heat (Max. Temp.)		93°C (200°F)	93°C (200°F)	121°C (250°F)	93°C (200°F)	93°C (200°F)	60°C (140°F)	232°C (450°F)	149°C (300°F)	204°C (400°F)	93°C (200°F)	177°C (350°F)
Static (Shelf)		Good	Good	Good	Very Good	Good	Fair	Good	Good	---	---	Good
Flex Cracking Resistance		Excellent	Good	Good	Excellent	Excellent	Fair	Fair	Excellent	---	Excellent	---
Compression Set Resistance		Good	Good	Very Good	Excellent	Fair	Poor	Good	Poor	Poor	Good	Fair
Low Temperature Flexibility (Max.)		-54°C (-65°F)	-46°C (-50°F)	-40°C (-40°F)	-40°C (-40°F)	-40°C (-40°F)	-40°C (-40°F)	-73°C (-100°F)	-29°C (-20°F)	-34°C (-30°F)	-40°C (-40°F)	-45°C (-50°F)
Permeability to Gases		Fair	Fair	Fair	Very Good	Very Good	Good	Fair	Very Good	Good	Good	Good
Resilience		Very Good	Fair	Fair	Very Good	Very Good	Poor	Good	Good	Good	Fair	Very Good
Elongation (Max.)		700%	500%	500%	500%	700%	400%	300%	300%	425%	625%	500%

Notes:
[1] Trademark of Thiokol Chemical Co.
[2] Trademark of E.I. DuPont Co.
[3] Do not use with ammonia.
[4] Do not use with petroleum base fluids. Use with ester base nonflammable hydraulic oils and low pressure steam applications to 300 °F (140°C).
See Appendix B for more details regarding fluid compatibility with elastomers.

Source: Control Valve Handbook, Fisher Controls Company, p. 57.

In addition, the amount of valve leakage is determined based on acceptability to process and design requirements. Control valve seats are classified in accordance with ANSI/FCI 70-2-1991 for leakage. These classifications are summarized in Table 10-5 and Table 10-6.

Table 10-5
Valve Seat Leakage Classifications

Leakage Class Designation	Maximum Allowable Leakage
I	---
II	0.5% of rated capacity
III	0.1% of rated capacity
IV	0.01% of rated capacity
V	5 x 10 $^{-12}$ m^3/s of water per mm of seat diameter per bar differential (0.0005 ml/min per inch of seat diameter per psi differential)
VI	Not to exceed amounts shown in Table 10-6 (based on seat diameter)

Source: ANSI/FCI 70-2-1991

Table 10-6
Class VI Seat Allowable Leakage

Nominal Port Diameter mm (in)	Allowable Leakage Rate (ml per minute)
≤25 (≤1)	0.15
38 (1½)	0.30
51 (2)	0.45
64 (2½)	0.60
76 (3)	0.90
102 (4)	1.70
152 (6)	4.00
203 (8)	6.75

Source: ANSI/FCI 70-2-1991

d. Packing

Most control valves use packing boxes with the packing retained and adjusted by flange and stud bolts. Several packing materials are available for use, depending upon the application. Table 10-7 provides information on some of the more typical packing arrangements.

e. End Connections

The common end connections for installing valves in pipe include screwed pipe threads, bolted gasketed flanges, welded connections, and flangeless (or wafer) valve bodies.

Screwed end connections are typically used with small valves. Threads are normally specified as tapered female National Pipe Thread (NPT). This end connection is limited to valves 50 mm (2 in) and smaller and is not recommended for elevated temperature service. This connection is also used in low maintenance or non-critical applications.

Flanged end valves are easily removed from piping and, with proper flange specifications, are suitable for use through the range of most control valve working pressures. Flanges are used on all valve sizes larger than 50 mm (2 in). The most common types of flanged end connections are flat faced, raised faced, and the ring joint. Flat faced flanges are typically used in low pressure, cast iron or brass valves and have the advantage of minimizing flange stresses. Raised faced flanges can be used for high pressure and temperature applications and are normally standard on ANSI Class 250 cast iron and on all steel and alloy steel bodies. The ring-type joint flange is typically used at extremely high pressures of up to 103 MPa (15,000 psig) but is generally not used at high temperatures. This type of flange is furnished only on steel and alloy valve bodies when specified.

Welding ends on valves have the advantage of being leak tight at all pressures and temperatures; however, welding end valves are very difficult to remove for maintenance and/or repairs. Welding ends are manufactured in two styles: socket and butt.

Flangeless valve bodies are also called wafer-style valve bodies. This body style is common to rotary shaft control valves such as butterfly valves and ball valves.

TABLE 10-7
Packing

Type	Application
PTFE	Resistant to most chemicals. Requires extremely smooth stem finish to seal properly. Will leak if stem or packing is damaged.
Laminated/Filament Graphite	Impervious to most liquids and radiation. Can be used at high temperatures, up to 650°C (1,200°F). Produces high stem friction.
Semi-Metallic	Used for high pressures and temperatures, up to 480°C (900°F).
Fiberglass	Good for general use. Used with process temperatures up to 288°C (550°F). Ferritic steel stems require additive to inhibit pitting.
Kevlar and Graphite	Good for general use. Used with process temperatures up to 288°C (550°F). Corrosion inhibitor is included to avoid stem corrosion.

Source: Compiled by SAIC, 1998

Flangeless bodies are clamped between two pipeline flanges by long through-bolts. One of the advantages of a wafer-style body is that it has a very short face-to-face body length.

f. Operators

Valve operators, also called actuators, are available in manual, pneumatic, electric, and hydraulic styles.

Manual operators are used where automatic control is not required. These valves may still result in good throttling control, if control is necessary. Gate, globe and stop check valves are often supplied with hand wheel operators. Ball and butterfly valves are supplied with hand levers. Manual operators can be supplied with direct mount chain wheels or extensions to actuate valves in hard-to-reach locations. Manually operated valves are often used in a three-valve bypass loop around control valves for manual control of the process during down time on the automatic system. Manual operators are much less expensive than automatic operators.

For sliding stem valves, that is, valves that are not rotary, the most common operator type is a pneumatic operator. A pneumatic operator can be a spring and diaphragm type or a pneumatic piston. While these pneumatic operators are also available for rotary shaft valves, electrical operators tend to be more common on the rotary valves.

Spring and diaphragm operators are pneumatically operated using low pressure air supplied from a controller position or other source. Styles of these operators include direct acting, in which increasing air pressure pushes down the diaphragm and extends the actuator stem; reverse acting, in which increasing air pressure pushes up the diaphragm and retracts the actuator stem; and direct acting for rotary valves. Pneumatic operators are simple, dependable, and economical. Molded diaphragms can be used to provide linear performance and increase travel. The sizes of the operators are dictated by the output thrust required and available air pressure supply.

Pneumatic piston operators are operated using high pressure air. The air pressure can be up to 1.03 MPa (150 psig), often eliminating the need for a pressure regulator that is required on a diaphragm actuator. The best design for piston actuators is double acting. This allows for the maximum force in both directions on the piston. Piston actuators can be supplied with accessories that will position the valve in the event of loss of air supply. These accessories include spring return, pneumatic trip valves, and lock-up type systems. It is common to include manual operators along with pneumatic piston operators in a design. These manual operators can then act as travel stops to limit either full opening or full closing of the valve.

Electric and electro-hydraulic operators are more expensive than pneumatic actuators; however, they offer advantages when no existing air supply source is available, where low ambient temperatures could affect pneumatic supply lines, or where very large stem forces or shaft forces are required. Electrical operators only require electrical power to the motors and electrical input signal from the controller in order to be positioned. Electrical operators are usually self-contained and operate within either a weather-proof or an explosion-proof casing.

An auxiliary positioner or booster is sometimes used on pneumatic operating systems when it is necessary to split the controller output to more than one valve, to amplify the controller above the standard range in order to provide increased actuator thrust, or to provide the best possible control with minimum overshoot and fastest possible recovery following a disturbance or load change. Determination of whether to use a positioner or a booster depends on the speed of the system response. If the system is relatively fast, such as is typical of pressure control and most flow control loops, the proper choice is a booster. If the system is relatively slow, as is typical of liquid level, blending, temperature and reactor control loads, the proper choice is a positioner[1].

Hydraulic snubbers dampen the instability of the valve plug in severe applications and are used on pneumatic piston and direct acting diaphragm actuators.

Limit switches can be used to operate signal lights, solenoid valves, electric relays, or alarms. The limit switches are typically provided with 1 to 6 individual switches and are operated by the movement of the valve stem. It is common for each switch to be individually adjustable and used to indicate the full open or full closed position on a valve.

Electro-pneumatic transducers and electro-pneumatic positioners are used in electronic control loops to position pneumatically operated control valves. The positioner or transducer receives a current input signal and then supplies a proportional pneumatic output signal to the pneumatic actuator to position the valve.

g. Supports

Specific pipe material design recommendations are followed when designing supports for valves. In general, one hanger or other support should be specified for each side of a valve, that is, along the two pipe sections immediately adjacent to the valve. The weight of the valve is included in the calculation of the maximum span of supports.

10-2. Valve Types

The main valve types have many variations and may have different names depending upon manufacturer. Careful selection and detailed specifications are required to insure that design and performance requirements are met.

a. Check Valves

Check valves are self-actuated. These valves are opened, and sustained in the open position, by the force of the liquid velocity pressure. They are closed by the force of gravity or backflow. The seating load and tightness is dependent upon the amount of back pressure. Typical check valves include swing check, tilting disc check, lift check, and stop check. Other check valve types are available, however.

Swing check valves are used to prevent flow reversal in horizontal or vertical upward pipelines (vertical pipes or pipes in any angle from horizontal to vertical with upward flow only). Swing check valves have discs that swing open and closed. The discs are typically designed to close on their own weight, and may be in a state of constant movement if velocity pressure is not sufficient to hold the valve in a wide open position. Premature wear or noisy operation of the swing check valves can be avoided by selecting the correct size on the basis of flow

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[1] Fisher Control Company, p. 35.

conditions. The minimum velocity required to hold a swing check valve in the open position is expressed by the empirical formula[2]:

$$V \ ' \ j\sqrt{v}$$

where:
V = liquid flow, m/s (ft/s)
v = specific volume of the liquid, m^3/N (ft^3/lb)
j = 133.7 (35) for Y-pattern
= 229.1 (60) for bolted cap
= 381.9 (100) for U/L listed

Tilting disc check valves are pivoted circular discs mounted in a cylindrical housing. These check valves have the ability to close rapidly, thereby minimizing slamming and vibrations. Tilting disc checks are used to prevent reversals in horizontal or vertical-up lines similar to swing check valves. The minimum velocity required for holding a tilting check valve wide open can be determined by the empirical formula[3]:

$$V \ ' \ j\sqrt{v}$$

where:
V = liquid flow, m/s (ft/s)
v = specific volume of the liquid, m^3/N (ft^3/lb)
j = 305.5 (80) for a 5° disc angle (typical for steel)
= 114.6 (30) for a 15° disc angle (typical for iron)

Lift check valves also operate automatically by line pressure. They are installed with pressure under the disc. A lift check valve typically has a disc that is free floating and is lifted by the flow. Liquid has an indirect line of flow, so the lift check is restricting the flow. Because of this, lift check valves are similar to globe valves and are generally used as a companion to globe valves. Lift check valves will only operate in horizontal lines. The minimum velocity required to hold a lift check valve open is calculated using the following empirical formula[4]:

$$V \ ' \ j\$^2\sqrt{<}$$

where:
V = liquid flow, m/s (ft/s)
v = specific volume of the liquid, m^3/N (ft^3/lb)
j = 152.8 (40) for bolted cap
= 534.7 (140) for Y-pattern
$ = ratio of port diameter to inside pipe diameter

Stop check valves are typically used in high pressure and hazardous applications. Stop check valves have a floating disc. Sizing of these valves is extremely important because of the floating disc, and manufacturer's recommended procedures should be used. Stop check valves typically have a manual operator and, in this manner, can be forced closed to prevent any backflow of materials. The minimum velocity required for a full disc lift in a stop check valve is estimated by the following empirical formula[5]:

$$V \ ' \ j\$^2\sqrt{<}$$

where:

V = liquid flow, m/s (ft/s)
v = specific volume of the liquid, m^3/N (ft^3/lb)
j = 210.0 (55) globe, OS&Y blocked bonnet
= 286.4 (7S) angle, OS&Y blocked bonnet
= 229.1 (60) Y-pattern, OS&Y bolted bonnet
= 534.7 (140) Y-pattern, threaded bonnet
$ = ratio of port diameter to inside pipe diameter

Use of these empirical methods may result in a check valve sized smaller than the piping which is used. If this is the case, reducers are used to decrease pipe size to the smaller valve. The pressure drop is no greater than that of the larger valve that is partially open, and valve life is extended[6].

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[2] Crane Valves, Engineering Data, p. 53.
[3] Ibid., p. 53.
[4] Ibid., p. 53.
[5] Ibid., p. 54.
[6] Crane Valves, Cast Steel Valves, p. 14.

b. Ball Valves

Ball valves with standard materials are low cost, compact, lightweight, easy to install, and easy to operate. They offer full flow with minimum turbulence and can balance or throttle fluids. Typically, ball valves move from closed to full open in a quarter of a turn of the shaft and are, therefore, referred to as quarter turn ball valves. Low torque requirements can permit ball valves to be used in quick manual or automatic operation, and these valves have a long reliable service life. Ball valves can be full ball or other configurations such as V-port.

Full ball valves employ a complete sphere as the flow controlling member. They are of rotary shaft design and include a flow passage. There are many varieties of the full ball valves, and they can be trunion mounted with a single piece ball and shaft to reduce torque requirements and lost motion.

One of the most popular flow controlling members of the throttling-type ball valves is a V-port ball valve. A V-port ball valve utilizes a partial sphere that has a V-shaped notch in it. This notch permits a wide range of service and produces an equal percentage flow characteristic. The straight-forward flow design produces very little pressure drop, and the valve is suited to the control of erosive and viscous fluids or other services that have entrained solids or fibers. The V-port ball remains in contact with the seal, which produces a shearing effect as the ball closes, thus minimizing clogging.

c. Gate Valves

The gate valve is one of the most common valves used in liquid piping. This valve, as a rule, is an isolation valve used to turn on and shut off the flow, isolating either a piece of equipment or a pipeline, as opposed to actually regulating flow. The gate valve has a gate-like disc which operates at a right angle to the flow path. As such, it has a straight through port that results in minimum turbulence erosion and resistance to flow. However, because the gate or the seating is perpendicular to the flow, gate valves are impractical for throttling service and are not used for frequent operation applications.

Repeated closure of a gate valve, or rather movement toward closure of a gate valve, results in high velocity flow. This creates the threat of wire drawing and erosion of seating services. Many gate valves have wedge discs with matching tapered seats. Therefore, the refacing or repairing of the seating surfaces is not a simple operation. Gate valves should not, therefore, be used frequently to avoid increased maintenance costs. In addition, a slightly open gate valve can cause turbulent flow with vibrating and chattering of the disc.

A gate valve usually requires multiple turns of its hand wheel manual operator in order to be opened fully. The volume of flow through the valve is not in direct proportion to the number of turns of the hand wheel.

d. Globe and Angle Valves

Liquid flow does not pass straight through globe valves. Therefore, it causes an increased resistance to flow and a considerable pressure drop. Angle valves are similar to globe valves; however, the inlet and outlet ports are at 90° angles to one another, rather than at 180° angles. Because of this difference, the angle valves have slightly less resistance to flow than globe valves. However, both valve types operate similarly in principle and, for the purposes of this document, discussion of globe valves will also pertain to angle valves.

There are a number of common globe valve seating types. Table 10-8 presents some of the more common seating types, along with advantages and disadvantages of each.

The seating of the plug in a globe valve is parallel to the line of liquid flow. Because of this seating arrangement, globe valves are very suitable for throttling flow with a minimal seat erosion or threat of wire drawing.

A globe valve opens in direct proportion to the number of turns of its actuator. This feature allows globe valves to closely regulate flow, even with manual operators. For example, if it takes four turns to open a globe valve fully, then approximately one turn of a hand wheel will release about 25% of the flow, two turns will release 50%, and three turns will release 75%. In addition, the shorter travel saves time and work, as well as wear on valve parts.

Maintenance is relatively easy with globe valves. The seats and discs are plugs, and most globe valves can be repaired without actually removing the valve from the pipe.

Table 10-8
Common Globe Valve Seating

Type	Comments
Plug	Long taper with matching seat provides wide seating contact area. Excellent for severe throttling applications. Resistant to leakage resulting from abrasion. With proper material selection, very effective for resisting erosion.
Conventional Disc	Narrow contact with seat. Good for normal service, but not for severe throttling applications. Subject to erosion and wire drawing. Good seating contact if uniform deposits (such as from coking actions) occur. Non-uniform deposits make tight closure difficult.
Composition Disc	"Soft" discs provided in different material combinations depending upon liquid service. Good for moderate pressure applications except for close throttling, which will rapidly erode the disc.
Needle	Sharp pointed disc with matching seat provides fine control of liquid flow in small-diameter piping. Stem threads are fine, so considerable stem movement is required to open or close.

Source: Compiled by SAIC, 1998

e. Butterfly Valves

Butterfly valves provide a high capacity with low pressure loss and are durable, efficient, and reliable. The chief advantage of the butterfly valve is its seating surface. The reason for this advantage is that the disc impinges against a resilient liner and provides bubble tightness with very low operating torque. Butterfly valves exhibit an approximately equal percentage of flow characteristic and can be used for throttling service or for on/off control.

Typical butterfly bodies include a wafer design, a lug wafer design (a wafer with the addition of lugs around the bodies), and a flanged design. In all designs, butterfly valves are typically made with standard raised face piping flanges. Butterfly valves are available standard in sizes up to 72 inches for many different applications. The operators can be either pneumatic or electric.

f. Pinch Valves

Pinch valves, as the name suggests, pinch an elastomeric sleeve shut in order to throttle the flow through the pipeline. Because of the streamlined flow path, the pinch valve has very good fluid capacity. Pinch valves typically have a fairly linear characteristic. However, some manufacturers offer field reversible cam-characterizable positioners. These positioners will vary the rate of stem change as a function of position in order to match the flow characteristics desired. In some instances, the cams are set up to provide an equal percentage flow characteristic through a pinch valve.

The pinch valve sleeve is available in various elastomer materials in order to adjust for chemical resistance. In addition, because the throttling takes place in the elastomer sleeve, and elastomers typically have very good abrasion resistance; pinch valves are often used for slurries or liquids that contain high amounts of solids.

g. Plug Valves

Plug valves are another type of isolation valve designed for uses similar to those of gate valves, where quick shutoff is required. They are not generally designed for flow regulation. Plug valves are sometimes also called cock valves. They are typically a quarter turn open and close. Plug valves have the capability of having multiple outlet ports. This is advantageous in that it can simplify piping. Plug valves are available with inlet and outlet ports with four-way multi-port valves which can be used in place of two, three or four straight valves.

h. Self-Contained Automatic Valves

Self-contained automatic valves are used for pressure-reducing stations. The valve body itself is normally a globe-type valve. It is normally diaphragm actuated and hydraulically operated. The valves are capable of maintaining constant downstream pressure regardless of the fluctuations in flow or upstream pressure by internal hydraulic controllers.

10-3. Valve Sizing and Selection

Valve sizing and type selection is a critical component of a piping design. Valve type is shown on P&IDs, and valve size is commonly provided on valve schedules. The sizing and selection procedures are different for non-control and control valves.

a. Non-Control Valves

Non-control valves used for isolation are the same size as the connecting pipe. This sizing reduces pressure loss. Check valves may be smaller than the connecting pipe, provided that the valves are properly sized to ensure full open operation without flow restriction. Materials of construction, wetted or otherwise, and end connections are in compliance with applicable codes and standards and address the fluid application for corrosivity (see Paragraph 10-1).

b. Control Valves

Control valves are sized and selected to optimize application. Valves that are sized too small will not pass the required flow. Control valves that are sized too large or are arbitrarily sized to match the connecting pipe, will result in increased capital costs, decreased valve life (due to the throttling and erosion effects when operating near to the closed position), and decreased performance (by limiting rangeability). Control valves are optimally selected by identifying the flow characteristic required, then calculating an expected flow coefficient and the maximum allowable pressure drop. These factors are then compared to manufacturers' data for specific valve types and sizes.

To select a control valve, the process application must be understood. Minimum information considered includes desired flow characteristics; type, temperature, viscosity, and specific gravity of the liquid; minimum and maximum flow capacity; minimum and maximum valve inlet pressure; and minimum and maximum valve outlet pressure.

For example, Figure 10-2 depicts a piping system curve, with and without the control valve, and an overlying pump curve. Typically, a valve differential pressure (ΔP) of approximately 33% of the total piping system friction drop at maximum flow is desired (as shown on Figure 10-2). For systems that require low turndown, or face abrasion or other problems, the valve ΔP may be as low as 15%[7].

Once a desired ΔP is determined, the valve flow coefficient (C_v) and allowable pressure drop (ΔP_{allow}) are calculated for a fully open valve in accordance with the flow chart depicted on Figure 10-3. The valve recovery factor (R_m) and cavitation index (K_c) are determined from manufacturers' data for a specific type and size of valve.

The sizing formulas for incompressible flow without mixed-phase fluids, dense slurries, dry solids or non-Newtonian liquids are as follows[8]:

$$C_v = \frac{Q}{N_1}\sqrt{\frac{s.g.}{\Delta P}}$$

where:

C_v = valve flow coefficient

Q = flow, m^3/hour (gpm)

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[7] Gardellin, p. 4.

[8] ISA-S75.01, pp. 15-18, 33-35.

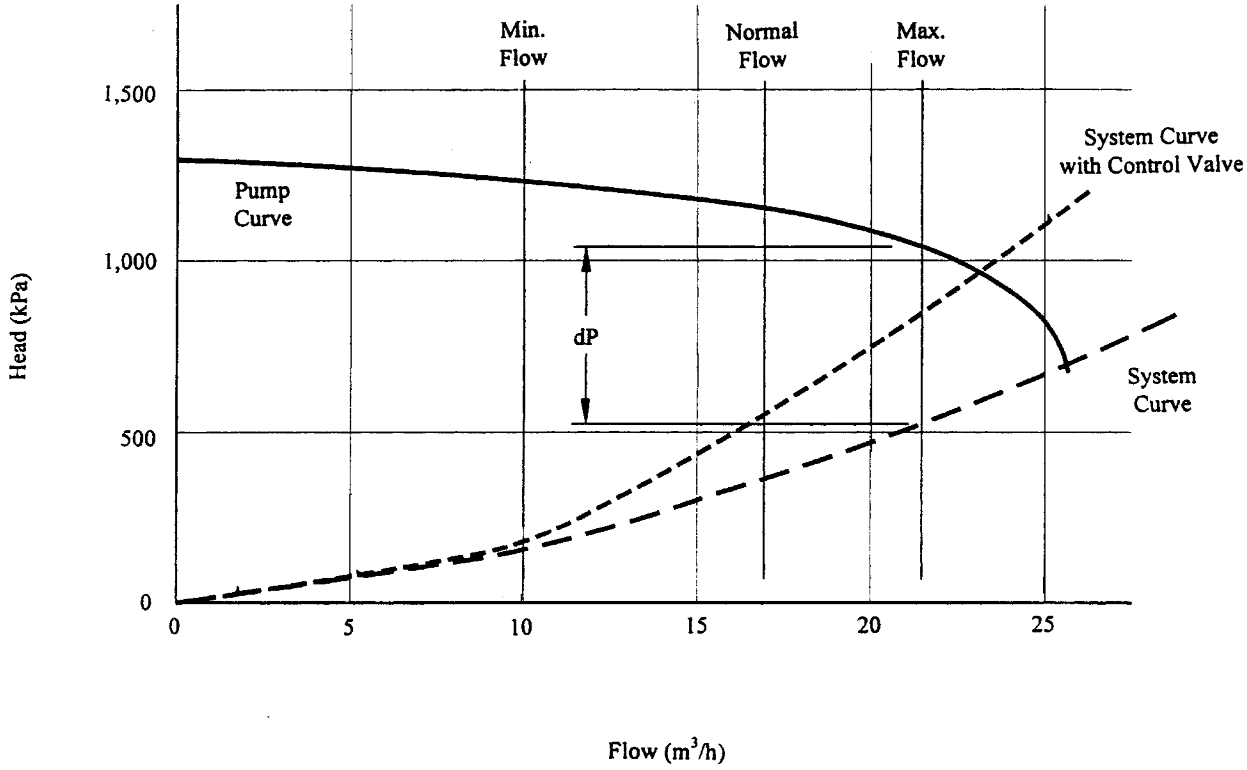


Figure 10-2. Control Valve Pressure Drop Curve
(Source: SAIC, 1998)

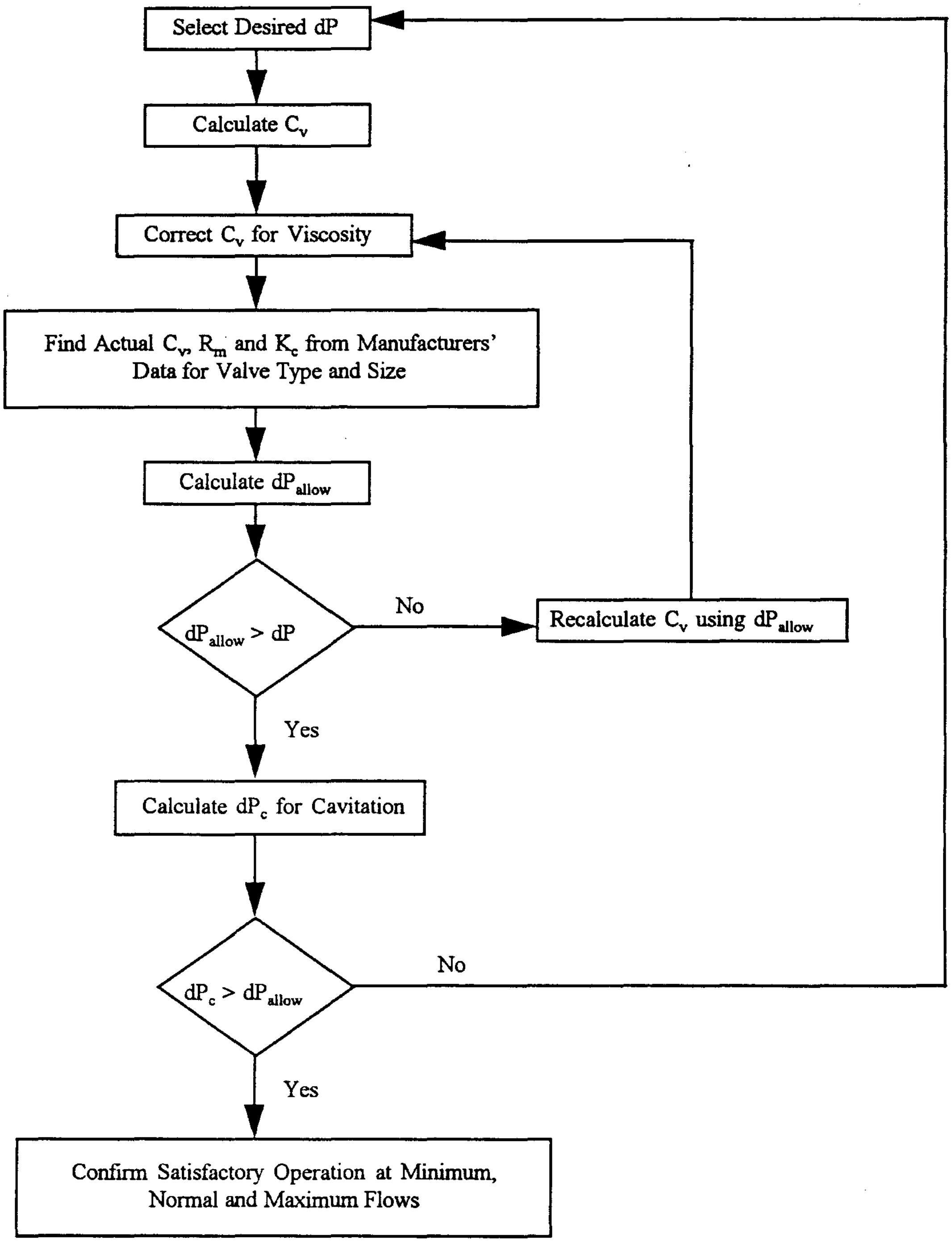


Figure 10-3. Control Valve Sizing
(Source: SAIC, 1998)

N_1 = Conversion factor, 0.085 when Q is in m^3/hour and ΔP is in kPa (1.00 when Q is in gpm and ΔP is in psi)

s.g. = specific gravity of liquid

ΔP = differential pressure across valve, kPa (psi)

$$Re_v = \frac{N_4\ F_d\ Q}{\nu\ R_m^{1/2} C_v^{1/2}} \left[\frac{R_m^2\ C_v^2}{N_2\ d^4} + 1 \right]^{1/4}$$

where:

Re_v = valve Reynolds number

N_4 = conversion factor, 76,000 when Q is in m^3/hour and d is in mm (17,300 when Q is in gpm and d is in inches)

F_d = valve style modifier, see Table 10-9

Q = volumetric flow rate, m^3/hour (gpm)

ν = kinematic viscosity, mm^2/sec (centistoke)

R_m = valve recovery factor, from manufacturers' data (see Table 10-9)

C_v = valve flow coefficient

N_2 = conversion factor, 0.00214 when d is in mm (890 when d is in inches)

d = valve inlet diameter, mm (in)

$$C_{vc} = \frac{C_v}{F_R}$$

where:

C_{vc} = valve flow coefficient corrected for viscosity

F_R = valve Reynolds number factor (see Figure 10-4)

$$\Delta P_{allow} = R_m^{\ 2}\ (P_i - r_c\ P_v)$$

where:

ΔP_{allow} = maximum valve ΔP to avoid choked flow, kPa (psi)

R_m = valve recovery factor, from manufacturers' data (see Table 10-9)

P_i = valve inlet pressure, kPa (psi)

r_c = critical pressure ratio, calculation as follows or see Figure 10-5

P_v = liquid vapor pressure, kPa (psia)

$$r_c = 0.96 - 0.28 \left(\frac{P_v}{P_c} \right)^{1/2}$$

where:

r_c = critical pressure ratio

P_v = liquid vapor pressure, kPa (psi)

P_c = absolute thermodynamic critical pressure, kPa (psi)

$$\Delta P_c = K_c\ (P_i - P_v)$$

where:

ΔP_c = valve ΔP at which cavitation damage occurs, kPa (psi)

K_c = cavitation index, from manufacturers' data

P_i = value inlet pressure, kPa (psi)

P_v = liquid vapor pressure, kPa (psi)

Example Problem 8:

Figure 10-2 represents the process to be controlled and control valve is for flow control purposes with an orifice plate flow measurement device. The liquid is water with trace hydrocarbons. The pipe size is 100 mm and the operating conditions are: T = 15.6°C; P_i = 517 kPa, 172.4 kPa, and 1030 kPa for normal, minimum, and maximum operating conditions, respectively.

Solution:

Step 1. From Figure 10-2, ΔP at max. flow = 496 kPa and Q = 17 m^3/hour normal
10 m^3/hour minimum
21.5 m^3/hour maximum

Step 2. The flow measurement device is proportional to flow squared so that an equal percentage for characteristic is desired. Assume a butterfly valve will be used so F_d = 0.7, and R_m = 0.7 (from Table 10-9)

Step 3. From common fluid mechanics reference materials: s.g. = 1.0; P_v = 1.85 kPa; P_c = 22.09 MPa; ν = 1.13 mm^2/sec.

Step 4. Therefore, the valve calculations are:

TABLE 10-9
Example Values of Valve Capacity Factors

Valve Type	Trim Type	Flow Direction[*]	R_m	F_d[**]	C_v/d^2[***]
Globe - Single port	Ported plug	Either	0.9	1.0	6,129 (9.5)
	Contoured plug	Open	0.9	1.0	7,098 (11)
		Close	0.8	1.0	7,098 (11)
	Characterized cage	Open	0.9	1.0	9,032 (14)
		Close	0.85	1.0	10,322 (16)
	Wing guided	Either	0.9	1.0	7,098 (11)
- Double port	Ported plug	Either	0.9	0.7	8,065 (12.5)
	Contoured plug	Either	0.85	0.7	8,387 (13)
	Wing guided	Either	0.9	0.7	9,032 (14)
- Rotary	Eccentric Spherical plug	Open	0.85	1.0	7,742 (12)
		Close	0.68	1.0	8,710 (13.5)
Angle	Contoured plug	Open	0.9	1.0	10,968 (17)
		Close	0.8	1.0	12,903 (20)
	Characterized cage	Open	0.85	1.0	7,742 (12)
		Close	0.8	1.0	7,742 (12)
	Venturi	Close	0.5	1.0	14,194 (22)
Ball	Segmented	Open	0.6	1.0	16,129 (25)
	Standard port (diameter ≅ 0.8d)	Either	0.55	1.0	14,194 (22)
Butterfly	60-Degree aligned	Either	0.68	0.7	11,290 (17.5)
	Fluted vane	Either	0.7	0.7	16,129 (25)
	90-Degree offset seat	Either	0.60	0.7	18,710 (29)

[*] Flow direction tends to open or close the valve: i.e., push the closure member away from or towards the seat.

[**] In general, an F_d value of 1.0 can be used for valves with a single flow passage. An F_d value of 0.7 can be used for valves with two flow passages, such as double-ported globe valves and butterfly valves.

[***] In this table, d may be taken as the nominal valve size, mm (in).

NOTE: The values are typical only for the types of valves shown at their rated travel for full-size trim. Significant variations in value may occur because of any of the following reasons: reduced travel, trim type, reduced port size, and valve manufacturer.

Source: ISA -S75.01, p. 31; Copyrighted material reprinted by permission of the Instrument Society of America, all rights reserved.

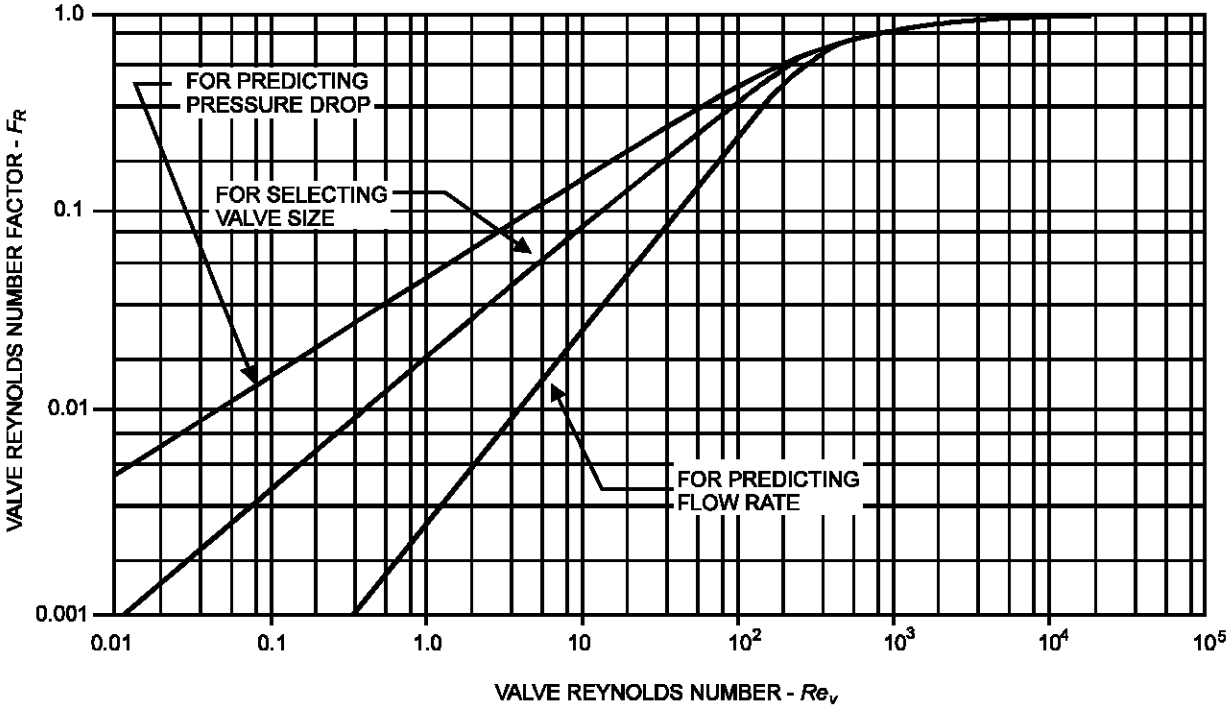
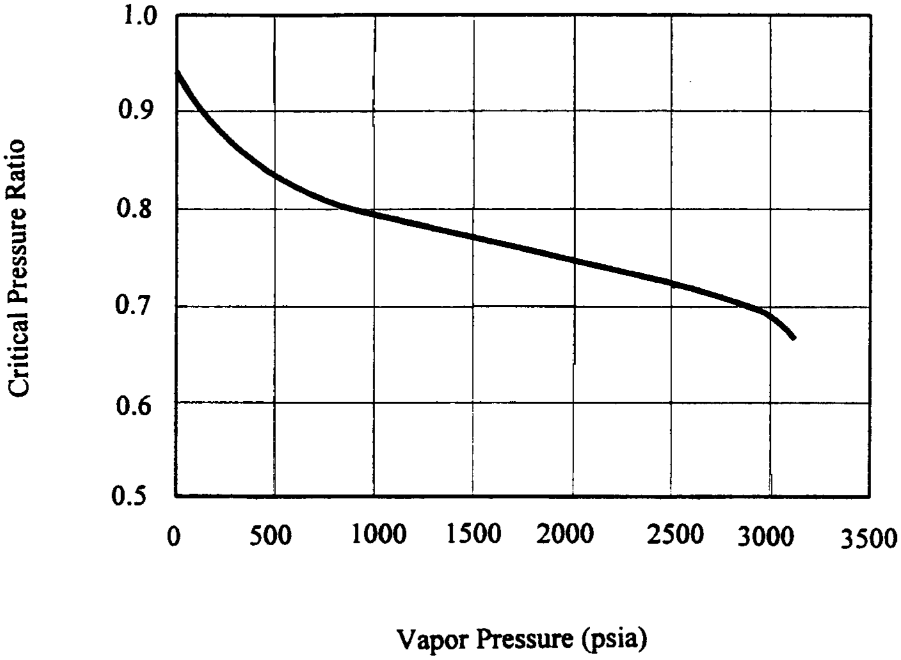
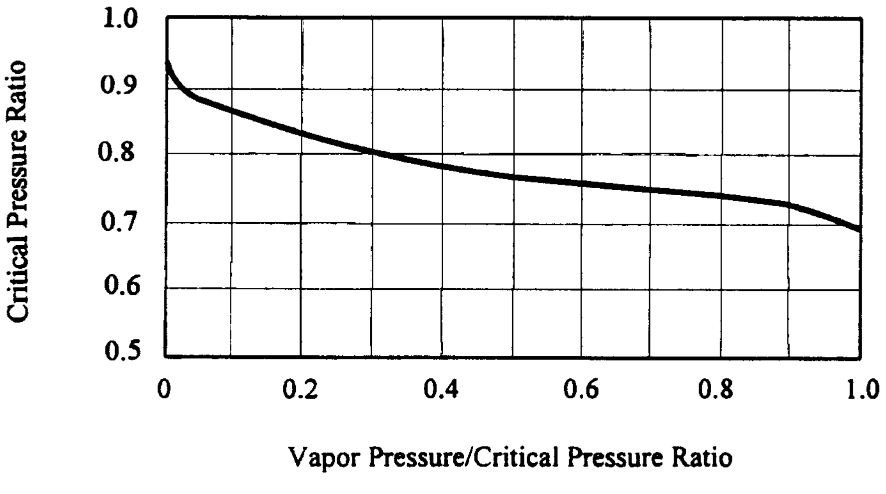


Figure 10-4. Valve Factor Diagram
(Source: ISA-S75.01-1985 (R 1995), p. 34.)



a. Curve to be Used for Water



b. Curve for Liquids Other Than Water

Figure 10-5. Critical Pressure Ratio
(Source: Fisher, Control Valve Handbook, 2nd Ed., p. 67)

$$C_v = \frac{Q}{N_1}\sqrt{\frac{s.g.}{\Delta P}}$$

$$C_v = \frac{21.5\ m^3/hour}{0.085}\sqrt{\frac{1.0}{496\ kPa}} = 11.4$$

$$Re_v = \frac{N_4\ F_d\ Q}{\pi\ R_m^{1/2} C_V^{1/2}}\left[\frac{R_m^2\ C_v^2}{N_2\ d^4} + 1\right]^{1/4}$$

$$Re_v = \frac{(76{,}000)(0.7)(21.5)}{(1.13)(0.7)^{1/2}(11.4)^{1/2}}\left[\frac{(0.7)^2(11.4)^2}{(0.00214)(100)^4} + 1\right]^{1/4}$$

$$Re_v = 3.57\ x\ 10^5$$

F_R = 1.0 from Figure 10-4 (a viscosity correction is not required due to the high Reynolds number).Therefore, C_{vc} = 11.4.

