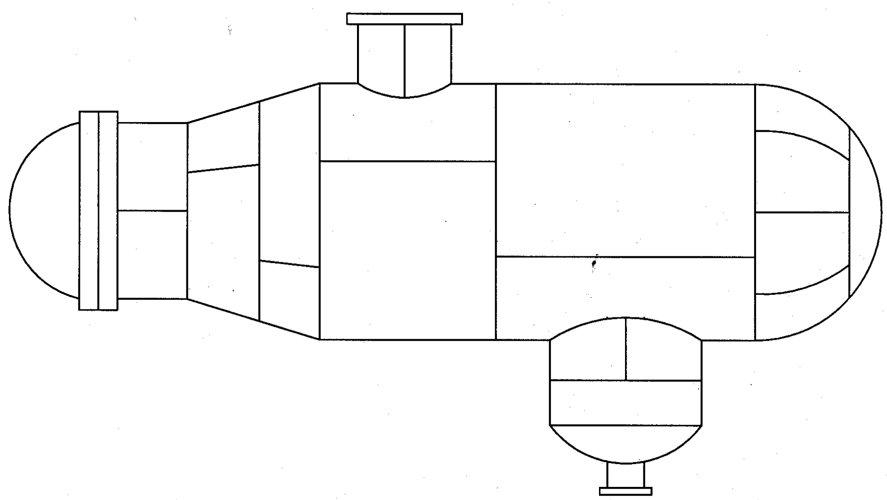
INSPECTION OF UNFIRED PRESSURE VESSELS



FACILITIES INSTRUCTIONS, STANDARDS, AND TECHNIQUES VOLUME 2-9

August 2001

United States Department of the Interior
Bureau of Reclamation
Hydroelectric Research and Technical Services Group
Denver, Colorado

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave Blank)***

2. REPORT DATE
August 2001

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE

Inspection and Testing of Unfired Pressure Vessels
Facilities Instructions, Standards, & Techniques, Volume 2-9

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Denver Federal Center
P.O. Box 25007
Denver, CO 80225-0007

8. PERFORMING ORGANIZATION REPORT NUMBER

Volume 2-9

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

FIST Volume 2-9 is a document that provides information related to the inspection and testing of unfired pressure vessels. This information includes inspection procedures and testing methods, inspector qualifications, and inspection of associated equipment such as safety devices and piping systems. The most frequent causes of deterioration in pressure vessels are also discussed.

14. SUBJECT TERMS - - pressure vessels, pressure relief valves, safety devices, tanks, air receivers, rupture disks, ultrasonic thickness surveys, hydrostatic tests, tank inspection, corrosion

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UC	UC	UC	UC

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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Inspection of Unfired Pressure Vessels

1 Introduction

All Bureau of Reclamation facilities contain a number of pressure vessels ranging from governor tanks and air receivers to heating boilers and hot water tanks. Many of the pressure vessels are over 40 years old. Because of the effects of corrosion and erosion, they may no longer have their original design strength, and because of changes in operating conditions, they may see more severe service than was originally anticipated.

Unfired pressure vessels owned by private industry and State agencies are regulated by State law. This normally means they are designed, built, and installed according to ASME Codes and are subject to meeting the inspection and certification requirements of the National Board Inspection Code, ANSI/NB-23. They are also required to comply with any specific regulations of the State in which they are located. Unfired pressure vessels owned by the Federal Government are not subject to State laws.

Design, installation, maintenance, and inspection of Reclamation pressure vessels is governed by Reclamation Safety and Health Standards. The Reclamation Safety and Health Standards require that Reclamation facilities design, construct, install, test, and maintain boilers and unfired pressure vessels according to:

- The current ASME Boiler and Pressure Vessel Code
- The current National Board Inspection Code, ANSI/NB 23
- The current codes and regulations of the State (in which they are installed)

The purpose of this document is to provide inspection and testing guidelines for unfired pressure vessels that meet or exceed the requirements of the above mentioned codes.

Unfired pressure vessels are not generally thought of as a safety hazard to personnel. However, it should be noted that, between 1992 and 1999, more people have died as a result of accidents involving unfired pressure vessels than those associated with fired pressure vessels, such as boilers. Table 1 shows incidents, injuries and deaths involving unfired pressure vessels compiled from statistics provided by the National Board:

Table 1.—Incidents, injuries, and deaths involving unfired pressure vessels

Year	Accidents	Injuries	Deaths
1992	187	12	3
1993	261	24	6
1994	387	19	5
1995	245	65	6
1996	319	22	6
1997	292	41	13
1998	153	12	9
1999	145	73	6

1.1 Purpose

The main purpose of implementing a pressure vessel inspection program is to ensure that each pressure vessel is safely operated and maintained. Some of the benefits that result from regularly scheduled pressure vessel inspections are listed below:

- Improvement of facility, personnel, and public safety
- Prevention of damage to the environment
- Improvement of reliability
- Reduction of operation and maintenance costs
- Minimization of unscheduled outages
- Minimization of liability

Much of the material presented in this document was obtained from the National Board Inspection Code and the Military Handbook for Inspection and Certification of Boilers and Unfired Pressure Vessels.

