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LIQUID PROCESS PIPING - VOL 1 OF 2

Main Category:	Mechanical Engineering
Sub Category:	Process Design
Course #:	MEC-116
Course Content:	153 pgs
PDH/CE Hours:	6

OFFICIAL COURSE/EXAM

(SEE INSTRUCTIONS ON NEXT PAGE)

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MEC-116 EXAM PREVIEW

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Exam Preview:

1. This course material generally follows the American Society of Mechanical Engineers (ASME) Code for Pressure Piping, B31.
    a. True
    b. False
2. Examples of static loads inherent to piping systems are pressure surges such as those caused by pump starts and stops, valve actuation, water hammer, and by the energy discharged by a pressure relief valve.
    a. True
    b. False
3. Vibration in a piping system is caused by the impact of fluctuating force or pressure acting on the system. Mechanical equipment such as pumps can cause vibrations. The potential for damage occurs when the pressure pulses or periodic forces equate with the ___of the piping system.
    a. mass momentum
    b. yield strength
    c. vibration threshold
    d. natural resonant frequencies
4. All valves should be installed to provide a minimum of ____ hand clearance around all hand wheels, allow space for valve parts removal or maintenance, and avoid creating water hammer conditions.
    a. 2.94"
    b. 3"
    c. 3.5"
    d. 3.94"

5. Piping components shall be designed for an internal pressure representing the most severe condition of coincident pressure and temperature expected in normal operation.
   a. True
   b. False
6. Welded or Seamless steel pipe has a Hazen-Williams Coefficient, C of:
   a. 120
   b. 110
   c. 130
   d. 140
7. Careful design of piping support systems of above grade piping systems is necessary to prevent failure. Where practical, a support should be located adjacent to directional changes of piping.
   a. True
   b. False
8. Intergranular corrosion is the localized attack which occurs at or in narrow zones immediately adjacent to the grain boundaries of an alloy. The use of extra-low carbon grades of stainless steel, for example, Type 304L, should not be used when intergranular corrosion could be a problem.
   a. True
   b. False
9. When stress-corrosion cracking occurs, the tensile stress involved is often much less than the yield strength of the material.
   a. True
   b. False
10. Copper is very ductile and malleable metal and does not corrode easily in normal wet/dry environments. Being a noble metal, it displaces hydrogen from a solution containing hydrogen ions.
    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

Description: The objective of this educational course is to review the fundamentals of the design of Liquid Process Piping. This course is vol 1 of 2. This course covers Design Strategy; General Piping Design; & Metallic Piping Systems

EXAM/COMPLETION CERTIFICATES

All completion exams are online. This includes home/self-paced course reviews as well as in-person & live video review sessions. Online exams are graded in real-time, and require a minimum score of 70%. Once a course is completed with a passing exam, the licensee will be presented with their completion certificate. We also keep a copy of all completion certificates indefinitely.

Chapter 1
Introduction

1-1. Purpose

This document provides information for the design of liquid process piping systems.

1-2. Applicability

Liquid process piping systems include all pipe and appurtenances which are used to convey liquids to, from and between pumping, storage and treatment units and which are not integral to any unit (i.e., piping that is furnished as a part of the unit). Plumbing is covered by TM 5-810-5, potable water piping is covered by TI 814-03, sewage piping is covered by TI 814-10, storm drainage, and fuel and lubricant supply piping are excluded.

1-3. References

Required and related references are listed in Appendix A.

1-4. Distribution

This manual is approved for public release; distribution is unlimited.

1-5. Scope

This manual includes criteria for the design of component parts and assemblies of liquid process piping systems. Compliance with these criteria requires only that fundamental design principles be followed. Materials and practices not prohibited by this manual or its basic references should also be considered. Where special conditions and problems are not specifically addressed in this manual, acceptable industry standards should be followed. Modifications or additions to existing systems solely for the purpose of meeting criteria in this manual are not authorized.

a. Cathodic Protection

All underground ferrous piping will be cathodically protected. TM 5-811-7 (Army) and MIL-HDBK-1004/10 (Air Force) contain additional guidance pertaining to cathodic protection of underground pipelines.

1-6. Metrics

Both the International System of Units (SI) (the Modernized Metric System) and the Inch-Pound (IP) ("English") system of measurement are used in this manual. Pipe and appurtenances are provided in standard dimensions, either in International Organization for Standardization (ISO) sizes which are SI based, or in American National Standards Institute (ANSI) sizes which are IP based. Table 1-1 compares the standard sizes of the measurement systems. Standard sizes under the two systems are close, but not equivalent. A similar table is included in the Tri-Service CADD Details Library.

a. SI Design Requirement

In accordance with ER 1110-1-4, where feasible, all project designs for new facilities after 1 January 1994 must be developed using the SI system of measurement. The USACE metric conversion has been closely coordinated with that of the construction industry. Where the industry has committed to a "hard" metric product, USACE must specify and use that product in its designs. Where the industry is as yet undecided, IP products should be used with a "soft" conversion when design efficiency or architectural treatments are not compromised. The limited availability of some metric products may require additional investigation, may result in more complex procurement, and may alter scheduling during construction.

1-7. Brand Names

The citation in this manual of brand names of commercially available products does not constitute official endorsement or approval of the use of such products.

1-8. Accompanying Guidance Specification

This manual is intended to be used in conjunction with CEGS 15200, Liquid Process Piping.

Table 1-1
Standard Pipe Dimensions

ANSI		ISO			
Nominal Pipe Size (in)	**Actual D_o (in)**	**Nominal Pipe Size**		**Actual D_o**	
		(mm)	**(in)**	**(mm)**	**(in)**
c	0.405	6	(0.236)	10	(0.394)
¼	0.540	8	(0.315)	12	(0.472)
d	0.675	10	(0.394)	16	(0.630)
½	0.840	15	(0.591)	20	(0.787)
¾	1.050	20	(0.787)	25	(0.984)
1	1.315	25	(0.984)	32	(1.260)
1¼	1.660	32	(1.260)	40	(1.575)
1½	1.900	40	(1.575)	50	(1.969)
2	2.375	50	(1.969)	63	(2.480)
2½	2.875	65	(2.559)	75	(2.953)
3	3.500	80	(3.150)	90	(3.543)
4	4.500	100	(3.937)	110	(4.331)
5	5.563	125	(4.921)	140	(5.512)
6	6.625	150	(5.906)	160	(6.299)
8	8.625	200	(7.874)	225	(8.858)
10	10.75	250	(9.843)	280	(11.024)
12	12.75	300	(11.81)	315	(12.402)
14	14.00	350	(13.78)	356	(14.00)
16	16.00	400	(15.75)	407	(16.00)
18	18.00	450	(17.72)	457	(18.00)
20	20.00	500	(19.69)	508	(20.00)
--	--	550	(21.65)	559	(22.00)
24	24.00	600	(23.62)	610	(24.02)
--	--	650	(25.59)	660	(25.98)
28	28.00	700	(27.56)	711	(27.99)
30	30.00	750	(29.53)	762	(30.00)
32	32.00	800	(31.50)	813	(32.00)
--	--	850	(33.46)	864	(34.02)
36	36.00	900	(35.43)	914	(35.98)
40	40.00	1000	(39.37)	1016	(40.00)
--	--	1050	(41.34)	1067	(42.00)
44	44.00	1100	(43.31)	1118	(44.00)
48	48.00	1200	(47.24)	1219	(48.00)
52	52.00	1300	(51.18)	1321	(52.00)
56	56.00	1400	(55.12)	1422	(56.00)
60	60.00	1500	(59.06)	1524	(60.00)

Note: D_o = Outer Diameter

1-9. Manual Organization

Chapter 2 of this manual provides basic principles and guidance for design. Chapter 3 presents engineering calculations and requirements for all piping systems, regardless of construction material. Subsequent chapters address engineering requirements for specific materials of construction, valves, ancillary equipment, and corrosion protection.

a. Fluid/Material Matrix

Appendix B contains a matrix that compares pipeline material suitability for different process applications. Design for specific process applications should consider temperature, pressure and carrier fluid. The use of Appendix B is addressed in Chapter 3.

Chapter 2
Design Strategy

2-1. Design Analyses

The design analyses includes the design of the process piping systems. The design criteria includes applicable codes and standards, environmental requirements, and other parameters which may constrain the work.

a. Calculations

Engineering calculations included in the design analyses document the piping system design. Combined with the piping design criteria, calculations define the process flow rates, system pressure and temperature, pipe wall thickness, and stress and pipe support requirements. Design calculations are clear, concise, and complete. The design computations should document assumptions made, design data, and sources of the data. All references (for example, manuals, handbooks, and catalog cuts), alternate designs investigated, and planned operating procedures are included. Computer-aided design programs can be used but are not a substitute for the designer's understanding of the design process.

b. System Descriptions

System descriptions provide the functions and major features of each major system and may require inputs from mechanical, electrical and process control disciplines. The system description contains system design bases, operating modes and control concepts, and both system and component performance ratings. System descriptions provide enough information to develop process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), and to obtain any permits or approvals necessary to proceed. Table 2-1 lists the typical contents of a system description.

Table 2-1
System Description

1. Function
2. Bases of Design
Environmental
Safety
Performance Requirements
Codes and Standards
3. Description
General Overview
System Operation
Major Components

2-2. Specifications

Piping specifications define material, fabrication, installation and service performance requirements. The work conforms to ER 1110-345-700, Design Analysis, Drawings and Specifications. In addition, the project design must adhere to general quality policy and principles as described in ER 1110-1-12, Quality Management.

2-3. Drawings

Contract drawings include layout piping drawings, fabrication or detail drawings, equipment schedules, and pipe support drawings. Isometric drawings may also be included and are recommended as a check for interferences and to assist in pipe stress analyses. A detailed pipe support drawing containing fabrication details is required. Piping supports can be designed by the engineer or the engineer may specify the load, type of support, direction and degree of restraint.

a. Drawings Requirements

The requirements and procedures for the preparation and approval of drawings shall meet ER 1110-345-700, Design Analysis, Drawings and Specifications. This regulation addresses the stages of design and construction, other than shop drawings.

b. Process Flow Diagram (PFD) Content

PFDs are the schematic illustrations of system descriptions. PFDs show the relationships between the major system components. PFDs also tabulate process design values for different operating modes, typically normal, maximum and minimum. PFDs do not show piping ratings or designations, minor piping systems, for example, sample lines or valve bypass lines;

instrumentation or other minor equipment, isolation valves, vents, drains or safety devices unless operable in a described mode. Table 2-2 lists the typical items contained on a PFD, and Figure 2-1 depicts a small and simplified PFD.

Table 2-2
PFDs

1. Major Equipment Symbols, Names, Identification Number
2. Process Piping
3. Control Valves and Other Valves that Affect Operations
4. System Interconnections
5. System Ratings and Operational Variables

   maximum, average, minimum flow
   maximum, average, minimum pressure
   maximum, average, minimum temperature
6. Fluid Composition

c. Piping and Instrumentation Diagram (P&ID) Content

P&IDs schematically illustrate the functional relationship of piping, instrumentation and system equipment components. P&IDs show all of the piping, including the intended physical sequence of branches, reducers, and valves, etc.; equipment; instrumentation and control interlocks. The P&IDs are used to operate the process systems. Table 2-3 lists the typical items contained on a P&ID, and Figure 2-2 depicts a small and simplified P&ID.

d. Piping Sketches

Major piping sketches may be included in a preliminary design submittal. Sketches of the major piping systems may be overlaid on preliminary equipment locations and structural plans to indicate new pipe runs and provide data input for a cost estimate.

Table 2-3
P&IDs

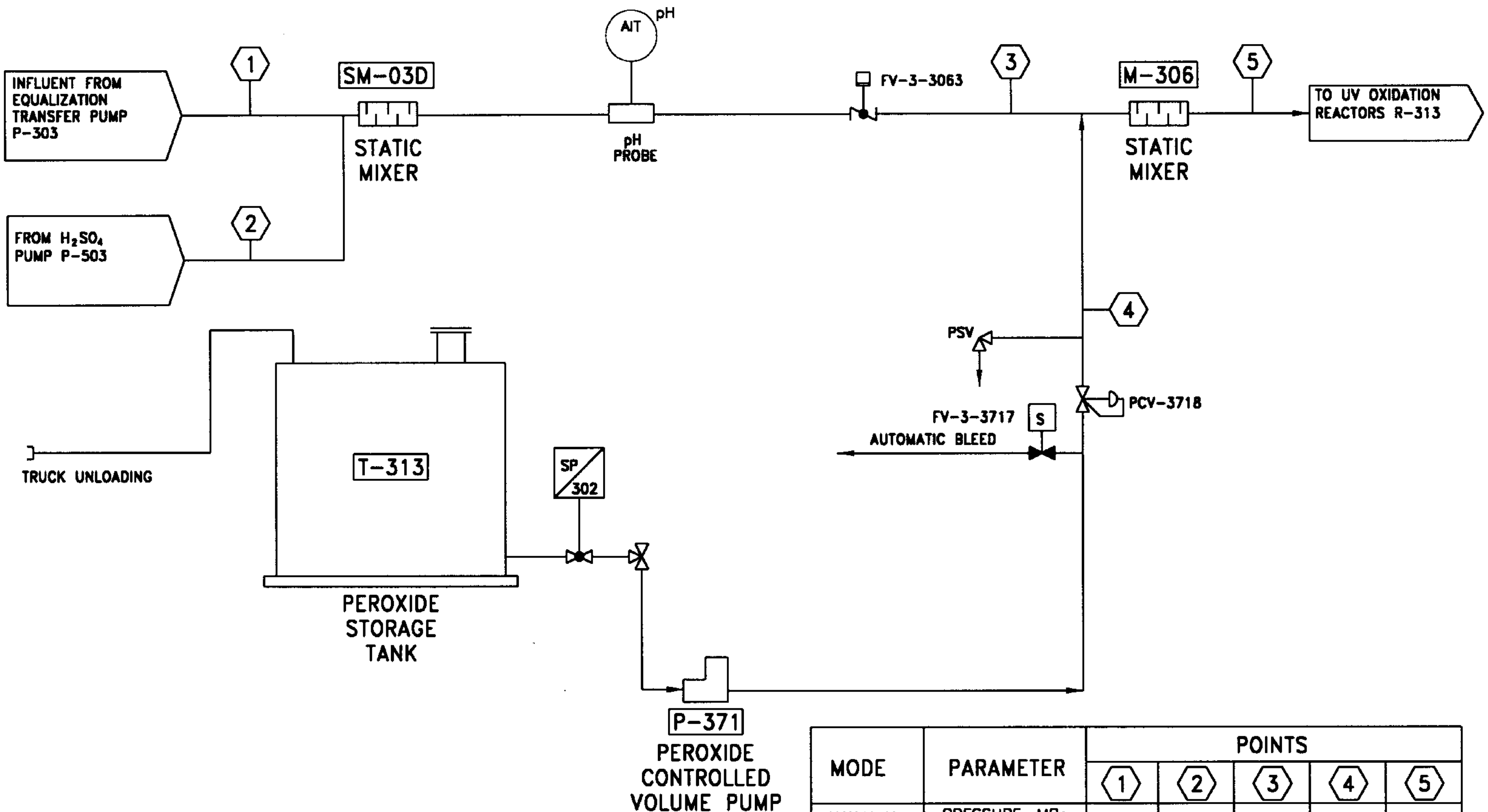
1. Mechanical Equipment, Names and Numbers
2. All Valves and Identification
3. Instrumentation and Designations
4. All Process Piping, Sizes and Identification
5. Miscellaneous Appurtenances including Vents, Drains, Special Fittings, Sampling Lines, Reducers and Increasers
6. Direction of Flow
7. Class Change
8. Interconnections
9. Control Inputs/Outputs and Interlocks

2-4. Bases of Design

The bases of design are the physical and material parameters; loading and service conditions; and environmental factors that are considered in the detailed design of a liquid process piping system to ensure a reasonable life cycle. The bases of design must be developed in order to perform design calculations and prepare drawings.

a. Predesign Surveys

Predesign surveys are recommended for the design of liquid process piping for new treatment processes and are a necessity for renovation or expansion of existing processes. A site visit provides an overview of the project. Design requirements are obtained from the customer, an overall sense of the project is acquired, and an understanding of the aesthetics that may be involved is developed. For an existing facility, a predesign survey can be used to evaluate piping material compatibility, confirm as-built drawings, establish connections, and develop requirements for aesthetics.



MODE	PARAMETER	POINTS 1	2	3	4	5
MAXIMUM	PRESSURE, MPa					
	TEMP, °C					
	FLOW, m^3/hr.					
NORMAL	PRESSURE, MPa					
	TEMP, °C					
	FLOW, m^3/hr.					
MINIMUM	PRESSURE, MPa					
	TEMP, °C					
	FLOW, m^3/hr.					

Figure 2-1. Process Flow Diagram (PFD)
(Source: SAIC, 1998.)

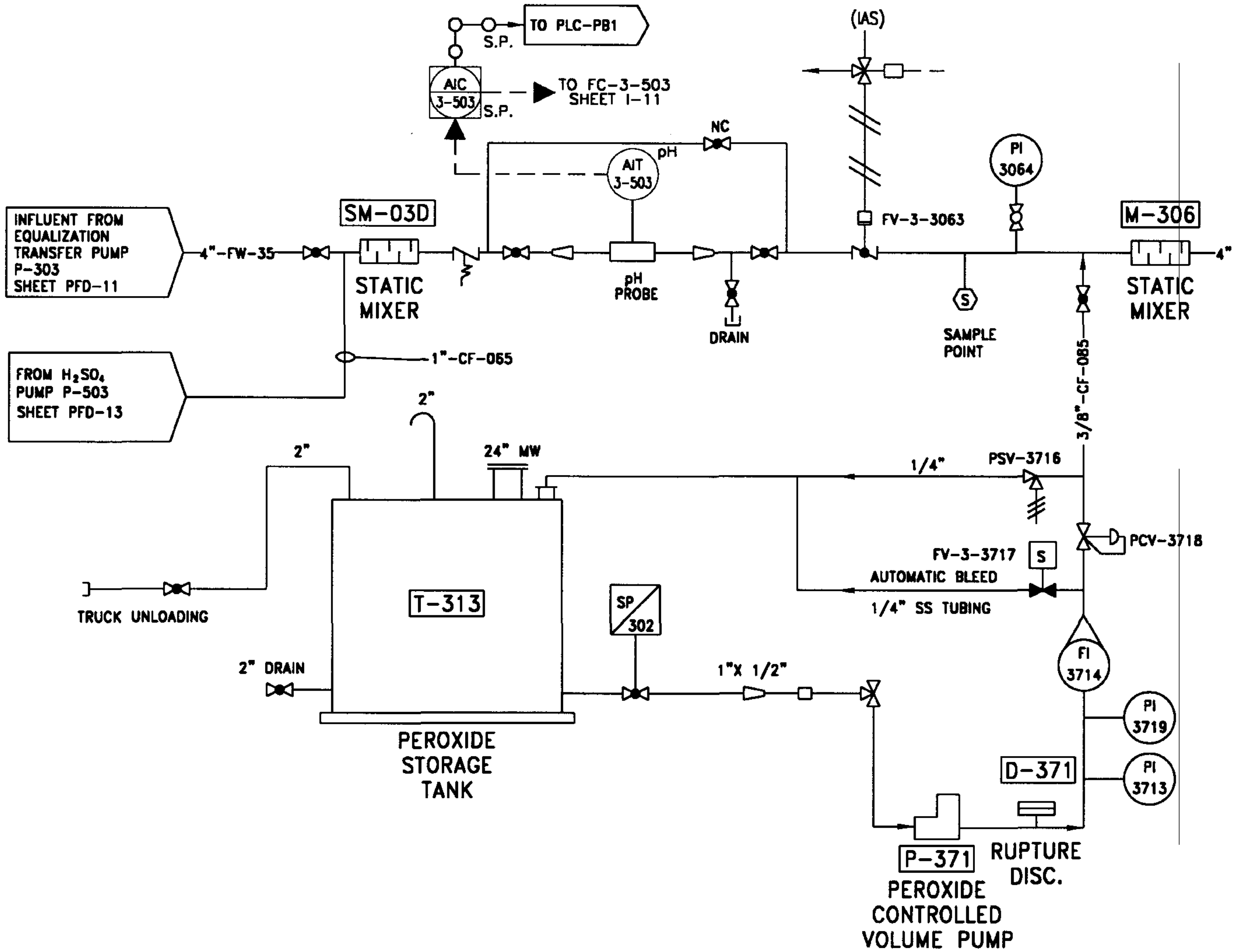


Figure 2-2. Piping and Instrumentation Diagram (P&ID)
(Source: SAIC, 1998.)

Soil conditions play a major role in the selection of piping systems. Soils which contain organic or carbonaceous matter such as coke, coal or cinders, or soils contaminated with acid wastes, are highly corrosive. These conditions impact ferrous metals more than nonferrous metals. For normally acceptable metals, soil variations may be significant. Buried pipes corrode faster at the junction line of dissimilar soils. In fact, electric potentials up to one (1) volt may be generated by placing a metal pipe where it crosses dissimilar soils.

Paragraph 12-2d addresses requirements for predesign surveys and soils sampling that may be necessary to design cathodic protection systems.

b. Service Conditions

The piping system is designed to accommodate all combinations of loading situations (pressure changes, temperature changes, thermal expansion/contraction and other forces or moments) that may occur simultaneously. These combinations are referred to as the service conditions of the piping. Service conditions are used to set design stress limits and may be defined or specified by code, or are determined based on the system description, site survey, and other design bases.

c. Design Codes and Standards

Standards, codes and specifications referenced throughout this document are issued by the organizations listed in Table 2-4. Codes and standards are reviewed based on project descriptions to determine and verify applicability. This manual generally follows the American Society of Mechanical Engineers (ASME) Code for Pressure Piping, B31. ASME B31 includes the minimum design requirements for various pressure piping applications. While this manual is not comprehensive in including code requirements, it includes standards and recommendations for design of pressure piping.

Table 2-4
Standards and Codes

ANSI	American National Standards Institute 11 West 42nd Street, New York, NY 10036
API	American Petroleum Institute 1220 L Street NW, Washington, DC 20005
ASME	The American Society of Mechanical Engineers 345 47th Street, New York, NY 10017
ASQC	American Society for Quality Control P. O. Box 3005, Milwaukee, WI 53201
ASTM	American Society for Testing and Materials 100 Barr Harbor Drive, West Conshohocken, PA 19428
ISO	International Organization for Standardization 1 Rue de Varembe, Geneva, Switzerland
MSS	Manufacturer’s Standardization Society for the Valves and Fittings Industry 127 Park Street NE, Vienna, VA 22180
NIST	National Institute of Standards and Technology Department of Commerce Washington, D.C.

Piping codes supply required design criteria. These criteria are rules and regulations to follow when designing a piping system. The following list is a sample of some of the parameters which are addressed by design criteria found in piping codes:

- allowable stresses and stress limits;
- allowable dead loads and load limits;
- allowable live loads and load limits;
- materials;
- minimum wall thickness;
- maximum deflection;
- seismic loads; and
- thermal expansion.

Codes do not include components such as fittings, valves, and meters. Design of these piping system components should follow industry standards. Standards supply required design criteria and rules for individual components or classes of components, such as valves, meters, and fittings. The purpose of standards is to specify rules for each manufacturer of these components. This permits component interchangeability in a piping system. Standards apply to both dimensions and performance of system components and are prescribed when specifying construction of a piping system.

d. Environmental Factors

The potential for damage due to corrosion must be addressed in the design of process piping. Physical damage may also occur due to credible operational and natural phenomena, such as fires, earthquakes, high winds, snow or ice loading, and subsidence. Two instances of temperature changes must be considered as a minimum. First, there are diurnal and seasonal changes. Second, thermal expansion where elevated liquid temperatures are used must be accommodated. Compensation for the resulting expansions and contractions are made in both the piping system and support systems. Internal wear and erosion also pose unseen hazards that can result in system failures.

Chapter 4 discusses why corrosion occurs in metallic piping, the problems that can result from corrosion, and how appropriate material choices can be made to minimize corrosion impacts. All underground ferrous piping must be cathodically protected. Chapter 12 of this manual, TM 5-811-7 (Army) and MIL-HDBK-1004/10 (Air Force), contain additional guidance pertaining to cathodic protection of underground pipelines.

Design concerns for the effects of physically damaging events fall into two broad categories: operational phenomena (for example, fires, spills, power outages, impacts/collisions, and breakdown or failure of associated equipment) and natural phenomena (for example, seismic occurrences, lightning strikes, wind, and floods). Risk is a combination of probability and consequence. There are infinite possibilities and all scenarios will not be covered by direct reference to codes. Design experience must be combined with a thorough evaluation of the likelihood of all abnormal events.

Working fluids carry abrasives that may wear internal surfaces. The accumulating damage may be impossible to observe until after system failure has occurred. The most effective defense against this damage is to design protection into the system. Depending upon the process, monitoring pipe wall thicknesses may be necessary as an additive or alternate method to prevent failure due to erosion.

It may not be practical in many cases to provide corrosion-resistant materials due to structural needs or other overriding physical constraints. In these cases, the most effective solution may be to design thicker components to allow for the effects of corrosion occurring, over time. However, an understanding of a system's environmental factors is required. For example, although it is generally true that thicker components will last longer in a corrosive situation, in a situation where severe pitting corrosion (see Paragraph 4-2 for definitions and description of various types of corrosion) is occurring thicker components may not last much longer than those with standard thicknesses. In this case other design solutions are provided.

The most common installation constraint is the need to avoid interconnection of dissimilar metals. For example, piping is often totally destroyed by connecting brass valves to carbon steel pipe. Short, easily replaced spools may be considered for installation on both sides of such components in order to protect the piping.

e. Safety Provisions

Safety provisions as required by EM 385-1-1, The Safety and Health Requirements Manual, USACE guide specifications, trade standards, codes, and other manuals are referenced here. Requirements of the Occupational Safety and Health Administration (OSHA) are minimum design constraints in USACE projects.

2-5. Loading Conditions

As described in Paragraph 2-4, the stresses on a piping system define the service conditions of the piping system and are a function of the loads on that system. The sources of these loads are internal pressure, piping system dead weight, differential expansion due to temperature changes, wind loads, and snow or ice loads. Loads on a piping system are classified as sustained or occasional loads.

a. Sustained Loads

Sustained loads are those loads that do not vary considerably over time and are constantly acting on the system. Examples of sustained loads are the pressures, both internal and external, acting on the system and the weight of the system. The weight of the system includes both that of the piping material and the operating fluid.

The sustained maximum system operating pressure is the basis for the design pressure. The design temperature is the liquid temperature at the design pressure. The minimum wall thickness of the pipe and the piping components pressure rating is determined by the design temperature and pressure. Although the design pressure is not to be exceeded during normal, steady-state operations, short-term system pressure excursions in excess of the design pressures occur. These excursions are acceptable if the pressure increase and the time durations are within code defined limits.

Piping codes provide design guidance and limits for design pressure excursions. If a code does not have an over-pressure allowance, transient conditions are accounted for within the system design pressure. A reasonable approach to over-pressure conditions for applications without a specific design code is:

(1) For transient pressure conditions which exceed the design pressure by 10 percent or less and act for less than 10 percent of the total operating time, neglect the transient and do not increase the design pressure.
(2) For transients whose magnitude or duration is greater than 10 percent of the design pressure or operating time, increase the design pressure to encompass the range of the transient.

The determination of design pressure and analysis of pressure transients are addressed in Paragraph 3-2.

Dead weight is the dead load of a piping system or the weight of the pipe and system components. Dead weight generally does not include the weight of the system fluid. The weight of the fluid is normally considered an occasional load by code.

For buried piping, dead weight is not a factor. However, a sustained load that is analyzed is the load from the earth above the buried piping. Because of the different potential for deformation, the effects of an earth load on flexible piping and rigid piping are analyzed differently. Paragraph 5-1 f addresses earth loads on buried flexible piping. The earth load on rigid piping may be calculated using the following formula.[1]

$$F_E = \frac{\gamma H}{a}$$

where:

F_E = earth load, kPa (psi)
γ = soil weight, kg/m^3 (lb/ft^3); typically 1,922 kg/m^3 (120 lb/ft^3)
H = height of cover, m (ft)
a = conversion factor, 102 kg/m^2/kPa (144 lb/ft^2/psi).

b. Occasional Loads

Occasional loads are those loads that act on the system on an intermittent basis. Examples of occasional loads are those placed on the system from the hydrostatic leak test, seismic loads, and other dynamic loads. Dynamic loads are those from forces acting on the system, such as forces

[1] AWWA C150, pp. 4-5.

caused by water hammer (defined on page 3-5) and the energy released by a pressure relief device. Another type of occasional load is caused by the expansion of the piping system material. An example of an expansion load is the thermal expansion of pipe against a restraint due to a change in temperature.

Wind load is a transient, live load (or dynamic load) applied to piping systems exposed to the effects of the wind. Obviously the effects of wind loading can be neglected for indoor installation. Wind load can cause other loads, such as vibratory loads, due to reaction from a deflection caused by the wind. The design wind speed is determined from ASCE 7 and/or TI 809-01, Load Assumptions for Buildings, although a minimum of 161 km/h (100 miles per hour) will be used. By manipulating Bernoulli's equation, the following equation may be obtained to calculate the horizontal wind load on a projected pipe length.

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

where:

F_W = design wind load per projected pipe length, N/m (lb/ft)
V_W = design wind speed, m/s (miles/hr)
C_D = drag coefficient, dimension less
D_o = pipe (and insulation) outside diameter, mm (in)
C_{W1} = constant, 2.543 x 10^{-6} (N/m)/[mm(m/s)] (2.13 x 10^{-4} (lb/ft)/[in(mile/hr)]).

The drag coefficient is obtained from ASCE 7 and is a function of the Reynolds Number, R_e, of the wind flow across the projected pipe.

$$R_e = C_{W2}\, V_W\, D_o$$

where:

R_e = Reynolds Number
V_W = design wind speed, m/s (miles/hr)
D_o = pipe (and insulation) outside diameter, mm (in)
C_{W2} = constant, 6.87 s/mm-m (780 hr/in-mile).

Snow and ice loads are live loads acting on a piping system. For most heavy snow climates, a minimum snow load of 1.2 kPa (25 psf) is used in the design. In some cases, local climate and topography dictate a larger load. This is determined from ANSI A58.1, local codes or by research and analysis of other data. Snow loads can be ignored for locations where the maximum snow is insignificant. Ice buildup may result from the environment, or from operating conditions.

