NDE Applied to Pressure Vessel Evaluations

PDH: 4 Hours

Ryan Malone, P.E.

PDH Now, LLC.
www.PDH*Now*.com

NDE Applied to Pressure Vessel Evaluations

PDH: 4 Hours

Ryan Malone, P.E.

Table of Contents

List of Figures

NDE Applied to Pressure Vessel Evaluations

Course Overview

Pressure vessels are a key component of many processing facilities. Nuclear plants, paper mills, refineries, and natural gas processing plants all depend on pressure vessels to process a product. It is often desired to assess or extend the remaining service life of these pressure vessels by performing an inspection and engineering evaluation. Pressure, thickness, and structural reinforcement calculations are completed to determine an estimated corrosion rate and remaining life. Pressure vessels are often de-rated or the scheduled inspection interval increased to allow for continued operation of the asset. This course will address the application of various nondestructive inspection techniques to facilitate pressure vessel suitability for service evaluations. Often the most difficult obstacle to overcome is obtaining access to critical areas. Many pressure vessels are tall towers and often fully insulated, making an external inspection difficult. An internal, direct visual inspection, supplemented with an ultrasonic thickness inspection, is often the best evaluation method. The difficulties of doing an internal inspection include accessibility, confined space entry safety issues, cleaning of hazardous chemicals and residue, and the expense of taking a pressure vessel out of service. A combination of direct and remote visual inspection, dye penetrant, dry magnetic particle, wet fluorescent magnetic particle, acoustic emission, hardness testing, and various ultrasonic thickness inspections are typically used to complete the evaluation. The primary focus of this course will be on the application of visual inspection supplemented by a variety of ultrasonic inspection techniques.

Learning Objectives

Upon successful completion of this professional development course, the professional engineer will be able to:

- Become familiar with applicable codes and standards governing pressure vessel evaluations
- Become familiar with common damage mechanisms affecting pressure vessels
- Review less common, but still applicable damage mechanisms impacting pressure vessels and their materials
- Review the common inspection techniques in pressure vessel evaluations and understand the advantages and shortcomings of each technique
- Become familiar with the engineering evaluation process for evaluating pressure vessels
- Review several examples of pressure vessel repairs resulting from non-destructive evaluation and engineering evaluation

Introduction

As pressure vessels age it becomes necessary to inspect and evaluate the remaining life of the pressure vessel. The inspection and subsequent evaluation will determine if the vessel should be repaired, rerated, or replaced. The future inspection interval is also determined. This process is collectively known as a fitness for service evaluation. These pressure vessels are typically major components of process critical equipment and subjected to corrosive environments and extreme environmental conditions. These vessels were typically designed for a 30-50 year design life. Between 1992 and 2001 a total of 23,338 pressure vessel accidents were reported with the highest yearly number of accidents equaling 2,686 in 2000 [1]. The total number of pressure vessel related fatalities during the first decade of this century was recorded as 127 [1]. Engineering codes and standards have improved since many vessels were placed in service, causing many operators to evaluate their facilities for compliance with existing codes and standards. Engineering evaluations are required to ensure existing equipment meets current safety standards, and are often completed to extend the service life of pressure vessels. Often the inspection and subsequent engineering evaluation are the result of a scheduled risk-based inspection program. According to Rick Peterson of Metegrity, Inc. the purpose of the scheduled risk-based inspection is to: Maintain the asset integrity, maintain reliability, ensure fitness for service, and prove due diligence [2]. Other suitability for service evaluations are initiated by the relocating of a pressure vessel to a new jurisdiction, change of service, or the purchase of an asset by a new operator [3].

Codes and Standards

There are many codes and standards used in the evaluation process, many of the codes referenced in this paper are from the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME). The laws vary by state, but generally it is required that all pressure vessels and boilers be built to ASME Section VIII, and registered with The National Board of Boiler and Pressure Vessel Inspectors and given a National Board number. Examples of typical codes and standards used in the inspection and evaluation of pressure vessels are:

1. API 510, Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration, provides details on inspecting and evaluating the remaining life of pressure vessels, and determining the required inspection interval [4].
2. NBIC NB-23, Part 2, Inspection and Part 3, Repairs and Alterations, provide details on inspecting, repairing, and altering pressure vessels [5] and [6].
3. ASME Section VIII, Division 1, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Rules for Construction of Pressure Vessels [7].
4. API RP 571, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, details specific damage mechanisms for pressure vessels in the refining industry [8].
5. API 579-1 / ASME FFS-1, Fitness-For-Service, provides evaluation methods for specific types of pressure vessel damage [9].

6. API RP 580, Risk Based Inspection, provides users of pressure retaining equipment with the basic elements for developing and implementing and risk based inspection program [10].

Damage Mechanisms

API 579-1, Fitness-for-Service provides details on methods of evaluating typical damage mechanisms found on pressure vessels in the petrochemical and refining industry [9]. The typical damage mechanisms and failure modes are described in API RP 571, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry [8]. These common damage mechanisms and failure modes are described below:

Brittle Fracture is a sudden stress fracture where the material exhibits no evidence of ductility or plastic deformation. This type of failure originates at a material flaw. Figures 1 and 2 below show brittle fracture during hydrotest on a 20-inch carbon steel pipeline and the gouges that caused the failure [8].

Figure 1 Brittle fracture failure during hydrotest of 20-inch OD carbon steel pipeline [8].

Figure 2 Fracture origin (arrow) and gouges that caused brittle fracture failure on 20-inch OD carbon steel pipeline [8].

Thermal fatigue is caused by cyclic stresses from temperature variations [8]. Typically a thermal fatigue crack will start on the component surface. An example is shown in Figure 3 below.

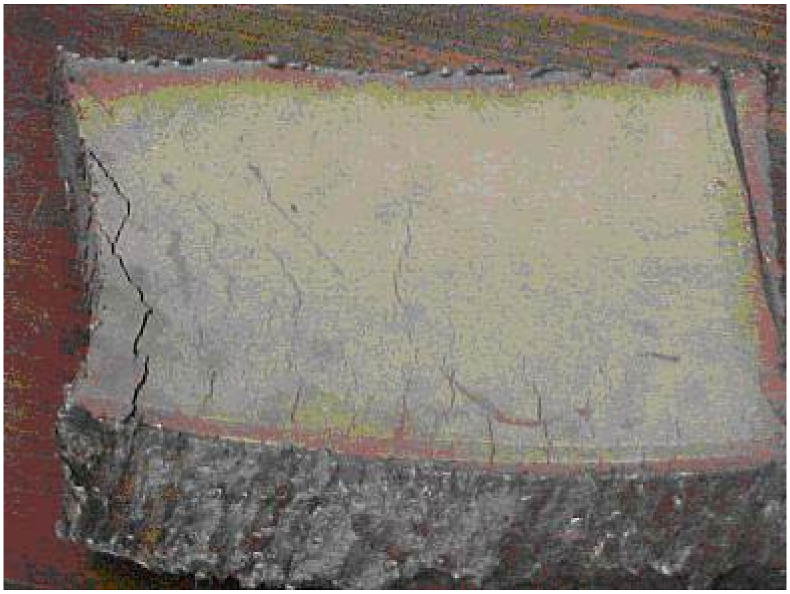


Figure 3 Heavy wall stainless steel pipe showing Thermal fatigue cracks on the inside surface [8].

