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Guide for Inspection of Refinery Equipment

Chapter VI—Pressure Vessels (Towers, Drums, and Reactors)

FOURTH EDITION, DECEMBER 1982



American Petroleum Institute
2101 L Street, Northwest
Washington, D.C. 20037



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Chapter VI—Pressure Vessels (Towers, Drums, and Reactors)

Refining Department

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OFFICIAL PUBLICATION



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PREFACE

This chapter is one of a series that make up the manual *Guide for Inspection of Refinery Equipment*. It is based on the accumulated knowledge and experience of engineers and other personnel of the petroleum industry. All users are invited to submit suggested revisions to the director of the Refining Department, American Petroleum Institute, 2101 L Street, Northwest, Washington, D.C. 20037.

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 been 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 qualified person.

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

Chapter I	Introduction
Chapter II	Conditions Causing Deterioration or Failures
Chapter III	General Preliminary and Preparatory Work
Chapter IV	Inspection Tools
Chapter V	Preparation of Equipment for Safe Entry and Work
Chapter VI	Pressure Vessels (Towers, Drums, and Reactors)
Chapter VII	Heat Exchangers, Condensers, and Cooler Boxes
Chapter VIII	Direct-Fired Boilers and Auxiliary Equipment
Chapter IX	Fired Heaters and Stacks
Chapter X	Pumps, Compressors, and Blowers, and Their Drivers
Chapter XI	Pipe, Valves, and Fittings
Chapter XII	Foundations, Structures, and Buildings
Chapter XIII	Atmospheric and Low-Pressure Storage Tanks
Chapter XIV	Electrical Systems
Chapter XV	Instruments and Control Equipment
Chapter XVI	Pressure-Relieving Devices
Chapter XVII	Auxiliary and Miscellaneous Equipment
Chapter XVIII	Protection of Idle Equipment
Appendix	Inspection of Welding

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Guide for Inspection of Refinery Equipment

CHAPTER VI—PRESSURE VESSELS (TOWERS, DRUMS, AND REACTORS)

6.1 Scope

This chapter covers the inspection of pressure vessels. It includes a description of the various types of pressure vessels and the standards for their construction and maintenance. The reasons for inspection, causes of deterioration, frequency and methods of inspection, methods of repair, and preparation of records and reports are covered. Safe and efficient operation are emphasized.

6.2 Referenced Publications

The most recent editions of the following standards, manuals, and specifications are cited in this chapter.

ASME¹

Boiler and Pressure Vessel Code

API

510 *Pressure Vessel Inspection Code*

RP 941 *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*

RP 942 *Controlling Weld Hardness of Carbon Steel Refinery Equipment to Prevent Environmental Cracking*

6.3 Description of Types

6.3.1 GENERAL

A pressure vessel is a container that falls within the scope of Section VIII of the ASME *Boiler and Pressure Vessel Code* and that has an external or internal design pressure greater than 15 pounds per square inch gage (103 kilopascals). External pressure can be caused by an internal vacuum or by a fluid pressure between an outer jacket and the vessel wall. Such vessels are usually inspected in the same manner as vessels with internal pressure. Storage vessels subject to internal pressures up to 15 pounds per square inch gage (103 kilopascals) are covered in IRE Guide, Chapter XIII.

Pressure vessels are designed in various shapes. They may be cylindrical (with flat, conical, toriconical, torispherical, semiellipsoidal, or hemispherical heads),

spheroidal, or spherical. Cylindrical vessels may be vertical or horizontal and may be supported in several ways. Spheroids are partially or completely supported by resting on the ground. Spheres are usually supported by steel columns attached to the shell or by skirts. Jacketed vessels are those built with a casing or outer shell that forms an annular space between itself and the main shell.

6.3.2 METHODS OF CONSTRUCTION

There are several different methods used for the construction of pressure vessels. Today most pressure vessels are constructed with welded joints. Prior to the development of welding, riveting was the most common method of construction. Seams were lapped and riveted or butted with butt straps and then riveted. To prevent leakage the edges of the seams and rivet heads were caulked. Under high temperatures it was difficult to keep this caulking tight and frequently a light bead of welding was applied to the caulking edges. This method of construction is seldom used today, but some vessels of this type can still be found in older refineries.

Forming of seamless cylindrical shell rings by hot forging is still commonly used by some vessel manufacturers for the fabrication of high pressure, heavy wall vessels such as those used for hydrotreater or hydrocracker reactors.

Another method of construction is known as the multilayer method. In this method, the cylindrical section is made up of a number of comparatively thin concentric cylinders fabricated together, one over the other, until the desired thickness is obtained. Multilayer construction is sometimes used for heavy wall reactors and drums subject to high pressure.

6.3.3 MATERIALS OF CONSTRUCTION

Carbon steel is the most common material used for constructing pressure vessels. For special purposes a suitable austenitic or ferritic alloy, Monel, nickel, or aluminum may be used. Copper and copper alloys (except Monel) are seldom used in refinery vessels but may be found in some petrochemical plant vessels.

If carbon steel will not resist the corrosion or erosion expected or would cause contamination of the product, vessels may be lined with other metals or nonmetals. A lined vessel is usually more economical than one built of

¹American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

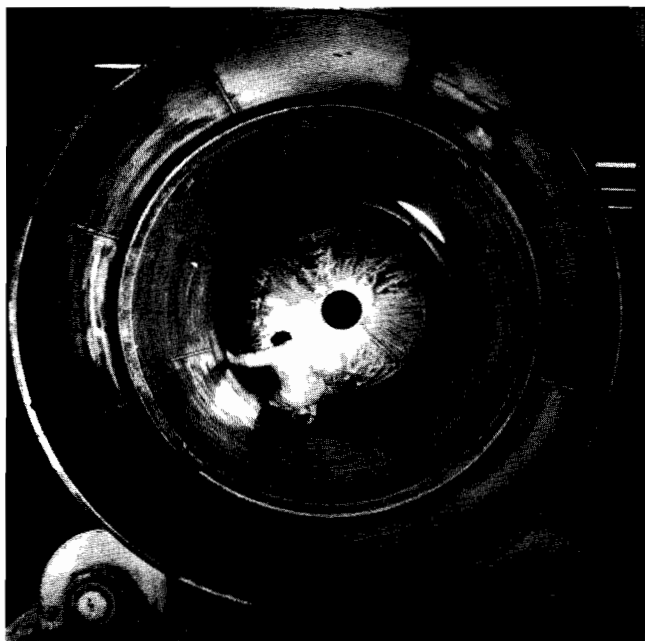


Figure 1—Tantalum Clad Vessel

a solid corrosion-resistant material. On the other hand, when the pressure vessel will operate at a high temperature or a high pressure, or both, solid high-strength alloy steels may be both necessary and economical.

Metallic liners are installed in various ways. They may be an integral part of the plate material rolled or explosion bonded before fabrication of the vessel, or they may be separate sheets of metal fastened to the vessel by welding. Corrosion-resistant metal can also be

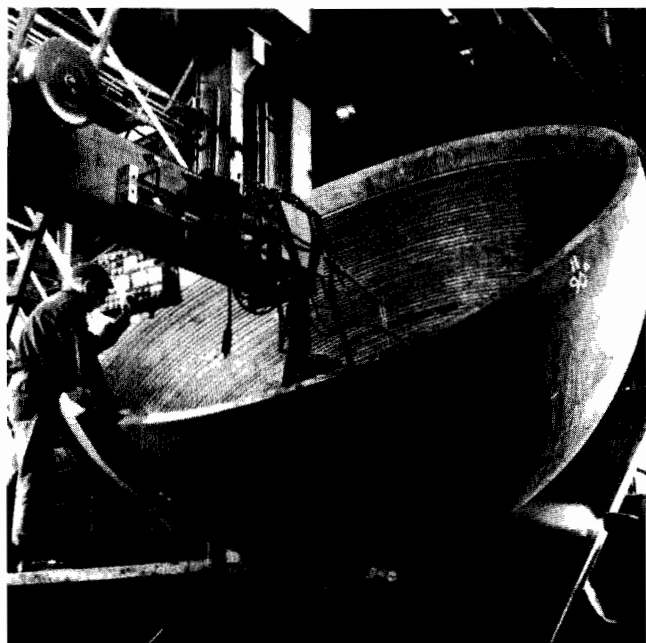


Figure 2—Weld Metal Surfacing

applied to the vessel surfaces by various welding processes. A metallic liner may be a ferritic alloy, Monel, nickel, lead, or any other metal resistant to the corrosive agent.

Nonmetallic liners may be used to resist corrosion and erosion or to insulate and reduce the temperature on the walls of a pressure vessel. The most common nonmetallic lining materials are reinforced concrete, acid brick, refractory material, insulating material, carbon brick or block, rubber, glass, and plastic. Figures 1 through 4 show various methods of applying metallic linings. Figure 5 shows a method of applying an insulating and refractory lining for catalytic regenerators.

6.3.4 INTERNAL EQUIPMENT

Many pressure vessels have no internal equipment. Others have various forms of internal equipment, such as baffles, trays, grids for supporting catalyst beds or ceramic materials, cyclones, pipe coils, spray nozzles, demister pads, and quench lines. Large spheroids may have internal bracing and ties and most vacuum vessels have either external or internal stiffening rings.

6.3.5 USES OF PRESSURE VESSELS

Pressure vessels are used in most processes in a refinery and for the storage of volatile liquids. They are used as both thermal and catalytic reactors to contain

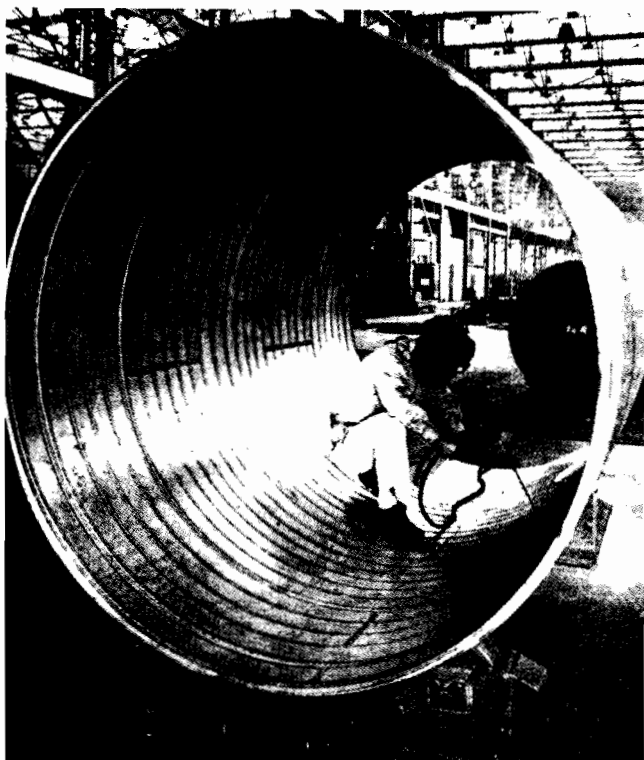


Figure 3—Strip Lined Vessel

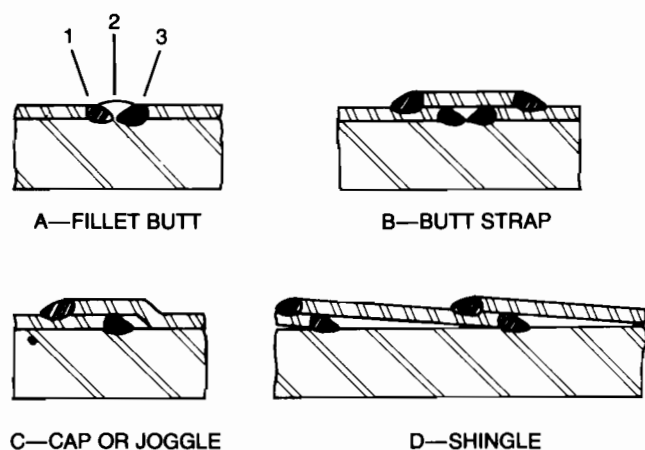


Figure 4—Principal Strip-Lining Methods

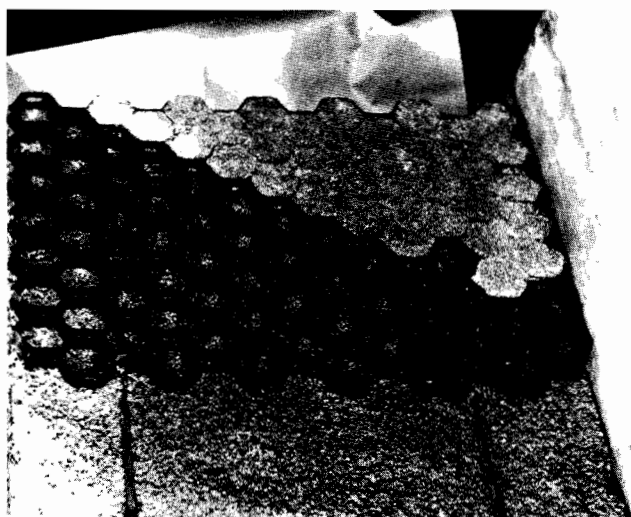


Figure 5—Insulating and Refractory Lining for Catalytic Regenerators

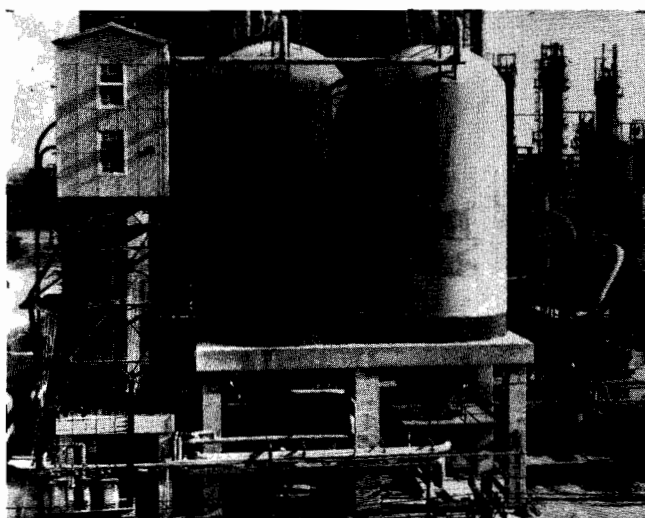


Figure 6—Catalyst Storage Hoppers

the chemical change required by the process; as fractionators to separate various constituents produced in the reaction; as separators to separate gases, chemicals, or catalyst from the product; as surge drums for liquids; as chemical treating units; as settling drums to permit separation of a chemical from a treated product; as regenerators to restore a catalyst or chemical to its original properties; and for various other purposes. Figures 6 through 13 illustrate various types of pressure vessels. Exchangers, condensers, and coolers are also pressure vessels, but are discussed separately in IRE Guide, Chapter VII.

6.4 Construction Standards

Prior to the early 1930s, most unfired pressure vessels for refineries were built to the design and specifications of the user or manufacturer. Later, most pressure vessels in the United States were built to conform either to the API-ASME *Code for Unfired Pressure Vessels for Petroleum Liquids and Gases* or to Section VIII, *Unified Pressure Vessels*, of the ASME *Boiler and Pressure Vessel Code*. Publication of the API-ASME Code was discontinued as of December 31, 1956 and it is no longer used for new vessels. Section VIII of the ASME *Boiler and Pressure Vessel Code* is divided into Division 1 and Division 2. Division 2 provides alternative and more stringent rules for the design, fabrication, and inspection of vessels. Most pressure vessels for refineries are now built in conformity with the latest edition of Section VIII, Division 1, of the ASME *Boiler and Pressure Vessel Code*. Some high-pressure vessels are designed and built in accordance with the specifications of Division 2. Generally, the application of Division 2 is limited by economic considerations to thick-wall vessels.