1.2 Unfired Pressure Vessels at Hydroelectric Facilities

There are a number of unfired pressure vessels in service at hydroelectric facilities that require inspection and certification. Some examples are:

- Oil tanks for governors
- Air receiver tanks
- Air circuit breakers
- Accumulator tanks for hydraulic operating systems

Most of the pressure vessels in service in the United States were designed and constructed according to one of the following two pressure vessel design codes:

- The ASME Code or Section VIII of the ASME (American Society of Mechanical Engineers) "Boiler and Pressure Vessel Code."

- The API Standard 620 or the American petroleum Institute Code, which provide rules for lower pressure vessels not covered by the ASME Code.

In addition, some vessels designed and constructed between 1934 to 1956 may have used the rules in the "API-ASME Code for Unfired Pressure Vessels for Petroleum Liquids and Gases." This code was discontinued in 1956.

During the inspection process, pressure vessels that were not fabricated according to the above mentioned codes and standards will need to be evaluated adequately to determine whether the factor of safety is appropriate.

Governor Oil Tank

Air Receiver Tank

Air Receiver Tank

2 Inspection of Unfired Pressure Vessels

Pressure vessels are designed for a variety of service conditions. The media that a pressure vessel contains and the temperature and pressure at which it operates should be considered in establishing the inspection criteria.

2.1 Frequency of Inspections

Unfired pressure vessels must be inspected and tested before being placed in service and after any alteration or major repair. The next inspection must be performed within 2 years, and the interval of subsequent inspections must not exceed 5 years (providing deterioration is shown to be low and at a predictable rate). Where deterioration is shown to be rapid in any part of a vessel, an inspection and testing interval will be either the interval determined according to the National Board Inspection Code or 2 years. The interval must be the shorter of the two. Hydrostatic or State acceptable tests shall be made when recommended by the qualified person performing the inspection.

2.2 Inspector qualifications

Inspections must be performed by qualified personnel meeting Federal or State certification requirements or by personnel satisfying the "Owner-User Inspector" education and experience requirement of the National Board Inspection Code, issued by the National Board of Boiler and Pressure Vessel Inspectors.

Bureau of Reclamation employees who perform the inspections must have the following education and experience:

a. A degree in engineering from an accredited school plus 1 year of experience in design, construction, repair, or inspection of pressure vessels. The inspector must also be an operator trained and certified to perform ultrasonic thickness examinations.

or

b. An associate degree in mechanical technology plus 2 years of experience in design, construction, repair, or inspection of pressure vessels. The inspector shall also be an operator trained and certified to perform ultrasonic thickness examinations.

or

c. A high school education or the equivalent plus 3 years of experience in design, construction, repair, or inspection of pressure vessels. The inspector shall also be an operator trained and certified to perform ultrasonic thickness examinations.

2.3 Pre-Inspection Activities

A review of the known history of the pressure vessel should be performed. This should include a review of information such as:

- Operating conditions
- Normal contents of the vessel
- Date of last inspection
- ASME Code Symbol stamping or mark of code of construction.
- The type of connections used during fabrication of the vessel to determine the proper joint efficiency to be used during stress analysis of the pressure vessel.
- Serial number and materials of construction
- Records of wall thickness surveys, especially on vessels where corrosion is a consideration

The following activities should be performed if required to support the inspection:

- Remove inspection plugs and covers
- Clean vessel sufficiently to allow for visual inspection of internal and external surfaces

ASME Code Symbol

2.4 Inspection Procedure

The type of installation given to pressure vessels should take into consideration the condition of the vessel and the environment in which it operates. This inspection may be external, internal, or both and use a variety of non-destructive examination techniques. The inspection may be performed with the vessel in service or depressurized, but should provide the necessary information that allows an adequate assessment of the pressure vessel.

A thorough inspection of a pressure vessel should include the following items:

1. A thorough external examination of the pressure vessel and associated equipment including verification of the welded connections to determine the proper joint efficiency to employ during the stress analysis.

2. An ultrasonic thickness examination of the pressure vessel wall and dished heads and documentation for permanent record keeping.

3. An internal examination of the pressure vessel, if required. An internal examination may not be required if the pressure vessel is stamped with the original wall thickness and the thickness survey shows no loss of material. Pressure vessels in which the original wall thickness is unknown should have an initial internal examination performed to determine the baseline condition of the vessel.

4. Ultrasonic measurement techniques to determine the shell and dished head wall thicknesses for each pressure vessel. Other types of non destructive examinations should be performed as required for any suspect areas identified during the external or internal examination.

5. A stress analysis based on actual wall thickness data acquired during the ultrasonic thickness survey, and the proper joint efficiencies, based on the type of construction used during fabrication of the pressure vessel. These results should be compared with the requirements of the applicable code that the pressure vessel was originally designed to, and these results should ensure that the proper safety factors are being met.

6. A thorough inspection of the pressure relief valves and other safety devices to ensure the vessel is operating within its specified pressure range and is being adequately protected. Functional testing of the relief valves should be performed by increasing the operating pressure of the pressure vessel just slightly above the set pressure of the relief valves to ensure the relief valve will operate as required.