The snow loads determined using ANSI A58.1 methods assume horizontal or sloping flat surfaces rather than rounded pipe. Assuming that snow laying on a pipe will take the approximate shape of an equilateral triangle with the base equal to the pipe diameter, the snow load is calculated with the following formula.

$$W_S = \tfrac{1}{2}\, n\, D_o\, S_L$$

where:

W_S = design snow load acting on the piping, N/m (lb/ft)
D_o = pipe (and insulation) outside diameter, mm (in)
S_L = snow load, Pa (lb/ft^2)
n = conversion factor, 10^{-3} m/mm (0.083 ft/in).

Ice loading information does not exist in data bases like snow loading. Unless local or regional data suggests otherwise, a reasonable assumption of 50 to 75 mm (2 to 3 in) maximum ice accumulatio is used to calculate an ice loading:

$$W_I = \pi\, n_3\, S_I\, t_I\, (D_o + t_I)$$

where:

W_I = design ice load, N/m (lbs/ft)
S_I = specific weight of ice, 8820 N/m^3 (56.1 lbs/ft^3)
t_I = thickness of ice, mm (in)
D_o = pipe (and insulation) outside diameter, mm (in)
n_3 = conversion factor, 10^{-6} m^2/mm^2 (6.9 x 10^{-3} ft^2/in^2).

Seismic loads induced by earthquake activity are live (dynamic) loads. These loads are transient in nature. Appropriate codes are consulted for specifying piping systems that may be influenced by seismic loads. Seismic zones for most geographical locations can be found in TM 5-809-10, American Water Works Association

(AWWA) D110, AWWA D103, or CEGS 13080, Seismic Protection for Mechanical Electrical Equipment. ASME B31.3 (Chemical Plant and Petroleum Refinery Piping) requires that the piping is designed for earthquake induced horizontal forces using the methods of ASCE 7 or the Uniform Building Code.

Hydraulic loads are by their nature transient loads caused by an active influence on a piping system. Examples of dynamic loads inherent to piping systems are pressure surges such as those caused by pump starts and stops, valve actuation, water hammer, and by the energy discharged by a pressure relief valve. Examples of hydraulic loads causing pressure transients and the effect upon the design are provided in Paragraph 3-2b.

Vibration in a piping system is caused by the impact of fluctuating force or pressure acting on the system. Mechanical equipment such as pumps can cause vibrations. Typically the low to moderate level of periodic excitation caused by pumps do not result in damaging vibration. The potential for damage occurs when the pressure pulses or periodic forces equate with the natural resonant frequencies of the piping system. TM 5-805-4, Noise and Vibration Control, provides design recommendations for vibration control, particularly vibration isolation for motor-pump assemblies. In addition, TM 5-805-4 recommends the following vibration isolation for piping systems:

For connections to rotating or vibrating equipment, use resilient pipe supports and:

- the first three supports nearest the vibrating equipment should have a static deflection equal to ½ of that required for the equipment; the remaining pipe supports should have a static deflection of 5 to 12.5 mm (0.2 to 0.49 in);
- provide a minimum 25 mm (1 in) clearance for a wall penetration, support the pipe on both sides of the penetration to prevent the pipe from resting on the wall, and seal the penetration with a suitable compound (fire-stop system, if required);
- use neoprene isolators in series with steel spring isolators;
- always include a neoprene washer or grommet with ceiling hangers; and
- inspect hanger rods during installation to ensure that they are not touching the side of the isolator housings.

Flexible pipe connections should have a length of 6 to 10 times the pipe diameter and be a bellows-type or wire-reinforced elastomeric piping. Tie-rods are not used to bolt the two end flanges together[2].

Loads applied to a piping system can be caused by forces resulting from thermal expansion and contraction. A load is applied to a piping system at restraints or anchors that prevent movement of the piping system. Within the pipe material, rapid changes in temperature can also cause loads on the piping system resulting in stresses in the pipe walls. Finally, loads can be introduced in the system by combining materials with different coefficients of expansion.

Movements exterior to a piping system can cause loads to be transmitted to the system. These loads can be transferred through anchors and supports. An example is the settlement of the supporting structure. The settling movement transfers transient, live loads to the piping system.

Live loads can result from the effects of vehicular traffic and are referred to as wheel loads. Because above ground piping is isolated from vehicle traffic, these live loads are only addressed during the design of buried piping. In general, wheel loads are insignificant when compared to sustained loads on pressure piping except when buried at "shallow" depths.[3] The term shallow is defined based upon both site specific conditions and the piping material. "However, as a rule, live loads diminish rapidly for laying depths greater than about four feet for highways and ten feet for railroads."[4] Wheel loads are calculated using information in AASHTO H20 and guidance for specific materials such as AWWA C150 (ductile-iron and metallic), AWWA C900 (PVC) and AWWA C950 (FRP). For example, wheel loads for rigid metallic piping over an effective length of 0.91 m (3 ft) can be calculated using the following formula.[5]

---

[2] TM 5-805-4, pp. 8-10 - 8-11.
[3] EM 1110-2-503, p. 7-15.
[4] Ibid., p. 7-15.
[5] AWWA C150, pp. 4-5.

$$F_W = \frac{C\ R\ P\ F}{b\ D_o}$$

where:

F_W = wheel load, kPa (psi)

C = surface load factor, see AWWA C150, Table 10.6M/10.6

R = reduction factor for a AASHTO H20 truck on an unpaved or flexible paved road, see AWWA C150, Table 10.4M/10.4

P = wheel weight, kg (lb); typically 7,257 kg (16,000 lb)

F = impact factor; typically 1.5

b = conversion factor, 0.031 kg/m/kPa (12 lb/ft/psi)

D_o = pipe outside diameter, mm (in).

2-6. Piping Layout

The bases of design establish the factors that must be included in liquid process piping design. The preparation of the piping layout requires a practical understanding of complete piping systems, including material selections, joining methods, equipment connections, and service applications. The standards and codes previously introduced establish criteria for design and construction but do not address the physical routing of piping.

a. Computer Aided Drafting and Design

Computer based design tools, such as computer aided draft and design (CADD) software, can provide powerful and effective means to develop piping layouts. Much of the commercially available software can improve productivity and may also assist in quality assurance, particularly with interference analyses. Some CADD software has the ability to generate either 3-dimensional drawings or 2-dimensional drawings, bills of material, and databases.

b. Piping Layout Design

System P&IDs; specifications; and equipment locations or layout drawings that are sufficiently developed to show equipment locations and dimensions, nozzle locations and pressure ratings are needed to develop the piping layout. A completely dimensioned pipe routing from one point of connection to another with all appurtenances and branches as shown on the P&ID is prepared.

Pipe flexibility is required to help control stress in liquid piping systems. Stress analysis may be performed using specialized software. The bases of the analyses are developed in Chapter 3. Considerations that must be accounted for in routing piping systems in order to minimize stress include: avoiding the use of a straight pipe run between two equipment connections or fixed anchor points (see Figure 2-3); locating fixed anchors near the center of pipe runs so thermal expansion can occur in two directions; and providing enough flexibility in branch connections for header shifts and expansions.

The load and minimum spacing requirements and support hardware are addressed throughout this manual. The layout design must also deal with piping support. Piping on racks are normally designed to bottom of pipe (BOP) elevations rather than centerline.

In addition, the piping layout should utilize the surrounding structure for support where possible. Horizontal and parallel pipe runs at different elevations are spaced for branch connections and also for independent pipe supports.

Interferences with other piping systems; structural work; electrical conduit and cable tray runs; heating, ventilation and air conditioning equipment; and other process equipment not associated with the liquid process of concern must be avoided. Insulation thickness must be accounted for in pipe clearances. To avoid interferences, composite drawings of the facility are typically used. This is greatly aided by the use of CADD software. Figure 2-4 presents a simple piping layout and Figure 2-5 is a CADD generated 3-dimensional drawing of the layout. However, as mentioned previously in this chapter communications between engineering disciplines must be maintained as facilities and systems are typically designed concurrently though designs may be in different stages of completion.

Lay lengths and other restrictions of in-line piping equipment and other system equipment constraints must be considered. For example, valve location considerations are listed in Table 2-5. Valves and other equipment such as flow instrumentation and safety relief devices have specific location requirements such as minimum diameters of straight run up- and downstream, vertical positioning and acceptable velocity ranges that require pipe diameter changes. Manufacturers should be consulted for specific requirements.

Piping connections to pumps affect both pump operating efficiency and pump life expectancy. To reduce the effects, the design follows the pump manufacturer's installation requirements and the Hydraulic Institute Standards, 14th Edition. Table 2-6 provides additional guidelines. The project process engineer should be consulted when unique piping arrangements are required.

Miscellaneous routing considerations are: providing piping insulation for personnel protection, access for future component maintenance, heat tracing access, hydrostatic test fill and drain ports, and air vents for testing and startup operations. System operability, maintenance, safety, and accessibility are all considerations that are addressed in the design.

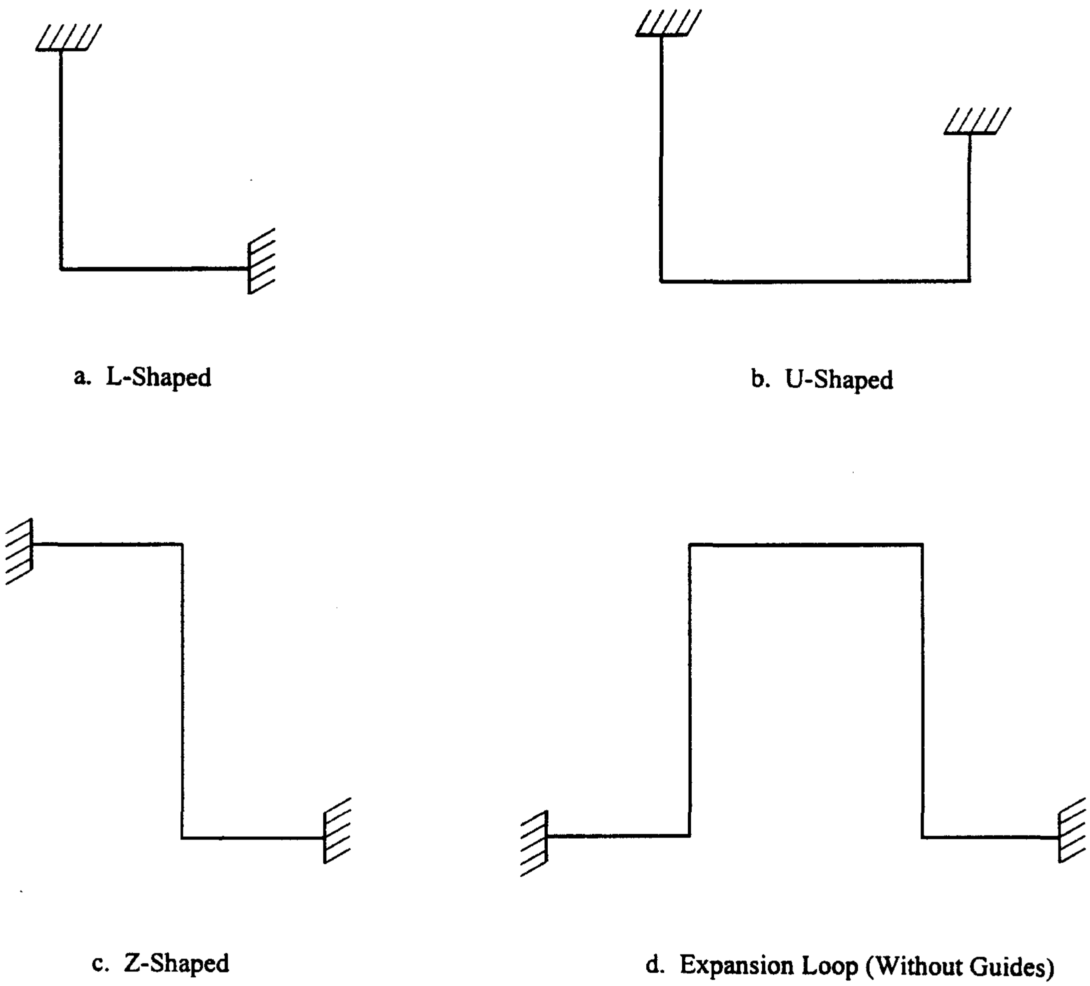


Figure 2-3. Flexibility Arrangements
(Source: SAIC, 1998.)

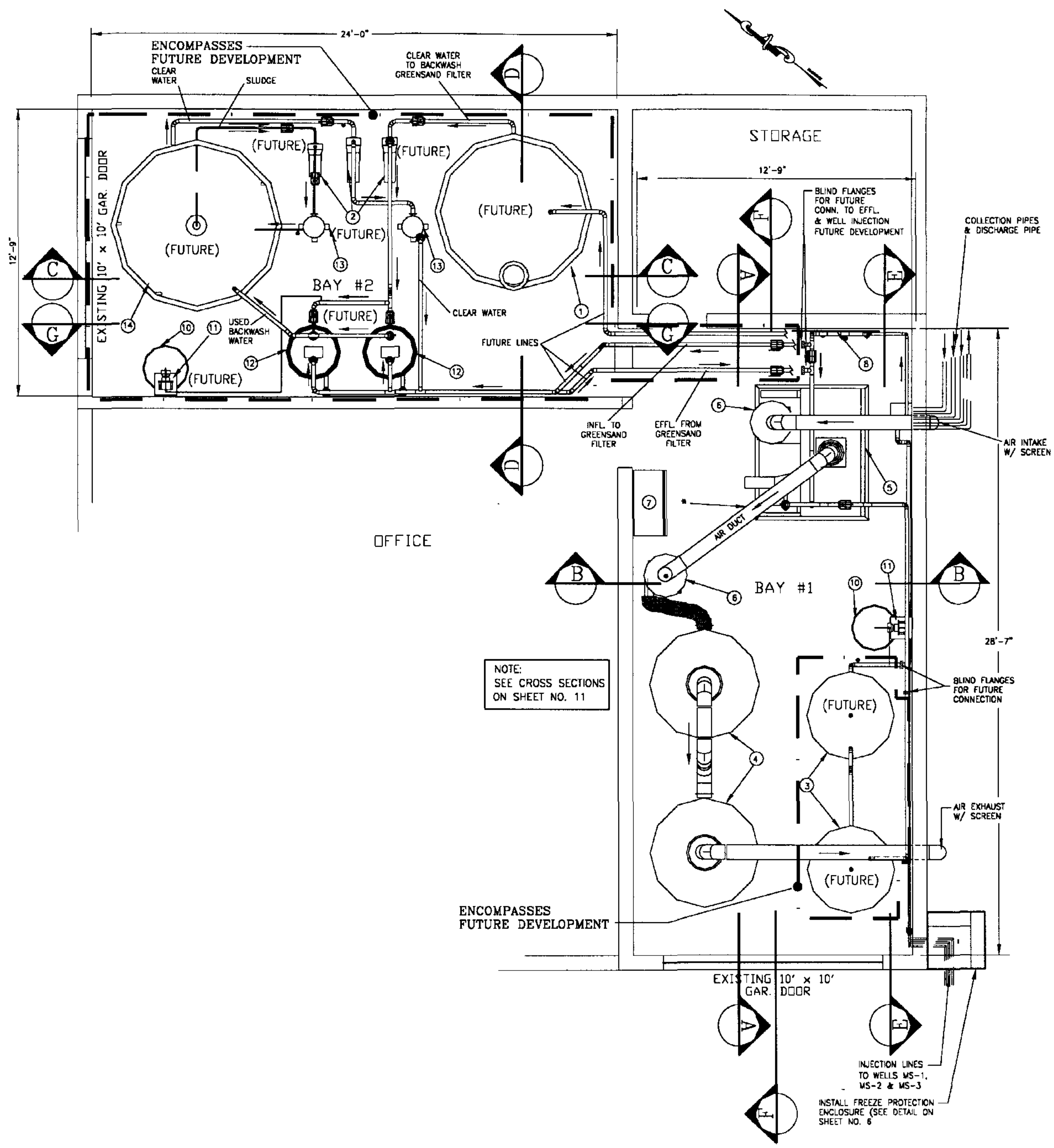


Figure 2-4. Remediation Process Piping Plan
(Source: SAIC, 1998.)

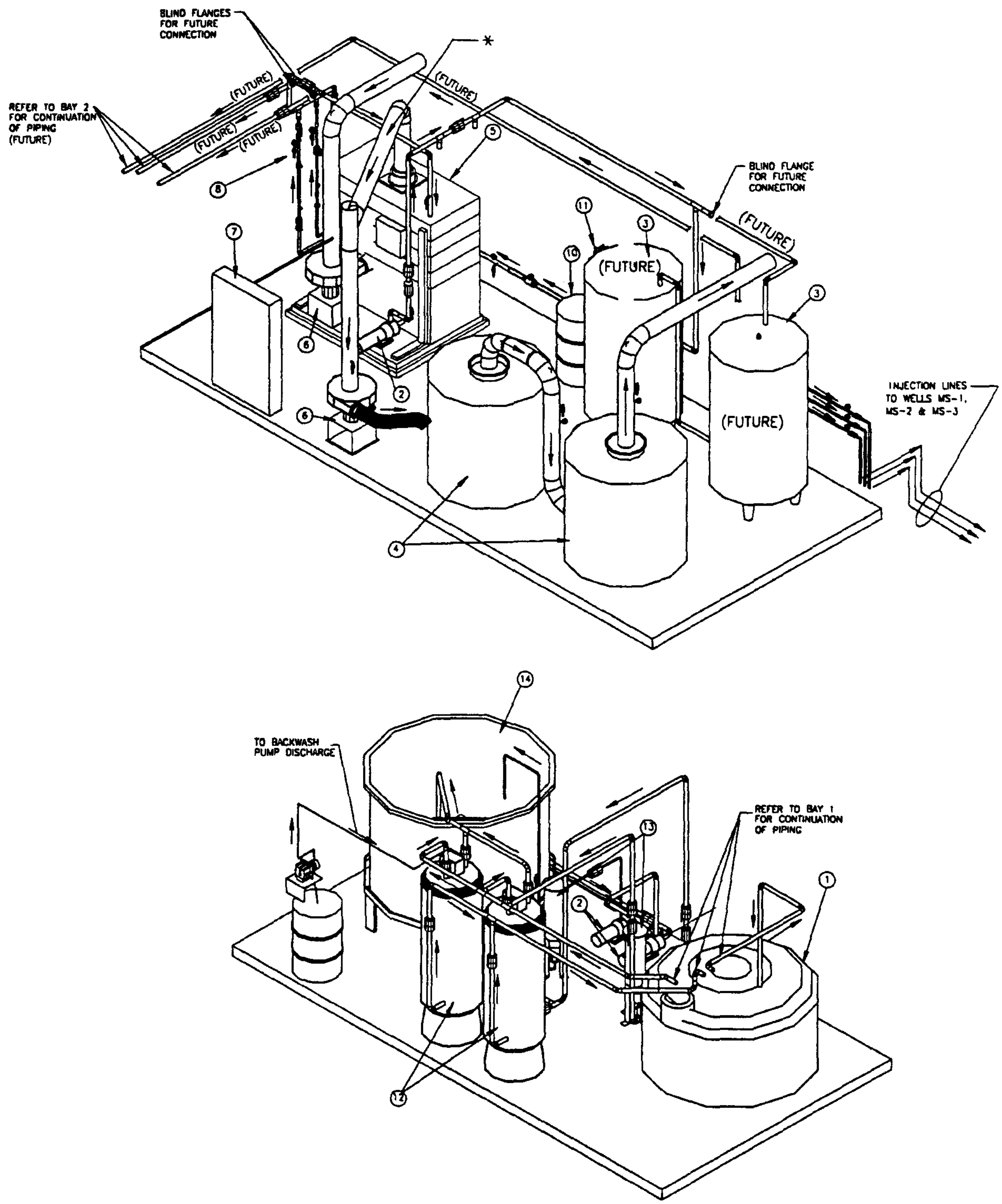


Figure 2-5. Isometric View
(Source: SAIC, 1998.)

Table 2-5
Valve Location Design

1. Control valves - install with a minimum of 3 diameters of straight run both upstream and downstream, and install vertically upright.
2. Butterfly and check valves - install with a minimum of 5 diameters of straight run upstream.
3. Non-control valves - install with stems in the horizontal to vertical positions and avoid head, knee, and tripping hazards.
4. Chemical service valves - locate below eye level.
5. All valves - provide a minimum of 100 mm (3.94 in.) hand clearance around all hand wheels, allow space for valve parts removal or maintenance, and avoid creating water hammer conditions.

Note: These guidelines are generally accepted practices. However, designs should conform to manufacturer's recommendations and commercial standards; for example, ASME and ISA standards.
Source: SAIC, 1998.

Table 2-6
Pump Connections Design

Supports	Piping is independently supported from the pump. A pipe anchor is provided between a flexible coupling and the pump.
Suction Connections	The pump suction is continuously flooded, has 3 diameters of straight run, uses long radius elbows, and can accommodate a temporary in-line strainer.
Fittings	An eccentric reducer, flat side up, is provided when a pipe reduction is required at the pipe suction. Flanges mating to flat faced pump flanges are also flat faced and use full-faced gaskets and common (normal strength) steel bolting.

Note: These guidelines are generally accepted practices. However, designs should conform to manufacturer's recommendations and Hydraulic Institute Standards.
Source: SAIC, 1998.

Chapter 3
General Piping Design

3-1. Materials of Construction

Most failures of liquid process systems occur at or within interconnect points - - the piping, flanges, valves, fittings, etc. It is, therefore, vital to select interconnecting equipment and materials that are compatible with each other and the expected environment. Materials selection is an optimization process, and the material selected for an application must be chosen for the sum of its properties. That is, the selected material may not rank first in each evaluation category; it should, however, be the best overall choice. Considerations include cost and availability. Key evaluation factors are strength, ductility, toughness, and corrosion resistance.

a. Strength

The strength of a material is defined using the following properties: modulus of elasticity, yield strength, and ultimate tensile strength. All of these properties are determined using ASTM standard test methods.

The modulus of elasticity is the ratio of normal stress to the corresponding strain for either tensile or compressive stresses. Where the ratio is linear through a range of stress, the material is elastic; that is, the material will return to its original, unstressed shape once the applied load is removed. If the material is loaded beyond the elastic range, it will begin to deform in a plastic manner. The stress at that deformation point is the yield strength. As the load is increased beyond the yield strength, its cross-sectional area will decrease until the point at which the material cannot handle any further load increase. The ultimate tensile strength is that load divided by the original cross-sectional area.

b. Ductility

Ductility is commonly measured by either the elongation in a given length or by the reduction in cross-sectional area when subjected to an applied load. The hardness of a material is a measure of its ability to resist deformation. Hardness is often measured by either of two standard scales, Brinell and Rockwell hardness.

c. Toughness

The toughness of a material is dependent upon both strength and ductility. Toughness is the capability of a material to resist brittle fracture (the sudden fracture of materials when a load is rapidly applied, typically with little ductility in the area of the fracture). Two common ASTM test methods used to measure toughness are the Charpy Impact and Drop-Weight tests. The Charpy brittle transition temperature and the Drop-Weight NDTT are important design parameters for materials that have poor toughness and may have lower operating temperatures. A material is subject to brittle, catastrophic failure if used below the transition temperature.

d. Corrosion Resistance

Appendix B provides a matrix that correlates process fluids, piping materials and maximum allowable process temperatures to assist in determining material suitability for applications.

e. Selection Process

Piping material is selected by optimizing the basis of design. First, eliminate from consideration those piping materials that:

- are not allowed by code or standard;
- are not chemically compatible with the fluid;
-have system rated pressure or temperatures that do not meet the full range of process operating conditions; and
- are not compatible with environmental conditions such as external corrosion potential, heat tracing requirements, ultraviolet degradation, impact potential and specific joint requirements.

The remaining materials are evaluated for advantages and disadvantages such as capital, fabrication and installation costs; support system complexity; compatibility to handle thermal cycling; and cathodic protection requirements. The highest ranked material of construction is then selected. The design proceeds with pipe sizing, pressure-integrity calculations and stress analyses. If the selected piping material does not meet those requirements, then the second ranked material is used and the pipe sizing, pressure-integrity calculations and stress analyses are repeated.

Example Problem 1:
Assume a recovered material process line that handles nearly 100% ethyl benzene at 1.20 MPa (174 psig) and 25°C (77°F) is required to be installed above ground. The piping material is selected as follows:

Solution:
Step 1. Above ground handling of a flammable liquid by thermoplastic piping is not allowed by ASME B31.3[1].

Step 2. Review of the Fluid/Material Corrosion Matrix (Appendix B) for ethyl benzene at 25°C (77°F) indicates that aluminum, Hastelloy C, Monel, TP316 stainless steel, reinforced furan resin thermoset and FEP lined pipe are acceptable for use. FKM is not available in piping.

Step 3. Reinforced furan resin piping is available to a system pressure rating of 689 kPa (100 psig)[2]; therefore, this material is eliminated from consideration. The remainder of the materials have available system pressure ratings and material allowable stresses greater than the design pressure.

Step 4. FEP lined piping is not readily available commercially. Since other material options exist, FEP lined piping is eliminated from consideration.

Step 5. The site specific environmental conditions are now evaluated to determine whether any of the remaining materials (aluminum, Hastelloy C, Monel or TP316 stainless steel) should be eliminated prior to ranking. The material is then selected based on site specific considerations and cost.

3-2. Design Pressure

After the piping system's functions, service conditions, materials of construction and design codes and standards have been established (as described in Chapter 2) the next step is to finalize the system operational pressures and temperatures. Up to this point, the system operating pressure has been addressed from a process requirement viewpoint to ensure proper operation of the system as a whole. At this point in the detail design of the piping system, it is necessary to ensure that the structural integrity of the pipe and piping system components is maintained during both normal and upset pressure and temperature conditions. In order to select the design pressure and temperature, it is necessary to have a full understanding and description of all operating processes and control system functions. The pressure rating of a piping system is determined by identifying the maximum steady state pressure, and determining and allowing for pressure transients.

a. Maximum Steady State Pressure

The determination of maximum steady state design pressure and temperature is based on an evaluation of specific operating conditions. The evaluation of conditions must consider all modes of operation. This is typically accomplished utilizing design references, codes and standards. An approach using the code requirements of ASME B31.3 for maximum pressure and temperature loads is used herein for demonstration.

Piping components shall be designed for an internal pressure representing the most severe condition of coincident pressure and temperature expected in normal operation.[3] This condition is by definition the one which results in the greatest required pipe thickness and the highest flange rating. In addition to hydraulic conditions based on operating pressures, potential back pressures, surges in pressures or temperature fluctuations, control system performance variations and process upsets must be considered. The system must also be evaluated and designed for the maximum external differential pressure conditions.

Piping components shall be designed for the temperature representing the most severe conditions described as follows:

- for fluid temperatures below 65°C (150°F), the metal design temperature of the pipe and components shall be taken as the fluid temperature.

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[1] ASME B31.3, p. 95.
[2] Schweitzer, Corrosion-Resistant Piping Systems, p. 140.
[3] ASME B31.3, p. 11.

- for fluid temperatures above 65°C (150°F), the metal design temperature of uninsulated pipe and components shall be taken as 95% of the fluid temperature, except flanges, lap joint flanges and bolting shall be 90%, 85% and 80% of the fluid temperature, respectively.
- for insulated pipe, the metal design temperature of the pipe shall be taken as the fluid temperature unless calculations, testing or experience based on actual field measurements can support the use of other temperatures.
- for insulated and heat traced pipe, the effect of the heat tracing shall be included in the determination of the metal design temperature.[4]

In addition to the impact of elevated temperatures on the internal pressure, the impact of cooling of gases or vapors resulting in vacuum conditions in the piping system must be evaluated.

b. Pressure Transients

As discussed in Paragraph 2-5, short-term system pressure excursions are addressed either through code defined limits or other reasonable approaches based on experience. The ASME B31.3 qualification of acceptable pressure excursions states:

"*302.2.4 Allowances for Pressure and Temperature Variations. Occasional variations of pressure or temperature, or both, above operating levels are characteristic of certain services. The most severe conditions of coincident pressure and temperature during the variation shall be used to determine the design conditions unless all of the following criteria are met.*

(a) The piping system shall have no pressure containing components of cast iron or other nonductile metal.

(b) Nominal pressure stresses shall not exceed the yield strength at temperature (see para. 302.3 of this Code [ASME B31.3] and Sy data in [ASME] BPV Code, Section II, Part D, Table Y-1).

(c) Combined longitudinal stress shall not exceed the limits established in paragraph 302.3.6 [of ASME B31.3].

(d) The total number of pressure-temperature variations above the design conditions shall not exceed 1000 during the life of the piping system.

(e) In no case shall the increased pressure exceed the test pressure used under para. 345 [of ASME B31.3] for the piping system.

(f) Occasional variations above design conditions shall remain within one of the following limits for pressure design.

(1) Subject to the owner's approval, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than:

(a) 33% for no more than 10 hour at any one time and no more than 100 hour per year; or

(b) 20% for no more than 50 hour at any one time and no more than 500 hour per year.

The effects of such variations shall be determined by the designer to be safe over the service life of the piping system by methods acceptable to the owner. (See Appendix V [of ASME B31.3])

(2) When the variation is self-limiting (e.g., due to a pressure relieving event), and lasts no more than 50 hour at any one time and not more than 500 hour/year, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than 20%.

(g) The combined effects of the sustained and cyclic variations on the serviceability of all components in the system shall have been evaluated.

(h) Temperature variations below the minimum temperature shown in Appendix A [of ASME B31.3] are not permitted unless the requirements of para. 323.2.2 [of ASME B31.3] are met for the lowest temperature during the variation.

[4] ASME B31.3, pp. 11-12.

(i) The application of pressures exceeding pressure-temperature ratings of valves may under certain conditions cause loss of seat tightness or difficulty of operation. The differential pressure on the valve closure element should not exceed the maximum differential pressure rating established by the valve manufacturer. Such applications are the owner's responsibility."[5]

The following example illustrates a typical procedure for the determination of design pressures.

Example Problem 2:
Two motor-driven boiler feed pumps installed on the ground floor of a power house supply 0.05 m^3/s (793 gpm) of water at 177°C (350°F) to a boiler drum which is 60 m (197 ft) above grade. Each pump discharge pipe is 100 mm (4 in), and the common discharge header to the boiler drum is a 150 mm (6 in) pipe. Each pump discharge pipe has a manual valve that can isolate it from the main header. A relief valve is installed upstream of each pump discharge valve to serve as a minimum flow bypass if the discharge valve is closed while the pump is operating. The back pressure at the boiler drum is 17.4 MPa (2,520 psig). The set pressure of the relief valve is 19.2 MPa (2,780 psig), and the shutoff head of each pump is 2,350 m (7,710 ft). The piping material is ASTM A 106, Grade C, with an allowable working stress of 121 MPa (17,500 psi), over the temperature range of -6.7 to 343°C (-20 to 650°F). The corrosion allowance is 2 mm (0.08 in) and the design code is ASME B31.1 (Power Piping).