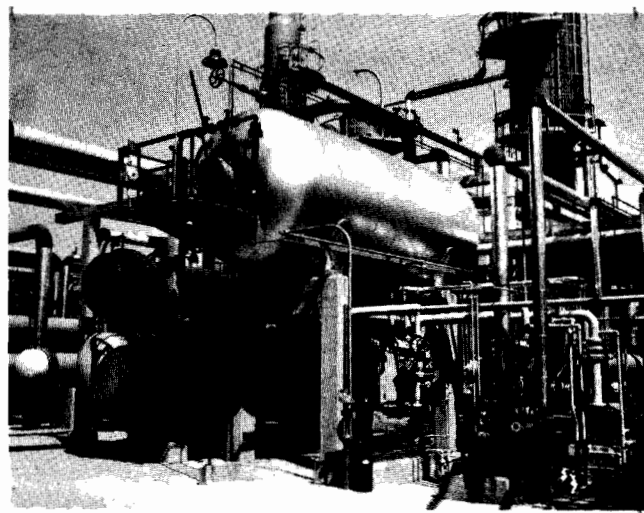


Figure 7—Horizontal Drum

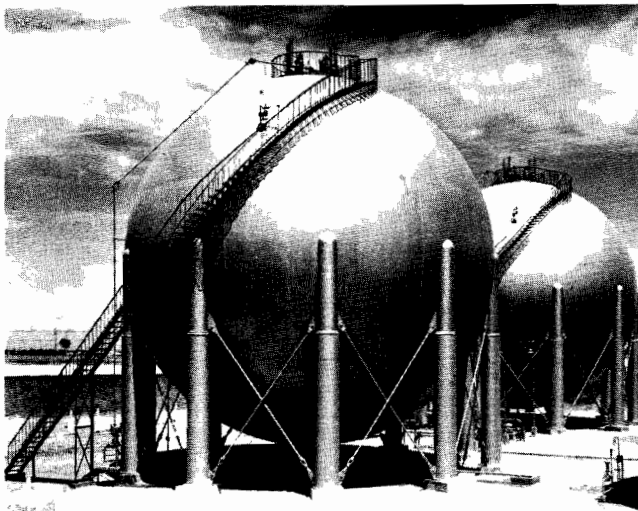


Figure 8—Spheres

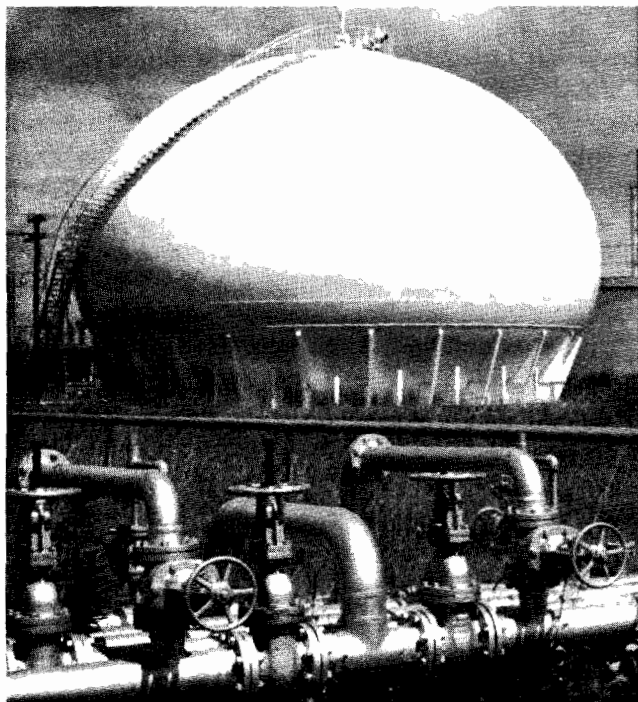


Figure 9—Spheroid

Both Divisions 1 and 2 of Section VIII require the manufacturer of an ASME vessel to have a quality control system. A written manual must be provided and the system must be implemented before the manufacturer can obtain a certificate of authorization from ASME. The quality control system requires detailed documentation of examinations, tests, and data regarding the vessel and makes available a history of the construction of the vessel. This documentation or other supplementary documentation the manufacturer may have can be helpful in the evaluation of vessels in service.

The ASME *Boiler and Pressure Vessel Code* lists materials that may be used for construction, gives formulas to be used in calculating thicknesses, provides rules on methods of manufacture, and specifies the procedures for testing completed vessels. Inspection of vessels is required during construction and testing. The code also prescribes the qualifications of the persons who perform the construction inspections.

After a qualified construction inspector certifies that a vessel has been built and tested as required by the code, the manufacturer is empowered to stamp the vessel with the appropriate symbol of the code and other pertinent data (including the year of completion). The symbol stamped on a pressure vessel is an assurance that the vessel has been designed, constructed, tested, and inspected as required by the ASME *Boiler and Pressure Vessel Code*.

Some states and cities and many countries have laws other than the regulations of the ASME *Boiler and Pressure Vessel Code* that govern the design, construction, testing, installation, inspection, and repair of pressure vessels used in their localities. These codes may supercede ASME minimum requirements.

6.5 Maintenance Inspection

Construction codes are subject to periodic revision as the knowledge of pressure vessel design improves and

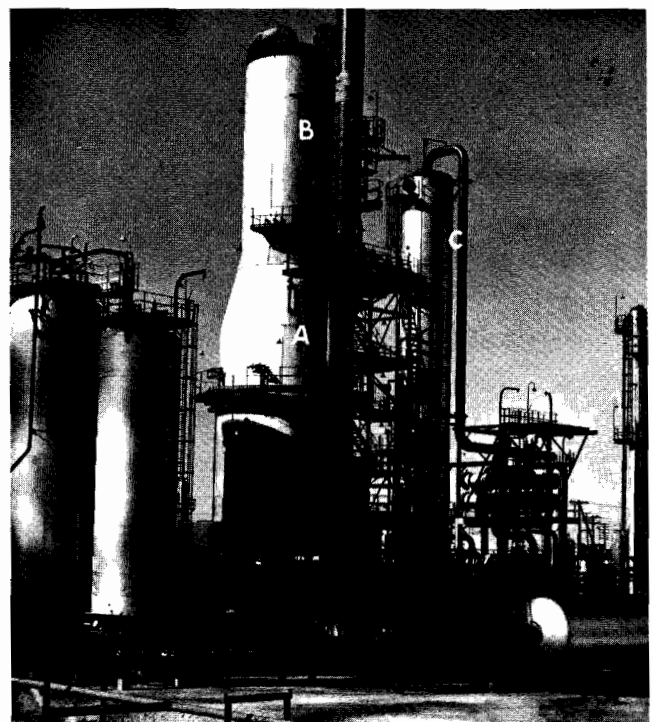


Figure 10—Catalytic Combined Reactor (A), Regenerator (B), and Tower (C)

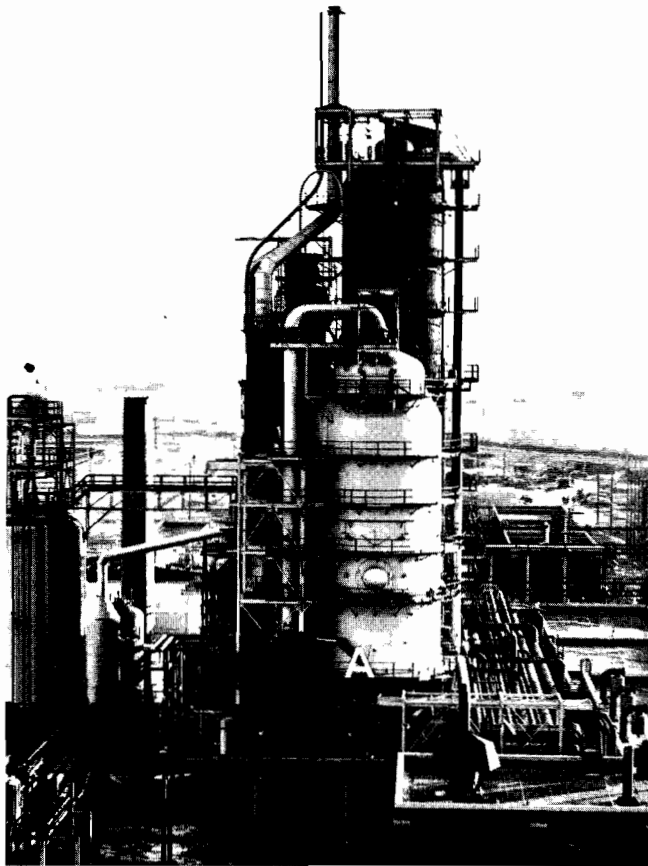


Figure 11—Fluid Catalytic Cracking Regenerator (A)

as new construction materials become available. A pressure vessel should be maintained according to the requirements under which it was designed and constructed or to the requirements under which it may have been re-rated. A refinery inspector should be familiar not only with the latest editions of existing codes but also with previous editions and other specifications under which any vessels he inspects were built. He should also familiarize himself with any regulations (including city, provincial, and state) governing inspection and maintenance of all equipment in the refinery and with the petroleum and chemical process industry inspection code, API 510, *Pressure Vessel Inspection Code, Maintenance Inspection, Rating, Repair, and Alteration*.

6.6 Reasons for Inspection

The basic reasons for inspection are to determine the physical condition of the vessel and the type, rate, and causes of deterioration. This information should be carefully documented after each inspection. With such data at hand, safety can be maintained, continuity of operation can be enhanced, the rate of deterioration

can sometimes be reduced, and future repair or replacement requirements can be predicted.

6.6.1 SAFETY

Periodic scheduled inspections can reveal conditions that if not discovered and corrected may result in hazardous leaks or vessel failures and unscheduled shut-downs. These unnecessary startups and shutdowns of equipment tend to be more hazardous than routine operation.

6.6.2 CONTINUITY

Periodic inspection can lead to a well-planned maintenance program. Corrosion rates and remaining corrosion allowances determined by inspection are the normal bases for predicting replacement or repair. These predictions provide for planned maintenance and continuity of operation.

6.6.3 EFFICIENCY

External inspections made with acoustic, ultrasonic, or radiographic instruments or other nondestructive

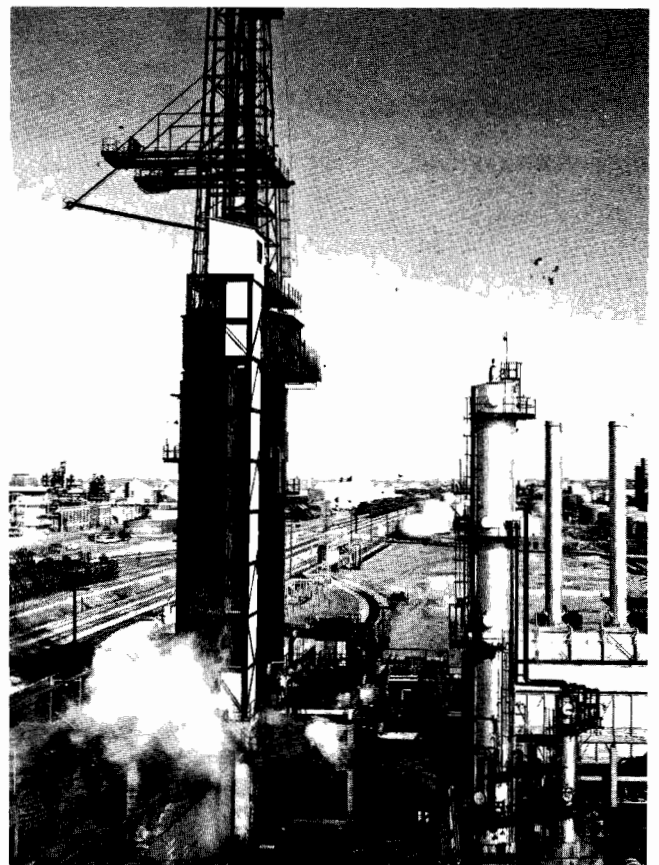


Figure 12—Coke Drum with Coke-Removal Equipment on Top

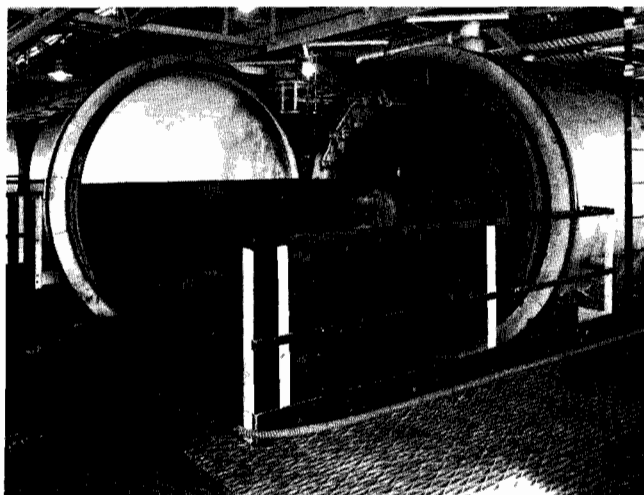


Figure 13—Rotary Filter

techniques while equipment is operating may reveal important information without requiring the equipment to be opened. Defects such as leaks, improper installation of parts, plugged lines, undue vibration, unusual noises, or other evidence of malfunctioning may be found. If these symptoms are properly analyzed and if corrective steps are taken, the overall efficiency of operations will be improved.

6.7 Causes of Deterioration

6.7.1 CORROSION

Corrosion is the prime cause of deterioration in pressure vessels. Various types of corrosion commonly experienced and the locations where each type is most likely to occur are discussed in this section. Additional information is given in IRE Guide, Chapter II.

The most common internal corrodents found in refineries are sulfur and chloride compounds. Caustics, inorganic acids, organic acids, and other chemicals used in a particular process may also cause trouble. The most frequent corrosive compounds are discussed in the following paragraphs, but as refinery processes become more complex, new corrosive chemicals are introduced. In addition, the expansion of chemical production also increases the number of corrodents present in pressure vessels.

External corrosion varies with atmospheric conditions, increasing with humidity and sometimes being accelerated by contaminants. Atmospheric conditions in industrial areas and seashore locations are especially corrosive.

6.7.1.1 Corrosion by Sulfur Compounds

Corrosion by sulfur compounds (hydrogen sulfide

being the most active) occurs in vessels such as accumulators and fractionating towers under two general conditions: (1) at temperatures below the dew point of water and (2) at temperatures above 500 F (260 C). The latter is by far the most damaging condition for most steels.

Corrosion by hot sulfur compounds at temperatures of 500-900 F (260-480 C) generally occurs in (1) the lower portions of fractionators on crude oil units, (2) catalytic and thermal cracking units, and (3) the upper portions of thermal reactors. This corrosion is usually general in nature and is most rapid where direct impingement against a vessel wall occurs.

When hydrogen is present in significant concentrations with hydrogen sulfide (as in catalytic hydrodesulfurizers and reformers), high-temperature sulfidation is accelerated. Low-chromium alloys are not resistant to this type of attack and stainless steels are often required. Thick iron sulfide scale may form on low-chromium alloys. Scale formed in this manner may spall off and plug reactor beds or exchangers.

Sulfur corrosion at a low temperature may occur in the tops of the vessel if the temperature is as low as the dew point of water. Such corrosion is often slight and easily overlooked if chloride corrosion has occurred in the area. Higher corrosion rates can occur if ammonia is present along with hydrogen sulfide, since the presence of ammonia greatly increases the solubility of the sulfide ion. The most damaging low-temperature corrosion from sulfur compounds will occur in areas where a continuously moving liquid stream contacts the vessel (for example, where condensation occurs and runs off). This type of attack may also give rise to hydrogen blistering.

6.7.1.2 Corrosion by Chloride Compounds

Corrosion by chloride compounds, mainly hydrogen chloride, occurs in areas where the temperature is below the dew point of water. It is often intense in reflux-accumulator draw-off pots, which operate at temperatures from 120-150 F (50-65 C), and on internal reflux coils. This type of corrosion is usually general in nature. Corrosion by chloride compounds may occur as rapid pitting on carbon steel surfaces. It may cause stress corrosion cracking of austenitic stainless steel. In the tops of fractionating towers this corrosion usually occurs on the portions of the shell or trays below the tray liquid level. It occurs on the shell and top head in the vapor space only when the temperature is below the dew point. Areas adjacent to welds are particularly susceptible to this type of corrosion. Grooves may occur where a continuously moving stream contacts the vessel. Such areas are found at the edges of overflow weirs or at flush nozzles where cold reflux streams are re-

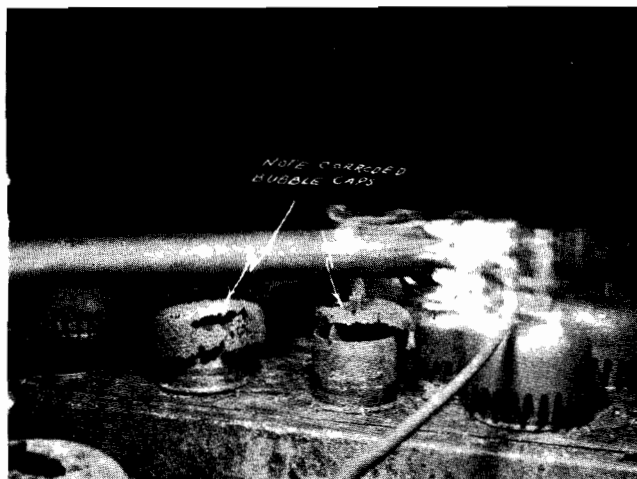


Figure 14—Chloride-Compound Corrosion

turned to the tower. Figure 14 shows an example of chloride-compound corrosion.