7. A hydrostatic pressure test to 1.5 times the maximum allowable working pressure should be performed if any repairs or alterations have been made to the pressure vessel. Hydrostatic pressure tests may be required by the inspector if there has been some significant material loss because of corrosion or erosion.

2.5 External Inspection

The external inspection provides information regarding the overall condition of the pressure vessel. The following items should be reviewed:

a. Insulation or other coverings.—If it is found that external coverings such as insulation and corrosion resistant coatings are in good condition and there is no reason to suspect any unsafe condition behind them, it is not necessary to remove them for inspection of the vessel. However, it may be advisable to remove small portions of the coverings to investigate their condition and the condition of the metal.

b. Evidence of leakage.—Any leakage of gas, vapor, or liquid should be investigated. Leakage coming from behind insulation coverings, supports, or settings or evidence of past leakage should be thoroughly investigated by removing any covering necessary until the source is determined.

c. Structural attachments.—The pressure vessel mountings should be checked for adequate allowance for expansion and contraction. Adequate allowance may be provided by slotted bolt holes or unobstructed saddle mountings. Attachments of legs, skirts, or other supports should be examined for distortion or cracks at welds.

Pressure Vessel Mounting Supports

d. Vessel connections.—Manholes, reinforcing plates, nozzles, or other connections should be examined for cracks, deformations, or other defects. Bolts and nuts should be checked for corrosion or defects. Weep holes in reinforcing plates should remain open to provide visual evidence of leakage as well as to prevent pressure buildup between the vessel and the reinforcing plate. Accessible flange faces should be examined for distortion and to determine the condition of gasket seating surfaces.

Manhole Connection

e. Miscellaneous conditions.—The surfaces of the vessel should be checked for erosion.

Dents in a vessel are deformations caused by contact with a blunt object in such a way that the thickness of the metal is not materially impaired. In some cases, a dent can be repaired by mechanically pushing out the indentation.

If any distortion is suspected or observed, the overall dimensions of the vessel should be checked to determine the extent and seriousness of the distortion.

Cuts or gouges can cause high stress concentrations and decrease the wall thickness. Depending on the extent of the defect, it may be necessary to repair the area by welding or patching. Blend grinding may be a useful method of eliminating some minor types of cuts or gouges.

f. Surface inspection.—The surfaces of shells and heads should be examined for possible cracks, blisters, bulges, and other evidence of deterioration, giving particular attention to the skirt and to the support attachment and knuckle regions of the heads.

g. Welded joints.—Welded joints and the adjacent heat affected zones should be examined for cracks or other defects. Magnetic particle and liquid penetrant examination is a useful means of examining suspect areas.

It is important to determine the weld configuration of the pressure vessel in order to use the proper joint efficiency when performing stress calculations. The Boiler and Pressure Vessel Code specifies six types of weld joints. Type 1 weld joints are double-welded butt joints. The quality of weld is the same inside and outside the vessel with double-welded butt joints. Backing strips, if used, are removed after welding. After the weld is made on one side, the other side of the joint is cleaned and rewelded. The weld quality is the same on both sides of the joint. Type 2 welds are single-welded butt joints with backing strips that remain in place after welding. Type 3 welds are single-welded butt joints without backing strips. Type 4 joints are double full-fillet lap joints. Type 5 joints are single full-fillet lap joints with plug welds. Type 6 joints are single full-fillet lap joints without plug welds. The six weld types are shown in figure 1, with their typical welding symbols.