Step 5. From manufacturer's data, a 25 mm, 60° V-port ball valve at full open in a 50 mm pipe has a C_v of 11.2 and a R_m of 0.75. Therefore, neck the connecting piping down to 50 mm, and select a 25 mm V-port ball valve (has an equal percentage flow characteristic).

Step 6. The allowable pressure drop of the system is compared to the actual valve differential pressure to confirm that the valve will operate satisfactorily.

$$r_c = 0.96 - 0.28\left(\frac{P_v}{P_c}\right)^{1/2}$$

$$= 0.96 - 0.28\left(\frac{1.85 kPa}{22{,}090 kPa}\right)^{1/2}$$

$$r_c = 0.96$$

$$\Delta P_{allow} = R_m^2\ (P_i - r_c\ P_v)$$

$$= (0.75)^2[1030\ kPa - (0.96)(1.85\ kPa)]$$

$$\Delta P_{allow} = 578\ kPa\ at\ \text{max.}\ flow\ (full\ open)$$

$\Delta P_{allow} \geq \Delta P$ at maximum flow, therefore, the valve is acceptable.

10-4. Valve Schedule

Many manufacturers have PC-based sizing programs that will size and select their optimum valve for a specific application. In addition, computerized piping system design programs may also have valve sizing and selection routines that will select the optimum valve in their databases. Although these sizing programs can provide useful data, the optimum valve for a particular application may be found elsewhere. For design purposes, contract drawings include a valve schedule to aid in the bidding and proper supply of valves.

a. Valve Schedule

Table 10-10 presents a valve schedule that is included in the contract drawings for liquid process piping design.

b. Valve Operators Schedule

Table 10-11 is a valve operator schedule that is sometimes included in the contract drawings. This schedule is used when additional information, beyond that shown on a valve schedule, is required.

Table 10-10
Valve Schedule

Valve Tag/Ref	Description	Size Range	Flange Rating	Screwed Ends	Design Rating	Body Materials	Trim Materials	Bolting Materials	Operation	Service	Remarks
V120	Ball Valve, Full Port Positive Shut-off	50 mm & Smaller	- -	Taper ANSI B2.1	1.39 MPa	316 SS	316 SS Ball & Stem Glass Filled TFE Seats, TFE Seals	- -	Lever	IWW, SLG, WPS	
V121	Ball Valve, Full Port Positive Shut-off	80 mm	ANSI B16.5 Class 150	- -	689 kPa	316 SS	316 SS Ball & Stem Glass Filled TFE Seats, TFE Seals	CS ASTM A 307 Gr B	Lever	SW, ALT, RO, AL, SWW, RL	Instrument Isolation Valves Only
V122	Ball Valve, Full Port Positive Shut-off	40 mm & Smaller	ANSI B16.5 Class 300	- -	1.03 MPa	316 SS	316 SS Ball & Stem Glass Filled TFE Seats, TFE Seals	CS ASTM A 307 Gr B	Lever	WCR	
V123	Solid Wedge Gate Valve O.S. & Y., Rising Stem	50 mm & Larger	ANSI B16.5 Class 300	- -	1.03 MPa	CS ASTM A 216 GR WCB	13% Cr Steel Seats & SS Stem	CS ASTM A 307 Gr B	Handwheel	SLP	
V124	Double Disc Gate Valve O.S. & Y., Rising Stem	50 mm & Larger	ANSI B16.5 Class 150	- -	689 kPa	CS ASTM A 216 GR WCB	UT Trim 316 SS Stem	CS ASTM A 307 Gr B	Handwheel	SL	
V150	Swing Check Valve	50 mm to 300 mm	ANSI B16.5 Class 150	- -	689 kPa	CS ASTM A 216 GR WCB	13% Cr Steel Seats & Disc	CS ASTM A 307 Gr B	- -	XLT, ALT, RL, AL, SLO, PLO	All Drain Points to be Threaded & Plugged
V151	Swing Check Valve	50 mm & Smaller	- -	Taper ANSI B2.1	1.39 MPa	Bronze	Bronze	- -	- -	PW	All Drain Points to be Threaded & Plugged
V152	Y-Pattern Check Valve	50 mm & Smaller	- -	Socket Weld	17.2 MPa	CS ASTM A 105	13% Cr Steel Seats & 302 SS Spring	- -	- -	FWH	
V153	Lined Wafer Check Valve	250 mm	Fit Between Class 150	- -	689 kPa	PFA Coated CS	PFA Coated Steel	- -	- -	DWH	
V154	Wafer Style Check Valve	100 mm to 250 mm	Fit Between Class 150	- -	689 kPa	410 SS ASTM A 276	302 SS	- -	- -	AP	All Drain Points to be Threaded & Plugged
PCV-452	Globe Valve, Bolted Bonnet, O.S. & Y., Rising Stem	100 mm	ANSI B16.5 Class 150	- -	689 kPa	CS ASTM A 216 GR WCB	SS	CS ASTM A 307 Gr B	Pneumatic Diaphragm R.A.	RCY	
FCV-501	Butterfly Valve	100 mm	Fit Between Class 150	- -	689 kPa	PFA Lined D.I.	PFA Lined D.I. & SS Stem	- -	Electric	AG, AV	
FCV-625	Butterfly Valve	300 mm	Fit Between Class 150	- -	689 kPa	PFTE Lined CS	PTFE Lined CS & SS Stem	- -	Electric, Enclosed Gear	DWH	

Source: Example Schedule by SAIC, 1998.

Table 10-11
Valve Operator Schedule

Operator Tag/Ref	Description	Type	Maximum Air Pressure	Electrical Supply	Action	Materials of Construction	Failure Mode	Enclosure Rating	Accessories	Associated Valve	Remarks
V120	Ball Valve, Full Port Positive Shut-off	Pneumatic, Diaphragm	103 kPa	- -	R.A	Manufacturer' s Standard with Epoxy Coating	F.O.	Weather Proof	Positioner, Filter/Regulator, Handwheel	PCV-452	
V121	Ball Valve, Full Port Positive Shut-off	Pneumatic, Piston	1.03 MPa	- -	D.A.	Manufacturer' s Standard with Epoxy Coating	F.C.	Weather Proof	Positioner, Filter, Handwheel	PCV-1013	
V122	Ball Valve, Full Port Positive Shut-off	Pneumatic, Rotary	1.03 MPa	- -	D.A.	Aluminum	F.L.	NEMA 4	I/P, Filter	FCV-485	
V123	Solid Wedge Gate Valve O.S. & Y., Rising Stem	Electric, Rotary	- -	120 V, 20 A, 1 ph	D.A.	Manufacturer' s Standard with Epoxy Coating	F.L.	NEMA 4		FCV-501	
V124	Double Disc Gate Valve O.S. & Y., Rising Stem	Electric, Rotary	- -	120 V, 20 A, 1 ph	D.A.	Manufacturer' s Standard	F.C.	NEMA 4X	Enclosed Gear,	FCV-625	

Source: Example Schedule by SAIC, 1998.

Chapter 11
Ancillary Equipment

11-1. Flexible Couplings

Flexible couplings are used to join pipe sections, to insulate sections from one other, to absorb concentrated pipe movement, and to join plain end pipe to flanged valves and other equipment. The basic purpose of flexible couplings is to provide flexible but leak-tight connections that will last for the life of the piping. Flexible couplings are generally available in sizes from 15 mm (½ in) to 1.8 m (6 feet) and larger.

a. Metallic Flexible Couplings

The basic configuration of a flexible coupling is a metallic middle ring that slips over the joint between two pipe sections with a gasket and a follower at each end. This configuration compresses the gasket and seals the middle ring (see Figure 11-1). The middle ring can be provided standard in a number of different materials, such as plastic or rubber lined, stainless steel, aluminum, Monel, carbon steel, and ductile iron (see Appendix B for the proper material and contact the manufacturers to determine availability). The gaskets are likewise available in different materials (typically, elastomers and rubber materials).

b. Transition Couplings

Similar to flexible couplings in construction, transition couplings connect pipe with a small difference in outside diameter: the middle ring in transition couplings is pre-deflected to adjust for the differences in diameter. As with the flexible couplings, the transitional coupling's middle ring and gaskets are available in different materials, depending upon the application.

c. Flanged Couplings

Flanged couplings are typically provided with a compression end connection on one end and a flange on the other. The flanges can be provided in different ANSI or AWWA standards, as required for the application. The manufacturer should be consulted for pressure ratings.

d. Couplings for Non-metallic Piping

Flexible couplings for non-metallic piping are very similar to metallic piping couplings. There are three main configuration alternatives for these couplings. The first is the same configuration as the metallic piping, in which there is a middle ring that is sealed by gaskets and held in place with end pieces that are bolted together. The second method is very similar, except that the end pieces are lock rings, similar to compression fittings, threaded to hold the middle ring in place. In both instances, the wetted-parts materials are selected in order to meet the application. The last type of typical flexible coupling for non-metallic piping is a bellows expansion joint (see Paragraph 11-8c). The bellows expansion joints can accommodate directional changes of compression/extension and lateral offset and angular rotation of the connected piping; however, these joints are not capable of absorbing torsional movement. If a bellows expansion joint is used as a flexible connector, a minimum of two corrugations should be provided. The potential movement of the bellows is calculated to obtain the proper number of corrugations.

11-2. Air and Vacuum Relief

During startup, shutdown and in normal operations, it is common for liquid process piping system to produce situations where air needs to be exhausted or allowed to re-enter. The devices used include air-release valves, air-vacuum valves, vacuum breakers, and combination air-release and air-vacuum valves. The type of valve required varies for the specific applications.

a. Air-release Valves

For liquid process piping in which air tends to collect within the lines (as occurs under pressure systems as air dissolves and then reappears as the pressure decreases), air-release valves are necessary. A very common operating problem occurs when air collects in the high places of the piping systems, producing air pockets. These air pockets can reduce the effective area of the pipe through which the liquid can flow, causing a problem known as air binding. Air binding results in pressure loss, thus increasing pumping costs.

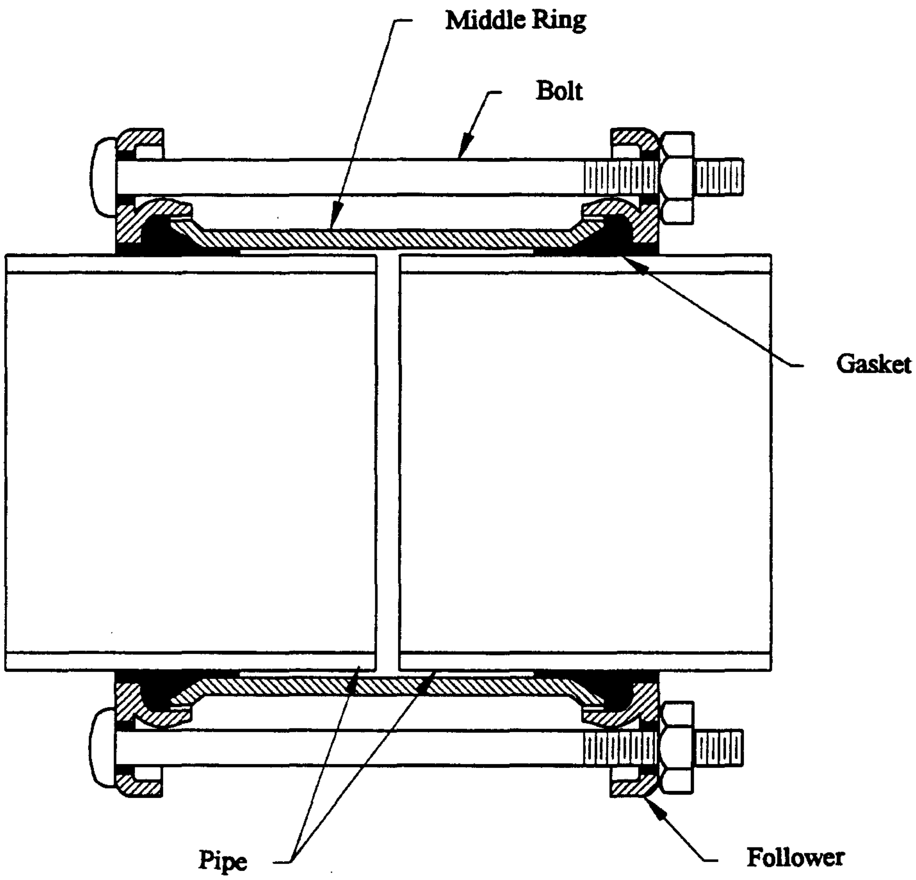


Figure 11-1. Flexible Coupling
(Source: Dresser Industries, Inc., “Style 38 Dresser Couplings for Steel
Pipe Sizes, Sizes and Specifications,” Form 877-C Rev. 1095)

It is typical for air-release valves to be installed to eliminate these problems. Air-release valves should be installed at pumping stations where air can enter the system, as well as at all high points in the pipeline system where air can collect. Air-release valves automatically vent any air that accumulates in the piping system while the system is in operation and under pressure. However, the potential for accumulating hazardous gases must be taken into account, and the vents located in a manner such that it does not cause a hazardous atmosphere for the operators. Air-release valves do not provide vacuum protection nor vent large quantities of air as required on pipeline filling; air-vacuum valves are designed for these purposes.

The sizing of air-release valves is based upon engineering judgement and experience. The parameters which affect valve size are the potential for air entrainment, pipe diameter, volumetric flow rate, system pressure, fluid viscosity, surface condition of the pipe wall, and the degree of pipe slope adjacent to the piping high point. Manufacturers' data can assist in the selection.

b. Air-Vacuum Valves

For piping systems that are used intermittently and are therefore periodically filled and drained, air-vacuum valves are used to prevent damage to the piping system. The damage could result from over-pressurization and velocity surges during filling, or collapse during draining.

Air-vacuum valves are installed at piping high points. These valves are float operated, have large discharge and inlet ports that are equal in size, and automatically allow large volumes of air to be rapidly exhausted from or admitted into a pipeline. As with air-release valves, the potential for releasing hazardous gases must be addressed in the design and the vents located to permit a hazard condition for personnel. Air-vacuum valves will not vent gases when the piping system is in normal operation and under pressure. Air-release valves are designed for that purpose.

The sizing of air-vacuum valves is performed independently for each location and requires the review of both functions; i.e., air exhaust and air intake. The largest valve required for either function is selected. The flow capacity required is compared to manufacturers' data relating acceptable pressure drop to valve size. The flow capacity requirements are determined as follows:

$$Q_{exhaust} = Q_{max}$$

where:

$Q_{exhaust}$ = volumetric flow rate of exhaust air, m^3/s (ft^3/s)
Q_{max} = maximum liquid filling rate, m^3/s (ft^3/s)

$$Q_{intake} = Q_{gravity}$$

where:

Q_{intake} = volumetric flow rate of intake air, m^3/s (ft^3/s)
$Q_{gravity}$ = gravity flow rate of liquid during draining, m^3/s (ft^3/s)

c. Vacuum Breakers

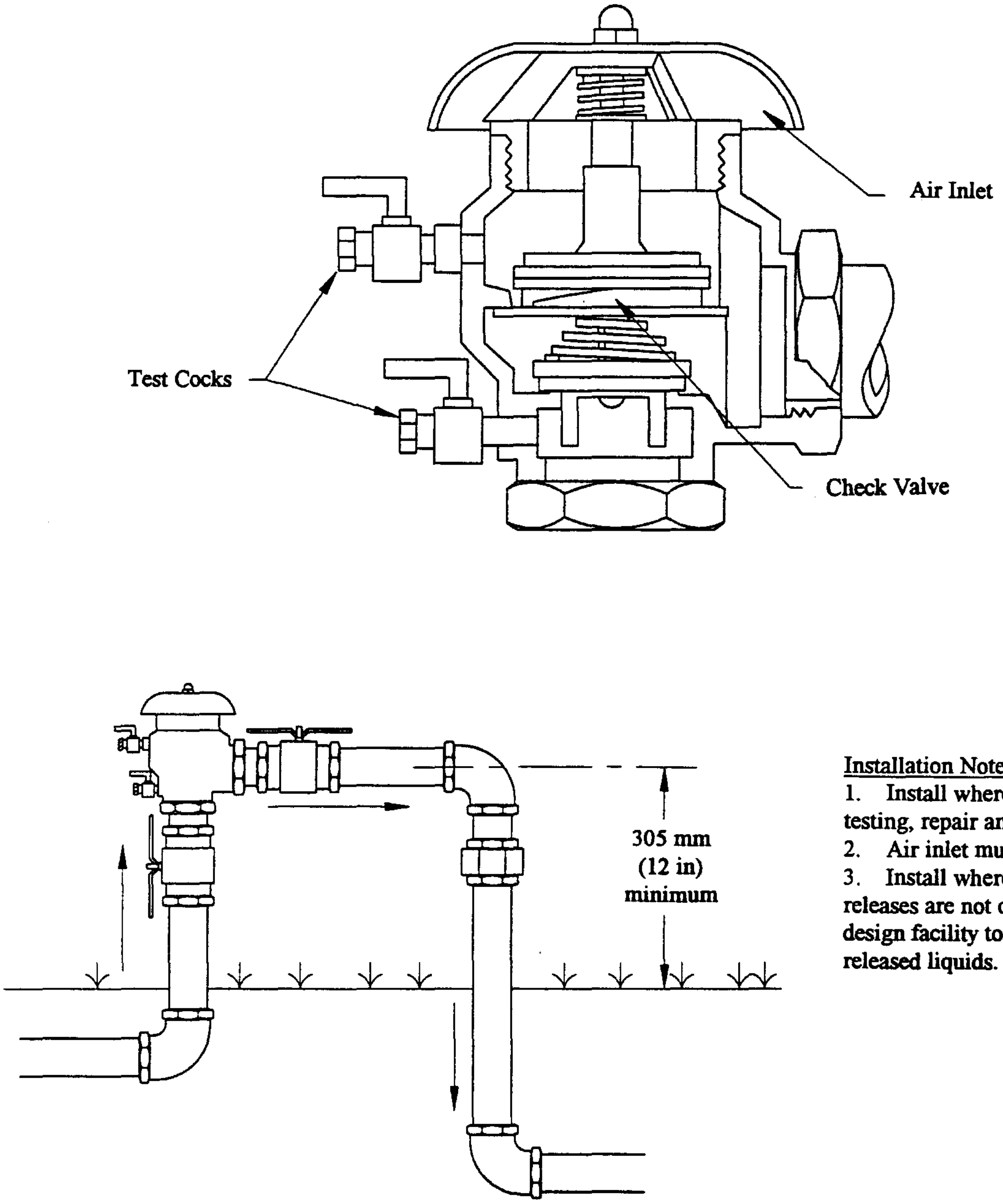
Two primary types of vacuum breakers are available -- atmospheric and pressure. Atmospheric vacuum breakers operate in the event of total pressure loss. Pressure vacuum breakers provide protection against back siphonage and pressure surges. The configuration of pressure vacuum breakers vary by manufacturer. The configuration used to prevent back siphonage of hazardous liquids often involves a check valve as well as an air intake.

Figure 11-2 depicts a combination pressure vacuum breaker and its typical installation requirements. The pressure vacuum breaker is a spring-loaded check valve that opens during forward flow and is closed by the spring when the flow stops. When the pressure drops to a low value, a second valve will open and allow air to enter the breaker.

The configuration used for applications that may involve pressure surges have associated air-release valves. The latter arrangement allows the large volumes of air, admitted by the vacuum breaker, to be slowly exhausted by the air-release valve under operating conditions and act as a pressure surge reservoir.

d. Combination Air-release and Air-Vacuum Valves

The operating functions of both an air-release valve and an air-vacuum valve are accommodated in a single combination air-release and air-vacuum valve. Using this type of valve in lieu of air-release and air-vacuum valves



Installation Notes

1. Install where accessible for testing, repair and maintenance.
2. Air inlet must be vertical.
3. Install where spillage or liquid releases are not objectionable, or design facility to accomodate the released liquids.

Figure 11-2. Pressure and Vacuum Breaker
(Source: FEBCO, Service Information Model 765 Pressure
Vacuum Breaker Assembly, vendor bulletin Oct 89)

typically provides the piping system with maximum protection. However, each individual location should be carefully reviewed.

e. Air and Vacuum Relief Application

Suggested application of air and vacuum relief devices into the piping design is as follows:

- Locate air-vacuum valves at all system high points where the piping system will be likely used intermittently. For non-hazardous service with continuous operations, manual valves or other methods may be more cost effective.
- Locate combination air-release and air-vacuum valves at all system high points where the potential for air accumulation exists.
- Locate air-release valves at intervals of 500 to 850 m (1,640 to 2,790 ft) on long horizontal pipe runs lacking a clearly defined high point. Air-release valves are installed with an isolation valve, typically a full port ball valve, between the air-release valve and the piping system for maintenance purposes.
- Locate vacuum breakers on closed vessels.

11-3. Drains

All low points in liquid process piping systems should be provided with drain or blow-off valves. These valves allow flushing of sediments from, or draining of, the entire lines. The most common valves used for draining purposes are gate valves. If rapid draining is not important, globe valves may also be used, provided that sediment accumulation is not a concern. Pipelines 50 mm (2 in) and smaller should use 15 mm (½ in) valves, as a minimum size. Pipelines that are 65 mm (2½ in) or greater should have a minimum valve size of 20 mm (¾ in).

11-4. Sample Ports

Materials of construction for sample ports and sample valves match the piping system and the required application. Coordination with CEGS 01450, Chemical Data Quality Control, is necessary to ensure proper sampling.

a. Port Locations

Sample piping should be as short as possible, protected from physical damage, and easily accessed by operators. Sample connections are made on feed, intermediate and product streams for process control. Process engineers are consulted in order to determine the number and location of sample ports.

b. Design Requirements

It is recommended that the minimum size connection to either the process equipment or the piping be 15 mm (¾ in). If the sample line is longer than a meter (approximately 3 feet), two valves are installed in the sample line. The first valve is located as close to the actual sample point as possible. The second valve is a final block valve and should be located near the end of the sample piping. The valves should be quick opening, either gate or ball type, and all materials of construction should meet the application.

11-5. Pressure Relief Devices

The ASME B31 Pressure Piping Code provides the standards and requirements for pressure relief devices and systems including piping downstream of pressure relief devices. Table 11-1 provides a summary of the relief pressure limits, but these limits shall not be used without consulting the proper ASME B31 section. Note that high pressure piping is not included.

a. Pressure Relief Valves

Pressure relief valves are automatic pressure relieving devices that protect piping systems and process equipment. The valves protect systems by releasing excess pressure. During normal operation, the valve disc is held against the valve seat by a spring. The spring is adjustable to the pressure at which the disc lifts. The valve disc lift is proportional to the system pressure so that, as the system pressure increases, the force exerted by the liquid on the disc forces the disc up and relieves the pressure. The valve will reseat when the pressure is reduced below the set spring pressure. Pressure relief valve materials and process pressure range must be accounted for to specify the correct pressure relief device.

Table 11-1
Summary of Pressure Device Limits

Service	Relief Set Limit	Code Reference
Metallic Piping - Category D Service*	≤ 120% design pressure	ASME B31.3 - 322.6
Nonmetallic Piping - Category D Service	= design pressure	ASME B31.3 - A322.6
Metallic Piping - Category M Service**	≤ 110% design pressure	ASME B31.3 - M322.6
Nonmetallic Piping - Category M Service	= design pressure	ASME B31.3 - MA322.6

Notes: *Category D Service is a fluid service in which the fluid handled is non-flammable, nontoxic and not damaging to human tissues; the design pressure does not exceed 1.035 MPa (psig); and the design temperature is from -29°C (-20°F) to 186°C (366°F). (ASME B31.3, p. 5.)
**Category M Service is a fluid service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken. (ASME B31.3, p. 5.)
Source: ASME B31.3, Reprinted by permission of ASME.

b. Rupture Discs

A rupture disc is another form of a pressure relief device. Rupture discs are designed to rupture automatically at a predetermined pressure and will not reclose. These discs can relieve very large volumes of liquid in a rapid manner. Materials of construction include metals, graphite or plastic materials held between special flanges and of such a thickness, diameter and shape, and material, that it will rupture at a pre-determined pressure. There are also metal rupture discs coated with plastics. In addition, for highly corrosive service, precious metals such as silver, gold, and platinum are also used.

Pressure relief valves and rupture discs may be used in series. In such cases, rupture discs are designed to rupture at a pressure approximately 5 to 10% above the pressure at which a relief valve is designed to activate. In this manner, the rupture disc acts as a backup device. It can be used upstream of a safety relief device to protect the valve components from corrosion or malfunction due to process materials. Rupture discs are occasionally placed downstream of relief valves in manifolded relief discharge systems where it is necessary to protect the discharge side of the pressure relief valve from corrosion. Gate valves (but not safety valves) may also be placed in front of rupture discs, allowing for shutoff or maintenance of the discs. Discs usually require periodic replacement as operating experience and conditions dictate.

Rupture disc sizing is based on the premise that, if adequate flow is allowed from the disc, pressure will be relieved. Rupture discs are not intended to be explosion relief devices. The following sizing equation is derived from Bernoulli's equation and the conservation of momentum, and can be used for liquid service. The equation assumes that the disc vents immediately to atmosphere (no relief piping) and that nozzle friction losses are negligible. Use of this equation complies with ASME B31 requirements, but its use should be reviewed with respect to local pressure vessel codes[1].

$$A = n \frac{Q}{K} \sqrt{\frac{s.g.}{P_r}}$$

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[1] Fike Metal Products, Rupture Discs & Explosion Protection, p. 9.

where:

A = required rupture disc area, mm^2 (in^2)
n = conversion coefficient, 2.280 x 10^4 for SI units and 0.0263 for IP units.
Q = flow, m^3/s (gpm)
K = flow coefficient (K = 0.62 per ASME B31)
s.g. = specific gravity
P_r = relieving pressure, MPa (psi)

Example Problem 9:
Assume that a toxic liquid with a specific gravity of 1.04 is flowing at a rate of 0.050 m^3/s (800 gpm) through stainless steel piping that has a maximum working pressure rating of 2.207 MPa (300 psi). A rupture disc will be used as the primary relief device.

Solution:
Step 1. In accordance with ASME B31.3, a primary pressure relief device should not exceed 10% over maximum allowable working pressure.

$$P_r = (2.17\ MPa)(110\%) = 2.39\ MPa\ (330\ psig)$$

Step 2.

$$A = (2.280\ x\ 10^4)\left(\frac{0.05\ m^3/s}{0.62}\right)\sqrt{\frac{1.04}{2.39\ MPa}}$$

$$= 1{,}213\ mm^2\ (1.88\ in^2)$$

$$A = \frac{\pi D_i^2}{4} \Rightarrow D_i = \left(\frac{4\ A}{\pi}\right)^{0.5}$$

$$D_i = 39.3\ mm\ (1.55\ in),\ minimum$$

Therefore, from Table 1-1 (page 1-2), the bore diameter of the pressure relief disc is 40 mm (1 ½ in).

c. Safety Considerations

The use of pressure relief devices requires careful material selection and determination of activation pressure. In addition, the design includes means to collect the released liquid once it leaves the pipeline to protect the operators and the environment.

11-6. Backflow Prevention

Backflow prevention is often handled by three main methods, one of which is check valves which were discussed in Chapter 10. Another method is the use of pressure and vacuum breakers, which were discussed in Paragraph 11-2. The third method is use of a reduced pressure backflow prevention assembly.

a. Reduced Pressure Backflow Prevention

Reduced pressure backflow prevention assemblies are mandatory for the mechanical protection of potable water against the hazards of cross-connection contamination. Whenever the potential exists for hazardous materials to come in contact with potable waters, reduced pressure backflow prevention assemblies are required per AWWA standards.

The reduced pressure backflow prevention assembly typically has two Y-type check valves in series, in between which is located an internal relief valve. In a flow condition, the check valves are open with a liquid pressure that is typically about 35 kPa (5.0 psi) lower than the inlet pressure. If flow or reversal of flow occurs, the relief valve, which activates on a differential pressure measurement, will open and discharge in order to maintain the zone between the check valves at least 14 kPa (2 psi) lower than the supply pressure. When normal flow resumes, the relief valve closes as the differential pressure resumes. The relief valve discharge is potentially hazardous material. The design of a facility takes that potential discharge into account.

Reduced pressure backflow prevention assemblies are used in different configurations. In one standard configuration, the inlet and outlet are in line. Another common configuration is an angle pattern in which the inlet to the assembly is vertical up and the outlet is vertical down.

b. Installation

Reduced pressure backflow prevention assemblies are installed, or designed to be installed, with a minimum of clearance of 305 mm (12 in) between the discharge port of the relief valve and the floor grade. The assemblies need to be installed in a location where testing and maintenance can be performed. Situations that could result in excessive pressure are eliminated. These situations include thermal water expansion and/or water hammer. Local plumbing codes are reviewed for specific installation requirements. Some codes prohibit vertical installation. Materials of construction are typically limited. Reduced pressure backflow prevention assemblies are normally used for potable water applications. Typical characteristics and materials of construction for the assemblies are presented in Table 11-2.

11-7. Static Mixers

Static mixers provide a means of in-line rapid mixing for chemical addition or the combination of two liquid streams. As opposed to conventional rapid mixers, such as turbines and hydraulic jumps, static mixers have no moving parts. This characteristic makes the static mixer a low maintenance alternative for rapid mixing.

a. Design Requirements

Static mixers are generally customized to meet the requirements of each application. Five parameters are evaluated in the design of a static mixer system: the materials of construction, the size of the pipe, the head loss requirements for the mixer, the number of mixing elements, and the quality of mixing to be achieved.

b. Materials of Construction

Common materials used for static mixers include stainless steel, carbon steel, polyvinyl chloride (PVC), reinforced fiberglass, polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). The materials available are dependent upon the manufacturer, and some manufacturers offer additional material options for specific applications.

In choosing the appropriate materials, the requirements of both the static mixer's housing and the mixing elements are accommodated. By combining materials, one can produce a static mixer which provides both chemical resistance and structural strength to the static mixer housing and mixing elements. See Appendix B for material compatibility with fluids.

Static mixers are commonly built from standard diameter piping. Available pipe diameters vary by manufacturer; however, common pipe diameters start at 20 mm (¾ in).

Table 11-2
Typical Reduced Pressure Backflow Prevention Assembly

Characteristic/Parts	Rating/Material
Assembly Body	Bronze, ASTM B 584-78
Relief Valve Body	Bronze, ASTM B 584-78
Seat Disc	Nitrile, ASTM D 2000 or Silicone
Diaphragm	Nitrile, fabric reinforced
Springs	SS, 300 series options
End Connections	Threaded, ASME B1.20.1
Maximum Working Pressure	1.2 MPa (175 psi)
Fluid Temperature Range	0°C to 60°C (32°F to 140°F)

Source: CMB Industries, FEBCO Backflow Prevention, Reduce Pressure Assembly for High Hazard Service, Model 825Y, vendor bulletin.

c. Pressure Loss

The end connections available for static mixers include ends prepared for welding, threaded NPT ends, and flanged ends of various classes. Both the pipe diameter and end connections are typically designed to match the process piping system used. However, the diameter of mixer housing can be sized based on the pressure drop available, or desired, if the application requires.

Whereas mechanical mixers require energy to drive the mixing motor, static mixers obtain their required energy the velocity of the fluids being mixed. Thus, every static mixer will have a resulting pressure drop. The pressure drop through the static mixer is dependent upon the flow rate through the static mixer, the specific gravity and viscosity of the fluids being mixed, the diameter of the mixer housing, and the friction loss attributable to the mixing elements. Each manufacturer has sizing equations and/or flow coefficients that are specific for their product. Although the sizing calculations are reviewed to ensure that correct parameter values are used, the specifications place performance requirements on the mixer manufacturer.

d. Configuration

The number of mixing elements effects the quality of mixing achieved, the length of the mixer, and the head loss requirements of the mixer. Factors which affect the number of mixing elements required include the flow regime, the difference in viscosities of the fluids being mixed, the volumetric ratio of the fluids being mixed, the method of injection, and the miscibility of the fluids. Different manufacturers produce mixing elements in different configurations. The different element configurations produce varying mixing results, and estimates on the number of elements required are best obtained by contacting the static mixer manufacturer.

The quality of mixing achieved by a static mixer is often discussed in terms of homogeneity. Homogeneity refers to how closely the combined fluid resembles a homogeneous mixture after passing through a static mixer. Homogeneity is often expressed as a percentage standard deviation from the mean, and is determined by sampling for the desired mixing parameter (concentration, temperature, conductivity) and determining the mean and standard deviation of the samples. Required homogeneity is application specific, and manufacturers can best determine the number of mixing elements required to achieve the desired homogeneity.

Additional considerations for the design of a static mixer include the number and location of injection ports and the method of chemical injection. The location, connection type and size of injection ports can be customized to match each application. Several types of injection quills are available, as options and specifications vary from manufacturer to manufacturer. It is advisable to contact static mixer manufacturers to determine what selections may suit the desired application and the reasons for recommendation of those options. The contract drawings and specifications are then coordinated to reflect acceptable alternatives.

11-8. Expansion Joints

Expansion joints are used to absorb pipeline expansion typically resulting from thermal extensions. The use of expansion joints is often required where expansion loops are undesirable or impractical. However, expansion joints are not used for direct buried service. Expansion joints are available slip-type, ball, and bellows configurations.

a. Slip-Type Expansion Joints

Slip-type expansion joints have a sleeve that telescopes into the body. Leakage is controlled by packing located between the sleeve and the body. Because packing is used, a leak-free seal is not assured. Properly specified, these expansion joints do not leak; however, because packing is used, these expansion joints should not be used where zero leakage is required. Occasional maintenance is required to repair, replace, and replenish the packing. Slip-type joints are particularly suited for axial movements of large magnitude. They cannot, however, tolerate lateral offset or angular rotation due to potential binding. Therefore, pipe alignment guides are necessary with slip-type expansion joints.

b. Ball Expansion Joints

Ball expansion joints consist of a socket and a ball, with seals placed in between the two parts. Ball expansion joints can handle angular and axial rotation; however, they cannot tolerate axial movements.

c. Bellows Expansion Joints

Bellows expansion joints can be metallic or rubber in material of construction. They do not have packing. These joints typically have bellows, or corrugations, that expand or contract as required to absorb piping expansion. End connections can be welded and/or flanged. Bellows expansion joints can adjust to lateral offset and angular rotation as well as to axial movements. However, they are not capable of handling torsional movement. In order to provide this flexibility, metal bellows are typically much thinner than the associated piping and are subject to over-pressure failure. Metal fatigue due to the cyclic life of the bellows is another factor that must be included in the design.

For example, a typical method to select and size a bellows expansion joint is as follows:

Step 1. Determine the basic type required by the piping system:
- standard without reinforced corrugations (non-equalizing);
- standard with reinforced corrugations (equalizing rings);
- hinged (single plane angular movement only);
- gimbal (multiple plane angular movement only);
- tied (lateral movement only);
- balanced (axial and lateral movement only);
- or other.

Step 2. Determine the body requirements of the expansion joint:
- maximum system pressure and temperature;
- internal diameter equal to the inner diameter of the pipe (D_i);
- end connections (flanged, welded end, combinations, or other);
- material of construction for bellows and sleeves, if required (select material based on application, see Appendix B and Table 11-3, Material Temperature Ranges);
- external body cover, if required (damage protection, insulation application).

