Pressure Vessel Newsletter

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***From The Editor's Desk*:**

One person I admire very much is Neil deGrasse Tyson. He is an American astrophysicist, and for past 20 years, the Director of Hayden Planetarium in New York City. Apart from being an outstanding researcher, he is also a very good story teller with a unique ability to enthrall an audience while explaining the nuances of the planets, the stars and the galaxies. He does it in a way that entertains a third grader while also satisfying the intellectual curiosity of a doctorate student at the same time. I find this ability of presenting one's trade with all the complexities removed and yet retaining the essence very appealing.

Being associated with training myself, I often experiment with different techniques for presenting my subject, trying to find that Goldilocks techniquewhich will keep the audience interested for the duration of the training.To understand pressure vessels is to understand the forces acting on the vessel, the stresses generated, the behavior of materials, the fabrication and inspection techniques, the codes and standards, transportation and installation,and so on. Sounds complicated? Sure it does, therefore one needs to take a leaf out of Neil deGrasse Tyson's book, and design the presentation in a way that appeals to the novice and the veteran alike.

I am a big advocate of training and, in general, of continuous learning. It is the organization's responsibility to ensure that its workforce is properly trained at all times; this may require formal classroom training once or twice a year. I prefer classroom training as it facilities interaction with the instructor as well amongst the participants in a way that is not possible with the online training. At the same time, it is the individual's responsibility to engage in continuous learning through online training, text books, articles etc. Doing so benefits both the individual who is always up to date with the subject, and the organization which now has access to a highly qualified workforce.

Ramesh K Tiwari

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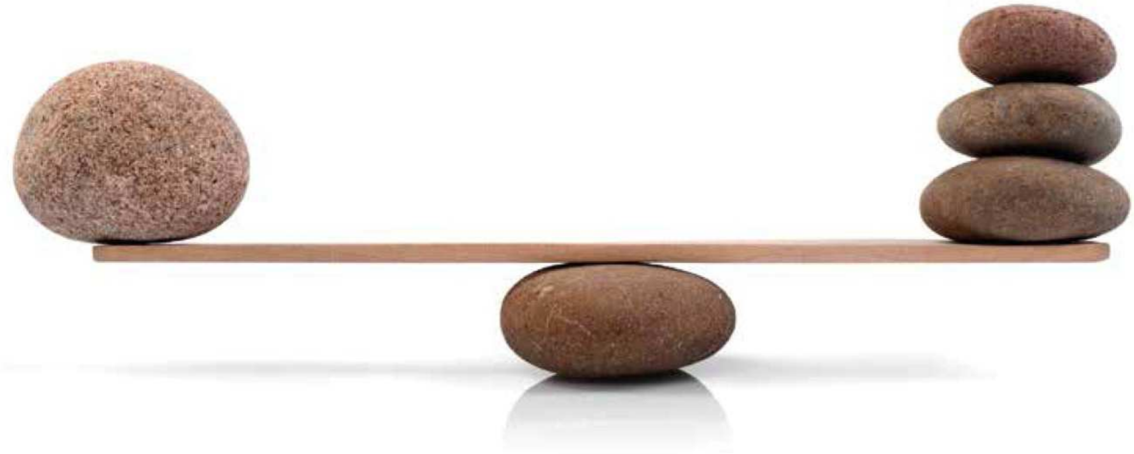

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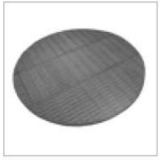

Mist Eliminators

NONDESTRUCTIVE TESTING

Introduction

The philosophy that often guides the fabrication of welded assemblies and structures is “to assure weld quality”. However, the term “weld quality” is relative. The application determines what is good or bad. Generally, any weld is of good quality if it meets appearance requirements and will continue indefinitely to do the job for which it is intended. The first step in assuring weld quality is to determine the degree required by the application. A standard should be established based on the service requirements. Use of appropriate examination techniques can provide assurance that the applicable standards are being met. Whatever the standard of quality, all welds should be inspected, even if the inspection involves nothing more than the welder looking over his own work after each weld pass. A good looking weld surface is many times considered indicative of high weld quality. However, surface appearance alone does not assure good workmanship or internal quality.

Nondestructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of the material, component or a system without causing damage. Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time. Common NDT methods include radiation, ultrasonic, liquid penetrant, magnetic particle, eddy current testing and visual examination. These methods rely on the use of electromagnetic radiation, sound and inherent properties of material to examine samples. This includes some kind of microscopy to examine external surfaces in detail; although sample preparation techniques for metallography, optical microscopy and electron microcopy are generally destructive as the surfaces must be made smooth through polishing or the sample must be electron transparent in thickness.Today, modern NDT are used in manufacturing, fabrication and in-service inspections to ensure product integrity and reliability, to control manufacturing processes, lower production costs and to maintain a uniform quality level.

Applications

In manufacturing, welds are commonly used to join two or more metal parts. Because these connections may encounter loads and fatigue during the product lifetime, there is a chance that they may fail if not created to a proper specification. For example, the base metal must reach a certain temperature during the welding process, must cool at a specific rate, and must be welded with compatible materials, or the joint may not be strong enough to hold the parts together, or cracks may form in the weld causing it to fail. The typical welding defects (lack of fusion of the weld to the base metal, cracks or porosity inside the weld, and the variations in the weld density) could cause a structure to break or a pipeline to rupture.

Welds may be tested using techniques such as:

- Radiograph using X-rays or gamma rays,
- Ultrasonic testing,
- Liquid penetrant testing,
- Magnetic particle testing,
- Eddy current testing, or
- Visual Examination.

In a proper weld, these tests would indicate a lack of cracks in the radiograph, show a clear passage of sound through the weld and back, or indicate a clear surface without penetrant captured in the cracks.

A review of each method will help in deciding which process or combination of processes to use for a specific job and in performing the examination most effectively. All methods except for the eddy current testing will be discussed in detail.

NDT Methods

Radiographic Examination

Radiography is one of the most important, versatile and widely accepted of all NDE methods. It is used to determine the internal soundness of welds. The term “X-ray quality” is used to indicate high quality in welds

Radiography is based on the ability of X-rays and gamma rays to pass through metal and other materials opaque to ordinary light, and produce photographic records of the transmitted radiant energy. All materials will absorb known amounts of this radiant energy and therefore, X-rays and gamma rays can be used to show discontinuities and inclusions within the opaque material. The permanent film record of the internal conditions will show the basic information by which weld soundness can be determined.

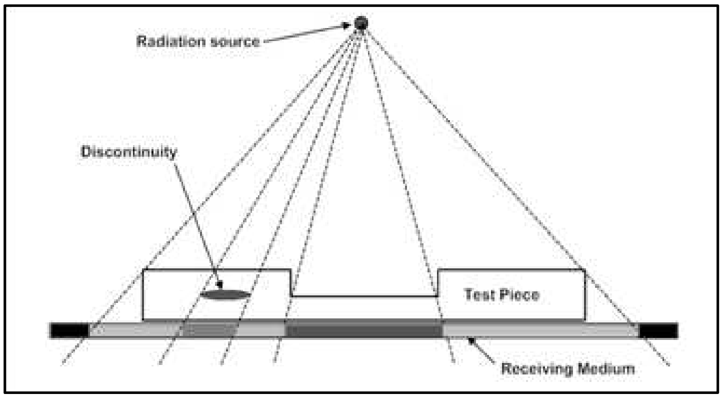

Figure 1: Radiographic Examination

X-rays are produced by high voltage generators. As the high voltage applied to an X-ray tube is increased, the wavelength the emitted X-ray becomes shorter, providing more penetrating power. Gamma rays are produced by the atomic disintegration of radioisotopes. The radioactive isotopes most widely used in industrial radiography are Cobalt 60 and Iridium 192. Gamma rays emitted from these isotopes are similar to X-rays, except their wavelengths are usually shorter. This allows them to penetrate to greater depths than X-rays of the same power; however, exposure times are considerably longer due to the lower intensity.