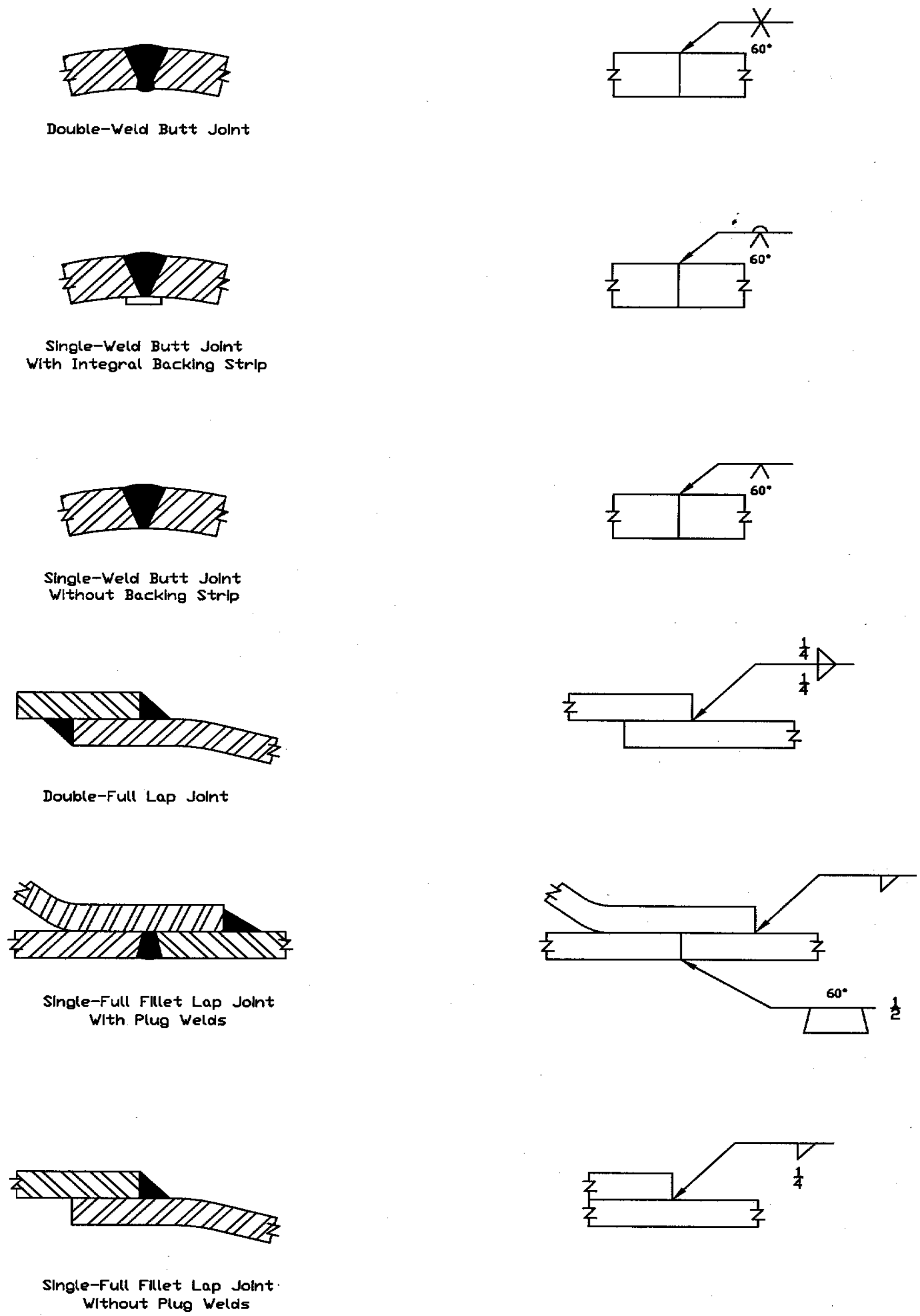

FIGURE #1

WELD CONFIGURATIONS

For joint efficiencies for welded joints subject to tension, the values depend on the type of weld and the testing processes. The strongest joints are double-welded butt joints (Type 1). Joint efficiencies for the butt joints and other welded connections are shown in table 2. The configuration for the joint types shown in table 2 are the same as shown in figure 1.

Table 2.—Efficiencies of Welded joints in Shells

Joint Type	Full Radiograph	Spot Radiograph	No radiograph
1	1.00	0.85	0.70
2	0.90	0.80	0.65
3			0.60
4			0.55
5			0.50
6			0.45

2.6 Thickness Survey

A thickness survey of the pressure vessel's wall and dished heads should be performed and documented by a certified inspector using ultrasonic testing equipment. The ultrasonic testing equipment should be properly calibrated and have a waveform display with peak-to-peak measurement mode capability and an accuracy of 0.01 inches per inch. The wall thickness data for each subsequent inspection should be used for comparisons to determine if any wall thinning may be taking place and compromising the factor of safety for the pressure vessel.

2.7 Stress Analysis

The thickness measurements for the shell and dished heads of the pressure vessels which were obtained using ultrasonic techniques and the joint efficiencies based on the original fabrication of the pressure vessel should be used to perform a stress analysis to calculate the factor of safety. The pressure vessels designed and fabricated according to the ASME Code typically have safety factors greater than 2.5. Pressure vessels with calculated factors of safety between 2 and 2.5 should be monitored closely, and any necessary repairs should be made to prevent the factor of safety from becoming lower than 2. It is recommended that any pressure vessel with a factor of safety lower than 2 be replaced.

2.8 Internal Inspection

An internal inspection may be required only if the ultrasonic wall thickness data indicate that there is some wall thinning occurring or if the pressure vessel does not have a stamp indicating the original wall thickness of the shell and dished heads.

A general visual inspection is the first step in making an internal inspection. A video borescope may also be used to facilitate the internal inspection of a pressure vessel. All parts of the vessel should be inspected for corrosion, erosion, hydrogen blistering, deformation, cracking, and laminations. The following items should be reviewed:

a. Vessel connections.—Threaded connections should be inspected to ensure that an adequate number of threads are engaged. All openings leading to any external fittings or controls should be examined as thoroughly as possible to ensure they are free from obstructions.

b. Vessel closures.—Any special closures including those on autoclaves, normally termed quick actuating (quick opening) closures which are used frequently in the operation of a pressure vessel, should be checked for adequacy and wear. A check should also be made for cracks at areas of high stress concentration.

c. Vessel internals.—Where pressure vessels are equipped with removable internals, these internals need not be completely removed, provided evidence exists that deterioration in regions rendered inaccessible by the internals is not occurring to an extent that might constitute a hazard or to an extent beyond that found in more readily accessible parts of the vessel.

d. Corrosion.—The type of corrosion (pitted or uniform), its location, and any obvious conditions should be established. Data collected for vessels in similar service will aid in locating and analyzing corrosion in the vessel being inspected. The liquid level lines, the bottom, and the shell area adjacent to and opposite inlet nozzles are often locations of most severe corrosion. Welded seams and nozzles and areas adjacent to welds are often subjected to accelerated corrosion.

