INSPECTIONEERING JOURNAL

September/October 2013 Volume 19, Issue 5

Since 1995, Inspectioneering Journal has provided the oil & gas and chemical industries with information to help optimally manage equipment risk and reliability, cradle to grave.

FEATURING:

NON-INTRUSIVE INSPECTION OF ABOVE GROUND STORAGE TANKS AND ITS USE IN A TANK RBI PROGRAM

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Non-Intrusive Inspection of Above Ground Storage Tanks and Its Use in a Tank RBI Program

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Maintaining the mechanical integrity of above ground storage tanks (AST's) is the focal point of tank inspection programs. Performing internal inspections is an integral part of a tank integrity program, however, deciding when to take a tank out of service to perform an internal inspection is not an easy determination to make. Tank operators are faced with the question, "do I really have to take this tank out of service right now? And, if so, what kind of damage and how extensive is the damage inside the tank, especially to the floor?"

There are industry standards such as the API Standard 653, Tank Inspection, Repair, Alteration and Reconstruction, which provide guidelines for tank openings. These recommendations are calendar based and may not always be the optimum interval for a tank opening. In some cases, the interval may be too short, thereby causing an unneeded expenditure of money and downtime for the tank. In other cases, the interval may be too long and excessive damage could result because of the overdue internal inspection. Therefore, the ongoing problem for the tank operator is "how can I optimize my on-stream inspection program while not significantly altering my risk of tank failure? What can I do to help ensure the tanks I open are those that are in most need of attention? Moreover, can I extend tanks that are in good condition?" For answers to these questions, tank operators are more frequently turning to Risk Based Inspection (RBI) programs. RBI programs help develop an inspection program based on the risk ranking (probability of failure vs. consequences of failure) of the tank.

WHY NON-INTRUSIVE INSPECTIONS

Most RBI programs use historical data and "what if" scenarios to assess risk and develop inspection programs. This includes original fabrication documentation and inspections, enhancement and modification records, past use and past inspection results. From this and other assumptions, a risk assessment is developed with an inspection program that is intended to maintain or reduce current risk based on a reduction in the probability of failure. Because the assessments are made utilizing historical and environmental information, they may lack information on the current operating condition of the tank. Recent changes in environment or usage may not be taken into account in the assessment or the inspection program. Most often the inspection recommendations are based on calendar information, and as a result, the intervals may not be optimized. By using inspections that assess the in-service condition of the tank, current degradation conditions can be identified and more effectively addressed in the assessment and the corresponding inspection program. Non-Intrusive inspections have become a priority for many companies. There are several reasons for this, some of which include:

<u>Safety</u> – eliminating entry into a confined space without any significant loss of information represents an improvement in overall plant operational safety.

<u>No interruptions of service</u> – The non-intrusive inspections are performed with the tank in service and product in the tank. There is little or no loss of availability of the tank due to the inspection.

<u>Cost</u> – It is very expensive to prepare a tank for internal inspection.

<u>No disturbance to tank</u> – For most inspections there is little or no disturbances to the tank. There is no paint removal, insulation stripping, no scaffolding, etc.

<u>Quick Results</u> – The results of the inspections are available during or shortly after the inspections are completed. Should a significant problem be detected, it can be identified and a corrective plan of action formulated. This can prevent an unexpected tank failure.

<u>Planning Work Scope for Internals</u> – When planning a tank opening, the condition of the tank floor, etc. are unknowns. Until an entry is made, the planners generally have minimal ideas as to what they will find, so they plan for a worst-case scenario and hope for the best. Non-intrusive inspections can provide the planners with information about the condition of the floor, as well as other areas of the tank. With this information, a better work scope can be planned, a more accurate determination can be made of what the material and labor needs will be, and the estimate of the turnaround of the tank will be more precise.

