Fundamentals of Liquid Process Piping Part 1

Florida Board of Professional Engineers

Approved Course No. 0010329

4 PDH Hours

A test is provided to assess your comprehension of the course material – 24 questions have been chosen from each of the above sections. You will need to answer at least 17 out of 24 questions correctly (>70%) in order to pass the overall course. You can review the course material and re-take the test if needed.

You are required to review each section of the course in its entirety. Because this course information is part of your Professional Licensure requirements it is important that your knowledge of the course contents and your ability to pass the test is based on your individual efforts.

Course Description:

This course material is based entirely on a design guide issued by the US Army Corps of Engineers (USACE). The course is Part 1 of 2 and covers Chapters 1 through 5 of the USACE Liquid Process Piping Engineering and Design manual. Part 2 covers Chapters 6 through 12. The courses closely follow American Society of Mechanical Engineers, ASME B31, which is the most commonly internationally used code for the Process industry.

In Part 1 - the course will cover the basic principles and guidance for design of liquid process piping systems, engineering calculations and requirements for all piping systems, basics of metal piping systems and thermoplastic piping systems.

In Part 2 - the course will continue from Part 1 and review the basics of Rubber and Elastomer Piping Systems, Thermoset Piping Systems, Double Containment Piping Systems, lined pipe systems, valves, and ancillary equipment.

How to reach Us …

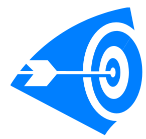
If you have any questions regarding this course or any of the content contained herein you are encouraged to contact us at Easy-PDH.com. Our normal business hours are Monday through Friday, 10:00 AM to 4:00 PM; any inquiries will be answered within 2 days or less. Contact us by:

EMAIL: bajohnstonpe@aol.com
Phone: 888-418-2844 (toll free)
FAX: 813-909-8643

Refer to Course No. 0010329,

Fundamentals of Liquid Process Piping Part 1

How the Course Works…

What do you want To do?	LOOK For This!
 **Search for Test Questions and the relevant review section**	 **Q1** **Search the PDF for: Q1 for Question 1, Q2 for Question 2, Q3 for Question 3, Etc…** **(Look for the icon on the left to keep you ON Target!)**

Easy-PDH.com (FBPE Approved Provider 442)
Britian Arthur Johnston PE (50603)
Johnston Service Corp
CA No. 30074
11909 Riverhills Drive, Tampa FL 33617
Email: bajohnstonpe@aol.com
Toll Free: 888-418-2844 FAX: 813-909-8643

24 QUESTIONS

Q1: Liquid process piping systems include all pipe and appurtenances which are used to:

(A) convey liquids to storage units
(B) convey liquids from storage units
(C) convey liquids to and from treatment units
(D) All of the Above

Q2: With a 4 inch ANSI Nominal Pipe size the actual pipe diameter is:

(A) 4.00 inches
(B) 4.25 inches
(C) 4.33 inches
(D) 4.50 inches

Q3: In system design, the system description contains all of the following EXCEPT:

(A) system design basis
(B) operating modes
(C) piping specifications
(D) control concepts

Q4: Piping and Instrument Diagrams include all of the following EXCEPT:

(A) Direction of Flow
(B) min, max, and average flows
(C) interconnections
(D) class changes

Q5: Soils which contain organic or carbonaceous matter such as WHAT are highly corrosive to buried pipes:

(A) coke
(B) coal
(C) caustic
(D) A and B

Q6: Transient pressure conditions can be disregarded and the design pressure maintained if:

(A) the transient exceeds the design pressure by less than 10 percent
(B) the transient temperature does not change
(C) the transient occurs for less than 10 percent of the total operating time
(D) A and C

Q7: Flexible pipe connections should have a length of:

(A) 2 to 3 times the pipe diameter
(B) 4 to 6 times the pipe diameter
(C) 6 to 10 times the pipe diameter
(D) 10 to 12 times the pipe diameter

Q8: Control valves should be installed with a minimum of how many pipe diameters upstream and downstream of the valve:

(A) 2
(B) 3
(C) 6
(D) 8

Q9: The hardness of a material is a measure of its ability to:

(A) resist cracking
(B) resist elongation
(C) resist deformation
(D) resist collapsing

Q10: For normal liquid service applications, the acceptable velocity in pipes is 7 feet per second:

(A) plus 3 feet per second
(B) minus 3 feet per second
(C) plus 4 feet per second
(D) A and B

Q11: The Reynolds number is proportionate to:

(A) the diameter of the pipe
(B) the velocity of the fluid through the pipe
(C) the fluid kinematic viscosity
(D) All of the Above

Q12: Ductile Iron has a Pipe Material Roughness Coefficients of:

(A) 0.0002 inches
(B) 0.0004 inches
(C) .002 inches
(D) .000005 inches

Q13: Once system operating conditions have been established, the minimum wall thickness of process piping is determined based on:

(A) corrosion allowances
(B) pressure integrity requirements
(C) company standards
(D) All of the Above

Q14: Of the 7 pressure classes for flanges in ASME B16.5, what is the next class above class 300:

(A) 400
(B) 500
(C) 600
(D) 900

Q15: Composition gaskets have an initial gasket compression value of:

(A) 27.6 to 41.4 psi
(B) 82.7 to 124 psi
(C) 207 psi
(D) 207 to 414 psi

Q16: Typically, a deflection of WHAT is allowed in process piping systems:

(A) 0.10 inches
(B) 0.25 inches
(C) 0.35 inches
(D) 0.50 inches

Q17: The selection of pipe support types is dependent on ALL of the following criteria EXCEPT:

(A) temperature rating of the system
(B) pressure rating of the system
(C) the mechanism by which the pipe attaches to the support
(D) attachment of the support to the building or other structures

Q18: For a Hydrostatic Leak Test the test pressure must be greater than or equal to:

(A) 1.0 times the design pressure
(B) 1.25 times the design pressure
(C) 1.50 times the design pressure
(D) 2.0 times the design pressure

Q19: Corrosion occurs by what process:

(A) photochemical
(B) electrochemical
(C) electromechanical
(D) electrophysical

Q20: The Stress-corrosion cracking is best described as a crack that is:

(A) initiated and propagated by the combined effect of a surface tensile stress and the environment
(B) initiated and propagated by the combined effect of a surface yield stress and the environment
(C) initiated and propagated by the combined effect of corrosion and the environment
(D) initiated and propagated by the combined effect of fluid flow and the environment

Q21: **Refer to Table 4-4, the maximum support spacing for an 8 inch pipe of any material is:**

(A) 16 feet
(B) 17
(C) 18 feet
(D) 19 feet

Q22: **What is the primary additive in Stainless Steel that makes it a highly corrosion resistant Alloy:**

(A) molybdenum
(B) chromium
(C) nickel
(D) manganese

Q23: **The chemical name for the thermoplastic material abbreviation PTFE is:**

(A) Polytetrafluoroethylene
(B) Polytitanfluoroethylene
(C) Polytitanfluoroethane
(D) Polytetrafluoroethane

Q24: **Refer to Table 5-4, comparing the MAXIMUM support spacing allowed for a 10 inch SCH 80 PVC pipe operating at 60 F or 140 F what happens to the MAXIMUM support spacing allowed:**

(A) 4 feet longer at 60 F
(B) 4 feet shorter at 60 F
(C) 6 feet longer at 60 F
(D) 6 feet shorter at 60 F

END OF TEST QUESTIONS

EM 1110-1-4008
5 May 1999

US Army Corps
of Engineers

ENGINEERING AND DESIGN

Liquid Process Piping

ENGINEER MANUAL

Chapter 1
Introduction

1-1. Purpose

This United States Army Corps of Engineers (USACE) Engineer Manual (EM) 1110-1-4008 provides information for the design of liquid process piping systems.

1-2. Applicability

Q1

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.

Q2

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.

Q3

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.

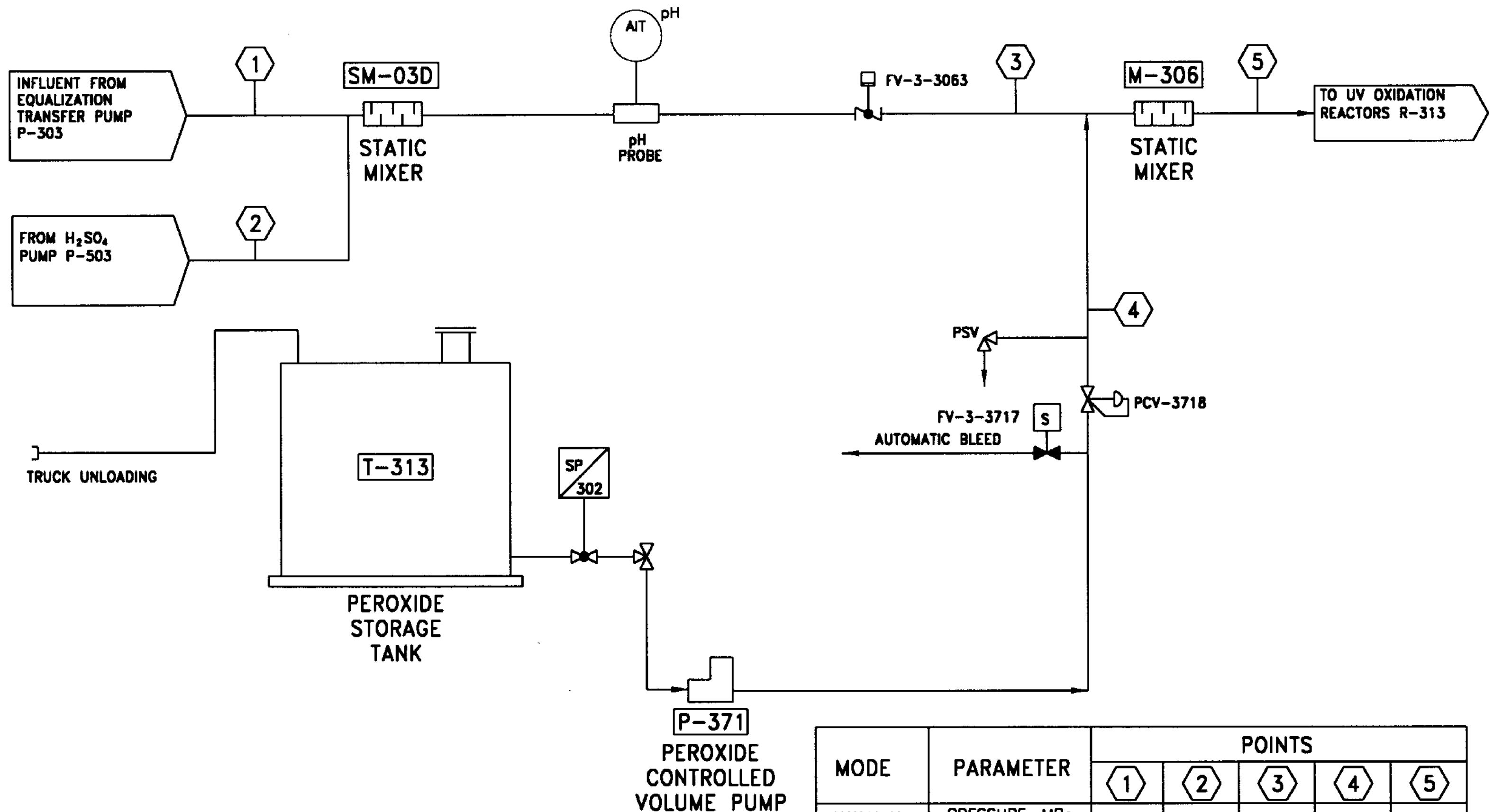
Table 2-3 P&IDs
1. Mechanical Equipment, Names and Numbers
2. All Valves and Identification
3. Instrumentation and Designations
4. All Process Piping, Sizes and Identification
5. Miscellaneous Appurtenances including Vents, Drains, Special Fittings, Sampling Lines, Reducers and Increasers
6. Direction 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.)