For thinner or less dense materials such as aluminum, electrically generated X- rays are commonly used, and for thicker or denser materials, gamma radiation is generally used. The radiation passing through the test object exposes the media, causing an end effect of having darker areas where more radiation has passed through the part, and lighter areas where less radiation has penetrated. If there is a void or defect in the part, more radiation passes through, causing a darker image on the film or detector, as shown in Figure 1.

Radiographic equipment produces radiation that can be harmful to body tissue in excessive amounts; so all safety precautions should be followed closely. All instructions should be followed carefully to achieve satisfactory results. Only personnel trained in radiation safety and qualified as industrial radiographers should be permitted to do radiographic testing.

Ultrasonic Testing

Ultrasonic testing (UT) uses the same principle as is used in naval SONAR and fish finders. Ultra-high frequency sound is introduced in the part being inspected and if the sound hits a material with a different acoustic impedance (density and acoustic velocity), some of the sound will reflect back to the sending unit and can be presented on a visual display. By knowing the speed of sound through the part (acoustic velocity) and the time required for the sound to return to the sending unit, the distance to the reflector (indication with different acoustic impedance) can be determined. The most common sound frequencies used in UT are between 1.0 and 10.0 MHz which are too high to be heard and do not travel through air. The lower frequencies have greater penetrating power but less sensitivity (ability to “see” small indication) while the higher frequencies do not penetrate as deeply but can detect smaller indication. The two most commonly used types of sound waves in industrial application are the compression (longitudinal) wave and the shear (transverse) wave, as shown in Figure 2. Compression waves cause the atoms in a part to vibrate back and forth parallel to the sound direction, and shear waves cause the atoms to vibrate perpendicularly (from side to side) to the direction of the sound. Shear waves travel at approximately half the speed of longitudinal waves. Both surface and subsurface defects in metals can be detected, located and measured by UT, including flaws too small to be detected by other methods.

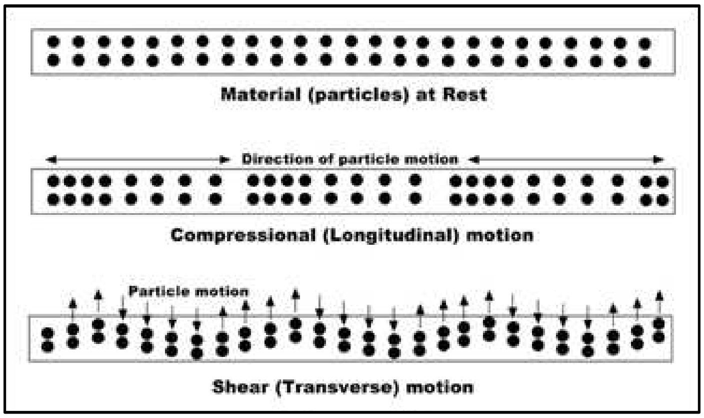

Figure 2: Sound Waves in Ultrasonic Testing

Sound is introduced into the part using an ultrasonic transducer ("probe") that converts electrical impulses from the UT machine into sound waves, then converts returning sound back into electric impulses that can be displayed as a visual representation on a digital or LCD screen. If the machine is properly calibrated, the operator can determine the distance from the transducer to the reflector, and in many cases, an experienced operator can determine the type of discontinuity (slag, porosity or cracks in a weld) that caused the reflector. Because ultrasound will not travel through air, a liquid or gel called "couplant" is used between the face of the transducer and the surface of the part to allow the sound to be transmitted into the part.

UT is less suitable than other NDE methods for determining porosity in welds, because round gas pores respond to ultrasonic tests as a series of single point reflectors. This results in low-amplitude responses that are easily confused with "base line noise" inherent with testing parameters. However, it is the preferred test method for detecting plainer-type discontinuities and lamination.

Liquid Penetrant

Surface cracks and pinholes that are not visible to the naked eye cab located by liquid penetrant inspection. It is widely used to locate leaks in welds and can be applied with austenitic steels and nonferrous materials where magnetic particle inspection would be useless. Liquid penetrant inspection is often referred to as an extension of visual inspection method.

The basic principle of liquid penetrant testing (PT) is that when a very low viscosity liquid (penetrant) is applied to the surface of a part, it will penetrate into the fissures and the voids that are open to the surface. Capillary action draws the liquid into the surface openings. Once the excess penetrant is removed, the penetrant trapped in these voids will flow back out, creating an indication that can be viewed by ultraviolet (black) light. The high contrast between the fluorescent material and the object makes it possible to detect minute traces of penetrant that indicate surface defects.

Penetrant testing can be performed on magnetic and nonmagnetic materials, but does not work well on porous materials. Penetrants may be "visible", meaning they can be seen in ambient light, or fluorescent requiring the use "black" light. The visible dye penetrant process is shown in Figure 3. The part to be inspected must be clean and dry, because any foreign matter could close the cracks or pinholes and exclude the penetrant. Penetrants can be applied by dipping, spraying or brushing, but sufficient time must be allowed for the liquid to be fully absorbed into the discontinuities. This may take an hour or more in very exacting work.

Liquid penetrant method is widely used for leak detection. A common procedure is to apply fluorescent material to one side of the joint, wait an adequate time for capillary action to take place, and then view the other side with ultraviolet light. In thin-walled vessels, this technique will identify leaks that ordinarily would not be located by the usual air test with pressures of 5 to 20 psi. When wall thickness exceeds ¼ in., however, sensitivity of the leak test decreases.

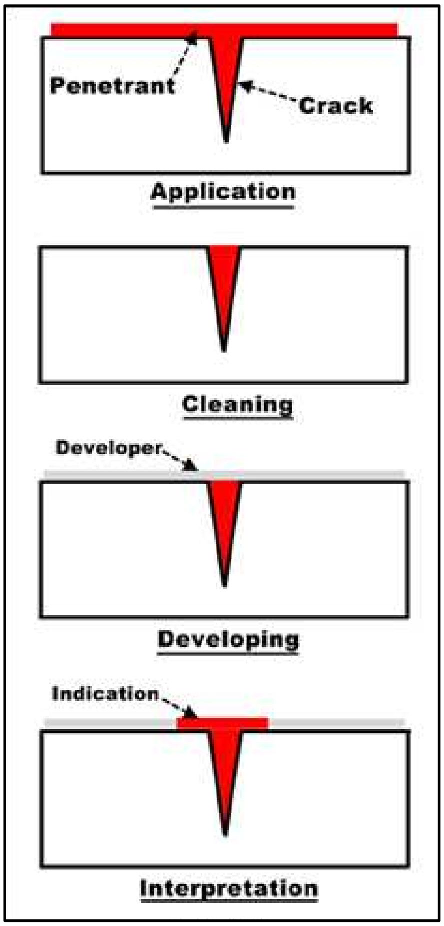

Figure 3: Visible Dye Penetrant Process

Magnetic Particle

Magnetic Particle testing uses one or more magnetic fields to locate surface and near-surface discontinuities in ferromagnetic materials. It is excellent for detecting surface defects in welds, including discontinuities that are too small to be seen with the naked eye, and those that are slightly subsurface. This method may be used to inspect plate edges prior to welding, in process inspection of each weld pass or layer, post weld evaluation, and to inspect repairs. It is a good method for detecting surface cracks of all sizes in both the weld and adjacent base metal, subsurface cracks, incomplete fusion, undercut and inadequate penetration in the weld, as well as defects on the repaired edges of the base metal.