TYPES OF NON-INTRUSIVE INSPECTION

Today the field of non-destructive testing (NDT) is divided into two general classes – traditional and advanced (ANDT). Traditional are those techniques that have been in use for many years and are well documented. These include X-ray, visual, and ultrasonic thickness. Advanced are more recently developed techniques, many of which are computer based. Automated ultrasonics, digital radiography, and acoustic emission are examples of advanced NDT. Non-intrusive inspections applied to above ground storage tanks are classified similarly, traditional NDT and advanced NDT.

The API 653 document contains an Appendix that provides a detailed checklist for in-service inspections of a tank. This checklist utilizes traditional NDT techniques to inspect much of the tank exterior. Examples of these are ultrasonic thickness measurements made on the tank shell and roof to check for general corrosion, and visual inspections to verify the integrity of stairways and ladders, gauging systems, vents and breathers. The checklist is extensive, and those mentioned here are a limited sample of the items on the list. Even though some thickness measurements are made on the shell and roof, there is very little information available regarding the interior of the tank. In order to optimize a tank inspection program, the condition of the floor and shell should be evaluated. To do this while the tank is in service requires the use of advanced NDT techniques.

API 653 indicates that a tank, in many cases, is going to leak or fail because of corrosion. Corrosion of the floor and shell are two of the areas that can develop problems that could lead to a tank failure. When developing an inspection program, it is paramount the technique(s) specified are capable of detecting the damage mechanism(s) present in the tank. If corrosion is the primary concern, then the advanced inspection technique(s) must be capable of detecting the presence of corrosion and, when possible, the location and effect of corrosion (loss of thickness).

Several ANDT techniques are used in the non-intrusive assessment of a storage tank. Some of these are robotic automated ultrasonic scanning (AUT), acoustic emission (AE), advanced ultrasonic, pulsed eddy current (PEC) and electromagnetic acoustic transducer (EMAT). The area of the tank to be assessed will determine which ANDT method(s) is used. For example, a tank floor screening evaluation can be performed with AE; the shell of tanks without insulation can be evaluated with AUT, and so forth. A description of these follows.

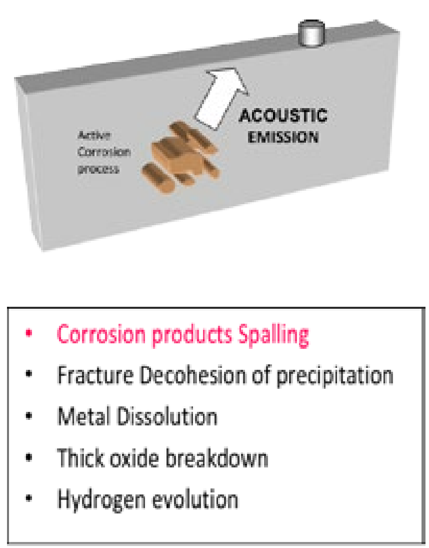
ADVANCED NDT OF ABOVE GROUND STORAGE TANKS

The areas of the tank that are inspected for corrosion by ANDT are the tank floor, the annular ring and the shell. For the tank floor, the acoustic emission technique is commonly used to determine if active corrosion is present, and, if so, where it is located. With this approach, active corrosion can be detected and located across the floor, and a map of its location and density can be provided. For the annular ring area, several techniques may be used depending on the type of information required. They range from techniques that give spot checks such as PEC and excavation, to techniques that can scan a larger area more quickly, such as ultrasonic guided wave, EMATS or ultrasonic shear wave. As an aid, the AE results can be used to help focus the inspection of the annular ring by highlighting those areas that were active during the AE test. For inspecting the shell of uninsulated tanks, Automated Ultrasonic Corrosion Mapping can be used to measure and record a large number of thickness readings using a magnetic tank crawler and scanning bridge. A color-coded thickness map of the scanned areas of the shell ("C" scan) is then generated that is capable of identifying small pits and other signs of corrosion. Of concern on the shell, in addition to general corrosion, is corrosion at the air to liquid interface.

