# GUIDE

FOR

# INSPECTION OF REFINERY EQUIPMENT

## CHAPTER XI
## PIPE, VALVES, AND FITTINGS

SECOND EDITION
1974



AMERICAN PETROLEUM INSTITUTE
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# PREFACE

This chapter is one of a series which make up the manual, *Guide for Inspection of Refinery Equipment*. It is based on the accumulated knowledge and experience of engineers of the petroleum industry. All users are invited to submit suggested revisions to the director of the Division of Refining, American Petroleum Institute, 1801 K Street, N.W., Washington, D. C. 20006.

The information contained in this publication has been arranged in its present form as a means of facilitating continuity of presentation and convenience of reference. It does not constitute, and should not be construed to be, a code of rules, regulations, or minimum safe practices. It is not intended that the practices described in this publication supplant practices that have proven satisfactory. Nor is it intended that this publication discourage innovation and originality in the inspection of refineries. Users of the publication are reminded that no book or manual is a substitute for the judgment of a responsible engineer.

The *Guide for Inspection of Refinery Equipment* is subdivided as follows:

# CONTENTS

## CHAPTER XI—PIPE, VALVES, AND FITTINGS

# CHAPTER XI

# PIPE, VALVES, AND FITTINGS

## 11.1 Scope

Chapter XI covers the inspection of pipe, valves (except control valves), tubing, and fittings used in a petroleum refinery. Chapter XV, *Instruments and Control Equipment,* covers control valves. However, many of the methods of inspection for valves described in this chapter are also applicable to valves controlled by instruments and are not repeated in Chapter XV.

## 11.2 Description of Types

### 11.2.1 PIPE

Pipe can be made from any ferrous or nonferrous material or alloy which can be drawn through dies to form a tubular section, which can be rolled and welded, or which can be cast. The oil industry generally uses seamless pipe for severe service. Pipe 12 inches and larger is usually made by rolling plates to size and welding the seams. Centrifugally cast pipe, which is being used more than in the past, can be cast or machined to any desired thickness. Steel or alloy pipe is manufactured to standard dimensions in sizes up to 24 inches and in standard thicknesses designated as "Schedules." The traditional thickness designations by standard weight, extra-strong and double extra-strong pipe differ from Schedules for certain sizes. (Refer to ANSI B36.10 for dimensions of pipe.) The thickness of drawn or cast pipe may vary from nominal by a manufacturing tolerance of as much as $\pm 12\frac{1}{2}$ percent. In all standard sizes the outside diameter remains nearly constant regardless of thickness. For pipe 12 inches and smaller, the size refers to the nominal inside diameter; for pipe 14 inches and larger, the size denotes the actual outside diameter. Pipe with beveled ends or with ends that are threaded with standard pipe threads can be obtained in various lengths. Pipe in different strength levels is obtainable depending on the grades of material, including alloying material, and heat treatments specified.

Cast iron pipe is frequently used for nonhazardous service, such as water, but is rarely used for pressurized hydrocarbon service. The standards and sizes of cast iron pipe are different from those of welded or seamless pipe.

### 11.2.2 TUBING

Tubing, not including furnace or exchanger tubes, is similar to pipe, but it is manufactured in many sizes of outside diameters and wall thicknesses. Tubing is generally seamless drawn, and the stated size is the actual outside diameter. In addition, it is usually made in small diameters and is mainly used for instrument piping, lubricating oil services, steam tracing, and other similar services.

### 11.2.3 VALVES

#### 11.2.3.1 General

The basic types of valves are gate, globe, plug valve or plug cock, ball valve or ball cock, diaphragm, butterfly, check, and slide.

Valves are made in standard sizes, materials, and pressure ratings necessary to permit their use in any pressure-temperature service in accordance with ANSI B16.5. The bodies of the valves can be cast, forged, machined from bar stock, or built up by welding a combination of two or more forms of materials. The seating surfaces in the body can be integral with the body, or can be made as inserts. These inserts can be of either the same material as, or different material than, the body. When special nonmetallic material that could fail in case of fire is used to prevent seat leakage, metal-to-metal backup seating surfaces can be provided. Other parts of trim (internal furnishings) may be of any suitable material and can be formed, forged, or machined from commercial rolled shapes. Valves can be obtained with the ends flanged, threaded for screwed connections, recessed for socket welding, or beveled for butt welding. Although many are manually operated, valves can be equipped with electric motors and gear operators or other power operators needed because of their large size, inaccessible location, or for actuation by instruments. Body thicknesses and other design data are given in applicable API valve specifications.

#### 11.2.3.2 Gate Valve

A gate valve is composed basically of a body containing a gate that interrupts the flow. The valve is normally used in the fully open or closed position. Gate valves larger than 2 inches in size usually have port openings of approximately the same size as valve end openings; however, venturi-type gate valves have smaller body and port openings than the end openings. Venturi-type valves may experience little pressure drop and may be economical, but increased erosion in certain services can occur due to higher velocity in the venturi section. Also,

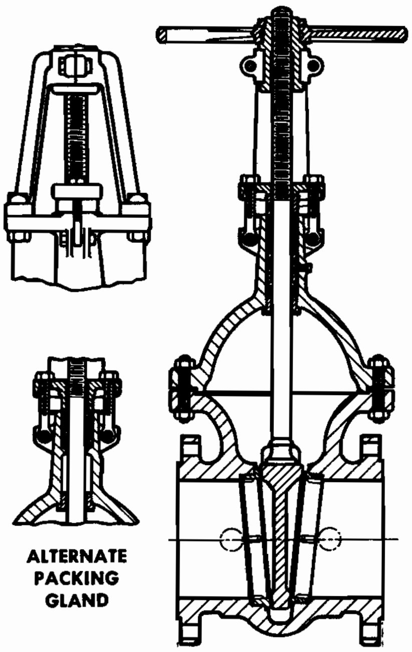



Figure 1—Cross-Section of a Wedge Gate Valve.

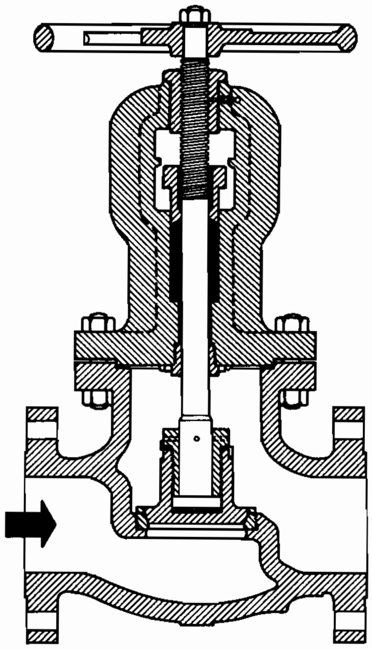


Figure 2—Cross-Section of a Globe Valve.

the smaller opening in a venturi-type valve may prevent complete drainage of piping and create an unsafe condition by trapping liquid in the line. Figure 1 illustrates a cross-section of a wedge gate valve.

### 11.2.3.3 Globe Valve

A globe valve, commonly used to regulate fluid flow, is composed basically of a valve body containing a disc that moves axially to the disc center line against a seat in the valve body. The stream flows upward through the seat against the disc and then changes direction to flow through the body to the outlet. The seating surface may be flat or tapered. For fine throttling service the tapered seat may be very steep; this type of globe valve is referred to as a needle valve. A globe valve is commonly constructed with its inlet and outlet in line and with its port opening at right angles to the inlet and outlet. Figure 2 illustrates a cross-section of a globe valve.

### 11.2.3.4 Plug Valve or Cock

A plug valve is composed basically of a tapered or cylindrical plug fitted snugly into a correspondingly shaped seat in the valve body. The plug is provided with an opening in line with the flow openings in the valve body. The valve is opened by turning the plug so that the openings in the valve body and plug are in line and is closed by turning the plug so that the plug opening is at right angles to the valve body openings. Plug valves may be operated by turning a wrench on the extended stem or by a gear-operated device. Small plug valves are usually referred to as plug cocks.

Plug valves are either lubricated or nonlubricated. Figure 3 illustrates both types of plug valves.

### 11.2.3.5 Ball Valve

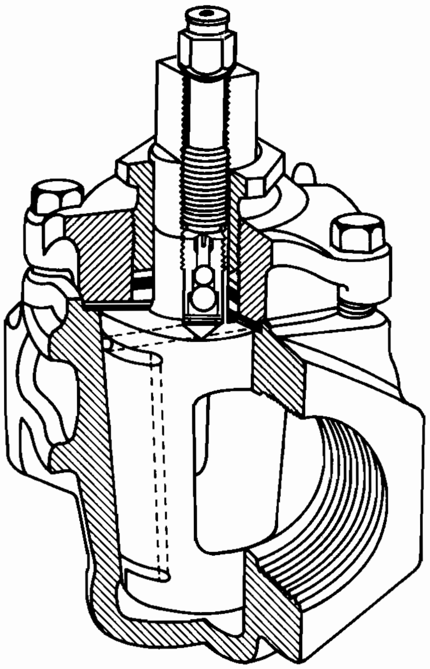
A ball valve is similar to a plug valve as described in Paragraph 11.2.3.4, except the plug in a ball valve is spherical instead of being tapered or cylindrical. Figure 4 illustrates a ball valve.

### 11.2.3.6 Diaphragm Valve

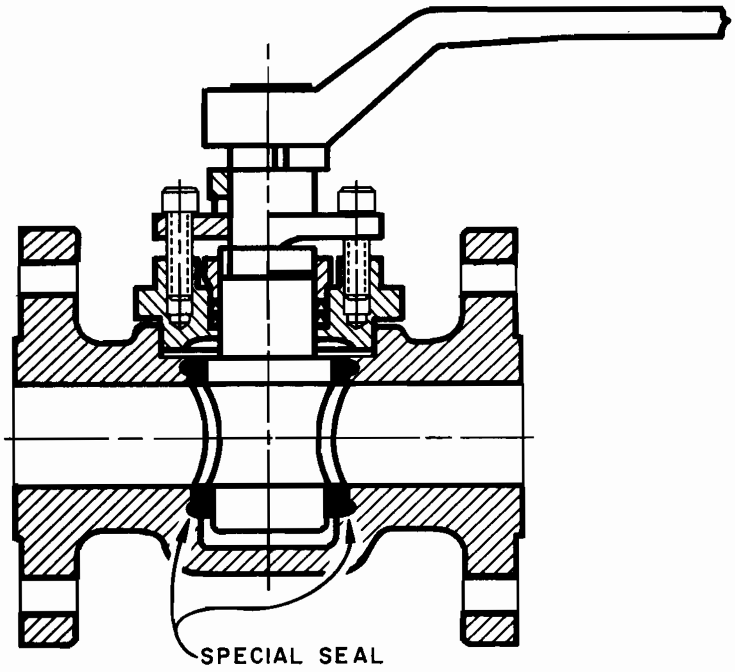
A diaphragm valve is a packless valve composed of a diaphragm made of a flexible material which functions as both a closure and a seal. When a mushroom-shaped compressor is screwed down, it forces the flexible diaphragm against a seat, or dam, in the valve body thus blocking the flow of fluid. Figure 5 illustrates a diaphragm valve.

### 11.2.3.7 Butterfly Valve

A butterfly valve is composed of a disc mounted on a stem in the flow path within the valve body. The body can be flanged or can be the lug type or the wafer type. A 90-degree turn of the stem changes the valve from closed to completely open. Butterfly valves are usually used in low-pressure service for coarse flow control, such as in flue-gas ducts, but they are available for use at higher pressures. Butterfly valves with metal-to-metal seats are not designed for tight closure, but they are available with special seats to enable tight shutoff. Large butterfly valves are generally mechanically oper-



LUBRICATED




NONLUBRICATED

Figure 3—Cross-Sections of a Lubricated Plug Valve and a Nonlubricated Plug Valve.

ated. The mechanical feature should prevent them from slamming shut in service. Figure 6 illustrates a butterfly valve.

**11.2.3.8 Check Valve**

A check valve is used to automatically prevent backflow. The different types of check valves are swing check, piston check, ball check, and spring-loaded wafer check. Cross-sectional views of each type of valve are shown in Figure 7. These views portray typical methods of preventing backflow.

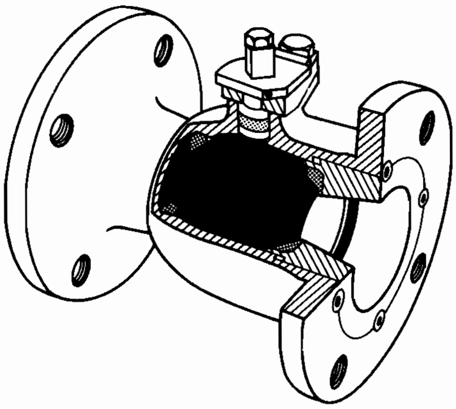


Figure 4—Cross-Section of a Ball Valve.