Erosion and erosion-corrosion are common damage mechanisms in pressure vessels. Erosion is caused by the impact of the internal fluid against the pressure vessel surface. Erosion-corrosion is described by a corrosion contribution to erosion by the removing protective surfaces layers allowing further erosion to act on the material [8]. Figure 4 below shows erosion on the inside surface of an elbow [8].

Figure 4 Erosion of return bend [8].

Mechanical fatigue is caused by cyclical stresses for an extended period, typically resulting in a sudden failure. This failure often occurs well below the material yield strength [8].

Figure 5 Transverse fatigue crack in weld [8].

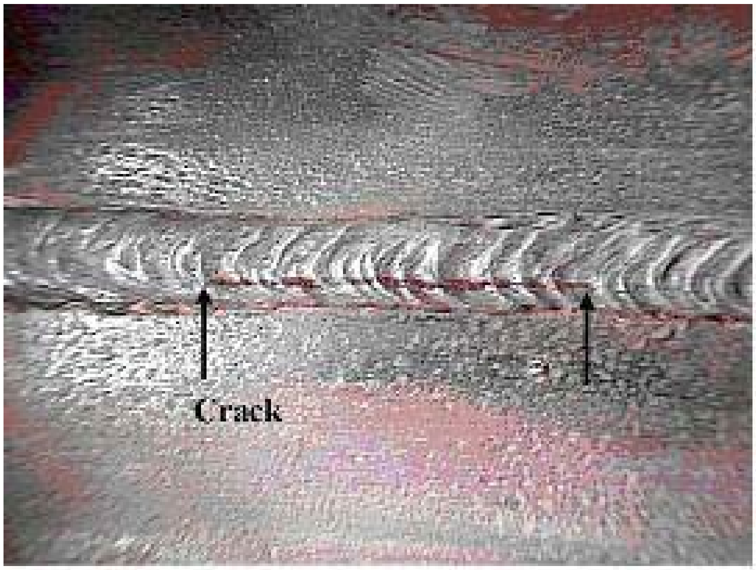


Figure 6 Longitudinal fatigue crack in weld [8].

Corrosion Under Insulation (CUI)

Pressure vessels are often insulated to prevent unwanted heat transfer from the pressure vessel. If the insulation is not properly sealed moisture can get between the vessel wall and the insulation causing aggressive corrosion. Between the temperatures of 212º F and 250º F the corrosion becomes more severe because the moisture is less likely to vaporize and the insulation remains wet for a longer period of time [8]. Figure 7 and 8 show an insulated liquid level bridal on a pressure vessel and a corresponding profile RT film [8].

Figure 7 Insulated liquid level bridal with CUI [8].

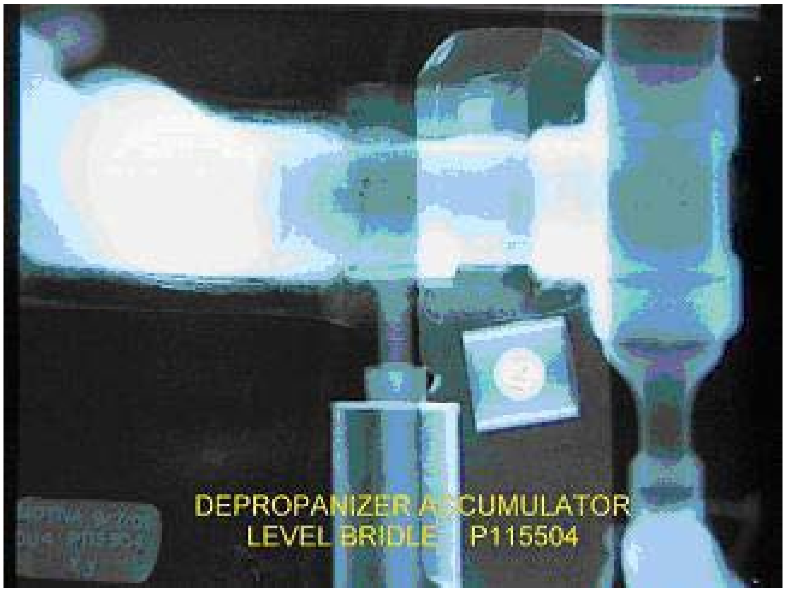


Figure 8 Profile RT of insulated liquid level bridal in Figure 7 [8].

Environment Assisted Cracking, Chloride Stress Corrosion Cracking

Stainless steel vessels are subject to chloride stress corrosion cracking (Cl SCC) when subjected to the combination of tensile stress, temperature, and an aqueous chloride environment. The presence of oxygen in solution increasing the probability of cracking [8]. Figure 9 shows an example of SCC.

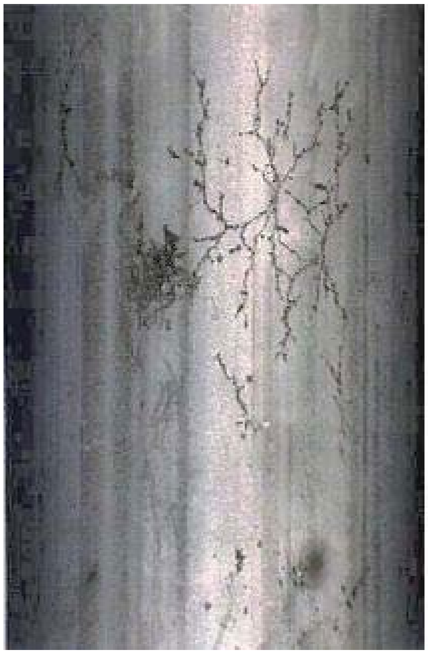


Figure 9 Close-up view of tight web appearing SSC cracks on Type 316L SS tubes in steam service [8].

Wet H2S Damage (Blistering/HIC/SOHIC/SCC)

Pressure vessels in wet H_2S environments are subject to four types of damage described below. These damage mechanisms result in blistering and/or cracking of carbon and low alloy steels.

Hydrogen blistering

Hydrogen atoms can form during the sulfide corrosion process and diffuse into the steel. These atoms can then collect at any discontinuity in the steel (inclusion or lamination). The hydrogen atoms combine to form hydrogen molecules that are too large to diffuse out, causing pressure to build, and form a local deformation or blister in the steel [8]. An example is shown in Figure 10 and 12 [8].

Hydrogen Induced Cracking (HIC)

Adjacent hydrogen blisters may develop cracks which will link together. Often the hydrogen blisters are at different depths within the steel, causing the interconnecting cracks to have a stair step appearance [8]. An example is shown in Figure 11 and 12 [8].

Stress Oriented Hydrogen Induced Cracking (SOHIC)

SOHIC is similar to HIC, but appears as layers of cracks, resulting in a through-thickness crack. The crack is perpendicular to the surface stress driver. These cracks usually appear in the base metal near the weld metal heat affected zone (HAZ) [8]. Examples are shown in Figure 13 and 14 [8].