Step 3. Calculate the maximum movements (contraction and expansion) to be absorbed by the expansion joint (see previous chapters for thermal expansion).

Step 4. Determine the expansion joint performance requirements and the required bellows configuration:
- calculate the required cycle life, for example, assume a process is anticipated to undergo 2 on-off cycles per week and a 10 year process life is desired

$$\left(\frac{2\ process\ cycles}{week}\right)\left(\frac{52\ weeks}{year}\right)(10\ years)$$
$$= 1{,}040\ cycles\ required$$

(note that a manufacturer's standard warranty is 2,000 cycles for axial movement with cycle life is increased to 7,000 if the expansion joint sized for movement = 75% expansion joint rating[2]);
- select the number of corrugations from manufacturers' data (function of corrugation size, wall thickness, amount of movement, and design cycle life, see Table 11-4);
- determine whether an internal sleeve is required. Sleeves are recommended when

  D ≤ 150 mm (6 in) and V > 0.02 m/s per mm diameter (1.66 ft/s per inch diameter),
  and when
  D > 150mm (6 in) and V > 3 m/s (10 ft/s);
  where:
    D = nominal pipe size, mm (in)
    V = fluid velocity, m/s (ft/s).[3]

11-9. Piping Insulation

Liquid process piping often has to be insulated when potential heat loss from piping cannot be tolerated in the process, freezing potential exists, or protection of personnel from hot piping is required. CEGS 15080, Thermal Insulation for Mechanical Systems, is used for engineering information and construction requirements.

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[2] ADSCO Manufacturing LLC, Expansion Joints Cat. 1196.
[3] Ibid.

Table 11-3
Material Temperature Ranges

Material	Acceptable Temperature Range
304 Stainless Steel	-185°C to 815°C (-300°F to 1,500°F)
316 Stainless Steel	-185°C to 815°C (-300°F to 1,500°F)
321 Stainless Steel	-185°C to 815°C (-300°F to 1,500°F)
347 Stainless Steel	-185°C to 815°C (-300°F to 1,500°F)
Aluminum	-198°C to 204°C (-325°F to 400°F)
Nickel 200	-156°C to 315°C (-250°F to 600°F)
Inconel 600	-156°C to 649°C (-250°F to 1,200°F)
Inconel 625	-156°C to 649°C (-250°F to 1,200°F)
Monel 400	-156°C to 815°C (-250°F to 1,500°F)
Incoloy 800	-156°C to 815°C (-250°F to 1,500°F)
Incoloy 825	-156°C to 538°C (-250°F to 1,000°F)

Source: ADSCO Manufacturing LLC, Expansion Joints Cat 1196

Table 11-4
Typical Manufacturers' Data List

Size, in	Number of Convolutions	Total Axial Movement, in
4	1	7/16
	2	7/8
	3	1-5/16
	4	1-3/4
	5	2-3/16
	6	2-5/8
	7	3-1/16
	8	3-1/2
	9	3-15/16
	10	4-3/8

Source: ADSCO Manufacturing LLC, Expansion Joints Cat. 1196

In addition, the specification provides guidance on insulation thickness based on pipe size, insulation thermal conductivity or material, and range of temperature service. CEGS 15080 is coordinated with the liquid process piping specification section and contract drawings.

11-10. Heat Tracing

For the purposes of liquid process piping, heat tracing is the continuous or intermittent application of heat to the piping system, including pipe and associated equipment, to replace heat loss. As with insulation, heat tracing is used when potential heat loss from the piping cannot be tolerated by the process or when freezing potential exists. Heat tracing may be accomplished through the use of fluids such as steam, organic/synthetic liquids, and glycol mixtures, or through electrical systems such as self-regulating parallel resistance cable (most common), zone parallel resistance cable, continuous-wattage cables and other methods.

a. Heat Tracing System Selection

The selection criteria for determining the most suitable heat tracing methods include: cost, availability of utilities such as steam or electricity, amount of heat to be provided, area hazardous classification as defined by the National Electric Code (NFPA 70), temperature control requirements and consequence of failure. Economics generally favor electrical heat tracing systems when the piping is less than 300 mm (12 in) in diameter and the temperature to be maintained is 120°C (248°F) or lower. Computer programs are available to assist in selecting the type of system that is most appropriate. In addition, many heat tracing vendors have software available to design a heat tracing system using their products. Typical inputs are piping size and geometry; ambient, process and desired maintenance temperature; control requirements; labor costs and utility rates. Outputs are typically worst case heat loss; a bill of materials for the heat tracing system; and capital, installation and operating costs.

Chapter 12
Corrosion Protection

12-1. Corrosion Protection

Among other factors, the integrity and life of a piping system is dependent upon corrosion control. As discussed in previous chapters of this manual, internal corrosion of piping systems is controlled by the selection of appropriate materials of construction, wall thickness, linings and by the addition of treatment chemicals. External corrosion can also be addressed through materials of construction. However, other methods may be required when metallic piping systems are applied.

a. Buried Installations

In buried installations, leaks due to corrosion in metallic piping systems can cause environmental damage. Furthermore, certain types of processes pose safety problems if cathodic protection is not properly installed and maintained. The design and installation of the piping system without consideration of cathodic protection is not acceptable.

b. Above Grade Installations

The external surfaces of metallic piping installed above grade will also exhibit electrochemical corrosion. The corrosion rate in air is controlled by the development of surface-insoluble films. This development is, in turn, affected by the presence of moisture, particulates, sulfur compounds, nitrogen-based compounds, and salt. This corrosion is typically uniform, although pitting and crevice corrosion are also common. Besides selecting a material of construction that is appropriate for the ambient environment, the primary method of corrosion control in above grade piping system is the application of protective coatings. However, a stray current survey must be performed to ensure that electrical currents have not been created through the piping support system.

12-2 Cathodic Protection

Cathodic protection and protective coatings shall both be provided for the following buried/submerged ferrous metallic structures, regardless of soil or water resistivity:

- natural gas propane piping;
- liquid fuel piping;
- oxygen piping;
- underground storage tanks;
- fire protection piping;
- ductile iron pressurized piping under floor (slab on grade) in soil;
- underground heat distribution and chilled water piping in ferrous metallic conduit in soils with resistivity of 30,000 ohm-cm or less; and
- other structures with hazardous products as identified by the user of the facility.

a. Cathodic Protection Requirements

The results of an economic analysis and the recommendation by a "corrosion expert" shall govern the application of cathodic protection and protective coatings for buried piping systems, regardless of soil resistivity. In addition, cathodic protection for metallic piping supported above ground may be warranted. TM 5-811-7, Electrical Design, Cathodic Protection, provides criteria for the design of cathodic protection for aboveground, buried, and submerged metallic structures including piping. Cathodic protection is mandatory for underground gas distribution lines, 946 m^3 (250,000 gal) or greater water storage tanks and underground piping systems located within 3 m (10 ft) of steel reinforced concrete.[1]

For ductile iron piping systems, the results of an analysis by a "corrosion expert," as defined in Paragraph 12-2b, shall govern the application of cathodic protection and/or bonded and unbonded coatings. Unbonded coatings are defined in AWWA C105.

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[1] TM 5-811-7, p. 2-2.

b. Cathodic Protection Designer

All pre-design surveys, cathodic protection designs, and acceptance surveys must be performed by a "corrosion expert." A corrosion expert is defined as a person who, by reason of thorough knowledge of the physical sciences and the principles of engineering and mathematics acquired by a professional education and related practical experience, is qualified to engage in the practice of corrosion control of buried or submerged metallic piping and tank systems. Such a person must be accredited or certified by the National Association of Corrosion Engineers (NACE) as a NACE Accredited Corrosion Specialist, or a NACE Certified Cathodic Protection Specialist licensing that includes education and experience in corrosion control of buried or submerged metallic piping and tank systems. The "corrosion expert" designing the system must have a minimum of five years experience in the design of cathodic protection systems, and the design experience must be type specific. For instance, a cathodic protection engineer who only has experience designing water tank systems should not design the cathodic protection system for an underground gas line.

The design of the cathodic protection system shall be completed prior to construction contract advertisement except for design-construct projects and pre-approved underground distribution systems. The liquid process piping specification section shall be coordinated with CEGS 13110, Cathodic Protection System (Sacrificial Anode); CEGS 13111, Cathodic Protection System (Steel Water Tanks); and CEGS 13112, Cathodic Protection System (Impressed Current) as required.

c. Cathodic Protection Methods

As previously discussed, galvanic corrosion is an electrochemical process in which a current leaves the pipe at the anode site, passes through an electrolyte, and re-enters the pipe at the cathode site. Cathodic protection reduces corrosion by minimizing the difference in potential between the anode and cathode. The two main types of cathodic protection systems, galvanic (or sacrificial) and impressed current, are depicted in Figure 12-1. A galvanic system makes use of the different corrosive potentials that are exhibited by different materials, whereas an external current is applied in an impressed current system. The difference between the two methods is that the galvanic system relies on the difference in potential between the anode and the pipe, and the impressed current system uses an external power source to drive the electrical cell.

d. Cathodic Protection Design

The design of a cathodic protection system must conform to the guidance contained in TM 5-811-7 (Army), and MIL-HDBK-1004/10 (Air Force). Field surveys and other information gathering procedures are available in TM 5-811-7. The following steps and information is required to ensure a cathodic protection system will perform as designed:

Step 1. Collect data:
- corrosion history of similar piping in the area;
- drawings;
- tests to include current requirement, potential survey, and soil resistivity survey;
- life of structures to be protected;
- coatings; and
- short circuits.

Step 2. Calculate the surface area to be protected and determine the current requirement.

Step 3. Select the anode type and calculate the number of anodes required.

Step 4. Calculate circuit resistance, required voltage, and current.

Step 5. Prepare life cycle cost analyses.

Step 6. Prepare plans and specifications.

12-3. Isolation Joints

When piping components, such as pipe segments, fittings, valves or other equipment, of dissimilar materials are connected, an electrical insulator must be used between the components to eliminate electrical current flow. Complete prevention of metal-to-metal contact must be achieved. Specification is made for dielectric unions between threaded dissimilar metallic components; isolation flanged joints between non-threaded dissimilar metallic components; flexible (sleeve-type) couplings for

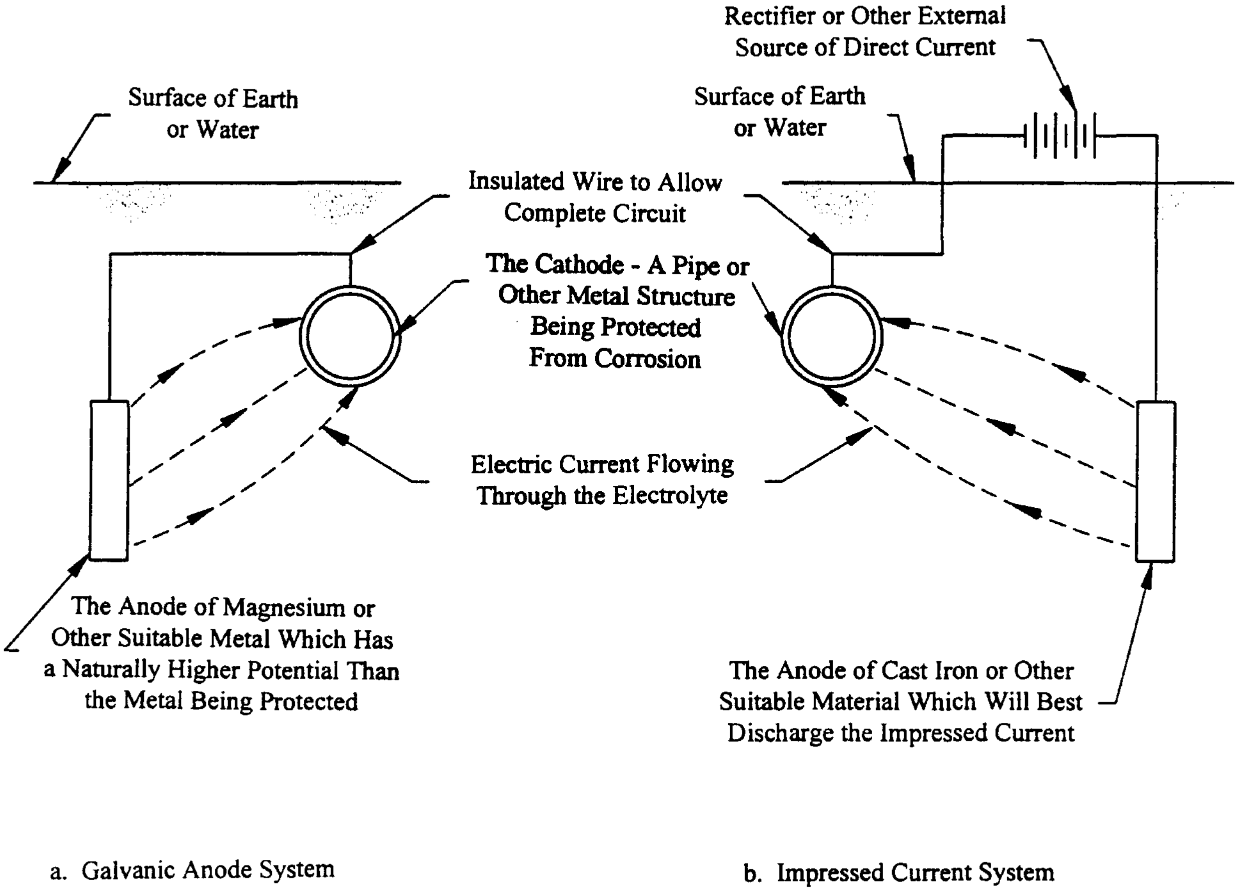

Figure 12-1. Cathodic Protection Methods
(Source: U.S. Air Force)

plain end pipe sections, see Chapter 11 for further information concerning these couplings; and under special aboveground situations that have USACE approval split-sleeve couplings. For the flanged isolation joints complete isolation is required; additional non-metallic bolt isolation washers, and full length bolt isolation sleeves are required. Dielectric isolation shall conform to NACE RP-0286. Copper water service lines will be dielectrically isolated from ferrous pipe.

a. Installation

Proper installation of isolation joints is critical. Installation procedures should follow the manufacturer's recommendations exactly.

b. Isolation from Concrete

A ferrous metallic pipe passing through concrete shall not be in contact with the concrete. The ferrous metal pipe shall be separated by a non-metallic sleeve with waterproof dielectric insulation between the pipe and the sleeve. Ferrous metal piping passing through a concrete thrust block or concrete anchor block shall be insulated from the concrete or cathodically protected.

c. Surge Protection

The need for surge and fault current protection at isolating devices (dielectrically insulated flanges) should be considered. If an insulated flange is installed in an area classified by National Fire Protection Association (NFPA) criteria, such as a flammable liquid pipe joint inside the classified area, a sealed, weatherproof surge arrester must be installed across each isolating device. The arrester should be the gapless, self-healing, solid state type, such as metal oxide varistor. Cable connections from arresters to isolating devices should be short, direct, and a size suitable for short-term, high current loading.

12-4. Protective Coatings

Since corrosion of metallic piping is electrochemical, if a protective coating that is continuous, impervious and insulating is applied to the piping exterior, the electrical circuit cannot be completed, and corrosion will not occur. The bases of selection for an exterior pipe coating are chemical inertness, adhesiveness, electrical resistance, imperviousness, and flexibility to adjust to both pipe deformation (for example, thermal expansion/contraction) and environmentally induced stress (for example, wind induced shear). Obviously, the coating must be applied without holidays and remain undamaged, without cracks or pinholes.

Appendix A
References

A-1. U.S. Army Corps of Engineers (CEGS, EM, TM, etc.)

TM 5-805-4
Noise and Vibration Control

TM 5-809-10
Seismic Design for Buildings

TM 5-810-5
Plumbing

TM 5-811-7
Electrical Design, Cathodic Protection

TM 5-813-9
Water Supply: Pumping Stations

MIL-HDBK-1004/10 (Air Force)
Electrical Engineering, Cathodic Protection

ER 1110-1-4
Metric Measurements in USACE Publication Media

ER 1110-1-12
Quality Management

ER 1110-345-700
Design Analysis, Drawings and Specifications

EM 385-1-1
Safety and Health Requirements Manual

EM 1110-2-503
Design of Small Water Systems

TI 809-01
Load Assumptions for Buildings

TI 814-01
Water Supply

TI 814-03
Water Distribution

TI 814-10
Wastewater Collection

CEGS 02150
Piping: Off-Gas

CEGS 05093
Welding Pressure Piping

CEGS 09900
Painting, General

CEGS 11145
Aviation Fueling Systems

CEGS 13080
Seismic Protection for Mechanical, Electrical Equipment

CEGS 13110
Cathodic Protection system (Sacrificial Anode)

CEGS 13111
Cathodic Protection system (Steel Water Tanks)

CEGS 13112
Cathodic Protection system (Impressed Current)

CEGS 15080
Thermal Insulation for Mechanical Systems

CEGS 15200
Liquid Process Piping

A-2. Industrial and Commercial References (NFPA, ASTM, ANSI, ASME, etc.)

a. American Association of State Highway and Transportation Officials

AASHTO H20
Highway Design Standards

b. American National Standards Institute

ANSI A13.1
Scheme for the Identification of Piping Systems

ANSI A58.1
Minimum Design Loads for Buildings and Other Structures

ANSI B36.10M/B36.10
Welded and Seamless Wrought Steel Pipe

c. American Petroleum Institute

API Spec 5L
Line Pipe

API Spec 15LR
Low Pressure Fiberglass Line Pipe

API 605
Large Diameter Carbon Steel Flanges

d. American Society of Civil Engineers

ASCE 7
Minimum Design Loads for Buildings and Other Structures

e. American Society of Mechanical Engineers

ASME Boiler and Pressure Vessel Code
Sections IV, V, VIII

ASME B1.1
Unified Screw Threads

ASME B1.20.1
Pipe Threads, General Purpose

ASME B16.1
Cast Iron Pipe Flanges and Flanged Fittings

ASME B16.5
Pipe Flanges and Flanged Fittings

ASME B16.9
Factory-Made Wrought Steel Buttwelding Fittings

ASME B16.11
Forged Fittings, Socket-Welding and Threaded

ASME B16.20
Metallic Gaskets for Pipe Flanges

ASME B16.21
Nonmetallic Gaskets for Pipe Flanges

ASME B16.24
Cast Copper Alloy Pipe Flanges and Flanged Fittings

ASME B16.25
Buttwelding Ends

ASME B16.28
Wrought steel Buttwelding Short Radius Elbows and Returns

ASME B16.31
Non-Ferrous Pipe Flanges

ASME B16.42
Ductile Iron Pipe Flanges and Flanged Fittings

ASME B16.47
Large Diameter Steel Flanges

ASME B31.1
Power Piping

ASME B31.3
Chemical Plant and Petroleum Refinery Piping

f. American Society for Testing and Materials

ASTM A 47M/A 47
Malleable Iron Castings

ASTM A 53
Pipe, Steel, Black and Hot-Dipped, Zinc Coated Welded and Seamless

ASTM A 105M/A 105
Carbon Steel Forgings

ASTM A 106
Seamless Carbon Steel Pipe

ASTM A 126
Gray Iron Castings for Valves, Flanges, and Pipe Fittings

ASTM A 135
Electric-Resistance-Welded Steel Pipe

ASTM A 182M/A 182
Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts

ASTM A 193M/A 193
Alloy-Steel and Stainless Steel Bolting Materials

ASTM A 194M/A 194
Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.

ASTM A 216M/A 216
Steel Castings, Carbon, for High Temperature Service

ASTM A 217M/A 217
Steel Castings, Martensitic Stainless Steel and Alloys, for High Temperature Service

ASTM A 307
Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength

ASTM A 312M/A 312
Seamless and Welded Austenitic Stainless Steel Pipes

ASTM A 333M/A 333
Seamless and Welded Steel pipe for Low-Temperature Service

ASTM A 351M/A 351
Castings, Austenitic, Austenitic-Ferric

ASTM A 403M/A 403
Wrought Austenitic Stainless Steel Piping Fittings

ASTM A 494
Castings, Nickel and Nickel Alloy.

ASTM A 587
Electric-Resistance-Welded Low-Carbon Steel Pipe

ASTM A 691
Carbon and Alloy Steel Pipe, EFW for High-Pressure Service at High Temperatures

ASTM A 727M/a 727
Carbon Steel Forgings for Piping Components

ASTM A 731M/A 731
Seamless, Welded Ferritic, and Martensitic Stainless Steel Pipe

ASTM A 813M/A 813
Single- or Double-Welded Austenitic Stainless Steel Pipe

ASTM A 814M/A 814
Cold-Worked Welded Austenitic Stainless Steel Pipe

ASTM A 815M/A 815
Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings

ASTM A 858M/A 858
Heat-Treated Carbon Steel Fittings

ASTM B 42
Seamless Copper Pipe, Standard Sizes

ASTM B 61
Steam or Valve Bronze Castings

ASTM B 62
Composition Bronze or Ounce Metal Castings

ASTM B 160
Nickel Rod and Bar

ASTM B 161
Nickel Seamless Pipe and Tube

ASTM B 165
Nickel-Copper Alloy (N04400) Seamless Pipe and Tube

ASTM B 241M/B 241
Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube

ASTM B 247M/B 247
Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings

ASTM B 345M/B 345
Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube for Gas and Oil Transmission and Distribution Piping Systems

ASTM B 361
Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings

ASTM B 366
Factory-Made Wrought Nickel and Nickel Alloy Fittings

ASTM B 517
Welded Nickel-Chromium-Iron Alloy (N06600), N06025, N06045 Pipe

ASTM B 564
Nickel Alloy Forgings

ASTM B 584
Copper Alloy Sand Castings for General Applications

ASTM B 608
Welded Copper-Alloy Pipe

ASTM B 619
Welded Nickel and Nickel-Cobalt Alloy Pipe

ASTM B 622
Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube

ASTM B 725
Welded Nickel (N02200/N02201) and Nickel-Copper Alloy (N04400)Pipe

ASTM B 775
General Requirements for Nickel and Nickel Alloy Welded Pipe

ASTM B 829
General Requirements for Nickel and Nickel Alloys Seamless Pipe and Tube

ASTM D 380
Test Methods for Rubber Hose

ASTM D 471
Test Method for Rubber Property-Effect of Liquids

ASTM D 729
Vinylidene Chloride Molding Compounds

ASTM D 1457
Polytetrafluoroethylene (PTFE) Molding and Extrusion Materials

ASTM D 1600
Terminology for Abbreviated Terms relating to Plastics

ASTM D 2000
Standard Classification for Rubber Products in Automotive Applications

ASTM D 2282
Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR)

ASTM D 2310
Standard Classification for Machine-Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe

ASTM D 2464
Threaded Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80

ASTM D 2466
Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40

ASTM D 2467
Socket-Type Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80

ASTM D 2657
Heat-Joining Polyolefin Pipe and Fittings

ASTM D 2661
Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste and Vent Pipe

ASTM D 2855
Making Solvent-Cemented Joints with Poly(Vinyl Chloride) (PVC) Pipe and Fittings

ASTM D 2996
Filament-Wound "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe

ASTM D 2997
Centrifugally Cast "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe

ASTM D 3139
Joints for Plastic Pressure Pipes using Flexible Elastomeric Seals

ASTM D 3222
Unmodified Poly (Vinylidene Fluoride) (PVDF) Molding, Extrusion and Coating Materials

ASTM D 3307
PFA-Fluorocarbon Molding and Extrusion Materials

ASTM D 3311
Drain, Waste, and Vent (DWV) Plastic Fittings Patterns

ASTM D 3517
"Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pressure Pipe

ASTM D 3754
"Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Sewer and Industrial Pressure Pipe

ASTM D 4000
Classification System for Specifying Plastic Materials

ASTM D 4024
Machine Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges

ASTM D 4101
Propylene Plastic Injection and Extrusion Materials

ASTM D 4161
"Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe Joints Using Flexible Elastomeric Seals

ASTM E 814
Fire Tests of Through-Penetration Fire Stops

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

ASTM F 437
Threaded Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80

ASTM F 438
Socket-Type Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40

ASTM F 439
Socket-Type Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80

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

ASTM F 492
Propylene and Polypropylene (PP) Plastic Lined Ferrous Metal Pipe and Fittings

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

ASTM F 628
Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste and Vent Pipe with a Cellular Core

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

ASTM F 1173
Epoxy Resin Fiberglass Pipe and Fittings for Marine Applications

ASTM F 1290
Electrofusion Joining Polyolefin Pipe and Fittings

g. American Water Works Association

AWWA C105
Polyethylene Encasement for Ductile-Iron Pipe Systems

AWWA C110
Ductile-Iron and Gray-Iron Fittings

AWWA C150
Thickness Design of Ductile-Iron Pipe

AWWA C900
Polyvinyl Chloride (PVC) Pressure Pipe

AWWA C950
Fiberglass Pressure Pipe

AWWA D103
Factory-Coated Bolted Steel Tanks for Water Storage

AWWA D110
Wire-Wound, Circular Prestressed Concrete Water Tanks

h. Fluid Controls Institute

FCI 70-2
Control Valve Seat Leakage

i. Instrument Society of America

ISA-S75.01
Flow Equations for Sizing Control Valves

j. Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)

MSS SP-43
Wrought Stainless Steel Buttwelding Fittings

MSS SP-44
Steel Pipeline Flanges

MSS SP-51
Class 150LW Corrosion Resistant Cast Flanges and Flanged Fittings

MSS SP-58
Pipe Hangers and Supports - Materials, Design and Manufacturer

MSS SP-69
Pipe Hangers and Supports - Selection and Application

MSS SP-73
Brazing Joints for Wrought and Cast Copper Alloy Solder Joint Pressure Fittings

MSS SP-89
Pipe Hangers and Supports - Fabrication and Installation Practices

MSS SP-104
Wrought Copper Solder Joint Pressure Fittings

MSS SP-106
Cast Copper Alloy Flanges and Flanged Fittings

MSS SP-114
Corrosion Resistant Pipe Fittings Threaded and Socket Welding

MSS SP-119
Balled End Socket Welding Fittings, Stainless Steel and Copper-Nickel

k. National Association of Corrosion Engineers

NACE RP-0286
Electrical Isolation of Cathodically Protected Pipelines

l. National Fire Protection Association

NFPA 70
National Electric Code

A-3. Other Sources (Journals, Textbooks, Vendor Information, etc.)

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A-4. Other Sources of Information (Not Referenced)

a. Metallic Piping Corrosion

Corrosion Data Survey, Metals Section, 6th Edition, National Association of Corrosion Engineers, Houston, Texas, 1985.

Phillip A. Schweitzer, Corrosion and Corrosion Protection Handbook, Marcel Dekker, Inc., New York, 1983.

b. Nonmetallic Piping Corrosion

Chemical Resistance Tables, Modern Plastics Encyclopedia, McGraw-Hill, New York, 1989.

Compass Corrosion Guide, La Mesa, California, 1983.

Corrosion Data Survey, Nonmetals Section, 5th Edition, National Association of Corrosion Engineers, Houston, Texas, 1985.

Handbook of PVC Pipe, 3rd Edition, Uni-Bell Plastic Pipe Association, Dallas, Texas, 1979.

c. Water Hammer

Ernest F. Braler and Horace W. King, Handbook of Hydraulics, 6th Ed.

Tyler & Hicks, Editor in Chief, Standard Handbook of Engineering Calculations, 3rd Ed.

d. Expansion Loops

Piping Design and Engineering, 5th Ed., ITT Grinnell Industrial Piping, Providence, Rhode Island, 1976.

Appendix B
Fluid/Material Matrix

If a potentially corrosive fluid, or a piping material, is not found in the fluid/material matrix, then the reference materials listed in Appendix A should be directly reviewed. If the references cannot satisfactorily resolve the issue, then a special study may be required to determine material compatibility and acceptable use. If doubt of material suitability remains after the study due to exceptional conditions, a report should be submitted to HQUSACE (CEMP-EG).

B-1. Use of the Fluid/Material Matrix

The following matrix is arranged alphabetically according to the list of fluids typically found or used at hazardous and toxic waste remediation sites. Unless otherwise noted, the liquids are considered pure. All percentages shown are expressed in percent by weight.

a. Corrosion Resistivity

The matrix provides the temperature above ambient conditions of 15°C (60°F) at which corrosion or chemical resistivity of a material is acceptable for use with an identified fluid. For metals, an acceptable corrosion rate is less than 1.27 mm (50 mils) penetration per year. For non-metals and other materials, acceptability is considered based on the material's resistance to solvation or chemical reaction. Although materials may be corrosion resistant below the listed temperatures, other physical or mechanical properties of that material may preclude its acceptability for a specific use. A thorough evaluation considering all physical and mechanical properties of a material for its intended use is required.

b. Temperature Correlation

The matrix temperatures are provided in both the metric and IP units (degrees C and degrees F, respectively). Materials with unsatisfactory chemical resistance or corrosion rates at temperatures above ambient temperatures are indicated with a "U". Matrix entries for materials with insufficient information are left blank.

B-2. Material Abbreviations

ABS	- Acrylonitrile-butadiene-styrene
CPVC	- Chlorinated polyvinyl chloride
Resins	
Furan	- Furfural alcohol
Polyester	- Bisphenol A-fumarate
HDPE	- High density polyethylene
PP	- Polypropylene
PTFE	- Teflon[1]
PVC Type 2	- Polyvinyl chloride Type 2
PVDF	- Polyvinylidene fluoride
Butyl	- Butyl rubber GR-1 (IIR)
EPDM	- Ethylene-propylene-diene
EPT	- Ethylene-propylene terpolymer
FEP	- Perfluorethylenepropylene
FKM	- Fluoroelastomer
Neoprene[2]	- Polychloroprene
Nitrile	- Butadiene-acrylonitrile
N-Rubber	- Natural rubber
PFA	- Perfluoroalkoxyalkane copolymer
PVDC	- Polyvinylidene chloride
SBR Styrene	- Butadiene-styrene-elastomer

B-3. Matrix

Data contained within this matrix was obtained primarily from Schweitzer, Corrosion Resistance Tables, 4th Edition, see Appendix A for the complete reference information.

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[1] Teflon is a registered trademark of E.I. DuPont.

[2] Neoprene is a registered trademark of E.I. DuPont.

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Acetic Acid 10%	Acetic Acid 20%	Acetic Acid 50%	Acetic Acid 80%	Acetic Acid Glacial	Acetone	Aluminum Chloride, Aq.
METALS							
Aluminum	65 (150)	87 (190)	76 (170)	76 (170)	98 (210)	260 (500)	U
Bronze	93 (200)	U	U	U	U	204 (400)	U
Carbon Steel	U	U	U	U	U	149 (300)	U
Copper	38 (100)	U	U	U	U	60 (140)	26 (80)
Ductile Iron, Pearlitic							
Hastelloy C	149 (300)	149 (300)	149 (300)	149 (300)	293 (560)	93 (200)	98 (210)
Inconel	26 (80)	32 (90)	54 (130)	32 (90)	104 (220)	87 (180)	U
Monel	26 (80)	98 (210)	93 (200)	93 (200)	143 (290)	87 (180)	U
Nickel	32 (90)	32 (90)	60 (140)	49 (120)	U	87 (180)	149 (300)
304 SS	93 (200)	104 (220)	104 (220)	110 (230)	98 (210)	87 (180)	U
316 SS	216 (420)	204 (400)	204 (400)	110 (230)	204 (400)	204 (400)	U
NON-METALS							
ABS	38 (100)	54 (130)	53 (130)	U	U	U	60 (140)
CPVC	32 (90)	82 (180)	U	U	U	U	93 (200)
Resins - Epoxy	82 (190)	43 (110)	43 (110)	43 (110)		43 (110)	
- Furan	127 (260)	121 (230)	93 (200)	93 (200)	132 (270)	93 (200)	127 (260)
- Polyester	104 (220)	93 (200)	71 (160)	71 (160)	U	U	93 (200)
- Vinyl Ester	93 (200)	93 (200)	82 (180)	65 (150)	65 (150)	U	127 (260)
HDPE	60 (140)	60 (140)	60 (140)	26 (80)	38 (100)	49 (120)	60 (140)
PP	104 (220)	104 (220)	93 (200)	93 (200)	85 (190)	104 (220)	93 (200)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	38 (100)	60 (140)	32 (90)	U	U	U	60 (140)
PVDF	149 (300)	149 (300)	149 (300)	87 (190)	87 (190)	U	149 (300)
OTHER MATERIALS							
Butyl	65 (150)	65 (150)	43 (110)	43 (110)	32 (90)	71 (160)	65 (150)
EPDM	149 (300)	60 (140)	60 (140)	60 (140)	149 (300)	149 (300)	149 9300)
EPT	U	U	U	U	U	U	82 (180)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	82 (180)	93 (200)	82 (180)	82 (180)	U	U	204 (400)
Borosilicate Glass	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	121 (250)	121 (250)
Neoprene	71 (160)	71 (160)	71 (160)	71 (160)	U	U	93 (200)
Nitrile	93 (200)	93 (200)	93 (160)	98 (210)	38 (100)	U	93 (200)
N-Rubber	65 (150)	26 (80)	U	U	U	U	60 (140)
PFA	93 (200)	93 (200)	93 (200)	93 (200)	121 (250)	93 (200)	93 (200)
PVDC	60 (140)	49 (120)	54 (130)	54 (130)	60 (140)	32 (90)	65 (150)
SBR Styrene	U	U	U	U	U	93 (200)	