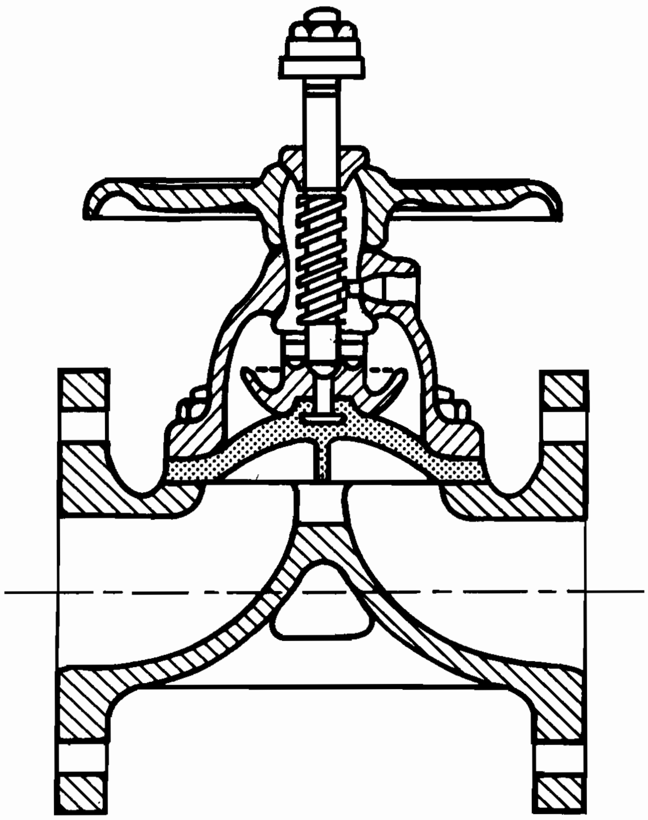


Figure 5—Cross-Section of a Diaphragm Valve.

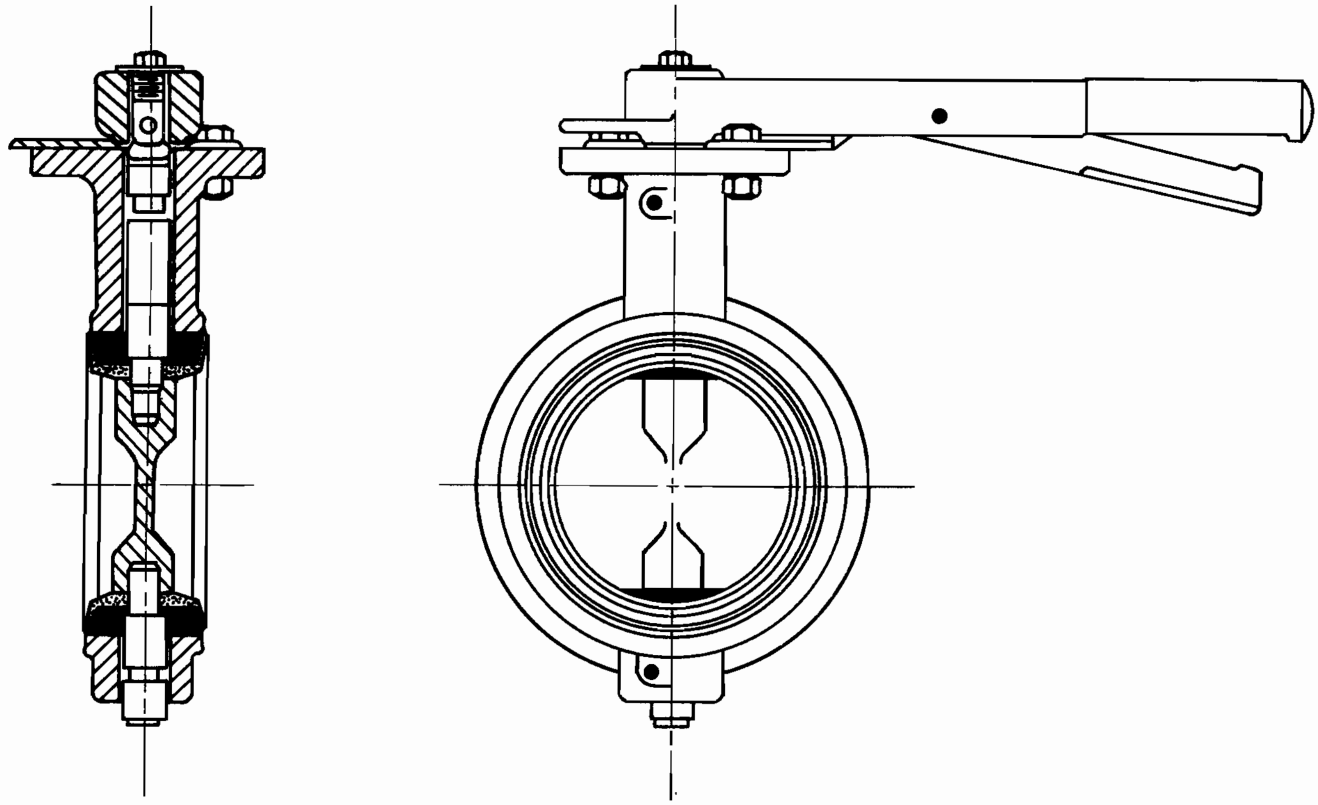



Figure 6—Butterfly Valve.

#### 11.2.3.9 Slide Valve

A slide valve is composed basically of a flat plate that slides against a seat. Slide valves are used mainly in low-pressure service and for coarse flow control. Figure 8 illustrates a slide valve.

### 11.2.4 FITTINGS

Fittings are used to connect various pipe sections and to change the direction of flow or to allow diversion of, or addition to, a flowing fluid stream in a run of pipe. They are made in various materials and to primary ANSI pressure ratings. They can be cast, forged, drawn seamless, or formed and welded. Fittings may be obtained with the ends flanged, recessed for socket welding, beveled for butt welding, or threaded for screwed connections. Fittings are made in various shapes, such as wyes, tees, elbows, crosses, laterals, and reducers. Figure 9 contains outline drawings of the various flanged fittings. Figure 10 illustrates various types of threaded fittings.

### 11.2.5 PIPE-JOINING METHODS

The common connections for joining pipe are screwed, welded, and bolted flanges. There are several special connections for cast iron pipe in addition to flanged connections. Because small-size tubing has a thin wall, special joining methods are used.

#### 11.2.5.1 Threaded Connections

Threaded connections for pipe 24 inches and smaller are standardized. See ANSI B2.1: *American Standard for Pipe Threads (Except Dryseal)*. Threaded connections are generally limited to pipe 2 inches and smaller. In critical services, threaded joints can be seal welded.

Lengths of pipe are joined by any of several types of threaded fittings (see Paragraph 11.2.4). Couplings —sleeves tapped at both ends for receiving the pipe— are normally used to connect threaded piping. When it is necessary to open the pipe joint, threaded unions are used. Mating flanges are also used when pipe must be opened (see Paragraph 11.2.5.3).

#### 11.2.5.2 Welded Connections

Welded joints have largely replaced threaded and flanged joints except for connecting pipe to equipment where the piping requires disconnection. Joints are either butt-welded in pipe of various sizes or socket-welded usually in pipe 2 inches and smaller.

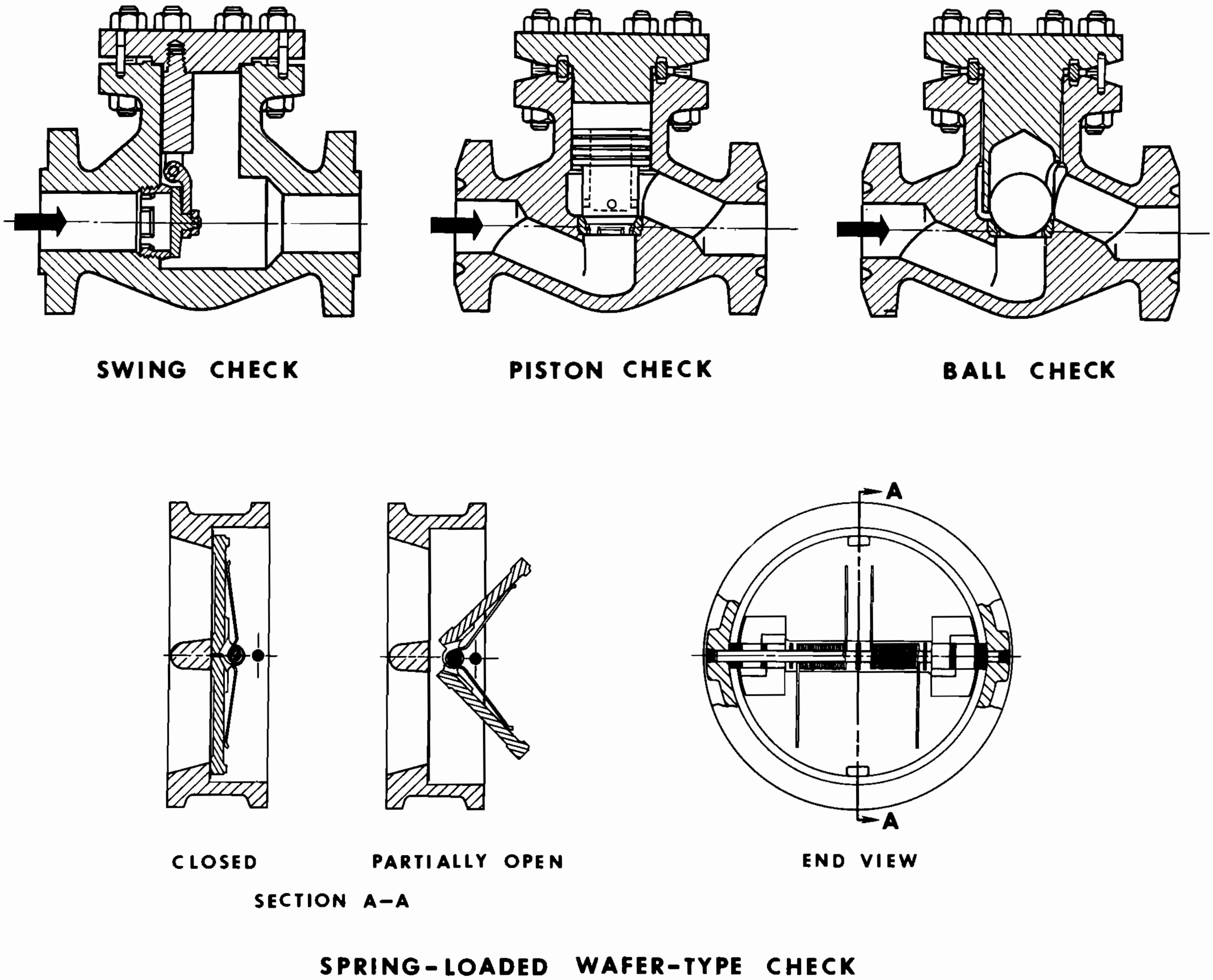



Figure 7—Cross-Sections of Check Valves.