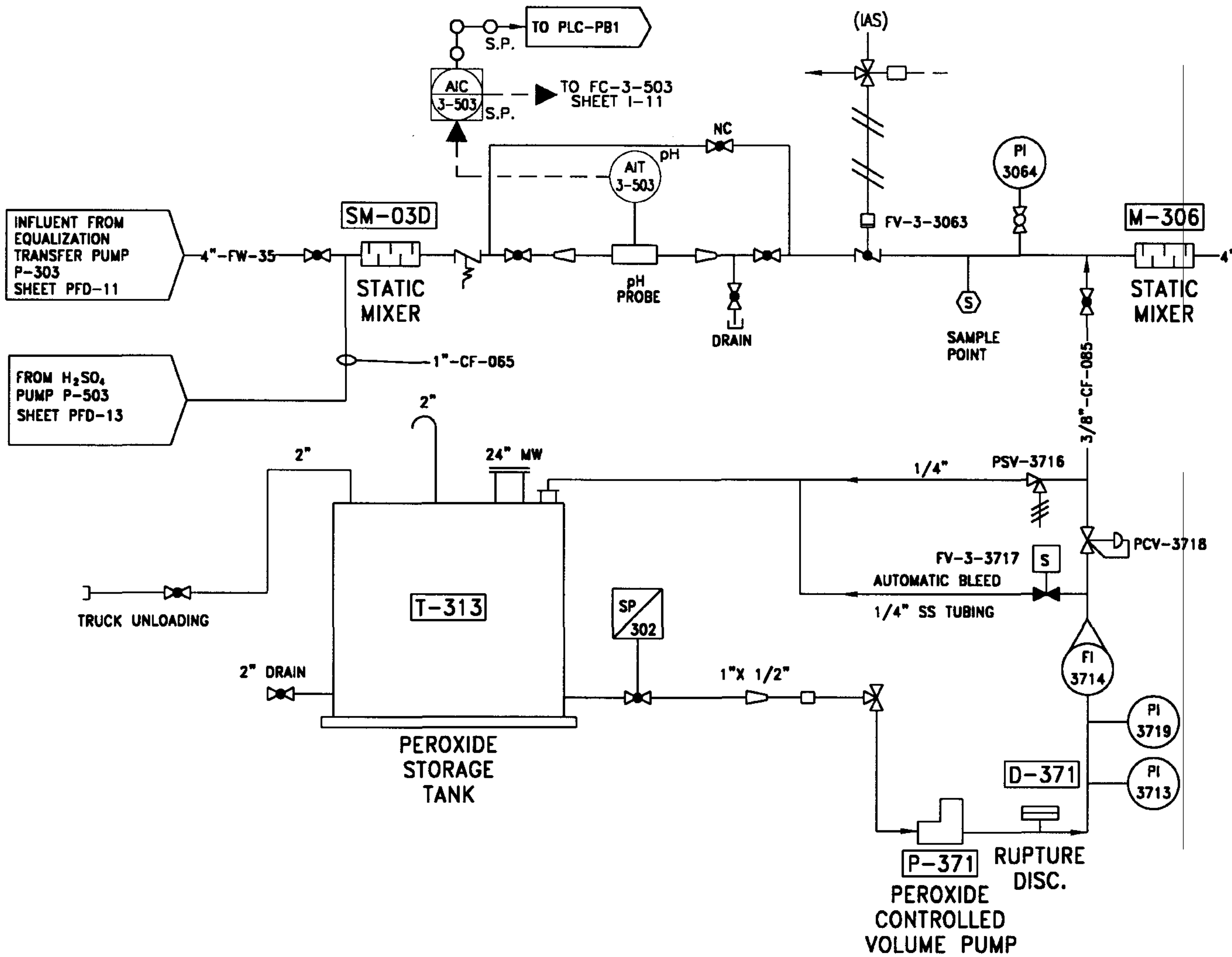


Figure 2-2. Piping and Instrumentation Diagram (P&ID)
(Source: SAIC, 1998.)