Sulfide Stress Corrosion Cracking (SSC)

SCC is cracking due to the combined effect of tensile stress and corrosion in the presence of water and H_2S. SCC is considered a form of hydrogen diffusion stress cracking. Since SCC often initiates at localized zones of high hardness in weld metal and HAZ, SCC can often be prevented by adequate pre-heating prior to welding and post weld heat treating (PWHT) [8].

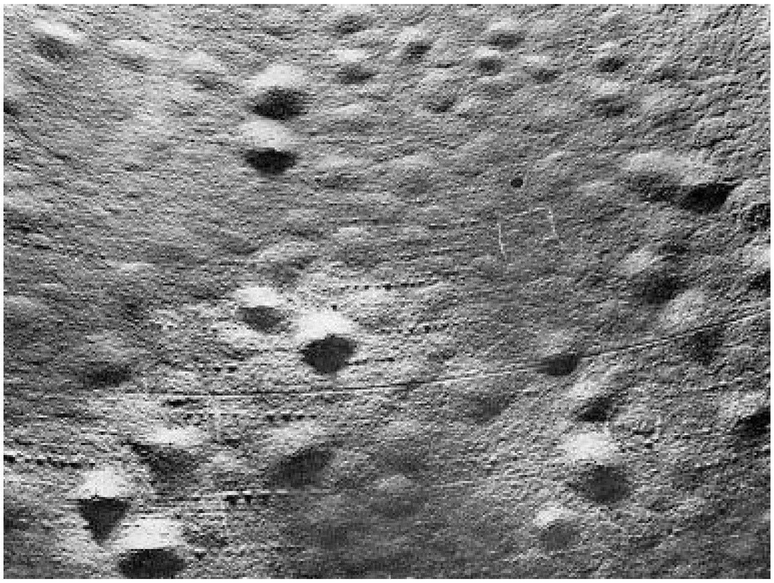


Figure 10 Pressure vessel with hydrogen blistering [8].

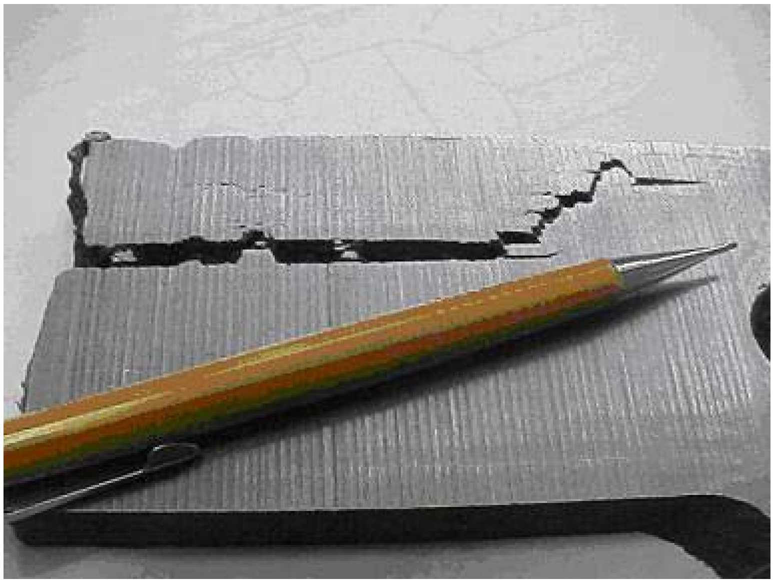


Figure 11 Stepwise cracking nature of HIC in pressure vessel shell [8].

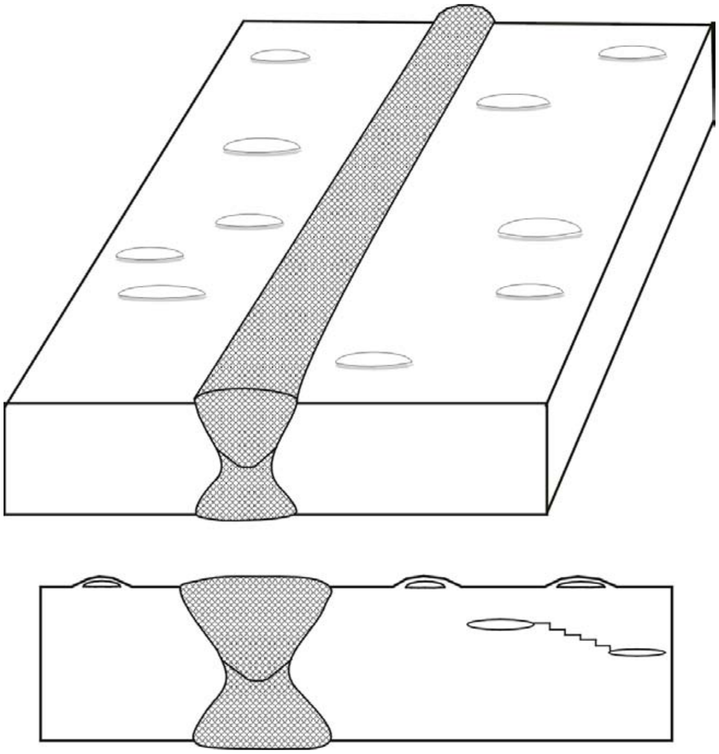


Figure 12 Schematic showing hydrogen blistering and HIC damage [8].

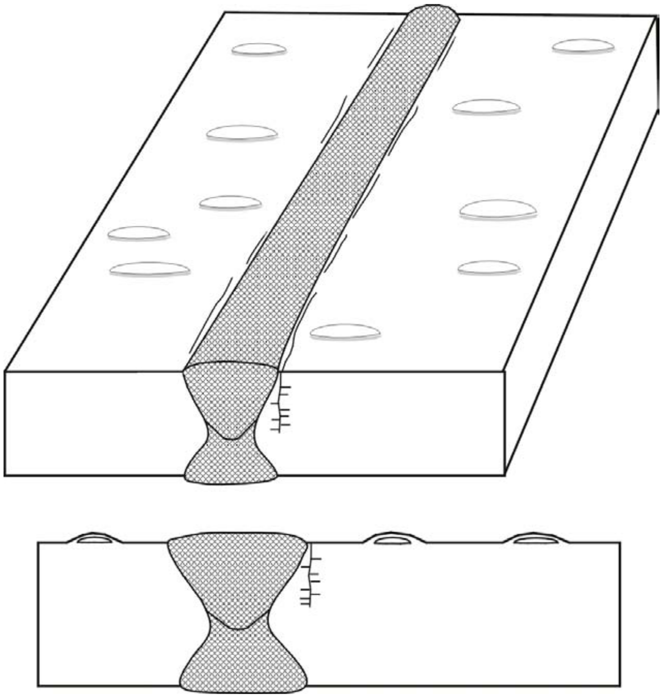


Figure 13 Hydrogen blistering shown with accompanying SOHIC damage at the weld [8].

Figure 14 SOHIC damage shown using WFMT [8].