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a. BUTT-WELDED CONNECTIONS

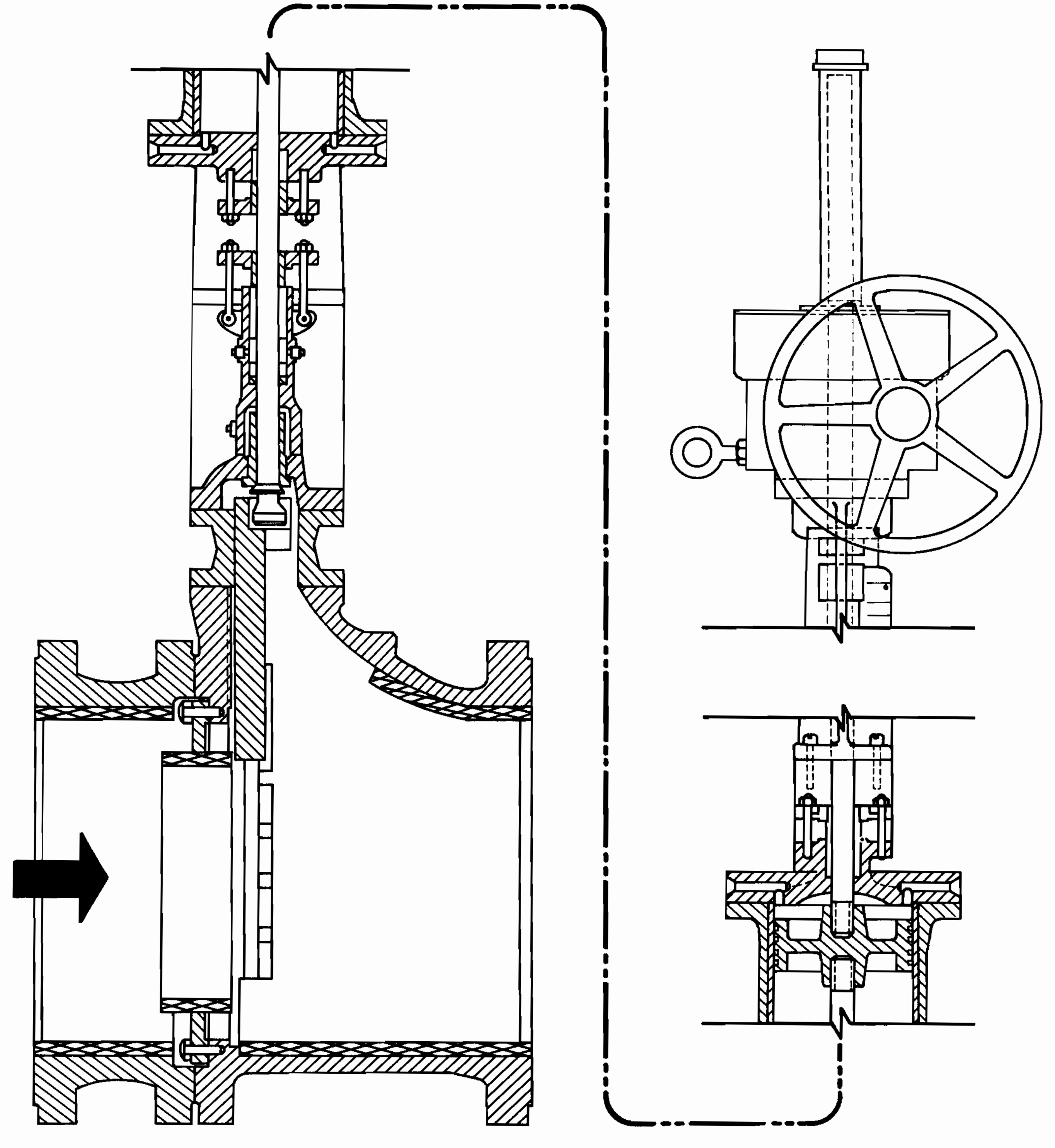
Butt-welded connections are the most common form of joints found in the petroleum industry. They are made by shaping the ends of the pipe, fitting, or valve; butting the adjoining ends; and fusion welding the joint.

b. SOCKET-WELDED CONNECTIONS

Socket-welded connections are made by inserting the end of the pipe into a recess in a fitting or valve and by fillet welding the joint. Space must be provided between end-of-pipe and bottom-of-socket to allow for expansion. Two lengths of pipe or tubing can be connected by this method, using a sleeve similar to a coupling. Figure 11 shows a cross-section of a socket-welded connection.

**11.2.5.3 Flanged Connections**

Flanged joints are made by bolting two flanges together with some form of gasket between the seating surfaces. The gasket surfaces may be flat and range from serrated (concentric or spiral) to smooth—depending on the type of gasket, gasket material, and service conditions—or grooves may be cut for seating metal ring gaskets. Common flange facings for various gaskets are shown in Figure 12. The flanges are welding neck, slip-on welding, threaded, blind, lap joint, or socket welding types and are illustrated in Figure 13.



**OPERATING MECHANISM**

Figure 8—Cross-Section of a Slide Valve.

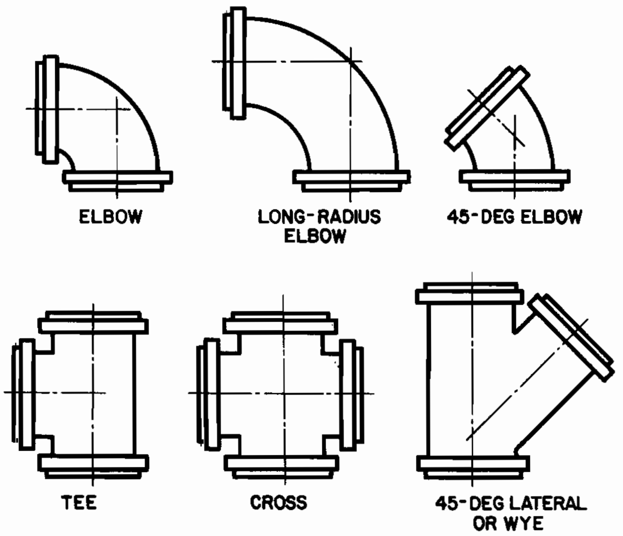



Figure 9—Shapes of Flanged End Fittings.

The flanges of fittings or valves are usually integral with the fitting or body of the valve.

#### 11.2.5.4 Cast Iron Pipe Joints

Cast iron pipe joints can be flanged, bell-and-spigot, or packed- and sleeve-type. Push-on joints with rubber or synthetic ring gaskets are available. Threaded joints are seldom used for cast iron. The most common joint is the bell-and-spigot joint as shown in Figure 14. Figure 15 illustrates cross-sectional views of packed and sleeve-type connections.

#### 11.2.5.5 Tubing Joints

Tubing can be joined by welding, soldering, brazing, or by using flared-type fittings or compression-type fittings. Figure 16 illustrates flared-type and compression-type joints.

#### 11.2.5.6 Special Joints

There are proprietary joints available incorporating unique designs of gaskets, clamps, and bolting arrangements. These offer advantages over conventional joints in certain services.

## 11.3 Reasons for Inspection

### 11.3.1 GENERAL

The primary purpose of inspection is to maintain plant safety and reliability. This requires information concerning the physical condition of equipment as well as the rate and cause of its deterioration. With such information available, preventive maintenance schedules can be effectively established by the inspection group. The group may recommend necessary repairs, predict future repairs and replacements, and act to prevent or

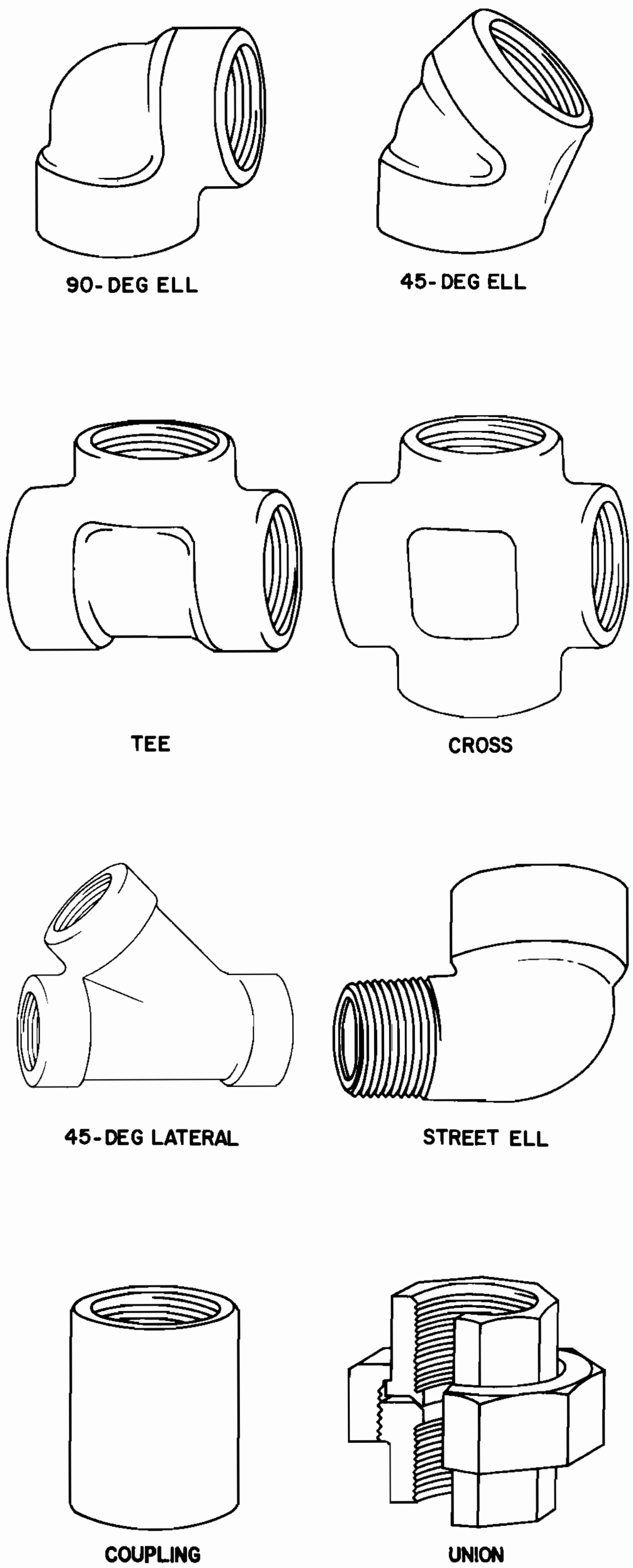



Figure 10—Types of Threaded Fittings.

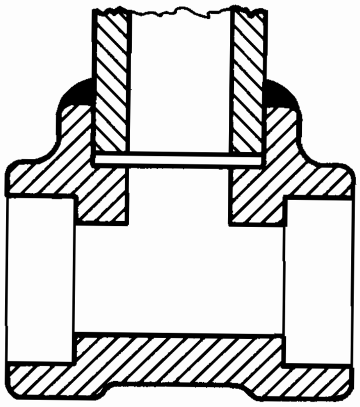


Figure 11—Cross-Section of a Socket-Welded Tee Connection.

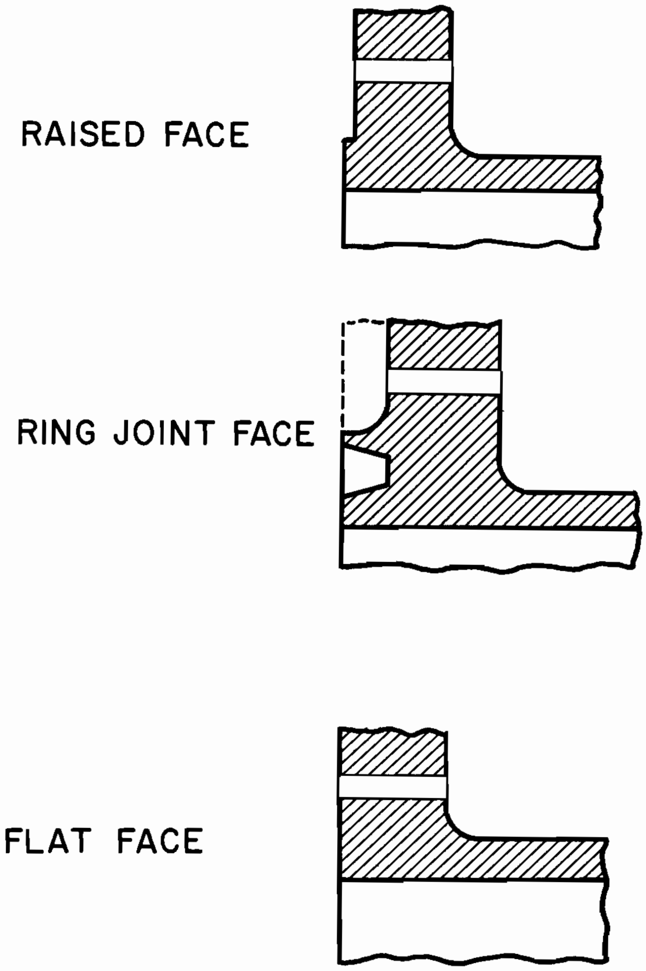



Figure 12—Flange Facings Commonly Used in Refinery Piping.

retard further deterioration. This effort should result in reduced maintenance costs and more reliable and efficient operations.

#### 11.3.2 SAFETY

A leak or failure in a piping system may be only a minor inconvenience or become a potential source of fire or explosion. Piping in a refinery may carry acids, alkalies, or other harmful chemicals; and leaks could be dangerous to personnel. Other piping may carry process streams which contain toxic or poisonous by-products generated during processing. Leaks in such lines could create dangerous atmospheric conditions. Adequate inspection is a prime requisite for maintaining piping in a safe, operable condition.

#### 11.3.3 RELIABILITY AND EFFICIENT OPERATION

Thorough inspection and analysis and utilization of detailed historical records of equipment are essential to attain reliability, efficient operation, and optimum on-stream service.