The magnetic field can be applied with a permanent magnet or an electromagnet. When using an electromagnet, the field is present only when the current is being applied. When the magnetic field encounters a discontinuity transverse to the direction of the magnetic field, the flux lines produce a magnetic flux leakage field of their own as shown in Figure 4. Because magnetic flux lines don't travel well in air, when very fine colored ferromagnetic particles ("magnetic particles") are applied to the surface of the part the particles will be drawn into the discontinuity, reducing the air gap and producing a visible indication on the surface of the part. The magnetic particles may be a dry powder or suspended in a liquid solution, and they may be colored with a visible dye or a fluorescent dye that fluoresces under an ultraviolet ("black") light.

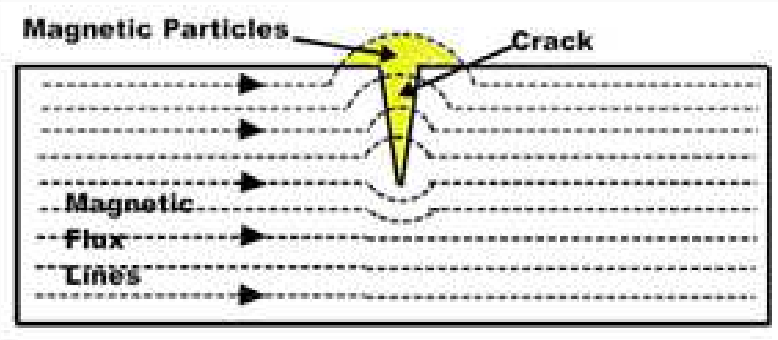

Figure 4: Magnetic Particle Testing

Although much simpler to use than radiographic inspection, the magnetic particle method is limited to use with ferromagnetic materials and cannot be used with austenitic steels. A joint between a base metal and a weld metal of different magnetic characteristics will create magnetic discontinuities that may be falsely interpreted as unsound. On the other hand, a true defect can be obscured by the powder clinging over the harmless magnetic discontinuity. Sensitivity decreases with the size of the defect and is also less with round forms such as gas pockets. It is best with elongated forms, such as cracks, and is limited to surface flaws and some subsurface flaws, mostly on thinner materials.

Eddy Current Testing

Eddy Current Testing uses the fact that when an alternating current coil induces an electromagnetic field into a conductive test piece, a small current is created around the magnetic flux field, much like a magnetic field is generated around an electric current. The flow pattern of this secondary current, called an "eddy" current, will be affected when it encounters a discontinuity in the test piece, and the change in the eddy current density can be detected and used to characterize the discontinuity causing that change. A simplified schematic of eddy currents generated by an alternating current coil ("probe") is shown in Figure 5-a. By varying the type of coil, this test method can be applied to flat surfaces or tubular products. This technique works best on smooth surfaces and has limited penetration, usually less than ¼".

Encircling coils (Figure 5-b) are used to test tubular and bar-shaped products. The tube or bar can be fed through the coil at a relatively high speed, allowing the full cross-section of the test object to be interrogated. However, due to the direction of the flux lines, circumferentially oriented discontinuities may not be detected with this application.

Visual Examination

Visual inspection is often the most cost-effective method, but it must take place prior to, during and after welding. Many standards require its use before other methods because there is no point in submitting and obviously bad weld to sophisticated inspection techniques. Visual inspection requires little equipment. Aside from good eyesight and sufficient light, all it takes is a pocket rule, a weld size gauge, a magnifying glass, and possibly a straight edge and square for checking straightness, alignment and perpendicularity.

Before the first arc is struck, materials should be examined to see if they meet specifications for quality, type, size, cleanliness and freedom from defects. Grease, paint, oil, oxide film or heavy scale should be removed. The pieces to be joined should be checked for flatness, straightness and dimensional accuracy. Likewise, alignment, fit-up and joint preparation should be examined. Finally, process and procedure variables should be verified, including electrode size and type, equipment settings and provisions for preheat and postheat. All of these precaustion apply regardless of the inspection method being used.

During fabrication, visual examination of a weld bead and the end crater may reveal problems such as cracks, inadequate penetration, and gas or slag inclusions. Among the weld defects that can be recognized visually are cracking, surface slag in inclusions, surface porosity and undercut. On simple welds, inspection at the beginning of each operation and periodically as work progresses may be adequate. Where more than one layer of filler metal is being deposited, however, it may be desirable to inspect each layer before depositing the next. The root pass of a multipass weld is the most critical to weld soundness. It is especially susceptible to cracking, and because it solidifies quickly, it may trap gas and slag. On subsequent passes, conditions caused by the shape of the weld bead or changes in the joint configuration can cause further cracking, as well as undercut and slag trapping. Repair costs can be minimized if visual inspection detects these flaws before the welding progresses.

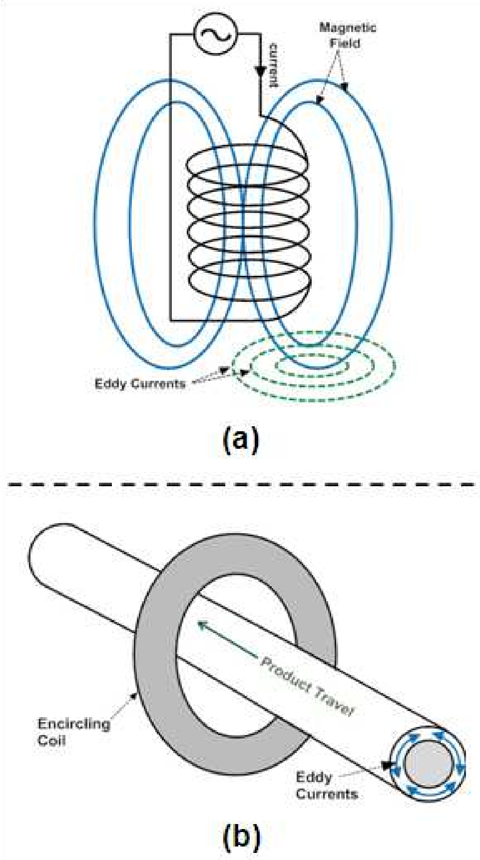

Figure 5: Eddy Current Testing

Visual inspection at an early stage of production can also prevent underwelding and overwelding. Welds that are smaller that called for in the specifications cannot be tolerated. Beads that are too large increase costs unnecessarily and can cause distortion through added shrinkage stress.

After welding, visual inspection can detect a variety of surface flaws, including cracks, porosity and unfilled craters, regardless of subsequent inspection procedures. Dimensional variances, warpage and appearance flaws, as well as weld size characteristics, can be evaluated. Before checking for the surface flaws, welds must be cleaned of slag. Shotblasting should not be done prior to examination, because the peening action may seal fine cracks and make them invisible.

Visual inspection can only locate defects in the weld surface. Specifications or applicable codes may require that the internal portion of the weld and the adjoining metal zones also be examined. NDE may be used to determine the presence of a flaw, but they cannot measure its influence on the serviceability of the product unless they are based on a correlation between the flaw and some characteristic that affects service. Otherwise, destructive test are the only sure way to determine weld serviceability.