2.9 Non Destructive Testing

Several different methods of non destructive testing may be used to properly assess the condition of a pressure vessel. The most important and useful technique is ultrasonic testing to determine actual wall thickness for the shell and dished heads of the pressure vessels. These examination techniques should be performed by experienced and qualified individuals. The type and amount of nondestructive examination should be determined by the inspector. Generally, some type of surface preparation will be required prior to the use of these examination methods. These examination methods include: magnetic particle examination, liquid penetrant examination, ultrasonic examination, radiography, eddy current examination, visual examination, metallographic examination, and acoustic emission.

2.10 Pressure Testing

The only acceptable medium for pressure testing of Reclamation pressure vessels is hydrostatic testing of the pressure vessel. It should be noted that **any other medium for pressure vessel pressure tests is prohibited (such as pneumatic testing by using air compressors to build up the pressure inside a pressure vessel) because this sets up the potential for an explosion**.

Pressure testing is not normally part of a periodic pressure vessel inspection. However, a pressure test may be required when the inspection discloses unusual, hard to evaluate forms of deterioration that may affect the safety factor of the pressure vessel. A pressure test may also be necessary after certain repairs and alterations have been made to the pressure vessel. Any repairs or alterations to a pressure vessel will require recertification or restamping of the pressure vessel.

To determine tightness, the test pressure should be no greater than the set pressure of the pressure relief valve having the lowest setting.

The pressure test should not exceed 1.5 times the maximum allowable working pressure adjusted for temperature. When the original test pressure includes consideration of corrosion allowance, the test pressure may be further adjusted based on the remaining corrosion allowance.

During a pressure test, where the test pressure will exceed the set pressure of the pressure relief device, the device must be prepared as recommended by the valve manufacturer.

The metal temperature during a pressure test should not be less than 60 °F unless the owner provides information on the toughness characteristics of the vessel material that indicates the acceptability of a lower test temperature.

The metal temperature is not to be more than 120 °F unless the owner specifies the requirement for a higher test temperature. If the test is conducted at 1.5 times the maximum allowable working pressure or the owner specifies a temperature higher than 120 °F, the pressure should be reduced to the maximum allowable working pressure and the temperature to 120 °F for close examination.

A thorough inspection of the vessel and its associated connections and components should be performed while under pressure. The test pressure shall be held for a period of 15 minutes. If the pressure drop exceeds more than 10 percent, leaks should be repaired and the test repeated. If the pressure drop is less than 10 percent and an inspection does not reveal leaks in the pressurized parts, it may be assumed that the leaks are through the isolation valves, manholes, and handholes.

3 Inspection of Safety Devices

The most important appurtenances on any pressurized system are the safety devices provided for over-pressure protection of that system. These are devices such as safety valves, safety relief valves, pilot valves, and rupture disks or other non-reclosing devices that are called on to operate and reduce an over-pressure condition.

These devices are not designed or intended to control the pressure in the system during normal operation. Instead, they are intended to function when normal operating controls fail or abnormal system conditions are encountered.

A pressure relief valve is required in every compressed air system ahead of the first point that could conceivably act as an air flow restriction. This includes shutoff valves, check valves, and even in-line filters because they could clog. A relief valve should also be installed on the receiver tanks, and there should be no restrictions between the tank and the valve. If there are no restrictions in the discharge line between the compressor and the receiver tank, the relief valve mounted on the receiver tank is sufficient to protect the system. **The set pressure of the relief valve shall be no higher than the maximum allowable working pressure (MAWP) marked on the pressure retaining item.** It should be noted that pressure regulators are not acceptable for protection against excessive system pressure because they do not vent air. Instead, they regulate pressure by restricting air flow.

Periodic inspection and maintenance of these important safety devices is critical to ensure their continued functioning and to provide assurance that they will be available when called on to operate.

Inspectors are cautioned that the operation of these safety devices involves the discharge of high pressure fluids or gas. Extreme caution should be used when working around these devices because of hazards to personnel. Because extremely high noise levels that can damage hearing may be encountered during testing, suitable hearing protection should be provided.

3.1 Safety Device Data

The following steps should be performed for each safety device:

a. Compare the nameplate marking or stamping of the device to the stamping on the pressure retaining item. **The set pressure shall be no higher than the maximum allowable working pressure (MAWP) marked on the pressure retaining item.**

b. Ensure that the difference between set pressure does not exceed that permitted by the original code of construction if multiple devices are provided.

c. Verify the nameplate capacity and, if possible, compare it to the system capacity requirements.

d. Check identification on seals and ensure they match nameplates or other identification (repair or reset nameplate) on the valve or device.