#### 11.3.4 REGULATORY REQUIREMENTS

Piping installation and inspection may be subject to regulatory statutes enacted by governmental bodies at various levels. These requirements should be checked to ensure compliance.

Regulatory requirements usually cover only those conditions affecting safety. Petroleum industry inspection groups, familiar with the industry's problems inspect not only for unsafe conditions but also for other conditions which adversely affect operation and maintenance.

### 11.4 Causes of Deterioration

Oil refinery piping carries crude oil; various process products in the form of liquids, vapors or gases; acids; alkalies; various chemicals; high- and low-pressure steam; fresh and salt water; various types of catalysts; inert gas; and other nonpetroleum gases such as hydrogen, chlorine, carbon monoxide, anhydrous ammonia, and air. These fluids may range from highly corrosive or erosive to noncorrosive or nonerosive. Piping aboveground is subject to atmospheric corrosion; buried piping is subject to soil corrosion. Figures 17, 18, 19, and 20 illustrate corrosion and erosion of piping. Chapter II, *Conditions Causing Deterioration or Failures,* contains detailed information on corrosion, erosion, the effects of high temperature and subnormal temperature, excessive pressure, overloading, earthquakes and earth settlement, mechanical and wind damage, and faulty material.

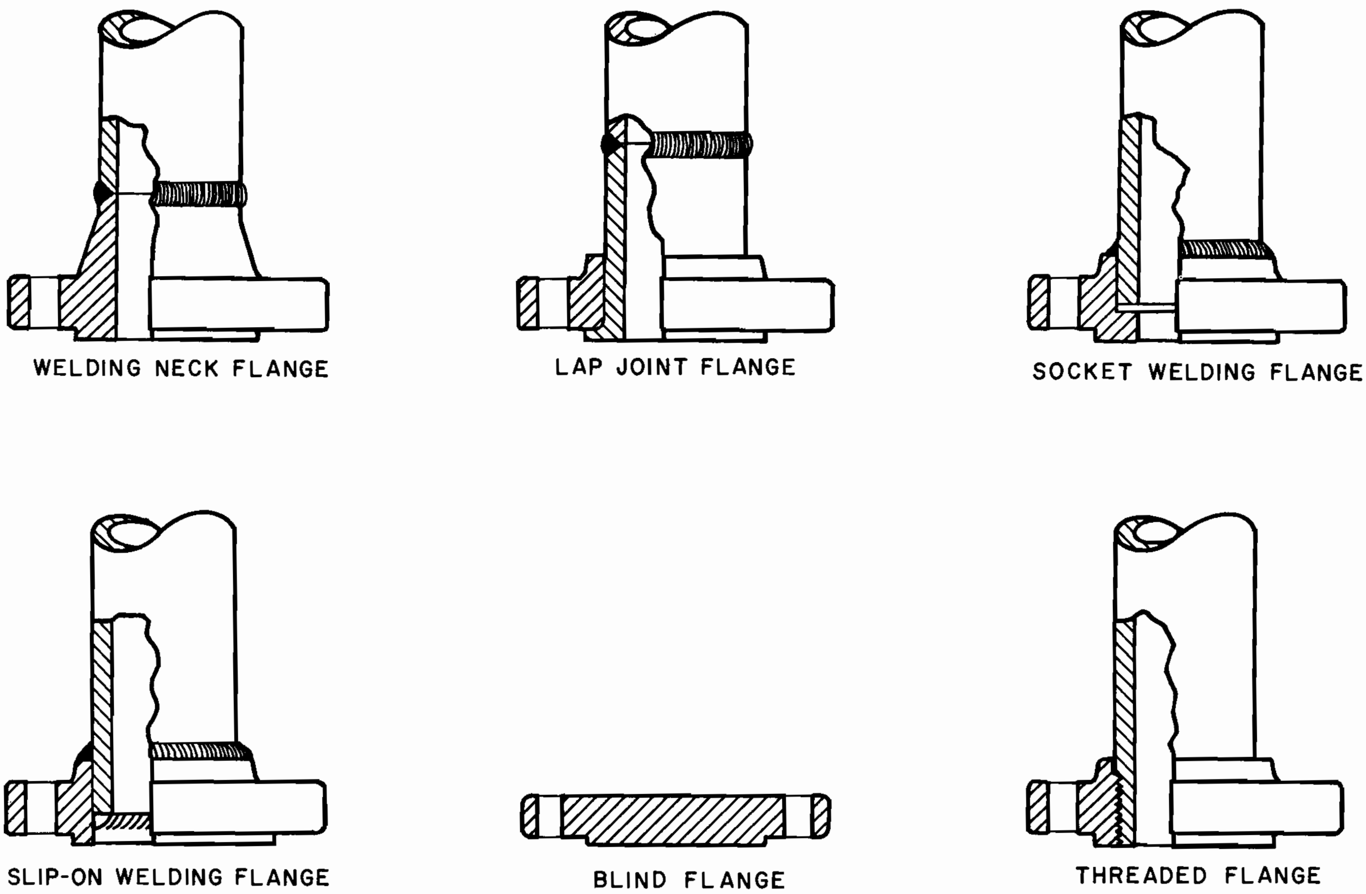



Figure 13—Types of Flanges.

## 11.5 Frequency of Inspection

The frequency and thoroughness of piping inspections will range from often and complete, where deterioration is extreme, to seldom and cursory in noncorrosive services.

The frequency of piping inspections should be determined on the basis of:

1. Severity of service.
2. Amount of corrosion allowance remaining.
3. Historical data available.
4. Regulatory requirements.

## 11.6 Time of Inspection

### 11.6.1 GENERAL

Some inspections can and should be made while the equipment is in operation. Inspections which cannot be made during operation must be made while the equipment is shut down.

### 11.6.2 INSPECTIONS WHILE EQUIPMENT IS IN OPERATION

An effective, integrated piping inspection program will include obtaining as many wall thickness measurements as possible while a plant is on-stream. Both ambient- and high-temperature ultrasonic thickness measurements may be taken. On most piping, wall thickness radiographs can be taken independently of process temperature measurements through undisturbed insulation. Radiographs can also be used to locate deposit accumulation during operation.

Historical records of piping should be studied to determine which sections will be approaching retiring thickness at the next planned maintenance shutdown. The results of this study can also be used to determine inspection locations and to establish a maintenance replacement schedule.

On-stream inspection can reduce downtime by:

1. Extending process runs and preventing some unscheduled shutdowns.

2. Permitting prefabrication of replacement piping prior to the shutdown.

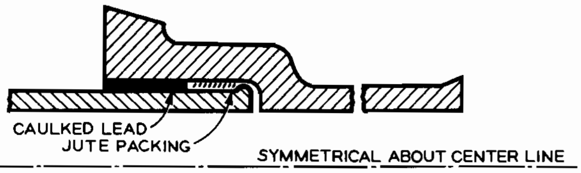



Figure 14—Cross-Section of a Bell-and-Spigot Joint.

3. Eliminating unnecessary work and saving manpower. For example, manpower otherwise used for removing insulation covering and for breaking flanges for inspection during the turnaround is available for other shutdown work.

4. Aiding in maintenance planning to reduce work load surges and, therefore, to better stabilize manpower.

Obviously, many other conditions in piping systems should be determined while the equipment is in operation. The following paragraphs cover the most important conditions that can be determined while the equipment is in operation.

Pipe system leaks are most easily detected while the equipment is in operation and should be looked for almost continuously. Operators should be encouraged to notify the inspector whenever a leak occurs so that he can check the seriousness of the condition.

Pipe supports may be inspected for distortion and damage, for settlement or movement of the foundation, and for condition of foundation bolts. Pipe anchors may be inspected for condition and adequacy. Pipe may be inspected for swaying or vibration. Pipe rollers may be inspected to ensure that they operate freely.

Inspection for external corrosion of pipe and supports and for the condition of protective coatings and insulation may be made. Inspection may also be made for spills of liquids that can cause corrosion of the pipe.

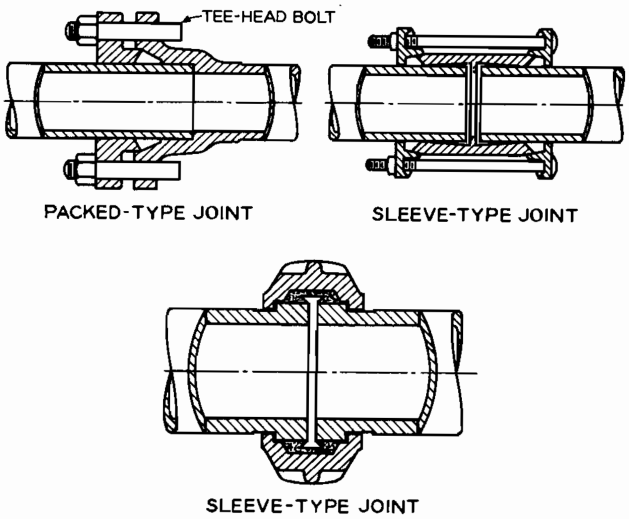



Figure 15—Cross-Sections of Packed- and Sleeve-Type Joints.

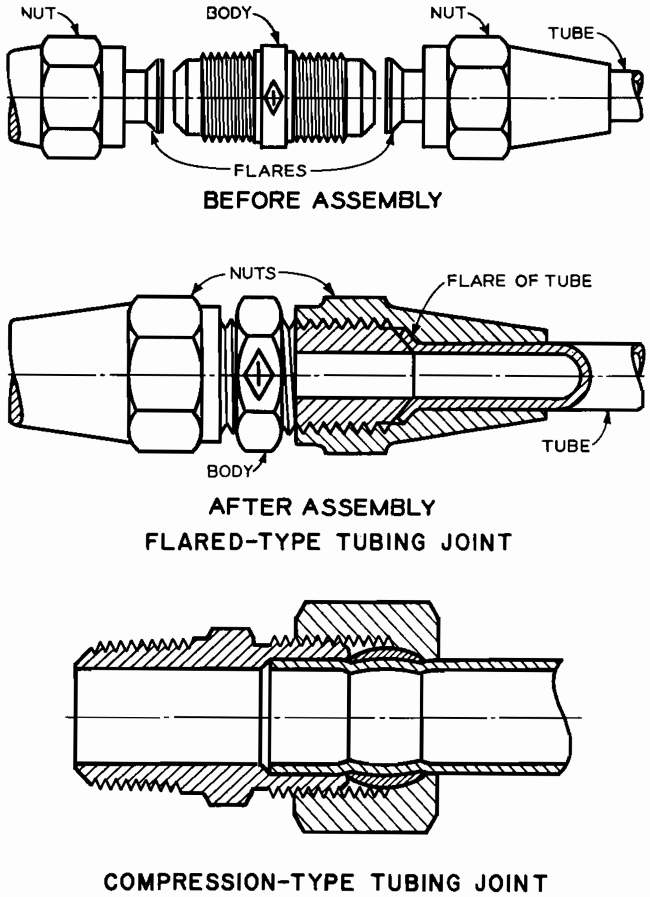



Figure 16—Tubing Joints.

### 11.6.3 INSPECTIONS WHILE EQUIPMENT IS SHUT DOWN

Inspections which cannot be made while the equipment is in operation should, of course, be made when the system is shut down. When pipe is opened for any reason, it should be inspected internally. Adequate follow-up inspections should be conducted to determine the causes of defects (such as leaks, misalignment, vibration, and swaying) detected while the unit was in operation.