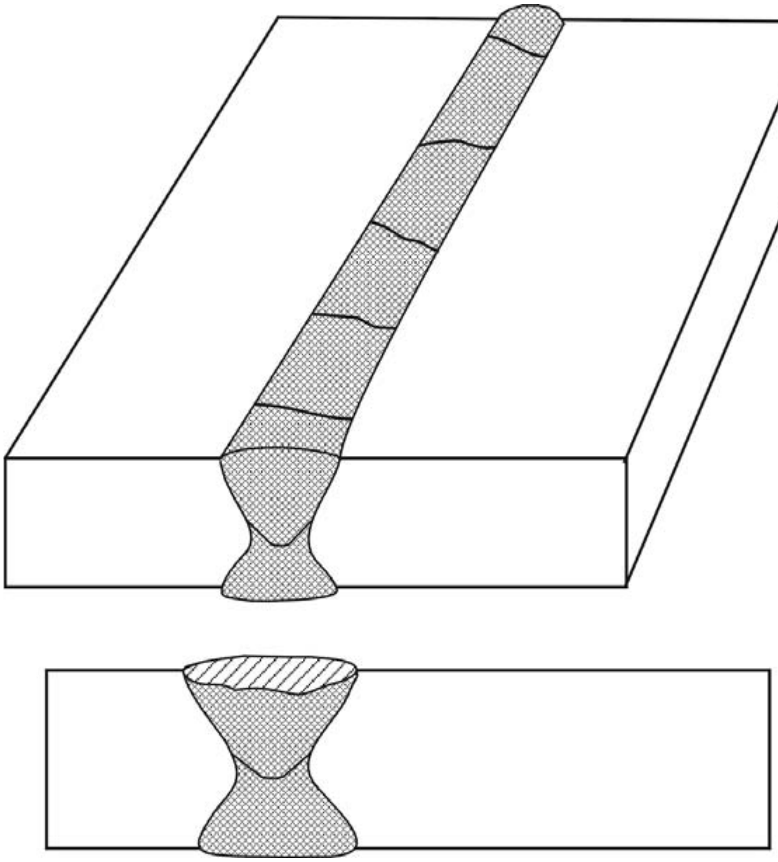


Figure 15 Schematic showing SCC damage on hard weld pass not tempered by subsequent weld passes [8].

Inspection Techniques

Many inspection techniques are used to assess the integrity of pressure vessels. The best method is a full internal and external visual inspection. This is often impossible due to the difficulty of obtaining access. Often pressure vessels are tightly packaged amongst other equipment, are tall towers, or are externally insulated making an external visual inspection very difficult. The expense of taking a vessel out of service, removing internal components, and internal cleaning, combined with confined space entry concerns often make an internal visual inspection a difficult and expensive proposition.

Typically, a visual inspection is supplemented with an ultrasonic thickness (UT) inspection. The simplest ultrasonic thickness inspection is completed by taking thickness readings at predetermined corrosion monitoring locations (CML). This evaluation technique is adequate for typical corrosion monitoring applications but may not be sufficient to fully characterize the condition of the vessel. UT on CML locations could be compare to "finding a needle in a haystack." It is possible that a CML location showing minimal wall thickness loss could be located adjacent to an area of significant corrosion. To fully assess the condition of a pressure vessel a combination of the following techniques can be used.

External Visual Inspection

An external visual inspection can be completed using the guidelines provided in API 510 Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration. The inspector should be close to the vessel and use light, magnifying glass, and scraping tools to look for possible issues. Often an external visual inspection can be an intimidating task requiring the technician to wear a safety harness and climb while carrying his inspection equipment. An example is shown in Figures 16, 17, and 18 below.

Figure 16 Amine contactor tower at major oil and gas company owned natural gas treating facility.

Figure 17 View looking up at amine contactor tower at a major oil and gas company natural gas treating facility.

Figure 18 View of outlet piping at top of amine contactor tower at a major oil and gas company natural gas treating facility.

Internal Visual Inspection

An internal visual inspection is the best method of assessing a pressure vessel. This is often a difficult task due to the complications involved with getting internal access and cleaning of a vessel. Typical tools used in an internal inspection include flash lights, magnifying glasses, pit depth gauges, and scrappers for removing surface residue. Some vessels easily accommodate an internal inspection. This filter vessel is often out of service and has a quick opening closure head, easily accommodating an internal inspection. Other internal inspections are more complicated requiring a vessel to be removed from service, internally cleaned, and air circulation provided. An example from Sandstone Engineering is shown in Figures 22, 23, and 24 below.

Figure 19 Filter Specialists, Inc. sock filter vessel on portable skid used for filtering water in natural gas drilling operations for a major oil and gas company.

Figure 20 Filter Specialists, Inc. sock filter vessel on portable skid with quick opening closure opened.

Figure 21 Pitting identified during internal inspection of pressure vessel.

Figure 22 View of liquids storage bullet tank at a major oil and gas producer's natural gas processing facility. Vessel built in 1955 by Riley Beaird and still in service in 2011.

Figure 23 Internal view after internal inspection on west head of bullet tank at a major oil and gas producer's natural gas processing facility.

Figure 24 Internal view after internal inspection on bottom of bullet tank at a major oil and gas producer's natural gas processing facility.

Borescope

If a pressure vessel is too small for an internal inspection or does not have a large enough manway to accommodate an internal inspection, a remote video borescope can be used. The vessel must be removed from service to accommodate the borescope inspection.

Figure 25 Internal inspection of vessel using an articulating borescope

Ultrasonic Thickness Inspection

Ultrasonic thickness inspection is widely used in suitability for service evaluation of pressure vessels. There are several variations of this technique allowing the technician to efficiently assess the condition of the vessel. Often the ultrasonic inspection is limited to ultrasonic thickness measurements at predetermined locations. These locations are periodically checked and input into a database to monitor the corrosion. If an abnormality is detected, then a more detailed inspection ensues [11]. When an internal inspection cannot be completed, and it is desired to ultrasonically scan a large surface area of a pressure vessel a "Pocket-UT" instrument can be used. This instrument uses water as the couplant and has a magnetic surface with a track ball transducer inside the scanner assembly allowing the technician to scan a significant surface area in a short amount of time. The transducer assembly resembles a computer mouse. By watching the waveform, the operator can identify low areas, which are marked and then more closely inspected with an ultrasonic A-Scan or B-Scan. A similar transducer attached to a "crawler" can be used to scan significant areas of a large pressure vessel. The "crawler" can be remotely controlled or attached to an extension pole.

Figure 26 "Pocket-UT" transducer assembly shown on a vessel top head, courtesy of Sandstone Engineering.

Figure 27 "Pocket-UT" transducer assembly shown on a vessel top head, courtesy of Sandstone Engineering.