The design pressures for the common discharge header and the pump discharge pipes upstream of the isolation valve must be determined. Also the maximum allowable pressure is to be calculated assuming the relief valve on a pump does not operate when its discharge valve is closed.

Solution:
Step 1. Determination of design pressure for the 150 mm (6 in) header is as follows. The specific volume of 177°C (350°F) saturated water is 0.001123 m^3/kg (0.01799 ft^3/lbm). The specific volume is corrected for the effects of compression to 17.2 MPa (2,500 psig) using steam tables:

$$\nu - \nu_f = -0.000013\ m^3/kg\ (-0.00021\ ft^3/lbm)$$

$$\nu_f \text{ at } 177°C\ (350°F) = 0.001123\ m^3/kg\ (0.01799\ ft^3/lbm),\ \textit{saturated}$$

$$\begin{aligned}\nu \text{ at } 17.2\ MPa\ (2{,}500\ psig) &= 0.001123\ m^3/kg + (-0.000013\ m^3/kg)\\ &= 0.001110\ m^3/kg\ (0.01778\ ft^3/lbm),\ \textit{compressed}\end{aligned}$$

where:
ν = specific volume of water, m^3/kg (ft^3/lbm)
ν_f = specific volume of feed water, m^3/kg (ft^3/lbm)

The static head above the pumps due to the elevation of the boiler drum is:

$$P_{st} = (60\ m)\left(\frac{1}{0.001110\ \frac{m^3}{kg}}\right)\left(9.81\ \frac{m}{s^2}\right) = 530\ kPa\ (76.9\ psig)$$

where:
P_{st} = static head, kPa (psig)

Step 2. The total discharge pressure at the pump exit is:

$$\begin{aligned}P &= P_b + P_{st}\\ &= 17.4\ MPa + 0.530\ MPa\\ &= 17.9\ MPa\ (2{,}600\ psig)\end{aligned}$$

where:
P = total discharge pressure, MPa (psig)
P_b = back pressure, MPa (psig)
P_{st} = static head, MPa (psig)

5 ASME B31.3, pp. 13-14.

The design pressure for the 150 mm (6 in) header should be set slightly above the maximum operating pressure. Therefore the design pressure for the 150 mm (6 in) header is 18.3 MPa (2,650 psig).

Step 3. Determination of design pressure for the 100 mm (4 in) pipe is as follows. The set pressure of the relief valve is 19.2 MPa (2,780 psig). The design pressure of the 100 mm (4 in) pipe upstream of the pump discharge valve should be set at the relief pressure of the relief valve. Although not shown in this example, the design pressure should also take into account any over-pressure allowance in the relief valve sizing determination. Therefore, for this example, the design pressure for the 100 mm (4 in) pipe upstream of the pump isolation valves is 19.2 MPa (2,780 psig).

Step 4. The maximum allowable pressure in the 100 mm (4 in) pipe is compared to that which would be observed during relief valve failure. The probability that a valve will fail to open is low. It is recognized that variations in pressure and temperature inevitably occur.

"*102.2.4 Ratings: Allowance for Variation From Normal Operation. The maximum internal pressure and temperature allowed shall include considerations for occasional loads and transients of pressure and temperature.*"[6]

The calculated stress resulting from such a variation in pressure and/or temperature may exceed the maximum allowable stress from ASME B31.1 Appendix A by 15% if the event duration occurs less than 10% of any 24- hour operating period, or 20% if the event duration occurs less than 1% of any 24-hour operating period.[7] The occasional load criteria of ASME B31.1, paragraph 102.2.4, is applied, and it is assumed that the relief valve failure-to-open event occurs less than 1% of the time. Therefore, the allowable stress is 20% higher than the basic code allowable stress of 121 MPa (17,500 psi).

Step 5. The higher allowable stress is denoted as S':

$$S' = 1.20\ (S) = 1.20\ (121\ MPa) = 145\ MPa\ (21{,}000\ psi)$$

where:

S' = higher allowable stress, MPa (psi)
S = code allowable stress, MPa (psi)

Step 6. The maximum pressure rating of the 100 mm (4 in) pipe is calculated using the following equation[8]:

$$P_{\max} = \frac{2\ S\ E\ (t_m - A)}{D_o - 2\ y\ (t_m - A)}$$

where:

P_{max} = maximum allowable pressure, MPa (psig)
S = code allowable stress, MPa (psi)
E = joint efficiency
t_m = pipe wall thickness, mm (in)
A = corrosion allowance, mm (in)
D_o = outside diameter of pipe, mm (in)
y = temperature-based coefficient, see ASME B31.1, for cast iron, non-ferrous metals, and for ferric steels, austenitic steels and Ni alloys less than 482°C (900°F), y = - 0.4.

Step 7. For this example, the value of S is set to equal to S' and E = 1.00 for seamless pipe. The pipe wall thickness is determined in accordance to pressure integrity, see Paragraph 3-3b, and is assumed equal to 87½% of the nominal wall thickness of schedule XXS pipe. Therefore:

$$t_m = 17.1\ mm\ (0.875) = 15.0\ mm\ (0.590\ in)$$

where

t_m = pipe wall thickness, mm (in)

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6 ASME B31.1, p. 13.
7 Ibid., p. 13.
8 Ibid., p. 17.

and

$$P_{max} = \frac{2(145\ MPa)(1.0)(15.0\ mm - 2\ mm)}{114.3\ mm - 2(0.4)(15.0\ mm - 2\ mm)}$$

$$= 36.3\ MPa\ (5{,}265\ psig)$$

where:

P_{max} = maximum allowable pressure, MPa (psig)

Step 8. Therefore, the maximum allowable pressure in the 100 mm (4 in) pipe section during a relief valve failure is 36.3 MPa (5,265 psig).

Another common transient pressure condition is caused by suddenly reducing the liquid flow in a pipe. When a valve is abruptly closed, dynamic energy is converted to elastic energy and a positive pressure wave is created upstream of the valve. This pressure wave travels at or near the speed of sound and has the potential to cause pipe failure. This phenomenon is called water hammer.

The maximum pressure rise is calculated by:

$$P_i = \rho\ \Delta V\ V_w\ n_1$$

where:

P_i = maximum pressure increase, MPa (psi)
ρ = fluid density, kg/m^3 (slugs/ft^3)
ΔV = sudden change in liquid velocity, m/s (ft/s)
V_w = pressure wave velocity, m/s (ft/s)
n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)

The maximum time of valve closure that is considered sudden (critical) is calculated by:

$$t_c = \frac{2\ L}{V_w}$$

where:

t_c = critical time, s
L = length of pipe, m (ft)
V_w = pressure wave velocity, m/s (ft/s)

The velocity of the pressure wave is affected by the fluid properties and by the elasticity of the pipe. The pressure wave velocity in water is approximately 1,480 m/s (4,800 ft/s). For a rigid pipe, the pressure wave velocity is calculated by:

$$V_w = \left(\frac{E_s}{n_1\ \rho}\right)^{1/2}$$

where:

V_w = pressure wave velocity, m/s (ft/s)
E_s = fluid's bulk modulus of elasticity, MPa (psi)
ρ = fluid density, kg/m^3 (slugs/ft^3)
n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)

Because of the potential expansion of an elastic pipe, the pressure wave for an elastic pipe is calculated by:

$$V_w = \left(\frac{E_s}{n_1\ \rho \left(1 + \frac{E_s\ D_i}{E_p\ t}\right)}\right)^{1/2}$$

where:

V_w = pressure wave velocity, m/s (ft/s)
E_s = fluid's bulk modulus of elasticity, MPa (psi)
ρ = fluid density, kg/m^3 (slugs/ft^3)
E_p = bulk modulus of elasticity for piping material, MPa (psi)
D_i = inner pipe diameter, mm (in)
t = pipe wall thickness, mm (in)
n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)

If the valve is slowly closed (i.e., the time of closure is greater than the critical time), a series of small pressure waves is transmitted up the pipe and returning negative pressure waves will be superimposed on the small pressure waves and full pressure will not occur. The pressure developed by gradual closure of a value is:

$$P'_i = \frac{2\ \rho\ L\ V\ n_1}{t_v}$$

where:

P'_I = pressure increase, MPa (psi)
t_v = valve closure time
ρ = fluid density, kg/m^3 (slugs/ft^3)
L = length of pipe, m (ft)
V = liquid velocity, m/s (ft/s)
n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)

CECER has a computer program, WHAMO, designed to simulate water hammer and mass oscillation in pumping facilities. The program determines time varying flow and head in a piping network which may includevalves, pumps, turbines, surge tanks and junctions arranged in a reasonable configuration. Transients are generated in the program due to any variation in the operation of pumps, valves, and turbines, or in changes in head.

Example Problem 3:
Water at 20°C (68°F) flows from a tank at a velocity of 3 m/s (9.8 ft/s) and an initial pressure of 275 kPa (40 psi) in a 50 mm (2 in) PVC pipe rated for 16 kgf/cm^2 (SDR 26); i.e., wall thickness is 4.7 mm (0.091 in for SDR 26). A valve 150 m (492 ft) downstream is closed. Determine the critical time of closure for the valve and the internal system pressure if the valve is closed suddenly versus gradually (10 times slower).

Solution:
Step 1. Velocity of the pressure wave assuming rigid pipe;

$$V_w = \left(\frac{E_s}{n_1\ \rho}\right)^{1/2}$$

where:

V_w = pressure wave velocity, m/s (ft/s)
E_s = fluid's bulk modulus of elasticity; for water at 20°C (68°F) = 2,180 MPa (319,000 psi)
n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)
ρ = fluid density, for water at 20°C (68°F) = 998.2 kg/m^3 (1.937 slugs/ft^3)

$$V_w = \left(\frac{2{,}180\ MPa}{(10^{-6}\ MPa/Pa)\ (998.2\ kg/m^3)}\right)^{1/2}$$
$$= 1{,}478\ m/s\ (4{,}848\ ft/s)$$

Step 2. Critical time for valve closure;

$$t_c = \frac{2\ L}{V_w} = \frac{2\ (150\ m)}{1{,}478\ m/s}$$
$$= 0.2\ s$$

where:

t_c = critical time, s
L = Length of pipe, m (ft)
V_w = pressure wave velocity, m/s (ft/s)

Step 3. Maximum pressure rise (valve closure time < critical time, t_c);

$$P_i = \rho\ \Delta V\ V_w\ n_1$$

where:

P_i = maximum pressure increase, MPa (psi)
ρ = fluid density, kg/m^3 (slugs/ft^3)
ΔV = sudden change in liquid velocity, m/s (ft/s)
V_w = pressure wave velocity, m/s (ft/s)
n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)

$$P_i = \left(998.2\frac{kg}{m^3}\right)\left(3\frac{m}{s}\right)\left(1{,}478\frac{m}{s}\right)\left(10^{-6}\frac{MPa}{Pa}\right)$$
$$= 4.43\ MPa\ (642\ psi)$$

Therefore, maximum system pressure is

$$P_{max} = 4.43\ MPa + 275\ kPa\ (10^{-3}\ MPa/kPa)$$
$$= 4.71\ MPa\ (682\ psig)$$

Step 4. Pressure increase with gradual valve closure (valve closure time = critical time, t_c x 10 = 2s)

$$P'_i = \frac{2\,\rho\,L\,V\,n_1}{t_v}$$

where:

- P'_I = pressure increase, MPa (psi)
- t_v = valve closure time
- ρ = fluid density, kg/m^3 (slugs/ft^3)
- L = length of pipe, m (ft)
- V = liquid velocity, m/s (ft/s)
- n_1 = conversion factor, 10^{-6} MPa/Pa for SI units (1 ft^2/144 in^2 for IP units)

$$P'_i = \frac{2\left(998.2\frac{kg}{m^3}\right)(150m)\left(3\frac{m}{s}\right)}{2\;s}\left(10^{-3}\frac{kPa}{Pa}\right)$$

$$= 449\;kPa\;(65\;psi)$$

Therefore, the maximum system pressure is 449 kPa + 275 kPa = 724 kPa (105 psig).

For a more complex review of water hammer effects in pipes, refer to the references found in Appendix A, Paragraph A-4.

3-3. Sizing

The sizing for any piping system consists of two basic components fluid flow design and pressure integrity design. Fluid flow design determines the minimum acceptable diameter of the piping necessary to transfer the fluid efficiently. Pressure integrity design determines the minimum pipe wall thickness necessary to safely handle the expected internal and external pressure and loads.

a. Fluid Flow Sizing

The primary elements in determining the minimum acceptable diameter of any pipe network are system design flow rates and pressure drops. The design flow rates are based on system demands that are normally established in the process design phase of a project.

Before the determination of the minimum inside diameter can be made, service conditions must be reviewed to determine operational requirements such as recommended fluid velocity for the application and liquid characteristics such as viscosity, temperature, suspended solids concentration, solids density and settling velocity, abrasiveness and corrosivity. This information is then used to determine the minimum inside diameter of the pipe for the network.

For normal liquid service applications, the acceptable velocity in pipes is 2.1 ± 0.9 m/s (7 ± 3 ft/s) with a maximum velocity limited to 2.1 m/s (7 ft/s) at piping discharge points including pump suction lines and drains. As stated, this velocity range is considered reasonable for normal applications. However, other limiting criteria such as potential for erosion or pressure transient conditions may overrule. In addition, other applications may allow greater velocities based on general industry practices; e.g., boiler feed water and petroleum liquids.

Pressure drops throughout the piping network are designed to provide an optimum balance between the installed cost of the piping system and operating costs of the system pumps. Primary factors that will impact these costs and system operating performance are internal pipe diameter (and the resulting fluid velocity), materials of construction and pipe routing.

Pressure drop, or head loss, is caused by friction between the pipe wall and the fluid, and by minor losses such as flow obstructions, changes in direction, changes in flow area, etc. Fluid head loss is added to elevation changes to determine pump requirements.

A common method for calculating pressure drop is the Darcy-Weisbach equation:

$$h_L = \left(\frac{f\,L}{D_i} + \Sigma K\right)\frac{V^2}{2\,g};\;\textit{loss coefficient method}$$

or

$$h_L = f\,\frac{(L + L_e)}{D_i}\,\frac{V^2}{2\,g};\;\textit{equivalent length method}$$

where:

h_L = head loss, m (ft)
f = friction factor
L = length of pipe, m (ft)
D_i = inside pipe diameter, m (ft)
L_e = equivalent length of pipe for minor losses, m (ft)
K = loss coefficients for minor losses
V = fluid velocity, m/s (ft/sec)
g = gravitational acceleration, 9.81 m/sec^2 (32.2 ft/sec^2)

The friction factor, f, is a function of the relative roughness of the piping material and the Reynolds number, R_e.

$$R_e = \frac{D_i\ V}{\nu}$$

where:

R_e = Reynolds number
D_i = inside pipe diameter, m (ft)
V = fluid velocity, m/s (ft/s)
ν = kinematic viscosity, m^2/s (ft^2/s)

If the flow is laminar ($R_e < 2{,}100$), then f is determined by:

$$f = \frac{64}{R_e}$$

where:

f = friction factor
R_e = Reynolds number

If the flow is transitional or turbulent ($R_e > 2{,}100$), then f is determined from the Moody Diagram, see Figure 3-1. The appropriate roughness curve on the diagram is determined by the ratio ϵ/D_i where ϵ is the specific surface roughness for the piping material (see Table 3-1) and D_i is the inside pipe diameter.

The method of equivalent lengths accounts for minor losses by converting each valve and fitting to the length of straight pipe whose friction loss equals the minor loss. The equivalent lengths vary by materials, manufacturer and size (see Table 3-2). The other method uses loss coefficients. This method must be used to calculate exit and entrance losses. The coefficients can be determined from Table 3-3.

Another method for calculating pressure drop is the Hazen-Williams formula:

$$h_L = (L + L_e)\left(\frac{V}{a\ C\ (D_i/4)^{0.63}}\right)^{1.85}$$

where:

h_L = head loss, m (ft)
L = length of pipe, m (ft)
L_e = equivalent length of pipe for minor losses, m (ft)
V = fluid velocity, m/s (ft/s)
a = empirical constant, 0.85 for SI units (1.318 for IP units)
C = Hazen-Williams coefficient
D_i = inside pipe diameter, m (ft)

The Hazen-Williams formula is empirically derived and is limited to use with fluids that have a kinematic viscosity of approximately 1.12 x 10^{-6} m^2/s (1.22 x 10^{-5} ft^2/s), which corresponds to water at 15.6°C (60°F), and for turbulent flow. Deviations from these conditions can lead to significant error. The Hazen-Williams coefficient, C, is independent of the Reynolds number. Table 3-1 provides values of C for various pipe materials.

The Chezy-Manning equation is occasionally applied to full pipe flow. The use of this equation requires turbulent flow and an accurate estimate of the Manning factor, n, which varies by material and increases with increasing pipe size. Table 3-1 provides values of n for various pipe materials. The Chezy-Manning equation is:

$$h_L = \frac{V^2\ n^2}{a\ (D_i/4)^{4/3}}\ (L + L_e)$$

where:

h_L = head loss, m (ft)
V = fluid velocity, m/s (ft/s)
n = Manning factor
a = empirical constant, 1.0 for SI units (2.22 for IP units)

Table 3-1
Pipe Material Roughness Coefficients

Pipe Material	Specific Roughness Factor, ,, mm (in)	Hazen-Williams Coefficient, C	Manning Factor, n
Steel, welded and seamless	0.061 (0.0002)	140	
Ductile Iron	0.061 (0.0002)	130	
Ductile Iron, asphalt coated	0.12 (0.0004)	130	0.013
Copper and Brass	0.61 (0.002)	140	0.010
Glass	0.0015 (0.000005)	140	
Thermoplastics	0.0015 (0.000005)	140	
Drawn Tubing	0.0015 (0.000005)		

Sources:
Hydraulic Institute, Engineering Data Book.
Various vendor data compiled by SAIC, 1998.

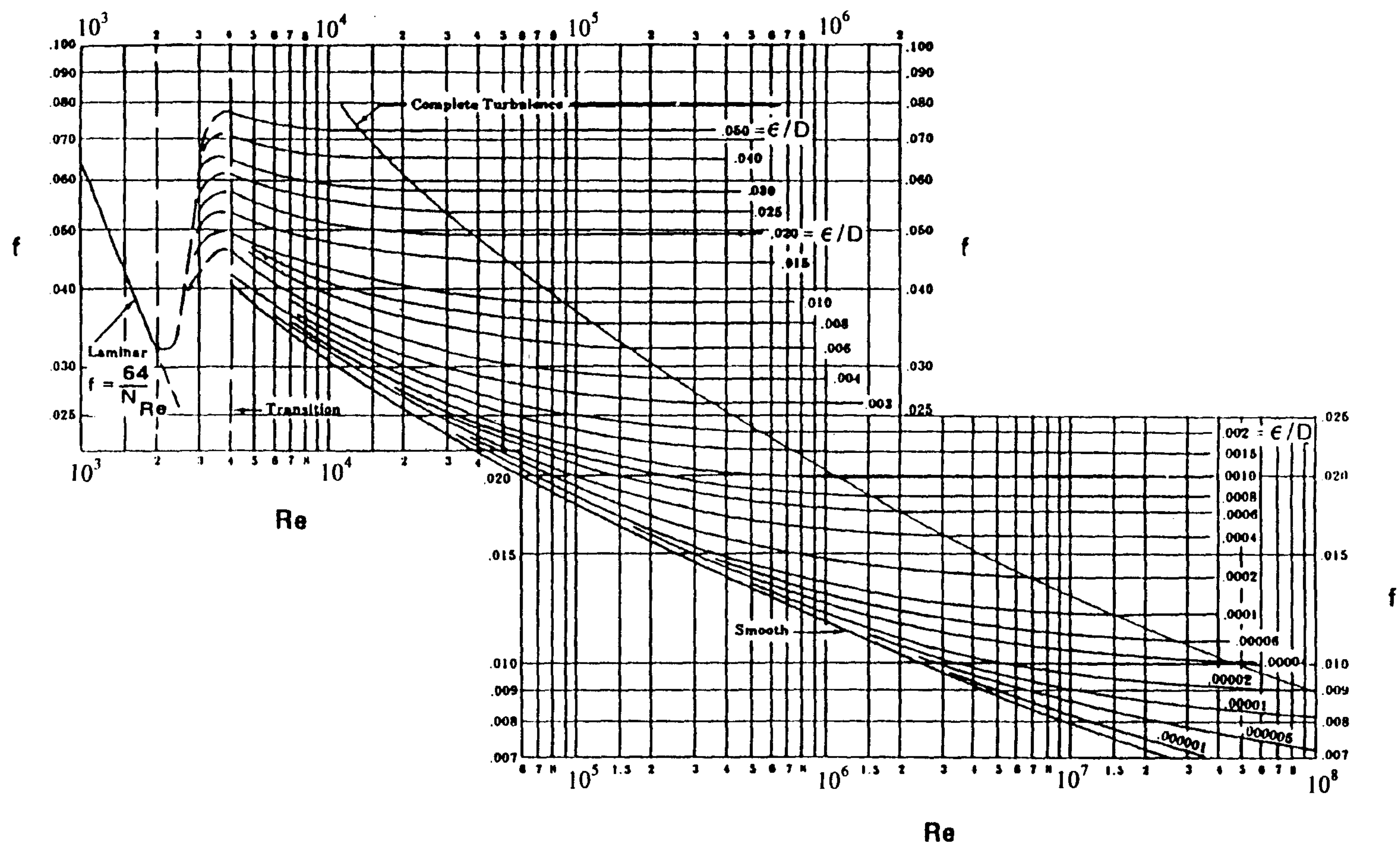

Figure 3-1. Moody Diagram
(Source: L.F. Moody, "Friction Factors for Pipe Flow," Transactions
of the ASME, Vol. 66, Nov. 1944, pp. 671-678, Reprinted by permission of ASME.)

Table 3-2
Estimated Pressure Drop for Thermoplastic Lined Fittings and Valves

Size mm (in)	Standard 90E elbow	Standard tee		Plug Valve	Diaphragm Valve	Vertical Check Valve	Horizontal Check Valve
		Through run	Through branch				
25 (1)	0.55 (1.8)	0.37 (1.2)	1.4 (4.5)	0.61 (2.0)	2.1 (7)	1.8 (6.0)	4.9 (16)
40 (1½)	1.1 (3.5)	0.70 (2.3)	2.3 (7.5)	1.3 (4.2)	3.0 (10)	1.8 (6.0)	7.0 (23)
50 (2)	1.4 (4.5)	0.91(3.0)	3.0 (10)	1.7 (5.5)	4.9 (16)	3.0 (10)	14 (45)
65 (2½)	1.7 (5.5)	1.2 (4.0)	3.7 (12)	N.A.	6.7 (22)	3.4 (11)	15 (50)
80 (3)	2.1 (7.0)	1.2 (4.1)	4.6 (15)	N.A.	10 (33)	3.7 (12)	18 (58)
100 (4)	3.0 (10)	1.8 (6.0)	6.1 (20)	N.A.	21 (68)	6.1 (20)	20 (65)
150 (6)	4.6 (15)	3.0 (10)	9.8 (32)	N.A.	26 (85)	9.4 (31)	46 (150)
200 (8)	5.8 (19)	4.3 (14)	13 (42)	N.A.	46 (150)	23 (77)	61 (200)
250 (10)	7.6 (25)	5.8 (19)	16 (53)	N.A.	N.A.	N.A.	N.A.
300 (12)	9.1 (30)	7.0 (23)	20 (64)	N.A.	N.A.	N.A.	N.A.

Notes:
Data is for water expressed as equal length of straight pipe in m (ft)
N.A. = Part is not available from source.
Source:
"Plastic Lined Piping Products Engineering Manual", p. 48.

Table 3-3
Minor Loss Coefficients (K)

Minor loss	Description	K
Pipe Entrance	sharp edged inward projected pipe rounded	0.5 1.0 0.05
Pipe Exit	all	1.0
Contractions	sudden gradual, N < 22° gradual, N > 22°	$0.5\ [1 - (\$^2)^2]$ $0.8\ (\sin N)\ (1 - \$^2)$ $0.5\ (\sin N)^{0.5}\ (1 - \$^2)$
Enlargements	sudden gradual, N < 22° gradual, N > 22°	$[1 - (\$^2)^2]^2$ $2.6\ (\sin N)\ (1 - \$^2)^2$ $(1 - \$^2)^2$
Bends	90° standard elbow 45° standard elbow	0.9 0.5
Tee	standard, flow through run standard, flow through branch	0.6 1.8
Valves	globe, fully open angle, fully open gate, fully open gate, ½ open ball, fully open butterfly, fully open swing check, fully open	10 4.4 0.2 5.6 4.5 0.6 2.5

Notes:
N = angle of convergence/divergence
\$ = ratio of small to large diameter

Sources:
Hydraulic Institute, "Pipe Friction Manual, 3rd Ed.
Valve data from Crane Company, "Flow of Fluids," Technical Paper 410; reprinted by permission of the Crane Valve Group.

D_i = inside pipe diameter, m (ft)
L = length of pipe, m (ft)
L_e = equivalent length of pipe for minor losses, m (ft)

It is common practice in design to use higher values of ϵ, and n and lower values of C than are tabulated for new pipe in order to allow for capacity loss with time.

Example Problem 4:
An equalization tank containing water with dissolved metals is to be connected to a process tank via above grade piping. A pump is required because the process tank liquid elevation is 30 m (98.4 ft) above the equalization tank level.

The piping layout indicates that the piping system requires:

- 2 isolation valves (gate);
- 1 swing check valve;
- 5 standard 90° elbows; and
- 65 m (213.5 ft) of piping.

The process conditions are:

- T = 25°C (77 °F); and
- Q = 0.05 m^3/s (1.77 ft^3/s).

The required piping material is PVC. The design program now requires the pipe to be sized and the pressure drop in the line to be determined in order to select the pump.

Solution:
Step 1. Select pipe size by dividing the volumetric flow rate by the desired velocity (normal service, V = 2.1 m/s).

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

$$D_i = \left[\frac{4}{\pi} \frac{0.05\ m^3/s}{2.1\ m/s}\right]^{0.5} \left(1000\ \frac{mm}{m}\right)$$

$$= 174\ mm\ (6.85\ in)$$

Step 2. From Table 1-1, select 150 mm (6 in) as the actual pipe size and calculate actual velocity in the pipe.

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

$$= \frac{0.05\ m^3/s}{\frac{\pi}{4}(0.150\ m)^2}$$

$$= 2.83\ m/s\ (9.29\ ft/s)$$

Step 3. At 25°C, $\nu = 8.94 \times 10^{-7}\ m^2/s$. So the Darcy-Weisbach equation is used to calculate the pressure drop through the piping.

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

Step 4. Determine the friction factor, f, from the Moody Diagram (Figure 3-1) and the following values.

$$R_e = \frac{D_i\ V}{\nu} = \frac{(0.150\ m)(2.83\ m/s)}{8.94\ x\ 10^{-7}\ m^2/s}$$

$$= 4.75\ x\ 10^5 - turbulent\ flow$$

$$\epsilon = 1.5\ x\ 10^{-6}\ m\ from\ Table\ 3-1$$

$$\epsilon/D_i = \frac{1.5\ x\ 10^{-6}\ m}{0.150\ m} = 0.00001;$$

therefore, f = 0.022 from Figure 3-1.

Step 5. Determine the sum of the minor loss coefficients from Table 3-3:

minor loss	K
entry	0.5
2 gate valves	0.2x2
check valve	2.5
5 elbows	0.35x5
exit	1.0
sum	6.15

Step 6. Calculate the head loss.

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

$$= \left[\frac{(0.022)(65\ m)}{0.150\ m} + 5.15 \right] \frac{(2.83\ m/s)^2}{2\ (9.81\ m/s^2)}$$

$$= 6.4\ m\ (21\ ft)$$

Step 7. The required pump head is equal to the sum of the elevation change and the piping pressure drop.

$$P_{head} = 30\ m + 6.4\ m = 36.4\ m$$

The prediction of pressures and pressure drops in a pipe network are usually solved by methods of successive approximation. This is routinely performed by computer applications now. In pipe networks, two conditions must be satisfied: continuity must be satisfied (the flow entering a junction equals the flow out of the junction); and there can be no discontinuity in pressure (the pressure drop between two junctions are the same regardless of the route).

The most common procedure in analyzing pipe networks is the Hardy Cross method. This procedure requires the flow in each pipe to be assumed so that condition 1 is satisfied. Head losses in each closed loop are calculated and then corrections to the flows are applied successively until condition 2 is satisfied within an acceptable margin.

b. Pressure Integrity

The previous design steps have concentrated on the evaluation of the pressure and temperature design bases and the design flow rate of the piping system. Once the system operating conditions have been established, the minimum wall thickness is determined based on the pressure integrity requirements.

The design process for consideration of pressure integrity uses allowable stresses, thickness allowances based on system requirements and manufacturing wall thickness tolerances to determine minimum wall thickness.

Allowable stress values for metallic pipe materials are generally contained in applicable design codes. The codes must be utilized to determine the allowable stress based on the requirements of the application and the material to be specified.

For piping materials that are not specifically listed in an applicable code, the allowable stress determination is based on applicable code references and good engineering design. For example, design references that address this type of allowable stress determination are contained in ASME B31.3 Sec. 302.3.2. These requirements address the use of cast iron, malleable iron, and other materials not specifically listed by the ASME B31.3.

After the allowable stress has been established for the application, the minimum pipe wall thickness required for pressure integrity is determined. For straight metallic pipe, this determination can be made using the requirements of ASME B31.3 Sec. 304 or other applicable codes. The determination of the minimum pipe wall thickness using the ASME B31.3 procedure is described below (see code for additional information). The procedure and following example described for the determination of minimum wall thickness using codes other than ASME B31.3 are similar and typically follow the same overall approach.

$$t_m = t + A$$

where:

- t_m = total minimum wall thickness required for pressure integrity, mm (in)
- t = pressure design thickness, mm (in)
- A = sum of mechanical allowances plus corrosion allowance plus erosion allowance, mm (in)

Allowances include thickness due to joining methods, corrosion/erosion, and unusual external loads. Some methods of joining pipe sections result in the reduction of wall thickness. Joining methods that will require this allowance include threading, grooving, and swagging. Anticipated thinning of the material due to effects of corrosion or mechanical wear over the design service life of the pipe may occur for some applications. Finally, site-specific conditions may require additional strength to account for external operating loads (thickness allowance for mechanical strength due to external loads). The stress associated with these loads should be considered in conjunction with the stress associated with the pressure integrity of the pipe. The greatest wall thickness requirement, based on either pressure integrity or external loading, will govern the final wall thickness specified. Paragraph 3-4 details stress analyses.