Q5

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.

Q6

(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]

$$F_E = \frac{T\,H}{a}$$

where:

F_E = earth load, kPa (psi)
T= 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.

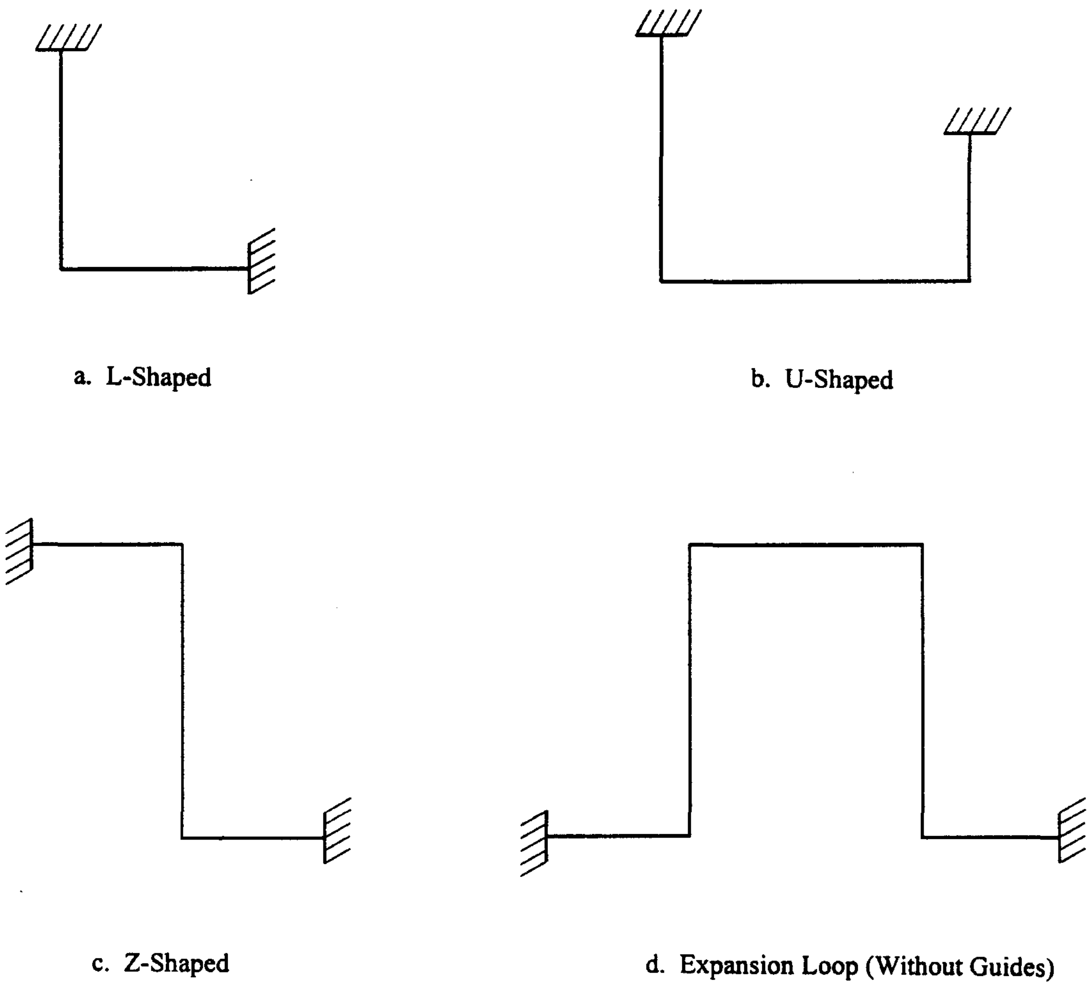


Figure 2-3. Flexibility Arrangements
(Source: SAIC, 1998.)