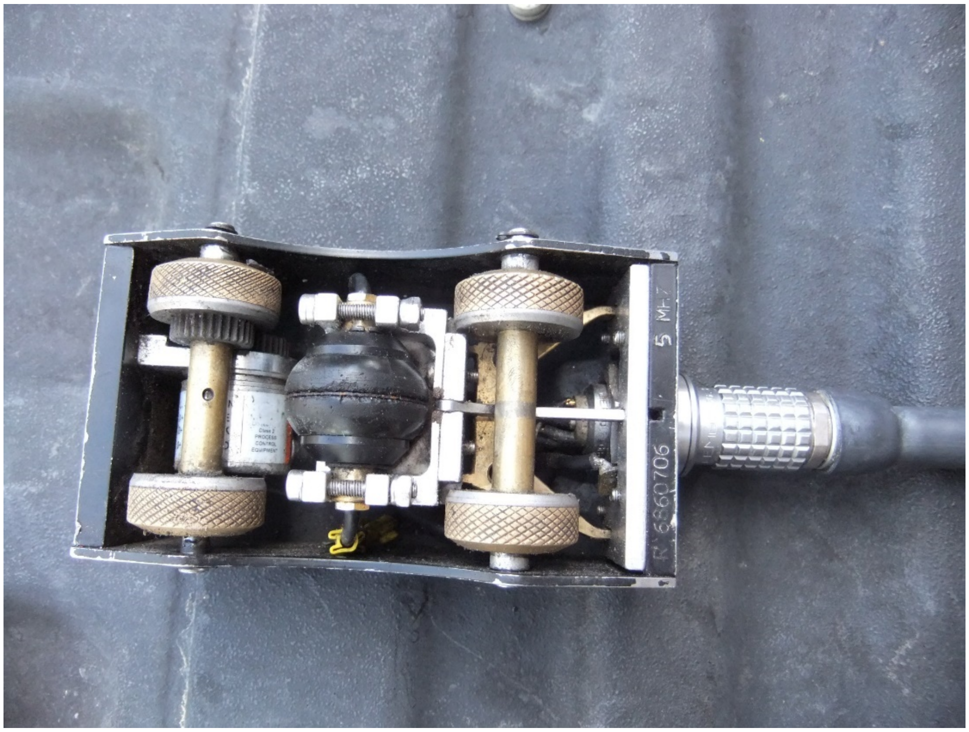


Figure 28 Bottom view of "Pocket-UT" transducer assembly with liquid filled track-ball and encoder

Figure 29 Bottom view of manual UT crawler and spring loaded transducer

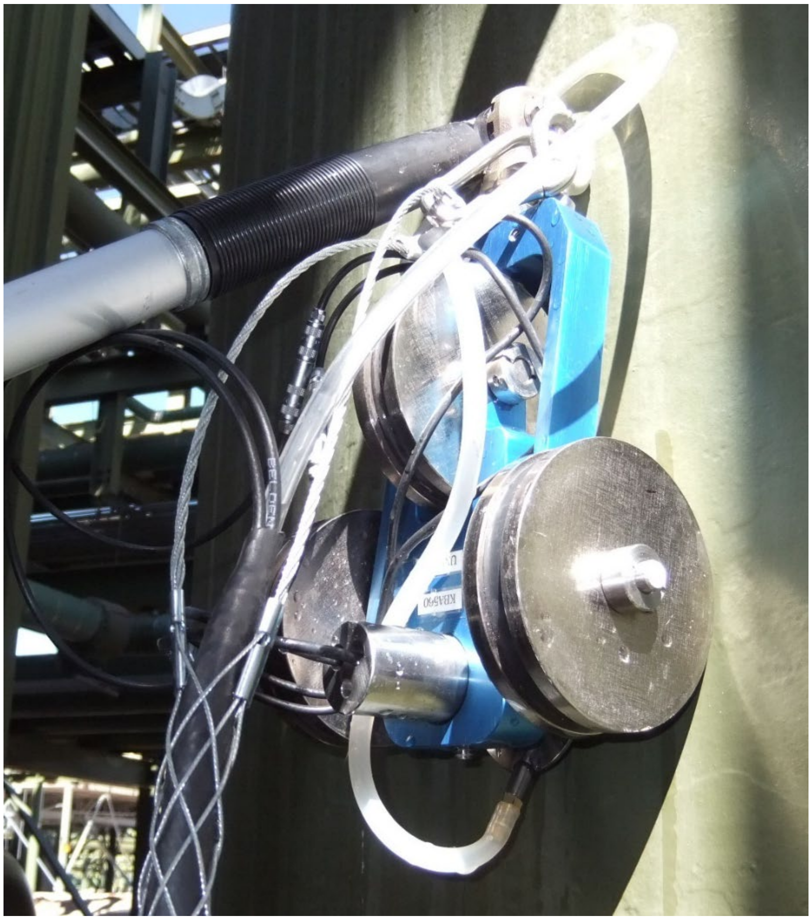


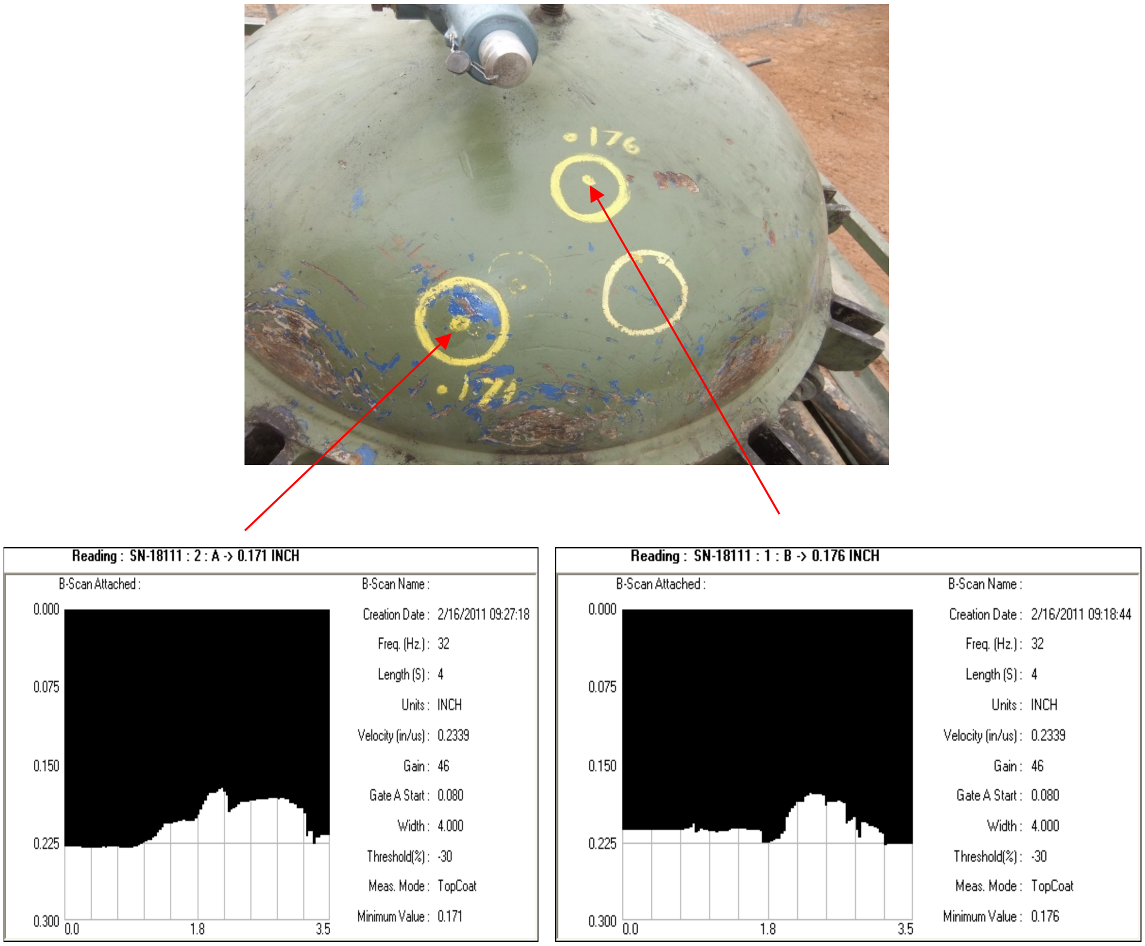
Figure 30 Top view of manual UT crawler on pressure vessel tower