Using information on liquid characteristics, the amount of corrosion and erosion allowance necessary for various materials of construction can be determined to ensure reasonable service life. Additional information concerning the determination of acceptable corrosion resistance and material allowances for various categories of fluids is contained in Paragraph 3-1a.

The overall formula used by ASME B31.3 for pressure design minimum thickness determination (t) is:

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

where:

- P = design pressure, MPa (psi)
- D_o = outside diameter of the pipe, mm (in)
- S = allowable stress, see Table A-1 from ASME B31.3, MPa (psi)
- E = weld joint efficiency or quality factor, see Table A-1A or Table A-1B from ASME B31.3
- y = dimensionless constant which varies with temperature, determined as follows:
- For $t < D_o/6$, see table 304.1.1 from ASME B31.3 for values of y
- For $t \geq D_o/6$ or $P/SE > 0.385$, then a special consideration of failure theory, fatigue and thermal stress may be required or ASME B31.3 also allows the use of the following equation to calculate y:

$$y = \frac{D_i + 2A}{D_o + D_i + 2A}$$

where:

- D_i = inside diameter of the pipe, mm (in)
- D_o = outside diameter of the pipe, mm (in)
- A = sum of mechanical allowances plus corrosion allowance plus erosion allowance, mm (in)

Example Problem 5:

In order to better illustrate the process for the determination of the minimum wall thickness, the example in Paragraph 3-2b will be used to determine the wall thickness of the two pipes. For the 150 mm (6 in) header, the values of the variables are:

- P = 18.3 MPa (2650 psig)
- D_o = 160 mm (6.299 in)
- S = 121 MPa (17,500 psi)
- Assume t <12.75 in/6, so y = 0.4 from ASME B31.3
- A = 2 mm (0.08 in)
- E = 1.0

Solution:

Step 1. Determine the minimum wall thickness.

$$t_m = t + A$$

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

Therefore,

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

$$= \frac{(18.3\ MPa)(160\ mm)}{2[(121\ MPa)(1.0) + (18.3\ MPa)(0.4)]} + 2\ mm$$

$$= 13.4\ mm\ (0.528\ in)$$

Step 2. The commercial wall thickness tolerance for seamless rolled pipe is +0, -12½%; therefore, to determine the nominal wall thickness, the minimum wall thickness is divided by the smallest possible thickness allowed by the manufacturing tolerances.

$$t_{NOM} = \frac{13.4\ mm}{1.0 - 0.125} = 15.3\ mm\ (0.603\ in)$$

Step 3. Select a commercially available pipe by referring to a commercial specification. For U.S. work ANSI B36.10M/B36.10 is used commercially; the nearest commercial 150 mm (6 in) pipe whose wall thickness exceeds 15.3 mm (0.603 in) is Schedule 160 with a nominal wall thickness of 18.3 mm (0.719 in). Therefore, 150 mm (6 in) Schedule 160 pipe meeting the requirements of ASTM A 106 Grade C is chosen for this application. This calculation does not consider the effects of bending. If bending loads are present, the required wall thickness may increase.

Step 4. For the 100 mm (4 in) header, the outside diameter of 100 mm (4 in) pipe = 110 mm (4.331 in). Therefore:

.

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

$$= \frac{(19.2\ MPa)(110\ mm)}{2[(121\ MPa)(1.0) + (19.2\ MPa)(0.4)]} + 2\ mm$$

$$= 10.2\ mm\ (0.402\ in)$$

$$t_{NOM} = \frac{10.2\ mm}{1.0 - 0.125} = 11.7\ mm\ (0.459\ in)$$

The required nominal wall thickness is 11.7 mm (0.459 in).

Step 5. Select a commercially available pipe by referring to a commercial standard. Using ANSI B36.10M/B36.10, XXS pipe with a nominal wall thickness of 17.1 mm (0.674 in) is selected.

Step 6. Check whether the wall thickness for the selected 100 mm (4 in) schedule XXS pipe is adequate to withstand a relief valve failure. The shutoff head of the pump was given as 2,350 m (7,710 ft), and the specific volume of pressurized water at 177°C (350°F) was previously determined to be 0.001110 m^3/kg (0.01778 ft^3/lbm). The pressure equivalent to the shutoff head may be calculated based upon this specific volume.

$$P = (2{,}350\ m)\left(\frac{1}{0.001110\ \frac{m^3}{kg}}\right)\left(9.81\ \frac{m}{s^2}\right)$$

$$= 20.8\ MPa\ (3{,}020\ psig)$$

Step 7. Since the previously determined maximum allowable pressure 36.3 MPa (5,265 psig) rating of the XXS pipe exceeds the 20.8 MPa (3,020 psig) shutoff head of the pump, the piping is adequate for the intended service.

The design procedures presented in the forgoing problem are valid for steel or other code-approved wrought materials. They would not be valid for cast iron or ductile iron piping and fittings. For piping design procedures which are suitable for use with cast iron or ductile iron pipe, see ASME B31.1, paragraph 104.1.2(b).

3-4. Stress Analysis

After piping materials, design pressure and sizes have been selected, a stress analysis is performed that relates the selected piping system to the piping layout (Paragraph 2-6) and piping supports (Paragraph 3-7). The analysis ensures that the piping system meets intended service and loading condition requirements while optimizing the layout and support design. The analysis may result in successive reiterations until a balance is struck between stresses and layout efficiency, and stresses and support locations and types. The stress analysis can be a simplified analysis or a computerized analysis depending upon system complexity and the design code.

a. Code Requirements

Many ASME and ANSI codes contain the reference data, formulae, and acceptability limits required for the stress analysis of different pressure piping systems and services. ASME B31.3 requires the analysis of three stress limits: stresses due to sustained loads, stresses due to displacement strains, and stresses due to occasional loads. Although not addressed by code, another effect resulting from stresses that is examined is fatigue.

b. Stresses due to Sustained Loads

The stress analysis for sustained loads includes internal pressure stresses, external pressure stresses and longitudinal stresses. ASME B31.3 considers stresses due to internal and external pressures to be safe if the wall thickness meets the pressure integrity requirements (Paragraph 3-3b). The sum of the longitudinal stresses in the piping system that result from pressure, weight and any other sustained loads do not exceed the basic allowable stress at the maximum metal temperature.

$$\Sigma S_L \leq S_h$$

where:

S_L = longitudinal stress, MPa (psi)
S_h = basic allowable stress at maximum material temperature, MPa (psi), from code (ASME B31.3 Appendix A).

The internal pressure in piping normally produces stresses in the pipe wall because the pressure forces are offset by pipe wall tension. The exception is due to pressure transients such as water hammer which add load to pipe supports. The longitudinal stress from pressure is calculated by:

$$S_L = \frac{P\, D_o}{4\, t}$$

where:

S_L = longitudinal stress, MPa (psi)
P = internal design pressure, MPa (psi)
D_o = outside pipe diameter, mm (in)
t = pipe wall thickness, mm (in)

The longitudinal stress due to weight is dependent upon support locations and pipe spans. A simplified method to calculate the pipe stress is:

$$S_L = 0.1\, \frac{W\, L^2}{n\, Z}$$

where:

S_L = longitudinal stress, MPa (psi)
W = distributed weight of pipe material, contents and insulation, N/m (lbs/ft)
L = pipe span, m (ft)
n = conversion factor, 10^{-3}m/mm (1 ft/12 in)
Z = pipe section modulus, mm^3 (in^3)

$$Z = \frac{\pi}{32}\, \frac{D_o^4 - D_i^4}{D_o}$$

where:

D_o = outer pipe diameter, mm (in)
D_i = inner pipe diameter, mm (in)

c. Stresses due to Displacement Strains

Constraint of piping displacements resulting from thermal expansion, seismic activities or piping support and terminal movements cause local stress conditions. These localized conditions can cause failure of piping or supports from fatigue or over-stress, leakage at joints or distortions. 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.

$$S_E \leq S_A$$

where:

S_E = displacement stress range, MPa (psi)
S_A = allowable displacement stress range, MPa (psi)

$$S_A = f\, [1.25\, (S_c + S_h) - S_L]$$

where:

S_A = allowable displacement stress range, MPa (psi)
f = stress reduction factor
S_c = basic allowable stress of minimum material temperature, MPa (psi), from code (ASME B31.3 Appendix A)
S_h = basic allowable stress at maximum material temperature, MPa (psi), from code (ASME B31.3 Appendix A)
S_L = longitudinal stress, MPa (psi)

$$f = 6.0\,(N)^{-0.2} \leq 1.0$$

where:

f = stress reduction factor
N = equivalent number of full displacement cycles during the expected service life, < 2 x 10^6.

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

where:

S_E = displacement stress range, MPa (psi)
S_b = resultant bending stress, MPa (psi)
S_t = torsional stress, MPa (psi)

$$S_b = \frac{[(i_i\,M_i)^2 + (i_o\,M_o)^2]^{0.5}}{n\,Z}$$

where:

S_b = resultant bending stress, MPa (psi)
i_i = in plane stress intensity factor (see Table in code, ASME B31.3 Appendix D)
M_i = in plane bending moment, N-m (lb-ft)
i_o = out plane stress intensity factor (see table in code, ASME B31.3 Appendix D)
M_o = out plane bending moment, N-m (lb-ft)
n = conversion factor, 10^{-3}m/mm (1 ft/12 in)
Z = Section modulus, mm^3 (in^3)

$$Z = \frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$$

where:

D_o = outer pipe diameter, mm (in)
D_i = inner pipe diameter, mm (in)

$$S_t = \frac{M_t}{2\,Z\,n}$$

where:

S_t = torsional stress, MPa (psi)
M_t = torsional moment, N-m (lb-ft)
Z = section modulus, mm^3 (in^3)
n = conversion factor, 10^{-3}m/mm (1 ft/12 in)

A formal flexibility analysis is not required when: (1) the new piping system replaces in kind, or without significant change, a system with a successful service record; (2) the new piping system can be readily judged adequate by comparison to previously analyzed systems; and (3) the new piping system is of uniform size, has 2 or less fixed points, has no intermediate restraints, and meets the following empirical condition.[9]

$$\frac{D_o\,Y}{(L - L_s)^2} \leq K_1$$

where:

D_o = outside pipe diameter, mm (in)
Y = resultant of total displacement strains, mm (in)
L = length of piping between anchors, m (ft)
L_s = straight line distance between anchors, m (ft)
K_1 = constant, 208.3 for SI units (0.03 for IP units)

d. Stresses due to Occasional Loads

The sum of the longitudinal stresses due to both sustained and occasional loads does not exceed 1.33 times the basic allowable stress at maximum material temperature.

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[9] ASME B31.3, p. 38.

$$\sum S'_L \le 1.33 \; S_h$$

where:

S'_L = longitudinal stress from sustained and occasional loads, MPa (psi)

S_h = basic allowable stress at maximum material temperature, MPa (psi), from code (ASME B31.3 Appendix A)

The longitudinal stress resulting from sustained loads is as discussed in Paragraph 3-4b. The occasional loads that are analyzed include seismic, wind, snow and ice, and dynamic loads. ASME B31.3 states that seismic and wind loads do not have to be considered as acting simultaneously.

e. Fatigue

Fatigue resistance is the ability to resist crack initiation and expansion under repeated cyclic loading. A material's fatigue resistance at an applied load is dependent upon many variables including strength, ductility, surface finish, product form, residual stress, and grain orientation.

Piping systems are normally subject to low cycle fatigue, where applied loading cycles rarely exceed 10^5. Failure from low cycle fatigue is prevented in design by ensuring that the predicted number of load cycles for system life is less than the number allowed on a fatigue curve, or S-N curve, which correlates applied stress with cycles to failure for a material. Because piping systems are generally subject to varying operating conditions that may subject the piping to stresses that have significantly different magnitudes, the following method can be used to combine the varying fatigue effects.

$$U = \sum \frac{n_i}{N_i}$$

$$U < 1.0$$

where:

U = cumulative usage factor

n_i = number of cycles operating at stress level i

N_i = number of cycles to failure at stress level i as per fatigue curve.

The assumption is made that fatigue damage will occur when the cumulative usage factor equals 1.0.

3-5. Flange, Gaskets and Bolting Materials

ANSI, in association with other technical organizations such as the ASME, has developed a number of predetermined pressure-temperature ratings and standards for piping components. Pipe flanges and flanged fittings are typically specified and designed to ASME B16.5 for most liquid process piping materials. The primary exception to this is ductile iron piping, which is normally specified and designed to AWWA standards. The use of other ASME pressure-integrity standards generally conforms to the procedures described below.

a. Flanges

Seven pressure classes -- 150, 300, 400, 600, 900, 1,500 and 2500 -- are provided for flanges in ASME B16.5. The ratings are presented in a matrix format for 33 material groups, with pressure ratings and maximum working temperatures. To determine the required pressure class for a flange:

Step 1. Determine the maximum operating pressure and temperature.

Step 2. Refer to the pressure rating table for the piping material group, and start at the class 150 column at the temperature rating that is the next highest above the maximum operating temperature.

Step 3. Proceed through the table columns on the selected temperature row until a pressure rating is reached that exceeds the maximum operating pressure.

Step 4. The column label at which the maximum operating pressure is exceeded at a temperature equal to or above the maximum operating temperature is the required pressure class for the flange.

Example Problem 6:

A nickel pipe, alloy 200, is required to operate at a maximum pressure of 2.75 MPa (399 psi) and 50°C (122°F).

Solution:

Nickel alloy 200 forged fitting materials are manufactured in accordance with ASTM B 160 grade

N02200 which is an ASME B16.5 material group 3.2. Entering Table 2-3.2 in ASME B16.5 at 200 degrees F, the next temperature rating above 50 °C (122 °F), a class 400 flange is found to have a 3.31 MPa (480 psi) rating and is therefore suitable for the operating conditions.

Care should be taken when mating flanges conforming to AWWA C110 with flanges that are specified using ASME B16.1 or B16.5 standards. For example, C110 flanges rated for 1.72 MPa (250 psi) have facing and drilling identical to B16.1 class 125 and B16.5 class 150 flanges; however, C110 flanges rated for 1.72 MPa (250 psi) will not mate with B16.1 class 250 flanges.[10]

b. Gaskets

Gaskets and seals are carefully selected to insure a leak-free system. A wide variety of gasket materials are available including different metallic and elastomeric products. Two primary parameters are considered, sealing force and compatibility. The force that is required at this interface is supplied by gasket manufacturers. Leakage will occur unless the gasket fills into and seals off all imperfections.

The metallic or elastomeric material used is compatible with all corrosive liquid or material to be contacted and is resistant to temperature degradation.

Gaskets may be composed of either metallic or nonmetallic materials. Metallic gaskets are commonly designed to ASME B16.20 and nonmetallic gaskets to ASME B16.21. Actual dimensions of the gaskets should be selected based on the type of gasket and its density, flexibility, resistance to the fluid, temperature limitation, and necessity for compression on its inner diameter, outer diameter or both. Gasket widths are commonly classified as group I (slip-on flange with raised face), group II (large tongue), or group III (small tongue width). Typically, a more narrow gasket face is used to obtain higher unit compression, thereby allowing reduced bolt loads and flange moments.

Consult manufacturers if gaskets are to be specified thinner than 3.2 mm (1/8 in) or if gasket material is specified to be something other than rubber.[11] For non-metallic gaskets, installation procedures are critical. The manufacturer's installation procedures should be followed exactly.

The compression used depends upon the bolt loading before internal pressure is applied. Typically, gasket compressions for steel raised-face flanges range from 28 to 43 times the working pressure in classes 150 to 400, and 11 to 28 times in classes 600 to 2,500 with an assumed bolt stress of 414 MPa (60,000 psi). Initial compressions typically used for other gasket materials are listed in Table 3-4.

Table 3-4
Gasket Compression

Gasket Material	Initial Compression, MPa (psi)
Soft Rubber	27.6 to 41.4 (4,000 to 6,000)
Laminated Asbestos	82.7 to 124 (12,000 to 18,000)
Composition	207 (30,000)
Metal Gaskets	207 to 414 (30,000 to 60,000)

Note: These guidelines are generally accepted practices. Designs conform to manufacturer's recommendations.
Source: SAIC, 1998

In addition to initial compression, a residual compression value, after internal pressure is applied, is required to maintain the seal. A minimum residual gasket compression of 4 to 6 times the working pressure is standard practice. See Paragraph 3-5c, following, for determination of bolting loads and torque.

[10] AWWA C110, p. ix-x.
[11] Ibid., p. 44.

c. Bolting Materials

Carbon steel bolts, generally ASTM A 307 grade B material, should be used where cast iron flanges are installed with flat ring gaskets that extend only to the bolts. Higher strength bolts may be used where cast iron flanges are installed with full-face gaskets and where ductile iron flanges are installed (using ring or full-face gaskets).[12] For other flange materials, acceptable bolting materials are tabulated in ASME B16.5. Threading for bolts and nuts commonly conform to ASME B1.1, Unified Screw Threads.

The code requirements for bolting are contained in Sections III and VIII of the ASME Boiler and Pressure Vessel Code. To determine the bolt loads in the design of a flanged connection that uses ring-type gaskets, two analyses are made and the most severe condition is applied. The two analyses are for operating conditions and gasket seating.

Under normal operating conditions, the flanged connection (i.e., the bolts) resists the hydrostatic end force of the design pressure and maintains sufficient compression on the gasket to assure a leak-free connection. The required bolt load is calculated by[13]:

$$W_{m1} = 0.785\ G^2\ P + (2\ b)(3.14\ G\ m\ P)$$

where:

W_{m1} = minimum bolt load for operating conditions, N (lb)
G = gasket diameter, mm (in)
= mean diameter of gasket contact face when seating width, b, ≤ 6.35 mm (0.25 in), or
= outside diameter of gasket contact face less 2 b when seating width, b, > 6.35 mm (0.25 in)
P = design pressure, MPa (psi)
b = effective gasket seating width, mm (in), see code (e.g., ASME Section VIII, Appendix 2, Table 2-5.2)
m = gasket factor, see Table 3-5

The required bolt area is then:

$$A_{m1} = \frac{W_{m1}}{S_b}$$

where:

A_{m1} = total cross-sectional area at root of thread, mm^2 (in^2)
W_{m1} = minimum bolt load for operating conditions, N (lb)
S_b = allowable bolt stress at design temperature, MPa (psi), see code (e.g. ASME Section VIII, UCS-23)

Gasket seating is obtained with an initial load during joint assembly at atmosphere temperature and pressure. The required bolt load is:

$$W_{m2} = 3.14\ b\ G\ y$$

where:

W_{m2} = minimum bolt load for gasket seating, N (lbs)
b = effective gasket seating width, mm (in), see code (e.g., ASME Section VIII, Appendix 2, Table 2-5.2)
G = gasket diameter, mm (in)
= mean diameter of gasket contact face when seating width, b, ≤ 6.35 mm (0.25 in)
= outside diameter of gasket contact face less 2b when seating width, b > 6.35 mm (0.25 in)
y = gasket unit seating load, MPa (psi), see Table 3-5

The required bolt area is then:

$$A_{m2} = \frac{W_{m2}}{S_a}$$

where:

A_{m2} = total cross-sectional area at root thread, mm^2 (in^2)
W_{m2} = minimum bolt load for gasket seating, N (lbs)
S_a = allowable bolt stress at ambient temperature, MPa (psi), see code (e.g. ASME Section VIII, UCS-23)

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12 AWWA C110, p. 44.
13 ASME Section VIII, pp. 327-333.

Table 3-5
Gasket Factors and Seating Stress

Gasket Material	Gasket Factor, m	Minimum Design Seating Stress, y, MPa (psi)
Self-energizing types (o-rings, metallic, elastomer)	0	0 (0)
Elastomers without fabric		
below 75A Shore Durometer	0.50	0 (0)
75A or higher Shore Durometer	1.00	1.38 (200)
Elastomers with cotton fabric insertion	1.25	2.76 (400)
Elastomers with asbestos fabric insertion (with or without wire reinforcement		
3-ply	2.25	15.2 (2,200)
2-ply	2.50	20.0 (2,900)
1-ply	2.75	25.5 (3,700)
Spiral-wound metal, asbestos filled		
carbon	2.50	68.9 (10,000)
stainless steel, Monel and nickel-based alloys	3.00	68.9 (10,000)
Corrugated metal, jacketed asbestos filled or asbestos inserted		
soft aluminum	2.50	20.0 (2,900)
soft copper or brass	2.75	25.5 (3,700)
iron or soft steel	3.00	31.0 (4,500)
Monel or 4% to 6% chrome	3.25	37.9 (5,500)
stainless steels and nickel-based alloys	3.50	44.8 (6,500)
Corrugated metal		
soft aluminum	2.75	25.5 (3,700)
soft copper or brass	3.00	31.0 (4,500)
iron or soft steel	3.25	37.9 (5,500)
Monel or 4% to 6% chrome	3.50	44.8 (6,500)
stainless steels and nickel-based alloys	3.75	52.4 (7,600)
Ring joint		
iron or soft steel	5.50	124 (18,000)
Monel or 4% to 6% chrome	6.00	150 (21,800)
stainless steels and nickel-based alloys	6.50	179 (26,000)

Notes:

This table provides a partial list of commonly used gasket materials and contact facings with recommended design values m and y. These values have generally proven satisfactory in actual service. However, these values are recommended and not mandatory; consult gasket supplier for other values.

Source:

ASME Section VIII of the Boiler and Pressure Vessel Code, Appendix 2, Table 2-5.1, Reprinted by permission of ASME.

The largest bolt load and bolt cross-sectional area controls the design. The bolting is selected to match the required bolt cross-sectional area by:

$$A_s = 0.7854 \left(D - \frac{0.9743}{N} \right)^2$$

where:
A_s = bolt stressed area, mm^2 (in^2)
D = nominal bolt diameter, mm (in)
N = threads per unit length, 1/mm (1/in)

The tightening torque is then calculated using the controlling bolt load[14]:

$$T_m = W_m \, K \, D \, n$$

where:
T_m = tightening torque, N-m (in-lb)
W_m = required bolt load, N (lb)
K = torque friction coefficient
= 0.20 for dry
= 0.15 for lubricated
D = nominal bolt diameter, mm (in)
n = conversion factor, 10^{-3} m/mm for SI units (1.0 for IP units)

3-6. Pipe Identification

Pipes in exposed areas and in accessible pipe spaces shall be provided with color band and titles adjacent to all valves at not more than 12 m (40 ft) spacing on straight pipe runs, adjacent to directional changes, and on both sides where pipes pass through wall or floors. Piping identification is specified based on CEGS 09900 which provides additional details and should be a part of the contract documents. Table 3-6 is a summary of the requirements

a. Additional Materials

Piping systems that carry materials not listed in Table 3-6 are addressed in liquid process piping designs in accordance with ANSI A13.1 unless otherwise stipulated by the using agency. ANSI A13.1 has three main classifications: materials inherently hazardous, materials of inherently low hazard, and fire-quenching materials. All materials inherently hazardous (flammable or explosive, chemically active or toxic, extreme temperatures or pressures, or radioactive) shall have yellow coloring or bands, and black legend lettering. All materials of inherently low hazard (liquid or liquid admixtures) shall have green coloring or bands, and white legend lettering. Fire-quenching materials shall be red with white legend lettering.

3-7. Piping Supports

Careful design of piping support systems of above grade piping systems is necessary to prevent failures. The design, selection and installation of supports follow the Manufacturers Standardization Society of the Valve and Fitting Industry, Inc. (MSS) standards SP-58, SP-69, and SP-89, respectively. The objective of the design of support systems for liquid process piping systems is to prevent sagging and damage to pipe and fittings. The design of the support systems includes selection of support type and proper location and spacing of supports. Support type selection and spacing can be affected by seismic zone(see Paragraph 2-5b).

a. Support Locations

The locations of piping supports are dependent upon four factors: pipe size, piping configuration, locations of valves and fittings, and the structure available for support. Individual piping materials have independent considerations for span and placement of supports.

Pipe size relates to the maximum allowable span between pipe supports. Span is a function of the weight that the supports must carry. As pipe size increases, the weight of the pipe also increases. The amount of fluid which the pipe can carry increases as well, thereby increasing the weight per unit length of pipe.

The configuration of the piping system affects the location of pipe supports. Where practical, a support should be located adjacent to directional changes of piping. Otherwise, common practice is to design the length of piping between supports equal to, or less than,

[14] Schweitzer, Corrosion-Resistant Piping Systems, p. 9.

Table 3-6
Color Codes for Marking Pipe

MATERIAL	LETTERS AND BAND	ARROW	LEGEND
Cold Water (potable)	Green	White	POTABLE WATER
Fire Protection Water	Red	White	FIRE PR. WATER
Hot Water (domestic)	Green	White	H. W.
Hot Water recirculating (domestic)	Green	White	H. W. R.
High Temp. Water Supply	Yellow	Black	H. T. W. S
High Temp. Water Return	Yellow	Black	H.T.W.R.
Boiler Feed Water	Yellow	Black	B. F.
Low Temp. Water Supply (heating)	Yellow	Black	L.T.W.S.
Low Temp. Water Return (heating)	Yellow	Black	L.T.W.R.
Condenser Water Supply	Green	White	COND. W.S.
Condenser Water Return	Green	White	COND. W.R.
Chilled Water Supply	Green	White	C.H.W.S.
Chilled Water Return	Green	White	C.H.W.R.
Treated Water	Yellow	Black	TR. WATER
Chemical Feed	Yellow	Black	CH. FEED
Compressed Air	Yellow	Black	COMP. AIR
Natural Gas	Blue	White	NAT. GAS
Freon	Blue	White	FREON
Fuel Oil	Yellow	Black	FUEL OIL
Steam	Yellow	Black	STM.
Condensate	Yellow	Black	COND.

Source: USACE, Guide Specification 09900, Painting, General, Table 1.

75% of the maximum span length where changes in direction occur between supports. Refer to the appropriate piping material chapters for maximum span lengths.

As discussed in Chapter 10, valves require independent support, as well as meters and other miscellaneous fittings. These items contribute concentrated loads to the piping system. Independent supports are provided at each side of the concentrated load.

Location, as well as selection, of pipe supports is dependent upon the available structure to which the support may be attached. The mounting point shall be able to accommodate the load from the support. Supports are not located where they will interfere with other design considerations. Some piping materials require that they are not supported in areas that will expose the piping material to excessive ambient temperatures. Also, piping is not rigidly anchored to surfaces that transmit vibrations. In this case, pipe supports isolate the piping system from vibration that could compromise the structural integrity of the system.

b. Support Spans

Spacing is a function of the size of the pipe, the fluid conveyed by piping system, the temperature of the fluid and the ambient temperature of the surrounding area. Determination of maximum allowable spacing, or span between supports, is based on the maximum amount that the pipeline may deflect due to load. Typically, a deflection of 2.5 mm (0.1 in) is allowed, provided that the maximum pipe stress is limited to 10.3 MPa (1,500 psi) or allowable design stress divided by a safety factor of 4[15], whichever is less. Some piping system manufacturers and support system manufacturers have information for their products that present recommended spans in tables or charts. These data are typically empirical and are based upon field experience. A method to calculate support spacing is as follows:

$$l = n \left(m \, C' \, \frac{Z \, S}{W} \right)^{0.5}$$

where:

l = span, m (ft)
n = conversion factor, 10^{-3} m/mm (1 ft/12 in)
m = beam coefficient, see Table 3-7
C′ = beam coefficient = 5/48 for simple, one-span beam (varies with beam type)
Z = section modulus, mm^3 (in^3)
S = allowable design stress, MPa (psi)
W = weight per length, N/mm (lb/in)

$$Z = \frac{\pi}{32} \, \frac{D_o^4 - D_i^4}{D_o}$$

where:

Z = section modulus, mm^3 (in^3)
D_o = outer pipe diameter, mm (in)
D_i = inner pipe diameter, mm (in)

Table 3-7
Beam Coefficient (m)

m	Beam Characteristic
76.8	simple, single span
185.2	continuous, 2-span
144.9	continuous, 3-span
153.8	continuous, 4 or more span

Note: These values assume a beam with free ends and uniform loads. For piping systems with a fixed support, cantilever beam coefficients may be more appropriate.
Source: Manual of Steel Construction, pp. 2-124 to 2-127.

The term W, weight per length, is the uniformly distributed total weight of the piping system and includes the weight of the pipe, the contained fluid, insulation and

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

jacket, if appropriate. Due to the many types of insulation, the weight must be calculated after the type of insulation is selected; see Chapter 11 for insulation design. The following formula can be used to determine the weight of insulation on piping:

$$W_i = \pi K \gamma T_i (D_o + T_i)$$

where:

- W_i = weight of insulation per length, N/mm (lbs/in)
- γ = insulation specific weight, N/m^3 (lbs/ft^3)
- K = conversion factor, 10^{-9} m^3/mm^3 (5.79 x 10^{-4} ft^3/in^3)
- T_i = insulation thickness, mm (in)
- D_o = outer pipe diameter, mm (in)

Proper spacing of supports is essential to the structural integrity of the piping system. An improperly spaced support system will allow excessive deflection in the line. This can cause structural failure of the piping system, typically at joints and fittings. Excessive stress can also allow for corrosion of the pipe material by inducing stress on the pipe and, thereby, weakening its resistance to corrosive fluids.

The amount of sag, or deflection in a span, is calculated from the following equation:

$$y = \frac{W (l/n)^4}{m E I}$$

where:

- y = deflection, mm (in)
- W = weight per length, N/mm (lb/in)
- l = span, m (ft)
- n = conversion factor, 10^{-3} m/mm (1 ft/12 in)
- m = beam coefficient, see Table 3-7.
- E = modulus of elasticity of pipe material, MPa (psi)
- I = moment of inertia, mm^4 (in^4)

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

where:

- I = moment of inertia, mm^4 (in^4)
- D_o = outer pipe diameter, mm (in)
- D_i = inner pipe diameter, mm (in)

Improper spacing of supports can allow fluids to collect in the sag of the pipe. Supports should be spaced and mounted so that piping will drain properly. The elevation of the down-slope pipe support should be lower than the elevation of the lowest point of the sag in the pipe. This is determined by calculating the amount of sag and geometrically determining the difference in height required.

$$h = \frac{(l/n)^2 \, y}{0.25 \, (l/n)^2 - y^2}$$

where:

- h = difference in elevation of span ends, mm, (in)
- l = span, m (ft)
- n = conversion factor, 10^{-3} m/mm (1 ft/12 in)
- y = deflection, mm (in)

c. Support Types

The type of support selected is equally important to the design of the piping system. The stresses and movements transmitted to the pipe factor in this selection. Pipe supports should not damage the pipe material or impart other stresses on the pipe system. The basic type of support is dictated by the expected movement at each support location.