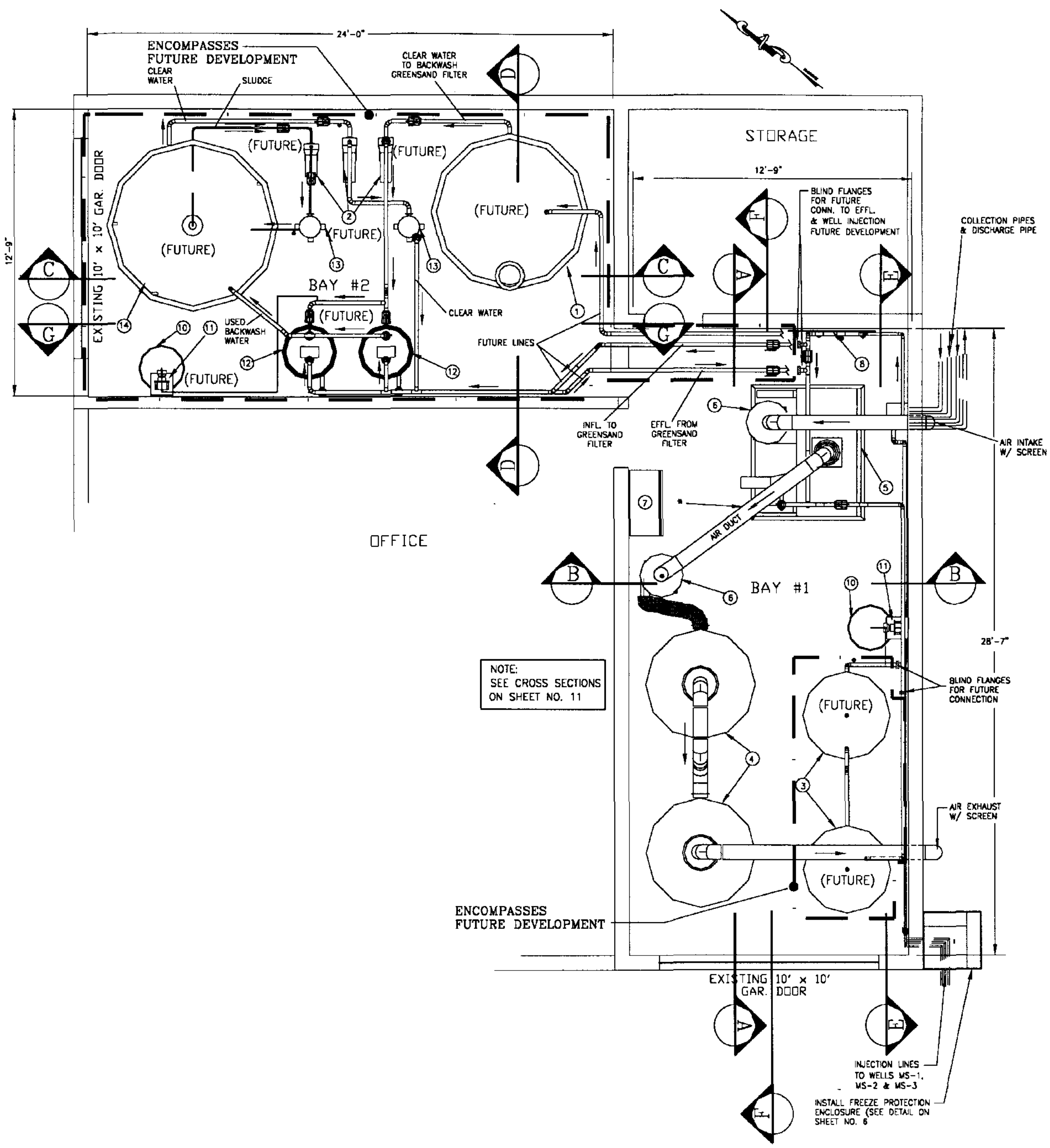


Figure 2-4. Remediation Process Piping Plan
(Source: SAIC, 1998.)