Reference Guide to Major Methods for the NDE of Welds

Inspection Method	Equipment Required	Enables Detection of	Advantages	Limitations	Remarks
Visual	Magnifying glass, weld sizing gauge, pocket rule, straight edge, workmanship standards	Surface flaws – cracks, porosity, unfilled craters, slag inclusions. Warpage, underwelding, overwelding, poorly formed beads, misalignments, improper fit-up.	Low cost. Can be applied while work is in process, permitting correction of faults. Gives indication of incorrect procedures.	Applicable to surface defects only. Provides no permanent record.	Should always be the primary method of inspection, no matter what other techniques are required. Is the only "productive" type of inspection. Is the necessary function of everyone who in any way contributes to the making of the weld.
Radiographic	Commercial X-ray or gamma units made especially for inspecting welds, castings and forgings, film and processing facilities, fluoroscopic viewing equipment	Interior macroscopic flaws – cracks, porosity, blow holes, nonmetallic inclusions, incomplete root penetrations, undercutting, icicles, and burnthourghs.	When indications are recorded on film, gives a permanent record. When viewed on a fluoroscopic screen, a low cost method of internal inspection.	Requires skill in choosing angle of exposure, operating equipment and interpreting indications. Requires safety precautions. Not generally suitable for fillet weld inspection.	X-ray inspection is required by many codes and specifications. Useful in qualification of welders and welding processes. Because of cost, its use should be limited to those areas where other methods will not provide the assurance required.
Ultrasonic	Special commercial equipment, either of the pulse-echo or transmission type. Standard reference patters for interpretation of RF or video patterns.	Surface and subsurface flaws including those too small to be detected by other NDE methods. Especially for detecting subsurface laminar-like defects.	Very sensitive. Permits probing of joints inaccessible to radiography.	Requires high degree of skill in interpreting pulse-echo patterns. Permanent record is not readily obtained.	Pulse-echo equipment is highly developed for weld inspection purposes. The transmission type equipment simplifies pattern interpretation where it is applicable.
Liquid Penetrant	Commercial kits containing fluorescent or dye penetrants and developers. Application equipment for the developer. A source of ultraviolet light – if fluorescent	Surface cracks not readily visible to the naked eye. Excellent for locating leaks in weldments.	Applicable to magnetic and nonmagnetic materials. Easy to use. Low cost.	Only surface defects are detectable. Cannot be used effectively on hot assemblies.	In thin-walled vessels, will reveal leaks not ordinarily located by usual air tests. Irrelevant surface conditions (smoke, slag) may give misleading indications.

	method id used.				
Magnetic Particle	Special commercial equipment. Magnetic powders – dry or wet form; may be fluorescent for viewing under ultraviolet light.	Excellent for detecting surface discontinuities – especially surface cracks.	Simpler to use than radiographic inspection. Permits controlled sensitivity. Relatively low-cost method.	Applicable to ferromagnetic materials only. Requires skill in interpretation of indications and recognition of irrelevant patterns. Difficult to use on rough surfaces.	Elongated defects parallel to the magnetic field may not give pattern; for this reason, the field should be applied from two directions at or near right angles to each other.

Personnel Training, Qualification and Certification

Successful and consistent application of NDT techniques depends heavily on personnel training, experience and integrity. Personnel involved in application of NDT methods and interpretation of results should be certified, and in some sectors, certification is enforced by law or by the applied codes and standards.

Certification refers to a written statement by an employer that an individual has met the applicable requirements of this standard. Qualification refers to the skills, training, knowledge, examinations, experience and visual capability required for personnel to properly perform to a particular level.

It is generally necessary that a person wishing to practice NDT successfully complete a theoretical and practical training program, as well as have performed several hundred hours of practical application of the particular method they wish to be trained in. At this point they may pass a certification examination. There are two approaches in personnel qualification:

1. Employer-based Certification: Under this concept, compiles their own written practice which defines the responsibilities of each level of certification, as implemented by the company, and describes the training, experience and examination requirements for each level of certification. The written practices are usually based on recommended practice SNT-TC-1A of the ASNT.
2. Personnel Central Certification: The concept of central certification is that an NDE operator can obtain certification from a central certification authority that is recognized by most employers, third parties and/ or government authorities. Industrial standards for central certification include ISO 9712 and ANSI/ ASNT CP-106; certification under these standards involves training, work experience under supervision and passing a written and practical examination set by an independent certification authority.

In US, employer-based certification are the norm whereas central certification is more widely used in European Union where certifications are issued by accredited bodies. Canada also implements ISO 9712 central certification scheme which is administered by Natural Resources Canada, a government agency.

Levels of Certification

Most NDT personnel certification schemes specify three levels of qualification and/ or certification, designated as Level 1, Level 2 and Level3. The roles and responsibilities of personnel in each level are generally as follows:

- Level 1 are technicians qualified to perform only specific calibrations and tests under close supervision and direction by higher level personnel. They can only report test results. Normally they work following specific work instructions for testing procedures and rejection criteria.
- Level 2 are engineers or experienced technicians who are able to set up and calibrate testing equipment, conduct the inspection according to codes and standards (instead of following work instructions) and compile work instructions for Level 1 technicians. They are also authorized to report,

interpret, evaluate and document testing results. They can also supervise and train Level 1 technicians. In addition to testing methods, they must be familiar with applicable codes and standards and have some knowledge of the manufacture and service of tested products.

- Level 3 are usually specialized engineers or very experienced technicians. They can establish NDT techniques and procedures and interpret codes and standards. They also direct NDT laboratories and have central role in personnel certification. They are expected to have wider knowledge covering materials, fabrications and product technology.

Choices Control Quality

A good NDE inspection program must recognize the inherent limitations of each process. For example, both radiography and ultrasound have distinct orientation factors that may guide the choice of which process to use for a particular job. Their strengths and weaknesses tend to complement each other. While radiography is unable to reliably detect lamination-like defects, ultrasound is much better at it. On the other hand, ultrasound is poorly suited to detecting scattered porosity, while radiography is very good.

Whatever inspection techniques are used, paying attention to the “Five P’s” of weld quality will help reduce subsequent inspection to a routine checking activity. Then, the proper use of NDE methods will serve as a check to keep variables in line and weld quality within standards.

The Five P’s are:

1. **Process Selection:** The process must be right for the job.
2. **Preparation:** The joint configuration must be right and compatible with the welding process.
3. **Procedures:** The procedures must be spelled out in detail and followed religiously during welding.
4. **Pretesting:** Full-scale mockups or simulated specimens should be used to prove that the process and procedures give the desired standard of quality.
5. **Personnel:** Qualified people must be assigned to the job.

Source: ABC’s of Nondestructive Weld Examination *by* Charles Hayes

Nondestructive Testing - Wikipedia

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MANUFACTURING THE SHELL

General

Pressure vessels consist of various components as shown in Figure 1. The two most important components in a pressure vessel are the heads (or dished ends) and the shell. The manufacture of heads is considered to be more difficult than that of the shell due to the difficulty in controlling its dimensions (the dimensions of shell can be controlled precisely). For this reason, if the pressure vessel has dished ends, they should be made first, and shells are made later to suit the dished ends.

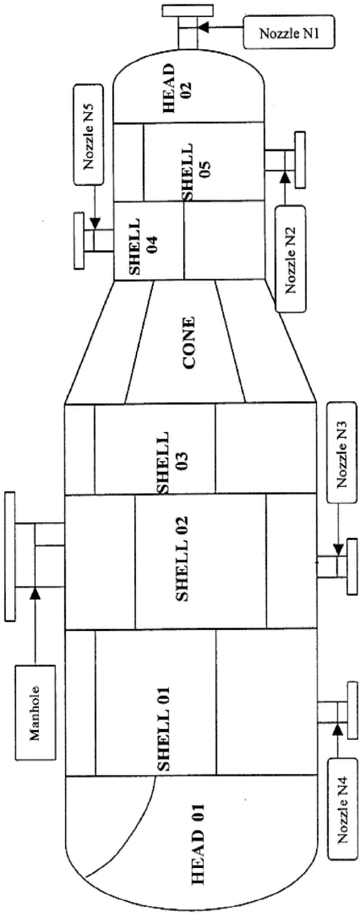

Figure 1: Typical Pressure Vessel

Manufacturing Processes

The basic manufacturing processes adopted for the fabrication of the pressure vessel is forming. Forming is the process by which the size or shape of the part is changed by application of force that produces stresses in the part which are greater than the yield strength and less than the fracture strength. Depending on the temperature during fabrication, it is categorized as hot, warm or cold forming. It is called hot forming when the temperature is above the recrystallization temperature of the material, warm forming if the temperature is sufficiently above the room temperature but below the recrystallization temperature, and cold forming when the temperature is very much below the recrystallization temperature, for example, at room temperature.