6.7.1.3 Corrosion by Other Acids

Certain specific acids (including sulfuric, phosphoric, and hydrofluoric acids) are used in various processes in many refineries. Acids such as sulfonic and other organic acids are formed as a result of certain process reactions. Naphthenic acids are found in many crude oils. Most of these acids will cause deterioration under certain conditions. Factors such as concentration, agitation, and temperature vary the rate of reaction.

6.7.1.4 Corrosion by a Caustic

A caustic is often used in pressure vessels for the neutralization of acidic components. In some processes a caustic is used as an extraction solvent. Occasionally, a caustic is used in grease manufacture. At temperatures below 150 F (65 C), caustics have very little corrosive effect on carbon steel. When the temperature is above 150 F (65 C), stress corrosion cracking may occur where residual stresses are high. Heat accelerates the corrosion and at points where steam coils or other hotlines enter a vessel, hotspots are particularly subject to attack. Figure 15 shows stress corrosion cracking caused by a caustic. This type of corrosion is frequently referred to as caustic embrittlement.

6.7.1.5 Low-Temperature Hydrogen Attack

Corrosion by a weak acid results in the formation of atomic hydrogen that may diffuse into the steel. When it reaches a void (such as a lamination), the atomic hydrogen immediately changes to molecular hydrogen and can no longer diffuse through the steel. The continued penetration of atomic hydrogen into the void

results in the continued formation of molecular hydrogen and increasing pressure in the void until it causes actual splitting of the steel and the appearance of blisters on the steel surface.

6.7.1.6 Graphitic Corrosion

Graphitic corrosion of cast iron occurs when operation takes place at temperatures below the dew point of water. It is most likely to occur in drums and vessels that receive cooled overhead streams from fractionators. Crude oils with high chloride content are more likely to cause this type of corrosion. Graphitic corrosion can be recognized by the soft, porous structure that remains in areas where it has occurred.

6.7.1.7 Stress Corrosion Cracking

Stress corrosion cracking is the brittle-type failure of normally ductile metals that occurs under the combined action of corrosion and tensile stress. There is no apparent deformation of the metal in this type of cracking. Stress may be residual or applied. The time required for cracking to occur may vary from minutes to years depending on the combination of stress level, corrodent, temperature, and the particular metal involved. Given the proper conditions, almost any alloy can be made to fail by a stress corrosion cracking mechanism. API RP 942 gives guidelines to help prevent stress corrosion cracking of carbon steels.

Some of the chemical agents commonly found in refinery fluids can cause stress corrosion. Perhaps the most familiar form of stress corrosion cracking is caustic embrittlement of carbon steel caused by sodium hydroxide and other strong alkalies. Aqueous ammonia solutions are potent stress cracking agents for copper alloys (particularly brasses with high zinc content). Aus-

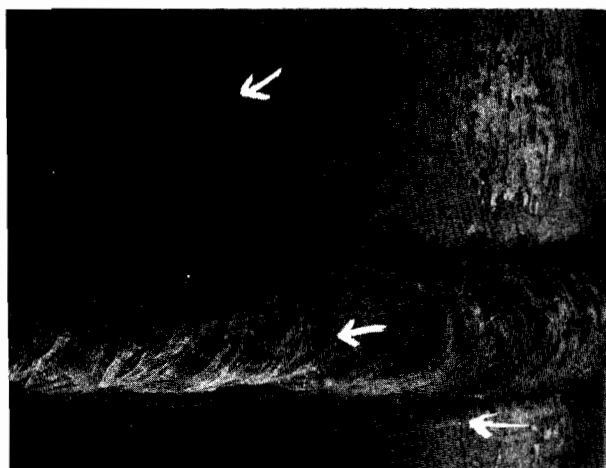


Figure 15—Caustic Stress Corrosion

tenitic chromium-nickel stainless steels are highly susceptible to cracking in the presence of chlorides. When susceptible to intergranular attack as a result of carbide precipitation and when subject to stresses and to corrosion by polythionic acids, austenitic stainless steels also crack. Aqueous hydrogen sulfide has long been recognized as causing cracks in high-strength carbon and alloy steels. Sulfide cracking is commonly associated with hydrogen penetration and embrittlement.

There are other chemicals less common in refinery fluids that can also cause stress corrosion. A few (such as amines, cyanides, nitrates, and even mercury and tin-lead solder) may occasionally cause trouble. In particular, aluminum alloys containing copper, magnesium, or zinc are susceptible to cracking when in contact with mercury or solder. Brasses are also susceptible to cracking when in contact with mercury or ammonia.

6.7.1.8 Atmospheric Corrosion

Atmospheric corrosion can occur on all external parts of a pressure vessel. The extent of this type of corrosion will depend on the atmospheric conditions in each locality. The presence of chemical fumes in the air may destroy coatings and increase the rate of corrosion. Any depression, crevice, or pocket where water can lie for long periods will be a point of likely attack.

The type of construction and support of the vessel can affect the location and extent of external corrosion. Riveted vessels though rarely built today are still in use and are susceptible to crevice corrosion. Corrosion can occur at concrete cradle or saddle supports if the crevices around such supports are not waterproofed.

Externally insulated vessels are subject to atmospheric corrosion if the insulation is not maintained in a waterproof condition. Cracks in the waterproofing permit seepage of water into the insulation and promote a corrosive environment on the metal portions of the vessel. Soluble materials leached out of the insulation may contribute to corrosion. Vessels insulated for cold service are as subject to this type of corrosion as vessels insulated for hot service, particularly if the shell temperature is below the dew point and above the freezing point of water.

6.7.2 EROSION

Erosion is the attrition of a surface from impingement of solid particles or liquid drops on the surface. It is usually found in areas where restrictions in flow, changes in direction, or disturbances result in localized high velocities. Erosion can typically be found at inlet and outlet nozzles, on internal piping, on grid or tray

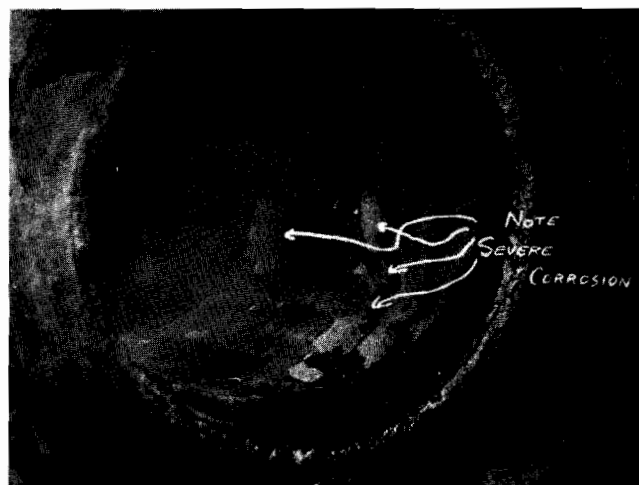


Figure 16—Corrosion

sections, on vessel walls opposite inlet nozzles, on internal support beams, and on impingement baffles.

Occasionally, corrosion and erosion combine, increasing rates of deterioration. Such a condition may exist opposite inlet nozzles in the bottom of fractionators of fluid catalytic cracking units. Figures 16 and 17 illustrate corrosion and erosion.

6.7.3 METALLURGICAL AND PHYSICAL CHANGES

Pressure vessel metals are exposed to service conditions that may cause microstructural or metallurgical changes in the metal. These changes often affect the mechanical properties of the metal and may result in cracking or other deterioration. Microstructural changes may result from either improper heating and cooling of the metal or from metallurgical chemical changes in the metal. More detailed descriptions of the

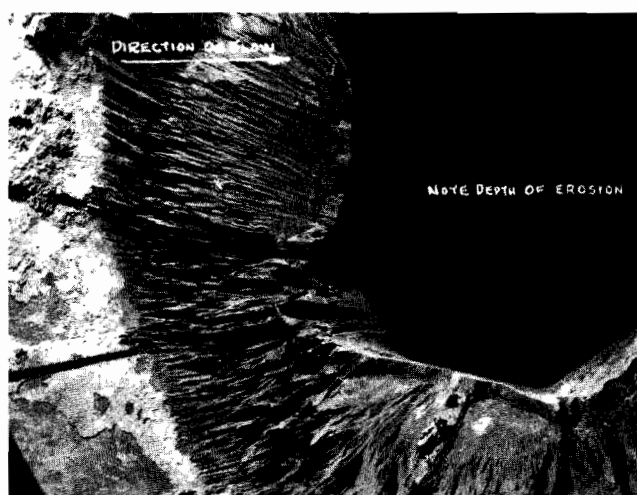


Figure 17—Erosion

types of deterioration mentioned in 6.7.3.1 through 6.7.3.4 are given in IRE Guide, Chapter II.

6.7.3.1 Graphitization

Graphitization may occur in carbon steels or carbon molybdenum steel when they are operated for long periods of time at temperatures in the range of 825-1400 F (440-760 C). Several cases of graphitization have been reported in catalytic cracking reactors and in fluid coking units.

6.7.3.2 High-Temperature Hydrogen Attack

Except in cases where blisters are formed, hydrogen attack at high temperatures cannot be detected by visual examination of the steel. The usual methods for detecting this type of attack are bend tests and microscopic examination. However, an experienced operator, using an ultrasonic instrument with an oscilloscope readout, can detect internal hydrogen damage. The number of back reflections that occur are measured on an oscilloscope and are indicative of the condition of the plate. To obtain meaningful readings, the instrument must be calibrated on new or undamaged plate. The operator of the ultrasonic equipment must have a good understanding of the acoustical absorption process.

At temperatures above 450 F (230 C), steel exposed to hydrogen can be weakened and embrittled as a result of dissociation of the hydrogen into the atomic form, diffusion of the hydrogen into the steel, and reaction of the hydrogen with carbon in the steel. Process units such as catalytic reformers, hydrodesulfurizers, hydrogenation plants, hydrofinishing units, ammonia synthesis plants, and hydrocracking units are more prone to this type of attack because they require operation of pressure vessels exposed to hydrogen at high temperatures.

The minimum temperature at which detectable hydrogen attack could occur within the normal operating life of a vessel depends upon the hydrogen partial pressure, the amount of alloy elements and impurities in the steel, the surface condition of the steel, stress, and other factors. Normally, carbon steel or an alloy steel is selected for hydrogen service on the basis of a conservative evaluation of data on limiting temperatures for hydrogen partial pressure and alloy content.

When hydrogen attack does occur, it begins with an incubation period during which the mechanical properties of the steel are not affected. This period (lasting hours, days, or years, depending upon the severity of conditions) is the time necessary for nucleation and for the development to a critical size of microscopic voids within the steel. Methane formed by the reaction of

hydrogen and carbon collects in these voids. the reaction then proceeds more rapidly and the voids grow into fissures. The strength of the steel is reduced by decarburization, and ductility is reduced by the many fissures. Sometimes blistering also occurs; the blisters in this case are caused by methane rather than hydrogen (as in the case of low-temperature hydrogen attack). API Publication 941 contains additional information on steels in hydrogen service.

6.7.3.3 Carbide Precipitation and Intergranular Corrosion

When unstabilized austenitic steels are heated in the temperature range of approximately 950-1450 F (510-790 C) or are cooled slowly through this range, a complex carbide precipitates along the grain boundaries. Although carbide precipitation in itself is not particularly harmful, steels in this condition are susceptible to intergranular corrosion by weak aqueous corrodents. In vessels, this type of susceptibility to attack may occur in the heat-affected zones adjacent to welds. Severe intergranular attack of the precipitated carbides may also occur as a result of the presence of moisture from a hydrostatic test, washing operations, or condensation in idle equipment. Under some conditions even the low carbon and stabilized grades of austenitic stainless steels can be sensitized and therefore susceptible to intergranular corrosion. Multipass welding of Types 321 or 347 can result in areas (thin lines) sensitized to knife-line attack in certain chemicals. Extremely oxidizing corrosives and severe heat treatments can result in intergranular corrosion of the low carbon grades. Figure 18 shows an example of this type of attack. In refineries, intergranular attack commonly takes the form of cracks.



Figure 18—Intergranular Corrosion

6.7.3.4 Embrittlement

High chromium ferritic steels, such as Types 405, 410, and 410S, are susceptible to embrittlement after prolonged exposure in the 800-950 F (370-510 C) range. This phenomenon is referred to as 885 F embrittlement and is related to the precipitation of a microscopic chromium-rich phase. The embrittlement is reversible by heating the affected steel to a temperature well above the upper temperature at which embrittlement may occur. Temper embrittlement of low chrome alloy steels, such as 2 1/4 percent chromium-1 percent molybdenum and 1 1/4 percent chromium-1/2 percent molybdenum can also occur.

6.7.4 MECHANICAL FORCES

Mechanical forces can cause a vessel to fail or to operate inefficiently if adequate provision for such forces has not been made. Thermal shock, cyclic temperature changes, vibration, excessive pressure surges from any cause, and external loads are examples of reasons for such forces. Cracks, bulges, distortion, and upset internal equipment are visual evidences of the application of mechanical forces. Detailed descriptions of the causes for mechanical forces are found in IRE Guide, Chapter II, and are only briefly referred to here.

6.7.4.1 Thermal Shock

Thermal shock is caused by a sudden marked change in temperature (either from hot to cold or from cold to hot). The stresses resulting from the sudden unequal expansion or contraction of the different parts of a vessel may cause only distortion or distortion resulting in cracking. Thick vessels are more susceptible to cracking than thin ones. Thermal shock may also damage the internals of a vessel by tearing them loose from their supports or by warping the internals to the extent that they are inoperative. Vessels that operate at relatively hot or cold temperatures are most likely to receive thermal shocks. Typical of vessels in this category are those in coking service. In the case of other vessels the most likely time of temperature shock is during unit startups. Consideration should be given to limiting heating or cooling rates. Figure 19 shows an example of distortion caused by thermal shock.

6.7.4.2 Cyclic Temperature Changes

Vessels that operate under cycling temperature conditions (particularly over a wide range) may develop cracks because of thermal fatigue. Cracks start at the surface of the material, progressing slowly at first and then more rapidly with each cycle of temperature change. Also, thermal fatigue is often found at locations

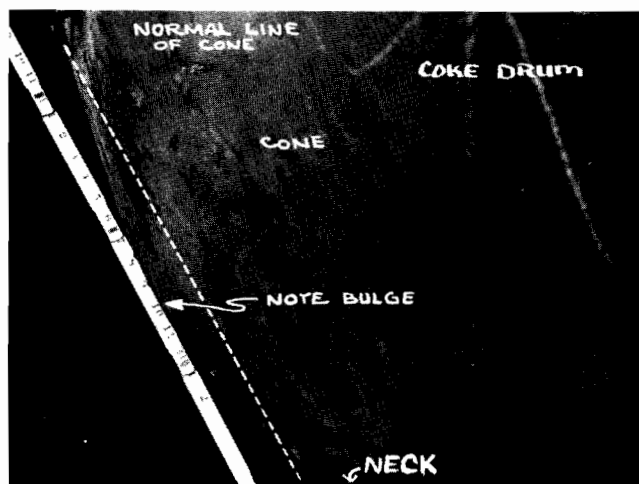


Figure 19—Damage Caused by Thermal Shock

where metals that have different coefficients of expansion are joined by welding; the cracks sometimes start when a vessel is shut down and cooled off. Figure 20 is an example of fatigue cracking.

6.7.4.3 Vibration

Vibration, present in many piping systems, may transmit forces to vessels and may cause undue loads on nozzles, internal piping, or the vessel wall. Excessive vibration is most likely to occur in systems that include reciprocating pumps, mixers, or compressors. The vibration may cause fatigue cracking of piping attachment nozzles as shown in Figure 20. Vibration may also cause cracking of a vessel wall, upset internals, or crack internal piping. Hydroformers, ammonia synthesis units, certain types of catalytic cracking units, and gas-compression systems are typical units in which large reciprocating machines may be used and in which vibrating forces may occur.