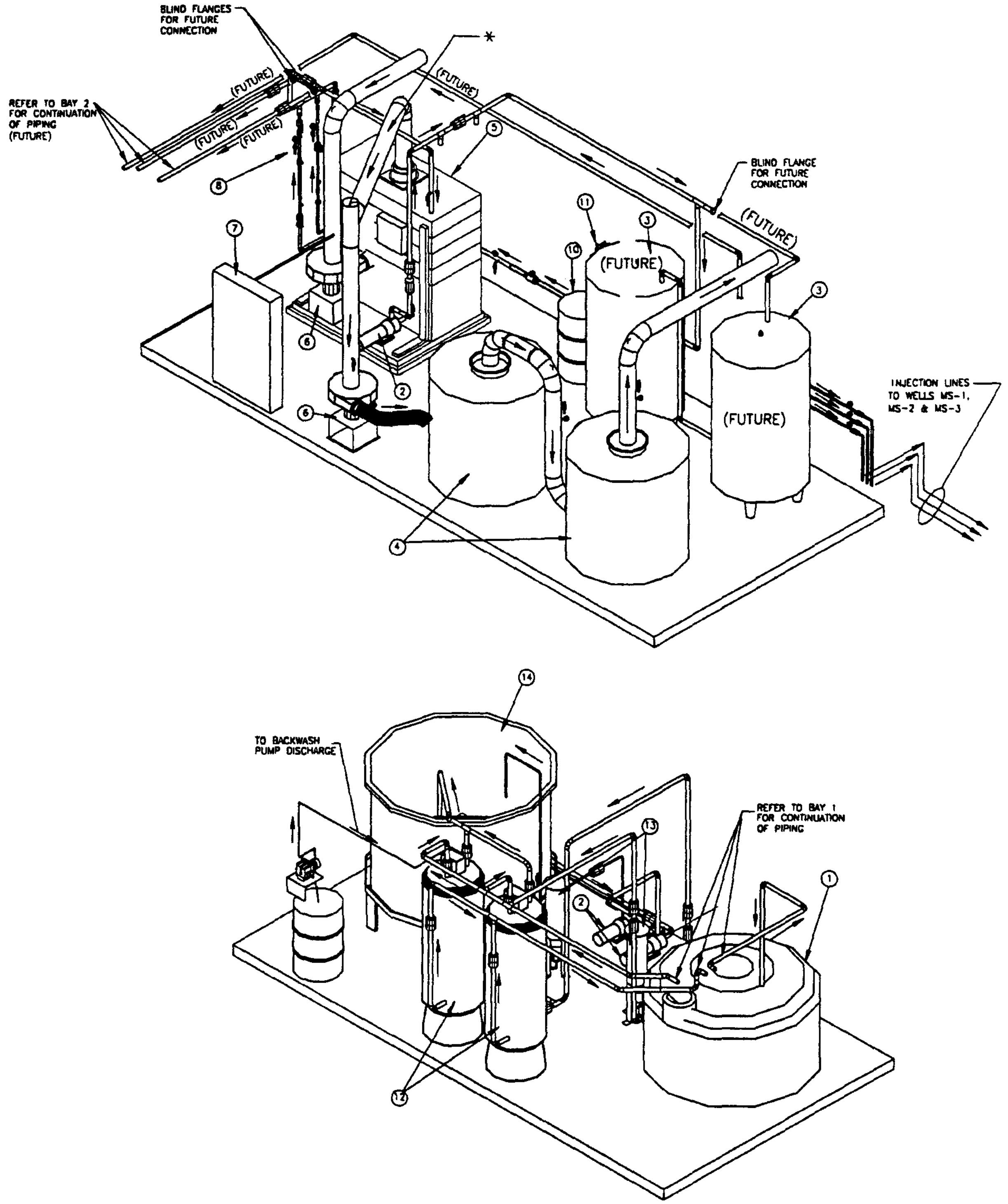


Figure 2-5. Isometric View
(Source: SAIC, 1998.)

Q8

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.

Q9

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.

---

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:

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

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

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

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:

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

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)

[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. Q10

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)

Q11

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)

Q12

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.

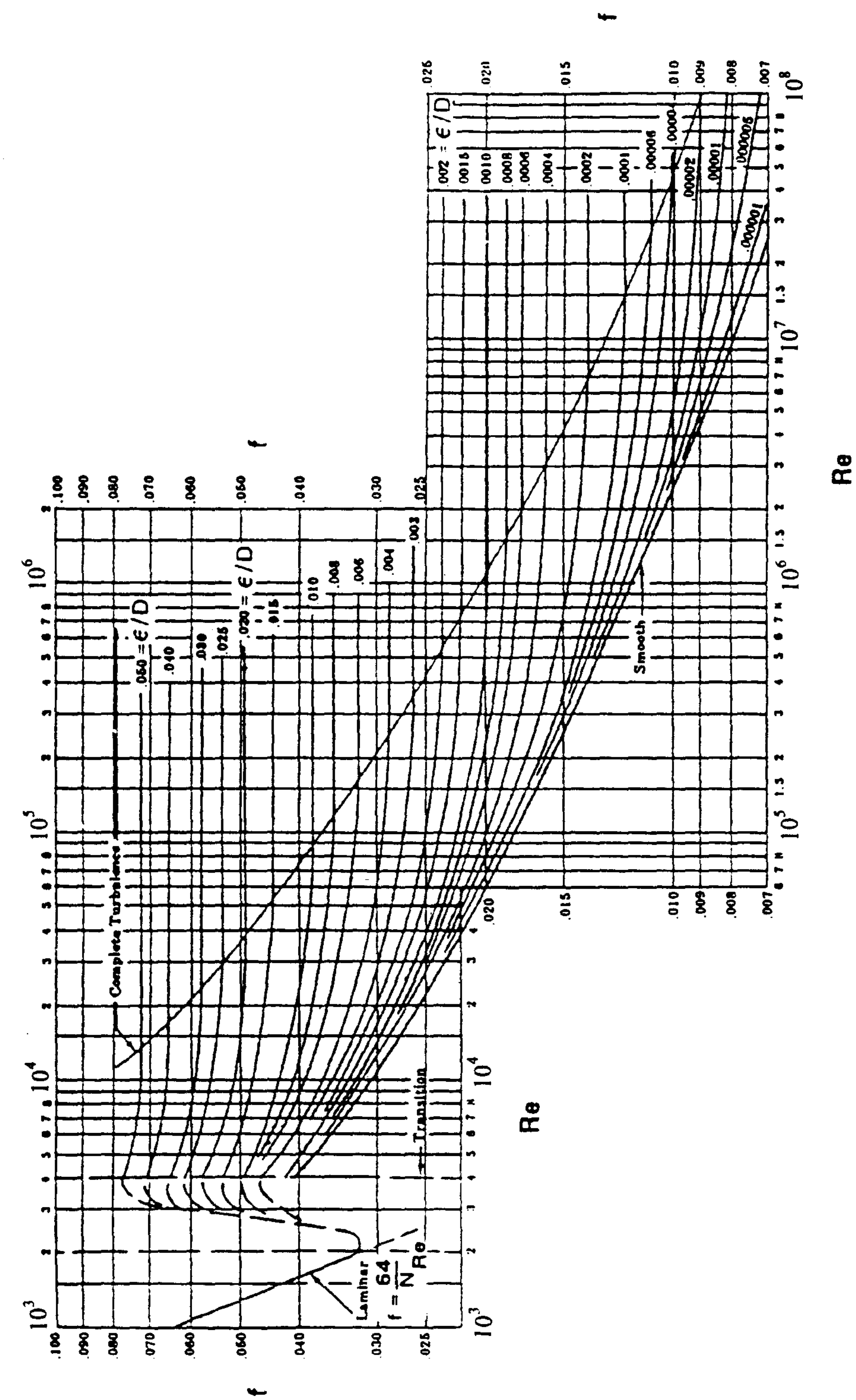


Figure 3-1. Moody Diagram
(Source: L.F. Moody, "Friction Factors for Pipe Flow," Transactions of the ASME, Vol. 66, Nov. 1944, pp. 671-678, Reprinted by permission of ASME.)