Shells

The manufacturing process used in the forming of shell is *bending*. This process is conventionally called “rolling” even though technically it does not meet the criteria for rolling. Rolling is a process where a thickness reduction to a plate takes place, whereas in bending only a curvature is given to the plate and no thickness reduction is expected.

The usual practice of bending is by passing the plate through either a three- or a five-roll plate bending machine of adequate capacity to bend the plate to the required diameter. The most commonly used bending machine is the three-roll plate bending machine – a schematic diagram is shown in Figure 2.

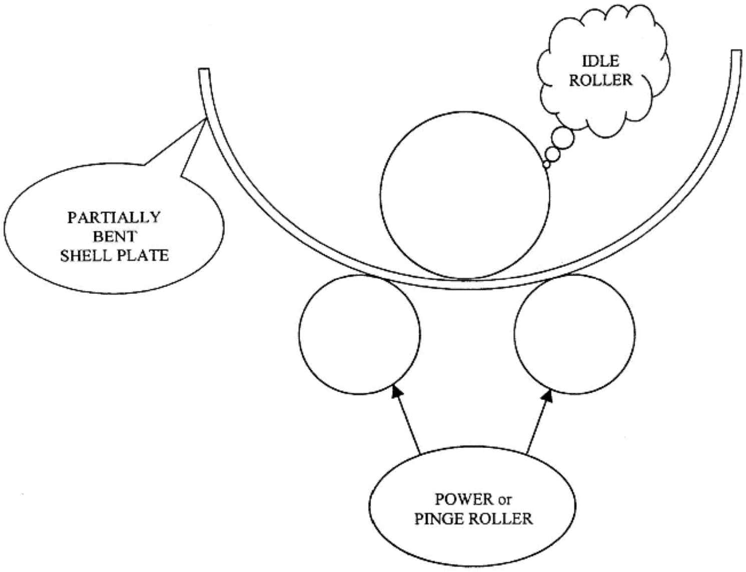

Figure 2: Schematic Diagram of Plate Bending

Prior to passing the complete length of the plate through the rollers, both edges of the plate are pressed to the required radius. This is called prepinging, and is achieved by pressing the two power/ drive rollers against the top idle roller and thereby bending the plate edge. Once both edges are pressed to the correct radius, the complete length of the plate is passed through the rollers to impart curvature in steps. If the diameter is large and the thickness is comparatively less (say up to 3/8 in or 10 mm), then the curvature can be given in one pass. If the thickness is high and the diameter is small, the full bending is carried out in stages. The profile of the shell is checked after bending using a template of required dimension.

Shells Made from Single Plate

If the length of the plate is sufficient to accommodate the full circumference of the shell, this is the preferred condition because the shell will have only one longitudinal seam. The plate is first cut to the required length and breadth and later on all four sides; a bevel is prepared as indicated in the applicable drawing. The cut edges are then ground back to the sound metal so that all the adversely affected material in the cut zone is removed. The dressed edges are then examined for defects like lamination and irregularity on the bevel due to incorrect cutting parameters. If laminations are found, they must be investigated in detail as per applicable specifications. In case of irregular cut edges, the irregularities shall be removed by buttering and subsequent dressing.

The plate is now prepinged on both ends first and then completely bent to the required diameter in a plate bending machine. Depending on the amount of curvature needed, the plate is passed through the roller a number of times to achieve the curvature in stages so that any elongation to the plate will be negligible. The various parameters of the shell section, like the diameter, profile, out-of-roundness etc. are checked and if found satisfactory, the shell is taken for longitudinal seam fitup.

Shells Made from Multiple Plates

If the length of the plate is not sufficient for making the shell, two or more plates are joined together to obtain the required shell length. This joining is done in a plate-to-plate fashion. As there is a possibility for the squareness to be lost while joining, the plate shall be checked for squareness after the full shell length is marked on the joined plate, and if needed, correction by trimming is performed. The plate shall be bent only after completing the weld from both sides. The reinforcement shall be ground off to the parent metal level to facilitate the smooth bending of the plate in the machine. In case the seams are to be radiographed, it is to be done after bending.

Measurement of Dimensions

The following dimensions are recorded:

1. Outside circumference at both ends as well as at the center of the shell.
2. Inside or outside diameter at four angles on either side of the shell.
3. Straightness of the shell through centerlines at 0, 90, 180 and 270 degrees.
4. Length of the shell at four center lines.

The methodology for the measurement is as follows: Bend the shell and tack weld the longitudinal seam as required. In case of thin shells with large diameter, provide spiders (at least four numbers) to maintain the circularity. Measure the circumference at both the edges and at the center of the shell by tightly stretching a steel measuring tape. The ID at four angles should be taken using a steel tape after providing stiffeners at both ends as shown in Figure 3.

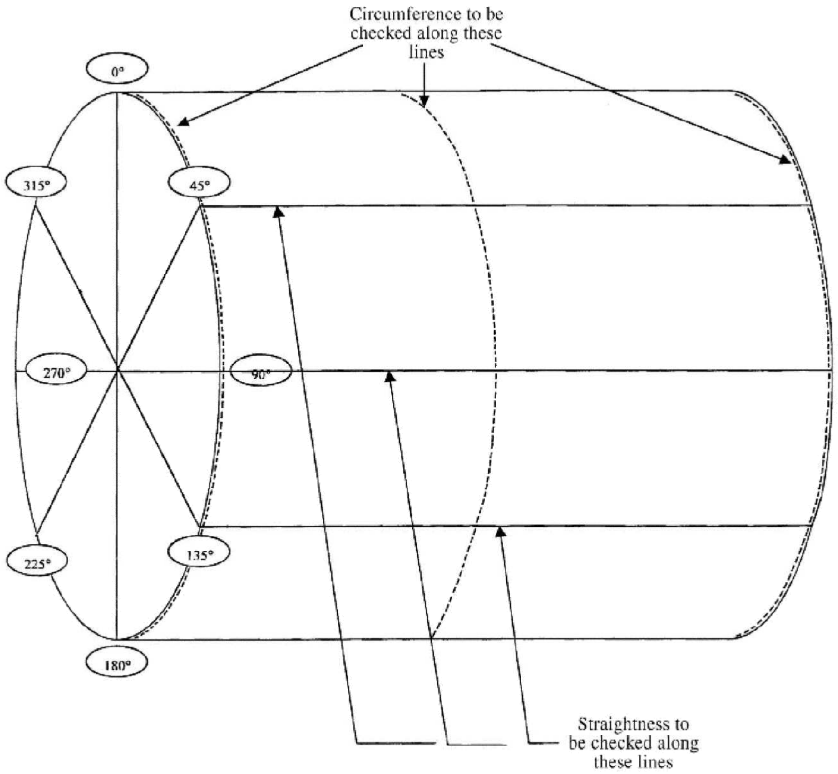

Figure 3: Dimensional Check of Shells

Straightness of the shell is to be measured and recorded using a stretched piano wire over standard machined blocks or 3/8- or ¾-in (10- or 20mm) thickness using a taper gauge. The length of the shell at four locations over the circumference is to be measured and recorded using steel measuring tape. The profile of the shell should be examined over the entire area, either inside or outside, using the template as specified in paragraph UG-29.2 of the ASME Section VIII, Division 1 Code. The deviation from the desired profile shall be measured by inserting a taper gauge between the template and the shell. The templates can be either on the outside or inside as shown in Figure 4.