The initial support design must address the load impact on each support. Typically, a moment-stress calculation is used for 2-dimensional piping, and a simple beam analysis is used for a straight pipe-run.

If a pipe needs to have freedom of axial movement due to thermal expansion and contraction or other axial movement, a roller type support is selected. If minor axial and transverse (and minimal vertical) movements are expected, a hanger allowing the pipe to 'swing' is selected. If vertical movement is required, supports with springs or hydraulic dampers are required. Other structural requirements and conditions that have the potential to affect piping systems and piping support systems are analyzed. Pipes that connect to heavy tanks or pass under footings are protected from differential settlement by flexible couplings. Similarly, piping attached to vibrating or rotating equipment are also attached with flexible couplings.

d. Selection of Support Types

The selection of support types is dependent upon four criteria: the temperature rating of the system, the mechanism by which the pipe attaches to the support, protective saddles that may be included with the support, and the attachment of the support to the building or other structures. Support types are most commonly classified in accordance with MSS SP-58. Figure 3-2 displays some of the support types applicable to liquid process piping systems. The selection of the appropriate support type is made according to MSS SP-69. Table 3-8 provides guidance for process system temperatures.

Some piping systems utilize protective saddles between the pipe and the support member. This is done to minimize the stress on the pipe from point loads. In addition, pipe insulation requires protection from supports. Saddles support piping without damaging insulation.

The method by which the supports attach to buildings or other structures is addressed by the design. Typical pipe supports are in the form of hangers, supporting the pipe from above. These hangers may be attached to a ceiling, beam, or other structural member. Pipelines may be supported from below as well, with pipe stanchions or pipe racks. Pipe supports may be rigidly attached to a structure, or allow for a pivoting axial motion, depending on the requirements of the system.

Table 3-8
Support Type Selection for Horizontal Attachments: Temperature Criteria

Process Temperature, EC (EF)	Typical MSS SP-58 Types	Application
A-1. Hot Systems 49 to 232°C (120 to 450°F)	2, 3, 24, 1, 5, 7, 9, 10, 35 through 38, 59, 41, 43 through 46, 39, 40	clamps hangers sliding rollers insulation protection
B. Ambient Systems 16 to 48°C (60 to 119°F)	3, 4, 24, 26, 1, 5, 7, 9, 10, 35 through 38, 59, 41, 43 through 46, 39, 40	clamps hangers sliding rollers insulation protection
C-1. Cold Systems 1 to 15°C (33 to 59°F)	3, 4, 26, 1, 5, 7, 9, 10, 36 through 38, 59, 41, 43 through 46, 40	clamps hangers sliding rollers insulation protection

Source:
MSS SP-69, pp. 1, 3-4.

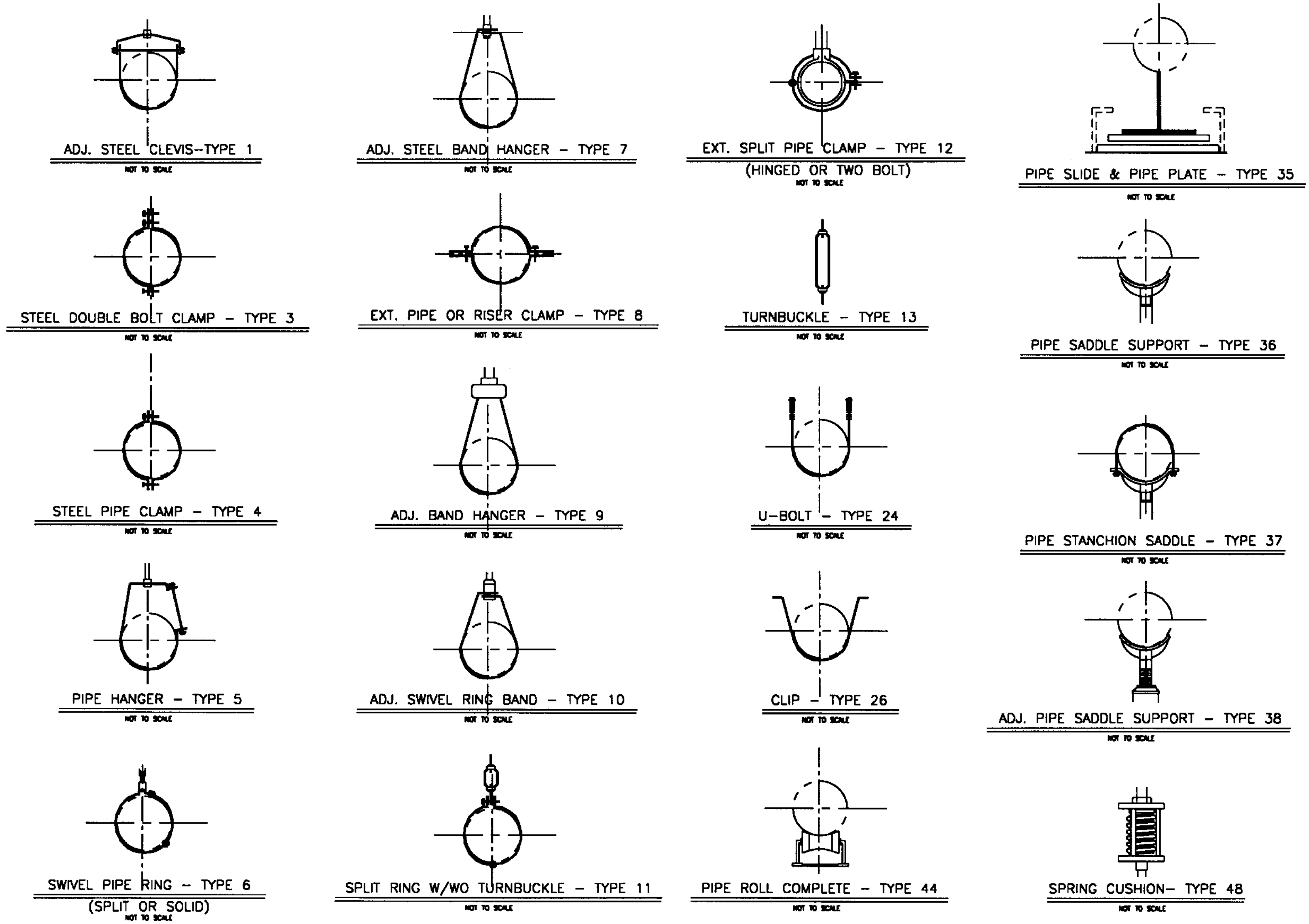

Figure 3-2. Pipe Supports for Ambient Applications
(Source: MSS SP-69, Pipe Hangers and Supports - Selection and Application, pp. 5-6)

Some piping systems require adjustable pipe supports. One reason for this requirement is the cold spring action. Cold spring is the action whereby a gap is left in the final joint of a piping run to allow for thermal expansion of the pipeline. This action results in the offset of all points along the piping system, including the attachments to pipe supports, and requires that supports be adjustable to accommodate this offset. From a maintenance consideration, cold springing should be avoided if possible through proper thermal expansion and stress analyses.

Vertical adjustment is also usually necessary for pipe supports. Settlement, particularly in new construction, may result in an improper deflection of the elevation of a pipe support. To maintain the proper slope in the pipeline, thereby avoiding excessive sag between supports and accumulation of the product being carried by the pipe, the possibility of vertical adjustment is accommodated in the design of pipe supports.

e. Coatings

Installation of piping systems in corrosive environments may warrant the specification of a protective coating on pipe supports. The coating may be metallic or non-metallic; MSS SP-58 is used to specify coatings. Support manufacturers can provide specific recommendations for coatings in specific environments, particularly for nonmetallic coatings. In addition, compatibility between the support materials and piping system materials is reviewed to avoid galvanic action. Electrical isolation pads or different support materials are sometimes required.

3-8. Testing and Flushing

This section addresses the requirements for pressure and leak testing of piping systems. In addition to these types of tests, welding procedures, welders and qualifications of welding operators must conform with the welding and nondestructive testing procedures for pressure piping specified in CEGS 05093, Welding Pressure Piping.

a. Test Procedure

A written test procedure is specified and utilized to perform a leak test. The procedure should prescribe standards for reporting results and implementing corrective actions, if necessary. Review items for preparing the test plans and procedures include:

(1) Determination of the test fluid.
(2) Comparison of the probable test fluid temperature relative to the brittle fracture toughness of the piping materials (heating the test fluid may be a solution).
(3) Depending upon the test fluid, placement of temporary supports where permanent supports were not designed to take the additional weight of the test fluid.
(4) Depending upon the test fluid, location of a relief valve to prevent excessive over-pressure from test fluid thermal expansion. No part of the system will exceed 90% of its yield strength.
(5) Isolation of restraints on expansion joints.
(6) Isolation of vessels, pumps and other equipment which may be over stressed at test pressure.
(7) Location of the test pump and the need for additional pressure gauges.
(8) Accessibility to joints for inspection (some codes require that the weld joints be left exposed until after the test). All joints in the pipe system must be exposed for inspection.
(9) Prior to beginning a leak test, the pipe line should be inspected for defects and errors and omissions.

Testing of piping systems is limited by pressure. The pressure used to test a system shall not produce stresses at the test temperature that exceed the yield strength of the pipe material. In addition, if thermal expansion of the test fluid in the system could occur during testing, precautions are taken to avoid extensive stress.

Testing of piping systems is also limited by temperature. The ductile-brittle transition temperature should be noted and temperatures outside the design range avoided. Heat treatment of piping systems is performed prior to leak testing. The piping system is returned to its ambient temperature prior to leak testing.

In general, piping systems should be re-tested after repairs or additions are made to the system. If a leak is detected during testing and then repaired, the system should be re-tested. If a system passes a leak test, and a component is added to the system, the system should be re-tested to ensure that no leaks are associated with the new component.

The documented test records required for each leak test are specified. The records are required to be standardized, completed by qualified, trained test personnel and retained for a period of at least 5 years. Test records include:

- date of the test;
- personnel performing the test and test location;
- identification of the piping system tested;
- test method, fluid/gas, pressure, and temperature; and
- certified results.

Flushing of a piping system prior to leak testing should be performed if there is evidence or suspicion of contaminants, such as dirt or grit, in the pipeline. These contaminants could damage valves, meters, nozzles, jets, ports, or other fittings. The flushing medium shall not react adversely or otherwise contaminate the pipeline, testing fluid, or service fluid. Flushing should be of sufficient time to thoroughly clean contaminants from every part of the pipeline.

b. Preparation

Requirements for preparation of a leak test are also specified. All joints in the piping system are exposed for the leak test in order to allow the inspector to observe the joints during the test to detect leaks. Specified leak test requirements provide for temporary supports. Temporary supports may be necessary if the test fluid weighs more than the design fluid.

c. Hydrostatic Leak Test

The fluid used for a typical hydrostatic leak test is water. If water is not used, the fluid shall be non-toxic and be non-flammable. The test pressure is greater than or equal to 1.5 times the design pressure.

$$P_T \geq 1.5\ P$$

where:
P_T = test pressure, MPa (psi)
P = design pressure, MPa (psi)

For cases in which the test temperature is less than the design temperature, the minimum test pressure is[16]:

$$P_T = \frac{1.5\ P\ S_T}{S}$$

and

$$\frac{S_T}{S} \leq 6.5$$

where:
P_T = test pressure, MPa (psi)
P = design pressure, MPa (psi)
S_T = stress at test temperature, MPa (psi)
S = stress at design temperature, MPa (psi)

For a typical liquid process piping system with temperatures approximately ambient and low pressure, the S_T/S ratio equals 1.0. If the test pressure would produce an S_T in excess of the material yield strength, then the test pressure may be reduced to limit S_T below the yield strength.

The time period required by ASME B31.3 for a hydrostatic leak test is at least ten (10) minutes, but normally one (1) hour is used.

d. Pneumatic Leak Test

Pneumatic leak tests are not recommended for liquid process piping systems and are only used when the liquid residue left from a hydrostatic test has a hazard potential. The test fluid for a pneumatic leak test is a gas. The gas shall be non-flammable and non-toxic. The hazard of released energy stored in a compressed gas shall be considered when specifying a pneumatic leak test. Safety must be considered when recommending a gas for use in this test.

The test temperature is a crucial consideration for the pneumatic leak test. Test temperature shall be considered

16 ASME B31.3, p. 83.

when selecting the pipe material. Brittle failure is a consideration in extremely low temperatures for some materials. The energy stored in a compressed gas, combined with the possibility of brittle failure, is an essential safety consideration of the pneumatic leak test.

A pressure relief device shall be specified when recommending the pneumatic leak test. The pressure relief device allows for the release of pressure in the piping system that exceeds a set maximum pressure. The set pressure for the pressure relief device shall be 110% of the test pressure, or 345 kPa (50 psi) above test pressure, whichever is lower.

The test pressure for a pneumatic leak test is 110% of the design pressure. The pressure shall gradually increase to 50% of the test pressure or 170 kPa (25 psig), whichever is lower, at which time the piping system is checked. Any leaks found are then fixed before retesting. The test shall then proceed up to the test pressure before examining for leakage.

e. Initial Service Leak Test

An initial service leak test is permitted by ASME B31.3 with the concurrence of the using agency. This test is a preliminary check for leakage at joints and connections. If this test is performed, and all observed leaks are repaired, it is permissible to omit joint and connection examination during the hydrostatic (or pneumatic) leak tests. The initial service leak test is limited to piping systems subject to Category D fluid service only.

A Category D fluid is defined as non-flammable, non-toxic, and not damaging to human tissues. For this system the operating pressure is less than 1.035 MPa (150 psi), and the operating temperature range is between -29°C (-20°F) to 186°C (366°F)[17].

Typically, the service fluid is used for the initial service leak test. This is possible for a Category D fluid. During the test, the pressure in the piping system should be gradually increased to operating pressure. The piping system is then inspected for leaks.

f. Sensitive Leak Test

A sensitive leak test is required for all Category M fluids (optional for Category D fluids) using the Gas and Bubble Test Method of the ASME Boiler and Pressure Vessel Code, Section V, Article 10, or equivalent. The test pressure for the sensitive leak test is 25% of the design pressure or 105 kPa (15 psig), whichever is lower.

Category M fluid service is one in which the potential for personnel exposure is judged to be possible, and in which a single exposure to a small quantity of the fluid (caused by leakage) can produce serious and irreversible personnel health damage upon either contact or breathing.[18]

g. Non-Metallic Piping Systems

Testing requirements, methods, and recommendations for plastic, rubber and elastomer, and thermoset piping systems are the same as those for metallic piping systems, with the following exceptions. The hydrostatic leak test method is recommended and a pneumatic leak test is only performed with the permission of the using agency. The test pressure shall not be less than 1.5 times the system design pressure. However, the test pressure is less than the lowest rated pressure of any component in the system.

$$P_T \geq 1.5\ P$$

$$\textit{and}$$

$$P_T < P_{\min}$$

where:

P_T = test pressure, MPa (psi)
P = system design pressure, MPa (psi)
P_{min} = lowest component rating, MPa (psi)

h. Double Containment and Lined Piping Systems

Testing requirements, methods, and recommendations for double containment and lined piping systems are identical to those pertaining to the outer (secondary) pipe material.

[17] ASME B31.3, p. 5.
[18] Ibid., p. 5.

Chapter 4
Metallic Piping Systems

4-1. General

The metallic materials that are commonly used in liquid process piping systems can be categorized as ferrous (ductile iron, carbon steel, stainless steel and alloys with iron as the principal component) and non-ferrous alloys of nickel, aluminum, copper and lead. Metallic piping systems other than those addressed in this chapter are available (e.g. zirconium, 416 SS). Such materials may be used if cost and technical criteria are met. Applicable design principles from this manual are applied to use these materials.

4-2. Corrosion

When metallic components are used, corrosion of some type(s) will occur. USACE policy requires that all underground ferrous piping be cathodically protected. Chapter 12, TM 5-811-7 and MIL-HDBK-1004/10 contain guidance pertaining to cathodic protection of underground pipelines. Conditions which promote corrosion are:

- contact between dissimilar metals which may become immersed in a conductive medium;
- exposure of piping to corrosive soils or water;
- high temperatures;
- low-velocity, stagnant-type flow conditions;
- abrasive effects that may cause the surfaces of metals to be eroded;
- application of tensile stresses within a corrosive environment;
- highly acidic solutions combined with holes near metal-to-metal surfaces or near sealing surfaces; and
- any metals close to sources of atomic hydrogen.

a. Theory of Corrosion

Corrosion occurs by an electrochemical process. The phenomenon is similar to that which takes place when a carbon-zinc "dry" cell generates a direct current. Basically, an anode (negative electrode), a cathode (positive electrode), electrolyte (corrosive environment), and a metallic circuit connecting the anode and the cathode are required for corrosion to occur. Dissolution of metal occurs at the anode where the corrosion current enters the electrolyte and flows to the cathode. The general reaction which occurs at the anode is the dissolution of metal as ions:

$$M \div M^{\%n} \% n\, e^{\&}$$

where:

M = metal involved
n = valence of the corroding metal species
e^- = represents the loss of electrons from the anode.

Examination of this basic reaction reveals that a loss of electrons, or oxidation, occurs at the anode. Electrons lost at the anode flow through the metallic circuit to the cathode and permit a cathodic reaction (or reactions) to occur.

Practically all corrosion problems and failures encountered in service can be associated with one or more of the following basic forms of corrosion. These are: general corrosion, galvanic corrosion, concentration cell (crevice) corrosion, pitting attack, intergranular corrosion, stress-corrosion cracking (environmentally-induced-delayed failure), dealloying (dezincification and graphitic corrosion), and erosion corrosion.

Corrosion control and avoidance is a highly specialized field. All pre-design surveys, Cathodic Protection (CP) designs, and acceptance surveys must be performed by a "corrosion expert." A "corrosion expert" is 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 CP Specialist or be a registered professional engineer who has certification or licensing that includes education and experience in corrosion control of buried or submerged metallic piping and tank systems. USACE Construction Engineering Research Laboratories (CECER) provides corrosion expertise on request.

For information on metallic piping system material compatibility with various chemicals, see appendix B. Material compatibility considers the type and concentration of chemical in the liquid, liquid temperature and total stress of the piping system. The selection of construction materials is made by an engineer experienced in corrosion. See Appendix A, paragraph A-4 - Other Sources of Information, for additional sources of corrosion data.

b. General Corrosion

General corrosion is sometimes referred to as uniform attack. When this form of corrosion occurs, anodic dissolution is uniformly distributed over the entire metallic surface. The corrosion rate is nearly constant at all locations. Microscopic anodes and cathodes, which are continuously changing their electrochemical behavior from anode to cathode and cathode to anode, are believed to provide the corrosion cells for uniform attack.

Readily obtained from weight-loss and electrochemical tests, the general corrosion rates for many metals and alloys in a wide variety of environments are known. When a metal or alloy is exposed to an environment where the corrosion rate is known, equipment-life expectancy can be estimated (providing general corrosion is the only form of corrosion which will occur). It is common practice to select materials having general corrosion rates which are acceptable for the application involved.

Time-to-failure should not be the only corrosion criteria used for materials selection. Quite often, even trace amounts of metal which are introduced into the environment by very low corrosion rates are, or should be, unacceptable. For example, relatively non-corrosive domestic waters can dissolve sufficient amounts of certain metals, such as lead and copper, from the piping to create a health hazard. Corrosion-produced trace elements which are considered toxic and frequently found in the domestic waters of buildings include cadmium and antimony (from solder) and lead (an impurity in hot-dip, galvanized coatings).

One of the environments where general corrosion can occur is soil. Steel is especially susceptible to general corrosion when exposed to soils having resistivities less than about 10,000 ohm-cm. Even galvanized-steel can be expected to fail in these aggressive environments. As the resistivity of the soil decreases, the magnitude of the corrosion damage increases.

c. Galvanic Corrosion

Galvanic corrosion can occur when two electrochemically-dissimilar metals or alloys (see Table 4-1) are metallically connected and exposed to a corrosive environment. The less noble material (anode) suffers accelerated attack and the more noble material (cathode) is protected by the galvanic current.

Table 4-1
Galvanic Series (Partial Listing)

Wasting End (anodic or least noble)
Magnesium alloys
Zinc
Galvanized steel
Aluminum
Aluminum alloys
Carbon steel
Cast iron
Stainless steel (active state)
Lead
Nickel (active state)
Brass
Copper
Bronze
Nickel alloys
Nickel (passive state)
Stainless steel (passive state)
Titanium
Graphite
Platinum
Protected End (cathodic or most noble)

Sources:
Schweitzer, Corrosion-Resistant Piping Systems, p. 264 (courtesy of Marcel Dekker, Inc.).
SAIC, 1998.

One common galvanic corrosion problem clearly illustrates the "area and distance effects". For example, consider a building where a copper water service line and a coated carbon steel natural gas service line are laid in the same ditch. Assuming soil in the area has low resistivity, it is easily recognized that a cathode (copper tube), an anode (steel pipe), and an electrolyte (soil) exist. In order to have a galvanic cell, only a metallic path for electron flow is needed; this is provided when the two dissimilar materials are metallically connected through the hot-water heater. Because the cathodic area is large (bare copper tube) and the anodic area is small (steel exposed at locations where "holidays", or defects, exist in the coating), corrosion produced leaks in the natural gas line can occur in relatively short times. (Generally, natural gas leaks occur first in soil near the foundations of buildings where fertilizing and watering have lowered the resistivity of the native soil.) The fact that the two service lines were laid only inches apart and in the same ditch is also a factor in this corrosion problem. Had the lines been located in separate ditches, the distance between them may have been sufficient to prevent the flow of galvanic current.

Severe galvanic corrosion is a problem in many potable-water systems. Providing the water is sufficiently aggressive, connecting steel or galvanized steel (the zinc coating is generally destroyed by threading) to copper or copper-base alloys will cause galvanic attack of the steel. Similarly, connecting aluminum and its alloys to copper-base materials exposed to corrosive potable waters generally accelerates attack of the aluminum. However, there are many waters where dissimilar metals and alloys can be directly connected without accelerated attack of the less noble material. In general, waters of high pH and low carbon dioxide, or those capable of producing a thin continuous layer of calcareous scale on the metal surface, do not promote galvanic attack.

Galvanic corrosion is also an important cause of rapid deterioration to underground aluminum-alloy structures. For example, in aircraft refueling areas, it is common practice to use aluminum-alloy pipe between the filter-meter pit and the hydrant outlets. Steel pipe is usually used between the filter meter pit and the fuel storage area. For safety, convenience, and aesthetic reasons, all of the pipe is underground. When the two dissimilar pipe materials (see Table 4-1) are metallically connected (for example, flanged at a filter meter pit) and exposed to a highly conductive, chloride containing soil, galvanic corrosion can be expected to occur. In these environments, galvanic corrosion of the aluminum alloy is generally characterized in a appearance by severe pitting attack. Cases are known where galvanic corrosion has perforated 7.6 mm (0.3 in) thick, aluminum-alloy pipe in two (2) years.

A number of methods and practices are available which will either prevent or minimize galvanic corrosion. These include: the use of materials which are electrochemically similar (that is, close together in the galvanic series); avoiding unfavorable (large) cathode-to-anode area ratios; breaking the metallic circuit by the proper use of insulators (for example, isolating flanges and insulating unions); the use of inhibitors (preferably cathodic inhibitors, or a sufficient amount of anodic inhibitor to insure that the anodic reaction will be completely stifled); keeping the dissimilar metals or alloys physically distant from each other; avoiding the use of threaded joints between dissimilar metals; cathodic protection; applying protective coatings to both dissimilar metals; and possibly increasing the resistivity of the environment.

d. Concentration Cell Corrosion

Electrochemical attack of a metal or alloy because of differences in the environment is called concentration cell corrosion. This form of corrosion is sometimes referred to as "crevice corrosion", "gasket corrosion", and "deposit corrosion" because it commonly occurs in localized areas where small volumes of stagnant solution exist. Normal mechanical construction can create crevices at sharp corners, spot welds, lap joints, fasteners, flanged fittings, couplings, threaded joints, and tube-sheet supports. Deposits which promote concentration cell corrosion can come from a number of sources; other sites for crevice attack can be established when electrolyte-absorbing materials are used for gaskets and the sealing of threaded joints.

There are at least five types of concentration cells. Of these, the "oxygen" and "metal ion" cell are most commonly considered in the technical literature. The "hydrogen ion", "neutral salt", and "inhibitor" cells must be considered in any discussion of concentration cell corrosion.

It is known that areas on a surface in contact with electrolyte having a high oxygen content will generally be cathodic relative to those areas where less oxygen is present. Oxygen can function as a cathodic depolarizer;

in neutral and alkaline environments, regions of high oxygen would be preferred cathodic sites where the reduction of oxygen can occur. This is the commonly referred to as an "oxygen concentration cell," see Figure 4-1.

A mechanism is proposed wherein the dissolution of metal (anodic process) and reduction of oxygen (cathodic process) initially occur uniformly over the entire surface, including the interior of the crevice. In time, the oxygen within the crevice is consumed and the localized (oxygen reduction) cathodic process stops in this area. The overall rate of oxygen reduction, however, remains essentially unaltered because the area within the crevice is quite small compared to the area outside of the crevice. The rate of corrosion within and outside the crevice remains equal.

Concentration cell corrosion can occur at threaded joints of pipe used to convey aggressive, liquids. When the joints are improperly sealed, rapid crevice attack occurs in the threaded area where stagnant, low-oxygen-content fluids exist. Since the wall thickness of the pipe is reduced by threading, failures due to concentration cell corrosion can be a frequent and common occurrence at threaded joints. Threaded joints sealed with liquid-absorbing materials (for example, string or hemp) can fail in times as short as nine months. Similarly, transport deposits of solids can be a major cause of concentration cell corrosion.

Some of the methods to reduce concentration cell corrosion damage include: using butt welds instead of riveted, spot-welded, and bolted joints; caulking, welding and soldering existing lap joints; avoiding the use of fluid absorbing materials for gaskets and threaded-joint sealants; providing a more uniform environment, for example, placing homogeneous sand around underground steel structures; removing suspended solids from solution; periodic cleaning to remove deposits from the surface; improving the design, for example, providing adequate slope on the inside bottoms of underground storage tanks so accumulated liquid will flow to the sump; cathodic protection; and protective coatings, especially on the interior surfaces of storage tanks and carbon steel piping.

e. Pitting Corrosion

Pitting corrosion is a randomly occurring, highly localized form of attack on a metal surface. In general, it is characterized by the observation that the depth of penetration is much greater than the diameter of the area affected. Pitting is similar to concentration cell-corrosion in many respects. The two should be distinguished, however, because crevices, deposits, or threaded joints are not requisites for pit initiation. Further, concentration cell corrosion can occur in environments where the metal or alloy is immune to pitting attack.

Pitting attack appears to occur in two distinct stages. First, there is an incubation period during which the pits are initiated; second, there is a propagation period during which the pits develop and penetrate into the metal. It is generally agreed that a sufficient concentration of an aggressive anion (generally chloride, but also bromide, iodide, and perchlorate) and an oxidizing agent (dissolved oxygen, Fe^{+++}, H_2O_2, Cu^{++}, and certain others) must be present in the electrolyte. A stagnant volume of liquid must exist in the pit or pitting will not occur. In addition, for a given metal/electrolyte system, the redox potential must be more noble than a certain critical value. It is also agreed that the corrosion processes within the pit produce conditions of low pH and high chloride ion content; these keep the localized anodic areas electrochemically active.

Many grades of stainless steel are particularly susceptible to pitting corrosion when exposed to saline environments. Alloying elements in a stainless steel, however, greatly affect its resistance to pitting attack; the tendency to pit decreases as the content in nickel, chromium and molybdenum increases. In sea water, austenitic stainless steels containing 18% chromium and a 2-3% molybdenum addition (e.g., Type 316 stainless steel) exhibit much better pitting-corrosion resistance than similar alloys which contain no molybdenum (e.g., Type 302 stainless steel). For certain grades of ferritic stainless steel, relatively low chloride content waters can cause severe pitting corrosion. For example, Type 430, ferritic grade, stainless steel (16% Cr) tubes failed by pitting corrosion and pinhole leaks when they were used to convey cooling water containing only a small amount of chlorides.

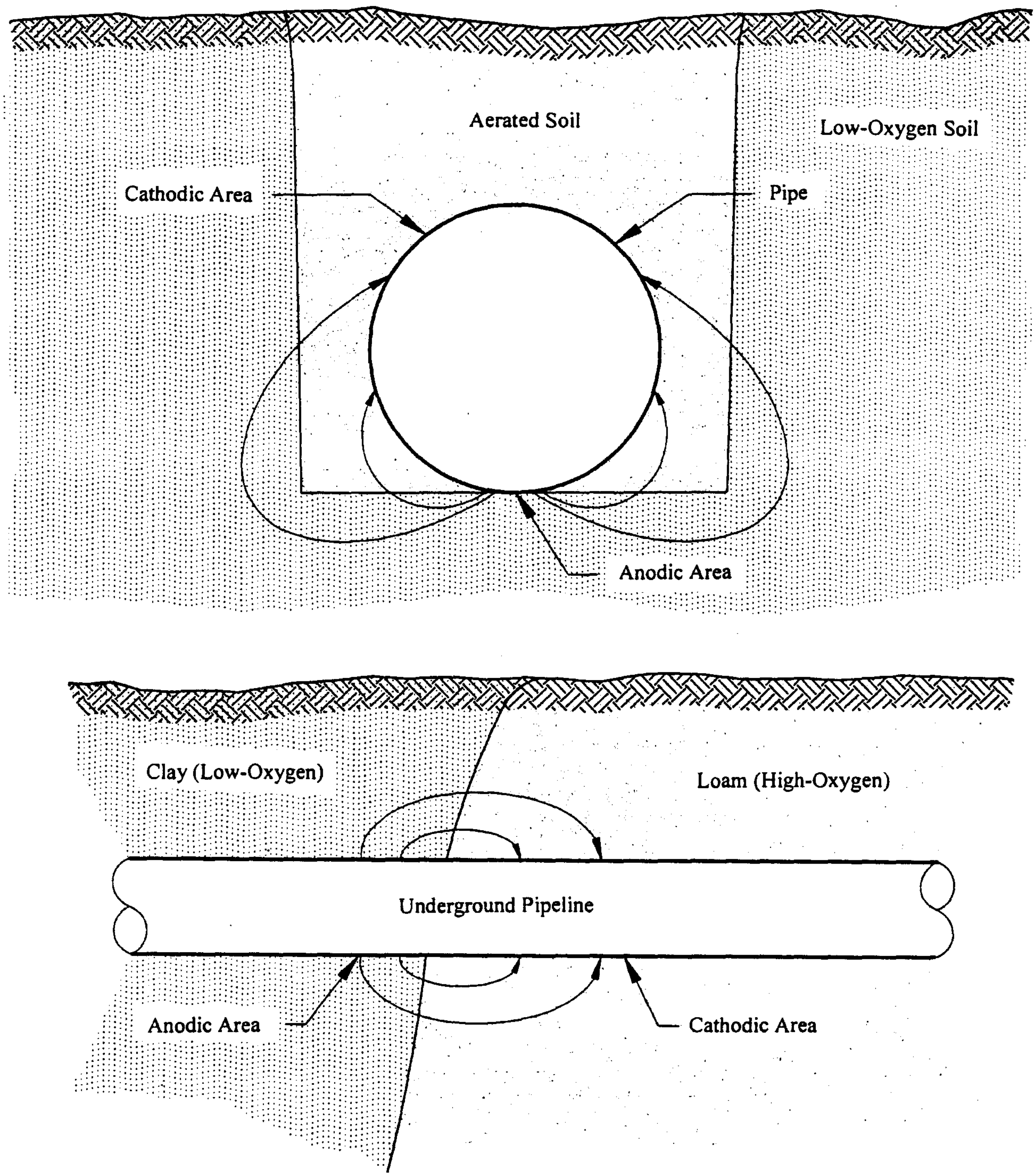

Figure 4-1. Concentration-Cell Corrosion of Underground Pipeline
(Source: USACE CECER, 1998.)