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Aluminum Sulfate (Sat.)	Ammonia (Anhydrous)	Ammonia Hydroxide 10%	Ammonia Hydroxide 25%	Ammonia Hydroxide (Sat.)	Ammonium Nitrate	Benzene
METALS							
Aluminum	U	82 (180)	176 (350)	176 (350)	176 (350)	176 (350)	98 (210)
Bronze	98 (210)	26 (80)	U	U	U	U	204 (400)
Carbon Steel	U	204 (400)	98 (210)	98 (210)	98 (210)	U	60 (140)
Copper	26 (80)	26 (80)	U	U	U	U	38 (100)
Ductile Iron, Pearlitic	26 (80)				85 (185)		
Hastelloy C	98 (210)	298 (570)	98 (210)	398 (570)	398 (570)	32 (90)	98 (210)
Inconel	U	298 (570)	32 (90)	26 (80)	32 (90)	32 (90)	98 (210)
Monel	98 (210)	298 (570)	U	U	U	U	98 (210)
Nickel	98 (210)	32 (90)	U	U	149 (300)	32 (90)	98 (210)
304 SS	98 (210)	249 (480)	98 (210)	110 (230)	98 (210)	98 (210)	110 (230)
316 SS	98 (210)	298 (570)	98 (210)	110 (230)	98 (210)	149 (300)	204 (400)
NON-METALS							
ABS	60 (140)	U	26 (80)	32 (90)	26 (80)	60 (140)	U
CPVC	93 (200)	82 (180)	93 (200)	82 (180)	82 (180)	93 (200)	U
Resins - Epoxy	149 (300)	U	87 (190)	60 (140)	71 (160)	121 (250)	82 (180)
- Furan	127 (260)	127 (260)	82 (180)	127 (260)	93 (200)	127 (260)	127 (260)
- Polyester	93 (200)	104 (220)	60 (140)	38 (100)		104 (220)	U
- Vinyl Ester	121 (250)	104 (220)	66 (150)	66 (150)		121 (250)	U
HDPE	60 (140)	60 (140)	60 (140)	60 (140)	60 (10)	60 (140)	U
PP	104 (220)	104 (220)	104 (220)	93 (200)	93 (200)	93 (200)	60 (140)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	32 (90)	60 (140)	60 (140)	60 (140)	60 (140)	U
PVDF	149 (300)	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)	65 (150)
OTHER MATERIALS							
Butyl	87 (190)	U	87 (190)	87 (190)	87 (190)	82 (180)	U
EPDM	149 (300)	149 (300)	98 (210)	38 (100)	149 (300)	149 (300)	U
EPT	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	82 (180)	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	198 (380)	U	87 (190)	87 (190)	87 (190)	U	204 (400)
Borosilicate Glass	121 (250)		122 (250)	122 (250)	122 (250)	93 (200)	121 (250)
Neoprene	93 (200)	93 (200)	90 (200)	93 (200)	98 (210)	93 (200)	U
Nitrile	93 (200)	87 (190)	93 (200)	93 (200)	98 (210)	82 (180)	U
N-Rubber	65 (150)	U	26 (80)	U	32 (90)	76 (170)	U
PFA	104 (220)	93 (200)	138 (280)	138 (280)	138 (280)	93 (200)	93 (200)
PVDC	82 (180)		U	U	U	49 (120)	26 (80)
SBR Styrene		93 (200)					U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Bleach 12.5% Active Cl	Calcium Chloride Dilute	Calcium Chloride (Sat.)	Calcium Hydroxide 10%	Calcium Hydroxide 20%	Calcium Hydroxide 30%	Calcium Hydroxide (Sat.)
METALS							
Aluminum	U	15 (60)	38 (100)	26 (80)	26 (80)	26 (80)	U
Bronze			98 (210)				
Carbon Steel	U	15 (60)	60 (140)	26 (80)	U	U	26 (80)
Copper		15 (60)	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)
Ductile Iron, Pearlitic			98 (210)				
Hastelloy C		93 (200)	176 (350)	76 (170)	76 (170)	76 (170)	
Inconel		15 (60)	26 (80)	98 (210)	98 (210)	98 (210)	32 (90)
Monel		98 (210)	176 (350)	98 (210)	98 (210)	98 (210)	93 (200)
Nickel		15 (60)	26 (80)	98 (210)	98 (210)	98 (210)	93 (200)
304 SS		65 (150)	26 (80)	98 (210)	98 (210)	98 (210)	93 (200)
316 SS	U	60 (140)	98 (210)	98 (210)	98 (210)	98 (210)	
NON-METALS							
ABS	U	60 (140)	60 (140)			60 (140)	60 (140)
CPVC	93 (200)	82 (180)	82 (180)	76 (170)	76 (170)	76 (170)	98 (210)
Resins - Epoxy		93 (200)	87 (190)	98 (210)	93 (200)	93 (200)	82 (180)
- Furan		127 (260)	127 (260)	104 (220)	104 (220)	104 (220)	127 (260)
- Polyester		104 (220)	104 (220)	82 (180)	71 (160)	71 (160)	71 (160)
- Vinyl Ester		82 (180)	82 (180)	82 (180)	98 (210)	98 (210)	
HDPE	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PP	60 (140)	104 (220)	104 (220)	93 (200)	93 (200)	93 (200)	104 (220)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	60 (140)				60 (140)
PVDF	138 (280)	138 (280)	138 (280)	132 (270)	132 (270)	149 (300)	138 (280)
OTHER MATERIALS							
Butyl	65 (150)	87 (190)	87 (190)	87 (190)	87 (190)	87 (190)	87 (190)
EPDM	149 (300)	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)	149 (300)
EPT	U	82 (180)	82 (180)	82 (180)	82 (180)	82 (180)	98 (210)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	204 (400)	143 (290)	149 (300)	149 (300)	149 (300)	149 (300)	204 (400)
Borosilicate Glass		122 (250)	121 (250)	U	U	U	U
Neoprene	32 (90)	93 (200)	93 (200)	104 (220)	104 (220)	104 (220)	104 (220)
Nitrile	U	93 (200)	82 (180)	82 (180)	76 (170)	82 (180)	82 (180)
N-Rubber	32 (90)	65 (150)	65 (150)	93 (200)	93 (200)	93 (200)	93 (200)
PFA		93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
PVDC		82 (180)	138 (280)	71 (160)	71 (160)	71 (160)	71 (160)
SBR Styrene	93 (200)		93 (200)	93 (200)	93 (200)	93 (200)	93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Calcium Hypochlorite 30%	Calcium Hypochlorite (Sat.)	Chlorine Water (Sat.)	Chlorobenzene	Chloroform	Chlorophenol, 5% Aq.	Copper Sulfate
METALS							
Aluminum	U	U	26 (80)	65 (150)	76 (170)		U
Bronze	U	U	U	204 (400)	204 (400)		U
Carbon Steel	U	U	U	98 (210)	U	15 (60)	U
Copper	U	U	U	32 (90)	26 (80)		U
Ductile Iron, Pearlitic							
Hastelloy C			98 (210)	176 (350)	98 (210)		98 (210)
Inconel		U	32 (90)	98 (210)	98 (210)		32 (90)
Monel	U	U	U	204 (400)	98 (210)		32 (90)
Nickel		U	U	49 (120)	98 (210)		32 (90)
304 SS	U	U	U	98 (210)	98 (210)	176 (350)	98 (210)
316 SS		26 (80)	U	138 (280)	98 (210)	176 (350)	204 (400)
NON-METALS							
ABS		60 (140)	60 (140)	U	U		60 (140)
CPVC	82 (180)	93 (204)	98 (210)	U	U	U	98 (210)
Resins - Epoxy			U	87 (190)	43 (110)		98 (210)
- Furan	U		127 (260)	127 (260)	116 (240)	104 (220)	127 (260)
- Polyester	98 (210)		104 (220)	U	U		104 (220)
- Vinyl Ester		82 (180)	82 (180)	43 (110)	U		116 (240)
HDPE		60 (140)	60 (140)	U	26 (80)		60 (140)
PP	65 (170)	98 (210)	60 (140)	U	U		93 (200)
PTFE	93 (200)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	60 (140)	U	U	U	60 (140)
PVDF	93 (200)	138 (280)	104 (220)	104 (220)	121 (250)	65 (150)	138 (280)
OTHER MATERIALS							
Butyl	U	65 (150)	U	U	U		87 (190)
EPDM	154 (310)	149 (300)	15 (60)	U	U		149 (300)
EPT		U	26 (80)	U	U		82 (180)
FEP		204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	204 (400)	204 (400)	87 (190)	204 (400)	204 (400)		204 (400)
Borosilicate Glass		121 (250)	93 (200)	121 (250)	121 (250)		121 (200)
Neoprene	26 (80)	15 (60)	U	U	U		93 (200)
Nitrile	U	U	U	U	U		93 (200)
N-Rubber	U	32 (90)	65 (150)	U	U		65 (150)
PFA		93 (200)		93 (200)	93 (200)		93 (200)
PVDC		49 (120)	82 (180)	26 (80)	U		82 (180)
SBR Styrene		U			U		93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Crude Oil	Cumene	Detergent Solution	Dichlorobenzene	Diesel Fuels	Ethyl Alcohol	Esters, General
METALS							
Aluminum	38 (100)			15 (60)	32 (90)	98 (210)	
Bronze	38 (100)				32 (90)	204 (400)	204 (400)
Carbon Steel	38 (100)			15 (60)	87 (190)	116 (240)	
Copper	26 (80)		15 (60)			38 (100)	
Ductile Iron, Pearlitic							
Hastelloy C	32 (90)	71 (160)		176 (350)	93 (200)	98 (210)	
Inconel						26 (80)	
Monel	149 (300)					98 (210)	
Nickel						93 (200)	
304 SS	98 (210)		82 (180)	26 (80)	32 (90)	93 (200)	
316 SS	98 (210)		82 (180)	43 (110)	32 (90)	93 (200)	204 (400)
NON-METALS							
ABS	32 (90)			U		49 (120)	
CPVC	98 (210)		71 (160)	U	38 (100)	82 (180)	U
Resins - Epoxy	149 (300)	60 (140)	121 (250)	87 (190)	122 (250)	66 (150)	71 (160)
- Furan		121 (250)		127 (260)	122 (250)	127 (260)	122 (250)
- Polyester	104 (220)	60 (140)		32 (90)	93 (200)	32 (90)	
- Vinyl Ester	121 (250)	60 (140)	49 (120)	43 (110)	104 (220)	38 (100)	66 (150)
HDPE	49 (120)		60 (140)	U	49 (120)	60 (140)	26 (80)
PP	65 (150)		65 (150)	65 (150)	38 (100)	82 (180)	
PTFE	243 (470)	149 (300)	243 (470)	243 (470)	243 (470)	243 (470)	244 (470)
PVC Type 2	60 (140)		60 (140)	U		60 (140)	U
PVDF	138 (280)			49 (120)	138 (280)	138 (280)	76 (170)
OTHER MATERIALS							
Butyl	U					88 (190)	
EPDM	U	U	143 (290)	U	U	144 (290)	
EPT	U		98 (210)	U	U	82 (180)	
FEP	204 (400)		204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	149 (300)	209 (140)	204 (400)	82 (180)	204 (400)	176 (350)	
Borosilicate Glass			93 (200)	93 (200)		93 (200)	
Neoprene	U	U	71 (160)	U	26 (80)	93 (200)	
Nitrile	82 (180)	U	87 (190)	U	93 (200)	82 (180)	
N-Rubber	U			U	U	66 (150)	
PFA	93 (200)		93 (200)		93 (200)	93 (200)	
PVDC	65 (150)			U	49 (120)	66 (150)	26 (80)
SBR Styrene	U		93 (200)		93 (200)	93 (200)	

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Ethers, General	Ethyl Benzene	Ethylene Glycol	Ferric Chloride, 50% Aq.	Ferric Nitrate (Sat.)	Ferric Sulfate	Formaldehyde Dilute
METALS							
Aluminum	32 (90)	66 (150)	38 (100)	U		U	
Bronze	93 (200)	U	171 (340)	U	U	U	66 (150)
Carbon Steel	93 (200)	U	38 (100)	U	U	U	
Copper	26 (80)		38 (100)	U	U	26 (80)	
Ductile Iron, Pearlitic			149 (300)				
Hastelloy C	93 (200)	116 (240)	299 (570)	98 (210)	66 (150)	66 (150)	98 (210)
Inconel	32 (90)		98 (210)	26 (80)	U	U	98 (210)
Monel	32 (90)	82 (180)	98 (210)	U	U	26 (80)	98 (210)
Nickel	26 (80)		98 (210)	U	U	U	98 (210)
304 SS	93 (200)	20 (70)	98 (210)	U		26 (80)	298 (570)
316 SS	92 (200)	66 (150)	171 (340)	U	60 (140)	93 (200)	110 (230)
NON-METALS							
ABS	U		60 (140)			60 (140)	38 (100)
CPVC	U		98 (210)	82 (180)	82 (180)	82 (180)	60 (140)
Resins - Epoxy	32 (90)	U	149 (300)	122 (250)	93 (200)	93 (200)	44 (110)
- Furan	32 (90)	98 (210)	127 (260)	116 (240)	122 (250)	127 (260)	71 (160)
- Polyester		U	104 (220)	104 (220)	93 (200)	104 (220)	26 (80)
- Vinyl Ester	82 (180)	U	98 (210)	98 (210)	93 (200)	93 (200)	66 (150)
HDPE	U	20 (70)	60 (140)	60 (140)			60 (140)
PP	U	U	110 (230)	98 (210)	93 (200)	93 (200)	93 (200)
PTFE	244 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	149 (300)
PVC Type 2	U	U	60 (140)		60 (140)	60 (140)	60 (140)
PVDF	49 (120)	60 (140)	138 (280)	138 (280)	138 (280)	138 (280)	49 (120)
OTHER MATERIALS							
Butyl	U		88 (190)	71 (160)		88 (190)	
EPDM		U	149 (300)	149 (300)	144 (290)	138 (280)	60 (140)
EPT	U	U	82 (180)	82 (180)	82 (180)	82 (180)	82 (180)
FEP	204 (400)	49 (120)	204 (400)	204 (400)		204 (400)	204 (400)
FKM	U	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	110 (230)
Borosilicate Glass	66 (170)		122 (250)	138 (280)		93 (200)	
Neoprene	U	U	71 (160)	71 (160)		93 (200)	60 (140)
Nitrile	49 (120)	U	93 (200)	82 (180)	82 (180)	93 (200)	U
N-Rubber	U	U	66 (150)	66 (150)		66 (150)	
PFA	93 (200)		93 (200)	93 (200)		93 (200)	93 (200)
PVDC			82 (180)	60 (140)	49 (120)	66 (150)	60 (140)
SBR Styrene			93 (200)	93 (200)			93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Formic Acid 5%	Formic Acid 10-85%	Formic Acid Anhydrous	Fuel Oil	Gasohol	Gasoline, Leaded	Gasoline, Refined
METALS							
Aluminum	U	98 (210)	98 (210)	60 (140)	66 (150)	38 (100)	98 (210)
Bronze		98 (210)	98 (210)	176 (350)	66 (150)	38 (100)	93 (200)
Carbon Steel		U	U	93 (200)	66 (150)	38 (100)	93 (200)
Copper	66 (150)	98 (210)	98 (210)	26 (80)	66 (150)	38 (100)	32 (90)
Ductile Iron, Pearlitic							
Hastelloy C	98(210)	98 (210)	98 (210)	93 (200)	66 (150)	38 (100)	93 (200)
Inconel	66 (150)	98 (210)	98 (210)	60 (140)		26 (80)	
Monel	66 (150)	98 (210)	98 (210)	82 (180)	66 (150)	38 (100)	38 (100)
Nickel	66 (150)	98 (210)	98 (210)	82 (180)		38 (100)	38 (100)
304 SS	66 (150)	104 (220)	54 (130)	122 (250)		32 (90)	132 (270)
316 SS	66 (150)	204 (400)	98 (210)	71 (160)	66 (150)	32 (90)	98 (210)
NON-METALS							
ABS		U	U		U	U	U
CPVC	26 (80)	60 (140)	76 (170)			U	66 (150)
Resins - Epoxy	38 (100)	20 (70)	32 (90)	122 (250)		122 (250)	66 (150)
- Furan	104 (220)	127 (260)	U	122 (250)		122 (250)	127 (260)
- Polyester	66 (150)	66 (150)	38 (100)	26 (80)		32 (90)	26 (80)
- Vinyl Ester	82 (180)	38 (100)	U	93 (200)		44 (110)	82 (180)
HDPE	60 (140)	60 (140)	71 (160)	93 (200)		U	U
PP	66 (150)	98 (210)	82 (180)	76 (170)	U	U	U
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	93 (200)	243 (470)	243 (470)
PVC Type 2		32 (90)		60 (140)	60 (140)		U
PVDF	122 (250)	122 (250)	60 (140)	138 (280)	138 (280)	138 (280)	
OTHER MATERIALS							
Butyl	66 (150)	66 (150)	66 (150)	U			
EPDM	98 (210)	149 (300)	32 (90)	U	U	U	
EPT	93 (200)	82 (180)	98 (210)			U	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)		204 (400)	204 (400)
FKM	82 (180)	88 (190)	66 (150)	199 (390)	32 (100)	88 (190)	82 (180)
Borosilicate Glass	122 (250)	122 (250)	122 (250)	122 (250)		71 (160)	122 (250)
Neoprene	93 (200)	71 (160)	38 (100)	93 (200)		32 (90)	32 (90)
Nitrile	U	U	U	104 (220)	26 (80)	88 (190)	93 (200)
N-Rubber		U	U	U		U	U
PFA	93 (200)	93 (200)	93 (200)	93 (200)		93 (200)	93 (200)
PVDC	66 (150)	66 (150)	66 (150)	49 (120)		71 (160)	32 (90)
SBR Styrene						U	U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Gasoline, Unleaded	Glycols	Heptane	Hexane	Hydrochloric Acid, Dilute	Hydrochloric Acid 20%	Hydrochloric Acid 35%
METALS							
Aluminum	98 (210)	26 (80)	38 (100)	26 (80)	U	U	U
Bronze	176 (350)	38 (100)	176 (350)	176 (350)	U	U	U
Carbon Steel	176 (350)	26 (80)	176 (350)	176 (350)	U	U	U
Copper	32 (90)		26 (80)		U	U	U
Ductile Iron, Pearlitic							
Hastelloy C	160 (320)		93 (200)	122 (250)	82 (180)	66 (150)	66 (150)
Inconel	26 (80)	38 (100)	93 (200)		32 (90)	26 (80)	U
Monel	38 (100)	38 (100)	93 (200)	38 (100)	32 (90)	26 (80)	U
Nickel	38 (100)		98 (210)	26 (80)	32 (90)	26 (80)	U
304 SS	26 (80)	38 (100)	122 (250)	122 (250)	U	U	U
316 SS	26 (80)	26 (80)	176 (350)	122 (250)	U	U	U
NON-METALS							
ABS	U	60 (140)	54 (130)	U	32 (90)	32 (90)	60 (140)
CPVC	U	82 (180)	82 (180)	66 (150)	82 (180)	82 (180)	66 (150)
Resins - Epoxy	122 (250)	149 (300)	66 (150)	82 (180)	88 (190)	93 (200)	32 (90)
- Furan	138 (280)		98 (210)	66 (150)	127 (260)	127 (260)	122 (250)
- Polyester	32 (90)	104 (220)	93 (200)	32 (90)	88 (190)	88 (190)	54 (130)
- Vinyl Ester	38 (100)	98 (210)	98 (210)	71 (160)	110 (230)	104 (220)	82 (180)
HDPE	60 (140)	60 (140)	44 (110)	26 (80)	71 (160)	60 (140)	60 (140)
PP	U	66 (150)	26 (80)	44 (110)	104 (220)	104 (220)	104 (220)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2		60 (140)	60 (140)	20 (70)	60 (140)	60 (140)	60 (140)
PVDF	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)
OTHER MATERIALS							
Butyl		66 (150)		U	49 (120)	U	U
EPDM	U	149 (300)	U	U	149 (300)	38 (100)	32 (90)
EPT	U	98 (210)	U	U	98 (210)	U	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	82 (180)	204 (400)	176 (350)	210 (410)	176 (350)	176 (350)	176 (350)
Borosilicate Glass	76 (170)		122 (250)	122 (250)	122 (250)	122 (250)	122 (250)
Neoprene	93 (200)	71 (160)	93 (200)	93 (200)	66 (150)	82 (180)	82 (180)
Nitrile	93 (200)	104 (220)	82 (180)	104 (220)	66 (150)	54 (130)	U
N-Rubber	U	49 (120)	U	U	60 (140)	66 (150)	82 (180)
PFA	93 (200)	93 (200)	93 (200)	93 (200)	122 (250)	122 (250)	122 (250)
PVDC	66 (150)		66 (150)	66 (150)	82 (180)	82 (180)	82 (180)
SBR Styrene	U		U	U			U

Notes: U = unsatisfactory

XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Hydrochloric Acid 38%	Hydrochloric Acid 50%	Hydrofluoric Acid, Dilute	Hydrofluoric Acid 30%	Hydrofluoric Acid 40%	Hydrofluoric Acid 50%	Hydrofluoric Acid 70%
METALS							
Aluminum	U	U	U	U	U	U	U
Bronze	U	U	66 (150)	60 (140)	26 (80)	U	U
Carbon Steel	U	U	U	U	U	U	U
Copper	U	U	66 (150)	60 (140)	26 (80)	U	U
Ductile Iron, Pearlitic							
Hastelloy C	60 (150)	26 (80)	98 (210)	98 (210)	93 (200)	110 (230)	93 (200)
Inconel	U	U	26 (80)	U	U	U	U
Monel	U	U	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
Nickel	U	U	44 (110)	76 (170)	60 (140)	71 (160)	38 (100)
304 SS	U	U	U	U	U	U	U
316 SS	U	U	U	U	U	U	U
NON-METALS							
ABS	60 (140)	54 (130)	U	U	U	U	U
CPVC	76 (170)	82 (180)	26 (80)	U	76 (170)	U	32 (90)
Resins - Epoxy	60 (140)	104 (220)	U	U	U	U	U
- Furan	122 (250)	32 (90)	127 (260)	U	U	U	
- Polyester	U	32 (90)	38 (100)	32 (90)	U		
- Vinyl Ester	82 (180)	60 (140)	71 (160)	U	U	U	U
HDPE	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	U
PP	93 (200)	44 (110)	93 (200)	82 (180)	93 (200)	93 (200)	93 (200)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	32 (90)	54 (130)	66 (150)	20 (70)	
PVDF	138 (280)	138 (280)	138 (280)	127 (260)	116 (240)	104 (220)	98 (210)
OTHER MATERIALS							
Butyl	U	54 (130)	176 (350)	176 (350)	66 (150)	66 (150)	66 (150)
EPDM	60 (140)		15 (60)	15 (60)	15 (60)	U	U
EPT	32 (90)	U	98 (210)	60 (140)	U	U	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	176 (350)	138 (280)	98 (210)	98 (210)	176 (350)	176 (350)	176 (350)
Borosilicate Glass	122 (250)	122 (250)	U	U	U	U	U
Neoprene	32 (90)	U	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
Nitrile	U	93 (200)	U	U	U	U	U
N-Rubber	82 (180)	82 (90)	38 (100)	38 (100)	32 (90)	38 (100)	U
PFA	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
PVDC	82 (180)	82 (180)	82 (180)	71 (160)	76 (170)	66 (150)	
SBR Styrene	U	U	U	U	U	U	U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Hydrofluoric Acid 100%	Hydrogen Peroxide, Dilute	Hydrogen Peroxide 30%	Hydrogen Peroxide 50%	Hydrogen Peroxide 90%	Hydrogen Sulfide, Aq. Soln.	Jet Fuel JP-4
METALS							
Aluminum	U	176 (350)	176 (350)	15 (60)	176 (350)		76 (170)
Bronze	72 (160)	U	U	U	32 (90)		204 (400)
Carbon Steel	66 (150)	U	U	U	U		76 (170)
Copper	U	U	U	U	U		
Ductile Iron, Pearlitic							
Hastelloy C	98 (210)	93 (200)	38 (100)	38 (100)	93 (200)	149 (300)	38 (100)
Inconel	49 (120)	66 (150)	60 (140)	26 (80)	32 (90)	93 (200)	32 (90)
Monel	98 (210)	49 (120)	15 (60)	32 (90)	32 (90)	98 (210)	32 (90)
Nickel	49 (120)	76 (170)			32 (90)	93 (200)	26 (80)
304 SS	U	98 (210)	98 (210)	93 (200)	93 (200)	U	38 (100)
316 SS	26 (80)	216 (420)	204 (400)	204 (400)	204 (400)	93 (200)	204 (400)
NON-METALS							
ABS	U	26 (80)	U	U	U	60 (140)	
CPVC	U	U	82 (180)	82 (180)	82 (180)	82 (180)	93 (200)
Resins - Epoxy	U	66 (150)	60 (140)	U	U	149 (300)	66 (150)
- Furan	138 (280)	U	U		26 (80)	127 (260)	60 (140)
- Polyester		66 (150)	32 (90)	U	U		26 (80)
- Vinyl Ester	U	60 (140)	76 (170)	44 (110)	66 (150)	71 (160)	82 (180)
HDPE		49 (120)	60 (140)	60 (140)	26 (80)	60 (140)	
PP	93 (200)	38 (100)	38 (100)	66 (150)	44 (110)	82 (180)	20 (70)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	244 (470)	243 (470)	243 (470)
PVC Type 2			U	38 (100)	U	60 (140)	60 (140)
PVDF	93 (200)	122 (250)	122 (250)	122 (250)	49 (120)	104 (220)	122 (250)
OTHER MATERIALS							
Butyl	U	U	U	U	U		U
EPDM	U	38 (100)	38 (100)	38 (100)	38 (100)	60 (140)	U
EPT	U	26 (80)	U	U	U	82 (180)	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	20 (70)	176 (350)	176 (350)	176 (350)	122 (250)	U	204 (400)
Borosilicate Glass	U	122 (250)	122 (250)	122 (250)	122 (250)	44 (110)	82 (180)
Neoprene	U	U	U	U	U		U
Nitrile	U	32 (90)	32 (90)	U	U	U	93 (200)
N-Rubber	U	26 (80)	U	U	U		U
PFA	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)		93 (200)
PVDC	U	49 (120)	49 (120)	54 (130)	49(120)	71 (160)	26 (80)
SBR Styrene	U	93 (200)					U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Jet Fuel JP-5	Kerosene	Ketones, General	Lime Slurry	Lubricating Oil	Machine Oil	Methyl Alcohol
METALS							
Aluminum	38 (100)	76 (170)	38 (100)		66 (150)		66 (150)
Bronze	204 (400)	176 (350)	38 (100)	66 (150)			188 (370)
Carbon Steel	38 (100)	176 (350)	93 (200)	66 (150)	66 (150)	98 (210)	98 (210)
Copper		32 (90)			32 (90)		98 (210)
Ductile Iron, Pearlitic							
Hastelloy C	38 (100)	98 (210)	38 (100)	49 (120)		98 (210)	122 (250)
Inconel	26 (80)	32 (90)					98 (210)
Monel	38 (100)	76 (170)	38 (100)	66 (150)	38 (100)		98 (210)
Nickel	26 (80)	98 (210)	38 (100)				98 (210)
304 SS	38 (100)	204 (400)	122 (250)		66 (150)	98 (210)	122 (250)
316 SS	204 (400)	204 (400)	132 (270)	66 (150)	66 (150)	98 (210)	176 (350)
NON-METALS							
ABS		32 (90)	U		38 (100)		U
CPVC	60 (140)	82 (180)	U		82 (180)	82 (180)	66 (150)
Resins - Epoxy	66 (150)	122 (250)	U	93 (200)	110 (230)		32 (90)
- Furan	66 (150)	122 (250)	38 (100)				122 (250)
- Polyester	32 (90)	66 (150)		98 (210)			66 (150)
- Vinyl Ester	49 (120)	132 (270)	U	82 (180)	93 (200)		38 (100)
HDPE		26 (80)	26 (80)		U		60 (140)
PP	20 (70)	32 (90)	44 (110)		20 (70)	44 (110)	88 (190)
PTFE	243 (470)	243 (470)	243 (470)	82 (180)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	U		60 (140)	60 (140)	60 (140)
PVDF	122 (250)	127 (260)	44 (110)		138 (280)	93 (200)	138 (280)
OTHER MATERIALS							
Butyl	U	U			U	U	88 (190)
EPDM	U	U	U	38 (100)	U	U	149 (300)
EPT	U	U			U	204 (400)	60 (140)
FEP	204 (400)	204 (400)	204 (400)		204 (400)	60 (140)	204 (400)
FKM	204 (400)	204 (400)	U		204 (400)	93 (200)	U
Borosilicate Glass	82 (180)	122 (250)	122 (250)		70 (160)		122 (250)
Neoprene	U	93 (200)	U	82 (180)	93 (200)	93 (200)	104 (220)
Nitrile	93 (200)	110 (230)	U		104 (220)		104 (220)
N-Rubber	U	U			U		71 (160)
PFA	93 (200)	93 (200)	93 (200)		93 (200)		93 (200)
PVDC	32 (90)	49 (120)	32 (90)		49 (120)		71 (160)
SBR Styrene	U	U			U		93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Methyl Ethyl Ketone (MEK)	Methyl Isobutyl Ketone	Methylene Chloride	Mineral Oil	Mixed Acids	Motor Oil	Naphtha
METALS							
Aluminum	60 (140)	66 (150)	98 (210)	76 (170)	U		82 (180)
Bronze	176 (350)	176 (350)	204 (400)		U	38 (100)	204 (400)
Carbon Steel	93 (200)	66 (150)	38 (100)	38 (100)	U	122 (250)	32 (90)
Copper	32 (90)	32 (90)	32 (90)	32 (90)		66 (150)	32 (90)
Ductile Iron, Pearlitic							
Hastelloy C	98 (210)	93 (200)	98 (210)				93 (200)
Inconel	98 (210)	93 (200)	98 (210)	38 (100)	32 (90)	32 (90)	66 (150)
Monel	93 (200)	93 (200)	98 (210)	38 (100)	U	32 (90)	49 (120)
Nickel		93 (200)	98 (210)	38 (100)	U		49 (120)
304 SS	66 (150)	93 (200)	98 (210)	32 (90)	66 (150)	122 (250)	122 (250)
316 SS	176 (350)	176 (350)	204 (400)	176 (350)	66 (150)	122 (250)	98 (210)
NON-METALS							
ABS	U	U	U	38 (100)		32 (90)	60 (140)
CPVC	U	U	U	82 (180)	93 (200)	82 (180)	60 (140)
Resins - Epoxy	32 (90)	60 (140)	20 (70)	110 (230)		26 (80)	104 (220)
- Furan	76 (170)	122 (250)	138 (280)		U		127 (260)
- Polyester	U	U	U	98 (210)			66 (150)
- Vinyl Ester	U	U	U	122 (250)		122 (250)	98 (210)
HDPE	U		U	26 (80)			26 (80)
PP	66 (150)	26 (60)	20 (70)	44 (110)	U	U	44 (110)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	U	U	U	60 (140)	20 (70)	60 (140)	60 (140)
PVDF	U	44 (110)	49 (120)	122 (250)		122 (250)	138 (280)
OTHER MATERIALS							
Butyl	38 (100)	26 (80)	U	U			U
EPDM	149 (300)	15 (60)	U	U		U	U
EPT	U	U	U	U		U	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	U	U	20 (70)	210(410)	38 (100)	88 (190)	204 (400)
Borosilicate Glass	122 (250)	122 (250)	122 (250)	76 (170)		160 (320)	93 (200)
Neoprene	U	U	U	93 (200)	U		U
Nitrile	U	U	U	82 (180)	U	88 (190)	60 (140)
N-Rubber	U	U	U	U			U
PFA	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
PVDC	U	26 (80)	U	49 (120)			66 (150)
SBR Styrene	U		U	U			U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Naphthalene	Nitric Acid 5%	Nitric Acid 10%	Nitric Acid 20%	Nitric Acid 30%	Nitric Acid 40%	Nitric Acid 50%
METALS							
Aluminum	98 (210)	U	U	U	U	U	U
Bronze	38 (100)	U	U	U	U	U	U
Carbon Steel	82 (180)	U	U	U	U	U	U
Copper	38 (100)	U	U	U	U	U	U
Ductile Iron, Pearlitic							
Hastelloy C	93 (200)	98 (210)	98 (210)	88 (190)	88 (190)	82 (180)	110 (230)
Inconel	98 (210)	32 (90)	32 (90)	26 (80)	26 (80)	26 (80)	26 (80)
Monel	98 (210)	U	U	U	U	U	U
Nickel	98 (210)	U	U	U	U	U	U
304 SS	204 (400)	98 (210)	160 (320)	149 (300)	98 (210)	98 (210)	93 (200)
316 SS	204 (400)	98 (210)	98 (210)	144 (290)	149 (300)	104 (220)	93 (200)
NON-METALS							
ABS	U	60 (140)	60 (140)	54 (130)	U	U	U
CPVC	U	82 (180)	82 (180)	71 (160)	93 (200)	82 (180)	82 (180)
Resins - Epoxy	93 (200)	71 (160)	60 (140)	38 (100)	U	U	U
- Furan	127 (260)	93 (200)	26 (80)	U	U	U	U
- Polyester	82 (180)	71 (160)	66 (150)	38 (100)	26 (80)	98 (210)	26 (80)
- Vinyl Ester	98 (210)	82 (180)	66 (150)	66 (150)	38 (100)	98 (210)	U
HDPE	26 (80)	60 (140)	60 (140)	60 (140)	60 (140)	U	U
PP	98 (210)	60 (140)	93 (200)	60 (140)	66 (150)	66 (150)	66 (150)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	U	38 (100)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PVDF	138 (280)	93 (200)	93 (200)	82 (180)	82 (180)	82 (180)	82 (180)
OTHER MATERIALS							
Butyl		71 (160)	71 (160)	71 (160)	49 (120)	38 (100)	U
EPDM	U	15 (160)	15 (160)	15 (160)	15 (60)	U	U
EPT	U	U	U	U	U	U	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
Borosilicate Glass		204 (400)	204 (400)	204 (400)	15 (60)	204 (400)	15 (60)
Neoprene	U	U	U	U	U	U	U
Nitrile	U	U	U	U	U	U	U
N-Rubber	U	U	U	U	U	U	U
PFA	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
PVDC		32 (90)	54 (130)	66 (150)	66 (150)	49 (120)	49 (120)
SBR Styrene		U	U	U	U	U	U

Notes: U = unsatisfactory

XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Nitric Acid 70%	Nitric Acid 100% (Anhydrous)	Oil and Fats	Oxalic Acid 5%	Oxalic Acid 10%	Oxalic Acid 50%	Oxalic Acid (Sat.)
METALS							
Aluminum	U	32 (90)	66 (150)	88 (190)	44 (110)	88 (190)	54 (130)
Bronze	U	U	66 (150)	98 (210)	98 (210)	98 (210)	98 (210)
Carbon Steel	U	U	66 (150)	U	U	U	U
Copper	U	U		98 (210)	98 (210)	98 (210)	98 (210)
Ductile Iron, Pearlitic							
Hastelloy C	93 (200)	26 (80)	122 (250)	98 (210)	98 (210)	98 (210)	98 (210)
Inconel	U	U		98 (210)	98 (210)	98 (210)	26 (80)
Monel	U	U		98 (210)	98 (210)	66 (150)	32 (90)
Nickel	U	U	15 (60)	32 (90)	38 (100)	49 (120)	98 (210)
304 SS	98 (210)	26 (80)	66 (150)	U	U	U	U
316 SS	204 (400)	44 (110)	122 (250)	176 (350)	176 (350)	176 (350)	U
NON-METALS							
ABS	U	U	60 (140)	60 (140)	38 (100)	38 (100)	38 (100)
CPVC	82 (180)	U	98 (210)	60 (140)	88 (190)	98 (210)	93 (200)
Resins - Epoxy	U	U		132 (270)	132 (270)	132 (270)	132 (270)
- Furan	U	U	122 (250)	88 (190)	93 (200)		
- Polyester			104 (220)	104 (220)	104 (220)	104 (220)	104 (220)
- Vinyl Ester	U	U	98 (210)	98 (210)	93 (200)	98 (210)	98 (210)
HDPE	U	U	U	60 (140)	60 (140)	60 (140)	60 (140)
PP	U	U	82 (180)	71 (160)	66 (150)	66 (150)	60 (140)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	U	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PVDF	49 (120)	66 (150)	144 (290)	71 (160)	66 (150)	93 (200)	60 (140)
OTHER MATERIALS							
Butyl	32 (90)	U		76 (170)	88 (190)	66 (150)	66 (150)
EPDM	U	U		154 (310)	149 (300)	149 (300)	144 (290)
EPT	U	U	U	60 (140)	60 (140)	60 (140)	98 (210)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	88 (190)	88 (190)	82 (180)	204 (400)	204 (400)	204 (400)	204 (400)
Borosilicate Glass	204 (400)	132 (270)	93 (200)	122 (250)	122 (250)	122 (250)	122 (250)
Neoprene	U	U	26 (80)	93 (200)	93 (200)	38 (100)	U
Nitrile	U	U	93 (200)	U	U	U	20 (70)
N-Rubber	U	U		66 (150)	66 (150)	66 (150)	66 (150)
PFA	122 (250)	26 (80)	93 (200)				
PVDC	U	U	66 (150)	82 (180)	76 (170)	76 (170)	49 (120)
SBR Styrene	U	U					

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Petroleum Oils, Refined	Petroleum Oils, Sour	Phenol	Phenol 10%	Phosphoric Acid 5%	Phosphoric Acid 10%	Phosphoric Acid 25-50%
METALS							
Aluminum	32 (90)	U	98 (210)	66 (150)	U	38 (100)	U
Bronze	26 (80)	U	U	38 (100)	U	U	65 (150)
Carbon Steel			98 (210)	93 (200)		U	U
Copper	32 (90)	U	U	49 (120)	32 (90)	U	U
Ductile Iron, Pearlitic							
Hastelloy C			299 (570)	176 (350)	32 (90)	98 (210)	98 (210)
Inconel			299 (570)	49 (120)	26 (80)	93 (200)	98 (210)
Monel	32 (90)	U	299 (570)	104 (220)	26 (80)	26 (80)	26 (80)
Nickel			299 (570)	93 (200)		26 (80)	26 (80)
304 SS	26 (80)	26 (80)	299 (570)	93 (200)	93 (200)	88 (190)	98 (210)
316 SS	26 (80)	26 (80)	299 (570)	93 (200)	98 (210)	144 (290)	93 (200)
NON-METALS							
ABS			U	U		60 (140)	38 (100)
CPVC	82 (180)	82 (180)	60 (140)	32 (90)	98 (210)	82 (180)	82 (180)
Resins - Epoxy			U	U	38 (100)	71 (160)	60 (140)
- Furan			98 (210)	U		122 (250)	121 (250)
- Polyester			U	U		104 (220)	104 (220)
- Vinyl Ester	93 (200)	93 (200)	U	38 (100)	98 (210)	93 (200)	93 (200)
HDPE	26 (80)	26 (80)	38 (100)	38 (100)	60 (140)	60 (140)	60 (140)
PP	66 (150)	32 (90)	82 (180)	93 (200)	82 (180)	122 (250)	98 (210)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2			U	U		60 (140)	60 (140)
PVDF	127 (260)	122 (250)	93 (200)	98 (210)	132 (270)	138 (280)	121 (250)
OTHER MATERIALS							
Butyl			66 (150)	66 (150)	66 (150)	66 (150)	87 (190)
EPDM	U		15 (60)	26 (80)	149 (300)	149 (300)	60 (140)
EPT	U	U	26 (80)	26 (80)	82 (180)	82 (180)	82 (180)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	88 (190)	88 (190)	98 (210)	216 (420)	204 (400)	204 (400)	87 (190)
Borosilicate Glass			93 (200)	93 (200)	149 (300)	149 (300)	149 (300)
Neoprene	38 (100)		U	U	93 (200)	93 (200)	82 (180)
Nitrile	82 (180)	82 (180)	U	U	U	U	U
N-Rubber	U		U	26 (80)	66 (150)	66 (150)	65 (150)
PFA					93 (200)	93 (200)	93 (200)
PVDC			U	26 (80)	76 (170)	82 (180)	49 (120)
SBR Styrene	U	U	U	U	93 (200)	93 (200)	