ACOUSTIC EMISSION TESTING OF TANK FLOORS

Acoustic emission is a passive screening technique that relies on the structure under test to generate a signal to be followed up with more quantitative detection and measurement techniques such as UT, for example. It is most often used in a dynamic test environment. That is, it is used to monitor for crack detection in pressure equipment when the equipment is experiencing an increase in stress. One exception to this is the detection of active corrosion. This test is a static test, screening for corrosion activity; that is, there is no change in applied stress. The source of the signal is the ongoing corrosion process. Figure 1 illustrates the detection of active corrosion with AE.

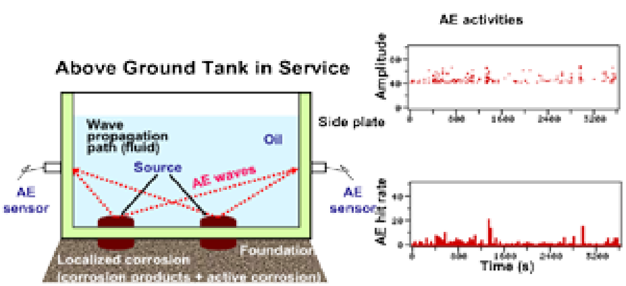
FIGURE 1. ACOUSTIC EMISSION GENERATED BY THE CORROSION PROCESS



During the corrosion process, several mechanisms generate AE. The signals generated are detected by the piezoelectric sensor and are converted to an electrical signal. The magnitude of these varies and that makes detection of some signals impossible in a field environment. The spalling of corrosion product generates some of the higher amplitude signals. It is this signal source that is focused on for detecting active corrosion on the tank floor.

Figure 2 illustrates the propagation path of the corrosion signals to the AE sensors. The corrosion can be top side or bottom side. There are two potential paths, one through the steel and one through the fluid. The path through the steel is more attenuative then the fluid path, so the sensors are designed to detect signals propagating in the fluid. This is shown on the left hand side of Figure 2. On the right are two historical plots of AE data. The upper plot is the amplitude of the corrosion signals and the lower is the rate at which the AE signals occur. They show that the rate at which corrosion occurs can vary over time and the intensity can vary with the rate.

FIGURE 2. PROPAGATION OF AE SIGNALS IN A TANK



When a tank floor is being tested, the intent is to detect and analyze AE signals from active corrosion. In the field, there are other potential sources of signals that are not related to corrosion. Roof movements, pipe born noise, condensation, particle impact, and valve leakage are some of these. Precautions must be taken so as not to include these noise sources in the final evaluation, otherwise an incorrect determination might be made.

The requirements of the tank operator are simple when performing an AE test. The tank needs to be stilled (no product in or out) anywhere from six to twenty-four hours (this depends on the size of the tank and the product) prior to testing. Historical information about the tank is requested to insure it is a candidate for AE testing. The test procedure itself involves attaching two rows of sensors using ultrasonic couplant and magnetic hold-downs. In most cases, the sensors can be attached to the tank without the removal of any paint or coating. One row of sensors is located approximately three feet above the tank floor with the second row about twelve feet above the floor. If it is an insulated tank access, holes (six inch square) are required in the insulation. Data is collected for a period of time, the length of which will depend on the tank and how active it is. After the data collection is completed, the data is analyzed and a composite grading assigned to the tank. The composite grade is a combination of the data associated with active corrosion and data associated with a possible leak in the tank floor. The grades are based on empirical data from work performed by users in the early years and reported by Van De Loo, P.J. and Shiginori Yuyama, et.al.

The composite gradings are:

I – No active damage, re-test in 3-5 years.
II – Minor active damage, re-test in 2-3 years.
III – Active damage re-test in max. 1 year*.
IV – Very active damage. Re-test in 0.5 year*.
* or schedule for internal inspection

The chart represents the combined, validated experiences of past tests performed for multinational oil and chemical companies.

Figure 3 is an example of AE test results from a sample tank. The plot in the upper left corner is the AE test results showing significant activity on the tank floor. The other three photos show the types of damage inside the tank in the areas of concentrated AE activity.