Figure 31 View of manual UT crawler on pressure vessel tower, courtesy of Sandstone Engineering

Once ultrasonic scanning instrumentation has been used to identify potential problems areas, a more detailed inspection is completed using a more accurate transducer and instrument. The most common is an ultrasonic thickness instrument capable of collecting A-Scan thickness measurements and B-Scan thickness profiles. An example of each is shown below, courtesy of Sandstone Engineering in Farmington, NM. Not shown below is an example of a C-Scan. Ultrasonic thickness transducers can be combined with position encoders. When automated encodes are combined with a B-scan, the result is known as a C-scan.

Figure 32 Topcoat ultrasonic transducer and couplant on pressure vessel head

Figure 33 GE DMS 2 A-Scan waveform output from pressure vessel inspection



Reading : SN-18111 : 2 : A -> 0.171 INCH

B-Scan Attached :

B-Scan Name :

Creation Date : 2/16/2011 09:27:18

Freq. (Hz.) : 32

Length (S) : 4

Units : INCH

Velocity (in/us) : 0.2339

Gain : 46

Gate A Start : 0.080

Width : 4.000

Threshold(%) : -30

Meas. Mode : TopCoat

Minimum Value : 0.171

Reading : SN-18111 : 1 : B -> 0.176 INCH

B-Scan Attached :

B-Scan Name :

Creation Date : 2/16/2011 09:18:44

Freq. (Hz.) : 32

Length (S) : 4

Units : INCH

Velocity (in/us) : 0.2339

Gain : 46

Gate A Start : 0.080

Width : 4.000

Threshold(%) : -30

Meas. Mode : TopCoat

Minimum Value : 0.176

Figure 34 GE DMS 2 B-Scan output from inspection of pressure vessel top head, ¼” nominal wall thickness. The large yellow circle identifies potential problems areas identified by the “Pocket UT”

When a weld inspection is required, or a potential material lamination is suspected an ultrasonic shear wave inspection or ultrasonic phased array inspection is often completed. These inspections are often referred to as angle beam ultrasonic inspections. By sending the sound wave into the material at an angle the technician is able to inspect for crack, inclusions, or laminations. Phased array inspection systems for pressure vessels allow electronic control of the sound beam allowing the operator to scan, sweep, steer, and focus the ultrasound [12]. A phased array ultrasonic inspection can also be used to inspect for cracks resulting from damage to a pressure vessel. Some phased array photographs are shown below.

Figure 35 Array transducer on wedge block [12].

Figure 36 OmniScan portable phased array equipment [12].

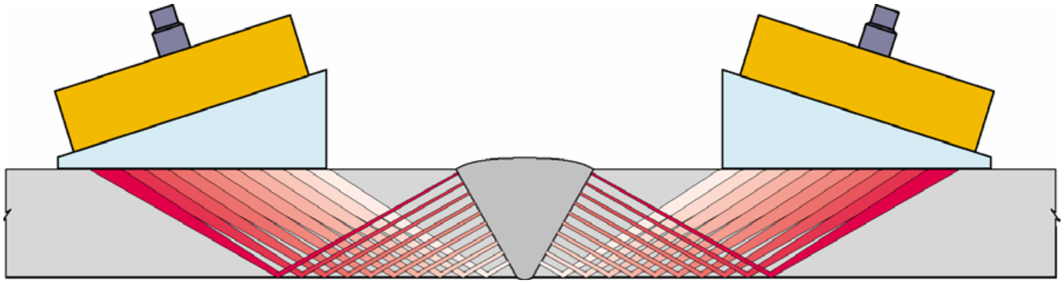


Figure 37 OmniScan portable phased array equipment [12].

Many technological advances in pressure vessel inspection have been made in recent years. There are many automated UT techniques beginning to be used alongside the fundamental manual UT method [13]. C-Scan technique (also called T-Scan), P-Scan technique, Time-of-flight diffraction (TOFD), and guided wave systems are beginning to see use in pressure vessel evaluations [13]. The increased accuracy of new inspection techniques combined with the ability to non-intrusively inspect result in more reliable and safer facilities and less inspection expense [14].

Magnetic Particle Inspection

Magnetic particle inspections are often completed on the welds if the vessel is in service potentially leading to cracking such as sulfide service. Other pressure vessel magnetic particle weld inspections are completed at scheduled intervals as part of the inspection program [15]. Detailed WFMT inspections are often completed at nozzle penetrations due to potential of crack formation at these locations [15]. Cracks can form due to excessive nozzle external piping loads, lack of adequate weld penetration, or chemical attack. By performing a magnetic particle inspection over the vessel welds any surface cracks can be identified. An example of wet fluorescent magnetic particle (WFMT) inspection is shown below.

Figure 38 Internal visual inspection showing post WFMT inspection of ~30% of hemispherical head welds.

Figure 39 Internal visual inspection showing post WFMT inspection of nozzle internal weld. Courtesy of Sandstone Engineering in Farmington, N.M.

Acoustic Emission

Acoustic emission is a very thorough inspection method capable of assessing the volumetric integrity of a pressure vessel during a pressure test period [16]. This method, like ultrasonic shear wave, has a code case (essentially an exemption) by ASME allowing its use in place of RT on some new pressure vessel inspections [16]. Acoustic emission sensors properly placed on a pressure vessel can detect the high-pitched sound caused by local metal deformation on a vessel [16]. By placing sensors and inducing stress (such as in a hydrostatic test) problem areas can be located on a vessel. European Pressure Equipment Directive member states have adopted regulations enabling acoustic emission monitoring of pneumatic pressure tests of pressure vessels in place of hydraulic proof tests [17]. The Centre for Technology and Innovation Management in the Netherlands has completed research showing the ability of using acoustic emission as a real time monitoring method to identify and locate possible weaknesses in pressure vessels [17]. An example is shown below.

Figure 40 Acoustic emission monitoring of pressure vessel final testing [17].

Radiographic Testing

Radiographic Testing (RT) is occasionally used on pressure vessels to evaluate the presence or condition of internal components. RT is also used to assess weld condition or internal corrosion. One limitation of RT is the inability to effectively and constantly interpret cracks when evaluating the RT film.