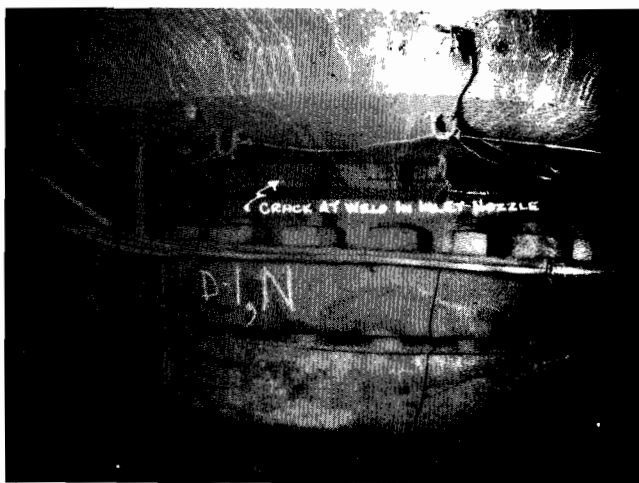


Figure 20—Fatigue Cracking at Nozzle

6.7.4.4 Pressure Surge

Rapid pressure surge or the failure of relief valves to open promptly at the set pressure may result in internal pressures in excess of the design pressure for equipment. These conditions may result in upsetting internal equipment or bulging the vessel wall.

6.7.4.5 Excessive Temperature

Operation of equipment at temperatures in excess of the design limits (even without higher pressure) may cause bulging of vessel walls if the strength of the walls is greatly decreased at the temperature attained. When vessel walls are protected against excessive temperature by internal insulation, failure of the insulation will result in localized overheating of the metal wall; this area is commonly referred to as a hot spot. The excessive temperature can cause reduced strength of the metal and may result in bulging, scaling, metal deterioration, or failure.

6.7.4.6 External Loading

External loading may be transmitted to vessels in many ways. Supporting pedestals, skirts, lugs, or support brackets for smaller vessels may all exert external loading on vessel walls. Wind is seldom of great importance except on tall or slender vessels. Horizontally supported vessels can slump over the horns of inadequately sized saddles especially when the vessel is filled with water for a hydrostatic test. Supports can be damaged where they do not allow for the thermal expansion of the vessel in high temperature service. However, trouble caused by these factors is not common because these loading conditions are normally considered in the design of the equipment. The weight and thermal expansion of connected piping systems transmit forces to the vessels. Platforms, walkways, and ladders are also sources of secondary external loading. Evidence of distortion or cracking caused by these forces would be most likely to occur at the point of attachment to the vessel.

External loading induced by foundation settling (although occurring only occasionally) can be more serious. Such loading can cause distortion or cracking of a vessel wall at nozzle connections. It can also cause buckling of the vessel supports. If the supports are concrete, cracking of the support is the most likely form of failure to expect. Settling is most likely to occur when equipment is supported on filled or marshy ground without the benefit of properly designed foundations or pilings.

6.7.5 FAULTY MATERIAL

Many of the troubles that may develop in pressure vessels are traceable to faulty material or fabrication.

Some of the troubles that may develop from such faults are cracking, leakage, blockage, and excessive corrosion.

The material used in the construction of a vessel may contain laminations located at a distance from the edges of a plate, and these laminations may not be discovered before or during fabrication. After the vessel has been in operation, these laminations may start to open and give the appearance of a crack; these openings travel at a slant rather than at right angles to the surface of the plate.

Castings may contain defects that are not visible on the surface. After corrosion has occurred, such defects may result in leaks. If the leaks are of sufficient magnitude or if many occur in close proximity, they may result in failure.

Lack of experience with a new process may result in the choice of an improper material that may lead to excessive corrosion. Unsuitable materials for repair work may also lead to excessive corrosion or to failure because the physical properties of the materials are unsuitable.

6.7.6 FAULTY FABRICATION

Faulty fabrication includes poor welding, improper heat treatment, dimensions outside the tolerances allowed by the ASME *Boiler and Pressure Vessel Code*, improper installation of internal equipment, and improper fit assembling flanged or threaded joints.

6.7.6.1 Poor Welding

The use of improper welding techniques or careless welding may result in incomplete penetration, lack of fusion, undercutting, slag inclusion in the welds, and porous welds. Any of these conditions may result in cracking or failure. Figure 21 shows cracks in the weld-

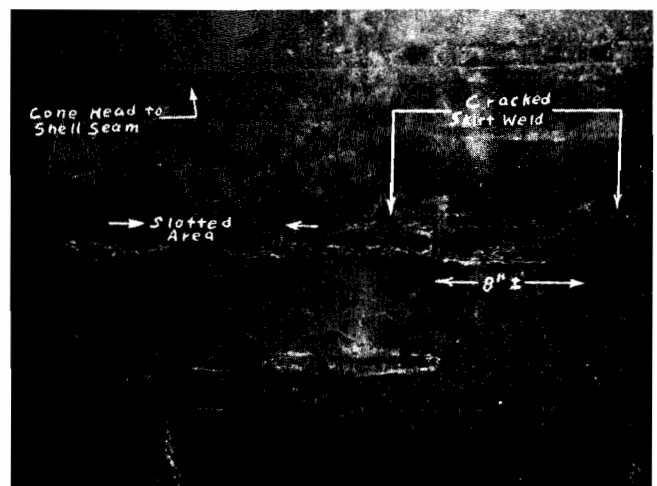


Figure 21—Cracks in Vessel-Skirt Welds

ing attaching a skirt sheet to the vessel. The cracks resulted from a combination of poor welding quality aggravated by thermal fatigue.

6.7.6.2 Improper Heat Treatment

Improper heat treatment may leave high residual stresses in the vicinity of welds or may affect either the physical properties or the corrosion resistance of the metal. High residual stresses may produce latent cracks (particularly around nozzle and reinforcement attachments) that may not be detected until the vessel has been operated for some time. Under corrosive conditions, high residual stresses may also lead to stress corrosion cracking. Changes in physical properties will usually be in the form of a more brittle material that may crack under shock. A change in corrosion-resistant properties may result in more rapid corrosion than anticipated.

Materials heated above the proper heat-treating temperature or held for too long a period at the proper temperature can be adversely affected to the extent that the physical properties may not meet specifications.

6.7.6.3 Dimensional Tolerance

Poor fabrication techniques can cause tolerances outside of those permitted by the ASME *Boiler and Pressure Vessel Code*. This can lead to stress concentrations and may lead to subsequent failure.

6.7.6.4 Improper Installation

Improper installation of internal equipment may result in inefficient operation, blockage of passages, and in the case of a pressure surge the displacement of the internal equipment.

6.7.6.5 Improper Fit

Improper fitting or tightening of flanged or threaded joints may result in leaks and in the case of threaded joints to complete failure.

6.8 Frequency and Time of Inspection

6.8.1 FACTORS GOVERNING FREQUENCY OF INSPECTION

The frequency with which a pressure vessel should be inspected depends on several factors, the most important being the rate of deterioration and the remaining corrosion allowance (see API 510). The corrosion rates will vary markedly with the types of crude oil or stocks being processed, the temperature of exposure, and the materials of construction. Local factors must be

individually appraised in establishing the initial inspection period for new equipment.

A service history record can be established after several inspections either by onstream methods or by internal examinations, or both. On the basis of this history, a regular inspection interval can be set to suit local conditions. The period between inspections should be planned so that some corrosion allowance remains when the vessel is taken out of service for inspection. The minimum margin of corrosion allowance should be a function of the corrosion rate and the predetermined frequency of inspection to allow for unanticipated changes in corrosion rates, uneven corrosion, or the like. Insurance and legal requirements may control the care of pressure vessels. Those responsible for inspection and maintenance of equipment should familiarize themselves with the applicable requirements. Recommendations in API 510, in the *National Board Inspection Code* of the National Board of Boiler and Pressure Vessel Inspectors, and in any jurisdictional requirements may be appropriate.

When changes in process operations are expected, they should be studied to determine whether they may affect the deterioration rate. When a change in the deterioration rate is anticipated, the recommended inspection interval should be changed accordingly.

Visual checks of the external parts of a vessel should be made frequently. Such inspections can be made without removing the vessel from service. These inspections may be made at comparatively short intervals, the interval depending on the service and previous conditions of the particular equipment involved.

On most units, operating needs such as minimum permissible internal functional cleanliness, maintenance of required heat-transfer rates, unexpected blockages, planned changes, and so forth will determine the length of a run. These requirements may fix the inspection interval on most vessels to the run length or to integral multiples of the run length if the runs are approximately uniform in length.

6.8.2 INSPECTION SCHEDULE

Scheduling internal inspections to coincide with downtimes for cleaning and reconditioning purposes is usually necessary and desirable. If an unscheduled shutdown occurs as a result of mechanical or process difficulties, checks of vessel areas where rapid corrosion, erosion, or other deterioration is known or suspected to occur may be made. Partial shutdowns of units for process reasons also provide opportunities for making some internal inspections to determine conditions, to verify onstream inspection findings, or to make needed repairs.

Inspection of external parts may be made while a vessel is in service. These inspections should include items such as the condition of the foundation, supports, insulation, paint, ladders, platforms, and other structural elements. The existence and location of abnormally high metal temperatures or hot spots on internally insulated units can also be detected. Any inspection work performed while the unit is in operation can reduce the workload when the unit is shut down for general maintenance work. Onstream inspection methods may be used successfully in detecting defects and measuring wall thicknesses. For example, thicknesses can be determined by using ultrasonic equipment or shadow shot radiography, where applicable.

An occasional check of operating records while a unit is running is sometimes helpful in locating the cause of functional deterioration. Increased pressure drop in towers can indicate a blockage that may be caused by corrosion products. Therefore, the inspector should always keep in close touch with those in charge of operations.

New vessels should be inspected at a reasonable time interval after being placed in service. This interval will depend on the service; past records on similar units may be used as a guide. All pertinent jurisdictional regulations should be observed.

Scheduling of shutdowns for maintenance or inspection is usually arranged through joint collaboration of the process and mechanical departments with inspection personnel. Occasionally, seasonal demands for certain products may make some units available for maintenance work and inspection at certain times without excessive interruption of operations. Naturally, an effort should be made to schedule unit shutdowns evenly throughout the year to lighten the workload on the mechanical and inspection groups.

In some instances, inspection schedules may be affected by regulatory requirements. However, operating requirements will usually fix the shutdown schedule and subsequent inspection schedule (subject to inspection-frequency requirements).

Corrosion rates and remaining thicknesses may at times determine shutdown intervals, particularly in units having extremely high corrosion rates. However, this will not usually be the case if these factors are watched with reference to the unit's normal operating period.

6.9 Methods of Inspection and Limits

Before starting the inspection of a pressure vessel, particularly one in severe service, the inspector should determine the pressure and temperature conditions under which the vessel has been operated since the last

inspection. He should also ascertain the character of the vessel contents and the function the vessel serves in the process. He should confer with the operators to determine whether there have been any abnormal conditions or upsets (such as excessive pressures or temperatures) and other pertinent data. These facts may offer valuable clues to the type and location of corrosion and to other forms of deterioration (scaling, bulging, warping, and so forth) that may have occurred. The inspector should develop and exercise sound judgment on the extent and kinds of inspection required for each vessel.

Careful visual inspection of every vessel is of paramount importance to determine other measures that may need to be taken. Adequate surface preparation is essential to proper visual examination and to the satisfactory application of some auxiliary procedures, such as magnetic-particle or dye penetrant inspection methods. The extent to which special surface preparation may be required is dependent on the particular circumstances involved. Wire brushing, sandblasting, chipping, grinding, or a combination of these operations may be required in addition to routine cleaning.

If external or internal coverings, such as insulation or refractory or corrosion-resistant linings, are in good condition and there is no reason to suspect an unsafe condition behind them, it is not necessary to remove them for inspection of the vessel. However, in the case of nonmetallic coverings, it may sometimes be advisable to remove small portions to investigate their condition and the condition of the metal behind them. When any covering (metallic or nonmetallic) is found to be defective, a sufficient amount of the covering in the vicinity of the defect should be removed to ascertain whether the base metal is deteriorating and the extent of the deterioration.

Where operating deposits such as coke are normally permitted to remain on a vessel surface, it is important to determine the condition of the vessel surface behind the deposits. This may require thorough removal of the deposit in selected critical areas for spot-check examination.

Where vessels are equipped with removable internals, the internals need not be completely removed, provided reasonable assurance exists that deterioration in regions rendered inaccessible by them is not occurring to an extent beyond that found in more readily accessible parts of the vessel.

The number of thickness determinations needed will depend largely on the corrosion pattern found in the vessel. In some cases of an extensively corroded area, an average of the least thicknesses found in the area may sometimes be considered as the thickness of the corroded area. Scattered or isolated corrosion pits

should be evaluated on the basis of their depth, number, and rate of progression.

6.9.1 SAFETY PRECAUTIONS AND PREPARATORY WORK

6.9.1.1 Safety

Safety precautions must be taken before entering a vessel. Because of limited access and confined spaces, safety precautions are probably more important in vessel inspection work than in the inspection of any other type of equipment.

The vessel should be isolated from all sources of liquids, gases, or vapors, using blinds or blind flanges of a suitable pressure-temperature rating. The vessel should be drained, purged, cleaned, and gas tested before it is entered. This will minimize danger from toxic gases, oxygen deficiency, explosive mixtures, and irritating chemicals. Clothing that will protect the body and eyes from the hazards existing in the vessel to be entered should be worn. Details of the precautions to be followed are covered in IRE Guide, Chapter V.

On occasion, it may be desirable to enter a vessel before it has been properly cleaned to search for internal causes of poor operation. This may be done by exercising the special precautions for such entry as given in IRE Guide, Chapter V.

The use of nondestructive devices for inspection is subject to safety requirements customarily followed in gaseous atmospheres. The safety measures listed in IRE Guide, Chapter V should be followed.

Before starting the inspection, all persons working around a vessel should be informed that men will be working inside the vessel. The posting of tags on the manways of tall towers is a worthwhile precaution. Frequently a helper can be stationed as a guard at the manway nearest the area under inspection and can record the data from the inspection findings. Men working inside a vessel should be informed when any work is going to be done on the exterior of the vessel to prevent their becoming alarmed by unexpected or unusual noise.

6.9.1.2 Preparatory Work

The tools needed for vessel inspection should be checked prior to the inspection for availability and proper working condition. This includes those tools and equipment needed for personnel safety. Similarly, necessary safety signs should be provided in advance of starting work in vessels.

Tools for use in inspection work are discussed in IRE Guide, Chapter IV. Specifically for pressure vessel inspections, the tools listed in Table 1 should be available

Table 1—Tools for Inspection of Pressure Vessels

Portable lights (including a flashlight)	Ultrasonic thickness-measurement equipment
Thin-bladed knife or silver	Steel rule
Broad chisel or scraper	Pit depth gage
Pointed scraper	Paint or crayon
Inspector's hammer	Notebook and pencil
Inside calipers	Straightedge
Outside calipers	Wire brush
Pocket knife	Plumb bob and line
Steel tape 50 feet (15 meters)	Magnet
Flange square	

Table 2—Tools Available If Required

Surveyor's level	Temperature-indicating crayons
Carpenter's or plumbers level	Thermocouples
Magnetic-particle inspection equipment	Metal sample cutting equipment
Micrometer	Material identification kit
Radiographic equipment	Camera
Megger ground tester	Portable hardness tester
Magnifying glass	CRT ultrasonic flaw detection instrument
Sandblasting equipment	
Dye-penetrant inspection equipment	

for most vessel inspections. Those listed in Table 2 should be available if the need for their use arises.

Other related equipment that might be provided for inspection includes planking, scaffolding, bosun's chairs, and portable ladders. If external scaffolding is necessary, it may be possible to erect it before the inspection starts.

6.9.2 EXTERNAL INSPECTION

As indicated in 6.8, much of the external inspection can be made while the vessel is in operation. Inspection made at this time will minimize the period during which the vessel will be out of service.

6.9.2.1 Ladders, Stairways, Platforms, and Walkways

The external inspection of pressure vessels should start with ladders, stairways, platforms, or walkways connected to or bearing on the vessel.

A careful visual inspection should be made for corroded or broken parts, cracks, tightness of bolts, condition of paint, wear of ladder rungs and stair treads, security of handrails, and condition of flooring on platforms and walkways. Visual inspection should be supplemented by hammering and scraping to remove oxide scales or other corrosion products. The tightness of bolts can be determined by tapping or trying the nuts with a wrench. Wear on metal stair treads and flooring not only may result in loss of strength but may cause them to become slippery when worn smooth.

Corrosion is most likely to occur at points where moisture can collect. On ladders and stairs, corrosion is likely to be most intense where rungs or treads fit into the runners or stringers. Crevice corrosion may exist around the heads of bolts and nuts, at bracket connections between stair treads and angle supports, and at connections between intermediate supports and the vessel wall. Welded bracket connections are particularly susceptible to corrosion as the welds are usually rough and it is difficult to obtain a good, void-free paint coating on them. Corrosion may exist beneath a paint film and will be indicated by rust stains showing through the paint or by a blistering or a general lifting of the paint film.