Notes: U = unsatisfactory

XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Phosphoric Acid 50-85%	Potassium Hydroxide 5%	Potassium Hydroxide 27%	Potassium Hydroxide 50%	Potassium Hydroxide 90%	Potassium Nitrate 1-5%	Potassium Nitrate 80%
METALS							
Aluminum	U	U	U	U	U	176 (350)	176 (350)
Bronze	U	32 (90)	15 (60)	32 (90)	26 (80)		98 (210)
Carbon Steel	U	98 (210)	93 (200)	32 (90)	26 (80)		54 (130)
Copper	U	38 (100)	32 (90)	98 (210)	26 (80)		32 (93)
Ductile Iron, Pearlitic							
Hastelloy C	98 (210)	98 (210)	127 (260)	127 (260)	65 (150)	98 (210)	98 (210)
Inconel	87 (190)	98 (210)	98 (210)	98 (210)	26 (80)	98 (210)	98 (210)
Monel	204 (400)	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)
Nickel	U	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)
304 SS	49 (120)	149 (300)	98 (210)	98 (210)	U	121 (250)	121 (250)
316 SS	204 (400)	176 (330)	176 (350)	171 (340)	176 (350)	176 (350)	176 (350)
NON-METALS							
ABS	54 (130)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
CPVC	82 (180)	82 (180)	82 (180)	82 (180)	127 (260)	82 (180)	82 (180)
Resins - Epoxy	43 (110)	93 (200)	82 (180)	98 (210)	65 (150)	127 (260)	149 (300)
- Furan	127 (260)	121 (250)	121 (250)	121 (250)	132 (270)		132 (270)
- Polyester	104 (220)	65 (150)	32 (90)	76 (170)		104 (220)	104 (220)
- Vinyl Ester	98 (210)	65 (150)	65 (150)	U	U	104 (220)	98 (210)
HDPE	38 (100)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PP	98 (210)	98 (210)	65 (150)	82 (180)	65 (150)	56 (150)	56 (150)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PVDF	121 (250)	98 (210)	104 (220)	98 (210)	98 (210)	138 (280)	138 (280)
OTHER MATERIALS							
Butyl	65 (150)	82 (180)	82 (108)	82 (180)	82 (180)		82 (180)
EPDM	60 (140)	149 (300)	149 (300)	149 (300)	149 (300)	149 (300)	149 (300)
EPT	82 (180)	98 (210)	98 (210)	98 (210)	98 (210)	82 (180)	82 (180)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	149 (300)	160 (320)	26 (80)	U	U	204 (400)	204 (400)
Borosilicate Glass	149 (300)	U	U	U	U	121 (250)	121 (250)
Neoprene	60 (140)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
Nitrile	U	26 (80)	15 (60)	65 (150)	65 (150)	104 (220)	104 (220)
N-Rubber	43 (110)	38 (100)	38 (100)	38 (100)	38 (100)		65 (150)
PFA	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
PVDC	54 (130)	38 (100)	38 (100)	38 (100)	38 (100)	65 (150)	65 (150)
SBR Styrene		U	U	U	U	93 (200)	93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Potassium Permanganate 10%	Potassium Permanganate 20%	Potassium Sulfate 10%	Propylene Glycol	Silicone Oil	Soap Solution 5%	Soap Solutions
METALS							
Aluminum	98 (210)	98 (210)	98 (210)	76 (170)	38 (100)		149 (300)
Bronze	93 (200)	26 (80)	26 (80)	98 (210)	176 (350)	176 (350)	176 (350)
Carbon Steel	26 (80)	26 (80)	98 (210)	98 (210)	38 (100)	65 (150)	76 (170)
Copper	26 (80)	26 (80)	65 (150)	32 (90)	38 (100)		26 (80)
Ductile Iron, Pearlitic							
Hastelloy C	98 (210)	98 (210)	98 (210)	32 (90)		38 (100)	32 (90)
Inconel	98 (210)	98 (210)	98 (210)	32 (90)		32 (90)	32 (90)
Monel	98 (210)	98 (210)	98 (210)	32 (90)		43 (110)	38 (100)
Nickel	98 (210)	98 (210)	98 (210)	32 (90)		65 (150)	60 (140)
304 SS	98 (210)	98 (210)	98 (210)	32 (90)	38 (100)	65 (150)	32 (90)
316 SS	175 (350)	176 (350)	176 (350)	98 (210)	38 (100)	65 (150)	32 (90)
NON-METALS							
ABS	U	32 (90)	60 (140)	32 (90)			
CPVC	87 (190)	60 (140)	82 (180)	U	87 (190)	83 (180)	82 (180)
Resins - Epoxy	65 (150)	65 (150)	121 (250)	98 (210)	26 (80)	32 (90)	
- Furan	127 (260)	71 (160)	121 (250)	121 (250)			
- Polyester	98 (210)	104 (220)	104 (220)	93 (200)		32 (90)	26 (80)
- Vinyl Ester	104 (220)	98 (210)	98 (210)	98 (210)		60 (140)	60 (140)
HDPE	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PP	65 (150)	60 (140)	104 (220)	60 (140)	60 (140)	60 (140)	82 (180)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	32 (90)	60 (140)	U		32 (90)	26 (80)
PVDF	138 (280)	138 (280)	138 (280)	127 (260)	121 (250)	26 (80)	38 (100)
OTHER MATERIALS							
Butyl	54 (130)	54 (130)	82 (180)		U		65 (150)
EPDM	98 (210)	60 (140)	149 (300)		149 (300)	149 (300)	154 (310)
EPT	98 (210)	87 (190)	98 (210)	149 (300)	93 (200)	98 (210)	98 (210)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	71 (160)	71 (160)	204 (400)	149 (300)	204 (400)	204 (400)	204 (400)
Borosilicate Glass	121 (250)	121 (250)	121 (250)	98 (210)		93 (200)	93 (200)
Neoprene	38 (100)	38 (100)	93 (200)	32 (90)	15 (60)	93 (200)	93 (200)
Nitrile	49 (120)	U	104 (220)	82 (180)	104 (220)	104 (220)	110 (230)
N-Rubber	U	U	65 (150)		U	65 (150)	65 (150)
PFA	93 (200)	93 (200)	93 (200)			93 (200)	98 (210)
PVDC	54 (130)	54 (130)	76 (170)			76 (170)	82 (180)
SBR Styrene						93 (200)	93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Sodium Aluminate	Sodium Bicarbonate 20%	Sodium Bisulfate	Sodium Carbonate	Sodium Chloride	Sodium Hydroxide 10%	Sodium Hydroxide 15%
METALS							
Aluminum	32 (90)	65 (150)	U	U	U	U	U
Bronze	U	32 (90)	38 (100)	38 (100)	98 (210)	87 (190)	98 (210)
Carbon Steel	65 (150)	38 (100)	49 (120)	49 (120)	71 (160)	98 (210)	98 (210)
Copper		26 (80)	38 (120)	38 (120)	98 (210)	98 (210)	98 (210)
Ductile Iron, Pearlitic		30 (86)			82 (180)	50 (122)	
Hastelloy C	65 (150)	98 (210)	98 (210)	98 (210)	98 (210)	109 (230)	98 (210)
Inconel		98 (210)	98 (210)	98 (210)	98 (210)	149 (300)	98 (210)
Monel	65 (150)	98 (210)	98 (210)	98 (210)	98 (210)	176 (350)	176 (350)
Nickel		98 (210)	98 (210)	98 (210)	98 (210)	98 (210)	209 (410)
304 SS	26 (80)	121 (250)	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)
316 SS	60 (140)	176 (350)	176 (350)	176 (350)	176 (350)	176 (350)	149 (300)
NON-METALS							
ABS		60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
CPVC		98 (210)	98 (210)	98 (210)	98 (210)	87 (190)	82 (180)
Resins - Epoxy		121 (250)	149 (300)	149 (300)	98 (210)	87 (190)	93 (200)
- Furan		127 (260)	127 (260)	127 (260)	127 (260)	U	U
- Polyester	65 (150)	71 (160)	71 (160)	71 (160)	104 (220)	54 (130)	65 (150)
- Vinyl Ester	65 (150)	93 (200)	82 (180)	82 (180)	82 (180)	76 (190)	65 (150)
HDPE		60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	76 (170)
PP		104 (220)	104 (220)	104 (220)	104 (220)	104 (220)	98 (210)
PTFE	149 (300)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2		60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PVDF		138 (280)	138 (280)	138 (280)	138 (280)	98 (210)	98 (210)
OTHER MATERIALS							
Butyl		82 (180)	82 (180)	82 (180)	82 (180)	82 (180)	82 (180)
EPDM	93 (200)	149 (300)	149 (300)	149 (300)	149 (300)	149 (300)	149 (300)
EPT		82 (180)	82 (180)	82 (180)	82 (180)	98 (210)	98 (210)
FEP	38 (100)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	93 (200)	204 (400)	87 (190)	87 (190)	204 (400)	15 (60)	15 (60)
Borosilicate Glass		121 (250)	121 (250)	121 (250)	121 (250)	U	U
Neoprene	65 (150)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)
Nitrile	82 (180)	104 (220)	93 (200)	93 (200)	109 (230)	71 (160)	71 (160)
N-Rubber		65 (150)	82 (180)	82 (180)	54 (130)	65 (150)	65 (150)
PFA		93 (200)	93 (200)	93 (200)	93 (200)	121 (250)	121 (250)
PVDC		82 (180)	82 (180)	82 (180)	82 (180)	32 (90)	32 (90)
SBR Styrene					93 (200)		U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Sodium Hydroxide 30%	Sodium Hydroxide 50%	Sodium Hydroxide 70%	Sodium Hydroxide Soln. (Cond	Sodium Hypochlorite 20%	Sodium Hypochlorite (Conc.)	Sodium Hyposulfite 5%
METALS							
Aluminum	U	U	U	U	26 (80)	U	
Bronze	38 (100)	60 (140)	32 (90)	26 (80)	26 (80)	U	
Carbon Steel	98 (210)	38 (100)	98 (210)	143 (290)	U	U	
Copper	32 (90)	60 (140)	65 (150)	26 (80)	26 (80)	U	32 (90)
Ductile Iron, Pearlitic		127 (260)	127 (260)				
Hastelloy C	98 (210)	98 (210)	104 (220)	49 (120)	U	54 (130)	32 (90)
Inconel	149 (300)	149 (300)	98 (210)	26 (80)	U	U	26 (80)
Monel	98 (210)	149 (300)	143 (290)	176 (350)	26 (80)	U	26 (80)
Nickel	149 (300)	149 (300)	98 (210)	93 (200)	U	U	26 (80)
304 SS	98 (210)	98 (210)	109 (230)	32 (90)	U	26 (80)	U
316 SS	98 (210)	176 (350)	109 (230)	176 (350)	U	26 (80)	U
NON-METALS							
ABS	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	
CPVC	82 (180)	82 (180)	82 (180)	87 (190)	87 (190)	82 (180)	
Resins - Epoxy	93 (200)	93 (200)	121 (250)		26 (80)		
- Furan	U	U	127 (260)	U	U	U	
- Polyester	65 (150)	104 (220)			U	60 (140)	82 (180)
- Vinyl Ester	65 (150)	104 (220)	U		82 (180)	38 (100)	98 (210)
HDPE	76 (170)	76 (170)	60 (140)		60 (140)	60 (140)	60 (140)
PP	98 (210)	104 (220)	104 (220)	60 (140)	49 (120)	43 (110)	
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	
PVDF	98 (210)	104 (220)	71 (160)	65 (150)	138 (280)	138 (280)	127 (260)
OTHER MATERIALS							
Butyl	82 (180)	87 (190)	82 (180)		54 (130)	32 (90)	
EPDM	154 (310)	149 (300)	149 (300)	149 (300)	71 (160)	60 (140)	60 (140)
EPT	98 (210)	93 (200)	87 (190)	26 (80)	U	U	
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	15 (60)	15 (60)	15 (60)	15 (60)	193 (380)	204 (400)	82 (180)
Borosilicate Glass	U	U	U	U	121 (250)	65 (140)	121 (250)
Neoprene	93 (200)	93 (200)	93 (200)	93 (200)	U	U	
Nitrile	71 (160)	65 (150)	71 (160)	65 (150)	U	U	
N-Rubber	65 (150)	65 (150)	65 (140)	65 (140)	32 (90)	32 (90)	
PFA	121 (250)	121 (250)	26 (80)		93 (200)		
PVDC	60 (140)	65 (150)	54 (80)	U	54 (130)	49 (120)	
SBR Styrene	U	U	U	U			

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Sodium Nitrate	Sodium Phosphate Acid	Sodium Phosphate Alkaline	Sodium Phosphate Neutral	Sodium Sulfite 10%	Sour Crude Oil	Solfonated Detergents
METALS							
Aluminum	176 (350)	U	U	U	98 (210)		
Bronze	38 (100)	98 (210)	32 (90)	98 (210)	U		
Carbon Steel	65 (150)		65 (150)		26 (80)		
Copper	43 (110)	26 (80)	32 (90)	32 (90)	26 (80)		
Ductile Iron, Pearlitic							
Hastelloy C	32 (90)	98 (210)	98 (210)	98 (210)	98 (210)	65 (150)	65 (150)
Inconel	93 (200)	98 (210)	98 (210)	98 (210)	98 (210)		
Monel	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)		
Nickel	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)		
304 SS	98 (210)	98 (210)	98 (210)	98 (210)	98 (210)		
316 SS	176 (350)	98 (210)	98 (210)	98 (210)	98 (210)		
NON-METALS							
ABS	60 (140)	60 (140)			60 (140)		
CPVC	82 (180)	76 (170)	82 (180)	82 (180)	82 (180)	87 (190)	76 (170)
Resins - Epoxy	149 (300)	U	U	U	121 (250)	87 (190)	121 (250)
- Furan	71 (160)	121 (250)		U	121 (250)		121 (250)
- Polyester	104 (220)	98 (210)			93 (200)	104 (220)	93 (200)
- Vinyl Ester	98 (210)	109 (320)	98 (210)	98 (210)	98 (210)	127 (260)	98 (210)
HDPE	60 (140)	32 (90)	26 (80)	26 (80)	60 (140)	26 (80)	
PP	98 (210)	93 (200)	98 (210)	93 (200)	60 (140)	65 (150)	49 (120)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)				60 (140)	
PVDF	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)	
OTHER MATERIALS							
Butyl	82 (180)	93 (200)	82 (180)	93 (200)	87 (190)		
EPDM	138 (280)	98 (210)	98 (210)	98 (210)	60 (140)	U	
EPT	82 (180)	98 (210)	98 (210)	98 (210)	98 (210)	U	
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	15 (60)	87 (190)	82 (180)	87 (190)	87 (190)	U	
Borosilicate Glass	121 (250)	98 (210)	93 (200)	98 (210)	U		98 (210)
Neoprene	93 (200)	60 (140)	93 (200)	60 (140)	87 (190)		
Nitrile	65 (150)	82 (180)	93 (200)	82 (180)	87 (190)	60 (140)	
N-Rubber	65 (150)	71 (160)	71 (160)	71 (160)	65 (150)		
PFA	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	93 (200)	
PVDC	65 (150)	65 (150)	65 (150)	65 (150)	65 (150)	65 (150)	
SBR Styrene							

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Sulfuric Acid 10%	Sulfuric Acid 30%	Sulfuric Acid 50%	Sulfuric Acid 60%	Sulfuric Acid 70%	Sulfuric Acid 80%	Sulfuric Acid 90%
METALS							
Aluminum	U	U	U	U	U	U	U
Bronze	U	U	U	U	U	U	U
Carbon Steel	U	U	U	U	U	U	U
Copper	U	U	U	U	U	U	U
Ductile Iron, Pearlitic						32 (90)	
Hastelloy C	98 (210)	87 (190)	109 (230)	127 (260)	93 (200)	116 (240)	87 (190)
Inconel	U	U	U	U	U	U	U
Monel	26 (80)	26 (80)	49 (120)	54 (130)	26 (80)	26 (80)	U
Nickel	26 (80)	26 (80)	32 (90)	32 (90)	U	U	U
304 SS	U	U	U	U	U	32 (90)	26 (80)
316 SS	U	U	U	U	U	43 (110)	26 (80)
NON-METALS							
ABS	60 (140)	32 (90)	54 (130)	U	U	U	U
CPVC	82 (180)	82 (180)	82 (180)	87 (190)	93 (200)	116 (240)	U
Resins - Epoxy	60 (140)	49 (1230)	43 (110)	43 (110)	43 (110)	U	U
- Furan	121 (250)	121 (250)	127 (260)	121 (250)	127 (260)	U	U
- Polyester	104 (220)	104 (220)	104 (220)	71 (160)	71 (160)	U	U
- Vinyl Ester	93 (200)	82 (180)	98 (210)	87 (190)	82 (180)	U	U
HDPE	60 (140)	60 (140)	60 (140)	26 (80)	26 (80)	U	U
PP	93 (200)	93 (200)	93 (200)	98 (210)	82 (180)	76 (170)	82 (180)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	U	U
PVDF	121 (240)	104 (220)	104 (220)	116 (240)	104 (220)	93 (200)	98 (210)
OTHER MATERIALS							
Butyl	82 (180)	82 (180)	65 (150)		38 (100)	38 (100)	U
EPDM	60 (140)	60 (140)	60 (140)		60 (140)	15 (60)	U
EPT	93 (200)	60 (140)	98 (210)		98 (210)	38 (100)	26 (80)
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
FKM	176 (350)	176 (350)	176 (350)		176 (350)	176 (350)	176 (350)
Borosilicate Glass	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)
Neoprene	93 (200)	93 (200)	93 (200)		93 (200)	U	U
Nitrile	60 (140)	60 (140)	93 (200)		U	15 (60)	U
N-Rubber	65 (150)	65 (150)	38 (100)		U	U	U
PFA	121 (250)	121 (250)	121 (250)	121 (250)	121 (250)	121 (250)	121 (250)
PVDC	49 (120)	26 (80)	U	U	U	U	U
SBR Styrene	U	U	U		U	U	U

Notes: U = unsatisfactory

XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Sulfuric Acid 95%	Sulfuric Acid 98%	Sulfuric Acid 100%	Sulfuric Acid 103%	Sulfuric Acid, Fuming	Sulfurous Acid	Tetrachloroethane
METALS							
Aluminum	U	U	U		32 (90)	187 (370)	15 (60)
Bronze	U	U	U		U	U	
Carbon Steel	32 (90)	38 (100)	43 (110)			U	26 (80)
Copper		U	U		U	38 (100)	15 (60)
Ductile Iron, Pearlitic	49 (120)	121 (250)	163 (325)				
Hastelloy C	143 (290)	98 (210)	87 (190)		32 (90)	187 (370)	71 (160)
Inconel	U	U	U	U	U	32 (90)	
Monel	U	U	U	U	U	U	
Nickel	U	U	U		U	U	
304 SS	32 (90)	26 (80)	26 (80)	U	32 (90)	U	26 (80)
316 SS	98 (210)	98 (210)	98 (210)	32 (90)	98 (210)	65 (150)	15 (60)
NON-METALS							
ABS	U	U	U	U	U	60 (140)	
CPVC	U	U	U	U	15 (60)	82 (180)	U
Resins - Epoxy	U	U	U	U	U	116 (240)	32 (90)
- Furan	U	U	U		U	71 (160)	71 (160)
- Polyester	U	U				43 (110)	
- Vinyl Ester	U	U	U	U	U	49 (120)	49 (120)
HDPE	U	U	U	U	U	60 (140)	U
PP	15 (60)	49 (120)	U	U	U	82 (180)	15 (60)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)	243 (470)
PVC Type 2	U	U	U	U	U	60 (140)	U
PVDF	98 (210)	60 (140)	U	U	U	121 (250)	121 (250)
OTHER MATERIALS							
Butyl	U	U	U	U		65 (150)	
EPDM	U	U	U	U	U	U	U
EPT	U	U	U	U		82 (180)	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)	204 (400)	216 (420)	204 (400)
FKM	176 (350)	198 (390)	87 (190)		93 (200)	204 (400)	93 (200)
Borosilicate Glass	204 (400)	204 (400)	204 (400)	204 (400)		109 (230)	
Neoprene	U	U	U	U	U	U	U
Nitrile	U	U		U	U	15 (60)	U
N-Rubber	U	U	U	U		U	U
PFA	121 (250)	93 (200)			26 (80)	98 (210)	
PVDC	U	U	U	U	U	26 (80)	
SBR Styrene	U	U	U	U	U		U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Tetrachloroethylene	Thread Cutting Oil	Toluene	Transformer Oil	Transformer Oil DTE/30	1,1,1 Trichloroethane	Trichloroethylene
METALS							
Aluminum	98 (210)		98 (210)	26 (80)	65 (150)		149 (300)
Bronze	32 (90)		176 (350)	32 (90)	65 (150)		26 (80)
Carbon Steel		82 (180)	176 (350)	26 (80)	65 (150)	26 (80)	26 (80)
Copper	32 (90)		98 (210)				26 (80)
Ductile Iron, Pearlitic							
Hastelloy C			98 (210)	32 (90)	65 (150)		98 (210)
Inconel			98 (210)				98 (210)
Monel			98 (210)	32 (90)	65 (150)		187 (370)
Nickel			98 (210)	32 (90)			98 (210)
304 SS		65 (150)	98 (210)	32 (90)		32 (90)	98 (210)
316 SS		65 (150)	176 (350)	32 (90)	65 (150)		187 (370)
NON-METALS							
ABS	U		U			U	U
CPVC	U	38 (100)	U	82 (180)	82 (180)	U	U
Resins - Epoxy	U		65 (150)	109 (230)			60 (140)
- Furan	121 (250)		127 (260)			26 (80)	82 (180)
- Polyester	43 (110)		U	104 (220)			U
- Vinyl Ester	49 (120)		49 (120)	149 (300)		U	U
HDPE	U		U	60 (140)	60 (140)	U	U
PP	U	49 (120)	15 (60)	43 (110)	65 (150)	U	15 (60)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	149 (300)	243 (470)	243 (470)
PVC Type 2	U		U			U	U
PVDF	121 (250)	93 (200)	98 (210)			49 (120)	127 (260)
OTHER MATERIALS							
Butyl			U	U			U
EPDM	U	U	U	U	U	U	U
EPT	U	U	U	U		U	U
FEP	204 (400)	204 (400)	204 (400)	204 (400)		204 (400)	204 (400)
FKM	204 (400)		204 (400)	204 (400)		26 (80)	204 (400)
Borosilicate Glass		98 (210)	121 (250)	32 (90)		93 (200)	132 (370)
Neoprene			U	54 (130)	U	U	U
Nitrile	U	15 (60)	65 (150)	104 (220)	60 (140)	U	U
N-Rubber			U	U			U
PFA	93 (200)		98 (210)	93 (200)			93 (200)
PVDC		49 (120)	28 (80)			32 (90)	26 (80)
SBR Styrene			U	U			U

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Turpentine	Water, Acid Mine	Water, Demineralized	Water, Distilled	Water, Potable	Water, Salt	Water, Sea
METALS							
Aluminum	87 (190)	U	82 (180)	U	98 (210)	U	38 (100)
Bronze	176 (350)	U		93 (200)	98 (210)	121 (250)	121 (250)
Carbon Steel	26 (80)	U	U	U		26 (80)	32 (90)
Copper	26 (80)	U		32 (90)	98 (210)	26 (80)	26 (80)
Ductile Iron, Pearlitic					30 (86)	32 (90)	32 (90)
Hastelloy C	38 (100)	32 (90)	93 (200)	298 (570)	98 (210)	149 (300)	298 (570)
Inconel	26 (80)	32 (90)	60 (140)	15 (60)		26 (80)	26 (80)
Monel	43 (110)			U	98 (210)	121 (250)	121 (250)
Nickel	26 (80)	U	93 (200)	26 (80)		26 (80)	32 (90)
304 SS	93 (200)	49 (120)	227 (440)	121 (250)	98 (210)	26 (80)	26 (80)
316 SS	176 (340)	49 (120)	227 (440)	121 (250)	98 (210)	121 (250)	121 (250)
NON-METALS							
ABS	U	60 (140)	60 (140)	60 (140)	26 (80)	60 (140)	32 (90)
CPVC	60 (140)	82 (180)	82 (180)	82 (180)	98 (210)	82 (180)	82 (180)
Resins - Epoxy	65 (150)	149 (300)	121 (250)	98 (210)		98 (210)	149 (300)
- Furan			121 (250)	93 (200)			121 (250)
- Polyester	26 (80)		71 (160)	93 (200)	98 (210)	82 (180)	104 (220)
- Vinyl Ester	65 (150)	98 (210)	98 (210)	98 (210)	98 (210)	82 (180)	82 (180)
HDPE	U	60 (140)	60 (140)	60 (140)		60 (140)	60 (140)
PP	26 (80)	104 (220)	104 (220)	104 (220)	82 (180)	104 (220)	104 (220)
PTFE	243 (470)	243 (470)	243 (470)	243 (470)	204 (400)	243 (470)	243 (470)
PVC Type 2	U	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)	60 (140)
PVDF	138 (280)	104 (220)	138 (280)	138 (280)	138 (280)	138 (280)	138 (280)
OTHER MATERIALS							
Butyl	U		60 (140)			87 (190)	
EPDM	U	93 (200)	121 (250)	149 (300)	121 (250)	121 (250)	121 (250)
EPT	U	98 (210)	98 (210)	98 (210)		93 (200)	93 (200)
FEP	204 (400)	204 (400)	204 (400)	204 (400)		204 (400)	204 (400)
FKM	209 (410)	87 (290)	87 (190)	87 (190)	149 (300)	87 (190)	87 (190)
Borosilicate Glass	121 (250)	98 (210)		121 (250)	98 (210)	98 (210)	98 (210)
Neoprene	U	98 (210)	98 (210)	93 (200)	82 (180)	98 (210)	98 (210)
Nitrile	104 (220)	98 (210)	98 (210)	98 (210)	82 (180)	98 (210)	98 (210)
N-Rubber	U		65 (150)	65 (150)		65 (150)	
PFA	93 (200)	93 (200)	93 (200)	93 (200)		93 (200)	93 (200)
PVDC	49 (120)	82 (180)	76 (170)	76 (170)	76 (170)	82 (180)	76 (170)
SBR Styrene	U	93 (200)	98 (210)	93 (200)		93 (200)	93 (200)

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Table B-1. Fluid/Material Matrix

FLUID/MATERIAL	Water, Sewage	Xylene	Zinc Chloride		
METALS					
Aluminum		93 (200)	U		
Bronze	32 (90)	121 (250)	U		
Carbon Steel	32 (90)	93 (200)	U		
Copper	32 (90)	93 (200)	U		
Ductile Iron, Pearlitic			U		
Hastelloy C		149 (300)	121 (250)		
Inconel		93 (200)	26 (80)		
Monel		39 (200)	93 (200)		
Nickel		93 (200)	93 (200)		
304 SS	32 (90)	93 (200)	U		
316 SS	32 (90)	93 (200)	93 (200)		
NON-METALS					
ABS	26 (80)	U	60 (140)		
CPVC	82 (180)	U	82 (180)		
Resins - Epoxy		60 (140)	121 (250)		
- Furan		127 (260)	127 (260)		
- Polyester		32 (90)	121 (250)		
- Vinyl Ester		60 (140)	82 (180)		
HDPE	60 (140)	U	60 (140)		
PP	104 (220)	15 (60)	93 (200)		
PTFE	243 (470)	243 (470)	243 (470)		
PVC Type 2	60 (140)	U	60 (140)		
PVDF	121 (250)	98 (210)	127 (260)		
OTHER MATERIALS					
Butyl		U	87 (190)		
EPDM	98 (210)	U	149 (300)		
EPT	60 (140)	U	82 (160)		
FEP	204 (400)	227 (440)	204 (400)		
FKM	87 (190)	204 (400)	204 (400)		
Borosilicate Glass		121 (250)	98 (210)		
Neoprene	71 (160)	U	71 (160)		
Nitrile	87 (190)	U	104 (220)		
N-Rubber		U	65 (150)		
PFA	93 (200)	93 (200)	93 (200)		
PVDC	76 (170)	U	76 (170)		
SBR Styrene		U			

Notes: U = unsatisfactory
XX (XX) = degrees C (degrees F)

Appendix C
Design Example

The following paragraphs present an example design that utilizes the material and information contained in Chapters 1 through 12, and Appendix B. The calculations and assumptions are specific to the example conditions presented, and may not necessarily represent conditions at an actual, specific site.

C-1. Design Example

A facility requires an upgrade and retrofit to their existing wastewater pretreatment system. The pretreatment system is required to reduce the dissolved metal content of two process waste waters before introduction into a biologically based central treatment plant. Due to process changes over the years and reduced effluent limits, the existing pretreatment facility no longer removes enough metals to consistently meet effluent requirements.

The waste waters are produced from a plating process (Process A) and from the finishing stages of a metal fabrication facility (Process B). The latter could include metal cleaning using organic solvents and painting operations. The retrofit is to include the renovation and splitting of an existing, covered, concrete wetwell (P1560). Half of the wetwell will now act as an influent wetwell (P1560) to a new treatment train and the other half will act as the clearwell (P1510) for the effluent from the new treatment system. The new treatment system will include a low-profile air stripper to reduce solvent concentrations followed by a ferrous-based precipitation reactor and associated flocculation tank and clarifier. Figure C-1 is the flow diagram of the proposed pretreatment system renovation, and Figure C-2 is the piping and instrumentation diagram. Figure C-3 is the general equipment arrangement with the anticipated piping layout.

The influent to the pretreatment system averages 3.79 x 10^{-3} m^3/s with a maximum future flow of 5.36 x 10^{-3} m^3/s and a process temperatures of 16°C-minimum, 23.9°C-normal, and 46°C-maximum. The average pH is 5.4 due to the presence of chromic and sulfuric acids, although occasional upsets have produced pH as low as 3.6. The pollutant concentrations are summarized in Table C-1.

Table C-1
Pollutant Concentrations

Parameter	Maximum (mg/l)	Average (mg/l)
Total Cyanide	0.368	0.078
Chromium	80.2	24.9
Nickel	74.9	15.3
Copper	6.29	0.71
Zinc	10.3	0.88
Lead	12.8	1.57
Silver	0.84	0.21
Cadmium	3.24	0.77
Xylene	210	53.2
Toluene	180	45.1
111-Trichloroethylene	500	48.3
Ethyl Ether	54.3	15.2

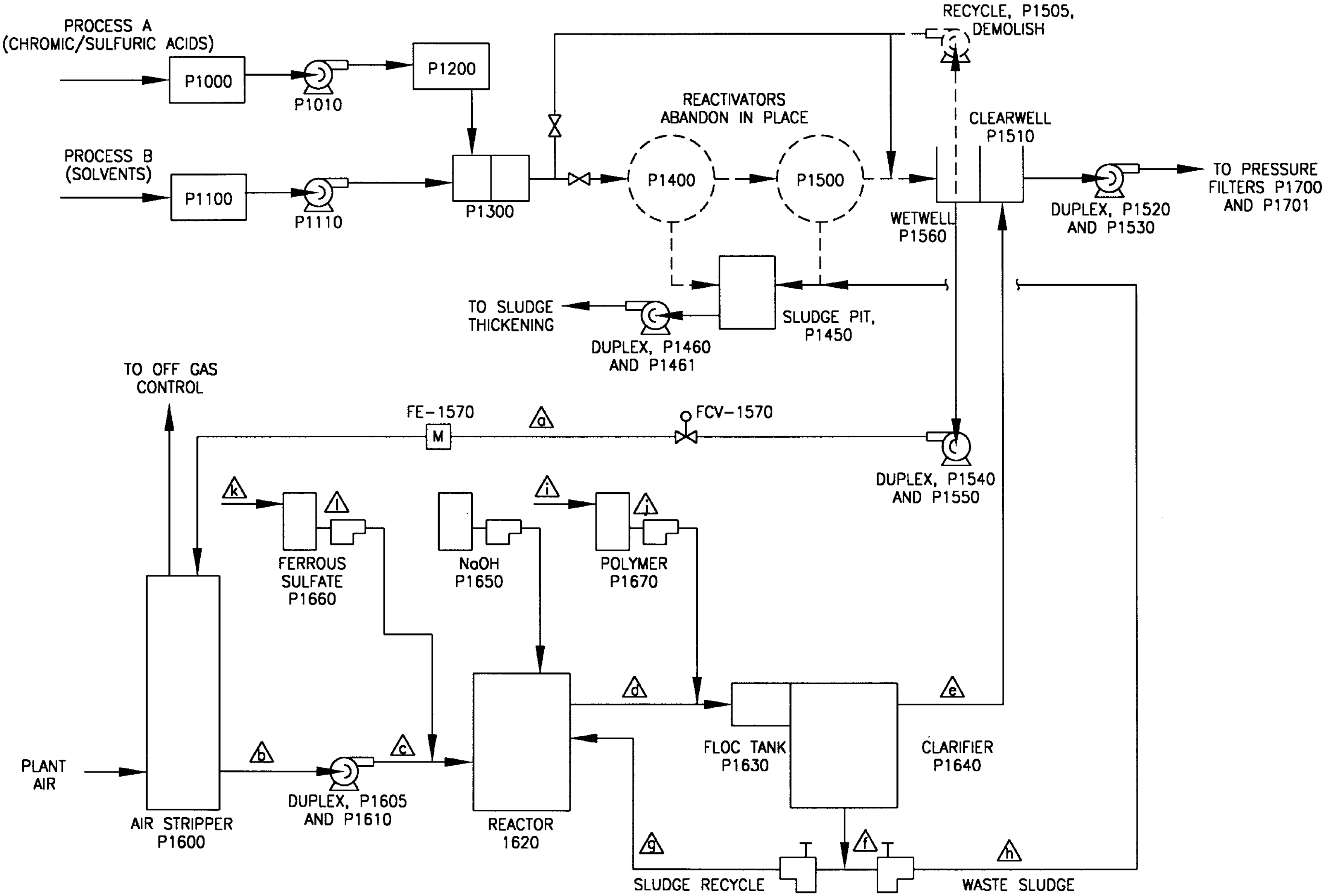


Figure C-1. Design Example Process Flow Diagram
(Process Conditions Table continued on next page)

Table C-2
Process Conditions, Design Example Process Flow Diagram, Continued

Point	Line Designation	Normal			Maximum			Minimum		
		Flow ($m^3/s \times 10^{-3}$)	Temp. (EC)	Pressure (kPa)	Flow ($m^3/s \times 10^{-3}$)	Temp. (EC)	Pressure (kPa)	Flow ($m^3/s \times 10^{-3}$)	Temp. (EC)	Pressure (kPa)
a	XXX-INF-1500	3.79	23.9	tbd	5.36	46.0	tbd	3.79	16.0	tbd
b	XXX-IAS-1600	3.79	23.9	tbd	5.36	46.0	tbd	3.79	16.0	tbd
c	XXX-IAS-1620	3.79	23.9	tbd	5.36	46.0	tbd	3.79	16.0	tbd
d	XXX-PRI-1630	3.79	23.9	gravity flow	5.36	46.0	gravity flow	3.79	16.0	gravity flow
e	XXX-EFF-1640	3.79	23.9	gravity flow	5.36	46.0	gravity flow	3.79	16.0	gravity flow
f	XXX-SLG-1650	2.30	23.9	250	2.75	46.0	250	2.30	16.0	250
g	XXX-SLG-1651	0.36	23.9	250	2.75	46.0	250	0.36	16.0	250
h	XXX-SLG-1660	1.94	23.9	250	2.75	46.0	250	1.94	16.0	250
I	XXX-PYS-101	0.438	23.9	tbd	0.438	46.0	79.5	0.438	16.0	tbd
j	XXX-PYS-102	0.00105	23.9	tbd	0.00131	46.0	79.5	0.00105	16.0	tbd
k	XXX-FES-111	0.842	23.9	tbd	0.842	46.0	79.5	0.842	16.0	tbd
l	XXX-FES-112	0.0105	23.9	tbd	0.0131	46.0	79.5	0.0105	16.0	tbd

Notes:

XXX - line size to be determined in calculations
tbd - to be determined

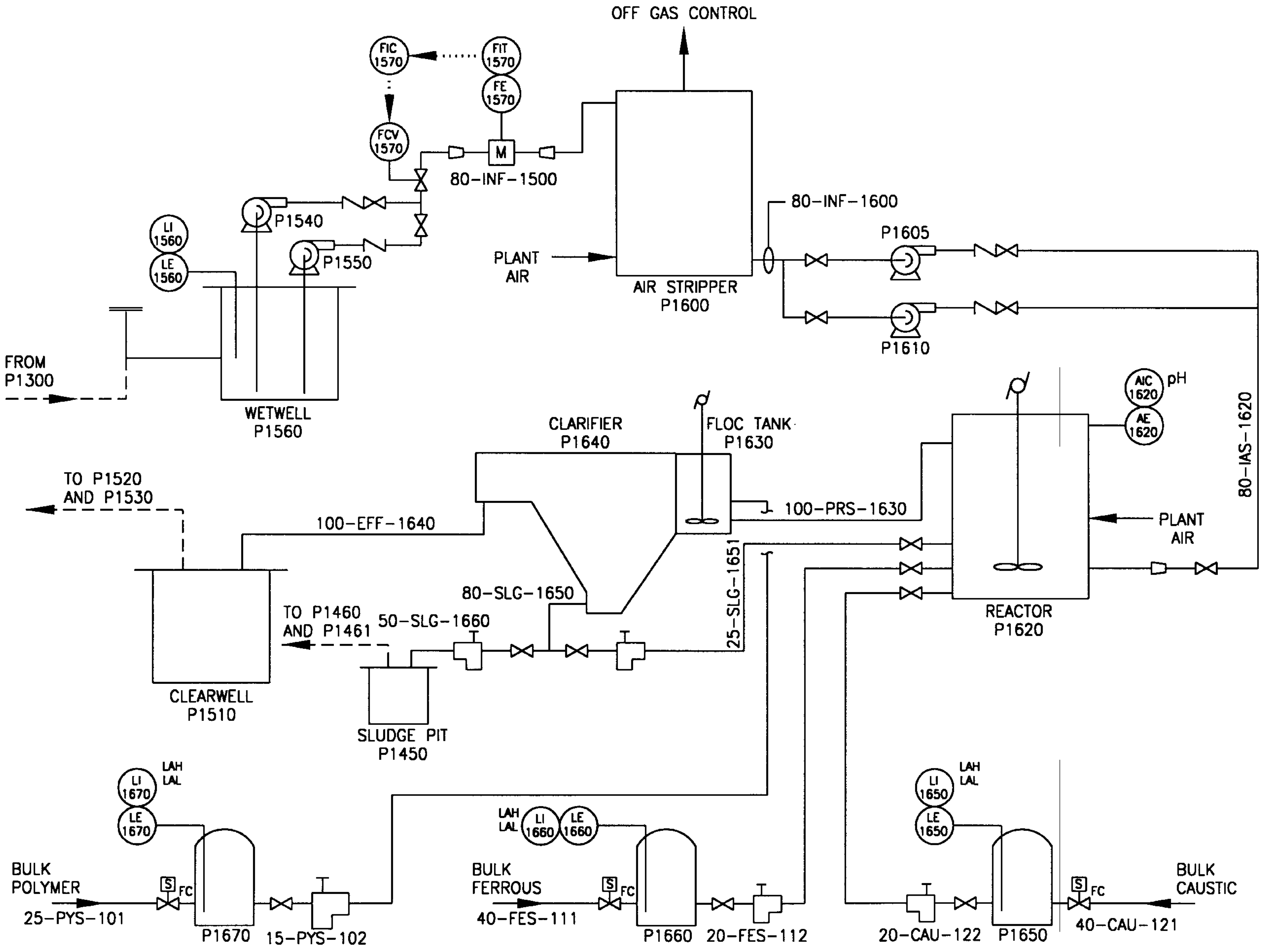


Figure C-2. Design Example Piping and Instrumentation Diagram

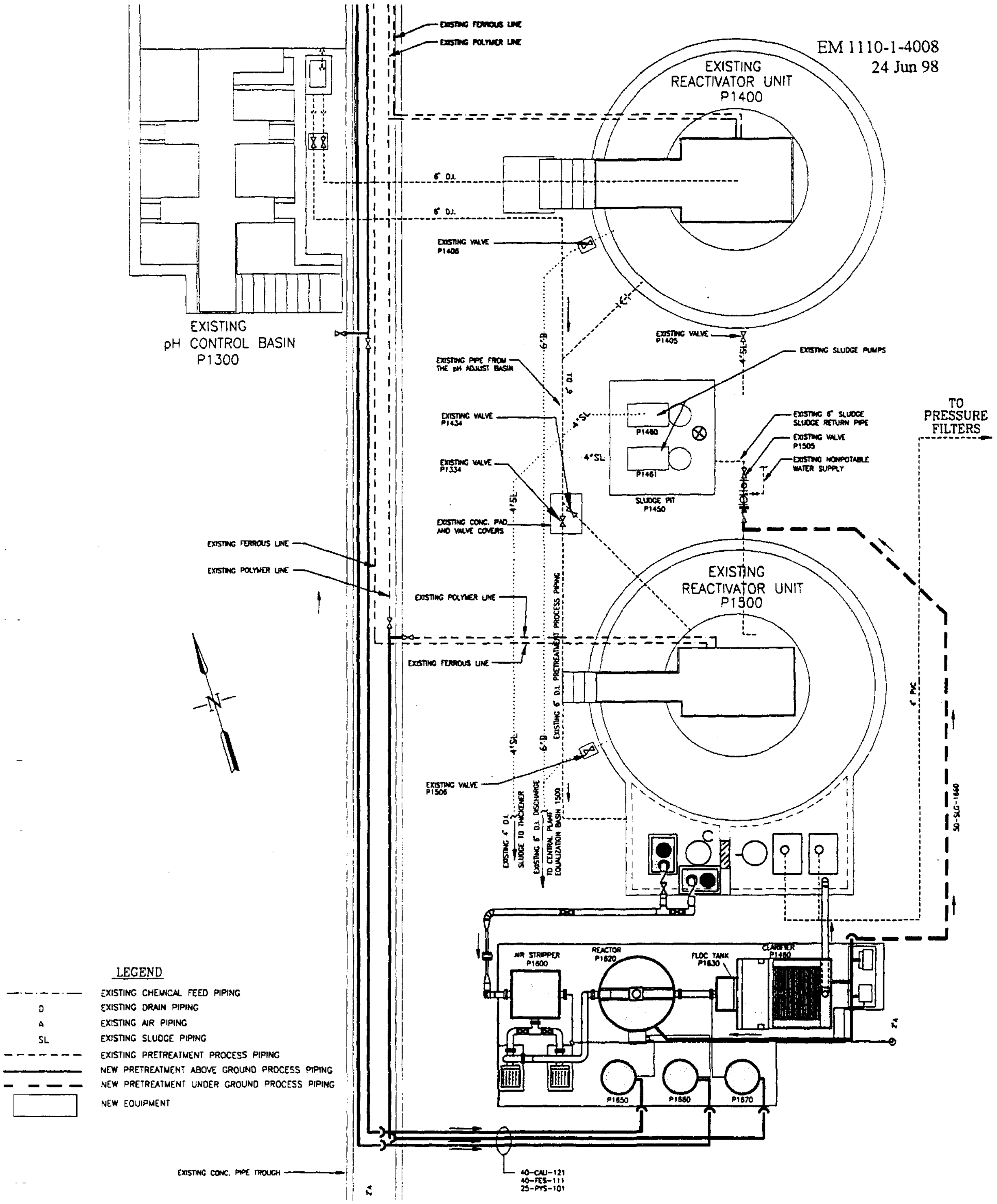
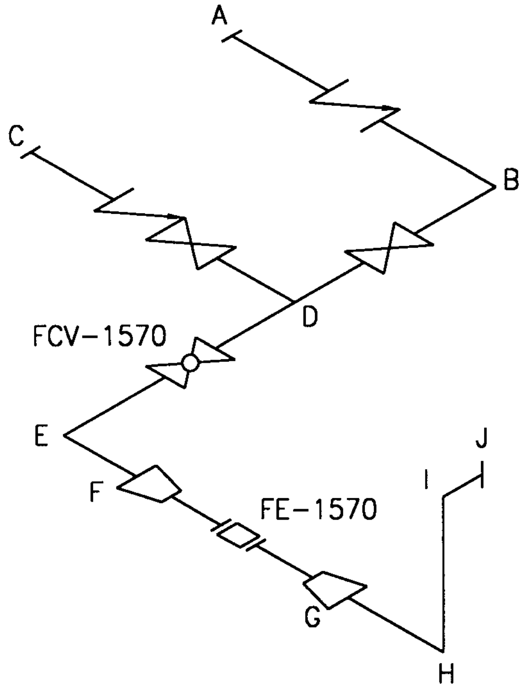


Figure C-3. Piping Layout Plan

C-2. Solution

a. Line XXX-INF-1500
Influent from Wetwell P1560 to Air Stripper P1600



Sketch C-1

Flow is either through A-D or C-D, but not both simultaneously

Maximum Flowrate, Q = 5.36 x 10^{-3} m^3/s

Elevation Change (H-I) = 2.44 m (= 23.9 kPa head)

Total run = 7.84 m for A-J
= 7.33 m for C-J

Fittings (identical for either A-J or C-J)
- 1 swing check valve
- 1 gate valve (isolation)
- 1 flow control valve
- 1 reducer
- 1 expansion

MATERIAL OF CONSTRUCTION

Referring to the fluid/material matrix in Appendix B, the potential for mixed acids eliminates aluminum, bronze, copper, carbon steel and stainless steel alloys; and the solvent content in the wastewater eliminates ABS, PVC, CPVC, HDPE and FRP. Similarly, examining the potential use of lined piping, the solvents eliminate rubber, PP and PVDC, However, PTFE and PVDF liners are acceptable.