In many cases, methods which minimize concentration cell corrosion can be used to successfully mitigate pitting attack. Widely-used practices and procedures for reducing damage by pitting corrosion include: keeping the fluid uniformly aerated; keeping the fluid at a low and uniform temperature; improving the homogeneity of the metal's surface by polishing, heat treating, or passivation; using inhibitors; implementing cathodic protection; reducing the concentration of aggressive ions in the electrolyte; selecting materials which have good pitting corrosion resistance; and using anodic protection by controlling the metal or alloy's potential in the passive range at a value more negative than the critical potential for pitting.

f. Intergranular Corrosion

Intergranular corrosion is the localized attack which occurs at or in narrow zones immediately adjacent to the grain boundaries of an alloy. Severe intergranular attack usually occurs without appreciable corrosion of the grains; eventually, the alloy disintegrates or loses a significant amount of its load-bearing capability. Although a number of alloy systems are susceptible to intergranular attack, most of the problems encountered in service involve austenitic stainless steels and the 2xxx and 7xxx series aluminum alloys. Welding, stress-relief annealing, improper heat treating, or overheating in service generally establish the microscopic, compositional inhomogeneities which make a material susceptible to intergranular corrosion.

Several grades of austenitic stainless steels (for example, Type 304, which contains about 0.08% carbon) are susceptible to intergranular corrosion after they have been heated into the temperature range of about 425°C to 790°C (800°F to 1450°F). Provided the time in this temperature range is sufficiently long, but not extended, the stainless steel becomes sensitized. Intergranular corrosion will occur if the alloy is subsequently exposed to certain environments.

Some of the environments which reportedly cause intergranular corrosion in sensitized, austenitic stainless steels are listed in Table 4-2. Examination of this table reveals that intergranular corrosion can occur in many environments where austenitic stainless steels normally exhibit excellent corrosion resistance.

Table 4-2
Environments Which Cause Intergranular Corrosion in Sensitized Austenitic Stainless Steels

Acetic Acid	Phosphoric Acid
Ammonium Nitrate	Phthalic Acid
Beet Juice	Salt Spray
Chromic Acid	Sea Water
Copper Sulfate	Sodium Bisulfate
Crude Oil	Sulfite Cooking Liquor
Fatty Acids	Sulfite Digestor Acid
Lactic Acid	Sulfamic Acid
Maleic Acid	Sulfur Dioxide (wet)
Nitric Acid	Sulfuric Acid
Oxalic Acid	Sulfurous Acid

Source: USACE CECER, 1998.

The use of extra-low carbon grades of stainless steel, for example, Type 304L, essentially eliminates the intergranular corrosion problem. These alloys are immune to sensitization because of their low carbon content. It is well known that sensitization can occur only if the carbon content of the alloy exceeds about 0.02 to 0.03%. The control of carbon to a maximum of 0.03%, by blowing oxygen through the melt and using low-carbon ferrochrome, has permitted steel manufacturers to produce alloys which can be welded, stress-relief annealed, and used in corrosive environments without major concern for intergranular attack.

g. Stress-Corrosion Cracking

Stress-corrosion cracking (environmentally-induced-delayed failure) describes the deleterious phenomena which can occur when many alloys are subjected to static, surface tensile stresses and exposed to certain corrosive environments. Cracks are initiated and propagated by the combined effect of a surface tensile stress and the environment. When stress-corrosion cracking occurs, the tensile stress involved is often much less than the yield strength of the material; the environment is generally one in which the material exhibits good resistance to general corrosion. For example, various steels have good general corrosion resistance to anhydrous liquid ammonia. Steel tanks are widely and successfully used for the storage and transport of this liquified gas. Stress-corrosion cracking failures have occurred in some large-diameter liquid ammonia tanks, however, probably because the high residual tensile stresses introduced during fabrication were not removed by stress-relief annealing. Several of the alloy/susceptible environment combinations where stress-corrosion cracking can occur are given in Table 4-3.

h. Dealloying

Dealloying, sometimes referred to as parting or selective leaching, is a corrosion process wherein one element is preferentially removed from an alloy. The process is unique in that corrosion occurs without appreciable change in the size or shape of the component being attacked. The affected areas become brittle, weak, and porous but the overall dimensions of the component do not change appreciably.

Table 4-3
Alloy/Susceptible Environment Combinations for Stress-Corrosion Cracking
(Partial Listing)

Alloy System	Environment	Type of Cracking
Mild Steel	OH^- NO_3^-	Intergranular Intergranular
Alpha Brass (70 Cu- 30 Zn)	NH_4^+	Transgranular at high pH; intergranular in neutral solutions
Austenitic Stainless Steel	Cl^-	Transgranular
2XXX - Series Al Alloys	Cl^-	Adjacent to grain boundaries
7XXX - Series Al Alloys	Cl^-	Intergranular
Cu-P Alloys	NH_4^+	Intergranular
Titanium Alloys*	Cl^-	Transgranular or intergranular
Mg-A1 Alloys	Cl^-	Intergranular; sometimes transgranular
Beta Brass	Cl^- NH_4^+	Transgranular Intergranular
Martensitic Low-Alloy	Cl^-	Along prior-austenite grain boundaries
18 Ni Maraging Steel	Cl^-	Along prior-austenite grain boundaries

Note: *Includes Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2.5Sn alloys.
Source: USACE CECER, 1998.

The two most important examples of dealloying are the preferential removal of zinc from copper-zinc alloys (dezincification) and the preferential removal of iron from gray-cast iron (graphitic corrosion). Other cases of dealloying include the preferential removal of aluminum, nickel, and tin from copper-base alloys and cobalt from a Co-W-Cr alloy.

Dezincification commonly occurs when yellow brass (67Cu-33Zn) is exposed to waters having a high chloride content, low temporary hardness, and pH above approximately 8. Other alloys which are susceptible to dezincification in many waters include Muntz metal (60Cu-40Zn) and non-inhibited aluminum brass (76Cu-22Zn-2.Al). Generally, higher zinc content brasses are more susceptible to dezincification than alloys containing smaller amounts of the solute element.

Dezincification problems are generally solved by changing alloys. This includes the use of low-zinc-content alloys such as red brass (85Cu-15Zn) and specially-alloyed materials such as arsenical Admiralty Metal (70Cu-29Zn-lSn-0.05As) and arsenical aluminum brass (76Cu-22Zn-2Al-0.05As). For severe applications, it may be necessary to use cupro-nickel alloys, for example, 90Cu-l0Ni, which contain a small amount of iron. In some process streams, dezincification can be eliminated by changing the fluid chemistry, but this should be done with caution and not without expert advice.

i. Erosion Corrosion

Most metals and alloys depend upon a protective surface-film for corrosion resistance. When the protective film or corrosion products have poor adherence, an acceleration or increase in the rate of localized corrosion can occur because of relative movement between the liquid and the metal. Generally, movement of the liquid is quite rapid and mechanical wear effects or abrasion (due to suspended solids and entrained gases in the environment) can be involved. Repetitive formation (a corrosion process) and destruction (a mechanical erosion process) of the surface films is referred to as erosion corrosion. The term includes impingement attack, a special form of erosion corrosion is cavitation.

Many metallic materials are susceptible to erosion corrosion at sufficiently high flow rates or excessive turbulence. Some of the equipment and components where erosion-corrosion damage frequently occurs include: piping systems (particularly at elbows, tees, and bends), pump impellers, valves, propellers, orifices of measuring devices, nozzles, heat-exchanger tubes, and turbine blades. Erosion corrosion is characterized in appearance by the presence of waves, valleys, deep grooves, and gullies on the metal surface. An absence of residual corrosion products and a clean metal appearance in the area of attack also suggest that the destructive process is erosion corrosion. For copper, the effected area is usually bright and shiny, resembling that of a new penny.

Some of the other material/environmental combinations where erosion corrosion can occur include: red brass (85Cu-15Zn) in potable hot waters; hard lead (92Pb-8Sb) in heated, dilute sulfuric acid solutions; carbon steel in heated, acidified distilled waters; austenitic stainless steels in heated sulfuric acid-ferrous sulfate slurries; and cupro-nickel alloys in heated sea water. It is important to appreciate that none of these environments would appreciably corrode the respective materials under static or low-flow conditions. For example, hard lead corrodes at a negligible rate in stagnant 10% sulfuric acid at 90°C (194°F). When the same sulfuric acid solution is circulated at 11.8 m/s (39 ft/s), the erosion-corrosion penetration rate of hard lead is about 1000 microns/y (40 mils/y).

A number of techniques are available for minimizing erosion corrosion. Velocities in a system must be considered before materials are selected and used. Materials which are susceptible to erosion corrosion should not be used when the environment is going to be circulated at high velocities. For this reason, copper tubing is not recommended for conveying aggressive, potable hot waters at temperatures above 60° C (140° F); 90-10 cupro-nickel should be used when high-temperature, potable waters must be circulated at high flow rates. Similarly, use of Monel can generally eliminate the "wire drawing" which occurs in brass valve seats.

Cavitation corrosion is a special form of erosion corrosion. The process is basically the result of gas bubbles forming at low pressure and collapsing under high pressure at or near the liquid-metal interface. Bubble collapse, which produces very high localized pressures (shock waves), destroys the metal's protective film. Repetitive formation and destruction of the film on a localized basis results in severe damage. Cavitation corrosion damaged surfaces are characterized by their deeply pitted and "spongy" appearance.

j. Microbially Induced Corrosion

Microbiological activity can induce corrosion as a result of byproducts such as carbon dioxide, hydrogen sulfide, ammonia and acids. In some instances microorganisms may also consume metal. Biological activity can be reduced through the use of biocides and/or occasional pH variations.

4-3. Design Pressure

In addition to the requirements of Paragraph 3-2, a key consideration when specifying metal pipe and components is compliance with established pressure and temperature rating of applicable codes and standards.

a. Maximum Steady Pressure

When using ASME B31.3 as the governing code, the following pressure and temperature rating issues must be addressed for the metal pipe to be specified:

(1) For listed components having established rating, utilization of materials falling within the acceptable service ratings are listed in the codes and standards contained in Table 326.1 of ASME B31.3.

(2) For listed components not having established ratings, utilization of components of the same materials with the same allowable stress as material specified in the codes and standards contained in Table 326.1, if the service ratings are based on straight seamless pipe and the pipe components to be utilized are not manufactured from straight seamless pipe. Because of this deviation from the listed rating, the pipe components should be rated using not more than 87.5% of the nominal wall thickness of the listed pipe less allowances applied to the pipe.

(3) Unlisted components, components not listed in ASME B31.3 but conforming to other published standards, may be utilized if the requirements of the published standard are comparable to ASME B31.3 requirements and if the pressure design satisfies the ASME B31.3 pressure design of components.

b. Pressure Transients

Most design codes for metal pipe provide allowances for short duration transient conditions which do not increase the design pressure and temperature. When following ASME B31.3 or similar codes, the limitations of using these allowances without increasing the design conditions are typically specified within the code. Before finalizing the system design pressure and temperature, allowances for transient conditions within the applicable design code are reviewed and the anticipated conditions that would be covered by the allowances in the code are fully evaluated.

4-4. Piping Supports for Metallic Piping Systems

Specific metallic piping materials have particular requirements for the design of piping supports. Care should be taken to minimize stress in the pipe that may induce corrosion. Concentrated loads, such as valves, meters, and other fittings, should be independently supported. As a rule of thumb, spans for insulated lines should be reduced by approximately 30% from those for uninsulated pipes.

Tables 4-4 through 4-7 present support spacing examples for various metals. Calculations should be performed for each application since material strength varies by temper and manufacturing method. Table 4-4 summarizes support spacing for carbon and stainless steel pipe.

Support of nickel pipe should follow similar principles of other metallic piping systems. Table 4-5 summarizes support spacing for nickel 200 and nickel 201. Nickel 200 is pure wrought nickel. Nickel 201 is a low-carbon alloy of nickel 200, for higher temperature applications.

When designing aluminum pipe system supports, either aluminum or padded pipe supports should be specified. Aluminum will corrode when exposed to other metals. Contact with metals such as copper, brass, nickel, and carbon steel should be avoided. The support spacing for aluminum alloy 6063 pipe is summarized in Table 4-6.

Table 4-4
Support Spacing for Steel Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft)				
	SS, Sch 5S	SS, Sch 10S	CS, Sch 40	SS Sch 40S	CS Sch 80
15 (0.5)	2.9 (9.4)	2.9 (9.6)	2.1 (7.0)*	2.9 (9.6)	2.5 (8.3)
20 (0.75)	3.2 (10.3)	3.2 (10.6)	2.1 (7.0)*	3.3 (10.7)	2.9 (9.4)
25 (1)	3.4 (11.2)	3.6 (11.9)	2.1 (7.0)*	3.6 (12.0)	3.2 (10.5)
40 (1.5)	3.8 (12.6)	4.2 (13.8)	2.7 (9.0)*	4.3 (14.2)	3.9 (12.7)
50 (2)	4.1 (13.4)	4.5 (14.9)	3.0 (10.0)*	4.8 (15.6)	4.3 (14.1)
80 (3)	4.8 (15.7)	5.2 (17.1)	3.7 (12.0)*	5.8 (18.9)	5.2 (17.1)
100 (4)	5.0 (16.5)	5.6 (18.3)	4.3 (14.0)*	6.4 (21.0)	5.8 (19.2)
150 (6)	5.9 (19.4)	6.3 (20.6)	5.2 (17.0)*	7.5 (24.6)	7.0 (23.0)
200 (8)	6.2 (20.2)	6.8 (22.4)	5.8 (19.0)*	8.3 (27.4)	7.9 (25.8)
250 (10)	7.1 (23.3)	7.4 (24.1)	6.1 (22.0)*	9.1 (30.0)	8.7 (28.7)
300 (12)	7.4 (24.3)	7.8 (25.6)	7.0 (23.0)*	9.8 (32.2)	9.5 (31.1)

Notes:

CS - electric resistance welded carbon steel ASTM A 53, grade A.

SS - seamless stainless steel ASTM A 312, TP316L.

Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).

*Maximum horizontal spacing based on MSS SP-69 (std. wt. steel pipe, water service)

Source: Calculations by SAIC, 1998

Table 4-5
Support Spacing for Nickel Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft)					
	Ni 200, Sch 5	Ni 201, Sch 5	Ni 200, Sch 10	Ni 201, Sch 10	Ni 200, Sch 40	Ni 201, Sch 40
15 (0.5)	2.4 (7.8)	2.1 (6.9)	2.4 (7.9)	2.1 (6.9)	2.4 (7.9)	2.1 (6.9)
20 (0.75)	2.6 (8.6)	2.3 (7.5)	2.7 (8.8)	2.3 (7.7)	2.7 (8.8)	2.4 (7.8)
25 (1)	2.9 (9.4)	2.5 (8.2)	3.0 (9.8)	2.6 (8.6)	3.0 (9.9)	2.6 (8.7)
40 (1.5)	3.2 (10.6)	2.8 (9.3)	3.5 (11.5)	3.1 (10.1)	3.6 (11.8)	3.1 (10.3)
50 (2)	3.4 (11.3)	3.0 (9.9)	3.8 (12.5)	3.3 (10.9)	4.0 (13.0)	3.5 (11.4)
80 (3)	4.0 (13.2)	3.5 (11.6)	4.4 (14.4)	3.8 (12.6)	4.8 (15.7)	4.2 (13.8)
100 (4)	4.3 (14.0)	3.7 (12.3)	4.7 (15.4)	4.1 (13.6)	5.3 (17.5)	4.7 (15.3)
150 (6)	4.5 (14.7)	4.0 (13.2)	4.8 (15.6)	4.3 (14.0)	5.6 (18.4)	5.0 (16.4)
200 (8)	4.7 (15.4)	4.2 (13.8)	5.2 (17.0)	4.6 (15.2)	6.3 (20.5)	5.6 (18.4)
250 (10)	5.4 (17.8)	4.8 (15.9)	5.6 (18.3)	5.0 (16.4)	6.9 (22.5)	6.1 (20.1)
300 (12)	5.7 (18.5)	5.1 (16.6)	5.9 (19.4)	5.3 (17.4)	7.4 (24.2)	6.6 (21.6)

Notes:
Ni 200 = seamless nickel ASTM B 161, alloy N02200, annealed.
Ni 201 = seamless nickel ASTM B 161, alloy N02201, annealed.
Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).
Source: Calculations by SAIC, 1998.

Table 4-6
Support Spacing for Aluminum Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft)			
	Al 6063, Sch 5	**Al 6063, Sch 10**	**Al 6063, Sch 40**	**Al 6063, Sch 80**
15 (0.5)	2.3 (7.6)	2.4 (8.0)	2.5 (8.3)	2.6 (8.5)
20 (0.75)	2.5 (8.1)	2.6 (8.6)	2.8 (9.1)	2.9 (9.4)
25 (1)	2.6 (8.5)	3.0 (9.7)	3.1 (10.1)	3.2 (10.5)
40 (1.5)	2.7 (9.0)	3.2 (10.6)	3.6 (11.4)	3.7 (12.2)
50 (2)	2.8 (9.3)	3.4 (11.1)	3.7 (12.3)	4.0 (13.3)
80 (3)	3.2 (10.7)	3.7 (12.2)	4.5 (14.7)	4.8 (15.9)
100 (4)	3.3 (10.9)	3.9 (12.6)	4.9 (16.0)	5.3 (17.5)
150 (6)	3.8 (12.6)	4.2 (13.8)	5.5 (18.1)	6.3 (20.5)
200 (8)	3.9 (12.9)	4.5 (14.7)	6.0 (19.8)	6.9 (22.7)
250 (10)	4.5 (14.8)	4.8 (15.6)	6.5 (21.4)	7.6 (25.0)
300 (12)	4.7 (15.4)	5.0 (16.4)	6.9 (22.7)	8.2 (27.1)

Notes:
Al 6063 = seamless aluminum ASTM B 241 A96063, type T6 with welded joints.
Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).
Source: Calculations by SAIC, 1998.

Design of copper pipe support follows principles similar to those for other metallic piping systems. Galvanic action between pipe supports and copper piping must be considered when specifying support materials. Table 4-7 summarizes support spacing for copper pipe.

4-5. Joining

Common methods for the joining of metallic pipe for liquid process systems include utilization of welded, flanged, threaded and mechanical joints including flared, flareless, compression, caulked, brazed and soldered joints. The application requirements and material specifications for these fittings are typically found in accompanying sections of the codes and standards used for the specification of the metallic pipe. The most common sources for application requirements and material specifications can be found in ASME, MSS and API standards. Table 4-8 presents applicable sections of relevant codes and standards for the metallic fittings. In selecting a joining method for liquid process piping systems, the advantages and disadvantages of each method must be evaluated.

4-6. Thermal Expansion

Thermal expansion can impact the design of the piping system in the following critical areas: excessive stress related to thermal loads on the liquid being contained by the piping system, reduction of allowable stress due to elevated material temperature and stresses caused by elongation of the metal pipe; excessive thrust loads or bending moments at connected equipment due to thermal expansion of the metal pipe; and leaking at pipe joints due to thermal expansion of the metal pipe.

Table 4-7
Support Spacing for Copper Pipe

Nominal Pipe Size, mm (in)	Maximum Support Spacing, m (ft)		
	Cu Light Wall	**Cu Regular Wall**	**Cu X-Strong Wall**
15 (0.5)	1.5 (5.0)*	1.5 (5.0)*	1.5 (5.0)*
20 (0.75)	1.5 (5.0)*	1.5 (5.0)*	1.5 (5.0)*
25 (1)	1.8 (6.0)*	1.8 (6.0)*	1.8 (6.0)*
40 (1.5)	2.2 (7.3)	2.4 (8.0)*	2.4 (8.0)*
50 (2)	2.4 (7.8)	2.4 (8.0)*	2.4 (8.0)*
80 (3)	2.8 (9.2)	3.0 (10.0)*	3.0 (10.0)*
100 (4)	3.2 (10.4)	3.7 (12.0)*	3.7 (12.0)*
150 (6)	3.8 (12.6)	4.2 (13.9)	4.3 (14.0)*
200 (8)	4.5 (14.6)	4.8 (15.8)	4.9 (16.0)*
250 (10)	4.9 (16.1)	5.3 (17.4)	5.5 (18.0)*
300 (12)	5.4 (17.6)	5.9 (19.4)	--

Notes:

Cu = seamless copper ASTM B 42, allow C 12200, drawn with brazed fittings.

Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).

*Maximum horizontal spacing based on MSS SP-69 (copper tube, water service).

Source: Calculations by SAIC, 1998.

Table 4-8
Applicable Codes for Metallic Fittings

Reference Standard	Key Aspects of Standard
API 605	Large Diameter Carbon Steel Flanges
ASME B16.1	Cast Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, 250, and 800
ASME B16.5	Pipe Flanges and Flanged Fittings
ASME B16.9	Factory Made, Wrought Steel Butt-Welding Fittings
ASME B16.11	Forged Steel Fittings, Socket Welding and Threaded
ASME B16.24	Bronze Pipe Flanges and Flanged Fittings, Classes 150 and 300
ASME B16.25	Butt-Welding Ends
ASME B16.31	Non-Ferrous Pipe Flanges
ASME B31.3	Chemical Plant and Petroleum Refinery Piping - Chapter II Design Parts 3 and 4, Chapter III, Chapter IV, and Chapter V
ASME B16.42	Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300
ASME B16.47	Large Diameter Steel Flanges
MSS SP-43	Wrought Stainless Steel Butt-welding Fittings
MSS SP-44	Steel Pipeline Flanges
MSS SP-51	Class 150 LW Corrosion Resistant Cost Flanges and Flanged Fittings
MSS SP-73	Brazing Joints for Wrought and Cast Copper Alloy Solder Joint Pressure Fittings
MSS SP-104	Wrought Copper Solder Joint Pressure Fittings
MSS SP-106	Cast Copper Alloy Flanges and Flanged Fittings, Class 125, 150 and 300
MSS SP-114	Corrosion Resistant Pipe Fittings Threaded and Socket Welding, Class 150 and 1000
MSS SP-119	Belled End Socket Welding Fittings, Stainless Steel and Copper Nickel

Source: Compiled by SAIC, 1998.

When designing a piping system subject to thermal expansion due to anticipated operating temperatures and in which the piping is restrained at supports, anchors, equipment nozzles and penetrations, thermal stresses and loads may be large and 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 to during operation. Based on this analysis, the design and material specification requirements are followed as an applicable standard.

The need for detailed thermal stress analysis is assessed for piping systems. An approach for this assessment is to first identify the 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 is performed. This analysis is performed by assuming no intermediate pipe supports, only terminal connections to anchors, equipment nozzles, and equipment penetrations. If, based on this analysis, the stress resulting from thermal expansion is less than 68.9 MPa (10 ksi), the pipe section analyzed has sufficient flexibility to accommodate the thermal expansion and rigid supports can be utilized. The 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 analysis at equipment and anchor terminations should consider the movement and stress impacts of the "cold" condition.

If the initial free thermal analysis indicates that the resulting stresses will require the piping system to be designed to accommodate thermal expansion, the design should conform to applicable codes and standards.

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 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 should be consulted to determine design and installation requirements. An alternative is an expansion loop. Expansion loops can be used in vertical or horizontal planes. If an expansion loop is to be required, the following formula can be used. This formula is based on guided-cantilever-beam theory in which both ends are fixed and limited pipe rotation is assumed. The loop is also geometrically similar (as depicted in Figure 2-3d) with the middle parallel leg equal to ½ of each of the tangential legs.

$$L = X + 2Y = (\Delta D E / C_1 S_A)^{0.5} \quad \text{(Metric Units)}$$ [1]

or

$$L = X + 2Y = (3\Delta D E / (144 \text{ in.}^2/\text{ft}^2) S_A)^{0.5} \quad \text{(English Units)}$$ [2]

where:

L = loop length to accommodate thermal expansion, mm (ft)
X = parallel leg of loop, mm (ft)
Y = $2X$ = tangential leg of loop, mm (ft)
D = actual outside pipe diameter, mm (in.)
E = modulus of elasticity at the working temperature, kPa (psi)
S_A = maximum allowable stress at the working temperature, kPa (psi)
Δ = change in length due to temperature change, mm (in.)
C_1 = constant, 0.3333

ASHRAE states that for the commonly used A53 Grade B seamless or electric resistance welded (ERW) pipe, an allowable stress S_A of 155 MPa (22,500 psi) can be used without overstressing the pipe. However, this may result in very high end reactions and anchor forces, especially with large-diameter pipe. Designing to a stress range S_A= 103 MPa (15,000 psi) and assuming $E = 1.92 \times 10^5$ MPa (27.9×10^6 psi), the above equation reduces to:

$$L = 74.7(\Delta D)^{0.5} \quad \text{(Metric Units)}$$

$$L = 6.225(\Delta D)^{0.5} \quad \text{(English Units)}$$

This provides reasonably low end reactions without requiring too much extra pipe. In addition, this equation may be used with A53 butt-welded pipe and B88 drawn copper tubing.

When welded fittings are used in expansion loops rather than pipe bends, another important consideration is the effects of bending on the fittings used to install the expansion loop. The loop should be installed 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.

Example Problem 7:
A 145-m-long (475-ft-long) steel, 200-mm (8-in.) diameter liquid process pipe operates at 90°C (194°F) and 1.55 MPa (225 psig). The expansion caused by the process stream must be absorbed using U-bends without damage to the pipe.

[1] 1988 ASHRAE Handbook, EQUIPMENT
[2] 2000 ASHRAE Handbook, Heating, Ventilating, and Air-Conditioning, SYSTEMS AND EQUIPMENT

Solution:
Step 1. Establish a temperature differential (ΔT). Assume an installation temperature of 4.4°C (40°F). This would be a conservative, yet reasonable, assumption. Therefore, the temperature differential would be 90°C – 4.4°C, or 85.6°C (194°F – 40°F, or 154°F).

Step 2. Determine the thermal expansion (Δ).

$$\Delta = \alpha L_0(\Delta T)$$

where:

Δ = thermal expansion of pipe run, mm (in.)
α = coefficient of thermal expansion, 11.7 × 10^{-6} mm/(mm °C), (6.5 × 10^{-6} in./[in. °F]) [3]
L_0 = original length of pipe run, mm (in.)
ΔT = temperature differential

Δ= 11.7 × 10^{-6} mm/(mm °C) × 145,000 mm × 85.6°C
(6.5 × 10^{-6} in./(in. °F) × 5700 in × 154°F)
Δ= 145.2 mm
(5.71 in.)

Step 3. Determine dimensions of expansion loop. The expansion loop is centered between anchored supports as schematically shown in Figure 2- 3d.

$$L = X + 2Y = 74.7(\Delta D)^{0.5} \quad 6.225(\Delta D)^{0.5}$$

and

$$Y = 2X$$

So

$L = 5X$= 74.7(145.2 mm × 220 mm)$^{0.5}$
6.225 (5.71 in. × 8.625 in.)$^{0.5}$
$L = 5X$= 13,351 mm (43.7 ft)
X = 2670 mm (8.74 ft)
Y = 2(2670 mm) = 5340 mm (17.5 ft)

The length of the parallel leg of the expansion loop is 2670 mm (8.74 ft), and the length of each of the two tangential legs of the expansion loop is 5340 mm (17.5 ft).

4-7. Ductile Iron

Ductile iron is a hard, nonmalleable ferrous metal that must be molded into the various component shapes. It is used for those piping applications requiring strength, shock resistance, and machinability. It has good resistance to general corrosion, but reacts readily with hydrogen sulfide.

a. Ductile Iron Specifications

Due to the long use of ductile iron in water service, ductile iron piping is most commonly specified pursuant to AWWA standards. As noted in Paragraph 3-5, care must be taken when joining AWWA piping systems to ASME piping systems.

4-8. Carbon Steel

Carbon steel is a hot-rolled, all-purpose material. It is the most common and economical metal used in industry. It will readily rust (corrode) in ambient atmospheres, and therefore casting applications should be considered. It will also become embrittled with prolonged contact with alkaline or strong caustic fluids and contact with acid accelerates corrosion. It may react directly with hydrogen sulfide gas. The material/fluid matrix in Appendix B should be consulted for each application.

a. Carbon Steel Pipe Specifications

A wide variety of mechanical properties is available by varying the carbon content and heat treatments. The most commonly specified carbon steel piping is manufactured to meet ASTM A 53. The type and grade of the pipe must be specified: type F (furnace-butt-welded), grade A; type E (electric-resistance welded), grade A or B; or type S (seamless), grade A or B. Type F should not be used if flanging is required, and grade A is preferred if cold-bending is to occur. Options that can be specified pursuant to ASTM A 53 include hot-dip galvanizing, threaded ends and dimensions, schedule 40, 80, 160 and others that may be available depending on pipe diameter.