The condition of most parts can be determined by hammering. Where corrosion appears to be severe, the actual thickness should be determined by caliper or by other means. More detailed information concerning inspection of external equipment is covered in IRE Guide, Chapter XII.

6.9.2.2 Foundations and Supports

Foundations for vessels are almost invariably constructed of steel-reinforced concrete or of structural steel fireproofed with concrete. They should be inspected for deterioration such as spalling, cracking, and settling.

Spalling can be caused by excessive heat, mechanical shock, corrosion of reinforcing steel too close to the surface, or by the freezing of entrapped moisture. Inspection for this type of damage consists of visual observation and scraping. Measurements of the depth of such damage can usually be made with a straight-edge or a steel rule.

Cracks may be caused by excessive heat, poor design or material, mechanical shock, and unequal settlement. Inspection for cracks is mostly visual. Some picking with a pointed scraper may be helpful.

Cracks caused by high temperature or by temperature changes can usually be identified by their hairlike appearance. Such cracks are not usually serious unless they are open to the extent that the steel reinforcement is exposed to corrosion.

When major cracks appear and propagate and measurements indicate that no settlement has taken place, the cracks are probably the result of poor design or poor material. A complete check or engineering study may be required. If such investigations show that the design is correct, the cracks are most likely caused by the use of poor concrete material. Careful visual examination and minor chipping with a hammer will usually suffice to confirm the diagnosis, but removal of a core for test purposes may be required.

Some settling is expected in any foundation. When settlement is even and of a nominal amount, no trouble should be experienced. However, if it is excessive or uneven, the situation should be corrected before serious damage occurs. Records of settlement should be maintained on vessels known to be settling. A rough check for uneven settling can be made with a plumb line and steel rule. When accurate measurements are desired, a surveyor's level may be used. When settlement is appreciable, it can be observed by noting the misalignment of the foundation with the surrounding paving or ground. The frequency with which settlement measurements are taken will depend on the rate and the seriousness of the settlement. Measurements should be taken until the settlement stops. Vessels supported on long concrete slabs or on two or more separate foundations are more likely to undergo uneven settlement.

Spalling, cracking, and settling are covered in more detail in IRE Guide, Chapter XII. When settlement has occurred, the condition of connecting lines should be checked. This is covered in a general discussion of nozzles in 6.9.2.7.

6.9.2.3 Anchor Bolts

Although the condition of anchor bolts cannot always be determined by visual inspection, the area of contact between the bolts and any concrete or steel should be scraped and closely examined for corrosion. This will not reveal the condition below the top surface of the baseplate or lugs; however, a sidewise blow with a hammer may reveal complete or nearly complete deterioration of the anchor bolt below the baseplate (see Figure 22). Distortion of anchor bolts may indicate serious foundation settlement. The nuts on anchor bolts should be inspected to determine whether they are properly tightened.

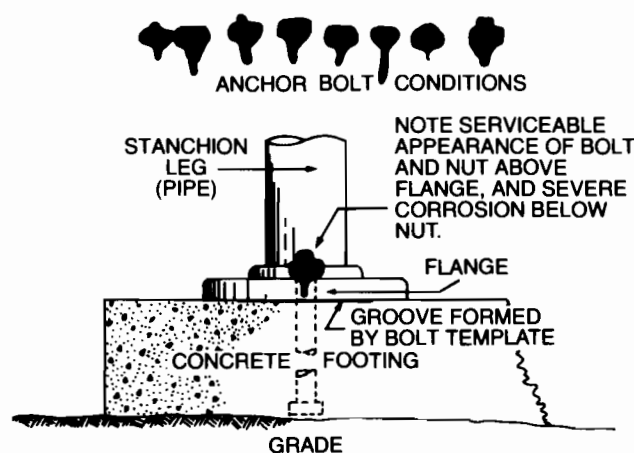


Figure 22—Severe Deterioration of Anchor Bolts

6.9.2.4 Concrete Supports

Inspection of concrete supports is similar to inspection of concrete foundations. The opening between concrete supports and a vessel shell or head should be sealed to prevent water from seeping between the supports and the vessel. A visual inspection with some picking and scraping should disclose the condition of this seal. A concentration cell could be set up at such a point causing rapid corrosion.

6.9.2.5 Steel Supports

Inspection of steel supports is a little more complicated than the inspection of concrete supports. Steel supports should be inspected for corrosion, distortion, and cracking.

The remaining thickness of corroded supporting elements (skirts, columns, and bracing) is of primary importance. This measurement can usually be determined by taking readings with transfer or indicating calipers in the most severely corroded areas. The readings should be compared with the original thickness (if known) or with the thickness of uncorroded sections to establish a corrosion rate. Visual examination of the support surfaces should be supplemented with wire brushing, picking and tapping. On large skirt supports, ultrasonic thickness-measuring devices can be used. Often corrosion of structural elements can be virtually eliminated simply by keeping the structural elements properly painted.

Columns and load-carrying beams should be inspected for buckling or excessive deflection. This can be done visually with the aid of a straightedge or plumb line where necessary. Distortion of round skirts can be checked by taking diameter measurements at several points approximately 60 degrees (1.0 radian) apart.

The inside surface of a skirt sheet is often subject to attack by condensed moisture. This is particularly true when the temperature in the enclosed area is less than approximately 100 F (40 C) or when steam is put in the skirt to warm the bottom of the vessel. Visual inspection will usually disclose the condition of the metal surface. If a scale or rust layer has built up, it should be wire brushed or scraped off before the inspection is made.

Vessel support lugs should be inspected to see that they are sound. Scraping will usually reveal corrosion. Tapping with a hammer will disclose extreme thinning. Connecting fasteners should be checked for corrosion and general tightness. Any crevices found should be examined by picking to check for crevice corrosion.

Cracks can occur in all types of supporting structures and lugs. However, they are most likely to appear in welded structures. The welds and the areas adjacent to

the welds are the places to look for cracks. If the vessel is in service, the inspection will probably be limited to visual methods of detecting cracks. Magnetic-particle or penetrant-dye methods may be used to supplement visual examination. The use of these methods will often require further surface preparation.

If supporting skirts are insulated, the insulation should be inspected. Visual inspection will usually disclose any deterioration of the insulation. If there is reason to suspect that water or moisture is seeping through to the steel, enough insulation should be removed to determine the extent of the corrosion that may be present.

The condition of fireproofing on support beams and skirts should be inspected. Such fireproofing is usually made of bricks or concrete. Visual examination aided by scraping will disclose most defects. Very light taps with a hammer will disclose lack of bond between concrete fireproofing and the protected steel. If moisture can get behind the fireproofing, the steel may corrode. Such corrosion may cause bulging of the fireproofing. It can sometimes be detected as a result of this bulging. Rust stains may appear on the surface of the fireproofing from corrosion of the metal underneath; stains help to locate such a corrosive condition.

6.9.2.6 Guy Wires

Most vessels are self-supporting structures but some towers or columns are guyed for support by steel cables. These cables radiate to the ground and end in the concrete deadmen beneath the ground surface. The connections to the tower and to each deadman should be inspected for tightness and strength. Visual examination should be sufficient. The cable should be inspected for corrosion and broken strands. The threaded parts of any turnbuckles are subject to crevice corrosion. Picking with a pointed scraper will disclose this condition.

6.9.2.7 Nozzles

Nozzles and adjacent shell areas should be inspected for distortion and cracking if any settling of the vessel has occurred. Excessive pipeline expansions, internal explosions, earthquakes, and fires may also damage piping connections. Flange faces may be checked with a flange square for distortion. If there is any evidence of distortion or cracks in the area around the nozzles, all seams and the shell in this area should be examined for cracks. The area should be sandblasted or wire brushed. Magnetic-particle, shear wave ultrasonics, or dye-penetrant techniques may be used to supplement visual examination.

Exposed gasket surfaces should be checked for scoring and corrosion. The surfaces should be cleaned

thoroughly and carefully for a good visual inspection.

If loss in wall thickness in nozzles is suspected, the wall thickness should be measured. Calipers, ultrasonic instruments, or radiography can be used.

Leaks are likely to occur at flanged or threaded piping attachments to the vessel wall. Leaks can best be located visually while the vessel is in service or under test conditions (see 6.9.4.2).

6.9.2.8 Grounding Connections

- Grounding connections should be visually examined to see that good electrical contact is maintained. These connections provide a path for the harmless discharge of lightning or static electricity into the ground. The system usually consists of a stranded copper conductor bolted to the vessel and the other end brazed or bolted to an iron or copper rod placed deep in the ground. The cable should be examined for broken strands. Its resistance may be checked at intervals. Reference should be made to IRE Guide, Chapter XIV for suggestions for measuring the resistance of the system.

6.9.2.9 Protective Coatings and Insulation

The condition of the protective coating or insulation on a vessel shell should be determined. Rust spots, blisters, and film lifting are the types of paint failures usually found. Rust spots and blisters are easily found by visual examination. Film lifting is not easily seen unless the film has bulged appreciably or has broken. It can be found by picking at the film with a scraper or knife in the suspected areas. Scraping paint away from blisters and rust spots often reveals pits in the vessel walls. The depth of such pitting can be measured with a pit gage or a depth gage. The most likely spots to search for paint failure are in crevices, in constantly moist areas, and at welded or riveted vessel seams. The bottom heads of vessels supported on skirts in humid locations are other likely points of paint failure.

Visual examination of insulation is normally sufficient to determine its condition. A few samples may be removed to better determine the condition of the insulation of the metal wall under it. The supporting clips, angles, bands, wires, and so forth should all be examined visually for corrosion and breakage. Occasionally, special blocks of insulation may be installed in such a way as to be easily removable. These blocks are installed at points (usually at welded seams) where it is desirable to make periodic inspections.

6.9.2.10 External Metal Surfaces

The external metal surfaces of a vessel may be inspected visually, supplemented by picking, scraping,

and limited hammering to locate corroded areas. If conditions warrant, scaffolding may be erected around a vessel to permit access to all surfaces.

The degree of surface preparation required for external inspection will depend on the type and extent of deterioration expected. Under normal conditions, thorough cleaning to bare metal will be needed only at those points where thickness measurements are taken. When cracking or extensive pitting is suspected, thorough cleaning of large areas (possibly the entire vessel shell) may be required.

Hand tools such as a pointed scraper, inspector's hammer, wire brush, scraper, and file can be used to clean small spots. For larger areas, power wire brushing or sandblasting will usually be cheaper and more effective than hand tools.

Any evidence of corrosion should be investigated and the depth and extent of the corrosion should be determined.

Thickness measurements of the vessel walls and heads are usually required at each complete vessel inspection. Whether these measurements are taken from the outside or inside of a vessel will depend on the location and accessibility of the corroded areas.

Under normal conditions, at least one measurement in each shell ring and one measurement on each head should be taken. However, if much corrosion is evident, it is desirable to take several readings in the most corroded areas. Ultrasonic instruments may be used for these measurements.

6.9.2.11 External Evidence of Corrosion

There are certain types of corrosion that may be found on external surfaces of a vessel. Among these are atmospheric corrosion, caustic embrittlement, hydrogen blistering, and soil corrosion. These types of corrosion are covered in detail in IRE Guide, Chapter II.

The extent of atmospheric corrosion on the outside of a vessel will vary with local climatic and service conditions. In humid areas and in areas where corrosive chemical vapors are present in the air, corrosion of external shell surfaces may be a problem. Vessels operating in a temperature range that will permit moisture to condense are most susceptible. Corrosion of this type is easily found by visual inspection.

If a caustic is stored or used in a vessel, the vessel should be checked for caustic embrittlement. This type of attack is most likely to occur at connections for internal heating units and in areas of high stress (residual or otherwise). The more susceptible areas are around nozzles and in or adjacent to welded seams. Frequently, visual inspection will disclose this type of attack. The caustic material seeping through the cracks will often

deposit white salts that are readily visible. Magnetic-particle and dye-penetrant methods may also be used to check for caustic embrittlement.

Those areas below the liquid level in vessels containing acidic corrodents are more likely to be subject to hydrogen blistering. Hydrogen blistering is more often found on the inside rather than on the outside of a vessel but may be found at either place depending on the location of the void that causes this condition. Blisters are found most easily by visual examination. A flashlight beam directed parallel to the metal surface will sometimes reveal blisters. When many small blisters occur, they can often be found by running the fingers over the metal surface.

Attention should be given to metal surfaces in contact with concrete saddles. In humid atmospheres, severe attack at the points of support may require weld repairs and subsequent application of protective coatings.

Vessels that are partially or completely underground are subject to soil corrosion wherever they are in contact with the ground. This corrosion will be particularly intense in areas where cinder fills were used or where acid splash over has occurred. Inspection of the vessel surface will require thorough cleaning. Sandblasting will usually provide the best surface preparation. Visual examination, supplemented by much picking and tapping, will disclose most faults. The location of any deep pitting should be recorded. Good judgment should be used in determining how much of the surface should be uncovered to permit this inspection. The most severe corrosion will usually be found at ground level or several inches below it.

In addition to corrosion, the external surfaces of the vessels should be examined for leaks, cracks, buckles, bulges, defects in the metal plates, and deformation and corrosion of any external stiffeners. If the vessel is insulated, small sections of insulation should be removed, particularly at points where moisture might accumulate to gain a general idea of whether or not external corrosion is occurring.

Leaks (unless readily visible) are best found by testing the vessel in accordance with 6.9.4.2 or by employing the methods described in 6.9.3. If there are indications that a leak comes through a crack, more thorough methods of examination should be employed.

In welded vessels, cracks are most commonly found at nozzle connections, in welded seams, and at bracket and support welds. In riveted vessels the most common location is at metal ligaments between the rivets. Usually, close visual inspection with some picking or scraping will disclose most cracks. When cracking is suspected in an area, the entire area should be sandblasted to facilitate inspection. If visual inspection is not sufficient, magnetic-particle, shear wave ultrasonics, dye-

penetrant, or acoustic emission analysis may be used to locate and provide additional information on the structural significance of cracks or other discontinuities.

Buckles and bulges will normally be quite evident. Small distortions can be found and measured by placing a straightedge against the shell of the vessel. Determining the cause of distortion is very important. Causes of distortion such as internal vapor explosions or excessive internal corrosion will be disclosed by the internal inspection. Settlement, earthquakes, extensive distortion in connected piping, and other sources can often be determined by external inspection. The extent of bulging or buckling can be determined by measuring the changes in circumferences or by making profiles of the vessel wall. Profiles are made by taking measurements from a line strung parallel to the vessel wall (see Figure 23).

Hot spots that have developed on the shell or heads of vessels that are internally insulated should be inspected at frequent intervals while the vessel is in service. Evidence of bulging should be noted and recorded. A check of the skin temperature of the metal in the hot-spot area can be made by using a portable thermocouple, infrared equipment, or temperature-

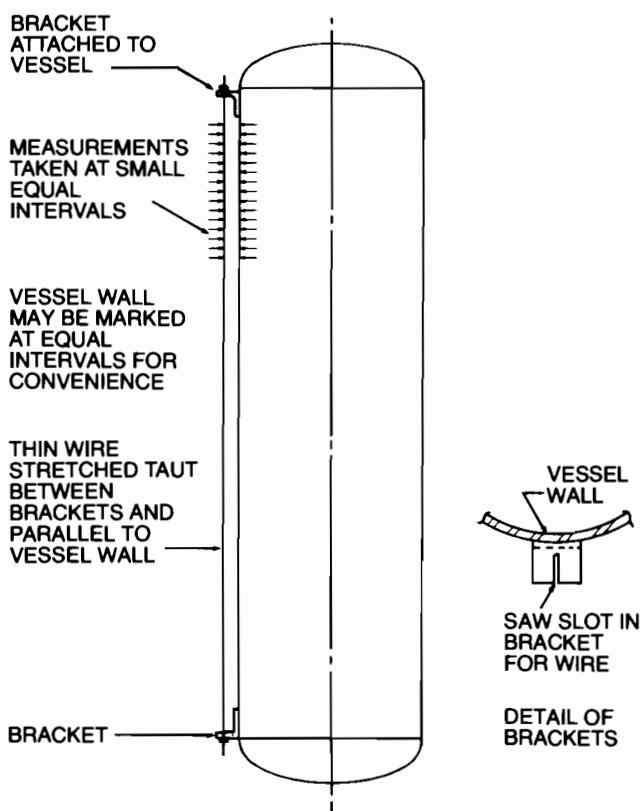


Figure 23—Method of Obtaining Vessel Profile Measurements

indicating crayons or special paints. IRE Guide, Chapter IV, covers special crayons and paints in detail. A complete dimensional check in the hot-spot area should be made when the vessel is shut down.