## 11.7 Safety Precautions and Preparatory Work

### 11.7.1 SAFETY PRECAUTIONS

Safety precautions must be taken before opening any piping and before performing some types of external inspection. In general, the section of piping to be opened should be blanked from all sources of harmful liquids, gases, or vapors and purged to remove all oil and toxic or flammable gases and vapors. Precautions should be taken before hammer testing, drilling test holes or telltale holes, or performing similar operations such as seal welding, welding for hot tapping, and

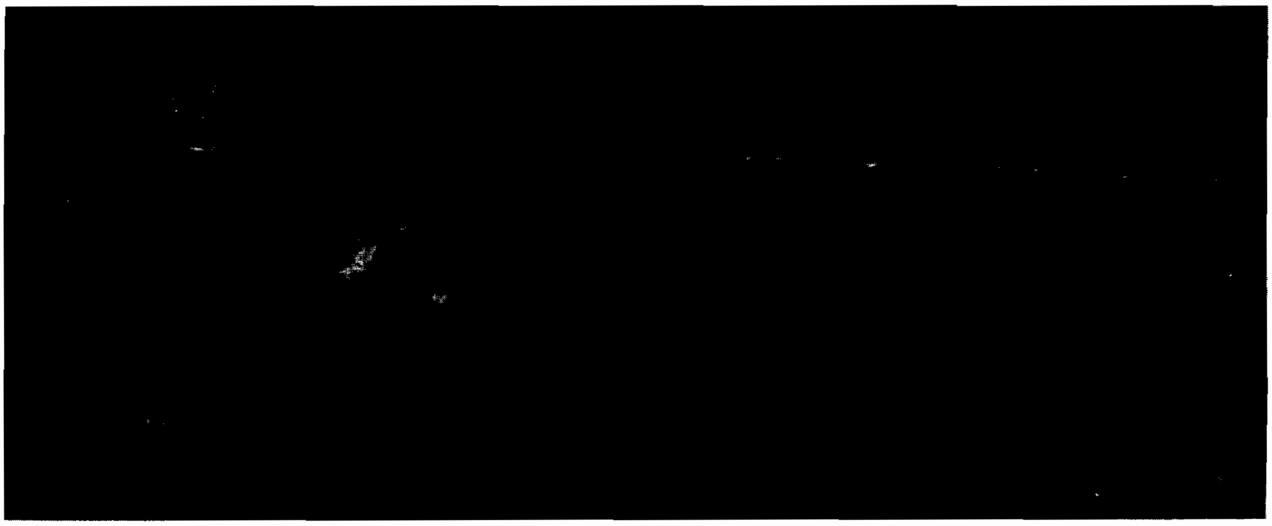


Figure 17—Erosion of Piping.

patching, that might cause failure or allow the contents of the piping to be released. When hot tapping lines in service, special precautions, other than piping inspection, must be taken to assure that the lines are full of product and that no oxygen is present. Chapter V, *Preparation of Equipment for Safe Entry and Work,* covers the necessary safety precautions that should be taken to avoid fires, explosions, and injury to personnel.

### 11.7.2 PREPARATORY WORK

All possible preparatory work should be done before the scheduled start of inspection. Scaffolds should

Figure 18—Corrosion of Piping.

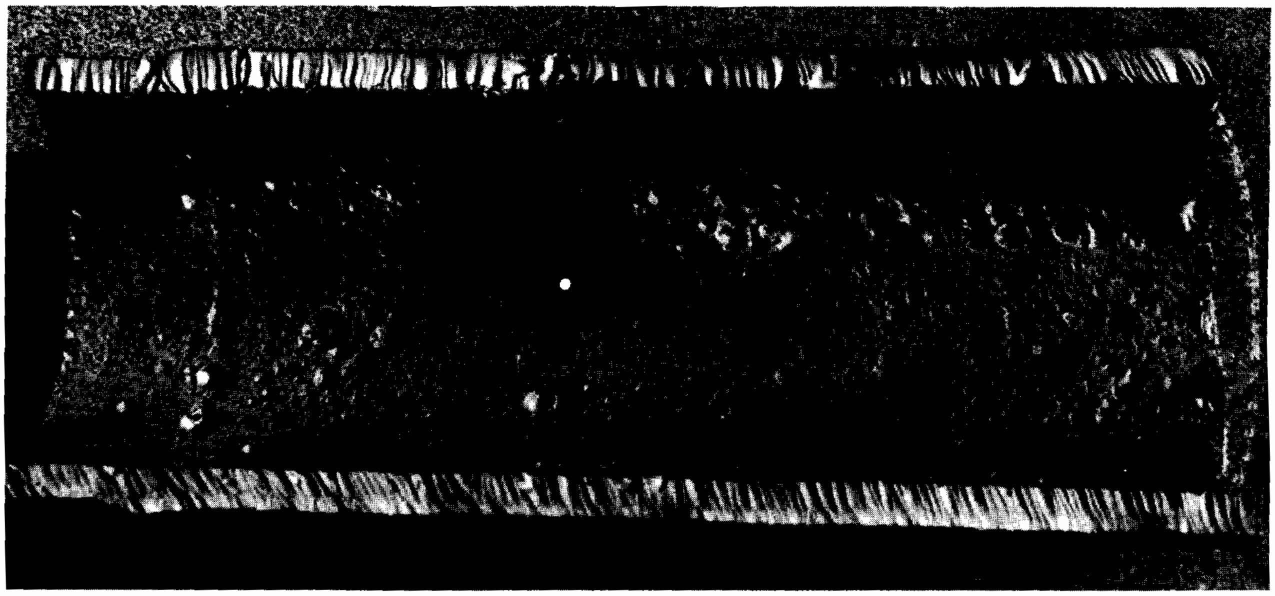


Figure 19—Internal Corrosion of Piping.

Figure 20—Severe Atmospheric Corrosion of Piping.

TABLE 1—Tools for Inspection of Piping

| | |
|---|---|
| Ultrasonic equipment | Borescope |
| Radiographic equipment | Magnet |
| Portable lights, including a flashlight | Wire brush |
| Thin-bladed knife | Small mirror |
| Scraper | Magnetic-particle equipment |
| Inspector's hammer | Penetrant-dye equipment |
| ID and OD transfer calipers | Paint or crayon |
| Direct-reading calipers with specially shaped legs | Notebook or sketches |
| Steel rule | Portable hardness tester |
| Thickness or hook gage | Material identification kit |
| Pit depth gage | Leak detector (sonic, gas test, or soap solution) |
| Magnifying glass | Infrared pyrometer and camera |

be erected where required and buried piping should be excavated at the points to be inspected. The tools needed for inspection should be checked for availability, proper working condition, and accuracy. Equipment required for personal safety should be checked for availability and condition. Any safety warning signs required should be obtained in advance, and barricades should be erected around all excavations. Chapter III, *General Preliminary and Preparatory Work,* covers preparatory work in detail and should be followed.

## 11.8 Inspection Tools

Almost all tools used for inspection of refinery equipment and their purposes are described in Chapter IV, *Inspection Tools.* Chapter IV also describes the methods of using these tools when they are not obvious or refers to literature which describes their use. Table 1 provides a list of tools commonly used for inspection of piping.

Test-hole equipment is seldom used on piping unless ultrasonic-type thickness-measurement instruments or radiographic equipment and persons trained in their use are unavailable. Contract inspection teams are available to perform this work.

In addition to the tools given in Table 1, sandblasting equipment may be required for removal of paint or other protective coating, dirt, or products of corrosion to enable inspection for cracks.

## 11.9 Inspection Procedures

### 11.9.1 GENERAL

Usually, a greater loss in metal thickness will be observed near a restriction in the line or a change in line direction because of the effects of turbulence or velocity. For this reason, it is preferable to inspect at pipe bends, elbows, tees, and at restrictions, such as orifice plates and throttling valves, or just downstream of them. Areas most subject to corrosion, erosion, or other forms of deterioration are:

1. Points at which condensation of acid gases and/or water is likely to occur.

2. Points at which acid carry-over from process operations is likely to occur.

3. Points at which naphthenic or other organic acids may be present in the process stream.

4. Points at which high sulfur streams of moderate to high temperatures exist.

5. Points at which high-temperature and low-temperature hydrogen attack may occur.

6. Dead ends subject to turbulence or where liquid-to-vapor interface or condensation occur.

7. Valve bodies and trim, fittings, ring grooves and rings, flange facings, and unexposed threads.

8. Welded areas subject to preferential attack.

9. Catalyst, flue gas, and slurry piping.

10. Steam systems subject to "wire cutting" or graphitization or where condensation occurs.

11. Ferrous and nonferrous piping subject to stress-corrosion cracking.

12. Alkali lines subject to caustic embrittlement with resultant cracking.

13. Areas near flanges or welded attachments, which act as cooling fins, thereby causing local corrosion because of slight temperature differences.

14. Locations where impingement or fluid velocity changes can cause local accelerated corrosion and/or erosion.

15. Chrome nickel and chrome molybdenum lines in high-temperature service near points of increased stress such as bends and anchor points.

16. Aluminum lines at points of accidental contact or insulator breakdown which causes contact with other metals.

17. Area of steam or electric tracing that contacts pipe handling materials, such as caustic soda, where concentrated heat can cause corrosion.

18. Underneath insulation on stainless steel lines where chlorides leached from insulation by moisture can cause stress-corrosion cracking of the stainless.

19. Area immediately downstream of chemical injection points where localized corrosion might occur in the reaction zone.

### 11.9.2 INSPECTIONS WHILE EQUIPMENT IS IN OPERATION

#### 11.9.2.1 Visual Inspection

a. FOR LEAKS

Leaks can be safety or fire hazards, can cause premature shutdown of equipment, and always result in an economic loss. Leaks in utility piping are seldom hazardous, seldom cause shutdown, but do result in an economic loss. Leaks in hot or volatile oil, gas, and chemical piping may result in a fire, an explosion, a toxic condition in the surrounding atmosphere, a serious pollution problem, or a premature shutdown. Frequent visual inspections should be made for leaks. Particular attention should be given to pipe connections; the packing glands of valves; and expansion joints on piping carrying flammable, toxic, corrosive, or other harmful materials. Many leaks can be stopped or minimized by tightening flange bolts or packing glands. Prompt repair of leaks will often prevent serious corrosion or erosion damage to gasket surfaces or packing glands. Operators should be encouraged to notify the inspector whenever a leak occurs so that the inspector can check the seriousness of the condition and determine the proper corrective action. It may be possible to make temporary or permanent repairs while lines are in service.

**b. For Misalignment**

Piping should be inspected for misalignment. The following are some observations which may indicate misalignment:

1. Pipe dislodged from its support so that the weight of the pipe is distributed unevenly on the hangers or saddles.

2. Deformation of the wall of the vessel in the vicinity of the pipe attachment.

3. Pipe supports forced out of plumb by expansion or contraction of the piping.

4. Excessive replacement or repair of bearings, impellers, and turbine wheels of centrifugal pumps and turbines to which the piping is connected.

5. Shifting of the base plate or shearing of the foundation bolts of mechanical equipment to which the piping is attached.

6. Cracks in the connecting flanges or cases of pumps or turbines to which the piping is attached.

**c. Of Supports**

Pipe supports should be visually inspected for the following:

1. Condition of protective coatings or fireproofing.

2. Evidence of corrosion.

3. Distortion.

4. General physical damage.

5. Movement or deterioration of concrete footings.

6. Condition of foundation bolts.

7. Secure attachment of brackets and beams to the support.

8. Free operation of pipe rollers.

9. Secure attachment and proper adjustment of pipe hangers, if used. Spring hanger loadings should be checked, both cold and hot, and the readings obtained should be checked against the original cold and hot readings.

10. Broken or otherwise defective pipe anchors.

11. Free operation of pulleys or pivot points of counterbalanced piping systems.

If the fireproofing is found defective, sufficient fireproofing should be removed to determine the extent of corrosion. If corrosion is noted, thickness measurements should be taken to determine whether sufficient metal is left to support the load.

If deterioration of concrete footings is found, the cause should be determined and corrective action taken.

Loose foundation bolts can be found by lightly rapping the bolt sideways with a hammer while holding a finger against the opposite side, in contact with the bearing plate. Movement of the bolt will be easily detected. Trying the bolts by tightening the nuts with a wrench will also indicate loose bolts. Broken bolts can be detected by the same methods as loose bolts. Shifting of the bearing plate on its foundation may indicate that the foundation bolts are sheared.

**d. For Vibration**

If vibration or swaying is observed, inspection should be made for cracks in welds, particularly at points of restraint such as where piping is attached to equipment and in the vicinity of anchors. Additional support should be considered for poorly braced, small size piping and valves and for the main vibrating line to which they are attached. In cases of severe vibration, it may be advisable to have a competent consultant recommend the remedial action, particularly if specialized equipment, such as a pulsation bottle, may be required.

**e. For External Corrosion**

Defects in protective coatings and the waterproof coating of insulation will permit moisture to come into contact with the piping. Sections of insulation should be removed from small connections, such as bleed lines and gage connections, because difficulty in obtaining a good seal in the insulation makes these locations particularly vulnerable to atmospheric attack. When defects are found in the waterproof coating of insulation, sufficient insulation should be removed to determine the extent and severity of corrosion.

Lines that "sweat" are susceptible to deterioration at areas of support. Corrosion may be found under clamps on suspended lines. Pipe mounted on rollers or welded support shoes is subject to moisture accumulation with resultant corrosion. Liquid spilled on piping, impingement of a jet of steam, or water dripping on a line can cause deterioration. Loss of vapor-sealing mastic from cold service piping insulation can result in local corrosion. All of these points should be investigated.

A loss in thickness can be determined by a comparison of the pipe diameter at the corroded area with the original pipe diameter. The depth of pits can be determined with a pit depth gage.