FIGURE 3. AE TEST RESULTS AND INTERNAL DAMAGE IN THE AREAS OF ACTIVITY

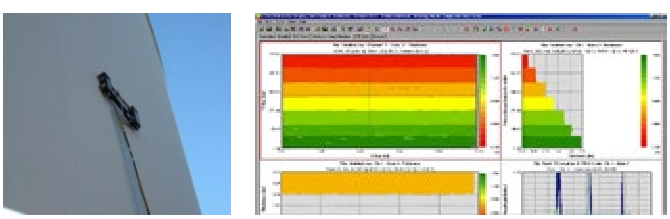
AE testing has proven to be very effective at identifying active corrosion on carbon steel tank floors. Corrosion characteristics are different in other metals such as stainless steel, however. The AE tank floor test is intended to provide a general condition assessment and therefore, it is limited to carbon steel floors. In addition, there are some products, like asphalt, that inhibit the propagation of the signal so they are typically tested under a best effort scenario.

Like other NDT techniques, AE testing must have a written test procedure that is followed by technicians trained in the technique, as well as in the test procedure. They should be properly certified under a written personnel certification program. The AE tank bottom test uses a high degree of sensitivity, more so then most other AE tests, and because of this, a proven test procedure and qualified personnel are paramount to a successful utilization.

AUT OF THE SHELL

Automated Ultrasonic Testing is a method whereby an ultrasonic thickness transducer is maneuvered to predetermined positions on a tank shell and thickness measurements, as well as position information, are recorded and electronically stored. Typically, the transducer is attached to a scanner that moves the transducer across and up or down the shell surface using strong magnetic wheels. The system records a large amount of data that can be reviewed either in a spreadsheet or in a color-coded display. A typical setup is to take a thickness reading every one inch horizontally and one inch vertically. Moving the scanner up or down the tank would constitute one drop. The number of drops will vary based on the size of the tank, but at least one drop per quadrant is recommended. Therefore, with a twenty-four inch scanner, there would be twenty-four thickness readings for each one-inch increment on the tank shell. On a sixty-foot high tank, there would be a little over 8,600 readings taken for each drop. If four drops are made, the number goes to almost 35,000 thickness measurements. This is a lot of data to review; consequently, automated classification software is used to find key measurements in the data file. *Figure 4* shows a scanner on a tank and the corresponding display of data from that drop.

FIGURE 4. AUT SCANNER AND DISPLAY OF ULTRASONIC THICKNESS DATA



The photo on the left shows the bridge on the tank. The UT transducer scans back and forth on the bridge as it moves up or down the tank. The two plots on the top of the display on the right show the varying thickness of the shell. The green area corresponds to the thicker plates at the bottom of the tank, and the orange corresponds to the thinner plates at the top. Should an area of interest be identified, that portion of the data can be expanded, as shown in the lower left display. On the lower right is the "a" scan, showing the analogue ultrasonic signal and the position of the window (gate) in which the signal is measured. This type of shell scanning provides much more detailed information about the condition of the shell than the few thickness measurements that would be made under the API 653. With this type of scanning, a more accurate evaluation of the shell condition is possible, especially when liquid to air interface pitting is a concern.

ANNULAR RING INSPECTION

Inspecting the annular ring/critical zone from the outside of the tank is as challenging as it is to inspect it from the inside. The problem is where to look for damage, since, in some cases, only a very small percentage of the total circumference may have a problem. With the approach put forward here, that is using the AE test results as a means of identifying potential problems areas in the annular ring, a better answer to that question is provided. In the AE software, there are special filtering techniques that focus on AE data from the annular plate area. It provides a plot of where potential damage is occurring. Once identified, further follow up inspections by other methods can be performed to characterize the damage. The AE data answers the question as to where to look; the next question is what to use to confirm the presence of damage and the to determine the extent of damage.