The design specifications shall be developed to allow a liner of either PVDF , minimum thickness of 4.45 mm (confirm with pipe sizing), or PTFE (to be provided with weep vents) and a carbon steel shell of ASTM A 106, Grade A. The shell is to be joined with chamfered threaded flanges. The PVDF liner is selected for the example calculations.

PIPE SIZING/PRESSURE DROP

Step 1. Select pipe size by dividing the volumetric flowrate by the desired velocity (normal service, V = 2.1 m/s with the mid-range preferred for most applications).

$$A = \pi \frac{D_i^2}{4} = \frac{Q}{V}$$

$$D_i = \left[\frac{4}{\pi}\ \frac{(5.36\ x\ 10^{-3})\ m^3/s}{2.1\ m/s}\right]^{0.5} \left(1000\ \frac{mm}{m}\right)$$

$$= 57\ mm$$

Step 2. From Table 1-1, the next largest nominal diameter is 65 mm. The commercial availability of 65 mm lined pipe is checked (65 mm is not a commonly used pipe size). This size is not available except through special order. The size choices are 50 mm or 80 mm.

50 mm pipe: From Table 9-8, a PVDF thickness of 4.37 mm is required to prevent permeation.

$$D_i = 50\ mm - (4.37\ mm)(2) = 41.3\ mm$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{5.36\ x\ 10^{-3}\ m^3/s}{\frac{\pi}{4}(0.0413\ m)^2} = 4.0\ m/s$$

The actual velocity, 4.0 m/s, > the acceptable range, 2.1 ± 0.9 m/s. Therefore, the 50 mm pipe size is rejected.

80 mm pipe: From Table 9-8, a PVDF thickness of 4.45 mm is required to prevent permeation.

$$D_i = 80\ mm - (4.45\ mm)(2) = 71.1\ mm$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{5.36\ x\ 10^{-3}\ m^3/s}{\frac{\pi}{4}(0.0711\ m)^2} = 1.35\ m/s$$

The actual velocity, 1.35 m/s, is within the acceptable range, 2.1 ± 0.9 m/s.

Therefore, the 80 mm PVDF lined pipe is specified and D_i = 71.1 mm, D_o = 90 mm and the structural wall thickness = 5 mm. The line designation is amended to: 80-INF-1500.

In addition, a pipe reduction is required to accommodate a magnetic flowmeter. From an instrument vendor nomograph over the process flow range, the magmeter should have a 40 mm bore with minimum straight, unobstructed runs of 3 x D_i upstream and 2 x D_i downstream. From lined piping catalogs, lined piping typically has a minimum section length. For 40 mm pipe, one vendor has fixed flange spools available with a minimum length of 819 mm. Use a 80 mm by 40 mm concentric reducer/expansion at one end of each straight pipe run; see Sketch C-2.

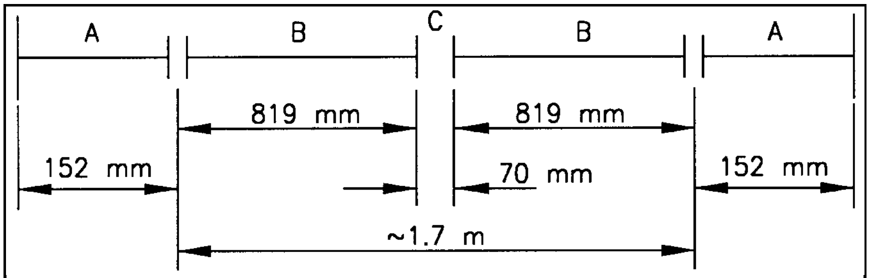
The actual velocity through the reduced section is required for pressure drop calculations. From Table 9-8, a PVDF thickness of 4.07 mm is required to prevent permeation.

$$D_i = 40\ mm - (4.07\ mm)(2) = 31.9\ mm$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{5.36\ x\ 10^{-3}\ m^3/s}{\frac{\pi}{4}(0.0319\ m)^2} = 6.71\ m/s$$

The 40 mm spools have a length of 819 mm which equals 25.7 x D_i. Therefore, the minimum unobstructed run requirement for the meter is satisfied.



Sketch C-2

Notes:
A= identical 80 mm by 40 mm concentric reducers, $\beta = 0.5$, $\theta = 7.56°$
B = identical 40 mm spools with flanged ends, 819 mm length
C = wafer style mag-meter, lay length is 70 mm.

Step 3. At 23.9°C, $\nu = 8.94 \times 10^{-7}$ m²/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]_{80\ mm} + \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]_{40\ mm}$$

80 mm pipe:

Ref. p. 3-8.

$$R_e = \frac{D_i\,V}{\nu} = \frac{(0.0711\ m)(1.35\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 1.1\ x\ 10^5 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{71.1\ mm} = 0.00002$$

Therefore, f = 0.028 from the Moody Diagram (Figure 3-1).

From Sketch C-1, for run A-J the sum of the minor loss coefficients from Table 3-3:

Table C-3
Minor Losses for 80-INF-1500: Run A-J

Minor Loss	**K**
1 gate valve (open)	0.2
1 swing check valve	2.5
4 x 90° elbows	4(0.9)
1 tee-flow through	0.6
1 concentric reducer	0.08
1 exit	1.0
ΣK =	7.98

$$h_{L80} = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.028)(7.84 - 1.7\ m)}{0.0711\ m} + 7.98\right]\frac{(1.35\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 0.97\ m$$

From Sketch C-1, for run C-J the sum of the minor loss coefficients from Table 3-3:

Table C-4
Minor Losses for 80-INF-1500: Run C-J

Minor Loss	**K**
1 swing check valve	2.5
3 x 90° elbows	3(0.9)
1 tee-branch flow	1.6
1 concentric reducer	0.08
1 exit	1.0
ΣK =	8.08

$$h_{L80} = \left(\frac{f\ L}{D_i} + \Sigma K\right) \frac{V^2}{2\ g}$$

$$= \left[\frac{(0.028)(7.33\ - 1.7\ m)}{0.0711\ m} + 8.08\right] \frac{(1.35\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 0.96\ m$$

Therefore, use run A-J as worst case for the 80 mm pipe section; h_L = 0.97 m.

40 mm pipe section:

Ref. p. 3-8.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.0319\ m)(6.71\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 2.4\ x\ 10^5\ -\ turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3-1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{31.9\ mm} = 0.00005$$

Therefore, f = 0.026 from the Moody Diagram (Figure 3-1).

From Sketch C-1, for run FG the sum of the minor loss coefficients from Table 3-3:

Table C-5
Minor Losses for 80-INF-1500: Run F-G

MinorLoss	K
1 enlargement	-0.19 (pressure gain)
ΣK =	-0.19

$$h_{L40} = \left(\frac{f\ L}{D_i} + \Sigma K\right) \frac{V^2}{2\ g}$$

$$= \left[\frac{(0.026)(1.7\ m)}{0.0319\ m} + (-0.19)\right] \frac{(6.71\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 2.74\ m$$

The total pressure drop through line 80-INF-1500: h_L = 0.97 m. + 2.74 m = 3.71 m or 35.4 kPa. This does not include the pressure drop resulting from the control valve, FCV-1570.

Step 4. Size the control valve, FCV-1570, such that the pressure drop through FCV-1570 = 33% of the piping system loss = 0.33 (36.4 kPa) = 12.0 kPa. The flow measurement device is proportional to flow squared so that an equal percentage for characteristic is desired. Assume a ball valve with V-port will be used so let F_d = 1.0, and R_m = 0.9 (from Table 10-9). From reference materials, s.g. = 1.0.

Ref. p. 10-13.

$$C_v = \frac{Q}{N_1}\sqrt{\frac{s.g.}{\Delta P}}$$

$$= \frac{(5.36\ x\ 10^{-3}\ m^3/s)(3600\ s/hr)}{0.085}\sqrt{\frac{1.0}{12.0\ kPa}}$$

$$= 65.5$$

$$Re_v = \frac{N_4\ F_d\ Q}{\nu\ R_m^{1/2} C_V^{1/2}}\left[\frac{R_m^2\ C_v^2}{N_2\ d^4} + 1\right]^{1/4} =$$

$$\frac{(76{,}000)(1.0)[(5.36\ x\ 10^{-3})(3600)]}{(.894)(0.9)^{1/2}(65.5)^{1/2}}\ x$$

$$\left[\frac{(0.9)^2(65.5)^2}{(0.00214)(80)^4} + 1\right]^{1/4} = 2.2\ x\ 10^5$$

F_R = 1.0 from Figure 10-4 (a viscosity correction is not required due to the high Reynolds number).

Ref. p. 10-13.

$$C_{vc} = (C_v)(F_R) = (65.5)(1.0) = 65.5$$

From manufacturer's data (see Table C-6), a 80 mm, 60° V-port ball valve at 80% travel in a 80 mm pipe has a C_v of 67.2 and a R_m of 0.86.

Ref. p. 10-13.

$$\Delta P_{actual} = \frac{s.g.}{\left(\frac{N_1\ C_v}{Q}\right)^2}$$

$$= \frac{1.0}{\left(\frac{(0.085)(67.2)}{(5.36\ x\ 10^{-3})(3600)}\right)^2} = 11.4\ kPa$$

Step 5. The required pump head is equal to the sum of the elevation change, the piping pressure drop and the valve pressure loss.

$$P_{head} = 23.9\ kPa + 36.4\ kPa + 11.4\ kPa$$

$$= 71.7\ kPa\ x\ 1.25\ safety\ factor$$

$$= 89.6\ kPa$$

Step 6. The control valve ΔP is checked. The valve inlet pressure, Pi, is equal to the required pump head less the piping losses from the pump to the valve (C-FCV on Sketch 1; approximately 4.9 kPa).

$$P_i = 89.6\ kPa - 4.9\ kPa = 84.7\ kPa$$

Ref. p. 10-17.

$$\Delta P_{allow} = R_m^2\ (P_i - r_c\ P_v)$$

$$= (0.86)^2\ [84.7\ kPa - (0.96)(13.17\ kPa)]$$

$$\Delta P_{allow} = 60.4\ kPa > \Delta P_v\ ,$$

so the valve is acceptable.

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 89.6 kPa. No potential pressure transients exist because the valve fails in the last position. An external corrosion allowance of 2 mm is to be designed. Pressure integrity is acceptable if the minimum wall thicknesses for both the 80 mm and 40 mm pipe sections meet ASME 31.3 code. For ASTM A 106, Grade A pipe, ASME B31.3 tables provide S = 110 MPa, E = 1.0, and y = 0.4.

Ref. p. 3-15.

$$t_m = t + A = \frac{P\ D_o}{2\ (S\ E + P\ y)} + A$$

80 mm pipe:

$$t_m = \frac{(0.0896\ MPa)(90\ mm)}{2[(110\ MPa)(1.0) + (0.0896\ MPa)(0.4)]}$$

$$+ 2\ mm = 2.04\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{2.04\ mm}{1.0 - 0.125} = 2.3\ mm$$

Nominal 80 mm pipe has a thickness of 5 mm; therefore, the 80 mm pipe section satisfies pressure intergrity.

Table C-6
Flow Coefficient - C_v - Characterized Seat Control Valves

Valve Size mm (in)	Line Size mm (in)	Percent of Rated Travel (Degree of Rotation)									
		10 (9)	20 (18)	30 (27)	40 (36)	50 (45)	60 (54)	70 (63)	80 (72)	90 (81)	100 (90)
12.7 (0.5), 6.35 (0.25), 0.79 (0.0313) Wide Slot	15 (½)	0.02	0.03	0.07	0.12	0.16	0.20	0.24	0.28	0.32	0.36
	20 (3/4)	0.02	0.03	0.07	0.10	0.14	0.18	0.21	0.25	0.29	0.32
	25 (1)	0.02	0.03	0.06	0.10	0.13	0.16	0.18	0.21	0.27	0.30
12.7 (0.5), 6.35 (0.25), 1.59 (0.0625) Wide Slot	15 (½)	0.02	0.07	0.20	0.33	0.46	0.60	0.73	0.86	0.99	1.10
	20 (3/4)	0.02	0.06	0.18	0.29	0.41	0.53	0.65	0.77	0.88	0.98
	25 (1)	0.02	0.06	0.17	0.27	0.38	0.50	0.61	0.71	0.82	0.91
12.7 (0.5), 6.35 (0.25) 30°V	15 (½)	0.02	0.10	0.20	0.34	0.55	0.83	1.11	1.59	2.08	2.50
	20 (3/4)	0.02	0.09	0.18	0.30	0.49	0.74	0.99	1.41	1.85	2.22
	25 (1)	0.02	0.08	0.17	0.28	0.46	0.69	0.92	1.32	1.73	2.07
12.7 (0.5), 6.35 (0.25) 60°V	15 (½)	0.02	0.12	0.33	0.90	0.84	1.35	1.95	3.10	4.37	5.92
	20 (3/4)	0.02	0.10	0.29	0.44	0.75	1.20	1.74	2.76	3.90	5.27
	25 (1)	0.02	0.10	0.27	0.41	0.70	1.12	1.62	2.57	3.63	4.91
25 (1) 30°V	25 (1)	0.02	0.21	0.56	0.96	1.58	2.39	3.43	4.62	6.15	7.26
	40 (1.5)	0.02	0.16	0.44	0.75	1.23	1.86	2.68	3.60	4.80	5.66
	50 (2)	0.02	0.15	0.40	0.69	1.14	1.72	2.47	3.33	4.43	5.23
25 (1) 60°V	25 (1)	0.02	0.30	0.78	1.24	2.27	3.59	5.28	8.29	11.6	15.5
	40 (1.5)	0.02	0.23	0.61	0.97	1.77	2.80	4.12	6.47	9.05	12.1
	50 (2)	0.02	0.22	0.56	0.89	1.63	2.58	3.80	5.97	8.35	11.2
50 (2) 30°V	50 (2)	0.02	0.55	1.72	3.41	5.65	8.26	12.1	16.6	22.2	26.5
	80 (3)	0.02	0.45	1.41	2.80	4.63	6.77	9.92	13.6	18.2	21.7
	100 (4)	0.02	0.41	1.27	2.52	4.18	6.11	8.95	12.3	16.4	19.6
50 (2) 60°V	50 (2)	0.02	0.70	2.64	4.90	9.32	15.5	22.2	32.1	47.2	61.6
	80 (3)	0.02	0.57	2.16	4.02	7.64	12.7	18.2	26.3	38.7	50.5
	100 (4)	0.02	0.52	1.95	3.63	6.90	11.5	16.4	23.8	34.9	45.6
80 (3) 30°V	80 (3)	0.02	0.75	2.68	6.00	10.2	16.9	24.5	33.9	44.8	54.2
	100 (4)	0.02	0.54	1.93	4.32	7.34	12.2	17.6	24.4	32.3	39.0
	150 (6)	0.02	0.41	1.47	3.30	5.61	9.30	13.5	18.6	24.6	29.8
80 (3) 60°V	80 (3)	0.02	0.95	4.25	10.1	18.6	29.4	46.3	**67.2**	94.4	124.6
	100 (4)	0.02	0.68	3.06	7.27	13.4	21.2	33.3	48.4	68.0	89.7
	150 (6)	0.02	0.52	2.34	5.56	10.2	16.2	25.5	37.0	51.9	68.5
100 (4) 30°V	100 (4)	0.02	0.80	3.59	8.50	16.1	26.8	40.2	56.6	72.5	89.8
	150 (6)	0.02	0.52	2.33	5.53	10.5	17.4	26.1	36.8	47.1	58.4
	200 (8)	0.02	0.44	1.97	4.68	8.86	14.7	22.1	31.1	39.9	49.4
100 (4) 60°V	100 (4)	0.02	0.90	5.69	15.4	28.8	48.6	73.4	107.0	150.7	200.0
	150 (6)	0.02	0.59	3.70	10.0	18.7	31.6	47.7	69.6	98.0	130.0
	200 (8)	0.02	0.50	3.13	8.47	15.8	26.7	40.4	58.9	82.9	110.0
R_M		0.96	0.95	0.94	0.93	0.92	0.90	0.88	**0.86**	0.82	0.75

Note: C_v is defined as the flow of liquid in gallons per minute through a valve with a pressure drop of 1 psi across the valve.
Source: Table condensed from Worchester Controls "Series CPT Characterized Seat Control Valve", PB-V-3, Supplement 1.

40 mm pipe:

$$t_m \; ' \; \frac{(0.0896\ MPa)(50\ mm)}{2[(110\ MPa)(1.0)\ \%\ (0.0896\ MPa)(0.4)]}$$

$$\%\ 2\ mm\ '\ 2.02\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM}\ '\ \frac{2.02\ mm}{1.0\ \&\ 0.125}\ '\ 2.3\ mm$$

Nominal 40 mm pipe has a thickness of 5 mm; therefore, the 40 mm pipe section satisfies pressure intergrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - The 80-INF-1500 dead weight is strictly the piping. 80-INF-1500 will not be insulated because it will be under continuous use. Because the piping section will be continuously full, the weight of the fluid will be determined as part of the dead weight.

$$W\ '\ W_P\ \%\ W_L\ '\ A_P\ *_P\ \%\ \frac{B}{4}\ D_i^2\ *_L$$

From a lined piping manufacturer, $(A_P)(*_P)$ = 133 N/m for 80 mm lined piping and 67.1 N/m for 40 mm lined piping.

80 mm pipe:

$$W_{80}\ '\ 133\ N/m\ \%\ \frac{B}{4}\ 71.1\ mm^2\ (9781\ N/m^3)\ x$$

$$(10^{\&6} m^2/mm^2)\ '\ 172\ N/m;\ uniformly\ distributed$$

40 mm pipe:

$$W_{40}\ '\ 67.1\ N/m\ \%\ \frac{B}{4}\ 31.9\ mm^2\ (9781\ N/m^3)\ x$$

$$(10^{\&6} m^2/mm^2)\ '\ 74.9\ N/m;\ uniformly\ distributed$$

Step 3. Wind - From TI 809-01, the basic wind speed is 40.2 m/s. The plant is located in an area with exposure C (open terrain with scattered obstructions having heights less than 10 m) so a gust factor of 33% is added to the basic wind speed to determine the design wind speed, V_{dw}.

$$V_{dw}\ '\ (40.2\ m/s)\ (1.33)\ '\ 53.5\ m/s$$

$$(or\ 192.6\ km/hr,\ >\ minimum\ of\ 161\ km/hr)$$

80 mm pipe:

Ref. p. 2-7.

$$R_{e80}\ '\ C_{W2}\ V_W\ D_o$$

$$'\ 6.87\ (53.5\ m/s)\ (90\ mm)\ '\ 3.3\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), C_D = 1.21.

Ref. p. 2-7.

$$F_{W80}\ '\ C_{W1}\ V_W^2\ C_D\ D_o\ '$$

$$(2.543x10^{\&6})(53.5\ m/s)^2(1.21)[90\ mm\%2(0)]$$

$$'\ 0.79\ N/m$$

40 mm pipe:

Ref. p. 2-7.

$$R_{e40} = C_{W2}\, V_W\, D_o$$

$$= 6.87\ (53.5\ m/s)\ (50\ mm) = 1.8\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), $C_D = 1.21$.

Ref. p. 2-7.

$$F_{W40} = C_{W1}\, V_W^2\, C_D\, D_o$$

$$= (2.543x10^{-6})(53.5\ m/s)^2(1.21)[50\ mm + 2(0)]$$

$$= 0.44\ N/m$$

The design wind loads are uniformly distributed horizontally (i.e., perpendicular to the weight load).

Step 4. Snow - From TI 809-01, the basic snow load is 239 kPa.

80 mm pipe:

Ref. p. 2-8.

$$W_{s80} = \tfrac{1}{2}\ n\ D_o\ S_L$$

$$= \tfrac{1}{2}\ (10^{-3}\ m/mm)\ [90\ mm + 2(0)]\ (239\ kPa)$$

$$= 10.8\ N/m$$

40 mm pipe:

Ref. p. 2-8.

$$W_{s40} = \tfrac{1}{2}\ n\ D_o\ S_L$$

$$= \tfrac{1}{2}\ (10^{-3}\ m/mm)\ [50\ mm + 2(0)]\ (239\ kPa)$$

$$= 5.98\ N/m$$

The design snow loads are uniformly distributed and additive to the weight.

Step 5. Ice - No data is readily available; therefore, assume a maximum buildup of 12.5 mm.

80 mm pipe:

Ref. p. 2-8.

$$W_{I80} = \pi\ n_3\ S_I\ t_I\ (D_o + t_I) = \pi\ (10^{-6} m^2/mm^2)\ x$$

$$(8820\ N/m^3)(12.5\ mm)(90 + 12.5\ mm)$$

$$= 35.5\ N/m$$

40 mm pipe:

Ref. p. 2-8.

$$W_{I40} = \pi\ n_3\ S_I\ t_I\ (D_o + t_I) = \pi\ (10^{-6} m^2/mm^2)\ x$$

$$(8820\ N/m^3)(12.5\ mm)(50 + 12.5\ mm)$$

$$= 21.6\ N/m$$

The design ice loads are uniformly distributed and additive to the weight.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = 1.11×10^{-5} mm/mm-°C over the range 16 to 46 °C.

STRESS ANALYSIS

Step 1. Internal Stresses - 80-INF-1500 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - For sustained loads, the sum of the longitudinal stresses must be less than the allowable stress at the highest operating temperature:

Ref. p. 3-17.

$$\Sigma\ S_L \leq S_h;$$

and for occasional loads, the sum of the longitudinal stresses due to both sustained and occasional loads must be less than 1.33 S_h:

$$\Sigma\ S'_L \leq 1.33\ S_h;$$

To determine the longitudinal stress due to uniformly distributed loads, the support spans and spacing must first be determined. Note that because the liner does not add structural strength, the liner thickness is not included as part of D_i for the purposes of calculating support spans.

80 mm pipe:

Ref. p. 3-25.

$$Z_{80} = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(90\ mm)^4 - (80\ mm)^4}{(90\ mm)}$$

$$= 2.69\ x\ 10^4\ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

$$W'_{80} = 172\ N/m + 35.5\ N/m$$

$$= 208\ N/m\ (10^{-3}\ m/mm) = 0.208\ N/mm$$

Ref. p. 3-25.

$$l_{80} = n\left(m\ C'\frac{Z\ S}{W}\right)^{0.5} = (10^{-3}\ m/mm)\ x$$

$$\left[(76.8)\left(\frac{5}{48}\right)\frac{(2.69\ x\ 10^4\ mm^3)\ (10.3\ MPa)}{(0.208\ N/mm)}\right]^{0.5}$$

$$= 3.26\ m$$

The span length is less than the MSS SP-69 guidance for schedule 40 carbon steel filled with water (3.7 m), so length is acceptable.

40 mm pipe:

Ref. p. 3-25.

$$Z_{40} = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(50\ mm)^4 - (40\ mm)^4}{(50\ mm)}$$

$$= 7.25\ x\ 10^3\ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

$$W'_{40} = 74.9\ N/m + 21.6\ N/m$$

$$= 96.5\ N/m\ (10^{-3}\ m/mm) = 9.65\ x\ 10^{-2}\ N/mm$$

Ref. p. 3-25.

$$l_{40} = n\left(m\ C'\ \frac{Z\ S}{W}\right)^{0.5} = (10^{-3}\ m/mm)\ x$$

$$\left[(76.8)\left(\frac{5}{48}\right)\frac{(7.25\ x\ 10^3\ mm^3)(10.3\ MPa)}{(9.65\ x\ 10^{-2}\ N/mm)}\right]^{0.5}$$

$$= 2.49\ m$$

The span length is less than the MSS SP-69 guidance for schedule 40 carbon steel filled with water (2.7 m), so length is acceptable.

Therefore, the check for longitudinal stresses from sustained loads is as follows.

80 mm pipe:

Ref. p. 3-17.

$$\Sigma S_{L80} = \frac{P\ D_o}{4\ t} + 0.1\frac{W\ L^2}{n\ Z}$$

$$= \frac{(0.0896\ MPa)(90\ mm)}{4\ (5\ mm)} +$$

$$0.1\ \frac{(172\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 6.6\ MPa$$

40 mm pipe:

Ref. p. 3-17.

$$\Sigma S_{L40} = \frac{P\ D_o}{4\ t} + 0.1\frac{W\ L^2}{n\ Z}$$

$$= \frac{(0.0896\ MPa)(50\ mm)}{4\ (5\ mm)} +$$

$$0.1\ \frac{(74.9\ N/m)(1.7\ m)^2}{(10^{-3} m/mm)(7.25\ x\ 10^3 mm^3)} = 2.9\ MPa$$

From ASME B31.3, Table A-1, S_h = 110 MPa. For both pipes, $\Sigma S_L \le S_h$; therefore, the pipes are acceptable for sustained loads.

Assuming that snow and ice will not occur simultaneously and ignoring the wind load (small and horizontal to the snow/ice load), the ice load will be the worst case and the check for occasional loads is as follows.

80 mm pipe:

Ref. p. 3-17.

$$\Sigma S'_{L80} = \Sigma S_{L80} + 0.1\ \frac{W\ L^2}{n\ Z} = 6.6\ MPa +$$

$$0.1\ \frac{(35.5\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 8.0\ MPa$$

40 mm pipe:

Ref. p. 3-17.

$$\Sigma S'_{L40} = \Sigma S_{L40} + 0.1\ \frac{W\ L^2}{n\ Z} = 2.9\ MPa +$$

$$0.1\ \frac{(21.6\ N/m)(1.7\ m)^2}{(10^{-3} m/mm)(7.25\ x\ 10^3 mm^3)} = 3.8\ MPa$$

$$1.33\ S_h = 1.33\ (110\ MPa) = 146\ MPa$$

For both pipes, $\Sigma S'_L \le 1.33S_h$; therefore, the pipes are acceptable for the anticipated occasional loads.

Step 3. To ensure that piping systems have sufficient flexibility to prevent these failures, ASME B31.3 requires that the displacement stress range does not exceed the allowable displacement stress range. Due to the length of the 40 mm pipe section, flexibility is not a factor. Therefore, only the flexibility of the 80 mm pipe section will be checked. From ASME B31.3, Table 302.3.5 and with the assumption that the total process cycles over the process life will be less than 7000, f = 1.0. From ASME B31.1, Table A-1, $S_c = S_h$ = 110 MPa.

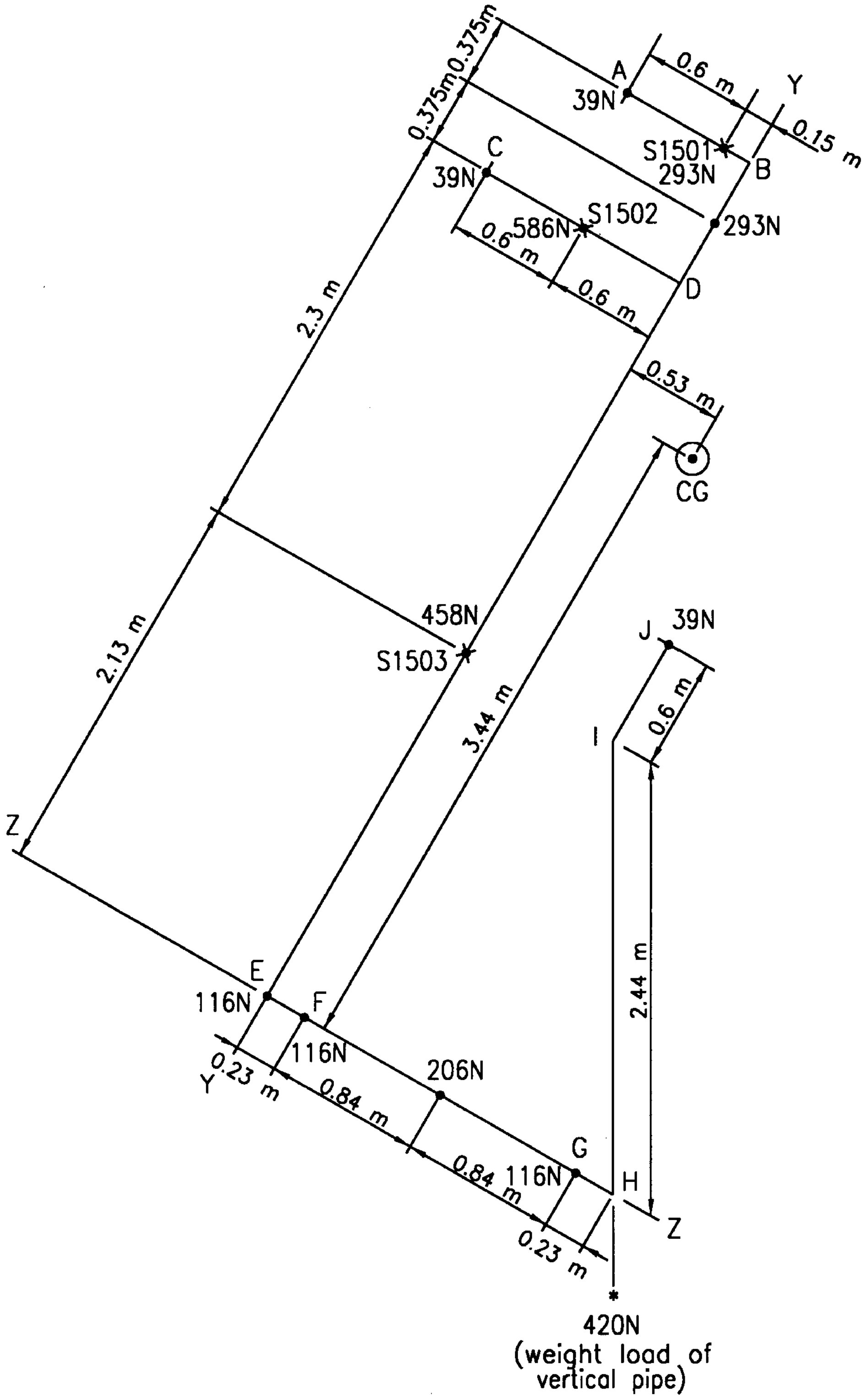
Ref. p. 3-18.

$$S_E \le S_A;\ and\ S_A = f\ [1.25\ (S_c + S_h) - S_L]$$

$$S_A = 1.0[(1.25)(110\ MPa + 110\ MPa) - 7\ MPa]$$

$$= 268\ MPa;\ therefore,\ S_E \le 268\ MPa$$

The center of gravity is located to review the stability of the system with respect to the fittings and equipment loads.


0.375m
0.375m
A
39N
0.6 m
Y
0.15 m
S1501
293N
B
C
39N
586N
S1502
293N
0.6 m
0.6 m
D
2.3 m
0.53 m
CG
458N
S1503
J
39N
0.6 m
I
2.13 m
3.44 m
Z
2.44 m
E
116N
F
116N
206N
Y
0.23 m
0.84 m
0.84 m
G
116N
H
Z
0.23 m
420N
(weight load of vertical pipe)

Sketch C-3

Referencing Sketch C-3:
x = support location (S1501 supports a check valve, S1502 supports a check valve and a gate valve, and S1503 supports the control valve).
! = component load
⊙ = center of gravity

The loads and their locations are as follows:
A - 39 N
S1501 - 293 N
BD - 293 N
C - 39 N
S1502 - 586 N
S1503 - 458 N
E - 116 N
F - 116 N
FG - 206 N
G - 116 N
H - 420 N
J - 39 N.

Table C-7 contains the results of the moment calculations. The center of gravity of the piping section is behind S1503; therefore, 2 more supports are needed for stability. Locate S1504 and S1505 at points F and G respectively. S1505 supports the vertical run and keeps the load off of the equipment flange.

Table C-7
Line 80-INF-1500 Moments

moment about axis y-y			**moment about axis z-z**		
N	m	N-m	N	m	N-m
39	-0.75	-29.3	39	0.6	23.4
293	-0.15	-44.0	103	0.3	30.9
129	-0.375	-48.4	39	5.18	202
39	-1.2	-46.8	293	5.18	1520
586	-0.6	-352	129	5.18	668
206	-0.6	-124	293	4.8	1410
39	2.14	83.5	39	4.43	173
103	2.14	220	586	4.43	2600
420	2.14	899	206	4.43	913
116	1.91	222	891	2.59	2710
206	1.07	220	458	2.13	976
116	0.23	26.7			
367	1.07	393			
2660		1420	3080		10600

$$\frac{1{,}420\ N\cdot m}{2{,}660\ N} = 0.53\ m\ \text{from}\ y\text{-}y;$$

$$\frac{10{,}600\ N\cdot m}{3{,}080\ N} = 3.44\ m\ \text{from}\ z\text{-}z.$$

The thermal expansion deflections are determined based on: 1) the manufacturer of the air stripper, P1600, has indicated that a 1.6 mm upward movement of the flange mating at point J will occur when operating conditions are established; 2) the flanges at points A and C mate with pumps and are not subject to movements; 3) support S1505, located at point G supports piping section H-I-J and will prevent vertical deflection at point H; and 4) given that the piping system will be installed at 21°C, the thermal expansion of the piping will be:

$$\Delta L = (1.11\ x\ 10^{-5}\ mm/mm\text{-}°C)\ x$$

$$(1{,}000\ mm/m)(46°C - 21°C) = 0.278\ mm/m.$$

Sketch C-4 depicts the approximate deflections that will occur. These deflections are:

- AB will deflect out at point B,(0.75 m) (0.278 mm/m) = 0.21 mm
- CD will deflect out at point D,(1.2 m) (0.278 mm/m) = 0.33 mm
- BE will deflect out at point E,(5.18 m) (0.278 mm/m) = 1.4 mm
- EH will deflect out at each end,[(0.5)(2.14 m)] (0.278 mm/m) = 0.30 mm
- HI will deflect up at point I,(2.44 m) (0.278 mm/m) = 0.68 mm
- IJ will deflect out at point I,(0.6 m) (0.278 mm/m) = 0.17 mm

From beam calculations,

1) for sections BE and EH:

$$M = \frac{3\ E\ I\ y}{a\ (l + a)}\ (n)$$

where:

a_{BE} = the length from S1503 to point E
a_{EH} = the length from S1504 to point E
n = 10^{-9} m^3/mm^3
E = 2.03 x 10^5 MPa (reference ASME B31.3, Table C-6)

$$I = \frac{\pi}{64}\ [(D_o)^4 - (D_i)^4]$$

$$= \frac{\pi}{64}\ [(90\ mm)^4 - (80\ mm)^4]$$

$$= 1.21\ x\ 10^6\ mm^4$$

2) for sections HI and IJ:

$$M = \frac{3\ E\ I\ y}{L^2}$$

where:

L_{HI} = length of HI
L_{IJ} = length of IJ

The displacement stress is now calculated from the deflections.