The external surfaces should be checked for laminations and mechanical damage. Laminations that come to the surface can be detected by visual inspection. Mechanical damage such as gouges and dents should be inspected. The depth and extent of any surface gouge should be measured when the gouge seems large enough to affect the strength of the vessel; all gouges should be reported.

Usually a certain amount of external auxiliary equipment is attached to a pressure vessel. This equipment includes items such as:

1. Drain lines and other connected piping (see IRE Guide, Chapter XI).
2. Gages for liquid-level, pressure, and temperature and other instruments (see IRE Guide, Chapter XV).
3. Safety and relief valves (see IRE Guide, Chapter XVI).
4. External water sprays and other fire-fighting equipment.

6.9.3 INTERNAL INSPECTION

All necessary inspection equipment including tools, ladders, lights, and so forth should be assembled in advance to minimize out-of-service time for the vessel.

6.9.3.1 Surface Preparation

The degree of surface preparation needed for internal inspection will vary depending on several factors. Foremost among these factors are:

1. The type of deterioration expected.
2. The location of any deterioration.

Often the cleanliness required by the operating department will be sufficient for inspection purposes. This would include the usual cleaning methods of washing with hot water, steaming, using solvents, and ordinary scraping. At those few points where better cleaning is needed, the inspector's hand tools will usually give the desired results.

The cleaning methods mentioned should be supplemented by power wire brushing, sandblasting, grinding, or power chipping when circumstances warrant. Extensive cracking or deep pitting and extensive weld deterioration require thorough cleaning over wide areas. Naturally, if the entire inside of the vessel is not accessible from one opening, the procedures discussed in 6.9.3.2 through 6.9.3.8 will have to be followed at each access opening.

6.9.3.2 Preliminary Visual Inspection

When possible, a preliminary general visual inspection is the first step in internal inspection. The type of corrosion (pitted or uniform), its location, and any other obvious data should be established. In refinery process vessels, certain areas corrode much more rapidly than others. This subject is covered in detail in 6.7.1. Data collected for vessels in similar service will aid in locating and analyzing corrosion in the vessel being inspected.

The bottom head and shell of fractionators processing high-sulfur crude oils are susceptible to sulfide corrosion. This corrosion will be most intense around the inlet lines.

The shell at the top of the fractionation and distillation towers is subject to chloride attack. The liquid-level lines at trays in towers and in the bottom of overhead accumulators are points of concentrated attack. Corrosion in the form of grooving will often be found at these locations.

In vessels where sludges may settle out, concentration cell corrosion sometimes occurs. The areas contacted by the sludge are most susceptible to corrosion. If the sludge contains acidic components, this corrosion may be rapid.

If steam is injected into a vessel, corrosion and erosion might occur at places directly opposite the steam inlet. Bottom heads and pockets that can collect condensate are also likely to be corroded.

Often a reboiler will be used at the bottom of a tower to maintain a desired temperature. The point where the hot process stream returns to the tower may be noticeably corroded. This is particularly true if the process stream contains components that may decompose when heat is added and form acid compounds. Alkylation units and soap plants are examples in this category.

Because of metallurgical changes (caused by the heat of welding) in welded seams and adjacent areas, accelerated corrosion often occurs at these locations. Most of the cracks that occur in pressure vessels will be found in these same areas. Areas opposite inlet streams are always subject to impingement attack or erosion.

The preliminary inspection of the vessel interior may indicate that additional cleaning is needed. If large areas are deeply corroded, sandblasting may be necessary. Normally, it is not necessary to remove light coatings of rust beyond what can be accomplished on a spot basis with a wire brush.

The preliminary inspection may reveal unsafe conditions such as loose internals that may fall, badly corroded or broken internal ladders or platforms, and so forth. These parts must be repaired or removed immediately before more detailed inspection may proceed.

6.9.3.3 Detailed Inspection

Detailed inspection should start at one end of the vessel and work toward the other end. A systematic procedure should be followed to avoid overlooking obscure but important items.

All parts of the vessel should be inspected for corrosion, erosion, hydrogen blistering, deformation, cracking, and laminations. A careful record should be made of the types and locations of all deterioration found.

Thickness measurements should be taken at those locations that show the most deterioration. When deterioration appears to be general, enough readings should be taken to assure an accurate determination of the remaining thickness. When deterioration is slight, one thickness measurement on each head and each shell sheet may be sufficient on small vessels, but more measurements should be taken on large vessels. Ultrasonic-type instruments can be used to obtain the necessary measurements. Other special methods of measuring wall thickness are discussed in 6.9.3.6.

Where corrosion is in the form of pitting, the pits can usually be found by scratching suspected areas with a pointed scraper. When extensive and deep pitting or grooving is found and depth measurements are wanted, the areas may have to be sandblasted. The depths of pits or grooves can be measured with a depth gage, a pit gage, or with a straightedge and a steel rule (in the case of large pits or wide grooves). An estimated depth can be found by extending the lead of a mechanical pencil as a simulated depth gage. Depressions or pockets that can hold sludge or water should be scraped clean and carefully examined for evidence of corrosion.

Nozzles connected to the vessel should be visually examined for internal corrosion. Wall thickness of nozzles can best be obtained with ultrasonic instruments. In some cases, a record of inside diameter measurements of nozzles may be desirable. These measurements can be made with a pair of internal, spring-type transfer calipers or with direct-reading, scissor-type, inside-diameter calipers. When the piping is disconnected, obtain actual nozzle wall thicknesses by caliper around the flange. In this way any eccentric corrosion of the nozzle will be revealed.

In most instances inspection of internal equipment should be made when adjacent shell areas are inspected; this may be impossible in some large vessels.

The supports for trays, baffles, screens, grids, piping, internal stiffeners, and other internal equipment should be inspected carefully. Most of this inspection will be visual. Light tapping with a hammer can be used as a check for soundness. If there appears to be any metal loss, the thickness of the support should be measured and checked against the original thickness. Transfer or

direct-reading calipers or micrometers can be used for these measurements.

The general condition of trays and related equipment should be noted. Shell and tray surfaces in contact with tray packing should be examined for possible loss of metal by corrosion. The condition of trays and related equipment will not affect the strength of the vessel but will affect the efficiency and continuity of operation. Visual inspection will ordinarily be all that is required for such equipment. If measurements are required, they can be obtained with calipers or ultrasonic instruments.

The performance of some trays is dependent upon the amount of leakage. If tray leakage is appreciable, efficiency is lost or the withdrawal of sidestreams from the tower or vessel may be almost impossible. Therefore, tray leakage should be held to a minimum. The process design will usually specify the amount of leakage that can be tolerated. Tests for leakage may be made by filling the tray with water to the height of the overflow weir and observing the time it takes for all of the water to leak through the gasket surfaces of the tray. Excessive leaks can be located by observing the underside of the tray during the test. If difficulty is encountered in determining the location of leaks, plug the weep or drain holes in the low sections of the tray prior to the test. Because of their design, ballast- and valve-type trays cannot be checked for leakage.

All internal piping (particularly at threaded connections) should be thoroughly inspected visually. Hammer testing of the pipe by an experienced inspector is a quick way to determine its condition. The sound, the feel, and any indentation will reveal thinness or cracking in the pipe. If excessive metal loss is indicated, the remaining wall thickness may be measured.

The internals of vessels such as catalytic reactors are very complicated. Figure 24 is an illustration of such internal equipment. Inspection of this equipment may be mostly visual, although some scraping, picking, and tapping may be necessary. Thickness measurements and corrosion rate calculations may be required in some areas, although operating efficiency rather than strength is the most important consideration.

Erosion usually differs in appearance from corrosion. Figure 16 shows examples of corrosion and erosion. Erosion is characterized by a smooth, bright appearance; marked absence of the erosion product; and metal loss, usually confined to a clearly marked local area. On the other hand, corroded areas are not commonly smooth or bright. See 6.7.2 for more detailed information on erosion.

In catalytic reactors and regenerators, the catalyst and air distribution facilities are particularly susceptible to erosion and should be examined closely for this type of attack.

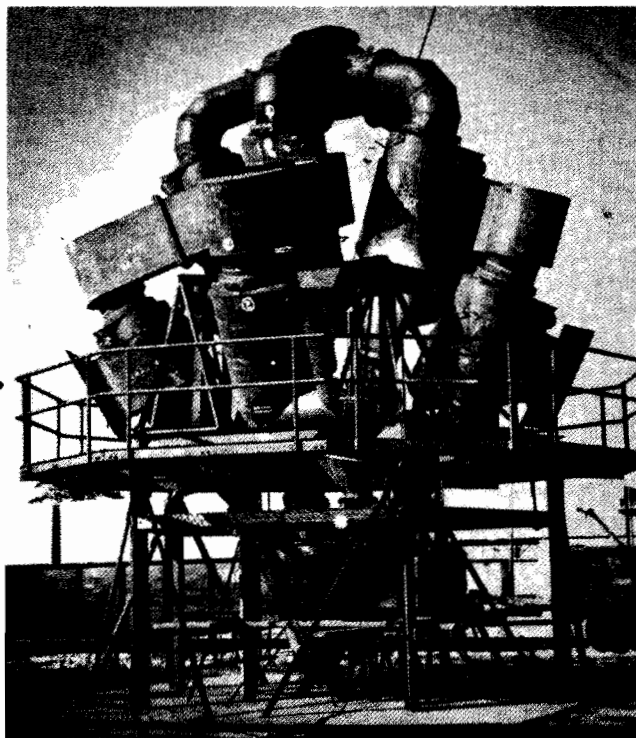


Figure 24—Catalytic-Reactor Internals—Cyclones

Wear plates, baffles, impingement plates, and the like are often provided to withstand the effects of wear and thereby save the vessel wall. These elements should be measured (usually with calipers) to determine the extent of wear.

Areas both above and below the liquid level in vessels containing acidic corrodents are subject to hydrogen blistering. Blisters are most easily found by visual examination. A flashlight beam directed across the metal surface will sometimes reveal blisters; observe the shadows created by the blisters. When many small blisters occur, they can often be found by running the fingers over the metal surface. The metal thickness of large blisters should be measured so the remaining effective

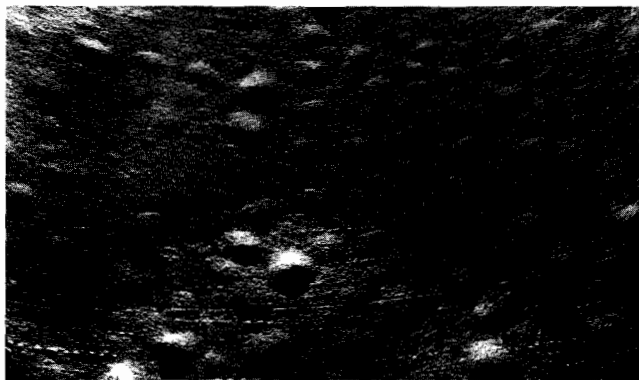


Figure 25—Hydrogen Blistering

wall thickness can be determined. Usually this can be done by using an ultrasonic thickness instrument or by drilling a hole at the highest point of the blister and measuring the thickness with a hook scale. Figures 25 and 26 illustrate hydrogen blistering.

Both the shell and heads should be inspected for deformation. Normally the shell is more likely to suffer deformation than the heads. However, some older vessels have heads formed with a small knuckle radius; these may be seriously deformed. Unless dimensions of head details such as crown radius or knuckle radius are a matter of record, these dimensions should be taken and recorded at the time of the first inspection. If deformation is suspected or indicated later, these measurements should be repeated and compared with the original dimensions or measurements.

Excessive deformation of the shell (either by bulging or collapsing) can usually be detected visually from the outside of the vessel unless it is externally insulated. Out-of-roundness or bulging may be evaluated by measuring the inside diameter of the vessel at the cross section of maximum deformation and comparing it with the inside diameter at the cross section of minimum deformation.

If the out-of-roundness occurs at intervals throughout the length of the vessel, similar measurements should be taken for each interval. In such cases the center-wire method or the plumb-line method can be used to measure the deformation. In the center-wire method, a steel wire is positioned on the centerline of the vessel and stretched taut. If no manways or nozzles exist in the centers of the heads, a plumb line may be used. When the deformation is restricted to one side of the vessel, it may be more convenient to measure offsets from a wire stretched parallel and adjacent to the wall rather than along the vessel axis (similar to the method shown in Figure 23, but with the brackets and wire inside the shell instead of outside). In horizontal vessels, some special

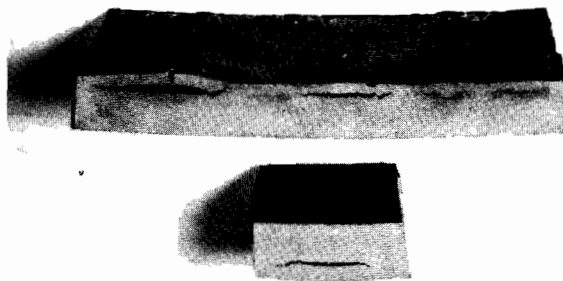


Figure 26—Cross Section Through Hydrogen Blisters Showing Various Types of Crack Propagation

method may have to be devised to hold the wire in position. The wire furnishes a reference line from which to measure the deformation. Sufficient measurements can be taken at intervals along the wire to permit drawing a profile view of the vessel wall. Local deformation can sometimes be measured by placing a straightedge parallel to the vessel axis against the vessel wall and using a steel rule to measure the extent of bulging. The best method for locating suspected deformation is to direct a flashlight beam parallel to the surface. Shadows will appear in depressions and on the unlighted side of internal bulges.

Careful inspection should be made for evidence of cracking. A strong light and a magnifying glass will be helpful when doing this work visually. A combination flashlight and magnifying glass (see IRE Guide, Chapter IV) is a useful tool for this work. If any evidence of cracking is found, a more thorough method of investigation by means of chipping, magnetic-particle, dye-penetrant, shear wave ultrasonic, or radiographic methods may be employed.

Supports are almost always welded to the shell. The point of attachment should be examined closely for cracking. A good light and a scraper will usually be sufficient for this examination.

Laminations have an appearance similar to cracks, but they run at a slant to the plate surface rather than at right angles as in the case of cracks. If open sufficiently for a thin feeler to be inserted, the angle of the lamination can be observed. If a lamination is suspected but not open sufficiently to permit insertion of a feeler, heating to approximately 200 F (75 C) with a torch will usually cause the edge of the lamination to lip upward.

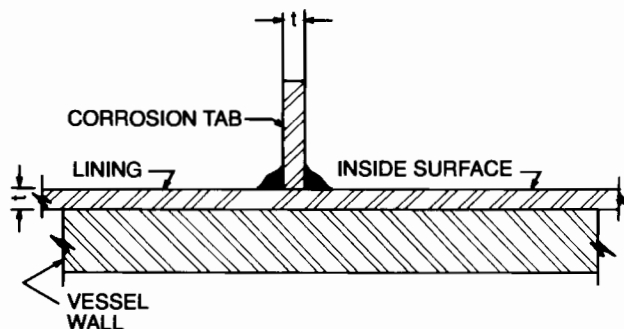
6.9.3.4 Inspection of Metallic Linings

Many vessels are provided with metallic linings. The primary purpose of these linings is to protect the vessels from the effects of corrosion or erosion. The most important factors to consider when checking linings are:

1. That there is no corrosion.
2. That they are properly installed.
3. That no holes or cracks exist.

Special attention should be given to the welds at nozzles or other attachments.

A careful visual examination is usually all that is required when checking a lining for corrosion. Light hammer taps will often disclose loose lining or heavily corroded sections. If corrosion has occurred, it may be necessary to obtain measurements of the remaining thickness. Unless the surface of the lining is relatively rough, these measurements can be made with the ultrasonic thickness measuring instrument. Another method of checking the thickness of the lining is to remove a



NOTE: Corrosion tab of same material and thickness as lining is installed as shown when vessel is lined.

Figure 27—Corrosion Tab Method of Determining Metal Loss on Vessel Linings

small section and check it with calipers. This method provides an opportunity to inspect the surface of the shell behind the lining.

Small 1-by-2 inch (2.5-by-5.0 centimeter) tabs of lining forming a right angle with one leg extending into the vessel may be welded on the lining. The thickness of the protruding leg is measured at each inspection. Since both sides of the tab are exposed to corrosive action, the loss in thickness would be twice that of the shell lining where only one side is exposed. This permits a fairly accurate check of any general corrosion of the lining. Figure 27 illustrates this lining inspection method.