3.2 Inspection of Safety Device Condition

The following steps should be performed to assist in evaluating the condition of each safety device:

a. Check for evidence that the valve or device is leaking or not sealing properly.

b. Check that seals are intact and show no evidence of tampering.

c. Check that connecting bolting is tight and all bolts intact.

d. Examine the valve for deposits or mineral buildup.

e. Check for evidence of rust or corrosion.

f. Check for damaged or misapplied parts.

g. Ensure that visible drain holes are not clogged with debris or deposits.

3.3 Inspection of Safety Device Installation

The following steps should be performed to assist in evaluating the installation of each safety device:

a. Inspect inlet piping and ensure that it meets the requirements of the original code of construction. Especially check that the inlet pipe size is not smaller than the device inlet size.

b. Inspect discharge piping and ensure that it meets the original code of construction. Check that the discharge pipe size is not smaller than the device outlet size.

c. Check that the valve drain piping is open.

d. Check drainage of discharge piping.

e. Check that the discharge piping is not binding on the valve body because binding can lead to distortion of the valve body and leakage or malfunction.

f. Check the adequacy and condition of pipe supports. Discharge piping support should be independent of the device itself.

g. Check for possible hazards to personnel from the valve discharge or discharge pipe.

h. Check that there are no intervening valves (such as a block valve) between the pressure source and the valve inlet or between the valve outlet and the point of discharge. Block valves may be permitted in some pressure vessel service under certain controlled conditions when shutting down the vessel to repair a damaged or leaking valve would be difficult. If block valves are used, their use should be carefully controlled by written procedures, and the block valves should have provisions to be locked in an open position when not being used.

3.4 Operational Inspection of Safety Devices

Pressure relief valves should be periodically tested to ensure that they are free to operate and will operate according to the requirements of the original code of construction.

Pressure Relief Valve

The valve may be checked by the owner for freedom of operation by activating the test or try lever. This test should be performed only at a pressure not greater than 75 percent of the stamped set pressure of the valve. At a higher pressure, the lifting device may be damaged. This test will indicate only that the valve is free to operate. The test does not provide any information on the actual set pressure.

An operational test of the pressure relief valve should be performed every 5 years. Basically, this test consists of increasing the working pressure inside the pressure vessel to a pressure just slightly above the set pressure of the relief valve. This will verify that the relief valve will open and operate as intended.

If a valve is found to be stuck closed or not functioning properly, the system should immediately be taken out of service until the condition can be corrected, unless special provisions (such as providing additional relief valve capacity by another valve) have been made to operate on a temporary basis.

3.5 Inspection of Rupture Disks

Rupture disks or other non-reclosing devices may be used as sole relieving devices or in combination with safety relief valves to protect pressure vessels. When rupture disks are used with safety relief valves, the following additional steps should be considered during inspection:

1. Check the rupture disk nameplate information, including stamped burst pressure and coincident temperature, to ensure it is compatible with the vessel and/or safety relief valve.

2. Carefully check markings indicating direction of flow to ensure they are correct. Some rupture disks when installed in the incorrect position may burst well above the stamped pressure.

3. Check that the space between a rupture disk and a safety relief valve is supplied with a pressure gage, try cock, or tell tale indicator to indicate signs of leakage through the rupture disk. Leaking disks should be replaced.

4. If a rupture disk is used on a valve outlet, the valve design must be of a type not influenced by back pressure from leakage through the valve. For non-toxic and non-hazardous fluids, vent or drain the space between the valve and the ruptured disk to prevent the accumulation of pressure.

5. For rupture disks installed on the valve inlet, review the installation to ensure that the combination rules of the code of construction have been applied.

4 Inspection of Piping Systems

Piping systems are designed for a variety of service conditions. Particular attention should be given to piping systems that are subject to corrosion, erosion, and fatigue and those that operate at high temperatures.

All pipe material and fittings should be properly rated for the maximum service conditions to which they are subjected under normal operations. Operating history should be reviewed to determine if there have been any changes in service conditions outside the original design. If operating conditions have changed, records should be reviewed to ensure piping system components are satisfactory.

Piping should be inspected to ensure there is:

- Provision for expansion
- Provision for adequate support
- No evidence of leakage
- Proper alinement of connections. The purpose is to determine if any changes of position have placed undue strain on the piping or other connections.
- Proper rating for the service conditions
- No evidence of corrosion, erosion, or cracking or other detrimental conditions.