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, ν = 8.94 x 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.

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

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

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

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

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.

Q13

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.

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

$$\sum S'_L \leq 1.33\ S_h$$

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.

Q15

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)

---

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.

Q16

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

Q17

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.

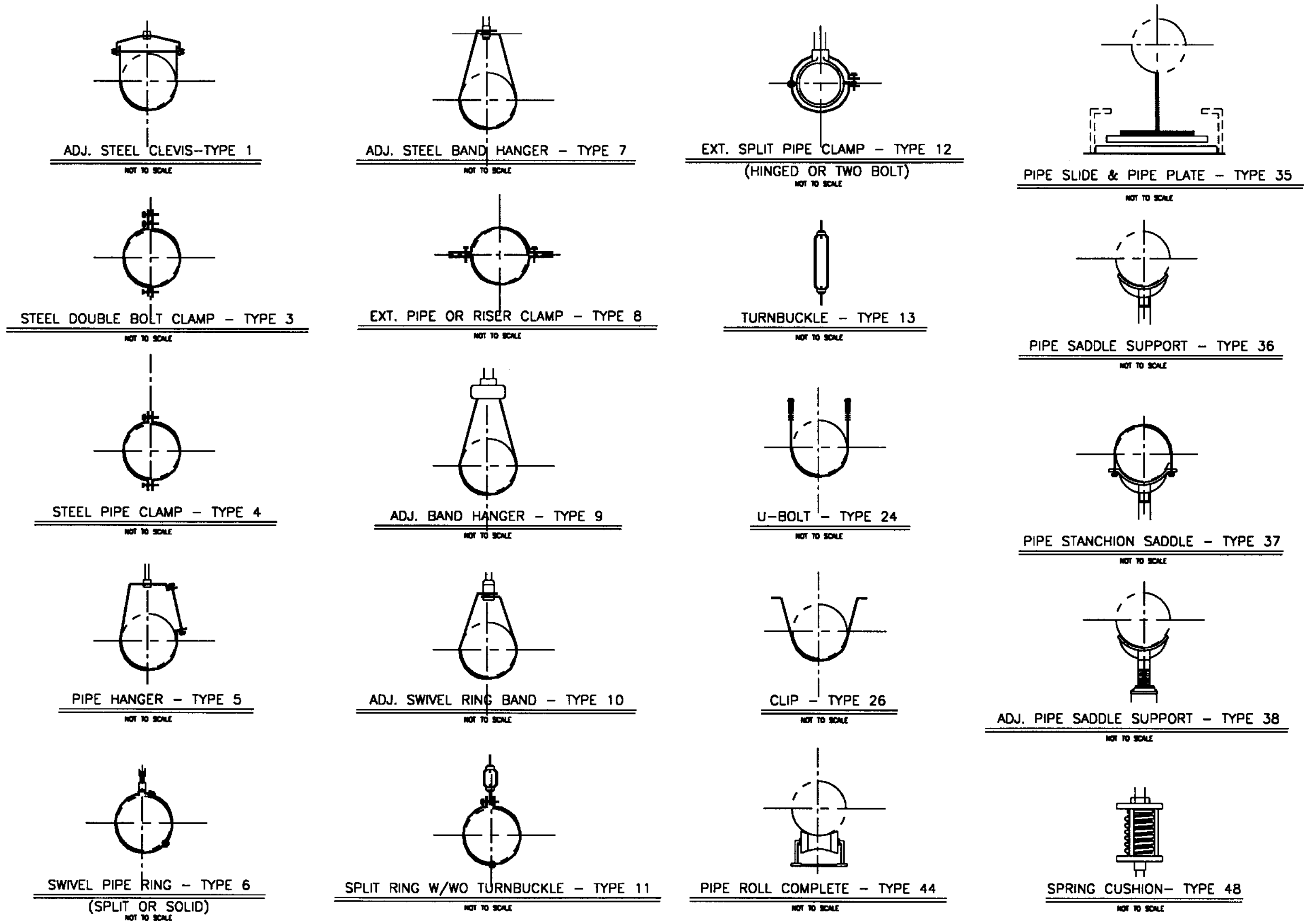


Figure 3-2. Pipe Supports for Ambient Applications
(Source: MSS SP-69, Pipe Hangers and Supports - Selection and Application, pp. 5-6)

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

Q18

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.

$$P_T \geq 1.5\ P$$

$$and$$

$$P_T < P_{min}$$

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.

Q19

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:

$$M \rightarrow M^{n+} + n e^{-}$$

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.