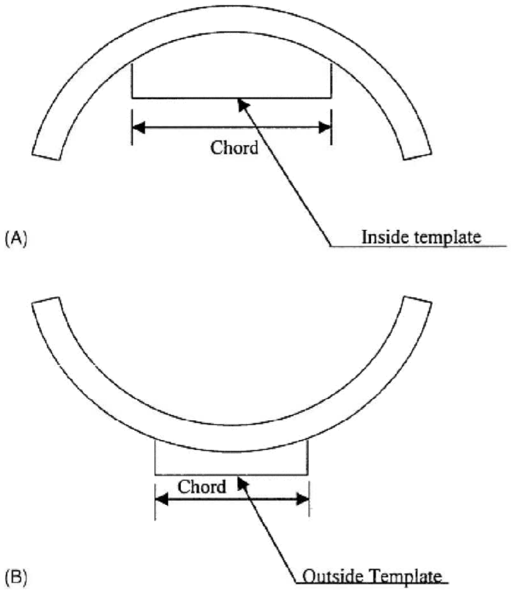

Figure 4: Templates for A) Inside and B) Outside

Source: Practical Guide to Pressure Vessel Manufacturing *by* Sunil Pullarcot

DEMINERALIZERS

What are demineralizers?

Dissolved impurities and foreign particles entrained in power plant fluid systems generate corrosion problems and decrease efficiency as a result of fouling of relevant heat exchange surfaces. Demineralization of water is one of the most commonly used processes to remove dissolved impurities.

Demineralizers (also called ion exchangers) hold ion exchange resins. Demineralization or ion exchange refers to the exchange of ions between a solid substance (called a resin) and an aqueous solution (makeup water). Ion exchange resins consist of very small beads, having an average diameter of 0.5 to 1 mm. After a certain period of time, ion exchange resins are *exhausted* and they have to be *regenerated*. During regeneration, an acid solution (for cation exchange units) or a caustic solution (for anion exchange units) is used, properly diluted with water, and typically distributed above the resins. Regeneration is usually a multistep process, also involving backwashing and rinsing stages in order to remove any entrained particles.

The most common design parameter of demineralizers is conductivity. Typical conductivity value for the demineralized water at the outlet of mixed bed demineralizers is less than 0.1µs/cm. Other typical design parameters of demineralizers also include the presence of silica, copper, iron and sodium in demineralizer water.

Layout of demineralizers or ion exchangers

A demineralizer is basically a cylindrical vessel with connections at the top for water inlet and resin addition, and connections at the bottom for water outlet. The resin elements are stored in the demineralizer by upper and lower retention elements which are strainers with a mesh size smaller than the ion exchange resin elements. The water to be purified enters the top at a specified flow rate and flows down through the resin elements where the flow is filtered and a chemical ion exchange also takes place. Deionized water is taken out from the bottom outlet.

Ion exchangers are generally divided into two groups: single bed ion exchangers and mixed bed ion exchangers.

Single bed demineralizers

A single bed demineralizer contains either cation resin elements or anion resin elements. A cation is an ion with a positive charge; common cations include Ca^{++}, Mg^{++}, Fe^{++}, and H^+. An anion is an ion with a negative charge; common anions include Cl^-, SO^- and OH^-. A cation resin is one that exchanges positive ions whereas anion resin is one that exchanges negative ions.

In most cases there are two, single bed ion exchangers, installed in series; the first one being a cation bed and the second one being an anion bed. Impurities in plant water are replaced with hydrogen ions in the cation bed and hydroxyl ions in the anion bed. The hydrogen ions and the hydroxyl ions then combine to form pure water.

Figure 1 illustrates a single bed demineralizer. When in use, water flows in through the inlet to a distributor at the top of the tank. The water flows down through the resin bed and exits out through the outlet. A support screen at the bottom prevents the resin from being forced out of the demineralizer tank.

Single bed regeneration

The regeneration of a single bed ion exchanger is a three-step process. The first step is a backwash, in which the water is pumped into the bottom of the ion exchanger and up through the resin. This fluffs the resin and washes out any entrained particles. The backwash water goes out through the normal inlet distributor piping at the top of the tank, but the valves are set to direct the stream to a drain so that the backwashed particles can be pumped to a container for waste disposal.

The second step is the actual regeneration step, which uses acid solution for cation units and caustic solution for anion units. The concentrated acid or caustic is diluted to approximately 10% with water by opening the dilution water valve, and is then introduced through a distribution system immediately above the resin bed. The regenerating solution flows through the resin and out the bottom of the tank to the waste drain.

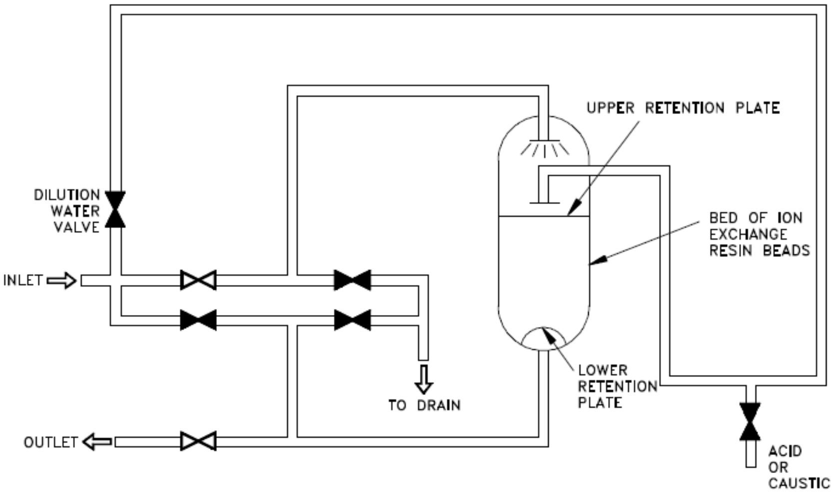

Figure 1: Typical Single Bed Demineralizer Scheme

The final step is a rinsing process which removes any excess regenerating solution. Water is pumped into the top of the tank, flow down through the resin bed and out at the bottom drain.

To return the ion exchanger to service, the drain valve is closed, the outlet valve is opened, and the ion exchanger is ready for service.

Single-bed demineralizers are usually regenerated “in place”. The resins are not pumped out to another location for regeneration. The regeneration process is the same for cation beds and for anion beds; only the regeneration solution is different. It is important to realize that if the ion exchanger has been exposed to radioactive materials, the backwash, regeneration, and the rinse solutions may be highly radioactive and must be treated as a radioactive waste.

Mixed bed demineralizer

A mixed bed demineralizer is one in which the cation and anion resin beads are mixed together. It is equivalent to a number of two-step demineralizers in series. In a mixed bed demineralizer, more impurities are replaced by hydrogen and hydroxyl ions, and the water that is produced is extremely pure. The conductivity of the produced water can often be less than 0.06 µS/ cm. Figure 2 illustrates a mixed bed demineralizer.

Mixed bed regeneration

The mixed bed demineralizer shown in Figure 3 is designed to be regenerated in place, but the process is more complicated than the regeneration of a single bed ion exchanger. The figure shows the mixed bed demineralizer in the operating or on-line mode. Water enters through a distribution header at the top and exits through the line at the bottom of the vessel. Regeneration causes the effluent water to increase in electrical conductivity.

The first regeneration step is backwash. As in single bed unit, backwash water enters the vessel at the bottom and exits through the top to a drain. In addition to washing out entrained particles, the backwash water in a mixed bed unit must also separate the resins into cation and anion beds. The anion resin has a lower specific gravity than the cation resin; therefore, as the water flows through the bed, the lighter anion resin beads float upward to the top. Thus the mixed bed becomes a split bed. The separation line between the anion bed at the top and the cation bed at the bottom is called the resin interface. Some resins can be separated only when they are in depleted state; other resins separate either in depleted form or the regenerated form.

The next step is the actual regeneration. Dilution water is mixed with caustic solution and introduced at the top of the vessel, just above the anion bed. At the same time, dilution water is mixed with acid and introduced at the bottom of the vessel, below the cation bed. The flow rate of the caustic solution down to the resin interface is the same as the flow rate of the acid solution up to the resin interface. Both solutions are removed at the interface and dumped to a drain.