Piping Connections

4.1 Piping Defects

a. Corrosion.―Corrosion occurs in the presence of free oxygen and dissolved salts, such as may be found in improperly treated boiler feedwater. If corrosion is found in a pressure vessel, the associated piping systems should be considered suspect. Corrosion can deteriorate large areas of the metal surfaces or it can be localized in the form of pitting or galvanic corrosion. For the purpose of estimating the effect of severe corrosion over large areas, the thickness of the remaining sound metal should be determined by the use of ultrasonic equipment or by drilling. The estimated thicknesses of the remaining sound metal will be used to estimate the safe working pressure.

b. Cracks.―Cracks may result from design and operating conditions that cause continual flexing. Flexing can be caused by thermal or mechanical fluctuations and can lead to metal fatigue. Cracking under these conditions may be accelerated by corrosion. Cracking may also result from fatigue at imperfections existing in material at the time of piping system fabrication. Cracks resulting from fabrication defects will normally occur first in corrosive environments in areas subject to high stress. Suspect areas should be examined periodically for cracking.

c. Erosion.―Erosion may occur as a result of the abrasive action of a liquid or vapor. The presence of solid particles of matter in suspension, or entrained liquids in vapor are factors in this type of mechanism. Erosion generally occurs in areas where flow is restricted or flow direction is changed. Suspect areas should be examined for evidence of erosion.

d. Leakage.―A leak should be thoroughly investigated and corrective action initiated. A pressure test may be required to obtain additional information regarding the extent of a defect or detrimental condition.

e. Improper support.―Visual inspection should include a check for evidence of improper support. The alignment of connections between anchored equipment should be observed to determine if any change in position of the equipment resulting from settling or other causes has placed an undue strain on the piping or its connection. Inadequate support or the lack of provision for expansion may cause broken attachment welds, cracks, or leakage at fittings. Any signs of leakage should be investigated to determine the cause and the condition corrected. Missing, damaged, or loose insulation may be an indication of vibration or pipe movements resulting from improper support.

4.2 Inspection of Pressure Gages

The pressure indicated by the required gage should be compared with other gages on the same system. If the pressure gage is not mounted on the vessel itself, it should be installed in such a manner that it correctly indicates the actual pressure in the vessel. When required, the accuracy of pressure gages should be verified by comparing the readings with a standard test gage or a dead weight tester.

Pressure Gage

5 Record Keeping

Post a copy of the inspector's approval or certification reports near or on the unfired pressure vessel.

Also, maintain a permanent record for each pressure vessel. This record should include the following information:

1. An ASME Manufacturer's Data Report or, if the vessel is not ASME Code stamped, other equivalent specifications.

2. A pressure vessel data report (first internal inspection). The data report should include the following information:

   - Manufacturer's Serial Number
   - Owner-User's Identification Number
   - Pressure vessel dimensional data (width, height, diameter, etc.)
   - Material of construction
   - Original wall thickness data for pressure vessel and dished heads
   - Original code of construction including NDE method
   - Safety factor computed from original code of construction.

3. Complete pressure relieving device information, including safety or safety relief valve spring data or rupture disk data, and the date of the latest inspection.

4. Progressive record including, but not limited to, the following:

   a. The location and thickness of monitor samples and other critical inspection locations, including locations and results of metal thickness surveys.

   b. The limiting metal temperature and the location on the vessel when this is a factor in determining the minimum allowable thickness.

   c. The computed required metal thicknesses and the maximum allowable working pressure for the design temperature and pressure relieving device opening pressure, static head, and other loadings.

   d. The scheduled date of the next inspection.

   e. The date of installation and the date of any significant change in service conditions (pressure, temperature, character of contents, or rate of corrosion)

   f. Drawings showing sufficient details to permit calculation of the service rating of all components on pressure vessels used in process operations subject to corrosive conditions. Detailed data with sketches, where necessary, may serve this purpose when drawings are not available.

   g. Stress calculations performed to determine if the factor of safety complies with the safety factor specified in the original code of construction.

6 Causes of Deterioration in Pressure Vessels

There are a variety of conditions that cause deterioration in pressure vessels. The common conditions are listed and described below:

a. Corrosion.—Corrosion is one of the most prevalent conditions found in pressure vessels. The following types of corrosion are commonly found:

   1. Pitting—Shallow, isolated, scattered pitting over a small area that does not substantially weaken the vessel. It could, however, eventually cause leakage.

   2. Line corrosion—This is a condition where pits are connected, or nearly connected, to each other in a narrow band or line. Line corrosion frequently occurs in the area of intersection of the support skirt and the bottom of the vessel and at the liquid-vapor interface.

   3. General corrosion—This is corrosion that covers a considerable area of the vessel. When this occurs, consider the safe working pressure of the vessel that is directly related to the remaining material thickness.

   4. Grooving—This type of corrosion is a form of metal deterioration caused by localized corrosion. It may be accelerated by stress concentration. Grooving may be found adjacent to riveted lap joints or welds and on flanged surfaces, particularly the flanges of unstayed heads.