Many other options exist. For example, ASTM A 587 specifies an electric-resistance welded carbon steel pipe intended for use in the chemical industry. The material is low-carbon and can also be specified for galvanizing; either of these factors will reduce corrosion effects. The pipe is available in two nominal wall thicknesses from 15 mm (½ in.) to 250 mm (10 in.) in diameter. Another carbon steel pipe standard is ASTM A 106 which specifies seamless carbon steel pipe for high temperature service, but

[3] Design of Machine Elements, 5th Edition, Spotts, M.F., Tables 2-1, 2-1A, Prentice Hall, 1978.

graphitization at prolonged high temperature may still occur. Additional manufacturing standards for specialized carbon steel piping include, but are not limited to: ASTM A 135, schedule 10 electric-resistance welded carbon steel pipe; ASTM A 333, seamless or welded carbon steel (and low-alloy steel) pipe for low temperature service; and ASTM A 691, 405 mm (16 in.) and larger diameter electric-fusion welded carbon steel (and low-alloy steel) pipe for high pressure service at high temperatures. ASTM standards are reviewed for unusual process conditions or requirements to select the material most compatible to the application.

b. Carbon Steel Fittings

Fittings for carbon steel piping can be threaded, welded or flanged; all are commonly used. Fitting materials can be cast malleable iron, forged carbon steel and low-carbon or other specialized steel. In non-corrosive applications with threaded fittings, malleable iron conforming to ASTM A 47 is typically used. However, as the process dictates, forged carbon steel threaded fittings pursuant to ASTM A 105 are applicable for ambient to high temperature service, and low-carbon steel threaded fittings pursuant to ASTM A 858 are applicable for ambient to low temperature or corrosive service. Welded fittings can be butt-welded or socket welded with ASTM A 105 or ASTM A 858 conforming materials. Malleable iron is not welded. Other ASTM materials may also be appropriate; select a material and fitting that are compatible to the application.

Due to the relative inexpense of carbon steel flanges, carbon steel piping is usually flanged at connections to equipment and appurtenances such as valves or other items that may have to be removed or replaced. Common flange material is ASTM A 105 forged carbon steel for ambient to high temperature and ASTM A 727 forged carbon steel for temperatures between –30EC (–20EF) and 345EC (650EF).

In addition to fittings described above, carbon steel piping may be joined by mechanical couplings. The pipe sections must, however, be specified with grooved ends. Most of the manufacturers that produce mechanical couplings for ductile iron piping also produce them for carbon steel piping.

4-9. Stainless Steel

Stainless steel is the product of steel alloyed with chromium and, to a lesser extent, nickel. Other elements such as molybdenum, copper, manganese and silicon may also be included as part of the alloy for various steel types. Chromium is the primary additive that makes steel "stainless"; stainless steels are actually a very broad range of highly corrosion-resistant alloys that have a variety of trace elements.

a. Stainless Steel Types

The most common types of stainless steel used for liquid process applications are 304 and 316. One caution: stainless steel is not totally corrosion resistant. Chemicals such as sodium bisulfide, ferric chloride, ozone and hydrochloric acid can attack stainless steel successfully. Check the material/fluid matrix in Appendix B for compatibility with the application. The most commonly used series for corrosion resistance are discussed below.

Types 304 and 304L are austenitic stainless steels that provide outstanding resistance to bases such as lime and sodium hydroxide. They are highly resistant to many acids, including hot or cold nitric. Types 316 and 316L are stainless steel types that exhibit better resistance to sulfides and chlorides than 304 and 304L, and will provide adequate resistance to corrosion from sulfuric acid. Otherwise, 316 and 316L provide the same outstanding resistance to acids and bases as 304 and 304L. The "L" designation indicates alloys developed to minimize post-welding intergranular corrosion, and these alloys are strongly recommended whenever welding is involved. In general, the "L" stainless steels provide more resistance to sulfuric acid/nitric acid mixed solutions than non-low carbon steels.

Austenitic stainless steel piping is commonly specified to conform to ASTM A 312, ASTM A 813 or ASTM A 814. All three of these standards address austenitic stainless steel pipe intended for general corrosive and/or high temperature service. ASTM A 312 specifies seamless and straight-seam welded pipe; ASTM A 813 covers straight-seam single- or double-welded pipe that is of fit-up and alignment quality; and ASTM A 814 addresses flanged and cold-bending quality (cold worked) straight-seam single- or double-welded pipe.

Austenitic stainless steel fittings may be threaded, welded or flanged. The materials should match the associated pipe. For example, WP316L fittings or F316L flanges should be used with type 316L pipe. Welding fittings are typically specified under ASTM A 403. Class WP welding fittings are standard use as they conform to ASME B16.9 and ASME B16.11. Class CR welding fittings are light weight and conform to MSS SP-43. Threaded and flanged fittings are commonly specified under ASTM A 182.

Ferritic and martensitic stainless steels are used less commonly than austenitic. Unlike austenitic steels, ferritic stainless steels do not contain nickel and do not resist reducing chemicals such as hydrochloric acids. Ferritic stainless steels have excellent resistance to chloride attack and organic acids.[4] A commonly used ferritic stainless steel is type 430. Martensitic stainless steels, however, may contain nickel because their chromium content is limited. Typically, martensitic steels exhibit less corrosion resistance than austenitic steels.

Ferritic and martensitic stainless steel piping should conform to ASTM A 731, which addresses both seamless and welded pipe intended for general corrosive and high-temperature service. Welding fittings are typically specified under ASTM A 815 as Class WP or CR similar to austenitic stainless steel fittings. Threaded and flanged fittings are specified in accordance with ASTM A 182.

b. Stainless Steel Pipe Construction

Standard nominal pipe sizes are 15 through 300 mm (½ through 12 in.) commonly available in schedules 5S, 10S, 40S and 80S. Schedule 5S and 10S piping can not be threaded due to wall thickness constraints.

4-10. Nickel and Nickel Alloys

Nickel is used for its strong resistance to certain corrosive chemicals.

a. Common Alloys

Refer to the corrosion compatibility tables for specific applications of these alloys. Although other nickel alloys are used for specialty applications, these are the more commonly prescribed.

Alloy 200 is commercially pure wrought nickel, and 201 is a low-carbon version of 200 that is used for applications above 315EC (600EF). Corrosion resistances are the same for both alloys. They are resistant to caustic soda and most alkalis (key exception: ammonium hydroxide). They are not subject to stress corrosion in chloride salts. They are excellent for dry handling of chlorine and hydrogen chloride at elevated temperatures.

Nickel alloy 200 and 201 pipe can be specified seamless or welded. Cold-worked seamless pipe is readily available in nominal pipe sizes 6 mm (1/8 in.) to 200 mm (8 in.), dimensioned as schedule 5, 10, 40, or 80, pursuant to ASTM B 161 and ASTM B 829. Welded pipe, intended for corrosive service, is manufactured in accordance with ASTM B 725 and B 775, and is readily available in nominal pipe sizes 6 mm (1/8 in.) to 750 mm (30 in.), dimensioned as schedule 5S, 10S, and 40S. The material condition must be specified for both seamless and welded pipe as annealed or stress relieved. The latter conditioning provides more tensile strength. For example, the tensile strength for a seamless alloy 200 pipe is 380 MPa (55,000 psi) annealed and 450 MPa (65,000 psi) stress relieved.

Hastelloy, a nickel-molybdenum-chromium alloy, offers excellent resistance to wet chlorine, hypochlorite bleach, ferric chloride and nitric acid. Hastelloy, and related alloys, can be seamless or welded. Seamless pipe is manufactured pursuant to ASTM B 622 and ASTM B 829, and is readily available in nominal pipe sizes 8 mm (1/4 in.) to 80 mm (3 in.), dimensioned to schedule 10, 40, or 80. Welded pipe is readily available in nominal pipe sizes 6 mm (1/8 in.) to 200 mm (8 in.), dimensioned to 5S, 10S, 40S, and 80S, pursuant to ASTM B 619 and ASTM B 775. The material class is specified as class 1 or 2. Class 1 pipe is welded and solution annealed, and class 2 is welded, cold-worked and then solution annealed. Class 1 pipe may have sunken welds up to 15% of the wall thickness, while class 2 pipe does not have sunken welds.

Monel, a nickel-copper alloy, combines high strength with high ductility (usually a tradeoff in metals selection), as well as excellent general corrosion resistance. It is specified particularly where seawater or industrial chemicals may be accompanied by high temperatures. It must not be exposed, when hot, to sulfur or molten metals.

Monel can also be provided either seamless or welded. Seamless, cold-worked pipe is available in nominal pipe sizes 6 mm (1/8 in.) to 200 mm (8 in.), dimensioned to schedule 5, 10, 40, or 80, pursuant to ASTM B 165 and ASTM B 829. Welded Monel, intended for general corrosive service, is manufactured in accordance with ASTM B 725 and ASTM B 775, and is readily available in nominal pipe sizes 6 mm (1/8 in.) to 750 mm (30 in.), dimensioned as schedules 5S, 10S, and 40S. The pipe material conditioning, either annealed or stress relieved, should be specified.

[4] Schweitzer, Corrosion-Resistant Piping Systems, p. 234.

Inconel, a nickel-chromium-iron alloy, is noted for having high temperature strength, while maintaining excellent corrosion resistance. Similar to all the nickel and nickel alloy piping systems, Inconel pipe can be provided either seamless or welded. Seamless Inconel pipe is available in nominal pipe sizes 8 mm (1/4 in.) to 150 mm (6 in.), dimensioned to schedule 5, 10, 40 or 80. It is manufactured pursuant to ASTM B 167 and ASTM B 829. The material conditioning should be specified; hot-worked, hot-worked annealed or cold-worked annealed. The conditioning determines tensile strength; for example, the tensile strength of a 150 mm (6 in.) seamless Inconel pipe is 515 MPa (75,000 psi) for hot-worked and hot-worked annealed tempering and is 550 MPa (80,000 psi) for cold-worked annealed tempering. Welded Inconel pipe, intended for general corrosive and heat resisting applications, is produced in accordance with ASTM B 517 and ASTM B 775. Manufacturers will have to be contacted to confirm available sizes and schedules.

b. Nickel and Nickel Alloy Fittings

Welding and threaded fittings for nickel and nickel alloy piping systems are manufactured in conformance with ASTM B 366. Threaded fittings meet ASME B 16.11. Welding fittings can be class WP, which conforms to ASME B 16.9, ASME B 16.11 and ASME B 16.28, or class CR which are light weight and conform to MSS SP-43. Flanges are commonly specified to ASTM B 564 (and ASTM B 160 for nickel alloys 200 and 201), annealed temper only. Fitting dimensions and ratings are specified pursuant to ASME standards.

4-11. Aluminum

Aluminum is highly ductile. Although it has relatively low strength, its high strength-to-weight ratio results in the extensive use of aluminum alloys where that feature is required.

a. Aluminum Pipe Use

Alloys 1060, 3003, 5052, 6061, and 6063 are the most common compositions of its aluminum pipe. Alloy 6063 is most widely used due to cost, good corrosion resistance, and mechanical properties. Alloys 3003 and 5052 are best used for extremely low temperatures. Alloy 5052 has the best corrosion resistance for slightly alkaline solutions.[5]

[5] Schweitzer, Corrosion-Resistant Piping Systems, p. 253.

Aluminum piping resists corrosion well by forming a protective aluminum oxide film. Refer to the fluid/material matrix in Appendix B for compatibility applications. It is very resistant to sulfur compounds and most organics, including halogenated organic compounds. Aluminum should not, however, directly contact concrete because alkalis in the concrete will attack the aluminum. One note of caution is that resistance of aluminum to some combinations of compounds is poor, even though aluminum may be strongly resistant to each compound in the mixture. An example would be strong resistance to either carbon tetrachloride or methyl alcohol separately, but poor resistance to a mixture of the two. Also, aluminum has poor resistance to contaminants such as halide ions (like chloride) and reducible metals (like copper) contained in commercial chemical grades of some chemicals. Aluminum piping is not compatible with most inorganic acids, bases and salts outside a pH range of approximately 4 to 9. In addition, nearly all dry acids, alcohols and phenols near their boiling points can cause excessive aluminum corrosion.[6]

b. Aluminum Pipe Construction

All alloys are available in nominal pipe sizes from 15 mm (½ in.) to 300 mm (12 in.), in schedules 5, 10, 40 and 80. The preferred method for joining aluminum pipe to handle corrosives is welding; however, welding reduces tensile strength. Only schedule 40 and 80 pipe can be threaded. Threading is not recommended for aluminum piping systems that handle corrosives. Flanges are not normally used to join pipe sections and should be limited to connecting aluminum pipe to equipment such as pumps and process vessels.

Aluminum piping materials are most commonly specified using ASTM B 241. This standard covers seamless pipe intended for pressure applications and includes many aluminum alloys and tempering options. The temper required to obtain the proper tensile strength must be specified. For example, temper T6 is the strongest tensile strength for alloy 6063—206.8 MPa (30,000 psi). As an option, pipe lengths specified by ASTM B 241 may also have threaded ends.

Aluminum piping materials may also be specified to meet ASTM B 345 which covers seamless pipe for internal pressure applications. The number of alloys and tempers available under this standard is less than ASTM B 241. However, additional options for pipe

[6] Ibid., p. 254.

length ends exist, including threaded, beveled, grooved, or specialty end configurations such as the V-groove or modified Vee. If used with end configurations for mechanical coupling, the burden of mating the end configuration with the mechanical coupling used should be placed on the coupling supplier in the specifications.

Welding fittings are addressed in ASTM B 361, and threaded or flanged fittings materials are forged in accordance with ASTM B 247. Dimensions and configurations for the fittings should reference the appropriate ASME standard(s).

4-12. Copper

Copper is very ductile and malleable metal and does not corrode easily in normal wet/dry environments. Being a noble metal, it does not normally displace hydrogen from a solution containing hydrogen ions. However, copper corrodes rapidly when exposed to oxidizing agents such as chlorine, ozone, hydrogen sulfide, nitric acid and chromic acid. It is very susceptible to galvanic action, and this demands that padded pipe hangers are used and that attention is paid to contact with dissimilar metals.

a. Copper Pipe Construction

Seamless copper pipe is specified pursuant to ASME B 42. Various alloys and tempers may be selected. The copper alloys vary based upon the oxygen and phosphorus contents, and temper is selected based on required tensile strength. Nominal pipe sizes range from 6 mm (1/8 in.) to 300 mm (12 in.), in three wall thicknesses: light, regular, and extra strong.

Other options for copper based piping exist. For example, ASTM B 608 provides copper alloys that contain nickel for brackish or sea water applications with nominal pipe sizes from 100 mm (4 in.) to 1,200 mm (48 in.). In addition, aluminum-bronze, copper-nickel and red brass piping materials are also available.

b. Copper and Copper Alloy Fittings

Flanges and fittings for copper piping systems are component casted. The material is typically produced in accordance with ASTM B 61 for high-grade metal (used in limited steam applications) and for valve-bronze alloys, or with ASTM B 62 for a lesser grade alloy. Configuration and pressure ratings must be specified pursuant to ASME standards.

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 Standardiz ation 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.)

ADSCO Manufacturing LLC, Expansion Joints Catalog 1196, Buffalo, New York, 1996.

American Institute of Steel Construction, Inc., Manual of Steel Construction, 8th Edition, Chicago, Illinois, 1980.

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Dresser Industries, Inc., Style 38 Dresser Couplings for Steel Pipe Sizes, Sizes and Specifications, Form 877-0C, Bradford, Pennsylvania, 1995.

Fibercast Company, Piping Design Manual, FC-680, Sand Springs, Oklahoma, 1995.

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Gardellin, David J., MOYNO® RKL Control Valve Sizing Handbook, Bulletin 250A, Robbins & Myers, Inc., Lumberton, New Jersey, 1982.

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Hydraulic Institute Engineering Data Book, Hydraulic Institute, Cleveland, Ohio.

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Schweitzer, Phillip, A., P.E., Corrosion Resistance Tables, Metals, Nonmetals, Coatings, Mortars, Plastics, Elastomers and Linings, and Fabrics, 4th Edition, Marcel Dekker Inc., New York, 1995.

Spotts, M.F., Design of Machine Elements, 5th Edition, Prentice Hall, 1978.

Worcester Controls, A BTR Company, Series CPT Characterized Seat Control Valve Catalog, PB-V-3, Marlborough, Massachusetts, 1998.

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.

[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

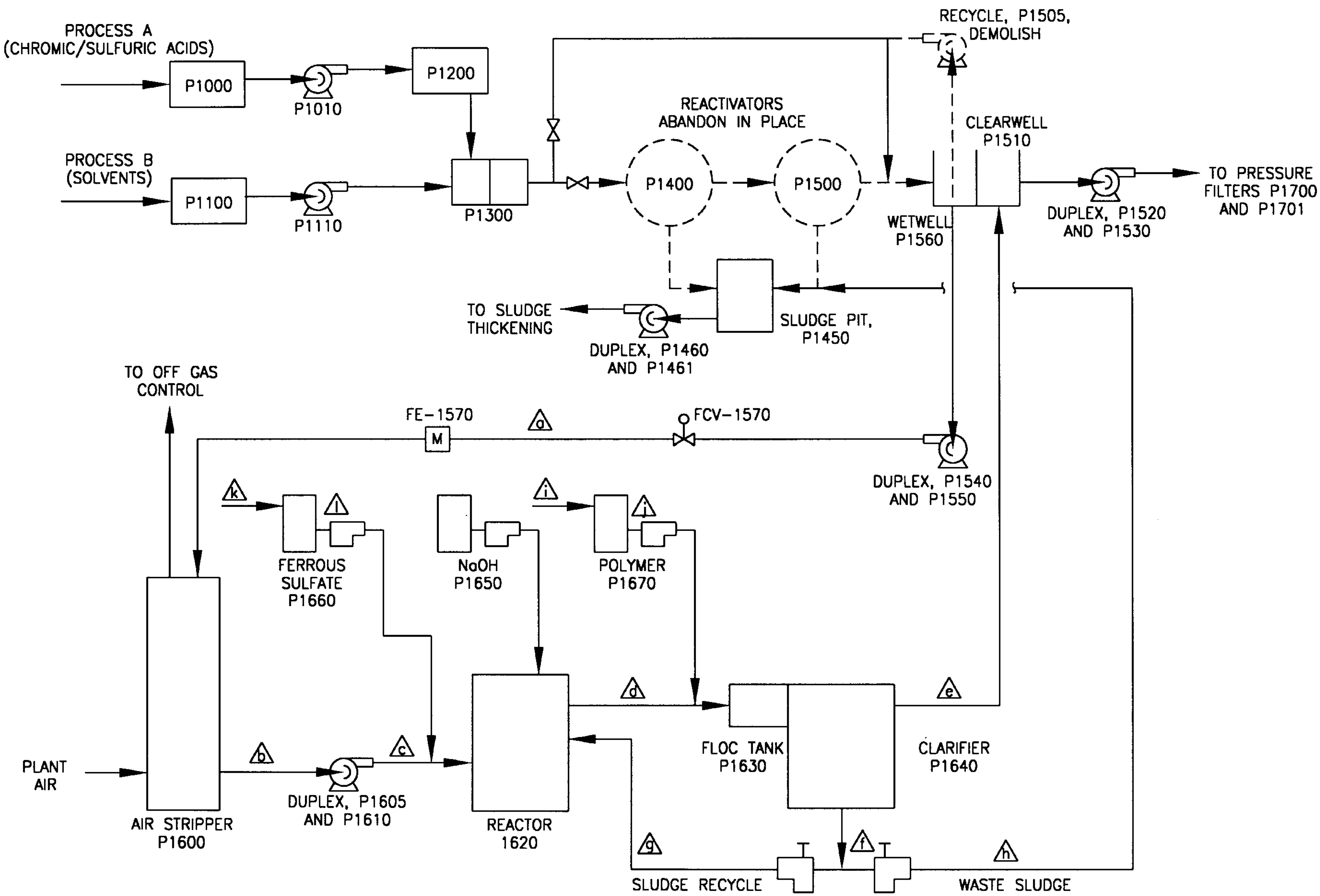


Figure C-1. Design Example Process Flow Diagram
(Process Conditions Table continued on next page)

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

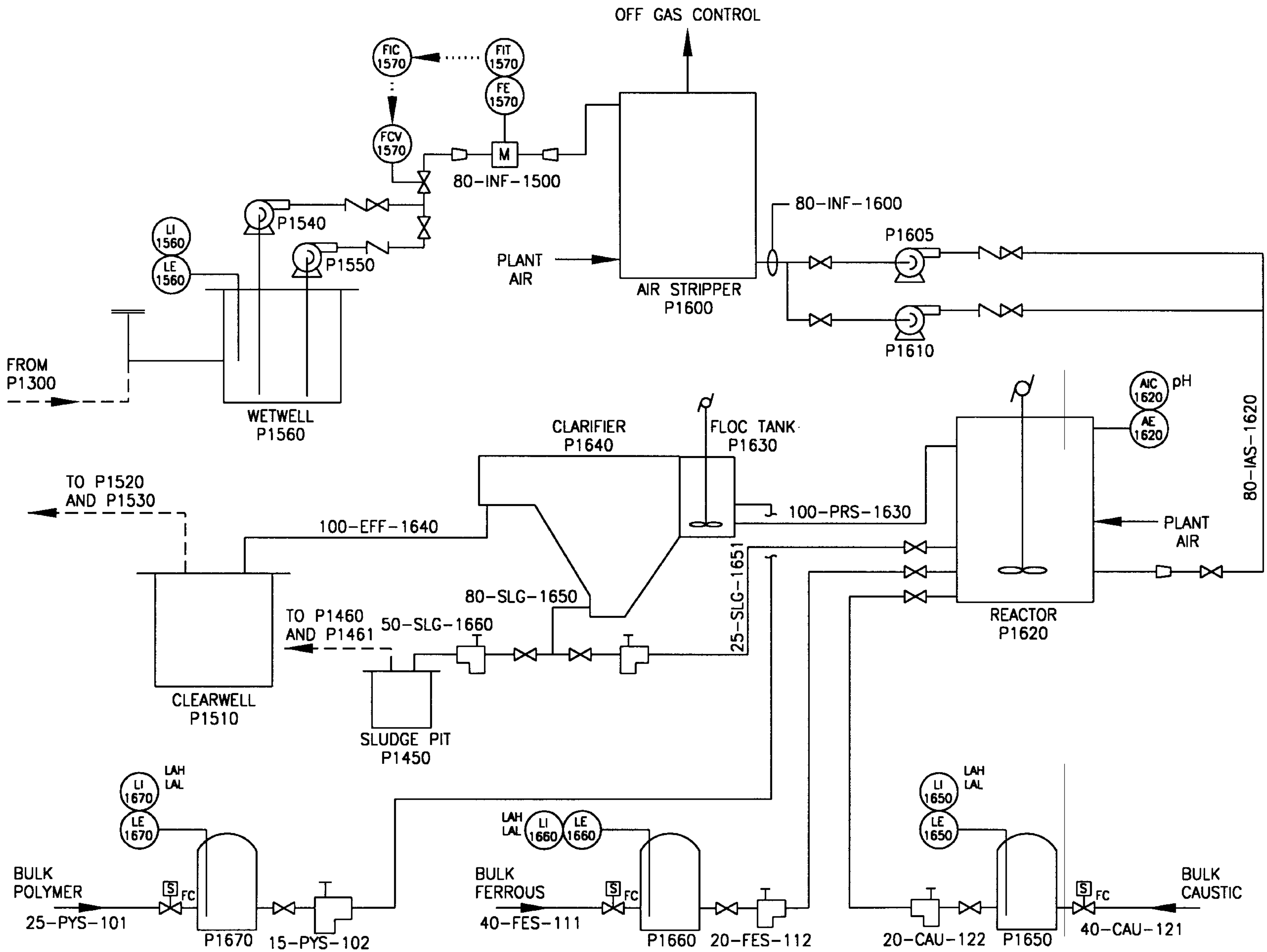


Figure C-2. Design Example Piping and Instrumentation Diagram

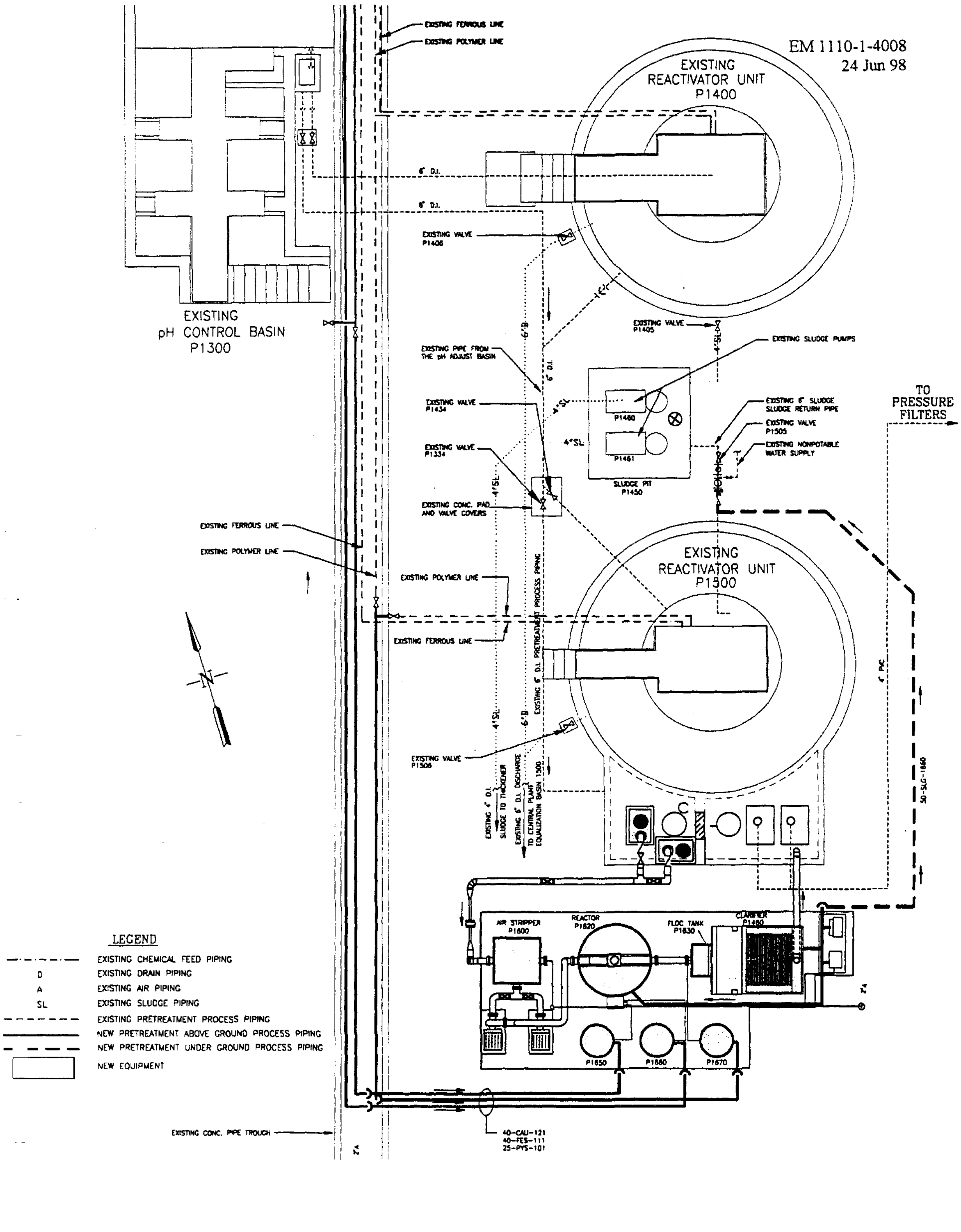
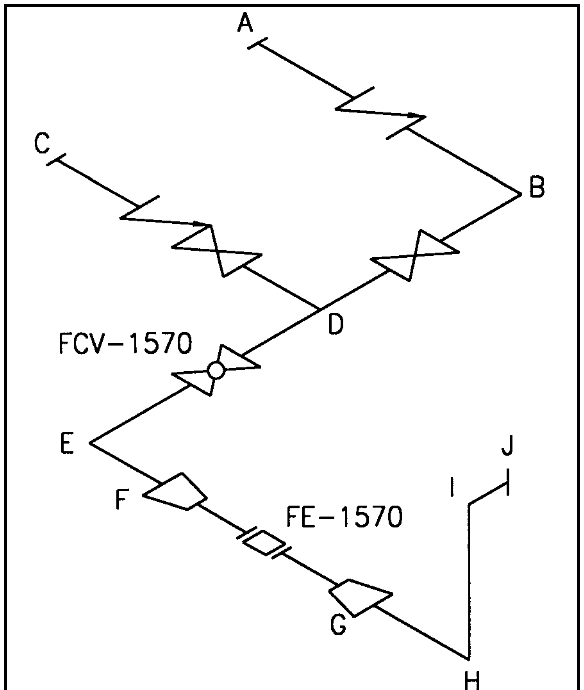


Figure C-3. Piping Layout Plan

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.

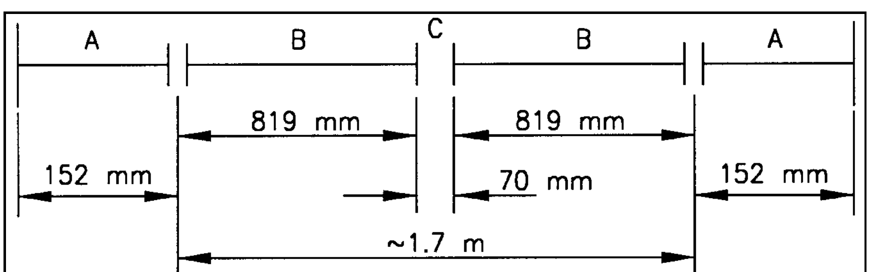
The actual velocity through the reduced section is required for pressure drop calculations. From Table 9-8, a PVDF thickness of 4.07 mm is required to prevent permeation.

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

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

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

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.