**f.** FOR ACCUMULATIONS OF CORROSIVE LIQUIDS

Spilled liquid, which has seeped into the ground, can usually be located by discoloration of the earth. The spill should be investigated to determine whether the liquid is corrosive to steel. This may involve chemical analysis of soil samples or of the liquid unless the source of the spill is known. Soil should be replaced or corrodent neutralized.

**g.** FOR INDICATIONS OF FOULING

An increase in pressure without an accompanying increase in throughput is an indication of fouling. The relative severity of the fouling will be indicated by the amount of pressure increase. If conditions permit, quite accurate measurements of the extent of fouling can be determined by personnel trained in the use of radiography. Refer to Paragraph 11.9.2.2**b** for the technique required to obtain this information.

### 11.9.2.2 Thickness Measurements

**a.** ULTRASONIC INSPECTION

Ultrasonic instruments are widely used for thickness measurements and have become standard equipment in most refinery inspection organizations. There are limitations on the use of these instruments, however. Because these instruments are not explosionproof, they must be used in areas that are free of explosive mixtures of gas. Also, transducers not equipped with delay-line material can be damaged by temperatures above 200 F. The maximum permissible temperature is dependent on the length of time that the transducer is in contact with the hot surface. Special delay-line materials and water-cooled transducers are available which permit use of pulse-echo type instruments at temperatures up to 1100 F.

The thickness measurements obtained with pulse-echo type instruments are average thicknesses of the area in contact with the crystal. Any pits in the area being measured can affect the average thickness reading. Dual crystals, available for use with pulse-echo instruments, will permit detection of pits as small as ⅛ inch in diameter when the crystal is positioned directly over the pit on the opposite side of the wall. An instrument with a scope will also indicate thicknesses at pits if high frequencies are used with tuned sensitivity. Thickness readings of areas with surface temperatures above 200 F are normally higher than actual thicknesses and may vary from approximately 1 percent higher at 300 F to 5 percent higher at 700 F. Temperature correction tables should be established for the instruments by comparing thickness readings of unheated and heated pipe samples. The presence of scale or other internal deposits can cause difficulty in obtaining a thickness measurement with some of the ultrasonic instruments.

Pulse-echo type instruments are used with special transducers to detect and trace out cracks or other flaws. Special training is required for personnel to perform flaw detection.

Chapter IV, *Inspection Tools,* covers the principles of operation and limitations of ultrasonic instruments.

**b.** RADIOGRAPHIC INSPECTION

Although X-ray techniques have been used for many years in weld quality evaluation, it was not until 1957 that isotope radiography was introduced as a refinery inspection method for wall thickness determination. Modern isotope radiographic techniques provide accurate pipe wall measurements and permit inspection of the internal items of some equipment. The primary function of this method is to detect metal loss and to check weld quality. The advantages of radiography are:

1. Pipe insulation can remain intact.
2. Fluid content and metal temperature of the line have little bearing on radiograph quality.
3. Films of small pipe connections, such as nipples and couplings, can be readily examined for thread contact, corrosion, and weld quality.
4. Film negatives provide a permanent visual record of the condition of the piping at the time of the shot.
5. Position of internal parts of valves (dropped gates) can be observed.
6. Radiographic equipment is quite maneuverable in the refinery.
7. Isotope radiography is not an ignition source in the presence of hydrocarbons.

Gamma rays traveling through the pipe wall between the outside radius and the inside radius of the pipe must penetrate metal that is approximately four times the wall thickness of the pipe. Thus, most of the rays are absorbed by the metal, leaving an unexposed area on the developed film. This area—white on the film—represents the projected image of the pipe wall, slightly enlarged. This image can be measured, and a correcting calculation establishes the thickness of the pipe wall. Any deposits or scale inside the pipe appear on the developed film as distinctly separate from the pipe wall. Pitting may also be visible on the film.

Because isotope radiographic inspection may be made while the equipment is in operation, the somewhat higher direct cost of the inspection may be more than offset by savings in downtime.

Iridium and cobalt have become the most frequently used isotopes when performing radiographic inspection. The use of cobalt 60 and iridium 192 is controlled by the U. S. Atomic Energy Commission, by the Atomic Energy Commission Ltd. in Canada, and by some individual localities or States. Personnel handling radioactive sources must be qualified, proper recommendations must be followed, and the safety of personnel must be considered.

Because standardized procedures, equipment, and measuring techniques have been developed to elevate radiography to the status of a major refinery inspection tool, trained operators are necessary. However, some refineries perform their own radiography, while others use contractors exclusively.

Occasionally, when radiographic inspection is being performed, process unit control systems, which also use isotopes (liquid-level indicators and controls), can be affected to give erroneous indications on the control panels. Purple peepers used for furnace or boiler fire indication may also be affected. Unit operators must be warned in advance of this possibility.

Radiographs taken while equipment was on-stream are shown in Figures 21, 22, and 23.

Figure 22—Corroded Pipe and Internal Surface Coated with Iron Sulfide Scale.

#### 11.9.2.3 Other Nondestructive Inspections

##### a. FOR HOT SPOTS

Operation of piping at temperatures in excess of the design limit or in the creep range, even without higher pressure, may cause bulging. In piping protected against excessive temperature by internal insulation, failure of the insulation will result in overheating of the metal wall, thereby causing a hot spot. The excessive temperature greatly reduces the strength of the metal and may cause bulging, scaling, metal deterioration, or complete failure. Frequent inspection should be made for hot spots on internally insulated piping. Any bulging or scaling should be noted for further investigation when the equipment is shut down. Some hot spots can be detected by a red glow, particularly if the inspection is made when it is dark. The skin temperature of indicated hot spots should be measured by a portable thermocouple, temperature-indicating crayons, special temperature-indicating paints, or an infrared temperature-indicating device. Chapter IV describes temperature-indicating crayons and paints and the methods of use. Cooling of severe hot spots with steam, as an interim measure, may be desirable or necessary until the system can be removed from service. The condition of both the pipe metal and the internal insulation in the vicinity of the hot spots should be investigated during the next shutdown period.

##### b. OF UNDERGROUND PIPING

Usually, underground piping is only spot inspected for external corrosion. Points of probable external corrosion can be located by a series of electrical resistance measurements of the surrounding soil or by pipe-to-soil electrical potential measurements. The piping should be excavated and uncovered for several feet at practical intervals. If serious external corrosion is found at any excavated location, other areas should be excavated in order to determine whether the entire line or only a local area is deteriorated. If it appears that only a local area is involved, the limits of deterioration can be determined by making a series of excavations until undeteriorated piping is found. Graphitization of the piping can be detected by scraping the surface with a sharp tool. The thickness and interior condition of under-

Figure 21—Catalytic Reformer Line.

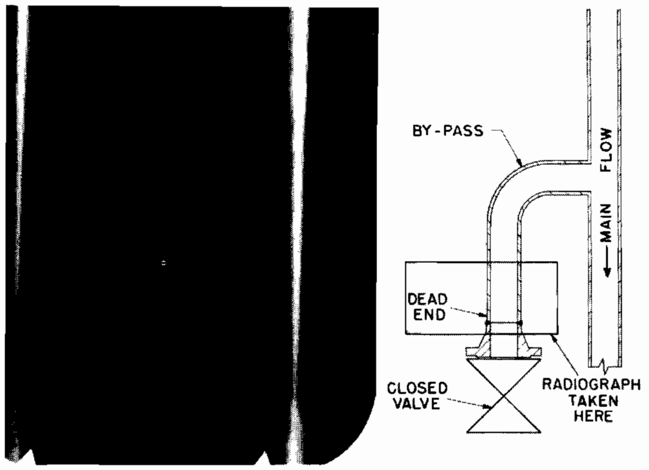



Figure 23—Sketch and Radiograph, Dead-End Corrosion.

ground piping at excavated locations can be determined by radiography or with ultrasonic type instruments.

Some serious leaks can be detected by a moist condition of the ground or actual seepage of the liquid carried in the underground piping. All lines should be inspected at and just below the point where they enter the earth or concrete slab, because serious corrosion frequently occurs at such location.

c. REVIEW OF RECORDS

A review should be made of the records of previous inspections and of inspections conducted during the current operating period. The review of records should provide lists of areas approaching retiring thickness, areas that have previously shown high corrosion rates, and areas where current inspection has indicated a need for further investigation. From these lists, a work schedule should be prepared for further inspection by on-stream techniques, if possible, and for inspections to be conducted during the next shut-down period. This schedule will assist in determining the number of inspectors to be assigned for this work.

Also, from the review of the records of previous inspections, a list should be made of all predictable repairs and replacements. This list should be submitted to the maintenance department enough in advance of the shutdown to permit sufficient lead time to obtain and, if necessary, to fabricate any material required. This list will also assist the maintenance department in determining the number of maintenance personnel required during the shutdown period.

### 11.9.3 INSPECTIONS WHILE EQUIPMENT IS SHUT DOWN

#### 11.9.3.1 Visual Inspection

a. FOR CORROSION, EROSION, AND FOULING

Piping can be opened at various places by removing a valve or fitting or by springing the pipe apart at flanged locations to permit visual inspection. The internal surfaces of the piping should be inspected visually over the greatest possible area. A flashlight or extension light is satisfactory in most cases. A probe-type instrument, such as a borescope, or a mirror and light will permit a more detailed view.

Where erratic corrosion or erosion conditions are noted in areas accessible for visual examination, it may be advisable to perform radiographic examination or to determine thicknesses by ultrasonic type instruments to extend coverage on those parts of the piping which are inaccessible for visual examination. This should apply particularly to piping which could not be, or was not, inspected during operation. Such conditions can also be pinpointed for closer examination by directing sunlight along the surface with a mirror or by shining a light parallel to the surface.

The amount of fouling should be noted in order to determine whether cleaning is necessary. The fouling should be investigated to determine whether it consists of deposits from the product stream or is a buildup of corrosion products. It may be necessary to take samples for chemical analysis.

b. FOR CRACKS

The locations most susceptible to cracking are welds, including construction tack welds at other than pressure welds, heat-affected areas adjoining welds, and points of restraint or excessive strain. Other locations requiring attention are those subject to stress-corrosion cracking, hydrogen attack, and caustic embrittlement. Exposed threads of threaded joints also require attention.

A clean surface is necessary for the detection of cracks. Cleaning can be accomplished by wire brushing, sandblasting, or chemical removal of coatings, deposits, or corrosion products. After thorough cleaning, the area should be visually inspected for any indications of cracks. Adequate lighting and a good magnifying glass will assist in locating such indications. Sometimes, it is not possible to differentiate between a surface scratch and a crack by visual inspection. Any mark having the appearance of a scratch should be investigated further by other methods. The magnetic-particle method can be used on magnetic materials. The penetrant-dye, fluorescent, and ultrasonic inspection methods, described in Paragraphs 402.037, 402.038, and 405.01, respectively, of Chapter IV, can be used on both nonmagnetic and magnetic materials. Dye penetrants containing chlorine compounds should not be used. It may not be possible to employ magnetic-particle, penetrant-dye, or fluorescent detection methods on interior surface cracks caused by stress corrosion or caustic embrittlement. In such cases, the methods available are radiography, ultrasonic shear wave or surface wave inspection, use of eddy current instruments, or the removal of a sample for microscopic inspection. The depth of a crack can often be determined by chipping or grinding until sound metal is reached.

c. OF GASKET FACES OF FLANGES

The gasket faces of flanged joints which have been opened should be inspected visually for corrosion and for defects (such as scratches, cuts, and gouges) which might cause leakage. The gasket faces should be checked for true flatness or warping by placing a straight edge across the diameter of the face of the flange and rotating it about an axis through the center line of the flange. Grooves and rings of ring joints should be checked for defects.

d. OF VALVES

Valves should be dismantled at specified intervals to permit examination of all internal parts. Body thickness measurements should be made at locations which were inaccessible before dismantling, particularly at locations showing evidence of corrosion or erosion. Bodies of valves operating in severe cyclic temperature service should be checked internally for cracks.

Gate valves which have been used for throttling should be measured for thickness at the bottom between the seats, as serious deterioration may have occurred because of turbulence. This is a particularly weak point because of the wedging action of the disc when the valve is closed. The seating surfaces should be inspected visually for defects which might cause leakage. The wedge guides should be inspected for corrosion and erosion.

The stem and threads on the stem and in the bonnet of all valves should be examined for corrosion which might cause failure. The connection between the stem and disc should be inspected to assure that the disc will not become detached from the stem during operation. Swing check valves can be inspected by removing the cover or cap. The clapper or disc should be checked for freedom of rotation and the nut holding it to the arm should be checked for security and the presence of a locking pin, lock washer, or tack weld. The arm should be free to swing, and the anchor pin should be inspected for wear. Also, the seating surfaces on both the disc and valve body can be checked for deterioration by feeling them with the fingers.