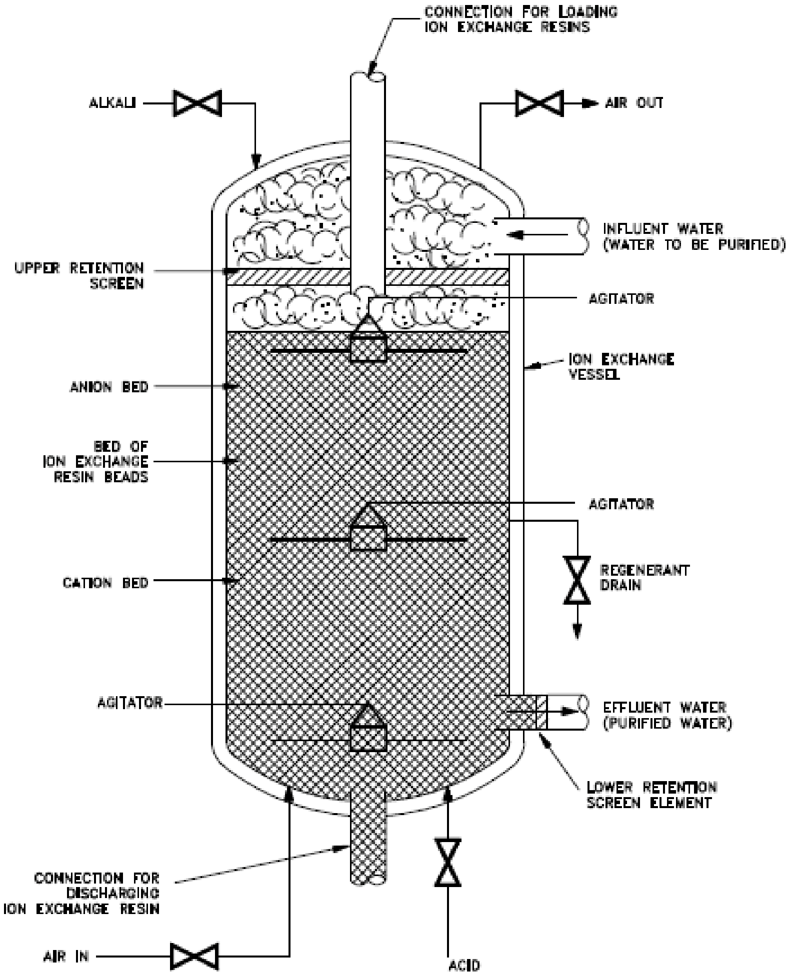

Figure 2: Typical Mixed Bed Demineralizer Schematic

During the regeneration step, it is important to maintain the cation and anion resins at the proper volume. If this is not done, the resin interface will not occur at the proper place in the vessel, and some resin will be exposed to the wrong regenerating solution. It is also important to realize that if the ion exchanger has been involved with radioactive materials, both the backwash and the regenerating solutions may be highly radioactive and must be treated as liquid radioactive waste.

The next step is the slow rinse step in which the flow of dilution water is continued, but the caustic and acid supplies are cut off. During this two-direction rinse, the last of regenerating solutions are flushed out of the two beds and into the interface drain. Rinsing from two directions at equal flow rates keeps the caustic solution from flowing down into the cation resin and depleting it.

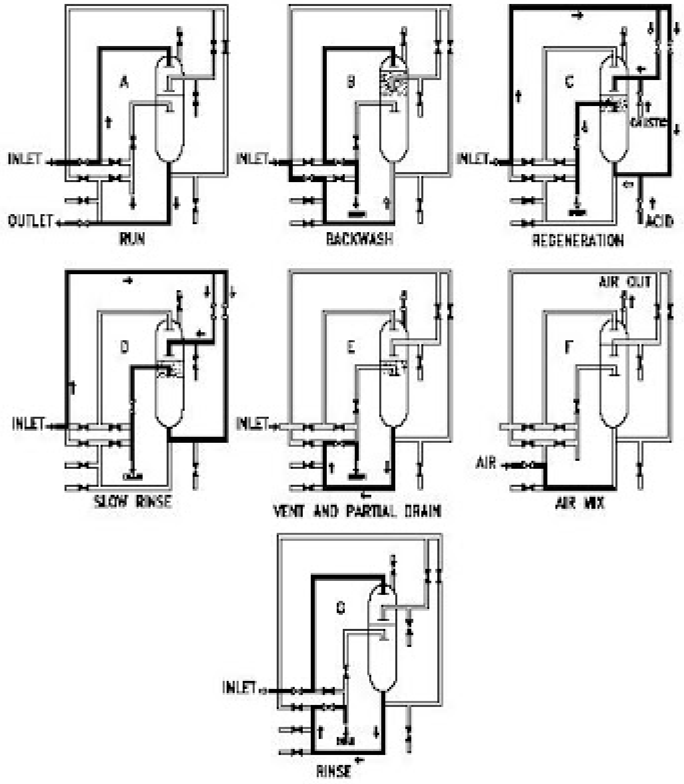

Figure 3: Regeneration of Mixed Bed Demineralizer

In the vent and partial drain step, the drain valve is opened, and some of the water is drained out of the vessel so that there will be space for the air that is needed to remix the resins. In the air mix step, air is usually supplied by a blower, which forces air in through the line entering the bottom of the ion exchanger. The air mixes the resin beads and then leaves through the vent in the top of the vessel. When the resin is mixed, it is dropped into position by slowly draining the water out of the interface drain while the air mix continues.

In the final rinse step, the air is turned off and the vessel is refilled with water that is pumped in through the top. The resin is rinsed by running water through the vessel from top to bottom and out the drain, until a low conductivity reading indicates that the ion exchanger is ready to return to service.

Source: Demineralizers or Ion Exchangers - Enggcyclopedia

TUBE-TO-TUBESHEET JOINTS

Introduction

The reliability of shell and tube heat exchanger depends upon the integrity of many parallel tube-to-tubesheet joints, each of which must be virtually free of defects. Therefore, the connection of the tubes to the tubesheets is a critical element. The part of tube fastened to the tubesheet is treated more severely than the main body of the tube, and most joint configurations allow only limited nondestructive examination. Accordingly, tube-to-tubesheet connections are frequently the site of failures. When tubes pull or push out under load or break at the tubesheet joint, structural damage to the exchanger may be substantial.

The main functions of the tube-to-tubesheet joints are:

- Seal the tubes tightly to the tubesheets. The joint must remain tight under test, startup, operating, upset, and shutdown conditions.
- Create firm contact between the tube and the tubesheet hole when tube metal embedded in the tubesheet is used to increase the plate's ability to resist bending. The tube must remain in fixed contact with the hole under all conditions of tubesheet loading.
- Transfer forces from the tubesheet to the tubes when the tubes stay the tubesheet against pressure induced loads. The joint must be strong enough to transfer pressure loads from the tubesheet to the tubes.
- Withstand thermal loads that stem from restrained differential expansion between the shell and tubes of fixed tubesheet units and between the hot and cold passes of all straight tube equipment.

The required degree of hydraulic tightness depends upon service conditions. Minor leaks in commercial low-pressure water heaters may be tolerated. In these units, it is barely significant if a drop of water leaks through a tube joint after an hour-long hydrostatic test. To try to reduce the leakage rate below water-tightness would hardly be worthwhile. On the other hand, consider that the maximum permissible chloride ion concentration in steam surface condensers is 0.1 ppm. A typical brackish condenser cooling water supply might have a chloride ion concentration of 5×10^{-3} ppm. A surface condenser producing 5000 gal/min of condensate could therefore tolerate a total brackinsh-water leak of approximately 0.1 gal/min. The number of tubes in a two-pass condenser that could handle the steam load would be approximately 50,000, making the average brackish-water leak through each joint 1×10^{-6}.