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

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

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

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

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	15 (½)	0.02	0.03	0.07	0.12	0.16	0.20	0.24	0.28	0.32	0.36
(0.25), 0.79 (0.0313)	20 (3/4)	0.02	0.03	0.07	0.10	0.14	0.18	0.21	0.25	0.29	0.32
Wide Slot	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	15 (½)	0.02	0.07	0.20	0.33	0.46	0.60	0.73	0.86	0.99	1.10
(0.25), 1.59 (0.0625)	20 (3/4)	0.02	0.06	0.18	0.29	0.41	0.53	0.65	0.77	0.88	0.98
Wide Slot	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),	15 (½)	0.02	0.10	0.20	0.34	0.55	0.83	1.11	1.59	2.08	2.50
6.35 (0.25)	20 (3/4)	0.02	0.09	0.18	0.30	0.49	0.74	0.99	1.41	1.85	2.22
30°V	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),	15 (½)	0.02	0.12	0.33	0.90	0.84	1.35	1.95	3.10	4.37	5.92
6.35 (0.25)	20 (3/4)	0.02	0.10	0.29	0.44	0.75	1.20	1.74	2.76	3.90	5.27
60°V	25 (1)	0.02	0.10	0.27	0.41	0.70	1.12	1.62	2.57	3.63	4.91
25 (1)	25 (1)	0.02	0.21	0.56	0.96	1.58	2.39	3.43	4.62	6.15	7.26
30°V	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)	25 (1)	0.02	0.30	0.78	1.24	2.27	3.59	5.28	8.29	11.6	15.5
60°V	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)	50 (2)	0.02	0.55	1.72	3.41	5.65	8.26	12.1	16.6	22.2	26.5
30°V	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)	50 (2)	0.02	0.70	2.64	4.90	9.32	15.5	22.2	32.1	47.2	61.6
60°V	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)	80 (3)	0.02	0.75	2.68	6.00	10.2	16.9	24.5	33.9	44.8	54.2
30°V	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)	80 (3)	0.02	0.95	4.25	10.1	18.6	29.4	46.3	**67.2**	94.4	124.6
60°V	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)	100 (4)	0.02	0.80	3.59	8.50	16.1	26.8	40.2	56.6	72.5	89.8
30°V	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)	0.02	0.90	5.69	15.4	28.8	48.6	73.4	107.0	150.7	200.0
100 (4)	150 (6)	0.02	0.59	3.70	10.0	18.7	31.6	47.7	69.6	98.0	130.0
60°V	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.

$$W = W_P + W_L = A_P\ \rho_P + \frac{\pi}{4}\ D_i^2\ \rho_L$$

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

80 mm pipe:

$$W_{80} = 133\ N/m + \frac{\pi}{4}\ 71.1\ mm^2\ (9781\ N/m^3)\ x\ (10^{-6} m^2/mm^2) = 172\ N/m;\ uniformly\ distributed$$

40 mm pipe:

$$W_{40} = 67.1\ N/m + \frac{\pi}{4}\ 31.9\ mm^2\ (9781\ N/m^3)\ x\ (10^{-6} m^2/mm^2) = 74.9\ N/m;\ uniformly\ distributed$$

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.

$$F_{W80} = C_{W1}\ V_W^2\ C_D\ D_o = (2.543 x 10^{-6})(53.5\ m/s)^2(1.21)[90\ mm + 2(0)] = 0.79\ N/m$$

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.

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

$$= (2.543 x 10^{-6})(53.5\ m/s)^2(1.21)[50\ mm + 2(0)]$$

$$= 0.44\ N/m$$

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.

$$W_{s80} = ½\ n\ D_o\ S_L$$

$$= ½\ (10^{-3}\ m/mm)\ [90\ mm + 2(0)]\ (239\ kPa)$$

$$= 10.8\ N/m$$

40 mm pipe:

Ref. p. 2-8.

$$W_{s40} = ½\ n\ D_o\ S_L$$

$$= ½\ (10^{-3}\ m/mm)\ [50\ mm + 2(0)]\ (239\ kPa)$$

$$= 5.98\ N/m$$

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 x 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:

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

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, $\Sigma S_L \leq S_h$; 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, $\Sigma S'_L \leq 1.33 S_h$; 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.

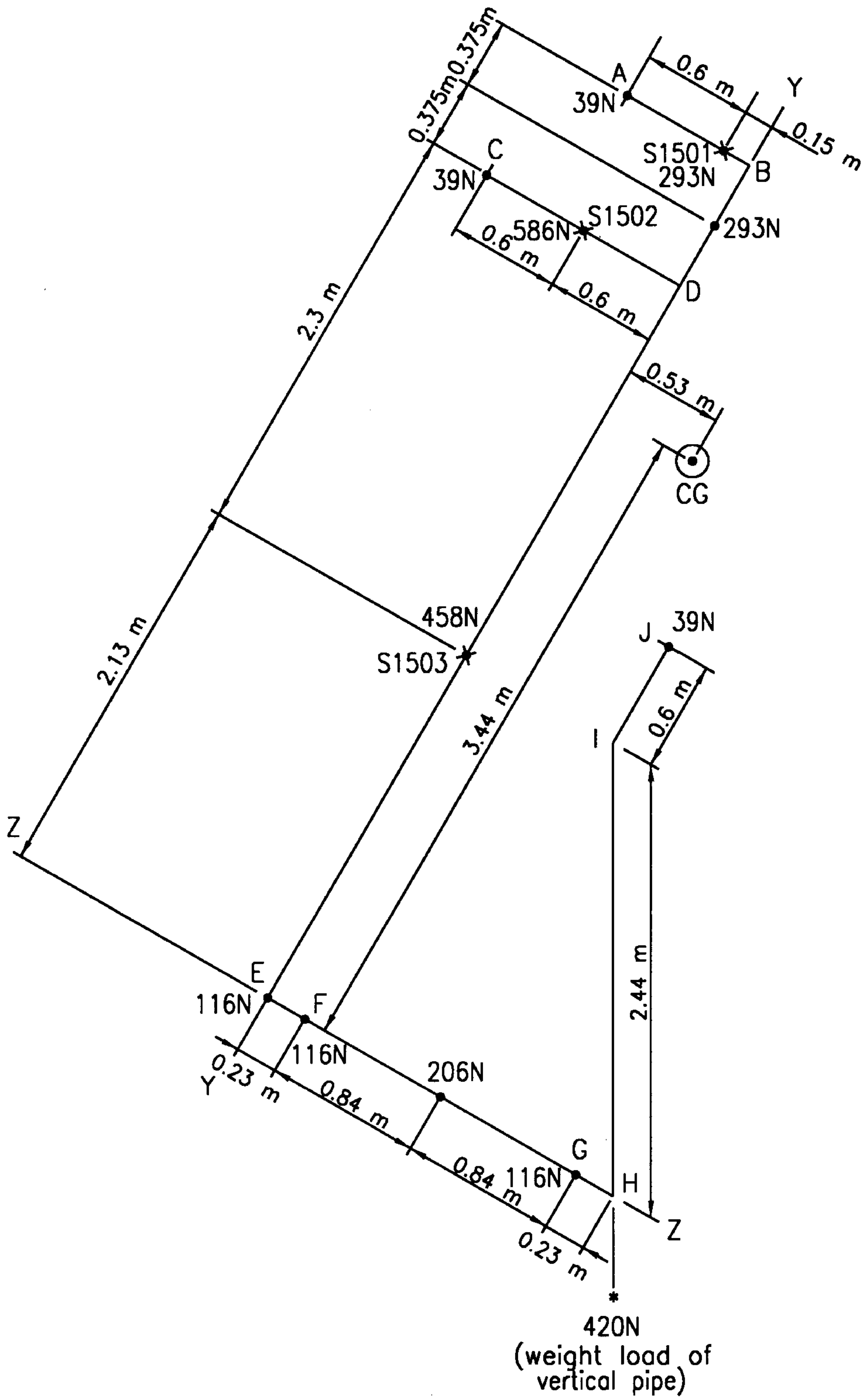
Ref. p. 3-18.

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

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

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

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
2.13 m
3.44 m
J
39N
0.6 m
I
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

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

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

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
$n = 10^{-9}\ m^3/mm^3$
$E = 2.03 \times 10^5$ MPa (reference ASME B31.3, Table C-6)

$$I = \frac{\pi}{64}\left[(D_o)^4 - (D_i)^4\right]$$
$$= \frac{\pi}{64}\left[(90\ mm)^4 - (80\ mm)^4\right]$$
$$= 1.21\ x\ 10^6\ mm^4$$

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.

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

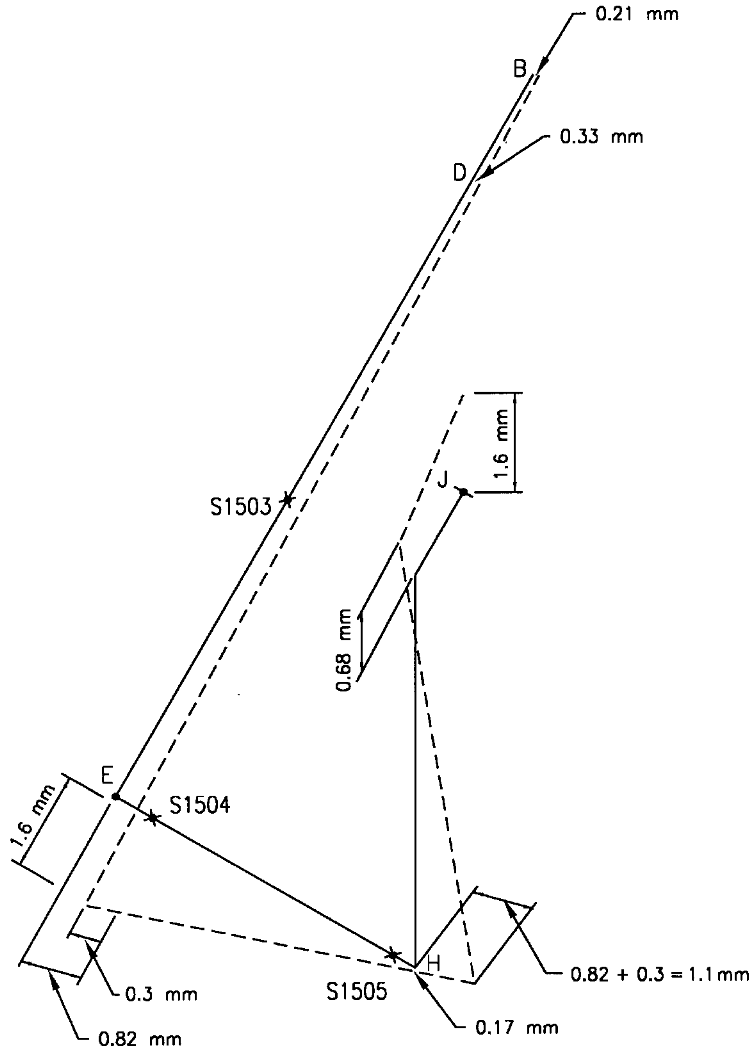
Ref. p. 3-18.

$$S_b = \frac{\left[(i_i\ M_i)^2 + (i_o\ M_o)^2\right]^{0.5}}{Z\ n};\ and$$

$$S_t = \frac{M_t}{2\ Z\ n}$$

where:
$M_o = 0$
$i_i = i_o = 1.0$
$Z = 2.69 \times 10^4\ mm^3$ (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

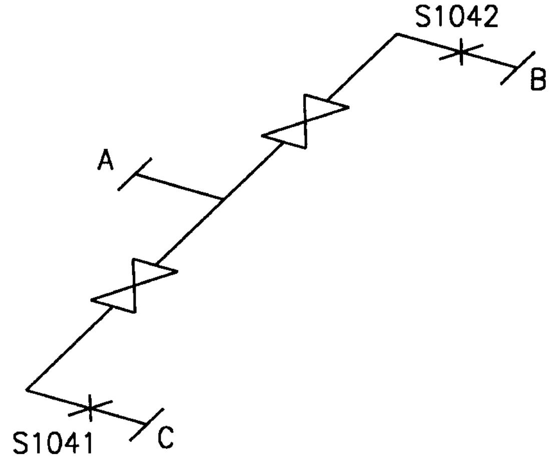
FLANGE CONNECTIONS

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.

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, $Q = 5.36 \times 10^{-3}$ 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 x 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, ν = 8.94 x 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.

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

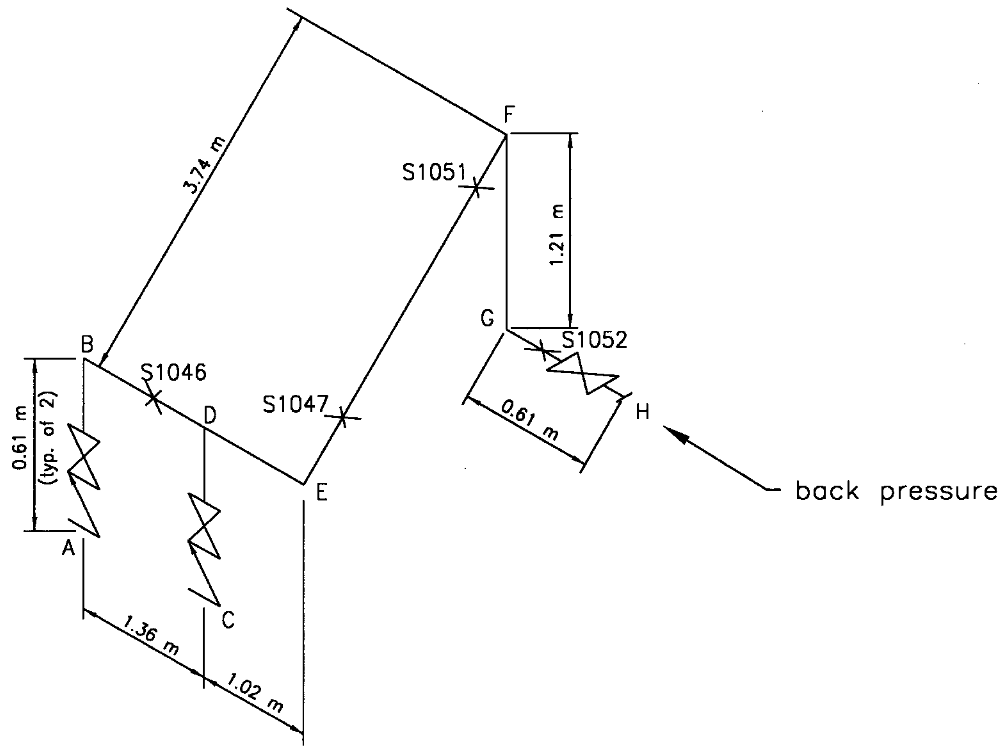
Ref. p. 3-8.

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

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

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

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



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
Σ 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.

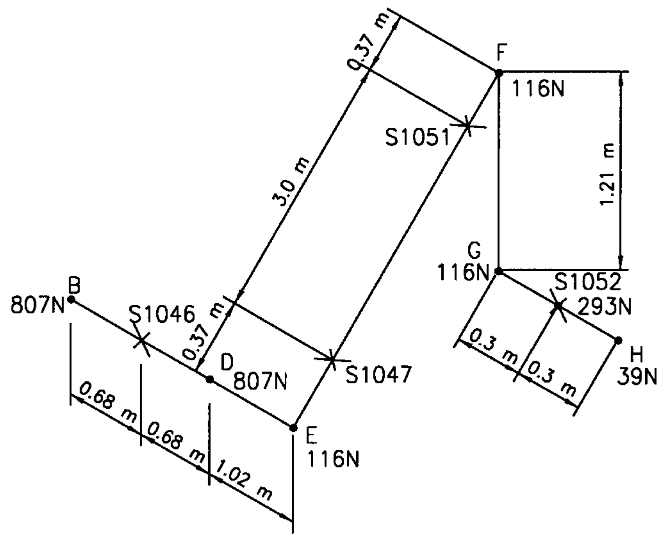
The thermal expansion deflections are determined based on: 1) the assumption that no substantial movement of the flange mating at point H will occur when operating conditions are established; 2) the flanges at points A and C mate with pumps and are not subject to movements; 3) support S1052, will prevent 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:

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

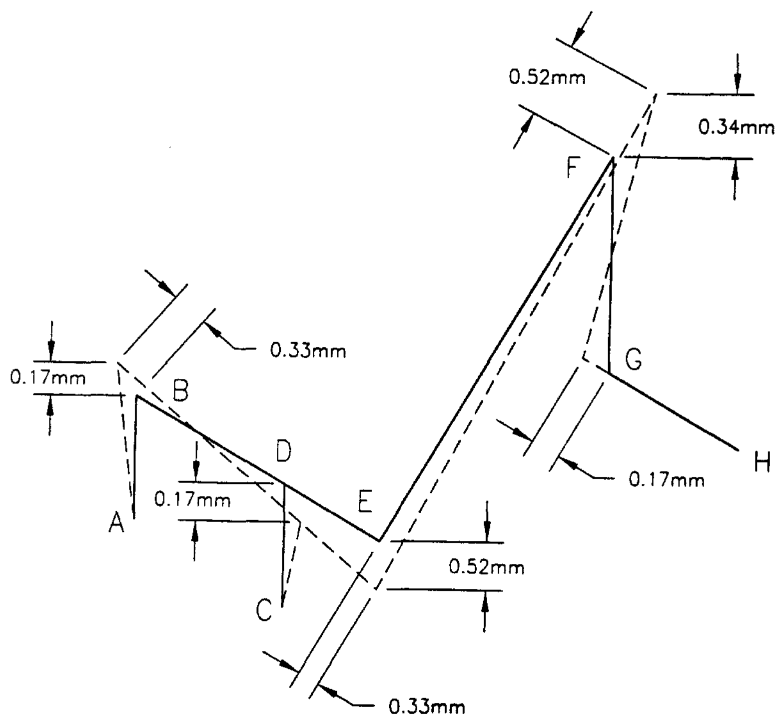
$$x\ (1{,}000\ mm/m)(46°C - 21°C) = 0.278\ mm/m$$

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.

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 x 10^{-3} m^3/s

Total run = 22.0 m
= 20.3 m below grade

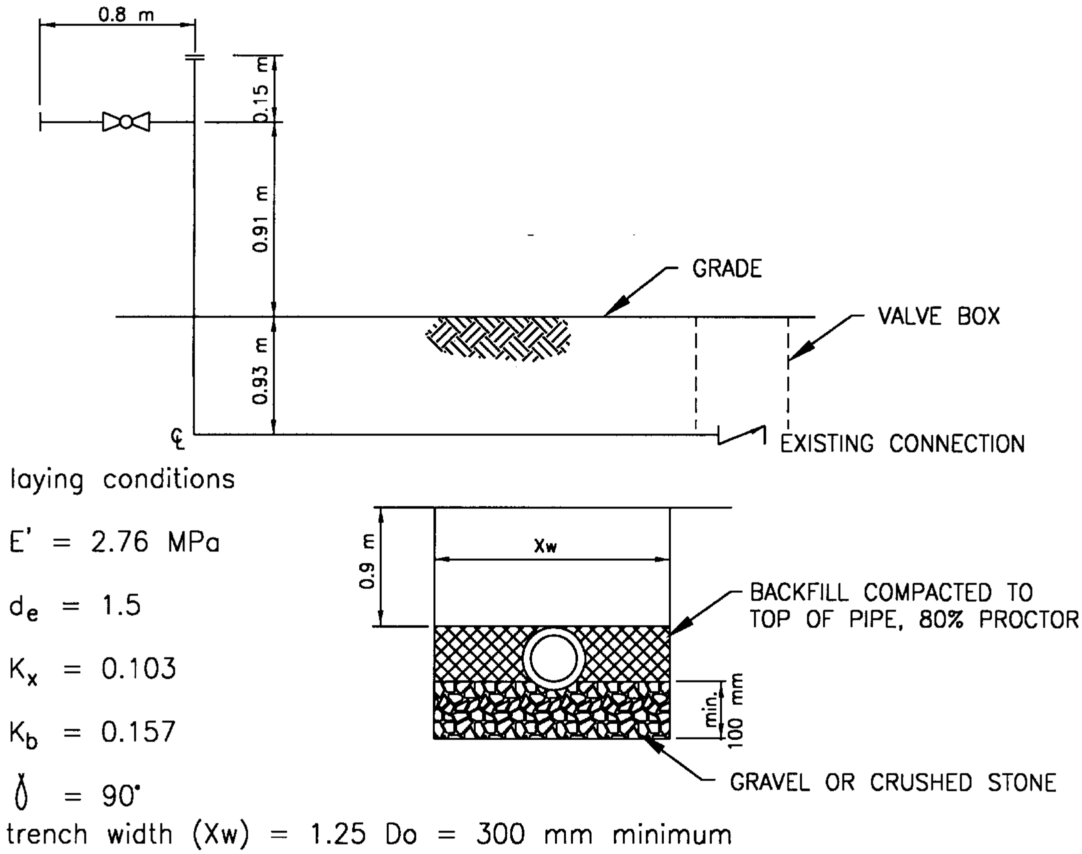
Buried depth = 0.9 m, t.o.p.

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

Ref. p. 3-8.

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

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.

$$F_E = \frac{w\,H}{a} = \frac{(1{,}922\ kg/m^3)(0.9\ m)}{\left(102\ \frac{kg/m^2}{kPa}\right)} = 17.0\ kPa$$

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).

$$T = 2\ \pi \left(\frac{D_o}{2}\right)^2 P\ \sin\left(\frac{\Delta}{2}\right)$$

where:

T = thrust generated, N
D_o = outer diameter of pipe, mm
P = design pressure, MPa
Δ = 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:

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} D_i^2} = \frac{4.38 \ x \ 10^{-4} m^3/s}{\frac{\pi}{4} \ (0.0243 \ m)^2}$$

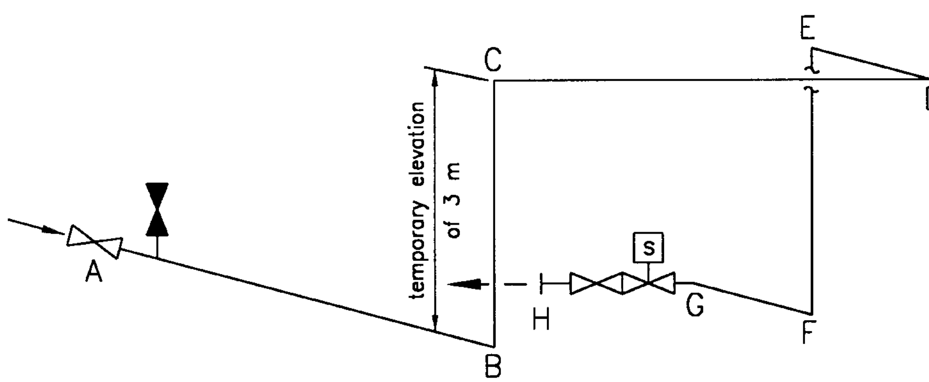
$$= 0.94 \ m/s$$

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 t_c = 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.

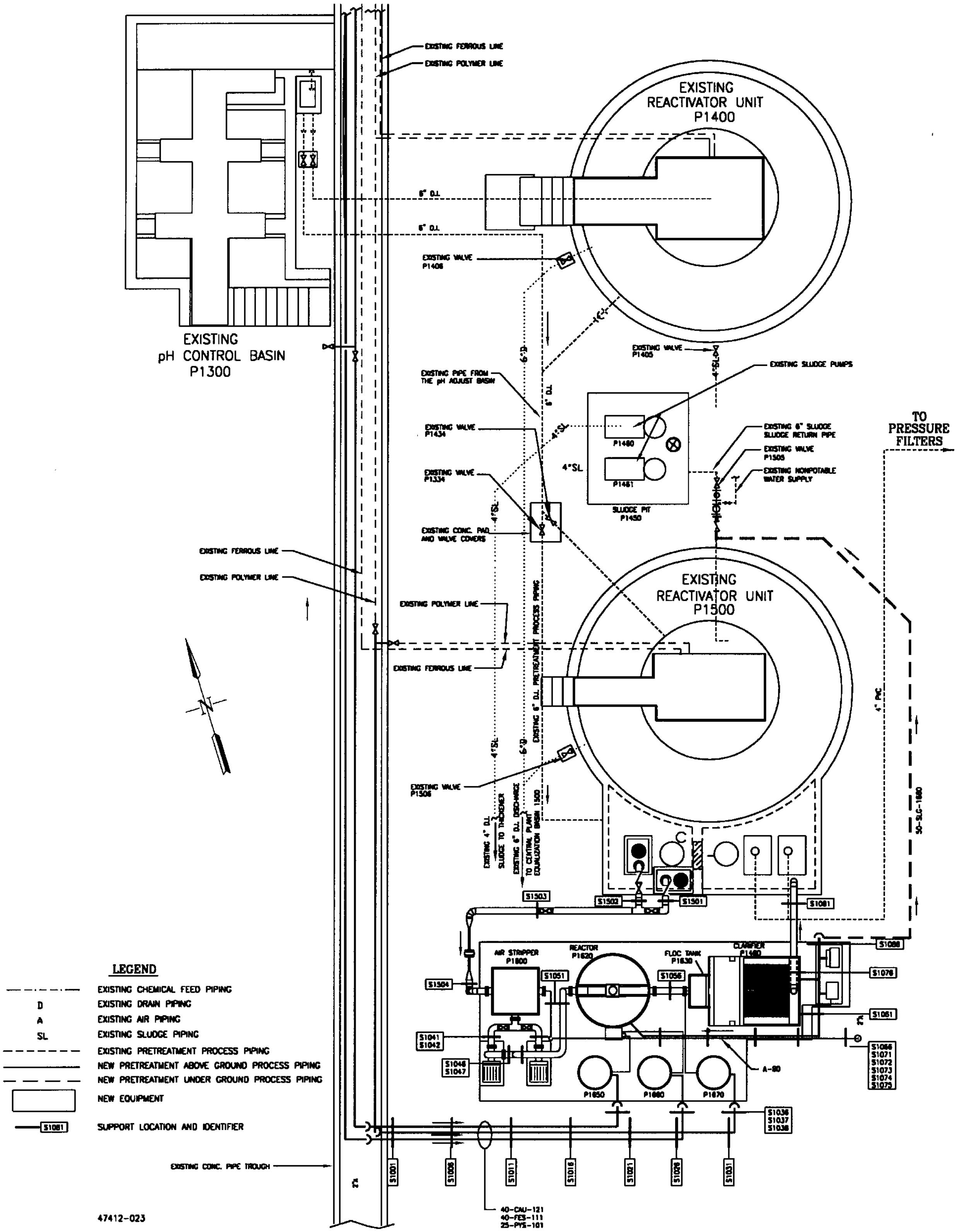
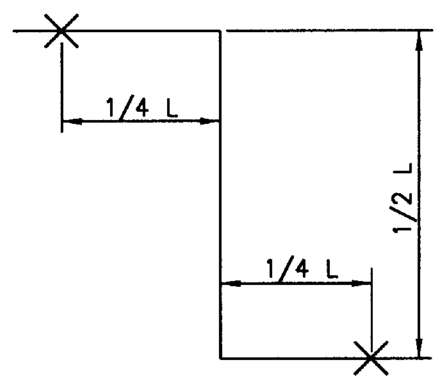


Figure C-4. Piping Layout Plan with Support Locations

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:

$$L = \frac{1\ m}{1{,}000\ mm}\left(\frac{3\ E\ D_o\ e}{S}\right)^{0.5}$$

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:

$$L_{ABCD} = \frac{1\ m}{1{,}000\ mm}\ x$$

$$\left(\frac{3(2{,}895MPa)(32mm)[(2.43x10^{-3}\frac{mm}{mm})(3{,}000mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.38\ m,\ minimum.$$

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:

$$L_{EFGH} = \frac{1\ m}{1,000\ mm} \times \left(\frac{3(2,895 MPa)(32 mm)[(2.43x10^{-3} \frac{mm}{mm})(1,500 mm)]}{13.8 MPa} \right)^{0.5}$$

$$= 0.27\ m,\ minimum.$$

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:

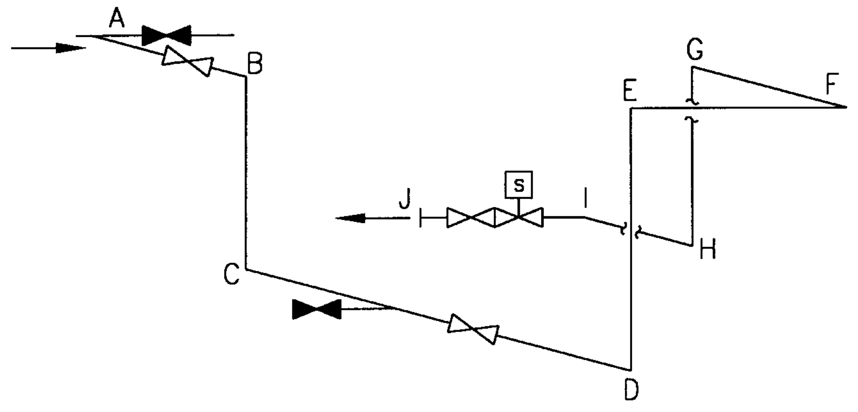
Ferrous sulfate demand = 0.757 m^3/day; therefore, assuming a 15 minute fill the maximum flow rate, Q = 5.05 x 10^{-2} m^3/min = 8.42 x 10^{-4} m^3/s

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:

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

$$= \frac{8.42 \times 10^{-4}\ m^3/s}{\frac{\pi}{4}(0.040\ m)^2} = 0.67\ m/s$$

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, $\nu = 1.05 \times 10^{-6}\ m^2/s$ 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.

$$R_e = \frac{D_i\,V}{\nu} = \frac{(0.040\ m)(0.67\ m/s)}{1.05 \times 10^{-6}\ m^2/s}$$

$$= 2.55 \times 10^4 \rightarrow turbulent\ flow$$

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

$$\epsilon/D_i = \frac{0.0015\ mm}{40\ mm} = 0.00004$$

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.

$$W_s = \tfrac{1}{2} \; n \; D_o \; S_L =$$
$$\tfrac{1}{2} \; (10^{-3} m/mm)[50 \; mm + 2(9.525 \; mm)](239 \; kPa)$$
$$= 8.25 \; N/m$$

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.

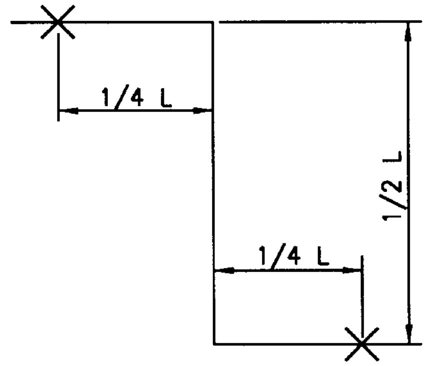
Ref. p. 3-17.

$$\Sigma S_L = (0.1) \frac{[27.4\ N/m + 28.2\ N/m](1.7\ m)^2}{(10^{-3}\ m/mm)(7{,}245\ mm^3)}$$

$$= 2.26\ MPa$$

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:

$$L = \frac{1\ m}{1{,}000\ mm} \left(\frac{3\ E\ D_o\ \varepsilon}{S} \right)^{0.5}$$

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:

$$L_{ABCD} = \frac{1\ m}{1{,}000\ mm}\ x \left(\frac{3(2{,}895MPa)(50mm)[(2.43x10^{-3}\frac{mm}{mm})(3{,}500mm)]}{13.8MPa}\right)^{0.5}$$

$$= 0.52\ m,\ minimum.$$

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.