After the valve has been reassembled, it should be hydrostatically and/or pneumatically tested for tightness. If tested pneumatically, a soap solution should be applied to the edges of the seating surfaces and observed for any evidence of leakage. Refer to API Standard 598, *Valve Inspection and Test*.

### e. Of Joints

The following paragraphs discuss methods of inspection for specific types of joints.

#### e.1 Flanged Joints

Flanged joints, when opened, should be visually inspected for cracks and for metal loss caused by corrosion and erosion. See Paragraph 11.9.3.1**b** for methods of inspection for cracks. The inspection of gasket faces is covered in Paragraph 11.9.3.1**c**.

Flange bolts should be inspected for stretching. Where excessive bolt loading is indicated or where flanges are deformed, nuts may be rotated along the entire length of the stud. If studs are stretched, thread pitch will be changed and nuts will not turn freely. Inspection involves checking to determine whether bolts of the proper specification have been used and may involve chemical analysis or physical tests to determine the yield point and the ultimate strength of the material. If flanges are bolted too tightly, they may bend until the outer edges of the flanges are in contact. When this occurs, there may be insufficient pressure on the gasket to assure a tight joint. Visual inspection of the gasket will reveal this condition. Permanently deformed flanges must be replaced.

#### e.2 Welded Joints

Welded joints may be subject to leaks caused either by cracks or by corrosion or erosion. Cracks in alloy-steel welds are often associated with excessive hardness resulting from improper control of the preheat or post-heat treatment. Therefore, the hardness of air-hardenable alloy steel welds should be checked after heat treatment. Carbon steel welds in environmental cracking service should be checked for hardness. Refer to API Publication 942.

Corrosion can occur in the form of pitting which has penetrated the weld or adjacent heat-affected metal. Both pitting and welding defects can be detected by radiography. If porosity is suspected and radiography is not feasible, the affected area can be chipped or gouged out until sound metal is reached and can then be rewelded.

Welded joints in carbon steel and carbon molybdenum steel exposed to elevated temperatures may be subject to graphitization. When this condition exists, a sample should be taken from a welded joint and examined metallurgically for evidence of excessive graphitization.

#### e.3 Threaded Joints

Threaded joints may leak because of improper assembly, loose threads, corrosion, poor fabrication, cross threading, or dirty threads at the time of assembly. If the leak cannot be stopped by tightening the joint, the joint should be unscrewed and examined visually to determine the cause.

#### e.4 Clamp-Type Joints

A clamp-type joint dependent on machined surfaces for tightness may leak because of corrosion of the mating faces or failure of the clamp to provide sufficient force on the mating faces for proper contact. A clamp-type joint dependent on a gasket for tightness may leak because of damaged gasket seating surfaces or failure of the clamp to provide sufficient pressure on the gasket. If tightening the clamp does not stop the leak, the joint should be dismantled and inspected visually to determine the cause of the leak.

### f. For Misalignment

If misalignment of piping was noted during operation, the cause should be determined and corrected. Misalignment is usually caused by:

1. Inadequate provision for expansion.
2. Broken or defective anchors.
3. Excessive friction on sliding saddles, indicating lack of lubrication or necessity of rollers.
4. Broken rollers or the inability of rollers to turn because of corrosion or lack of lubrication.
5. Broken or improperly adjusted hangers.

6. Hangers which are too short and thus limit movement of the piping or cause lifting of the piping.

Since small degrees of misalignment or binding may be permissible, each case must be considered individually to ascertain whether correction should be made. Points to be considered are the materials of construction, expansion expected during operation, direction of misalignment with reference to the equipment to which the piping is attached, amount of misalignment, and size and thickness of piping.

**g.** FOR VIBRATION

Where excessive vibration or swaying was noted during operation, inspection should be made for points of abrasion and external wear and for cracks in welds at locations which could not be inspected during operation. The inspection methods described in Paragraph 11.9.2.1**d** should be followed. The conditions causing excessive vibration or swaying should be corrected.

**h.** FOR HOT SPOTS

Where hot spots on internally insulated pipe were noted during operation, the internal insulation should be inspected visually for bypassing or complete failure. The condition causing the hot spot should be corrected. The pipe wall in the vicinity of the hot spot should be inspected visually for oxidation and resultant scaling. The scale should be removed to sound metal and the area should be examined for incipient cracks. The thickness of sound metal should be measured to assure that sufficient thickness is left for the service. The outside diameter of piping in high-temperature service (about 800 F metal temperature and above) should be measured to check for creep (deformation with time under stress). To ensure that an in-service fracture will not occur, the amount of creep permitted should be based on established data for the contemplated service life.

#### 11.9.3.2 Thickness Measurements

When piping is opened, the thickness of pipe and fittings can be measured behind the flange with transfer or indicating calipers. The thickness of inaccessible pipe that could not be measured by radiographic or ultrasonic instruments during operation can be measured by these instruments during shutdown.

The thickness of valve bodies and bonnets and of fittings should be measured by using transfer or indicating calipers with special legs designed to reach inaccessible areas.

The exterior of piping that could not be examined during operation should be inspected for corrosion at the same locations and using the same methods described in Paragraph 11.9.2.1**e**.

Special attention should be given to small connections, such as nipples. Nipple thickness is difficult to determine unless the nipple is removed from the line. Radiography has been used successfully in determining nipple thickness. Sounding nipples with a hammer is common practice. Care must be taken not to hammer hard enough to cause cracking at the root of the threads or toe of the weld.

#### 11.9.3.3 Pressure Tests

A pressure test conducted on piping may function as a design test on newly installed piping, as a leakage and tightness test before placing a unit back on-stream, or as a method of inspection for piping systems where other methods are not possible or cannot be economically conducted. Piping systems included in this last category are:

1. Underground lines and other inaccessible piping.
2. Water and other nonhazardous utility lines.
3. Long oil-transfer lines in areas where a leak or spill would not be hazardous to personnel or harm the environment.
4. Complicated manifold systems.
5. Small pipe and tubing systems.
6. All systems, after a chemical cleaning operation.

Generally, the rules for pressure testing equipment and piping are the same. When a pressure test is made on the vessels of process units, the main lines connected to the vessels are usually pressure tested at the same time.

Complete isolation of any system being tested is necessary to prevent the testing medium from entering connecting lines, where its presence may be harmful or undesirable. Blind flanges and slip blinds should be designed so that distortion does not occur during pressure testing. Slip blinds of insufficient thickness can bulge to such an extent that removal becomes difficult. When isolating a piping system; the instrument lines, gage glasses, pressure gages, control valves, pressure-relief valves, and similar connecting lines are frequently overlooked causing damage and unnecessary expense. Expansion joints must be either properly protected against excessive pressure or isolated during testing.

If there are any regulatory laws or codes governing the requirements for and methods and frequency of pressure testing, the applicable regulations should be followed.

During liquid pressure testing, all air should be expelled from the piping through vents provided at all high points. If the system is not full of liquid, the trapped air will compress. With large quantities of compressible medium in the system, a failure will be more violent than in a system full of liquid because of expansion of the compressible medium.

Care should be taken not to overpressurize the system. Calibrated pressure gages of the proper range should be used and watched carefully during the pressuring period. When all air is expelled from the system, the pressure will rise rapidly. A sudden rise in pressure may cause shock, with resultant failure of the equipment being tested.

The pressure for a liquid pressure test is usually supplied by an available pump. If a pump of sufficient head is not available, the necessary test pressure can be supplied by bottled inert gas, such as nitrogen, bled in at the top of the system after the system is filled with test liquid. This method has the disadvantage of introducing a compressible medium into the system, but the quantity may be kept small. In either case, if overpressurizing can occur, a relief device should be installed to protect the system.

Various fluids may be used for pressure testing. Those most commonly used include:

1. Water with or without an inhibitor, freezing point depressant, or wetting agent.

2. Liquid products normally carried in the system, if not toxic nor likely to cause a fire in case of a leak or failure.

3. Steam.

4. Air, carbon dioxide, nitrogen, helium, or other inert gas.

If a leak or failure occurs, any fluid used in a pressure test may be released in the area of the piping being tested. For this reason, the fluid used should not be harmful to adjoining equipment or to the refinery sewer system.

Water may not be suitable as a test fluid in some piping systems, such as acid lines or air drier systems. Uninhibited salt water can cause corrosion of certain nonferrous alloys and stress-corrosion cracking of certain stainless steels. Water can freeze in cold weather unless a freezing-point depressant is used. The depressant should not be harmful to the sewer system or other place of disposal. Steam is sometimes used to warm the water and thus prevent freezing. The transition temperature of steel should be considered in order to prevent brittle failure when testing during cold weather or with cold fluids.

A steam test may be advantageous where steam is used for heating or purging equipment prior to operation. The steam pressure should not exceed the operating pressure. Steam does have an advantage in that it heats the pipe, thereby popping flux from welds in pipe that could have otherwise passed a water test. Steam testing does have several disadvantages, however. Condensation occurs, and it may be necessary to drain off any condensate before starting operations. When high-pressure steam is used, leaks are difficult to detect and may cause serious burns to inspectors or other personnel in the area of the equipment. Also, steam has the disadvantage of compressible mediums, mentioned previously.

Pneumatic tests in conjunction with soap solution, foaming agent, or sonic leak detector are valuable for pressurizing small lines or systems. The preferred test medium for pneumatic testing is an inert gas. Compressed air should not be used where petroleum fluids or other flammable fluids may be present. Leaks that would not be detected during a liquid pressure test can often be detected by a pneumatic test. Because nitrogen and helium are more penetrating than air, they are used when service conditions are particularly critical.

Systems (such as underground lines) that cannot be inspected visually for leaks should be tested by applying the desired pressure and then removing the source of pressure. The pressure drop, observed for an extended period, will be an indication of system tightness. However, lengthy test periods may require temperature corrections. When employing this method, pressure recorders are used to furnish a permanent record of the test.

WARNING: Hammer testing of equipment undergoing a pressure test may cause failure resulting in possible injury or death to those performing the test.

#### 11.9.3.4 Hammer Testing

Hammer testing of pipe, valves, and fittings—except cast iron and stress-relieved lines in caustic and corrosive service, which should never be hammered—is a method of extending the scope of measurements to detect the presence of unexpected thin sections. Hammer testing can be used to supplement other measurement methods. Care should be taken not to hammer hard enough to damage otherwise sound piping. Hammer testing should not be performed on glass-lined, cement-lined, or internally coated lines. Also, hammer testing on some alloys can cause stress-corrosion cracking. Therefore, care and sound judgment should be used when employing this inspection method at locations where permitted.

#### 11.9.3.5 Weld Inspection of Piping

Piping prepared for replacement installation and that welded on the unit should be inspected carefully for weld quality according to the recommendations in Appendix, *Inspection of Welding,* of this Guide and in the references given therein.

### 11.9.4 INSPECTION OF NEW CONSTRUCTION

#### 11.9.4.1 General

The various procedures for inspection of piping systems while equipment is shut down are adaptable to inspection of new construction. These procedures include thickness measurements; inspection for cracks; inspection of gasket faces, valves, and several types of joints; inspection for misalignment of pipe; pressure testing; and weld inspection. Piping material should be selected on the basis of service conditions and experience with piping in the same or similar service. Existing connecting systems may require checks to determine whether re-rating is necessary to meet the specified conditions. The extent of inspection during fabrication and installation is largely dependent on the severity of the service and the quality of workmanship.

#### 11.9.4.2 Materials Inspection

The materials, as well as fabrication, should be checked for conformance with the appropriate code and specifications for the plant. Some piping systems, such as those used in steam generation, may be subject to other regulatory requirements. Although the pipe, valves, and fittings can be specified in sufficient detail when ordering for new construction, there should be a positive means of identifying the materials needed for the intended systems. Checks can be made by using material test kits or other identification aids. Also, manufacturer's material and test data can be obtained for review, particularly when special quality requirements are specified.

Examination of welds by radiographic or other special techniques is important in new construction. (Refer to Appendix, *Inspection of Welding,* of this guide.) A representative number of welds may be selected to check the quality or the hardness of the weld and heat-affected area. Observation with the aid of dye-penetrant or magnetic-particle inspection equipment can also reveal cracks or surface defects. Similar techniques can be used to check for defects in castings and in machined surfaces such as gasket facings. Surface inspections often provide clues as to whether destructive or other nondestructive test methods should be used.

#### 11.9.4.3 Deviations

Deviations from specifications or standards in materials, tolerances, or workmanship are usually evaluated on the basis of their effects upon such factors as safety, strength, corrosion resistance, or serviceability. Special reviews may be required to determine whether piping items deviate to an extent that necessitates rejection. Any deviations that have been accepted should be properly recorded and identified for future reference.