Engineering Evaluation

After the inspection is completed an engineering evaluation is used to determine the pressure retaining capability, corrosion rate, and remaining life of a vessel. All relevant loads must be considered in the engineering evaluation including pressure, hydrostatic head pressure, internal and external component weight, external piping loads, snow loads, wind loads, and seismic loads. The engineering evaluation often results in repair recommendations, increased inspection interval recommendations, pressure de-rate recommendations, or vessel replacement recommendations. API 510 Pressure Vessel Inspection Code [4], ANSI NB 23 National Board Inspection Code [6], and ASME Section VIII [7] are typically used to complete the engineering evaluation. If specific damage mechanisms are identified API 579-1/ASME FFS-1 provide guidelines on evaluating the integrity of the vessel. The long-term (LT) and short-term (ST) corrosion rates can be calculated in accordance with API 510 as shown below, where $t_{initial}$ is the original component nominal wall thickness, t_{actual} is the measured thickness at time of inspection, and $t_{previous}$ is the component wall thickness at the last inspection [4]:

$$Corrosion\_Rate(LT) = \frac{t_{initial} - t_{actual}}{time\_between\_t_{initial}\_and\_t_{actual}\,(years)}$$

$$Corrosion\_Rate(ST) = \frac{t_{previous} - t_{actual}}{time\_between\_t_{previous}\_and\_t_{actual}\,(years)}$$

The pressure vessel remaining life, determined in accordance with API 510 is shown below [4], where $t_{required}$ is the minimum required component wall thickness calculated in accordance with ASME Section VIII [7]:

$$\mathrm{Re}maining\_Life = \frac{t_{actual} - t_{required}}{Corrosion\_Rate}$$

To calculate the remaining life the engineer must first determine the required pressure rating, component materials, and nozzle joint design to complete the pressure and thickness calculations. Often the pressure vessel will not have enough remaining wall thickness to meet the required pressure. API 510 [4] and API 579-1/ASME FFS-1 [9] provide guidelines for averaging wall pitting and ignoring isolated pitting. If the guidelines are not met the vessel must be repaired, de-rated, or replaced. Occasionally the pressure vessel engineer will discover the pressure vessel was never built to the correct specifications. Often the vessel design and vessel drawing are done correctly, but the fabrication facility incorrectly built a nozzle from the wrong schedule of pipe resulting in insufficient reinforcement area for the nozzle.

Repairs

Repairing a pressure vessel requires a National Board “R” certificate holder to complete the work. API 510 [4] and NB 23 Part 3 [6] provide very detailed direction on the repair and re-rating of pressure vessels. The repairs must be performed under direct supervision and control of a qualified inspector [18]. Typical repairs include the gouging out of cracks, weld build-up over deep pitting or localized corrosion, and occasionally the replacement of a large corroded area with a patch. An example of a patch replacement and adjacent weld build up is shown in the following pictures. This repair was conducted on an amine contactor tower at a natural gas processing facility belonging to a major oil and gas producer. The vessel was subjected to pre-heat prior to welding and localized post weld heat treatment PWHT after the repair. Detailed NDE is completed after a repair using all of the techniques discussed above.

06/05/2008

Figure 41 Photograph of fit-up of flush patch from inside of amine contactor tower and adjacent pitting. Photograph courtesy of Sandstone Engineering in Farmington, N.M.

06/07/2008

Figure 42 Photograph of flush patch and weld build-up from inside of amine contactor tower. Photograph courtesy of Sandstone Engineering in Farmington, N.M.

Post repair inspection usually includes a very thorough visual inspection both during and after the repair. The welding is typically inspected by shear wave UT or RT both before and after PWHT.

Conclusion

As pressure vessels age it becomes necessary to inspect and evaluate the remaining life of the equipment. The inspection and subsequent evaluation will determine if the vessel should be repaired, rerated, or replaced. The future inspection interval is also determined. This process is collectively known as a fitness for service evaluation. These pressure vessels are typically major components of process critical equipment and are subjected to corrosive environments and extreme environmental conditions. Non-destructive evaluation plays a critical role in this process. Proper inspection, and identification of corrosion mechanisms or potential failure areas, is required to adequately assess the ability of a pressure vessel to remain in service. The consequences of inadequate or improper vessel integrity management involve detrimental outcomes to human health, safety, and the environment. Additionally, the economic impacts from a pressure vessel failure far outweigh the cost of inspecting and evaluating pressure vessels as part of a scheduled integrity management program.

References

1. Ladokun, Temilade, et al., "Accidents in Pressure Vessels: Hazard Awareness," Proceedings of the World Congress on Engineering 2010, Volume II, June 30 – July 2, 2010, London, U.K.
2. Peterson, Rick, "Risk Based Inspection as Part of an Overall Inspection Management Program," Presented at Corrosion 2003 Conference, March 2003, San Diego, CA, http://visionsenterprise.com/pdf/rbimanagementprogram.pdf
3. Nightengale, Patrick M., Parson, John T., "Pressure Vessels: Analyzing Changer," *National Board Bulletin*, Spring 1994, http://www.nationalboard.org/index.aspx?pageID=164&ID=212
4. API 510 Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration, 8th Edition, American Petroleum Institute, June 1, 1997.
5. ANSI NB 23 National Board Inspection Code, NBIC 2007 Edition, Part 2, Inspection.
6. ANSI NB 23 National Board Inspection Code, NBIC 2007 Edition, Part 3, Repairs and Alterations.
7. ASME Section VIII, Division 1, 2010 Edition, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Rules for Construction of Pressure Vessels.
8. API RP 571, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, American Petroleum Institute, December 1, 2003.
9. API 579-1 / ASME FFS-1, Fitness-For-Service, 2nd Edition, American Petroleum Institute, June 5, 2007.
10. API RP 580, Risk-Based Inspection, 2nd Edition, American Petroleum Institute, November 1, 2009.
11. Rao, Rajeshwar, "Application of NDT for In-Service Inspection of Pressure Vessels and Heat Exchangers," http://www.ndt.net/article/wcndt00/papers/idn619/idn619.htm
12. Moles, Michael, and Labbe, Simon, "Ultrasonic Inspection of Pressure Vessel Construction Welds using Phased Arrys," www.ndt.net – 3rd MENDT – Middle East Nondestructive Testing Conference & Exhibition, November 27-30, 2005, Bahrain, Manama.
13. Bresciani, Francesco, et al, "Advances of NDE Techniques and Reliability Engineering Assessments for Piping and Storage Tanks in Refineries and Petrochemical Plants,"
14. Solberg, Arild, et al, "Practical Experiences in the Application of Advanced NDT Methods to Decrease Downtime Through Non Intrusive, True Condition Assessment," http://www.ndt.net/article/ecndt98/chemical/120/120.htm
15. Unknown, "Identifying Pressure Vessel Nozzle Problems From the Cracking Pattern," *National Board Bulletin*, Summer 1999, http://www.nationalboard.org/index.aspx?pageID=164&ID=243

16. White, Dennis, "Acoustic Emission Examination of Metal Pressure Vessels," *National Board Bulletin*, 57th General in 1988, http://www.nationalboard.org/index.aspx?pageID=164&ID=210
17. Mediouni, M, et al, "Developpement [sic] and Use of NDE Methods on Pressure Equipment: Industrial Experience in Applying Acoustic Emission," ECNDT 2006 – Fr.1.2.2, http://www.ndt.net/article/ecndt2006/doc/Fr.1.2.2.pdf
18. Gupte, S.V., "Inspection and Welding Repairs of Pressure Vessels," http://www.plant-maintenance.com/articles/Pressure_Vessel_Repairs.pdf