How Tube-to-Tubesheet Joints are made

Tube-to-Tubesheet joints are made in the following ways:

1. Packed Joints

   Figure 1 is the sketch of a typical packed joint. At the inner side of the tubesheet, the clearance between the tube and the hole is just large enough to let the tube slide through. The counterbored recess at the outer side of the hole is threaded for approximately half its depth. A slotted, threaded ferrule is used to squeeze packing rings into the chamber. The friction of the compressed packing against the tube and hole surfaces determines the strength and tightness of the joint.

   More economical and positive methods have largely replaced packed joints. Aside from some small auxiliary exchangers, their principal use today is in vertical, low pressure fixed tubesheet heat recuperators and economizers.

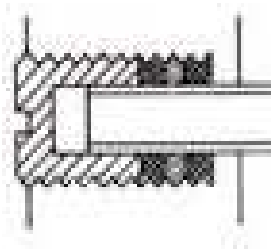

Figure 1: Packed Tube-to-Tubesheet Joint

2. Interference-fit Joints

   If the perforated tubesheet were to be shrunk onto the tubes, interference between the tubes and hole walls would create interfacial pressure. The practical way to make interference-fit joints is to expand the tubes into holes. Expanding is the most frequently used way to join tubes to tubesheets. It is the standard method for exchangers built to the TEMA standards. Annular grooves are machined into tube holes in an effort to improve the expanded joint strength and tightness. Some of the many groove configurations that have been used are illustrated in Figure 2.

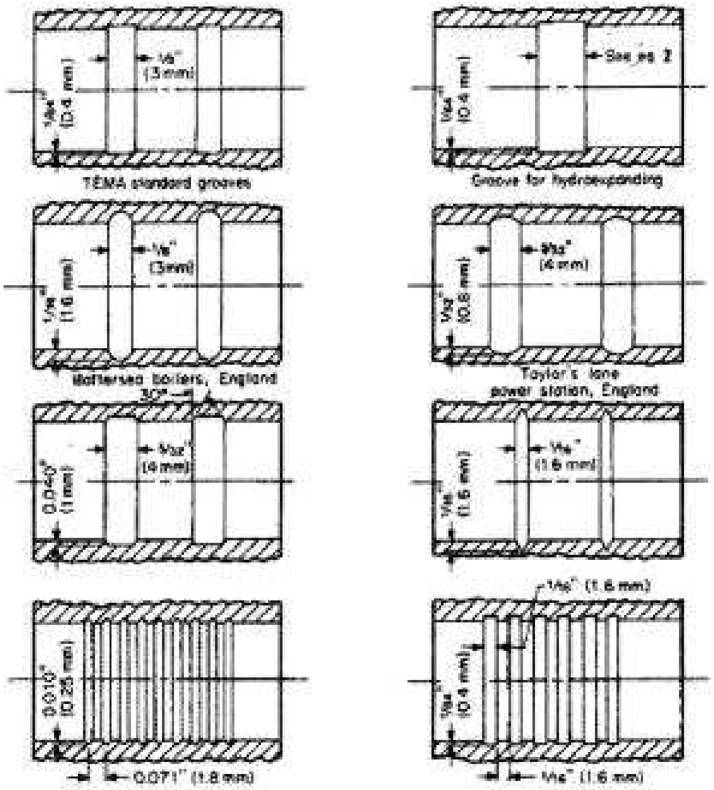

Figure 2: Some Typical Tube Hole Grooves

3. Welded and Brazed Joints

   The technology of welding and brazing tubes to tubesheets is highly advanced. There is often confusion about what is meant by strength welding and seal welding tube-to-tubesheet joints. In strength welding, the primary purpose is to produce a load bearing joint; the joint's ability to carry a load depends upon its design. Of course, the joint must also be leak-tight. The purpose of seal welding is only to seal the joint against leakage. Consequently, seal welding is used as a tightness backup for strength-expanded joints.

Despite the fact that seal welding must be done by qualified welders using qualified welding procedures, no credit may be taken for any additional strength that seal welding confers on the tube-to-tubesheet joint.

Testing Joint Tightness

One way to assess the quality of tube-to-tubesheet joints is to measure how tight they are. It is reasonable to assume that a measured leak rate below the tolerable service rate provides some assurance that joint quality is acceptable. Fluids commonly used as media for measuring rates of leakage are air, nitrogen, helium, refrigerant gases, water and lubricating oils. ASME Boiler and Pressure Vessel Code has recommendations in Section V (Nondestructive Testing) for selecting tightness testing methods and for selecting acceptance standards. The following ways to gauge tightness are arranged in rough order of sensitivity:

1. <u>Visual observation during liquid pressure testing</u>

   The purpose of ASME Code hydrostatic pressure testing is to stress the structure under controlled conditions to make sure it is safe to be put into service. Generally, the ASME Code test pressure is 1.3 times the design pressure adjusted for the difference between the design and test temperatures. If there are no visible leaks or structural distortions after at least half an hour, the authorized inspector (AI) can accept the structure as sound.

2. <u>Bubble testing</u>

   Direct pressure technique using bubble solution is very common. To do this test, fill the shell with inert gas or air at the design pressure. After a pressure soak time of at least 15 minutes, flow bubble solution over the joint or tube ends, or brush or spray the tube ends and joints with the bubble former. Generally, the surfaces must be in the temperature range of 40 to 125^{o}F. The test solution must not break away from the test surface or break down rapidly because of air drawing or low surface tension.

3. <u>Gas leak testing</u>

   Following is the procedure for a gas leak test. 1) Pressurize the shell side of the heat exchanger with air or nitrogen to the maximum allowable working pressure at room temperature, 2) set the unit vertically and seal a 1- or 2-inch high ring dam to the tubesheet, 3) fill the tubeside with water to the level of dam, and 4) observe for air or nitrogen bubbles.

4. <u>Detector-probe methods</u>

   The halogen and helium detector probe (sniffer) methods are inexpensive compared with helium tracer probe and hood techniques. They are often used when an exchanger is to handle lethal or noxious fluids and for ensuring that air-conditioning and refrigeration heat exchangers are not leaking refrigerant gases. Because the helium sniffer leak-testing system is somewhat less sensitive than that of the halogen sniffer system, use halogen leak testing except where the halogen tracer gas can cause corrosion.

5. <u>Helium Tracer-probe and Hood Methods</u>

   These methods are used when even very small leaks present a hazard to life and property. The hood techniques is used when quantitative leak rates must be determined. Both techniques require precise system calibration. To use these methods for tube-to-tubesheet joint testing, evacuate the shellside and detect leakage of 100% helium gas into the evacuated space.

   In the tracer-probe method, a stream of helium gas is directed from the probe at each joint. In hood testing, the channel side of the tubesheet is enclosed in a hood filled with helium. The instrument then detects the total leakage through all the joints and the tubes into the shell.

Testing Joint Strength

It is neither convenient nor practical to measure tube-to-tubesheet joint strength directly. Instead pullout or pushout (shear load) tests are made on representative specimens. The test specimens are full size tube-to-tubesheet joints, made in test block models that represent the production tubesheets. The shear load test subjects the specimens to axial loads until either the tube or the joint fails. The reasons for this shear load test are:

1. To investigate the variation of strength with joint design and production parameters
2. To compare joint strengths achieved by various joining methods
3. To establish joint efficiencies for use in determining ASME Code allowable joint loads when the tubes stay the tubesheet

For the third purpose, Appendix A of the ASME VIII-1 has requirements for establishing joint efficiencies. It tabulates two sets of joint efficiency factors that apply to various types of joints, $f_{r\ (test)}$ and $f_{r\ (no\ test)}$. The tabulated values of f_r established by test are maximum values; the values tabulated for joints that are not tested may be used as shown.

Source: A Working Guide to Shell and Tube Heat Exchangers *by* Stanley Yokell

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