## 11.10 Determination of Retiring Thickness

### 11.10.1 PIPING

ANSI B31.3: *Petroleum Refinery Piping Code,* a section of the *American National Standards Institute Code for Pressure Piping,* contains formulas and data for determining the wall thickness required for piping. It relates the thickness, diameter, and allowable stress to the maximum safe working pressure. In specifying pipe for original installation, ANSI B31.3 requires that additional thickness be provided for corrosion allowance; for threading (if used); and for stresses caused by mechanical loading, hydraulic surge pressure, thermal expansion, and other conditions which can impose stresses on the piping. The additional thickness required by such stresses should be calculated in accordance with the best engineering practice and data and added to the thickness required by the formulas contained in ANSI B31.3. Manufacturing tolerance must be considered in establishing required thickness.

In addition, ANSI B31.3 contains a formula with material factors for determining the required thickness but permits the use of the simple Barlow formula, without reservation, for determining the required thickness. The Barlow formula is as follows:

$$t=\frac{PD}{2SE}$$

*Where:*

$t$ = required thickness of the pipe wall, in inches.
$P$ = pressure within the pipe, in pounds per square inch.
$D$ = outside diameter of the pipe, in inches.
$S$ = allowable unit stress, in pounds per square inch, at the maximum operating temperature.
$E$ = longitudinal joint efficiency.

The Barlow formula gives results practically equivalent to those obtained by the more elaborate formula, except at high pressures where thick-walled tubing is required or at high temperatures where the creep properties of the pipe metal become important in determining the ultimate service strength. Metallic pipe with $t \geqq D/4$ requires special consideration.

ANSI B31.3 also contains the allowable unit stresses to be used in the formulas published therein. These stresses are functions of the pipe material and the temperature.

At low pressures and low temperatures, the thicknesses determined by the formula may be so small that the pipe would have insufficient structural strength. For this reason, an absolute minimum thickness should be determined for each size of pipe. The thickness of the pipe wall should not be permitted to deteriorate below this minimum thickness, regardless of the results obtained by the formula.

### 11.10.2 VALVES AND FLANGED FITTINGS

Valves and flanged fittings are subject to stress from internal pressure as well as to stress from mechanical loadings and temperature changes. Valves are also subject to closing stresses and stress concentrations because of their shape. These stresses are difficult to calculate with certainty. For this reason, the thickness of valves and flanged fittings is substantially greater than that of a simple cylinder. ANSI B16.5 establishes the minimum valve thickness at 1.5 times the thickness of a simple cylinder designed for a stress of 7,000 psi and subjected to an internal pressure equal to the primary service pressure. This is in accordance with ANSI B16.5-1968, Paragraph 6.1, however, latest revisions should be referred to. The thicknesses given in the ANSI B16.5 tables always exceed these calculated values by 0.1 to 0.2 inch. Valves furnished in accordance with API Standard 600 have additional thickness requirements above those given in B16.5.

If corrosion or erosion is anticipated, reference thickness measurements should be made when valves are installed so that corrosion rate and metal loss can be determined.

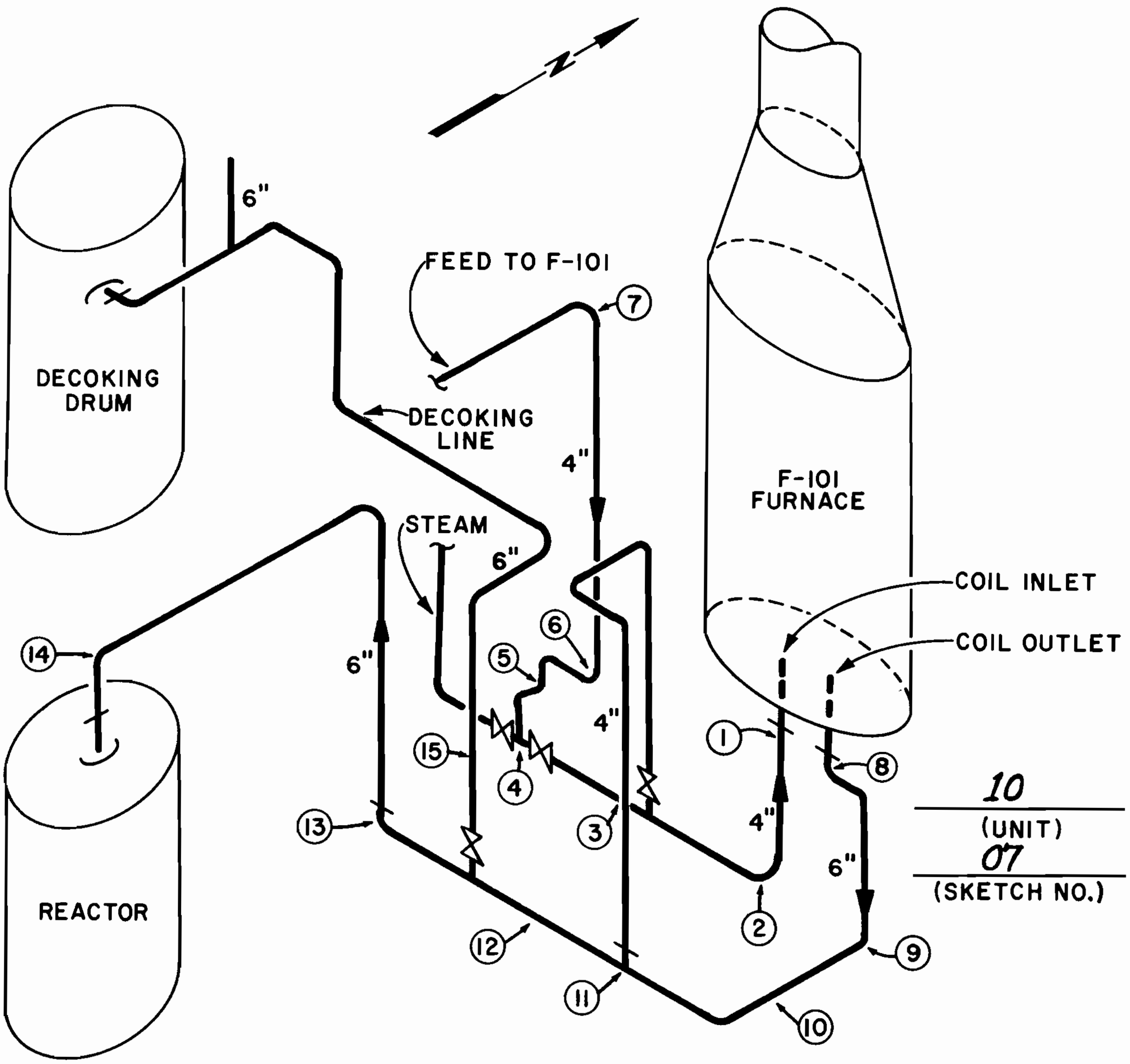
The formula for calculating retirement thickness of pipe can be adapted for valves and flanged fittings by utilizing the factor of 1.5 and the allowable stress for the material as quoted in ANSI B31.3. In some cases, the calculated thickness will be impractical from a structural standpoint so that arbitrary minimum thicknesses should be established.

The calculations described previously do not apply to welding fittings. The calculations for pipe can be applied to welding fittings by appropriate corrections for shape if necessary.

## 11.11 Records

### 11.11.1 GENERAL

The necessity of keeping complete records in a detailed and orderly manner is well recognized. If properly kept, such records will enable an evaluation of service life on any piping, valve, or fitting. From such records a comprehensive picture of the general condition




NOTE: Circled numbers indicate thickness monitor points to be used by the inspector when recording on the thickness data sheet (Figure 26).

Figure 24—Isometric Sketch.

of any piping system can be determined. Such records, when properly organized, form a permanent record from which corrosion rates and probable replacement or repairs can be determined. A computer program can be used to assist in a more complete evaluation of recorded information and to determine the next inspection date.

All inspection records should contain the original date of installation; the specifications and strength levels of materials used; the original thickness measurements; the locations and dates of all subsequent thickness measurements; and the calculated retiring thickness. These data and other pertinent data should be arranged on suitable forms so that successive inspection records will furnish a chronological picture. Each inspection force should develop the necessary forms which best suit the conditions.

### 11.11.2 SKETCHES

Isometric or oblique drawings, schematic in nature, provide a means of recording the size of lines and the locations where thickness measurements were taken. These may be original construction drawings or separate sketches made by the inspectors. A practical isometric sketch for recording field data is shown in Figure 24.

Sketches have several important functions as follows:

1. To identify particular piping systems in terms of location, size, material specification, general process flow, and service conditions.

2. To inform the mechanical department of points to be opened for visual inspection and parts requiring replacement or repair.

3. To serve as field data sheets on which locations of thickness measurements, serious corrosion, and sections requiring immediate replacement can be recorded. These data can then be transferred to continuous records at a later date.

4. To assist at future inspections in determining locations most urgently requiring examination.

### 11.11.3 NUMBERING SYSTEMS

It may be advisable to use a coding system which identifies the process unit, the piping system, and the individual items composing the system. Figure 25 shows a sketch numbering system used by one company.

### 11.11.4 THICKNESS DATA

A record of thickness data obtained during periodic or scheduled inspections provides a means to arrive at corrosion or erosion rates and expected material life. Computerized record systems are used for this purpose by some companies. The data may be shown on sketches or as tabulated information attached to the sketches. Figure 26 shows one method of tabulating thickness readings and other information.

| Unit | | Sketch | |
|---|---|---|---|
| Type of Unit | Refinery Unit No. | Equipment Subdivision | Sketch No. |
| 10 | 1 | 4 | 07 |

| Type of Unit | Refinery Unit No. | Equipment Subdivision | Sketch No. |
|---|---|---|---|
| 01–Alkylation | 1 | 1–Furnaces | |
| 02–Asphalt | 2 | 2–Towers | |
| 03–Blending and Mixing | 3 | 3–Pressure Vessels | |
| 04–Blowdown and Flare | 4 | 4–Piping | |
| 05–Catalytic Polymerization | 5 | 5–Exchangers | 01 |
| 06–Catalytic Cracking | 6 | 6–Pumps and Compressors | to |
| 07–Crude Oil, Vacuum | 7 | 7–Safety Valves | 99 |
| 08–Delayed Coking | 8 | 8–Stacks | |
| 09–Gas Plant | 9 | 9–Storage Tanks | |
| 10–Lube Hydrofining | | 0–Miscellaneous | |

Figure 25—Sketch Numbering System.

| Identification Number | ☒ Piping | ☐ Vessel |
|---|---|---|
| 1 0 0 1 0 4 0 7 | Description: Piping to and from Furnance F-101 | (Unit) |

| Insp Interval | | Design Cond | | Operating Cond | | Mat'l | |
|---|---|---|---|---|---|---|---|
| Int | Ext | Temp | Pressure | Temp | Pressure | | REMAINING LIFE (Years/Months): 1 yr - 9 mo. |
| | | | | | | | SET BY LAST READING AT POINT NO.: 4B |
| 36 mo | 10 mo | 350 F 800 F | 800# | 300 F 750 F | 750# | C.S. | NEXT RECOMMENDED INSPECTION DATE: 4/73 |

| Point Loc | Reading Location | Size | Limit | Original Reading | | | | Insp Temp | Subsequent Reading | | | | Insp Temp | Subsequent Reading | | | | Insp Temp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Inches | M * | Mo | Yr | | Inches | M * | Mo | Yr | | Inches | M * | Mo | Yr | |
| 1S | Pipe run - 12" fr. flg. | 4. | 0.150 | 0.337 | U | 12 | 70 | 300F | 0.305 | U | 6 | 72 | 300F | | | | | |
| 1N | Pipe run - 12" fr. flg. | 4. | 0.150 | 0.337 | U | 12 | 70 | 300F | 0.306 | U | 6 | 72 | 300 F | | | | | |
| 2B | Ell-bottom | 4. | 0.150 | 0.337 | U | 12 | 70 | 300F | 0.260 | U | 6 | 72 | 300 F | | | | | |
| 3T | Pipe run - 10" fr. tee | 4. | 0.150 | 0.337 | U | 12 | 70 | 300F | 0.290 | U | 6 | 72 | 300 F | | | | | |
| 4B | Tee-bottom | 4. | 0.150 | 0.337 | U | 12 | 70 | 300F | 0.250 | U | 6 | 72 | 300F | | | | | |

Inspector: ______ Inspector: ______ Inspector: ______

* Indicate method of obtaining thickness measurement (e.g., N = nominal; U = ultrasonics; X = radiography; C = calipers).

Figure 26—Thickness Data.

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