Ref. p. 3-18.

$$S_E = (S_b^2 + 4S_t^2)^{0.5}$$

Ref. p. 3-18.

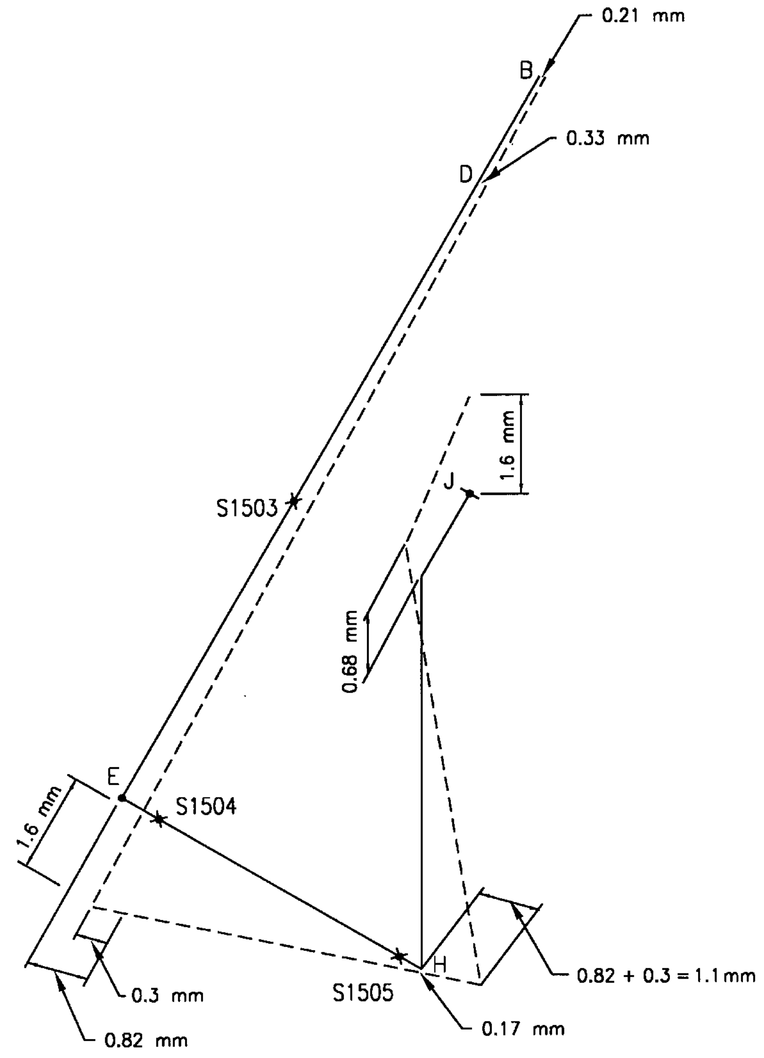
$$S_b = \frac{\left[(i_i\ M_i)^2 + (i_o\ M_o)^2\right]^{0.5}}{Z\ n};\ and$$

$$S_t = \frac{M_t}{2\ Z\ n}$$

where:

M_o = 0
$i_i = i_o$ = 1.0
Z = 2.69 x 10^4 mm^3 (see page C-17 for calculation)
n = 10^{-3} m/mm

Table C-8 summarizes the results of the calculations for each piping segment.



Sketch C-4

Table C-8
Line 80-INF-1500 Displacement Stresses

Segment	M_i (N-m)	S_b (MPa)	M_t (N-m)	S_t (MPa)	S_E (MPa)
BE	20.0	0.74	0	0	0.74
EH	2395	89.0	42.0	0.78	89.0
HI	21.0	0.78	0	0	0.78
IJ	1883	70.0	272	5.1	70.7

In all of the piping segments, $S_E < S_A$ (268 MPa); therefore, line 80-INF-1500 satisfies required flexibility constraints.

SUPPORTS

The support spacing and spans were calculated as part of the stress analyses. The types of supports are selected based upon process temperature (see Table 3-8) and application (see Figure 3-2 and MSS SP-69).

Table C-9
Line 80-INF-1500 Supports

Support	Type (MSS SP-58)
S1501	36
S1502	36
S1503	36
S1504	36
S1505	37

FLANGE CONNECTIONS

From Table 9-2, the flange connections for the thermoplastic lined 80-INF-1500 shall have the following bolting requirements:

80 mm flanges:	4 x 16 mm bolts per flange ASTM A 193 bolts and nuts, lightly oiled 169 N-m bolt torque for PVDF lined piping.
40 mm flanges:	4 x 14 mm bolts per flange ASTM A 193 bolts and nuts, lightly oiled 81 N-m bolt torque for PVDF lined piping.

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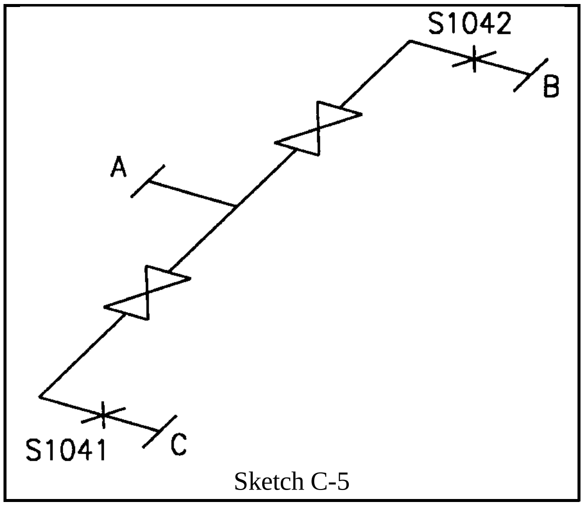
b. Line XXX-IAS-1600
Air Stripper P1600 Effluent to Duplex Pumps P1605/1610



Sketch C-5

Flow is either through A-B or A-C, but not both simultaneously

Maximum Flowrate, Q = 5.36 x 10^{-3} m^3/s

MATERIAL OF CONSTRUCTION

Line XXX-IAS-1600 handles essentially the same fluid as 80-INF-1500 except that most of the volatile organic solvents have been stripped out. Therefore, for constructability purposes, make the materials of construction identical to 80-INF-1500:

The piping shall be ASTM A 106, Grade A, carbon steel lined with PVDF that has a minimum thickness of 4.45 mm. Because the line is on the influent side of the pumps, the piping shall be full vacuum rated pursuant to ASTM F 423. Joints and fittings shall be chamfered threaded flanges.

The sizing is identical to 80-INF-1500 because the maximum flowrate is identical. Therefore, the line designation is amended to 80-IAS-1600.

The pressure integrity, loads, stress analysis and flexibility are similar to 80-INF-1500; therefore, line 80-IAS-1600 is acceptable.

SUPPORTS

Locate supports as shown (spans are less than the maximum spans calculated for 80-INF-1500); support type as follows.

Table C-10
Line 80-IAS-1600 Supports

Support	Type (MSS SP-58)
S1041	36
S1042	36

FLANGE CONNECTIONS

From Table 9-2, the flange connections for the thermoplastic lined 80-IAS-1600 shall have the following bolting requirements:

80 mm flanges:	4 x 16 mm bolts per flange ASTM A 193 bolts and nuts, lightly oiled 169 N-m bolt torque for PVDF lined piping.

---

c. Line XXX-IAS-1620
Duplex Pumps P1605/1610 Discharge to Reactor P1620

Referencing Sketch C-6:

Flow is either through A-D or C-D, but not both simultaneously

Maximum Flowrate, $Q = 5.36 \times 10^{-3}$ m^3/s

Elevation Change = -0.61 m (= -5.98 kPa)

Total run
= 8.55 m for A-H
= 7.19 m for C-H

Back-pressure from liquid level in Reactor P1620 = 3.65 m (35.8 kPa).

Fittings (identical for either A-H or C-H)
1 swing check valve
2 gate valves (isolation)

MATERIAL OF CONSTRUCTION

Line XXX-IAS-1620 handles essentially the same fluid as 80-IAS-1600. Therefore, for constructability purposes, make the materials of construction identical to 80-INF-1500 and 80-IAS-1600:

The piping shall be ASTM A 106, Grade A, carbon steel lined with PVDF that has a minimum thickness of 4.45 mm. Because the line is on the influent side of the pumps, the piping shall be full vacuum rated pursuant to ASTM F 423. Joints and fittings shall be chamfered threaded flanges.

SIZING/PRESSURE DROP

The sizing is identical to 80-INF-1500 and 80-IAS-1600 because the maximum flowrate is identical: lined D_i = 71.1 mm, V = 1.35 m/s, and D_o = 90 mm (5 mm wall thickness). Therefore, the line designation is amended to 80-IAS-1620.

At 23.9°C, $\nu = 8.94 \times 10^{-7}$ m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping. The worst case pressure drop will be run A-H due to the additional pipe length.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]$$

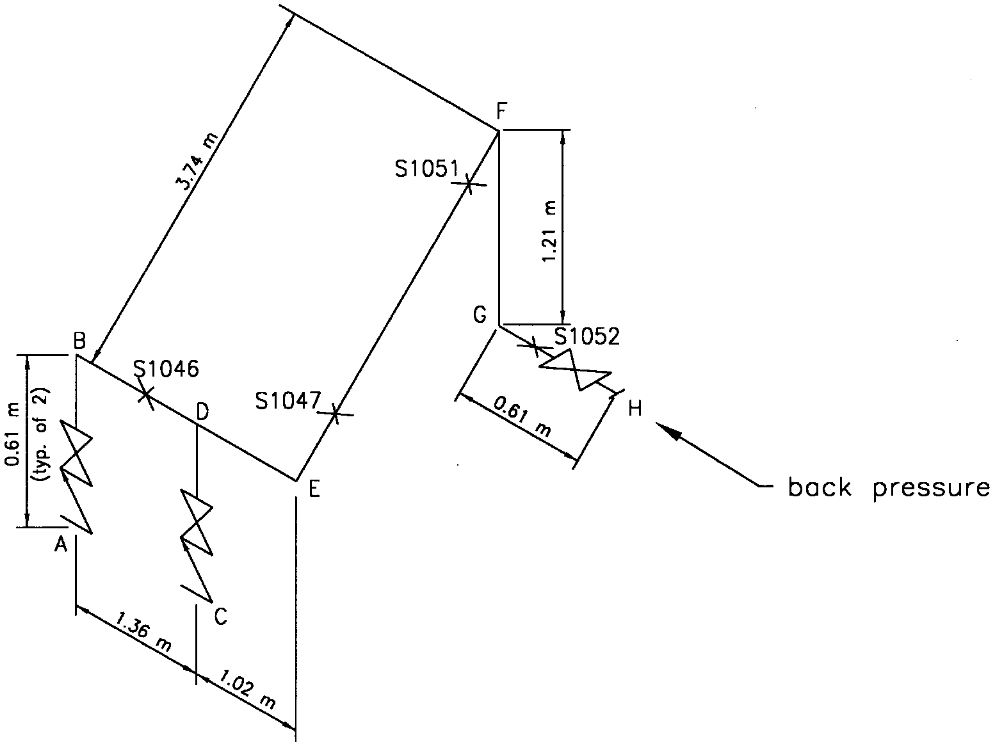
Ref. p. 3-8.

$$R_e = \frac{D_i\,V}{\nu} = \frac{(0.0711\ m)(1.35\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 1.1\ x\ 10^5 \rightarrow turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{71.1\ mm} = 0.00002$$



Sketch C-6

Therefore, f = 0.028 from the Moody Diagram (Figure 3-1). From Sketch C-6, for run A-H the sum of the minor loss coefficients from Table 3-3:

Table C-11
Minor Losses for 80-IAS-1620: Run A-H

Minor Loss	K
2 gate valves (open)	2(0.2)
1 swing check valve	2.5
4 x 90° elbows	4(0.9)
1 tee-flow through	0.6
1 exit	1.0
$\Sigma K =$	8.1

$$h_L = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.028)(8.55\ m)}{0.0711\ m} + 8.1\right]\frac{(1.35\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 1.1\ m\ (10.8\ kPa)$$

The required pump head is equal to the sum of the elevation change, the piping pressure drop and the back pressure from the reactor P1620.

$$P_{head} = -5.98\ kPa + 10.8\ kPa + 35.8\ kPa$$

$$= 40.6\ kPa\ x\ 1.25\ safety\ factor = 50.8\ kPa$$

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 50.8 kPa. No potential pressure transients exist. The design external corrosion allowance is 2 mm. Pressure integrity is acceptable if the minimum wall thickness meets ASME 31.3 code. According to ASME B31.3, for ASTM A 106, Grade A pipe, S = 110 MPa, E = 1.0, and y = 0.4.

Ref. p. 3-15.

$$t_m = t + A = \frac{P\ D_o}{2\ (S\ E + P\ y)} + A$$

$$t_m = \frac{(0.0508\ MPa)(90\ mm)}{2[(110\ MPa)(1.0) + (0.0508\ MPa)(0.4)]} + 2\ mm = 2.02\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{2.02\ mm}{1.0 - 0.125} = 2.3\ mm$$

Nominal 80 mm pipe has a thickness of 5 mm; therefore, the 80 mm piping satisfies pressure integrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - Load per unit length will be identical to 80-INF-1500; W = 172 N/m (including liquid content).

Step 3. Wind - Load per unit length will be identical to 80-INF-1500; F_w = 0.79 N/m (horizontal).

Step 4. Snow - Load per unit length will be identical to 80-INF-1500; W_s = 10.8 N/m.

Step 5. Ice - Load per unit length will be identical to 80-INF-1500; W_I = 35.5 N/m.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = 1.11 x 10^{-5} mm/mm-°C over the range 16 to 46 °C.

STRESS ANALYSIS

Step 1. Internal Stresses - Line 80-IAS-1620 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - For sustained loads, the sum of the longitudinal stresses must be less than the allowable stress at the highest operating temperature:

Ref. p. 3-17.

$$\Sigma\ S_L \leq S_h;$$

and for occasional loads, the sum of the longitudinal stresses due to both sustained and occasional loads must be less than 1.33 S_h:

$$\Sigma\ S'_L \leq 1.33\ S_h;$$

To determine the longitudinal stress due to uniformly distributed loads, the support spans and spacing must first be determined: maximum support span length, L, = 3.26 m (see 80-INF-1500 stress analysis). Therefore, the check for longitudinal stresses from sustained loads is as follows.

Ref. p. 3-25.

$$Z_{80} = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(90\ mm)^4 - (80\ mm)^4}{(90\ mm)}$$

$$= 2.69\ x\ 10^4\ mm^3$$

Ref. p. 3-17.

$$\Sigma S_L = \frac{P\ D_o}{4\ t} + 0.1\frac{W\ L^2}{n\ Z} = \frac{(0.0508 MPa)(90 mm)}{4\ (5 mm)}$$

$$+ 0.1\frac{(172\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 7.02\ MPa$$

From ASME B31.3, Table A-1, S_h = 110 MPa. For 80-IAS-1620, $\Sigma S_L \leq S_h$; therefore, the pipe is acceptable for sustained loads.

Assuming that snow and ice will not occur simultaneously and ignoring the wind load (small and horizontal to the snow/ice load), the ice load will be the worst case and the check for occasional loads is as follows.

Ref. p. 3-17.

$$\Sigma S'_L = \Sigma S_L + 0.1\ \frac{W\ L^2}{n\ Z} = 7.02\ MPa +$$

$$0.1\ \frac{(35.5\ N/m)(3.26\ m)^2}{(10^{-3} m/mm)(2.69\ x\ 10^4 mm^3)} = 8.42\ MPa$$

For 80-IAS-1620, $\Sigma S'_L \leq 1.33 S_h$; therefore, the pipe is acceptable for the anticipated occasional loads.

Step 3. To ensure that piping systems have sufficient flexibility to prevent failures resulting from displacement strains, ASME B31.3 requires that the displacement stress range does not exceed the allowable displacement stress range. From ASME B31.3, Table 302.3.5 and with the assumption that the total process cycles over the process life will be less than 7000, f = 1.0. From ASME B31.1, Table A-1, $S_c = S_h$ = 110 MPa.

Ref. p. 3-18.

$$S_E \leq S_A;\ and\ S_A = f\ [1.25\ (S_c + S_h) - S_L]$$

$$S_A = 1.0[(1.25)(110\ MPa + 110\ MPa) - 7\ MPa]$$

$$= 268\ MPa;\ therefore,\ S_E \leq 268\ MPa$$

Referencing Sketch C-7:

x = support location

! = component load

The loads and their locations are as follows:

B - 807 N
D - 807 N
E - 116 N
F - 116 N
G - 116 N
S1052 - 293 N
H - 39 N.

Based upon the symmetry of the piping segment, the system is stable with the supports located where shown. Support S1046 supports the two vertical runs AB and CD, and the check valves and gate valve at the pump outlets, and S1052 supports the vertical run FG and keeps that load off of the equipment flange. Supports S1047 and S1051 are needed for stability and to keep the maximum span length within the constraint.

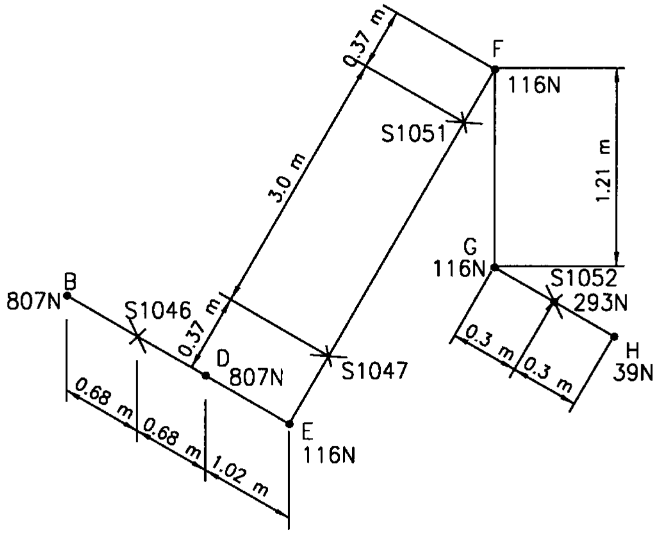
The thermal expansion deflections are determined based on: 1) the assumption that no substantial movement of the flange mating at point H will occur when operating conditions are established; 2) the flanges at points A and C mate with pumps and are not subject to movements; 3) support S1052, will prevent vertical deflection at point G; and 4) given that the piping system will be installed at 21°C, the thermal expansion of the piping will be:

$$\Delta L = (1.11\ x\ 10^{-5}\ mm/mm-°C)$$

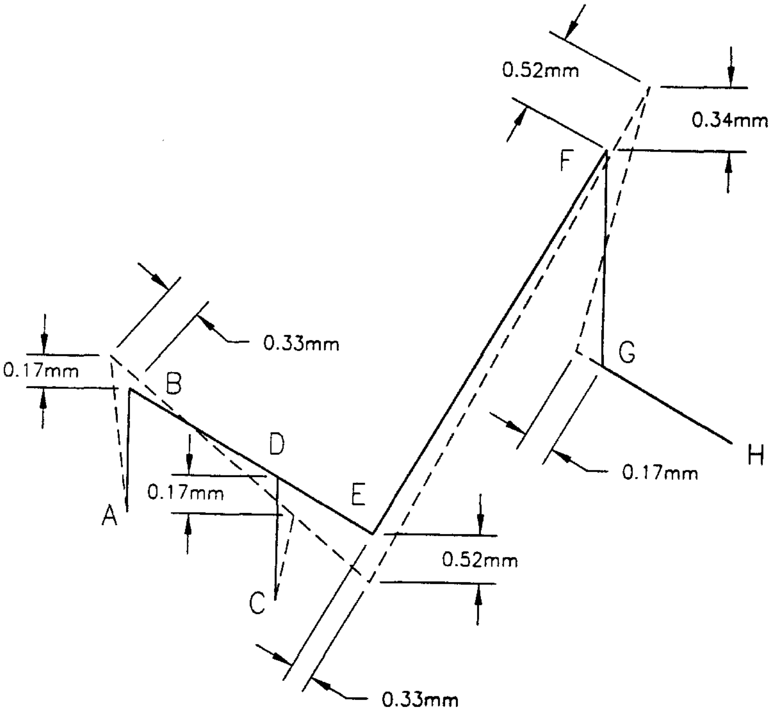
$$x\ (1,000\ mm/m)(46°C - 21°C) = 0.278\ mm/m$$

Sketch C-8 depicts the approximate deflections that will occur. These deflections are:

- AB will deflect up at point B, (0.61 m) (0.278 mm/m) = 0.17 mm
- CD will deflect up at point D, (0.61 m) (0.278 mm/m) = 0.17 mm
- BE will deflect out at each end, [(0.5)(2.38 m) (0.278 mm/m) = 0.33 mm
- EF will deflect out at each end, [(0.5)(3.74 m)] (0.278 mm/m) = 0.52 mm
- FG will deflect up at point F, (1.21 m) (0.278 mm/m) = 0.34 mm
- GH will deflect out at point G, (0.61 m) (0.278 mm/m) = 0.17 mm



Sketch C-7



Sketch C-8

From beam calculations,

1) for sections BE (M_o caused) and EF (M_o and M_i caused):

$$M = \frac{3\ E\ I\ y}{a\ (l + a)}\ (n)$$

where:
  a_{BE} = 0.37 m
  a_{EH} = 1.7 m
  n = 10^{-9} m^3/mm^3
  E = 2.03 x 10^5 MPa (reference ASME B31.3, Table C-6)
  I = 1.21 x 10^6 mm^4 (see 80-INF-1500 calculations)

2) for sections AB, CD and FG:

$$M = \frac{3\ E\ I\ y}{L^2}$$

where:
  L_{AB} = length of AB
  L_{CD} = length of CD
  L_{FG} = length of FG

The displacement stress is now calculated from the deflections.

Ref. p. 3-18:

$$S_E = (S_b^2 + 4S_t^2)^{0.5}$$

$$S_b = \frac{\left[(i_i\ M_i)^2 + (i_o\ M_o)^2\right]^{0.5}}{Z\ n} \quad and \quad S_t = \frac{M_t}{2\ Z\ n}$$

where:
  $i_i = i_o = 1.0$
  Z = 2.69 x 10^4 mm3 (see page C-16 for calculation)
  n = 10^{-3} m/mm

Table C-12 summarizes the results of the calculations for each piping segment.

In all of the piping segments, SE < SA (268 MPa); therefore, line 80-IAS-1620 satisfies required flexibility constraints.

Table C-12
Line 80-IAS-1620 Displacement Stresses

Segment	M_i (N-m)	M_o (N-m)	S_b (MPa)	M_t (N-m)	S_t (MPa)	S_E (MPa)
AB	654	0	24.3	135	2.51	24.8
CD	277	0	10.3	736	13.7	29.3
BE	67.6	31	2.76	35.8	0.67	3.07
EF	176	181	9.39	0	0	9.39
FG	262	85.6	10.2	0	0	10.2
GH	0	0	0	523	9.72	19.4

SUPPORTS

The support spacing and spans were calculated as part of the stress analyses. The types of supports are selected based upon process temperature (see Table 3-8) and application (see Figure 3-2 and MSS SP-69).

Table C-13
Line 80-IAS-1620 Supports

Support	Type (MSS SP-58)
S1046	38
S1047	38
S1051	38
S1052	37

FLANGE CONNECTIONS

From Table 9-2, the flange connections for the thermoplastic lined 80-IAS-1620 shall have the following bolting requirements:

80 mm flanges: 4 x 16 mm bolts per flange
ASTM A 193 bolts and nuts, lightly oiled
169 N-m bolt torque for PVDF lined piping.

---

d. Line 100-PRI-1630
Process Flow from Reactor P1620 to Floc Tank P1630

The line is gravity flow. Design in accordance with TI 814-10 Wastewater Collection; Gravity Sewers and Appurtenances.

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e. Line 100-EFF-1640
Clarifier P1640 Effluent to Clearwell P1510

The line is gravity flow. Design in accordance with TI 814-10 Wastewater Collection; Gravity Sewers and Appurtenances.

---

f. Line 80-SLG-1650
Sludge Discharge from Clarifier P1640 to Sludge Pumps

The line is supplied by the process system manufacturer. Provide performance requirements for the piping in the equipment specifications.

---

g. Line 25-SLG-1651
Sludge Recycle from Sludge Pumps to Reactor P1620

The line is supplied by the process system manufacturer. Provide performance requirements for the piping in the equipment specifications.

---

h. Line XXX-SLG-1660
Waste Sludge Discharge from Sludge Pumps to Sludge Pit P1450

Referencing Sketch C-9:

Maximum Flowrate, Q = 2.75×10^{-3} m^3/s

Total run = 22.0 m
= 20.3 m below grade

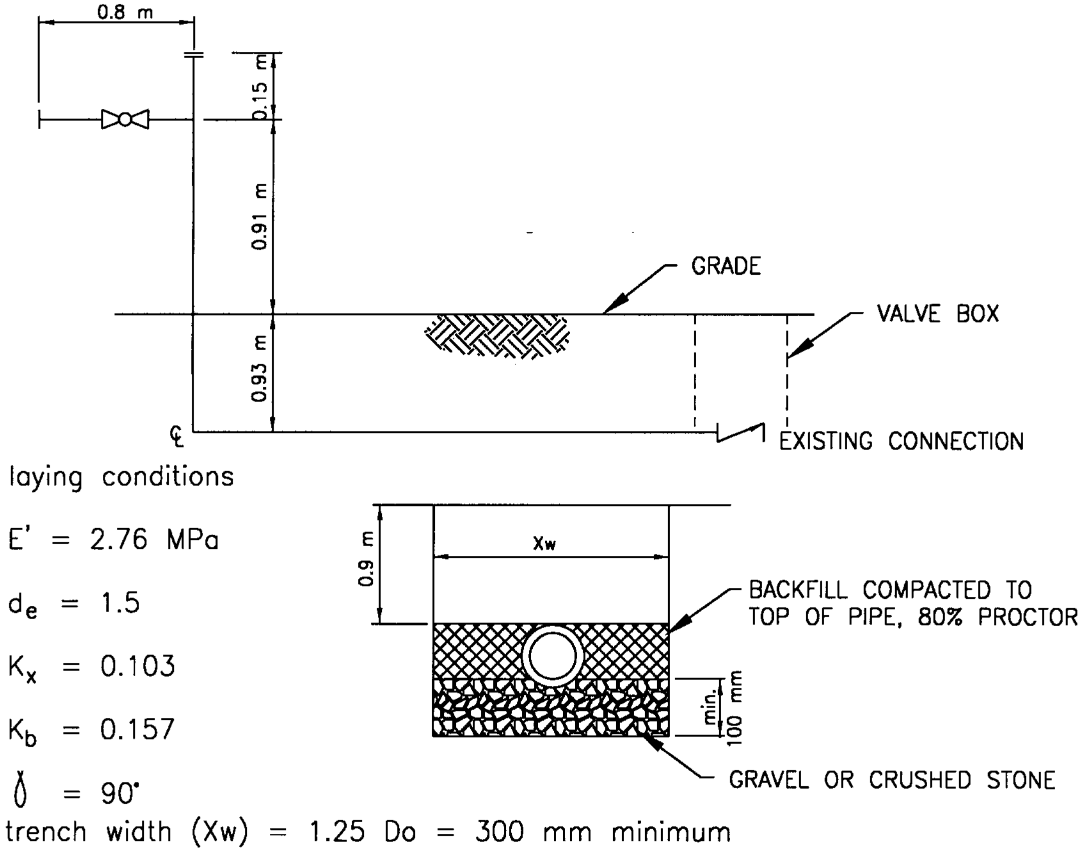
Buried depth = 0.9 m, t.o.p.

Fittings below grade:
3 x 90° elbows
2 x 45° bends
1 x swing check valve

Sludge Pump Head = 250 kPa.

MATERIAL OF CONSTRUCTION

To match other materials at the facility, the piping shall be zinc coated ASTM A 53, Type E, Grade A, carbon steel. Joints shall be buttwelded with chill rings. Below grade fittings shall be forged ASTM A 105M steel of the same thickness of the piping and shall conform to ASME B 16.9, buttweld type. The exception to this shall be the connection to the swing check valve; this end connection shall be a welding neck flange and located in a valve box.



Sketch C-9

The flange connections to the existing sludge line should be field inspected to ensure a compatible connection. The above ground connection to the waste sludge pump, isolation ball valve and clean-out shall also be flanged. All flanges shall be constructed of ASTM A 105M material.

PIPE SIZING/PRESSURE DROP

Step 1. Select pipe size by dividing the volumetric flowrate by the desired velocity (normal service, V = 2.1 m/s).

$$A = \pi \frac{D_i^2}{4} = \frac{Q}{V}$$

$$D_i = \left[\frac{4}{\pi}\ \frac{(2.75\ x\ 10^{-3})\ m^3/s}{2.1\ m/s}\right]^{0.5} \left(1000\ \frac{mm}{m}\right)$$

$$= 40.8\ mm$$

Step 2. From Table 1-1, the size choices are 40 mm or 50 mm. Select 40 mm as the actual pipe size and calculate actual velocity in the pipe.

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2} = \frac{2.75x10^{-3} m^3/s}{\frac{\pi}{4}\ (0.040\ m)^2} = 2.19\ m/s$$

The actual velocity, 2.19 m/s, is within the normal acceptable range, 2.1 ± 0.9 m/s. Therefore, a 40 mm pipe is acceptable, the line designation is amended to 40-SLG-1660, and D_i = 40 mm, D_o = 50 mm, and V = 2.19 m/s.

At 23.9°C, $\nu = 8.94 \times 10^{-7}$ m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}\right]$$

Ref. p. 3-8.

$$R_e = \frac{D_i\,V}{\nu} = \frac{(0.040\ m)(2.19\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 9.8\ x\ 10^4 - turbulent\ flow$$

$$\varepsilon = 0.061\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.061\ mm}{40\ mm} = 0.0015$$

Therefore, f = 0.024 from the Moody Diagram (Figure 3-1). From Sketch C-9, the sum of the minor loss coefficients from Table 3-3:

Table C-14
Minor Losses for 40-SLG-1660

Minor Loss	K
1 ball valve (open)	4.5
1 tee-branch flow	1.8
3 x 90° elbows	3(0.9)
2 x 45° bends	2(0.5)
1 swing check valve	2.5
1 exit	1.0
ΣK =	12.5

$$h_L = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g}$$

$$= \left[\frac{(0.024)(22.0\ m)}{0.040\ m} + 12.5\right]\frac{(2.19\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 6.28\ m\ (61.7\ kPa)$$

The maximum waste sludge pump head is 250 kPa which is adequate to overcome the piping pressure drop.

PRESSURE INTEGRITY

The design pressure is equal to the maximum pump head = 250 kPa. No potential pressure transients exist. An external corrosion allowance of 2 mm and an internal erosion allowance of 2 mm are to be designed. Pressure integrity is acceptable if the minimum wall thickness meets ASME 31.3 code. For ASTM A 53, Grade A pipe, ASME B31.3 tables provide S = 110 MPa, E = 1.0, and y = 0.4.

Ref. p. 3-15.

$$t_m = t + A = \frac{P\ D_o}{2\ (S\ E + P\ y)} + A$$

$$t_m = \frac{(0.250\ MPa)(50\ mm)}{2[(110\ MPa)(1.0) + (0.250\ MPa)(0.4)]}$$

$$+ 4\ mm = 4.06\ mm$$

The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%.

$$t_{NOM} = \frac{4.06\ mm}{1.0 - 0.125} = 4.64\ mm$$

Nominal 40 mm pipe has a thickness of 5 mm; therefore, the 40 mm piping satisfies pressure integrity.

LOADS

Based on the previous calculations for this site, the above ground piping segment will be acceptable for the loads applied. The below grade piping will be subject to internal and external pressure loads.

Step 1. Internal Pressure - See the pressure integrity calculations for the design pressure.

Step 2. External Pressure/Loads - The external pressure/loads will result from the earth load and perhaps a wheel load, a sustained load and an occasional load respectively.

Earth Load:

Ref. p. 2-7.

$$F_E = \frac{\rho H}{a} = \frac{(1{,}922\ kg/m^3)(0.9\ m)}{\left(102\ \frac{kg/m^2}{kPa}\right)} = 17.0\ kPa$$

Wheel Load:

Ref. pp. 2-9 - 2-10.

$$F_W = \frac{C\ R\ P\ F}{b\ D_o} = \frac{(0.098\ /m)(7{,}257\ kg)(1.5)}{\left(0.031\ \frac{kg/m}{kPa}\right)(50\ mm)}$$

$$= 688\ kPa$$

STRESS ANALYSIS

Step 1. Internal Stresses - Line 40-SLG-1660 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - For sustained loads, the sum of the longitudinal stresses must be less than the allowable stress at the highest operating temperature:

Ref. p. 3-17.

$$\Sigma\ S_L \leq S_h$$

For occasional loads, the sum of the longitudinal stresses due to both sustained and occasional loads must be less than 1.33 S_h:

$$\Sigma\ S'_L \leq 1.33\ S_h$$

With below grade placement, the piping is continuously supported and sustained loads are a result of longitudinal pressure and earth pressure. Therefore, the check for longitudinal stresses from sustained loads is as follows.

Ref. p. 3-17.

$$\Sigma S_L = \frac{P\ D_o}{4\ t} + F_E = \frac{(275\ kPa)(50\ mm)}{4\ (5\ mm)}$$

$$+ 17.0\ kPa = 705\ kPa$$

From ASME B31.3, Table A-1, S_h = 110 MPa. For 40-SLG-1660, $\Sigma S_L \leq S_h$; therefore, the pipe is acceptable for sustained loads.

The only additional occasional load is a wheel load. Therefore, the check for occasional loads is as follows.

Ref. p. 3-17.

$$\Sigma S'_L = \Sigma S_L + F_W = 705\ kPa + 688\ kPa$$

$$= 1.39\ MPa$$

For 40-SLG-1660, $\Sigma S'_L \leq 1.33 S_h$; therefore, the pipe is acceptable for the anticipated occasional loads.

FLANGE CONNECTIONS

The flange connections will be carbon steel welding neck flanges, raised face, and 1.03 MPa rated (class 150) pursuant to ASME B16.5.

Operating bolt load:

Ref. pp. 3-21 - 3-22.

$$W_{m1} = 0.785\ G^2\ P + (2\ b)(3.14\ G\ m\ P)$$

from ASME B16.5, Table E1, for a flange on a 40 mm pipe, G = 48.7 mm and b = 12.2 mm;
from Table 3-5, m = 0.5 for an elastomeric gasket;

$$W_{m1} = (0.785)(48.7\ mm)^2(0.250\ MPa)$$
$$+ (2)(12.2\ mm)(3.14)(48.7\ mm)(0.5)(0.250\ MPa)$$
$$= 932\ N$$

$$A_{m1} = \frac{W_{m1}}{S_b}$$

from ASME B31.3, Table A-2, for alloy steel ASTM A 193, B7M, S_b = 137 MPa.

$$A_{m1} = \frac{932\ N}{137\ MPa} = 6.80\ mm^2$$

Initial load during assembly:

Ref. p. 3-21.

$$W_{m2} = 3.14\ b\ G\ y$$

from Table 3-5, y = 0; therefore, W_{m2} = 0.

Thus the design is controlled by the operating condition and the bolting is selected to match the required bolt cross-sectional area:

Ref. p. 3-23.

$$A_s = 0.7854\left(D - \frac{0.9743}{N}\right)^2$$

select 14 mm bolts with a coarse thread (pitch = 1/N = 2)

$$A_s = 0.7854\left[(14) - \left(\frac{0.9743}{1/2}\right)\right]^2 = 114\ mm^2$$

$A_s > A_{m1}$; therefore, the selected bolting is acceptable.

CATHODIC PROTECTION
(See TM 5-811-7 Electrical Design, Cathodic Protection for Guidance)

40-SLG-1660 is a zinc coated steel pipe installed below grade; therefore, cathodic protection is required. Due to the small size of the structure, galvanic protection is selected. Existing data and the design bases are reviewed to obtain the following design data:

average soil resistivity (p) = 4,500 Ω-cm,
90 % coating (zinc) efficiency is anticipated,
20 year life is desired,
21.5 ma/m^2 is required, and
packaged type magnesium anodes are to be specified.