+++++++++++++++ **The End** ++++++++++++++

Any questions please contact the instructor at info@pdhnow.com

QUIZ for NDE Applied to Pressure Vessel Evaluations

1. Pressure vessels are often de-rated or the scheduled inspection interval increased to allow for continued operation
    a. True
    b. False

2. When evaluating an existing in-service pressure vessel for continued service the following minimum calculations are required:
    a. Wind and seismic loading
    b. Corrosion rate and remaining life
    c. Fatigue analysis
    d. Minimum Design Metal Temperature

3. Common challenges of completing a pressure vessel internal inspection include:
    a. Accessibility
    b. Confined space entry
    c. Expense of taking a pressure vessel out of service
    d. All of the above

4. One output from a pressure vessel evaluation is determination of the future inspection interval
    a. True
    b. False

5. Engineering codes and standards have improved since many vessels were placed in service, causing many operators to evaluate their facilities for compliance with existing codes and standards.
    a. True
    b. False

6. Pressure vessel laws and regulations are uniform between US States:
    a. True
    b. False

7. The Code/Standard that typically governs the Inspection, Repair, and Alteration of pressure vessels is:
    a. API 510 Pressure Vessel Inspection Code
    b. NBIC NB-23
    c. ASME Section VIII
    d. API RP 571

8. The Code/Standard which provides details on methods of evaluating typical damage mechanisms found on pressure vessels in the refining industry is:
    a. API 510 Pressure Vessel Inspection Code
    b. NBIC NB-23
    c. ASME Section VIII
    d. API 597-1

9. Brittle Fracture failures originate at a material flaw
    a. True
    b. False

10. A volumetric inspection technique used to evaluate a pressure vessel is:
    a. Ultrasonic Thickness
    b. Magnetic Particle
    c. Acoustic Emission
    d. Visual Inspection

11. A sudden stress fracture where the material exhibits no evidence of ductility or plastic deformation is known as:
    a. Thermal Fatigue
    b. Mechanical Fatigue
    c. Brittle Fracture
    d. Corrosion Under Insulation

12. Erosion-corrosion is described by a corrosion contribution to erosion by removing the protective surface layers allowing further erosion to act on the material:
    a. True
    b. False

13. The temperatures at which Corrosion Under Insulation becomes more severe is:
    a. 250ºF – 300ºF
    b. 100ºF – 150ºF
    c. 150ºF – 200ºF
    d. 212ºF – 250ºF

14. Ultrasonic shear wave and ultrasonic phased array inspections are both known as angle beam ultrasonic inspections
    a. True
    b. False

15. Carbon steel vessels are subject to Chloride Stress Corrosion Cracking when subjected to the combination of tensile stress, temperature, and an aqueous chloride environment:
    a. True
    b. False

16. Stress Oriented Hydrogen Induced Cracking is similar to HIC, but appears as layers of cracks, resulting in through-thickness crack. These cracks usually appear in the base metal near:
    a. Corner joints
    b. Head to shell seams
    c. Shell longitudinal seams
    d. The weld metal HAZ

17. The best NDE method used for pressure vessel inspections is:
    a. Visual inspection
    b. Ultrasonic thickness inspection
    c. Radiography
    d. All of the above

18. Although a visual inspection supplemented with UT is often the most common pressure vessel inspection technique it has some disadvantages including:
    a. May not be sufficient to fully characterize the condition of the vessel
    b. CML locations can be compared to finding a needle in a haystack
    c. It is possible a CML location showing minimal corrosion could be located adjacent to an area of significant corrosion
    d. All of the above

19. Ultrasonic angle beam inspections are used to evaluate pressure vessels for:
    a. Cracks
    b. Weld Inclusions
    c. Laminations
    d. All of the above

20. Although a visual pressure vessel inspection can be quite simple it is often the most expensive option:
    a. True
    b. False

21. Codes and standards typically used to evaluate a pressure vessel are:
    a. API 510
    b. ANSI NB 23
    c. ASME Section VIII
    d. All of the above

22. Some of the best NDE inspection tools used for pressure vessel inspections are:
    a. Gamma ray sources and film
    b. Flashlights, magnifying glasses, and scrappers
    c. Ultrasonic thickness transducers
    d. Acoustic Emission Instruments

23. Radiography or RT is a volumetric inspection technique used for:
    a. Weld inspections
    b. Evaluate internal corrosion
    c. Inspect for cracks
    d. Both a and b

24. The primary tool used for collecting quantitative material thicknesses is an ultrasonic thickness transducer
    a. True
    b. False

25. Pre-determined locations, which are used to periodically monitor material thickness are known as:
    a. Ultrasonic thickness locations
    b. Erosion monitoring locations
    c. Corrosion monitoring locations
    d. Circle monitoring locations

26. The instrument used to scan and evaluate the thickness of a vessel over a larger surface area is called a:
    a. Pocket-UT
    b. Scanner UT
    c. Crawler
    d. “a” and “c”

27. When using ultrasonic thickness scans:
    a. A-scans are used for thickness measurements
    b. B-Scans are used for thickness profiles
    c. C-Scans are B-Scans with automated position tracking from an integrated encoder
    d. All of the above

28. Magnetic particle inspections (MT) are used to inspect for:
    a. Material thickness
    b. Corrosion and erosion
    c. Cracks
    d. All of the above

29. Acoustic emission sensors detect metal deformation on a vessel by
    a. Measuring the thickness
    b. Detecting the high-pitched sound
    c. Sensing the emission
    d. All of the above

30. Acoustic Emission inspections can be used in place of Radiography on some new pressure vessel inspections
    a. True
    b. False

31. A pressure vessel engineering evaluation is completed to determine:
    a. Pressure retaining capability
    b. Corrosion Rate
    c. Remaining Life
    d. All of the above

32. A pressure vessel with a 1.00" original nominal thickness was inspected 10 years after being placed in service with a resulting thickness of 0.900". After another 10 years, the inspection results indicate a remaining thickness of 0.820". The governing corrosion rate used to calculate the remaining life is:
    a. Long Term Corrosion Rate
    b. Shor Term Corrosion Rate
    c. Neither a or b
    d. Both a and b

33. In the problem 32 above the governing corrosion rate is:
    a. 0.006 inches /year
    b. 0.009 inches / year
    c. 0.008 inches / year
    d. 0.007 inches / year

34. In problem 32 the required thickness to for the vessel pressure rating is 0.750". The Remaining Life of the vessel is calculated to be:
    a. 1.233 years
    b. 6.677 years
    c. 7.78 years
    d. 10.233 years

35. Although many advances in NDE technologies have been made the best and most reliable inspection tool is a thorough visual inspection from inside the pressure vessel:
    a. True
    b. False

36. Replacing a section of a pressure vessel wall by cutting it out and welding in a new section is an acceptable repair.
    a. True
    b. False

37. The economic impacts from a pressure vessel failure typically do not outweigh the cost if inspecting and evaluating pressure vessels.
    a. True
    b. False

38. Which type of crack is perpendicular to the surface stress driver"
    a. HIC
    b. SOHIC
    c. SCC
    d. All of the above