Cracks in metallic linings can usually be located by visual inspection and by light hammering. Cracked sections of a liner or a loose liner give a peculiar tinny sound when tapped with a hammer. If cracking is expected, dye-penetrant methods may be used to supplement visual inspection. With the major exception of the straight-chrome steels, most of the materials used as linings are essentially nonmagnetic. Magnetic-particle inspection cannot be used on such materials.

Bulges and buckling often occur in metallic linings. When such conditions are found, they usually indicate that cracks or leaks exist in the bulged section of the lining or that pinholes exist in the adjacent welding. The bulges are formed either by the expansion or buildup of a material that seeps behind the lining during operation or by differential expansion. In the first case, if the trapped material cannot escape when the vessel pressure is reduced for a shutdown, the lining may bulge. In vacuum service the lining might bulge in service and depress when the vessel is shut down. This condition may actually wrinkle the liner. When bulges or wrinkling become excessive, it may be necessary to inspect the lining for cracks or pinholes that can be repaired or to replace the lining. Figures 28, 29, and 30 illustrate the deterioration of strip- and spot-welded linings.

Where a lining is known to be leaking, determine whether corrosion has taken place behind the lining. In



Figure 28—Strip-Lining Deterioration

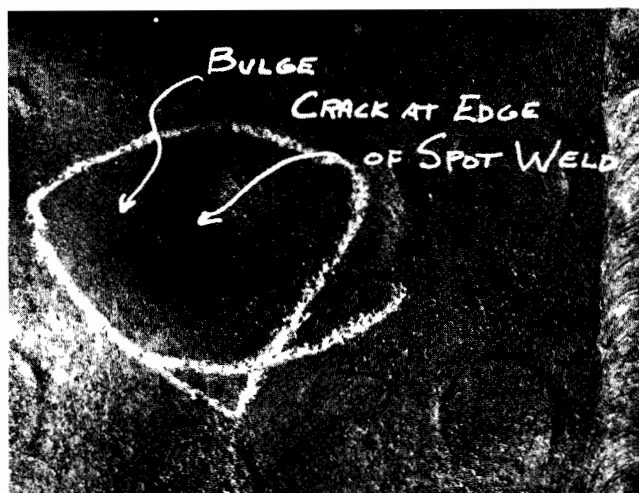


Figure 29—Spot-Welded Lining Deterioration

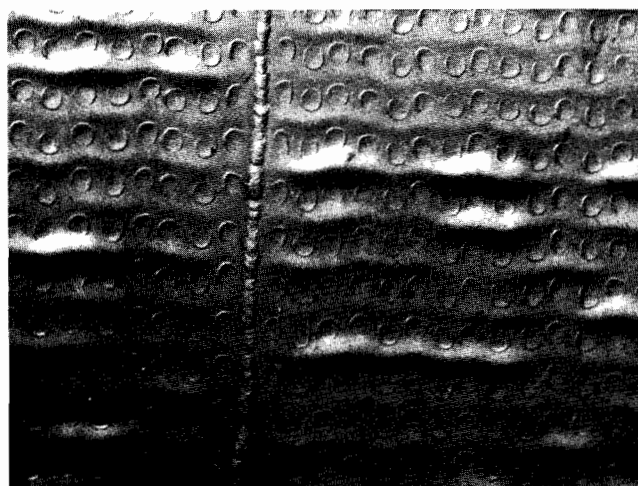


Figure 30—Spot-Welded Lining Deterioration by Bulging

some cases ultrasonic testing from the outside may be used. Removal of representative lining sections to permit visual examination of the vessel wall is always preferred, whenever it is feasible.

6.9.3.5 Inspection of Nonmetallic Linings

There are various kinds of nonmetallic linings: glass, plastic, rubber, concrete, and carbon block or brick. These materials are used most often for corrosion resistance. Some forms of refractory concrete are used as an internal insulation to keep down the shell temperatures of vessels operating at high temperatures. Refractory tile is also used for insulation.

The effectiveness of these linings in lessening corrosion is appreciably reduced by breaks in the film or coatings. For the most part inspection will consist of a visual examination for discontinuities in the coatings. These breaks are sometimes called holidays. Bulging, blistering, or chipping are all indications that openings exist in the lining. The spark-tester method of inspection for leaks in paint, glass, plastic, and rubber linings is quite thorough. A high-voltage, low-current, brush-type electrode is passed over the nonconductive lining. The other end of the circuit is attached to the shell of the vessel. An electric arc will form between the brush electrode and the vessel shell through any holes in the lining. This method is described in detail in IRE Guide, Chapter IV. It cannot be used for concrete, brick, tile, or refractory linings. The voltage used in this inspection should not exceed the dielectric strength of the film.

Considerable care should be exercised when working inside vessels lined with glass, rubber, plastic sheets, or paint. These coatings are highly susceptible to mechanical damage. Glass-lined vessels are particularly susceptible to damage that is costly and hard to repair.

Concrete and refractory lining may spall and crack in service. Inspection of such linings will be mostly visual. Mechanical damage, such as spalling and large cracks, is readily seen. Figure 31 illustrates the cracking of a refractory-tile lining. Minor cracks and areas of porosity are more difficult to find. Light scraping will sometimes reveal such conditions. Bulging can be located visually and is usually accompanied by cracking. In most cases if corrosion occurs behind a concrete lining, the lining will lose its bond with the steel. The sound and feel of light hammer tapping will usually make such looseness evident. If corrosion behind a lining is suspected, small sections of the lining may be removed and the shell inspected. This will also permit a cross section examination of the lining.

Some refractory-tile linings are hung with a blanket of asbestos or other insulation between the shell and the tile. Broken or missing tiles create lanes for the chan-

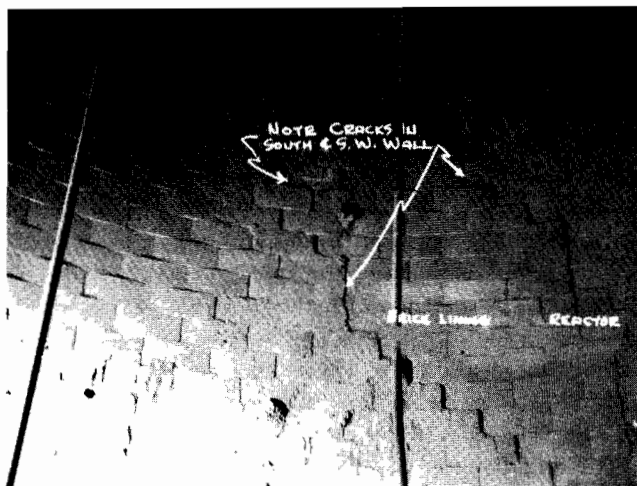


Figure 31—Cracks in Refractory-Tile Lining

neling of any fluid that gets behind the lining. This results in the washing away of some of the insulation. Inspection of tile linings should include a visual inspection of the insulation in the vicinity of broken or missing tile and may be done by removing enough tiles to disclose the damaged areas.

In all cases where bare metal has been exposed because of lining failures, a visual inspection should be made of the exposed metal. If corrosion has taken place, the remaining wall thickness should be measured. Ultrasonic-type instruments are best suited for this job.

Internally insulated vessels are sometimes subject to severe corrosion resulting from condensation on the shell behind the insulation during operation. If the shell-metal temperatures are near the calculated dew point of the process stream, shell corrosion should be suspected and the shell should be checked. A frequently used corrective measure is the reduction of internal insulation or the addition of extra external insulation. Precautions should be taken to assure that design metal temperatures are not exceeded when these measures are used.

6.9.3.6 Thickness Measuring Methods

There are many tools designed for use in measuring metal thicknesses. The selection of tools used will depend on several factors:

1. Accessibility to both sides of the area to be measured.
2. Desire for nondestructive methods.
3. Time available.
4. Accuracy desired.
5. Economy.

Ultrasonic instruments are now the primary means of obtaining thickness measurements on equipment.

Methods such as depth drilling, corrosion buttons, and test holes are used to a limited extent at some special locations.

Corrosion buttons or plugs are fabricated from materials highly resistant to corrosion and are fastened to the vessel wall in sets of two. Losses in thickness are obtained by placing a steel straightedge on the two plugs and measuring the distance from the bottom of the straightedge to the surface of the vessel.

Where the corroded surface is very rough, test holes through the vessel wall may be used to determine thickness.

Depth drilling is used similarly for determining corrosion rates. In this method a hole is drilled in the vessel wall at a location where the most corrosion is expected. The depth from the bottom of the hole to the inside surface of the vessel is measured with a depth gage. Future readings taken at subsequent inspections will permit calculation of the corrosion loss. Between readings a corrosion-resistant plug is screwed into the hole to protect the bottom of the hole from corrosion.

6.9.3.7 Detecting Mechanical Defects (Special Methods)

Visual examination will usually reveal most mechanical defects. Certain other methods have already been mentioned in the text, namely, magnetic-particle and dye-penetrant methods. Other methods such as radiography, shear wave ultrasonics, etching, or sample removal are available and may be used when conditions warrant.

Radiography and shear wave ultrasonics are used to analyze defects (usually in welded seams) that are not visible on the surface of the metal.

Etching of small areas may sometimes be used to find small surface cracks. First, the surface must be sand-blasted clean. Then, etching solution (usually an acid) is used to wash the suspected area. Because of the nature of the resulting reaction, any cracks will stand out in contrast to the surrounding area.

Sample removal can be used to spot check welds and to investigate cracks, laminations, or other flaws. Small metal samples from the affected area are removed by means of a trepan or weld probe tools. The sample is then analyzed under a microscope or with an ordinary magnifying glass. If they can be adequately cleaned, the filings obtained during the cutting operation may be used in making a chemical analysis of the metal. Repair of the hole left in the vessel wall by sample removal must be carefully done and thoroughly inspected. The decision to remove samples should be made by someone who knows how to analyze the problems related to repair of the sample holes. A complete description of

these tools and methods is found in IRE Guide, Chapter IV.

6.9.3.8 Detecting Metallurgical Changes

The methods used to detect mechanical changes can also be used to detect metallurgical changes. In-place metallography can be used to detect these changes, using portable polishing equipment and replica transfer techniques. Hardness, chemical spot, and magnetic tests are three additional methods of detecting metallurgical changes; see IRE Guide, Chapter IV for a detailed discussion.

Portable hardness testers can be used to detect faulty annealing, carburization, nitriding, decarburization, and other conditions that cause changes in hardness.

Local chemical tests are most often used to detect the installation of materials other than those specified. Chemicals such as nitric acid in varying concentrations are used. A spot is cleaned on the metal surface and a drop of a chemical is placed on the surface. An experienced observer can observe the reactions of the metal being tested to the acid and identify the metal. Eddy current, x-ray fluorescence, and portable light emission spectroscopy instruments are also used for metal identification.

Carburization of austenitic stainless steel can sometimes be detected by a magnet because normally nonmagnetic steel usually becomes magnetic when carburized.

6.9.4 TESTING

6.9.4.1 Hammer Testing

The text has made frequent reference to hammer testing, wherein an inspector's hammer is used to supplement visual inspection (see also IRE Guide, Chapter IV). The hammer is used to:

1. Locate thin sections in vessel walls, heads, and attachments.
2. Check tightness of rivets, bolts, brackets, and the like.
3. Check for cracks in metallic linings and lack of bond in concrete linings.
4. Remove scale accumulations for spot inspection.

The hammer is used for these jobs by lightly striking or tapping the object being inspected and observing the sound, feel, and indentation resulting from the blow. The proper striking force to be used for the different jobs can be learned only through experience. Hammer testing is used much less today than previously. It is not recommended to hammer test objects under pressure.

6.9.4.2 Pressure and Vacuum Testing

When pressure vessels are fabricated, they are tested for integrity and tightness in accordance with the standard or construction code to which they were built. These same methods of testing may also be used subsequently in connection with inspection for leaks and to check repair work. When major repair work, such as replacing a head, a large nozzle, or a section of the shell plate, is performed, the vessel should be tested as if it were a new installation. A large vessel and its structural supports may not necessarily be designed to support the weight of the vessel when it is filled with water. This factor should be checked before a hydrostatic test is made. If the vessel or its supports are inadequate for a hydrostatic test, then a pneumatic test must be applied.

Pressure tests consist of filling a vessel with liquid or gas and building up an internal pressure to a desired level. The pressure and procedures used should be in accordance with the applicable construction code requirements consistent with the existing thickness of the vessel and the appropriate joint efficiencies. In certain circumstances, the rules for inspection in service also require periodic pressure testing, even though no repair work has been necessary. When pressure vessels form a component part of an operating unit, the entire unit is sometimes pressure tested. Oil or water is used as a testing medium and the charge pumps of the unit are used to provide the test pressure. While the vessel or vessels are under pressure, the external surfaces are given a thorough visual examination for leaks and signs of deformation.

In recent years acoustic emission analysis has been developed for use in conjunction with pressure testing. With this combination, it is possible to determine the overall structural integrity of a pressure vessel. It can be especially useful for vessels of complex design or where the vessel contents cannot be easily removed to permit an internal inspection.

When testing pneumatically, an ultrasonic sound detector or soap solution should be used as an aid to visual inspection. The soap solution is brushed over the seams and joints of the vessel. The vessel is then examined for evidence of bubbles as an indication of leakage.

Often a vessel that operates at a vacuum may be pressure tested. When feasible, this is the preferred testing method because it permits locating any leaks. When pressure testing is not feasible, a vacuum vessel can be tested for leaks by creating a vacuum by means of evacuators or vacuum pumps installed on the unit. If the vacuum can be held for a specified time after closing off the evacuators or vacuum pumps, it is an indication that the vessel is free of leaks. If the vacuum cannot be held, leaks are present. However, since this method

gives no indication of the locations of leaks, a search, which may be difficult, must then be made to locate the leaks.

Consideration should be given to the temperature at which testing is done. Many of the common steels used in fabrication exhibit severe reduction in impact resistance at low temperatures. The ASME *Boiler and Pressure Vessel Code* recommends that vessels constructed with these steels be tested at temperatures above 60 F (15 C).

When conducting hydrostatic or pneumatic pressure tests, it is a good safety practice for all personnel not connected with the test to remain away from the area until the test is completed and the pressure is released. Inspection personnel in the area should be limited to the number necessary to run the test. When making pneumatic pressure tests, the recommendations set forth in the ASME *Boiler and Pressure Vessel Code* should be followed.

6.9.5 LIMITS OF THICKNESS

The limits of corrosion or other deterioration that may be tolerated must be known or an inspection will lose much of its value. The two most important phases of this problem are:

1. The retiring thickness of the part considered.
2. The rate of deterioration.

Before determining the limiting or retiring thickness of any pressure vessel, what code and which edition of that code it is to be rated under and whether there are any regulations regarding limits and allowable repairs must be determined.

There are a great many variables (such as size, shape, material, and method of construction) that affect the minimum thickness. For this reason it is not possible in this chapter to present a set of precalculated minimum or retiring thicknesses. API 510 contains additional guidance on the rating of pressure vessels.

When corrosion or erosion is causing deterioration, the rate of metal loss can usually be obtained by comparing consecutive inspection records. Sometimes a graph that shows this information is drawn and is kept with the vessel records. In many cases, computerization of inspection data has been helpful in quickly determining corrosion rates and in estimating retirement dates. The ability to predict the time when a vessel will reach the retiring thickness is important. Scheduling of repairs and replacements will be greatly influenced by such predictions.

When the safe limit of thickness is approached or reached, decisive action is necessary. In some cases decisions will have to be made quickly without much time for study or consideration and review by others.

The minimum thickness should be known in advance for each vessel or the methods of calculating the thickness should be well known. Remember that different parts of a vessel may have different retiring thicknesses. As mentioned before, computer treatment of the data could have special value.

Most vessels are built with some excess thickness (over that required to withstand the internal operating pressures) in vessel walls and heads. This excess thickness may result from any of the following factors:

1. Excess thickness deliberately added in the design as corrosion allowance.
2. Excess thickness as a result of using a nominal plate thickness rather than the exact (smaller) value calculated.
3. Excess thickness as a result of setting minimum plate thicknesses for construction purposes.
4. Excess thickness resulting from a change in vessel service (reduction of the safety valve setting or maximum metal temperature, or both).

When this excess thickness and the corrosion rate are known, the date when repairs or replacement will be needed for any vessel can be predicted with reasonable accuracy. It should be cautioned that the excess thickness of the shell or head plates is at times used by the designer as nozzle reinforcement.

Since the ASME *Boiler and Pressure Vessel Code* is a design and construction standard for vessels, the methods for calculating the retirement thicknesses for many accessories of pressure vessels are not covered. Some of these parts are trays, internal tray supports, valves, grids, baffles, ladders, and platforms. For some of this equipment, there are generally accepted methods of setting the retiring thickness. Minimum thicknesses should be developed for all such equipment. The results of possible failure of equipment should be considered when setting these limits. Safety and continuous efficient operation are the prime factors affecting retiring thickness.