Step 1. The total area of the underground piping is calculated.

$$A = \pi\ D_o\ L = \pi\ (0.050\ m)(20.3\ m)$$
$$= 3.19\ m^2$$

and the total piping area to be protected is determined.

$$A_T = A\ (0.10) = (3.19\ m^2)\ (0.10) = 0.319\ m^2$$

Step 2. The maximum protective current, I, is:

$$I = (21.5\ ma/m^2)\ A_T$$
$$= (21.5\ ma/m^2)(0.319\ m^2) = 68.6\ ma$$

Step 3. The weight of the anode based on a 20 year life is calculated (see TM 5-811-7, eqn. C-1).

$$W = \frac{Y\ S\ I}{E}$$

$$= \frac{(20\ years)(4.0\ kg/A\text{-}yr)(0.0069\ A)}{0.50} = 1.10\ kg$$

Step 4. A standard, package anode will be used so this type of anode is reviewed to determine how many anodes are required to satisfy the current. The weight of a standard packaged magnesium anode is 1.4 kg (see TM 5-811-7, Table C-4). The current output to ground is calculated for the anode (see TM 5-811-7, eqn. C-2).

$$i = \frac{C\ f\ y}{P}$$

where:

C = 120,000 for a well coated structure (see TM 5-811-7)
f = 0.53 (see TM 5-811-7, Table C-4)
y = 1.0 (see TM 5-811-7, Table C-5)
P = average soil resistivity = 4,500 Ω-cm

$$i = \frac{C\ f\ y}{P} = \frac{(120{,}000)\ (0.53)\ (1.0)}{4{,}500\ \Omega \cdot cm} = 14.1\ ma$$

Step 5. The number of anodes required is determined (see TM 5-811-7, eqn. C-3).

$$\frac{I}{i} = \frac{6.85\ ma}{14.1\ ma} = 0.49$$

The 1.4 kg anode satisfies the current output requirements. Smaller packages anodes are not readily available.

THRUST BLOCKS
(see TI 814-03, Water Distribution, for guidance)

Thrust blocks are required at the 90° and 45° bends. Concrete thrust blocks will be used so the area of the thrust block will be determined. Because the pipes are already cathodically protected, additional protection or insulation between the concrete and the pipe is not required. The thrust at each bend is calculated first (see TI 814-03, eqn. C-1).

$$T = 2\ \pi \left(\frac{D_o}{2}\right)^2 P\ \sin\left(\frac{\theta}{2}\right)$$

where:

T = thrust generated, N
D_o = outer diameter of pipe, mm
P = design pressure, MPa
θ = angle of bend, degree

For the 90° bends:

$$T_{90} = 2\ \pi \left(\frac{50\ mm}{2}\right)^2 (0.250\ MPa)\ \sin\left(\frac{90}{2}\right)$$
$$= 694\ N$$

For the 45° bends:

$$T_{45} = 2\ \pi \left(\frac{50\ mm}{2}\right)^2 (0.250\ MPa)\ \sin\left(\frac{45}{2}\right)$$
$$= 376\ N$$

The area of the thrust block is calculated by (see TI 814-03 equation C-2):

$$A_{TB} = \frac{T}{a}\ f_s$$

where:

A_{TB} = area of thrust block (mm^2)
T = thrust generated, N
a = safe soil bearing value, MPa; assume 20.5 MPa
f_s = safety factor, typically 1.5

For the 90° bends:

$$A_{90TB} = \frac{694\ N}{20.5\ MPa}\ 1.5 = 51\ mm^2$$

For the 45° bends:

$$A_{90TB} = \frac{376\ N}{20.5\ MPa}\ 1.5 = 28\ mm^2$$

i. Line XXX-PYS-101
Chemical Feed from Bulk Polymer to Polymer Day Tank

Referencing Sketch C-10:

Polymer demand = 0.3785 m^3/day;
therefore, assuming a 15 minute fill the maximum flow rate,
Q = 2.628 x 10^{-2} m^3/min = 4.38 x 10^{-4} m^3/s

Existing run = 50.0 m
New run = 25.0 m

Maximum elevation change = 3.0 m

Existing polymer pump head = 8.1 m (79.5 kPa)

Fittings:
- 6 x 90° elbows
- 1 branch Tee
- 3 isolation ball valves

MATERIAL OF CONSTRUCTION

The existing polymer line is 25 mm diameter, schedule 80 PVC. The polymer makeup is proprietary but is approximately 99% water. From a site inspection there is no evidence of existing pipe erosion or breakdown. Therefore, the extension or new pipe run will also use 25 mm diameter, schedule 80 PVC with electrical heat tracing and insulation to maintain 20°C (maximum temperature differential will be 45°C).

PIPE SIZING/PRESSURE DROP

Step 1. Using the same size nominal pipe size of the existing pipe results in an actual D_i of 24.3 mm. Therefore, the liquid velocity is:

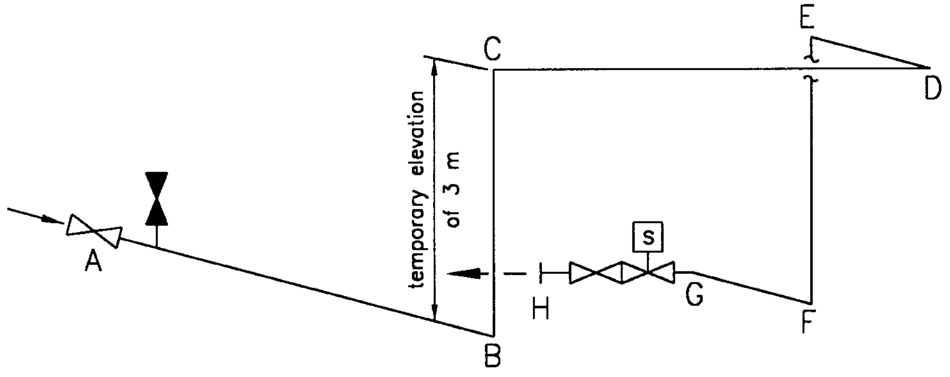
$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2} = \frac{4.38\ x\ 10^{-4} m^3/s}{\frac{\pi}{4}\ (0.0243\ m)^2}$$
$$= 0.94\ m/s$$

The actual velocity, 0.94 m/s, is somewhat slower than the acceptable range, 2.1 ± 0.9 m/s, but the pressure drop will be checked using this velocity due to the limited pump head. The line designation is amended to 25-PYS-101.

Step 2. At 23.9°C, ν = 8.94 x 10^{-7} m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f\,L}{D_i} + \Sigma K \right) \frac{V^2}{2\,g} \right]$$



Sketch C-10

Ref. p. 3-8.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.0243\ m)(0.94\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 2.56\ x\ 10^4 - turbulent\ flow$$

$$\varepsilon = 0.0015\ mm\ from\ Table\ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015\ mm}{24.3\ mm} = 0.00006$$

Therefore, f = 0.024 from the Moody Diagram (Figure 3-1). From Sketch C-10, the sum of the minor loss coefficients from Table 3-3:

Table C-15
Minor Losses for 25-PYS-101

Minor Loss	**K**
3 x ball valves (open)	3(4.5)
1 tee-flow through	0.6
6 x 90° elbows	6(0.5)
1 exit	1.0
ΣK =	18.1

$$h_L = \left(\frac{f\ L}{D_i} + \Sigma K\right) \frac{V^2}{2\ g}$$

$$= \left[\frac{(0.024)(75.0\ m)}{0.0243\ m} + 18.1\right] \frac{(0.94\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 4.15\ m$$

The total pump head required is the sum of the piping losses, h_L, and the temporary elevation of 3 m over the walkway. Therefore, the total pump head required is 7.15 m and the actual pump head available is 8.1 m. The pipe should not be sized smaller (even though the flow is below the desired range) unless the pump is to be replaced.

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 79.5 kPa. A pressure transients exists due to potential water hammer conditions from the solenoid valve at the tank inlet. Therefore, the transient will be minimized by having the valve be a "slow-opening" valve.

Ref. p. 3-6.

$$V_w = \left(\frac{E_s}{n_1\ \rho}\right)^{0.5}$$

$$= \left(\frac{2{,}180\ MPa}{(10^{-6} MPa/Pa)(998.2\ kg/m^3)}\right)^{0.5} = 1{,}478\ m/s$$

and

$$t_c = \frac{2\ L}{V_w} = \frac{2\ (75\ m)}{1{,}478\ m/s} = 0.10\ s$$

A gradual valve closure, t_v, = 20 $x_c t$ = 2 s is to be provided. Therefore, the pressure rise is determined.

Ref. p. 3-6.

$$P_i' = \frac{2\ \rho\ L\ V\ n_1}{t_v} =$$

$$\frac{2\ (998.2\ kg/m^3)(75\ m)(0.94\ m/s)(10^{-3} kPa/Pa)}{2\ s}$$

$$= 70.4\ kPa$$

Because the pressure transient is significant (>10% of the operating pressure), it must be included as part of the design pressure.

$$P = 79.5\ kPa + 70.4\ kPa = 150\ kPa$$

From ASME B31.3, the minimum wall thickness, t_m, for thermoplastic pipe is:

$$t_m = \frac{P\ D_o}{(2\ S + P)}$$

S = hydrostatic design stress = 13.8 MPa (reference ASME B31.3, Table B-1)

$$t_m = \frac{(0.150\ MPa)(24.3\ mm)}{[2\ (13.8\ MPa) + (0.150\ MPa)]} = 0.131\ mm$$

Nominal 25 mm, schedule 80 pipe has a thickness of 4.5 mm; therefore, the 25 mm pipe section satisfies pressure integrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - The 25-PYS-101 dead weight is the piping and the insulation. Because the piping section will be continuously full, the weight of the fluid will be determined as part of the dead weight.

The insulation for the piping was selected pursuant to CEGS 15250 to be flexible cellular (elastomeric) foam, 9.525 mm thick and with a specific weight of approximately 314 N/m^3.

$$W = W_P + W_i + W_L$$

$$= A_P\ \gamma_{PVC} + \pi\ \gamma_I\ T_i\ (D_o + T_i) + \frac{\pi}{4}\ D_i^2\ \gamma_L$$

$$W = (4.12\ x\ 10^{-4} m^2)(13{,}517\ N/m^3)$$

$$+ \pi\ (314\ N/m^3)(9.525\ mm)\ x$$

$$(32\ mm + 9.525\ mm)(10^{-6} m^2/mm^2)$$

$$+ \frac{\pi}{4}\ (24.3\ mm)^2(9{,}795\ N/m^3)(10^{-6} m^2/mm^2)$$

$$= 10.5\ N/m;\ uniformly\ distributed$$

Step 3. Wind - From TI 809-01, the basic wind speed is 40.2 m/s. The plant is located in an area with exposure C (open terrain with scattered obstructions having heights less than 10 m) so a gust factor of 33% is added to the basic wind speed to determine the design wind speed, V_{dw}.

$$V_{dw} = (40.2\ m/s)\ (1.33) = 53.5\ m/s$$

$$(or\ 192.6\ km/hr,\ >\ minimum\ of\ 161\ km/hr)$$

Ref. p. 2-7.

$$R_e = C_{W2}\ V_W\ D_o$$

$$= (6.87)(53.5\ m/s)[32\ mm + 2\ (9.525\ mm)]$$

$$= 1.9\ x\ 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), C_D = 1.21.

Ref. p. 2-7.

$$F_W = C_{W1}\ V_W^2\ C_D\ D_o$$

$$= (2.543\ x\ 10^{-6})(53.5\ m/s)^2(1.21)\ x$$

$$[32\ mm + 2\ (9.525\ mm)] = 0.45\ N/m$$

The design wind loads are uniformly distributed horizontally (i.e., perpendicular to the weight load).

Step 4. Snow - From TI 809-01, the basic snow load is 239 kPa.

Ref. p. 2-8.

$$W_s = ½\ n\ D_o\ S_L$$

$$= ½\ (10^{-3}\ m/mm)[32\ mm + 2\ (9.525\ mm)]\ x$$

$$(239\ kPa) = 6.1\ N/m$$

The design snow loads are uniformly distributed and additive to the weight.

Step 5. Ice - No data is readily available; therefore, assume a maximum buildup of 12.5 mm.

Ref. p. 2-8.

$$W_I = \pi\ n_3\ S_I\ t_I\ (D_o + t_I)$$

$$= \pi\ (10^{-6}\ m^2/mm^2)(8{,}820\ N/m^3)(12.5\ mm)\ x$$

$$[32\ mm + 2\ (9.525\ mm) + 12.5\ mm] = 22.0\ N/m$$

The design ice loads are uniformly distributed and additive to the weight.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = $(54 \times 10^{-6}$ mm/mm-°C) (45°C) = 2.43×10^{-3} mm/mm.

STRESS ANALYSIS

Step 1. Internal Stresses - 25-PYS-101 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - In accordance with ASME B31.3, for thermoplastic piping the sum of the external stresses resulting from loads must be less than 1.33 S_h:

Ref. p. 3-17.

$$\Sigma\ S_L \leq 1.33\ S_h$$

From ASME B31.3, Table A-1, S_h = 13.8 MPa.

$$1.33 S_h = 1.33\ (13.8\ MPa) = 18.4\ MPa$$

To determine the longitudinal stress due to uniformly distributed loads such as weight, the support spans and spacing must first be determined. Referring to Figure C-3, Piping Layout Plan, all three chemical feed lines will be run parallel and will be supported on a pipe rack. As the smallest diameter pipe of the three chemical feed lines, 25-PYS-101 will control the support spacing. From manufacturer's data (see Table 5-4), the maximum support spacing, L, for 25 mm PVC pipe is 1.7 m; see Figure C-4, Piping Layout Plan with Support Locations.

Ref. p. 3-17.

$$\Sigma S_L = 0.1\ \frac{W\ L^2}{n\ Z}$$

Ref. p. 3-25.

$$Z = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(32\ mm)^4 - (24.3\ mm)^4}{(32\ mm)} = 2{,}147\ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

Ref. p. 3-17.

$$\Sigma S_L = (0.1)\ \frac{[(10.5\ N/m) + (22.0\ N/m)](1.7\ m)^2}{(10^{-3}\ m/mm)(2{,}147\ mm^3)}$$

$$= 4.4\ MPa$$

For 25-PYS-101, $\Sigma S_L \leq 1.33 S_h$; therefore, the system is acceptable for the design stress loading.

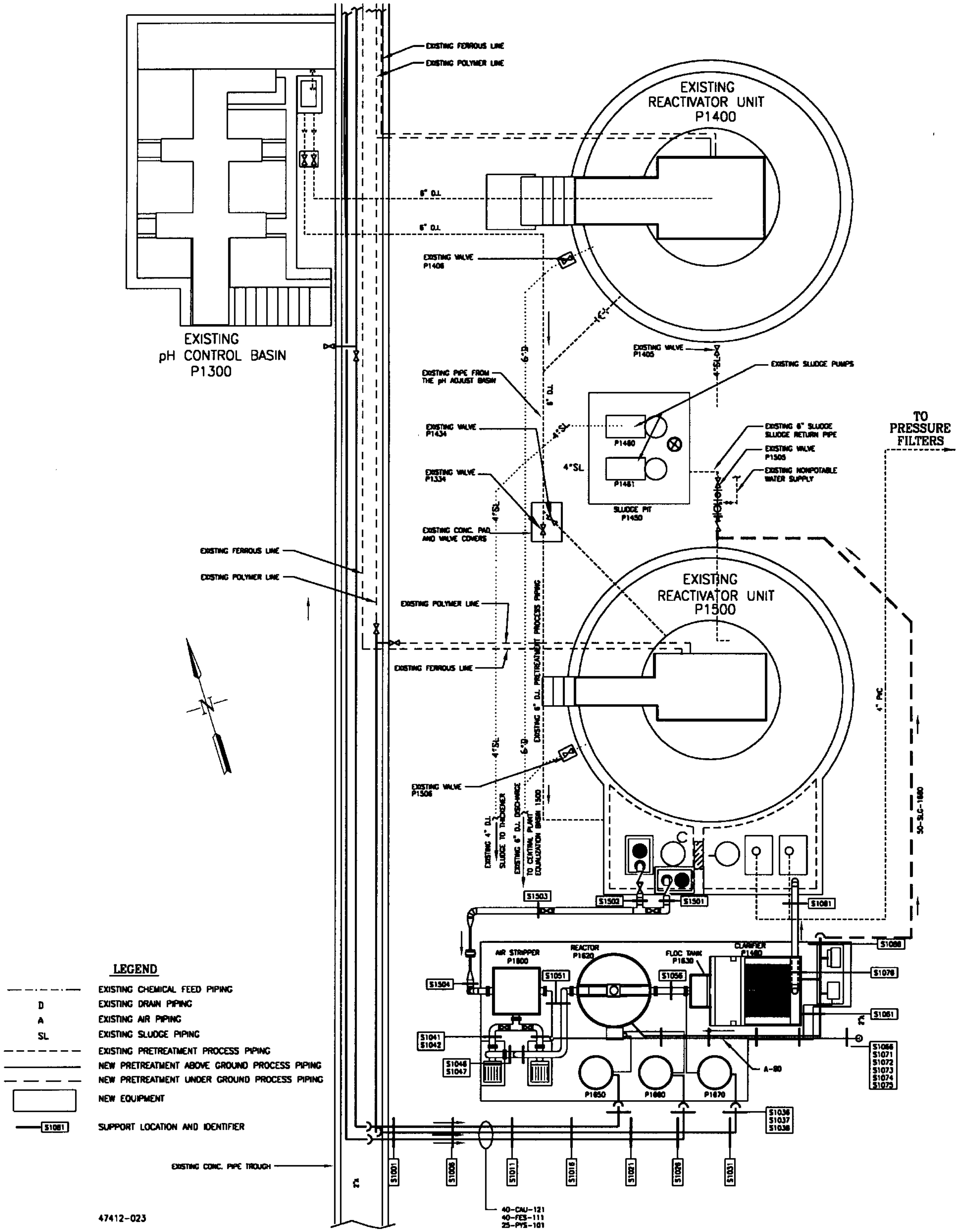
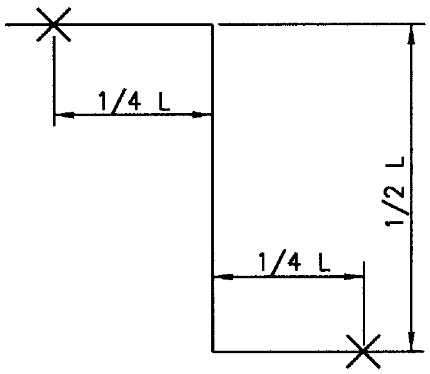


Figure C-4. Piping Layout Plan with Support Locations

Step 3. Stresses are imposed upon the piping system due to thermal expansion and contraction. To ensure that thermoplastic piping systems have sufficient flexibility to prevent these failures, a minimum offset is required between a bend and a restrained anchor. For 25-PYS-101, there are a series of Z-shaped arrangements: A-B-C-D, C-D-E-F, and E-F-G-H; see Sketch C-10.



Sketch C-11

Referencing Sketch C-11, for Z-shapes:

$$L = \frac{1\ m}{1{,}000\ mm}\left(\frac{3\ E\ D_o\ \varepsilon}{S}\right)^{0.5}$$

where:

L = offset pipe length, m
E = modulus of elasticity = 2,895 MPa
S = allowable stress = 13.8 MPa
D_o = outer pipe diameter = 32 mm
ε = thermal expansion coefficient = 2.43 x 10^{-3} mm/mm

For pipe section A-B-C-D with a length of approximately 3 m:

$$L_{ABCD} = \frac{1\ m}{1{,}000\ mm}\ x$$

$$\left(\frac{3(2{,}895MPa)(32mm)[(2.43x10^{-3}\frac{mm}{mm})(3{,}000mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.38\ m,\ minimum.$$

Since ½ (B-C) = ½ (3 m) > L_{ABCD}, the flexibility of the piping segment is acceptable. The restraints (anchors) should be located at a minimum 1/4 L = 1/4 (0.38 m) = 0.10 m from the bends. That is, a pipe guide should be located at support no. S1006 and another within the existing pipe trench - field check rack location.

For pipe section C-D-E-F with a length of approximately 10.7 m:

$$L_{CDEF} = \frac{1\ m}{1{,}000\ mm}\ x$$

$$\left(\frac{3(2{,}895MPa)(32mm)[(2.43x10^{-3}\frac{mm}{mm})(10{,}700mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.72\ m,\ minimum.$$

Since ½ (D-E) = ½ (10.7 m) > L_{CDEF}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.72 m) = 0.36 m from the bends. That is, a pipe guide should be located at support no. S1026 and a vertical guide 0.36 m from bottom of pipe (BOP) on support no. S1038.

For pipe section E-F-G-H with a length of approximately 1.5 m:

$$L_{EFGH} = \frac{1\ m}{1{,}000\ mm}\ x$$

$$\left(\frac{3(2{,}895 MPa)(32 mm)[(2.43x10^{-3}\frac{mm}{mm})(1{,}500 mm)]}{13.8 MPa}\right)^{0.5}$$

$$= 0.27\ m,\ minimum.$$

Since ½ (F-G) = ½ (3 m) > L_{EFGH}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.27 m) = 0.07 m from the bends. That is, relocate the vertical pipe guide established on S1038 at 0.36 m BOP down to ½ the vertical run, ½ (2 m) = 1 m BOP. Also locate the support for the solenoid valve at 0.07 m from the bend at G.

---

j. Line 15-PYS-102
Chemical Feed from Polymer Day Tank to Polymer Controlled Volume Pump

The controlled volume pump has a 15 mm female taper threaded connection. The piping from the pump to the process injection point is supplied by the process unit manufacturer and is 15 mm SAE 100R7 hose. Therefore, 15-PYS-102 is selected to be identical to the process hose: 15 mm SAE 100R7 hose (thermoplastic tube, synthetic-fiber reinforcement, thermoplastic cover) with 15 mm male taper threaded end connections, built-in fittings. Minimum hose length is 3 m.

Ensure that the process engineer, or the engineer that is specifying the day tanks, designs the polymer day tank with the proper discharge port - 15 mm taper threaded nozzle, female.

---

k. Line XXX-FES-111
Chemical Feed from Bulk Ferrous Sulfate to Ferrous Sulfate Day Tank

Referencing Sketch C-12:

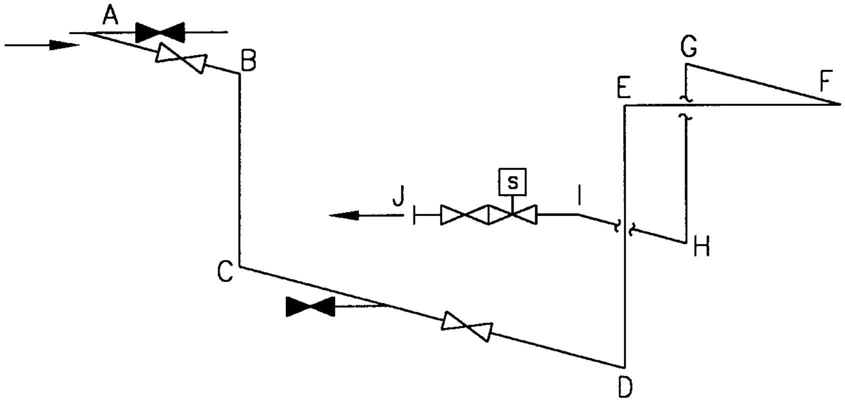
Ferrous sulfate demand = 0.757 m^3/day; therefore, assuming a 15 minute fill the maximum flow rate, Q = 5.05 x 10^{-2} m^3/min = 8.42 x 10^{-4} m^3/s

Existing run = 30.0 m
New run = 50.0 m

Maximum elevation change = -0.5 m (the elevation difference between E and A is 0.5 m down)

Existing ferrous sulfate pump head = 3.05 m (29.9 kPa)

Fittings:
- 8 x 90° elbows
- 1 x Tee, branch flow
- 1 x Tee, flow-through
- 4 x isolation ball valves



Sketch C-12

MATERIAL OF CONSTRUCTION

The existing ferrous sulfate line is 40 mm diameter, schedule 80 PVC. The ferrous sulfate is 20% solution with a specific gravity, s.g. = 1.18. Ferrous sulfate is compatible with PVC and from a site inspection there is no evidence of existing pipe erosion or breakdown. Therefore, the extension or new pipe run will also use 40 mm diameter, schedule 80 PVC with electrical heat tracing and insulation to maintain 20°C (maximum temperature differential will be 45°C).

PIPE SIZING/PRESSURE DROP

Step 1. Using the same size nominal pipe size of the existing pipe results in an actual D_i of 40 mm. Therefore, the liquid velocity is:

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2}$$

$$= \frac{8.42 \ x \ 10^{-4} \ m^3/s}{\frac{\pi}{4} \ (0.040 \ m)^2} = 0.67 \ m/s$$

The actual velocity, 0.67 m/s, is somewhat slower than the acceptable range, 2.1 ± 0.9 m/s, but the pressure drop will be checked using this velocity due to the limited pump head. The line designation is amended to 40-FES-111.

Step 2. At 23.9°C, $\nu = 1.05 \text{ x } 10^{-6}$ m^2/s and the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

Ref. p. 3-8.

$$h_L = \left[\left(\frac{f \ L}{D_i} + \Sigma K\right) \frac{V^2}{2 \ g}\right]$$

Ref. p. 3-8.

$$R_e = \frac{D_i \ V}{\nu} = \frac{(0.040 \ m)(0.67 \ m/s)}{1.05 \ x \ 10^{-6} \ m^2/s}$$

$$= 2.55 \ x \ 10^4 - turbulent \ flow$$

$$\varepsilon = 0.0015 \ mm \ from \ Table \ 3\text{-}1$$

$$\varepsilon/D_i = \frac{0.0015 \ mm}{40 \ mm} = 0.00004$$

Therefore, f = 0.024 from the Moody Diagram (Figure 3-1). From Sketch C-12, the sum of the minor loss coefficients from Table 3-3:

Table C-16
Minor Losses for 40-FES-111

Minor Loss	**K**
4 x ball valves (open)	4(4.5)
1 tee-branch flow	1.8
1 tee-flow through	0.6
8 x 90° elbows	8(0.5)
1 exit	1.0
ΣK =	25.4

$$h_L = \left(\frac{f \ L}{D_i} + \Sigma K\right) \frac{V^2}{2 \ g}$$

$$= \left[\frac{(0.024)(80.0 \ m)}{0.040 \ m} + 25.4\right] \frac{(0.67 \ m/s)^2}{2 \ (9.81 \ m/s^2)}$$

$$= 1.68 \ m$$

The total pump head required is the sum of the piping losses, h_L, and the elevation gain of - 0.5 m. Therefore, the total pump head required is 1.98 m + (-0.5 m) = 1.48 m and the actual pump head available is 3.05 m. The pipe should not be sized smaller (even though the flow is below the desired range) unless the pump is to be replaced.

PRESSURE INTEGRITY

The design pressure is equal to the required pump head = 29.9 kPa. A pressure transients exists due to potential water hammer conditions from the solenoid valve at the tank inlet. Therefore, the transient will be minimized by having the valve be a “slow-opening” valve.

Ref. p. 3-6.

$$V_w = \left(\frac{E_s}{n_1\ \rho}\right)^{0.5}$$

$$= \left(\frac{2{,}180\ MPa}{(10^{-6} MPa/Pa)(1{,}178\ kg/m^3)}\right)^{0.5} = 1{,}360\ m/s$$

and

$$t_c = \frac{2\ L}{V_w} = \frac{2\ (80\ m)}{1{,}360\ m/s} = 0.12\ s$$

A gradual valve closure, t_v, of 2 s is to be provided. Therefore, the pressure rise is determined.

Ref. p. 3-6.

$$P_i' = \frac{2\ \rho\ L\ V\ n_1}{t_v} =$$

$$\frac{2\ (1{,}178\ kg/m^3)(80\ m)(0.67\ m/s)(10^{-3} kPa/Pa)}{2\ s}$$

$$= 63.1\ kPa$$

Because the pressure transient is significant (>10% of the operating pressure), it must be included as part of the design pressure.

$$P = 29.9\ kPa + 63.1\ kPa = 93\ kPa$$

From ASME B31.3, the minimum wall thickness, t_m, for thermoplastic pipe is:

$$t_m = \frac{P\ D_o}{(2\ S + P)}$$

S = hydrostatic design stress = 13.8 MPa (reference ASME B31.3, Table B-1)

$$t_m = \frac{(0.093\ MPa)(40\ mm)}{[2\ (13.8\ MPa) + (0.093\ MPa)]}$$

$$= 0.134\ mm$$

Nominal 40 mm, schedule 80 pipe has a thickness of 5.1 mm; therefore, the 40 mm pipe section satisfies pressure integrity.

LOADS

Step 1. Pressure - See the pressure integrity calculations for the design pressure.

Step 2. Weight - The 40-FES-111 dead weight is the piping and the insulation. Because the piping section will be continuously full, the weight of the fluid will be determined as part of the dead weight.

The insulation for the piping was selected pursuant to GS 15250 to be flexible cellular (elastomeric) foam, 9.525 mm thick and with a specific weight of approximately 314 N/m^3.

$$W = W_P + W_i + W_L$$

$$= A_P\ \gamma_{PVC} + \pi\ \gamma_I\ T_i\ (D_o + T_i) + \frac{\pi}{4}\ D_i^2\ \gamma_L$$

$$W = (6.89 \; x \; 10^{-4} m^2)\;(13{,}517 \; N/m^3)$$
$$+ \; \pi \; (314 \; N/m^3)(9.525 \; mm) \; x$$
$$(50 \; mm + 9.525 \; mm)(10^{-6} m^2/mm^2)$$
$$+ \; \frac{\pi}{4} \; (40 \; mm)^2 (11{,}560 \; N/m^3)(10^{-6} \; m^2/mm^2)$$
$$= \; 24.4 \; N/m; \; uniformly \; distributed$$

Step 3. Wind - From TI 809-01, the basic wind speed is 40.2 m/s. The plant is located in an area with exposure C (open terrain with scattered obstructions having heights less than 10 m) so a gust factor of 33% is added to the basic wind speed to determine the design wind speed, V_{dw}.

$$V_{dw} = (40.2 \; m/s)\;(1.33) = 53.5 \; m/s$$
$$(or \; 192.6 \; km/hr, \; > \; minimum \; of \; 161 \; km/hr)$$

Ref. p. 2-7.

$$R_e = C_{W2} \; V_W \; D_o$$
$$= (6.87)(53.5 \; m/s)[50 \; mm + 2 \; (9.525 \; mm)]$$
$$= 2.54 \; x \; 10^4$$

Using the R_e value in the ASCE 7 drag coefficient chart and assuming an infinite circular cylinder (i.e., L:D > 5:1), $C_D = 1.21$.

Ref. p. 2-7.

$$F_W = C_{W1} \; V_W^2 \; C_D \; D_o$$
$$= (2.543 \; x \; 10^{-6})(53.5 \; m/s)^2 (1.21) \; x$$
$$[50 \; mm + 2 \; (9.525 \; mm)] = 0.61 \; N/m$$

The design wind loads are uniformly distributed horizontally (i.e., perpendicular to the weight load).

Step 4. Snow - From TI 809-01, the basic snow load is 239 kPa.

Ref. p. 2-8.

$$W_s = ½ \; n \; D_o \; S_L =$$
$$½ \; (10^{-3} m/mm)[50 \; mm + 2(9.525 \; mm)](239 \; kPa)$$
$$= 8.25 \; N/m$$

The design snow loads are uniformly distributed and additive to the weight.

Step 5. Ice - No data is readily available; therefore, assume a maximum buildup of 12.5 mm.

Ref. p. 2-8.

$$W_I = \pi \; n_3 \; S_I \; t_I \; (D_o + t_I)$$
$$= \pi \; (10^{-6} m^2/mm^2)(8{,}820 \; N/m^3)(12.5 \; mm) \; x$$
$$[50 \; mm + 2(9.525 \; mm) + 12.5 \; mm] = 28.2 \; N/m$$

The design ice loads are uniformly distributed and additive to the weight.

Step 6. Seismic - From TM 5-809-10, the facility is located in a seismic zone 0; therefore, the seismic loading is not applicable.

Step 7. Thermal - Thermal loads will be examined under the stress analysis. The coefficient of thermal expansion = (54 x 10^{-6} mm/mm-°C) (45°C) = 2.43 x 10^{-3} mm/mm.

STRESS ANALYSIS

Step 1. Internal Stresses - 40-FES-111 meets the pressure integrity requirements; therefore, the limits of stress due to internal pressure are satisfied.

Step 2. External Stresses - In accordance with ASME B31.3, for thermoplastic piping the sum of the external stresses resulting from loads must be less than 1.33 S_h:

Ref. p. 3-17.

$$\Sigma S_L \leq 1.33\ S_h$$

From ASME B31.3, Table A-1, S_h = 13.8 MPa.

$$1.33 S_h = 1.33\ (13.8\ MPa) = 18.4\ MPa$$

To determine the longitudinal stress due to uniformly distributed loads such as weight, the support spans and spacing must first be determined. Referring to Figure C-3, Piping Layout Plan, all three chemical feed lines will be run parallel and will be supported on a pipe rack. As the smallest diameter pipe of the three chemical feed lines, 40-FES-111 will control the support spacing. From manufacturer's data (see Table 5-4), the maximum support spacing, L, for 40 mm PVC pipe is 1.7 m; see Figure C-4, Piping Layout Plan with Support Locations.

Ref. p. 3-17.

$$\Sigma S_L = 0.1\ \frac{W\ L^2}{n\ Z}$$

Ref. p. 3-25.

$$Z = \frac{\pi}{32}\ \frac{D_o^4 - D_i^4}{D_o}$$

$$= \frac{\pi}{32}\ \frac{(50\ mm)^4 - (40\ mm)^4}{(50\ mm)} = 7{,}245\ mm^3$$

It is assumed that snow and ice will not occur concurrently and since the ice loading is greater than the snow loading, the sustained loads are equal to the weight of the piping system and the ice.

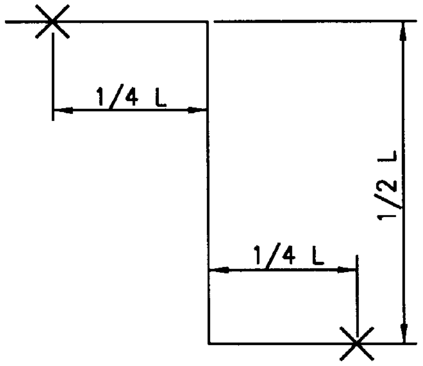
Ref. p. 3-17.

$$\Sigma S_L = (0.1) \frac{[27.4\ N/m + 28.2\ N/m](1.7\ m)^2}{(10^{-3}\ m/mm)(7{,}245\ mm^3)}$$

$$= 2.26\ MPa$$

For 40-FES-111, $\Sigma S_L \leq 1.33 S_h$; therefore, the system is acceptable for the design stress loading.

Step 3. Stresses are imposed upon the piping system due to thermal expansion and contraction. To ensure that thermoplastic piping systems have sufficient flexibility to prevent these failures, a minimum offset is required between a bend and a restrained anchor. For 40-FES-111, there are a series of Z-shaped arrangements: A-B-C-D, C-D-E-F, E-F-G-H, and G-H-I-J; see Sketch C-12.



Sketch C-13

Referencing Sketch C-13, for Z-shapes:

$$L = \frac{1\ m}{1{,}000\ mm} \left(\frac{3\ E\ D_o\ e}{S} \right)^{0.5}$$

where:

L = offset pipe length, m
E = modulus of elasticity = 2,895 MPa
S = allowable stress = 13.8 MPa
D_o = outer pipe diameter = 32 mm
e = thermal expansion coefficient = 2.43 x 10^{-3} mm/mm

For pipe section A-B-C-D with a length of approximately 3 m:

$$L_{ABCD} = \frac{1\ m}{1{,}000\ mm}\ x\ \left(\frac{3(2{,}895MPa)(50mm)[(2.43x10^{-3}\frac{mm}{mm})(3{,}500mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.52\ m,\ minimum.$$

Since ½ (B-C) = ½ (3.5 m) > L_{ABCD}, the flexibility of the piping segment is acceptable. The restraints (anchors) should be located at a minimum 1/4 L = 1/4 (0.52 m) = 0.13 m from the bends.

For pipe section C-D-E-F with a length of approximately 3 m:

$$L_{CDEF} = \frac{1\ m}{1{,}000\ mm}\ x\ \left(\frac{3(2{,}895MPa)(50mm)[(2.43x10^{-3}\frac{mm}{mm})(3{,}000mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.34\ m,\ minimum.$$

Since ½ (D-E) = ½ (3 m) > L_{CDEF}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.34 m) = 0.08 m from the bends. That is, a pipe guide should be located at support no. S1006 and another within the existing pipe trench.

For pipe section E-F-G-H with a length of approximately 7.5 m:

$$L_{EFGH} = \frac{1\ m}{1{,}000\ mm}\ x\ \left(\frac{3(2{,}895MPa)(50mm)[(2.43x10^{-3}\frac{mm}{mm})(7{,}500mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.75\ m,\ minimum.$$

Since ½ (F-G) = ½ (7.5 m) > L_{EFGH}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.75 m) = 0.19 m from the bends. That is, a pipe guide should be located at support no. 1016 and a vertical pipe guide established at 0.2 m from BOP on support no. S1036.

For pipe section G-H-I-J with a length of approximately 1.5 m:

$$L_{GHIJ} = \frac{1\ m}{1{,}000\ mm}\ x\ \left(\frac{3(2{,}895MPa)(50mm)[(2.43x10^{-3}\frac{mm}{mm})(1{,}500mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.24\ m,\ minimum.$$

Since ½ (H-I) = ½ (1.5 m) > L_{GHIJ}, the flexibility of the piping segment is acceptable. The anchors should be located at a minimum 1/4 L = 1/4 (0.24 m) = 0.06 m from the bends. That is, relocate the vertical pipe guide established on S1036 at 0.20 m BOP down to ½ the vertical run, ½ (2 m) = 1 m BOP. Also locate the support for the solenoid valve at 0.06 m from the bend at I.

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l. Line 20-FES-112

Chemical Feed from Ferrous Sulfate Day Tank
to Ferrous Sulfate Controlled Volume Pump

The controlled volume pump has a 20 mm female taper threaded connection. The piping from the pump to the process injection point is supplied by the process unit manufacturer and is 20 mm SAE 100R7 hose. Therefore, 20-FES-112 is selected to be identical to the process hose: 20 mm SAE 100R7 hose (thermoplastic tube, synthetic-fiber reinforcement, thermoplastic cover) with 20 mm male taper threaded end connections, built-in fittings. Minimum hose length is 2 m.

Ensure that the process engineer, or the engineer that is specifying the day tanks, designs the ferrous sulfate day tank with the proper discharge port - 20 mm taper threaded nozzle, female.

Appendix D
Index

Numerals before and after colons designate chapters and pages respectively (for example, 4:6 designates page 4-6). Italicized numerals indicate that the subject is illustrated in a figure.