   5. Galvanic corrosion—Two dissimilar metals in contact with each other and with an electrolyte (i.e., a film of water containing dissolved oxygen, nitrogen, and carbon dioxide) constitute an electrolyte cell, and the electric current flowing through the circuit may cause rapid corrosion of the less noble metal (the one having the greater electrode potential). This corrosion mechanism is most active when there are large differences between the electrode potentials of the two metals, but galvanic corrosion may also exist with relatively minor changes of alloy composition (i.e., between a weld metal and the base metal). Neutral (i.e., an oxide coating on aluminum) or protective coatings may inhibit galvanic corrosion, but in most instances, the metals or alloys must be selected on the basis of intrinsic resistance to corrosion. In pressure vessels, the effects of galvanic corrosion are most noticeable at rivets, welds, and flanged and bolted connections.

b. Fatigue.—Stress reversals (such as cyclic loading) in parts of equipment are common, particularly at points of high secondary stress. If stresses are high and reversals frequent, failure of parts may occur because of fatigue. Fatigue failures in pressure vessels may also result from cyclic temperature and pressure changes. Locations where metals having different thermal coefficients of expansion are joined by welding may be susceptible to thermal fatigue.

c. Creep.—Creep may occur if equipment is subject to temperatures above those for which the equipment is designed. Since metals become weaker at higher temperatures, such distortion may result in failure, particularly at points of stress concentration. If excessive temperatures are encountered, structural property and chemical changes in metals may also take place that may permanently weaken equipment. Because creep depends on time, temperature, and stress, the actual or estimated levels of those quantities should be used in any evaluations.

d. Temperature.―At sub-freezing temperatures, water and some chemicals handled in pressure vessels may freeze and cause failure. Carbon and low alloy steels may be susceptible to brittle failure at ambient temperatures. A number of failures have been attributed to brittle fracture of steels that were exposed to temperatures below their transition temperature and which were exposed to pressures greater than 20 percent of the hydrostatic test pressure. However, most brittle fractures have occurred on the first application of a particular stress level (that is, the first hydrostatic test or overload). Special attention should be given to low-alloy steels because they are prone to temper embrittlement. (Temper embrittlement is defined as a loss of ductility and notch toughness caused by postweld heat treatment or high temperature service, service above 700 degrees Fahrenheit.

e. Hydrogen embrittlement.―Hydrogen embrittlement is a loss of strength or ductility in steels caused by atomic hydrogen dissolved in the steel. It is a low temperature phenomenon, seldom encountered above 200 degrees Fahrenheit, and most often occurs as a result of hydrogen evolved from aqueous corrosion reactions. It can vary in appearance and can occur in differing environments, thus giving rise to the various terms by which it is known, including sulfide stress cracking, wet H2S cracking, hydrogen stress cracking, blistering, blister cracking, hydrogen-induced cracking (HIC), and stress-oriented hydrogen-induced cracking (SOHIC). Weld underbead cracking (also known as delayed cracking and cold cracking) is also a form of hydrogen embrittlement; however, in this case, the hydrogen comes from the welding operation rather than from a corrosion reaction.

Some forms of hydrogen embrittlement require an applied stress or residual stress for cracking to occur (sulfide stress cracking, SOHIC, weld underbead cracking), and others occur in the absence of applied or residual stress, the internal pressure from the recombined hydrogen gas being sufficient to cause the damage (blistering, HIC).

Susceptibility to sulfide stress cracking and similar forms of hydrogen embrittlement depends on the strength of the steel. Higher strength steels are more susceptible. The strength level at which susceptibility arises depends on the severity of the environment that the steel is exposed to. Hydrogen sulfide, hydrogen cyanide, and arsenic, in aqueous solutions, all greatly increase the severity of the environment regarding hydrogen embrittlement by increasing the amount of hydrogen that is absorbed by the steel during the corrosion reaction. In hydrogen sulfide environments, cracking can generally be avoided by using steels with a strength level below that equivalent to a hardness of Rockwell C-22.

Similarly, weld underbead cracking is caused by hydrogen dissolved in a hard, high-strength, weld-heat affected zone. Practicing low hydrogen welding to minimize dissolved hydrogen or using high preheat or post-weld heat treatment to reduce heat affected zone hardness will reduce the likelihood of weld underbead cracking in a susceptible steel.

Hydrogen embrittlement is reversible as long as no physical damage, e.g., cracking, has occurred in the steel. If the atomic hydrogen is removed from the steel before any damage occurs, for example by heating for a short time in the absence of hydrogen to between 300 and 400 °F, normal mechanical properties will be restored.

Cracking that can occur in vessels operating in aqueous H_2S service (i.e., wet H_2S cracking) will not always be readily apparent on visual inspection. Other methods, such as magnetic particle (including wet flourescent) or liquid penetrant, may be required to reveal the cracks.

Welding procedures, repair methods, and inspection procedures must include careful consideration of potential failure in corrosive environments, including failure from the various forms of hydrogen embrittlement.

f. Stress corrosion cracking.―Cracking of a metal caused by the combined action of stress and a corrosive environment. Stress corrosion cracking only occurs with specific combinations of metal and environment. The stress required may be either applied or residual. Examples of stress corrosion cracking include chloride stress corrosion cracking of stainless steels in hot, aqueous chloride solutions and ammonia stress corrosion cracking of brass in ammonia solutions (season cracking).

Corrosion alone is not a good indicator of the likelihood of a particular environment to cause stress corrosion cracking in a particular metal. Solutions that are highly corrosive to a material almost never promote stress corrosion cracking.

The principal variables affecting stress corrosion cracking are tensile stress, service temperature, solution chemistry, duration of exposure, and metal properties. Sufficiently modifying any one of these parameters can reduce or eliminate the possibility of stress corrosion cracking occurring in service.

7 References

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