Normally no minimum thickness is set for applied metallic linings. As long as the lining remains free of leaks or does not require excessive repairs, it should be satisfactory for further service. IRE Guide, Chapter XI covers the inspection of pipes, valves, and fittings.

6.10 Methods of Repair

Repair and maintenance are not specifically classified as part of inspection. Therefore, no attempt has been made to discuss these items in detail in this chapter. However, repairs that affect the pressure rating of a vessel and that require reinspection for safety reasons are briefly reviewed.

Before any repairs are made to a vessel, the applicable codes and standards under which it is to be rated should be studied to ascertain that the method of repair will not violate appropriate requirements. API 510 sets forth minimum petroleum and chemical process industry repair requirements.

All defects requiring repair and the repair procedures employed should be recorded in the field notebook and later in the permanent records maintained on the vessel. Most repairs on the shell and heads of a vessel are made to maintain the strength and safety of the vessel and will therefore require reinspection and may require radiography or stress relieving, or both. A quick visual check of all other repairs is also desirable to make certain that they have been completed.

Repairs made by welding to the shell and heads of a vessel should be inspected: The inspection should include a check for completion and quality. Normally, a visual examination will be sufficient for minor repairs; however, magnetic-particle and dye-penetrant methods should be used on major repairs and, if required by the applicable construction code, radiographic examination should also be made. A pressure test should be applied after major repairs. The repair of sample holes left by a trepan or weld probe tools must be closely inspected. The weld quality in such repairs is likely to be poor unless carefully controlled. Therefore, the removal of samples for weld inspection should be avoided if possible.

Sections of shell plates may be replaced to remove locally deteriorated areas. The calculated joint efficiency of the patch should be equal to or greater than the calculated efficiency of the original joints in the shell.

Cracks in vessel walls or heads may be repaired by chipping, gouging, or grinding the crack from end to end then welding it. If a crack extends completely through the plate, it may be expedient to cut a groove from both sides of the plate. In any event, complete removal of the crack is absolutely essential before welding is begun. Magnetic-particle techniques should preferably be employed to assure removal of the crack. If several cracks occur in any one plate, it may be wise to replace the entire plate. Cracks repaired by welding should be checked carefully. If the cavity caused by grinding out a defect is not deep and the thickness of the remaining metal is of adequate strength, the repair may be completed without welding by bevelling the edges of the cavity.

Scattered pits in pressure vessels are best repaired by welding. As a means of temporary repair, proprietary plastic materials are available that can be packed into pits to prevent further corrosion. Of course, such material must be capable of resisting the service conditions. In all cases, pits should be well cleaned (preferably by

sandblasting) before repairs are made.

Repair of appurtenances such as platforms, ladders, and stairways will usually consist of replacing excessively worn parts. Stairway treads that have been worn smooth can be roughened by placing weld beads on worn surfaces.

Linings are repaired by replacing parts that are corroded through or cracked. Repairs of metallic linings will require welding. Visual inspection of welding after thorough slag removal will normally be sufficient to check weld quality, unless code requirements specify radiographic examination of the weld.

6.11 Records and Reports

6.11.1 RECORDS

Inspection records are required by API 510. They are very important since they supply the basis of a scheduled maintenance program. A complete record file should contain three types of records:

1. Basic data.
2. Field notes.
3. Continuous file.

Basic data include the manufacturer's drawings, data reports and specifications, design information, and the results of any material tests and analyses available.

Field notes consist of notes and measurements recorded on site either on prepared forms (see appendix) or in a field notebook. These notes should include in rough form the condition of all parts inspected and a record of the repairs required.

The continuous file includes all information on operating history, descriptions and measurements from previous inspections, corrosion rate tables (if any), and records of repairs and replacements.

As indicated earlier, some companies have developed extensive programs for computerization of inspection data. These programs when kept current are very effective in establishing corrosion rates, retirement dates, and schedules and permit quick and comprehensive examination of all accumulated inspection data. These programs can be extended to include the inspection report issued to the interested departments or parties.

6.11.2 REPORTS

Copies of reports recommending repairs should be sent to all management groups, which would normally include engineering, operating, and maintenance departments. These reports should include the location, extent, and reasons for recommended repairs.

Copies of general inspection reports (see appendix) may be sent to interested parties such as the operating, maintenance, and engineering departments. This of course will vary according to the refinery organization. These reports should include metal thickness mea-

surements, corrosion rates, conditions found, descriptions of the repairs required, estimated remaining life, allowable operating conditions, and any recommendations. Occasionally special reports covering unusual conditions may be circulated.

APPENDIX—TYPICAL FORMS

Typical Inspection Record for Vessel in Service

This form provides an example of an inspection record for pressure vessels in service. Most plants develop a more detailed set of forms to include not only the data shown on this form but other pertinent data found advisable to record.

Typical Permanent Pressure Vessel Record

This form provides a place for recording all the basic data of an individual pressure vessel and forms the permanent record for that vessel.

Typical Vessel Inspection Sheet

This form provides a place for keeping a progressive record of thicknesses found from which a corrosion rate can be calculated. Three copies of this form are pro-

vided in the appendix. One is blank and the other two show example sketches for different types of pressure vessels. A form would be provided for each pressure vessel inspected.

Normally, an inspector would have one copy of this form for recording field data and another copy would be retained as an office record. An inspector might also use this form without a sketch when inspecting a vessel that was not previously inspected or for which no basic data are available. In such cases, he would make a field sketch of the vessel, including all pertinent dimensions and data obtainable in the field.

Typical Pressure Vessel Record for All Pressure Vessels on an Operating Unit

This form provides a place for recording and reporting the physical condition and allowable operating conditions of all pressure vessels on an operating unit.

TYPICAL INSPECTION RECORD FOR PRESSURE VESSEL IN SERVICE

OWNER OR USER NO. _____ OWNER _____ DATE _____
 JURISDICTION OR
 NATIONAL BOARD NO. _____ OWNER _____ DATE _____
 MANUFACTURER _____
 MANUFACTURER'S SERIAL NO. _____
 DESIGN PRESSURE _____ TEMPERATURE _____
 MAXIMUM ALLOWABLE ORIGINAL HYDROSTATIC
 WORKING PRESSURE _____ TEST PRESSURE _____
 ORIGINAL THICKNESS A _____ B _____ C _____ D _____
 CORROSION ALLOWANCE A _____ B _____ C _____ D _____

DATE OF INSPECTION	THICKNESS AT CRITICAL POINTS				MAXIMUM METAL TEMPERATURE AT CRITICAL POINTS				MINIMUM ALLOWABLE METAL THICKNESS AT CRITICAL POINTS				DATE OF NEXT INSPECTION	SIGNATURE OF INSPECTOR
	A	B	C	D	A	B	C	D	A	B	C	D		

DISCRIPTION OF LOCATION _____ DATE _____
 DISCRIPTION OF LOCATION _____ DATE _____
 DISCRIPTION OF LOCATION _____ DATE _____
 DISCRIPTION OF LOCATION _____ DATE _____
 DISCRIPTION OF LOCATION _____ DATE _____

NOTE: MANUFACTURE'S DRAWING CAN BE USED TO SHOW THE LOCATION OF A, B, C, AND D.

TYPICAL PERMANENT PRESSURE VESSEL RECORD

NAME OF UNIT _____
VESSEL NAME _____
LOCATION _____
ORIGINAL ITEM NO. _____
DATE _____

HISTORY

ESTIMATE NO. _____
ORDER NO. _____
MANUFACTURED BY _____
MANUFACTURER'S SERIAL NO. _____
MANUFACTURER'S INSPECTOR _____
MANUFACTURER'S TEST PRESSURE _____
DATE RECEIVED _____
DATE INSTALLED _____
COMPANY NO. _____
COMPANY INSPECTOR _____

DESCRIPTION

GENERAL

DRAWING NO. _____
FABRICATOR'S _____
CONTRACTOR'S _____
COMPANY _____
POSITION (VERTICAL OR HORIZONTAL) _____
CODE CONSTRUCTED _____
CODE _____ YEAR _____
CODE STAMP _____
MATERIAL SPECIFIED AND GRADE OR TYPE _____
BASE _____
LINING _____
THICKNESS _____
STRESS RELIEVED (ORIGINAL) _____
RADIOGRAPHED (ORIGINAL) _____
COMPLETE _____
WELD INTERSECTIONS _____
SIZE _____
NOMINAL INSIDE DIAMETER _____
LENGTH BASE LINE TO BASE LINE _____
DESIGN _____
PRESSURE, psi _____
TEMPERATURE, F _____
STRESS, psi _____
MAXIMUM ALLOWABLE OPERATING PRESSURE, psi _____
MAXIMUM ALLOWABLE TEMPERATURE, F _____
LIMITED BY _____
SHELL _____
TYPE OF CONSTRUCTION _____
JOINT EFFICIENCY _____
TYPE OF SUPPORT _____
INTERIOR OR EXTERIOR STIFFENERS _____
ORIGINAL THICKNESS _____
CORROSION ALLOWANCE _____
MANWAYS _____
NO. _____
SIZE _____
FLANGE RATING _____
REINFORCEMENT _____
FACTORY OR FIELD _____

TOP HEAD TYPE

ELLIPTICAL _____ HEMISPHERICAL _____
DISHED _____
CROWN REGION _____ KNUCKLE REGION _____
CONICAL (ANGLE) _____
FLAT _____
JOINT EFFICIENCY _____
ORIGINAL THICKNESS _____
CORROSION ALLOWANCE _____
MANWAYS _____
NO. _____
SIZE _____
FLANGE RATING _____
REINFORCEMENT _____
FACTORY OR FIELD _____

BOTTOM HEAD TYPE

ELLIPTICAL _____ HEMISPHERICAL _____
DISHED _____
CROWN REGION _____ KNUCKLE REGION _____
CONICAL (ANGLE) _____
FLAT _____
JOINT EFFICIENCY _____
ORIGINAL THICKNESS _____
CORROSION ALLOWANCE _____
MANWAYS _____
NO. _____
SIZE _____
FLANGE RATING _____
REINFORCEMENT _____
FACTORY OR FIELD _____
NOZZLES _____
MINIMUM FLANGE RATING _____
TYPE FACING _____
OPENINGS REINFORCED _____

REMARKS

NOTE: A COPY OF THIS SHEET SHALL BE PREPARED FOR EACH INDIVIDUAL VESSEL IN A UNIT. IF NEW VESSELS ARE INSTALLED OR ANY CHANGES ARE MADE TO PRESENT VESSELS AFFECTING THE DESCRIPTION ITEMS, A NEW OR REVISED COPY OF THIS SHEET SHALL BE SUBMITTED WITH THE CURRENT INSPECTION REPORT.

TYPICAL VESSEL INSPECTION SHEET

UNIT _____
 NAME OF VESSEL _____
 DIAMETER _____
 LENGTH _____
 VESSEL NUMBER _____

DRAWINGS

	SHELL	LINING	INTERNAL
FABRICATOR	_____	_____	_____
CONTRACTOR	_____	_____	_____
COMPANY	_____	_____	_____

SKETCH

WALL THICKNESS MEASUREMENTS

POINT NO.		ORIGINAL THICKNESS	MINIMUM ALLOWABLE THICKNESS	DATE							
INSPECTION INTERVALS	NO.										
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										

TYPICAL VESSEL INSPECTION SHEET

UNIT _____
 NAME OF VESSEL _____
 DIAMETER _____
 LENGTH _____
 VESSEL NUMBER _____

DRAWINGS

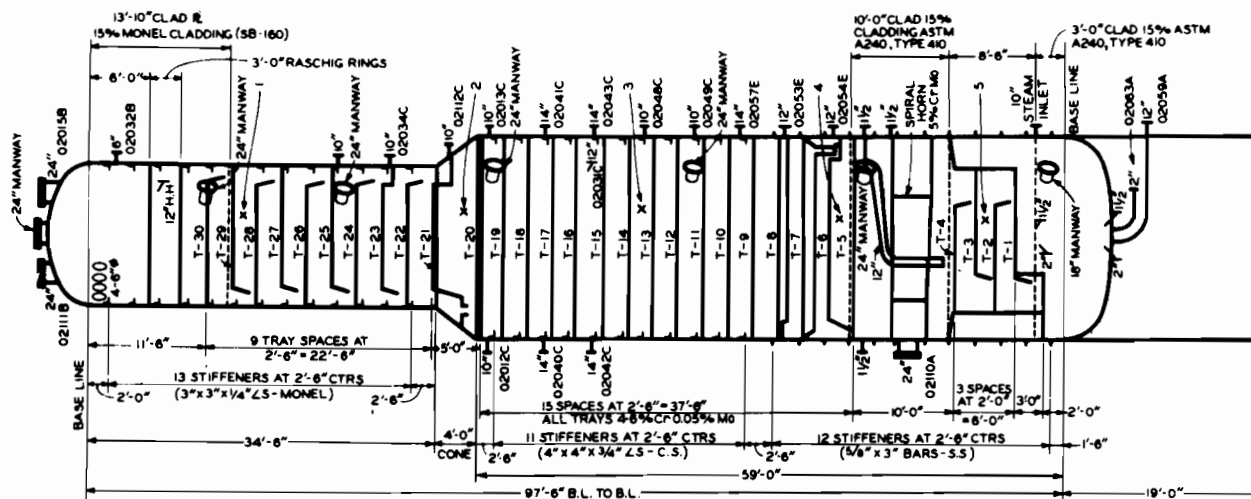
FABRICATOR
 CONTRACTOR
 COMPANY

SHELL

LINING

INTERNAL

SKETCH



WALL THICKNESS MEASUREMENTS

POINT NO.		ORIGINAL THICKNESS	MINIMUM ALLOWABLE THICKNESS	DATE							
INSPECTION INTERVALS	NO.										
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										

UNIT _____
NAME OF VESSEL _____
DIAMETER _____
LENGTH _____
VESSEL NUMBER _____

	SHELL	LINING	INTERNAL
FABRICATOR			
CONTRACTOR			
COMPANY			

[illegible][illegible]

TYPICAL PRESSURE VESSEL RECORD FOR ALL PRESSURE VESSELS ON AN OPERATING UNIT

NAME OF UNIT _____
 LOCATION _____
 INSPECTION AND TEST NO. _____
 DATE _____
 PAGE 1 of 2

NAME OF VESSEL

COMPANY VESSEL AND SKETCH NO.

OPERATING DATA

HOURS UNDER PRESSURE TO DATE

SERVICE DATA

AVERAGE MAXIMUM OPERATING PRESSURE, psi

AVERAGE MAXIMUM OPERATING TEMPERATURE, F

TOP

BOTTOM

NO. TRAYS

NO. BAFFLES

NO. COILS

INSPECTION AND TEST DATA

INSPECTOR

NOMINAL INSIDE DIAMETER

MINIMUM THICKNESS

SHELL

LOCATION

TOP HEAD

BOTTOM HEAD

JOINT EFFICIENCY

SHELL

HEADS

HEAD FACTOR

TOP

BOTTOM

LAST INSPECTION

INSIDE WELDS

OUTSIDE WELDS

UNDER INSULATION

EXTENT INSPECTION

TYPICAL PRESSURE VESSEL RECORD FOR ALL PRESSURE VESSELS ON AN OPERATING UNIT

NAME OF UNIT _____
 LOCATION _____
 INSPECTION AND TEST NO. _____
 DATE _____
 PAGE 2 of 2

NAME OF VESSEL _____

COMPANY VESSEL AND SKETCH NO. _____

TEST PRESSURE
 VESSEL, psi _____
 COILS, psi _____
TEST MEDIUM _____
 TIME PRESSURE HELD -(1) + (2) _____
 MAXIMUM ALLOWABLE OPERATING PRESSURE, psi _____
 MAXIMUM ALLOWABLE OPERATING
 TEMPERATURE, F _____
 LIMITED BY _____
 WORKING STRESS AT OPERATING
 TEMPERATURE, psi _____
 APPROVED OPERATING PRESSURE, psi _____
 APPROVED OPERATING TEMPERATURE, F _____
 SAFETY VALVE SETTING, psi _____

PROTECTIVE LINING DATA
 DRAWING NO. _____
 DATE INSTALLED _____
 MATERIAL AND TYPE _____
 SECTION LINED _____
 DATE REPAIRED _____
 EXTENT OF REPAIRS _____
 DATE PREVIOUS LINING REMOVED _____
 CAUSE OF REMOVAL _____

REMARKS _____