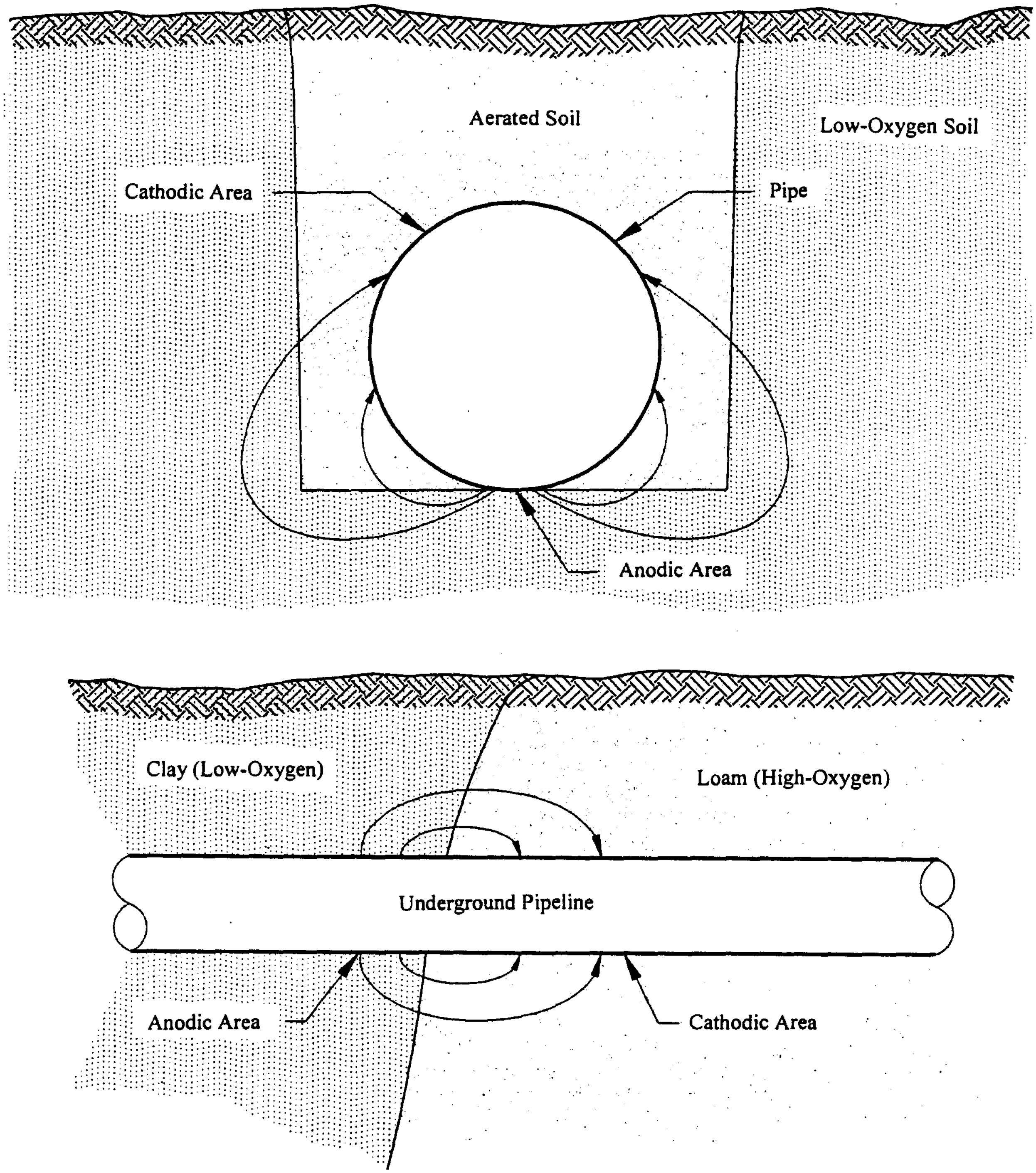


Figure 4-1. Concentration-Cell Corrosion of Underground Pipeline
(Source: USACE CECER, 1998.)

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

Q20

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.

Q21

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.

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

or

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

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

$\Delta = 11.7 \times 10^{-6}$ 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

$L = 5X = 74.7(145.2 \text{ mm} \times 220 \text{ mm})^{0.5}$
$6.225 (5.71 \text{ in.} \times 8.625 \text{ in.})^{0.5}$
$L = 5X$ = 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.

Q22

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.

Chapter 5
Plastic Piping Systems

5-1. General

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

a. Corrosion

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

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

Q23

Table 5-1
Abbreviations for Thermoplastic Materials

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

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

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

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

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

b. Operating Pressures and Temperatures

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

c. Sizing

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

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

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

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

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

d. Joining

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

e. Thermal Expansion

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

Table 5-2
Thermoplastic Joining Methods

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

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

Table 5-3
Thermoplastic Joining Standards

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

Source: Compiled by SAIC, 1998.

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

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

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

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

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

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

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

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

where:

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

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

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

f. Piping Support and Burial

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[3] ASTM D 2412, Appendices.

Q24

Table 5-4
Support Spacing for Schedule 80 PVC Pipe

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

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

Table 5-5
Support Spacing for Schedule 80 PVDF Pipe

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

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

Table 5-6
Support Spacing for Schedule 80 CPVC Pipe

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

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.
Source: Harvel Plastics, Product Bulletin 112/401 (rev. 10/1/95), p. 63.

Table 5-7
Bedding Factor, K_x

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

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

Table 5-8
Deflection Lag Factor, d_e

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

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

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

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

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

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

5-2. Polyvinyl Chloride (PVC)

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

a. PVC Specifications

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

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

b. PVC Installation

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

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

5-3. Polytetrafluoroethylene (PTFE)

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

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

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

a. ABS Standards

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

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

b. ABS Limitations

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

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

5-5. Chlorinated Polyvinyl Chloride (CPVC)

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

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

5-6. Polyethylene (PE)

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

5-7. Polypropylene (PP)

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

5-8. Polyvinylidene Fluoride (PVDF)

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

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

---

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

[5] Ibid., p. 43.

Table 5-10
Polyethylene Designations

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

Source: Compiled by SAIC, 1998