There are several methods that can be considered for performing follow-up inspections of the annular ring. Excavation is a relatively straightforward technique that allows visual and other NDT examinations to be performed from the bottom of the tank. However, there is risk associated with the removal of the support material, especially if significant plate thinning has occurred in the area. PEC is another method for a spot check, but it also requires some removal of support material from the bottom of the tank floor. The probe is inserted under the tank floor and a measurement is made.

The alternatives to spot checks are techniques that can be used to scan an area of the annular ring using either manual or automatic scanning. They include ultrasonic shear wave, EMATS, and guided ultrasonic waves (guide bulk waves). With these techniques, the transducer is placed on the chime and the signal induced into the annular plate. Depending on the technique being used, indications of pitting, grooving or general thinning can be detected. *Figure 5* illustrates this concept.

Since these techniques involve inducing a signal into the annular ring plate, the condition, thickness and size of the chime are important. The surface must be relatively smooth so surface preparation with sand blasting is usually required. Some other variables affecting the techniques are orientation of defect, operator variability, etc. Also of concern is the ability to provide information about the critical zone. Piezoelectric transducers create a dead zone that can occur in parts of or in the entire critical zone, preventing information about its integrity from being evaluated. There are ongoing developments with several techniques

FIGURE 5. ULTRASONIC SCANNING TECHNIQUE FOR ANNULAR PLATE INSPECTION

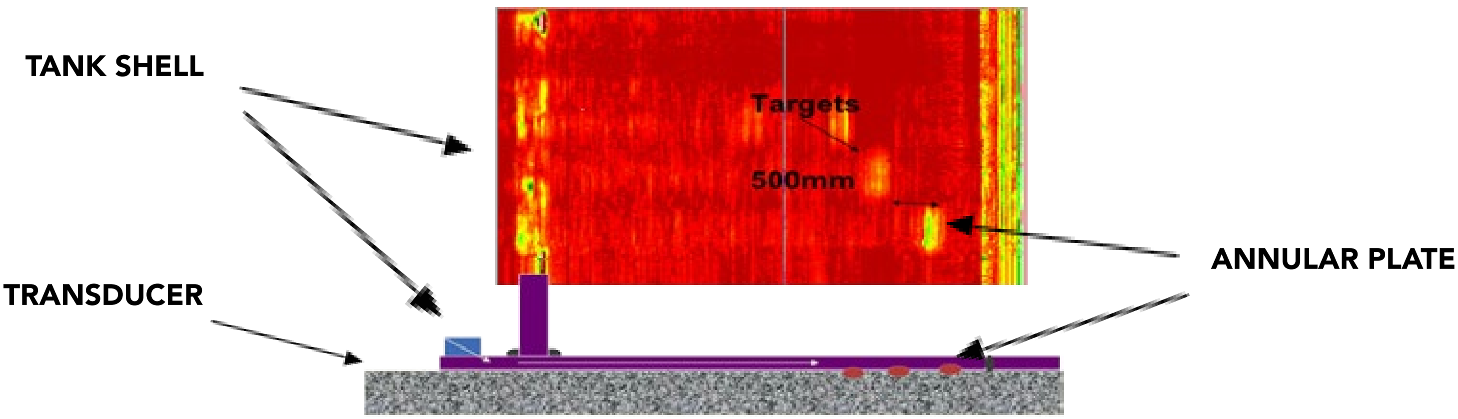


FIGURE 6A. ULTRASONIC SHEAR WAVE SCANNER

FIGURE 6B. GUIDED WAVE SCANNING HEAD

to improve the detection capability in the critical zone. Figure 6 shows two scanners.

Figures 6A and *6B* show ultrasonic scanners. In *Figure 6A*, an automated shear wave scanner is shown. The transducer is located on the left side of the scanner and it traverses along the chime with the transducer contacting the chime and inducing a shear wave signal into the chime. Because UT requires a smooth surface at the point of contact, the chime has been sandblasted and cleaned. Water is used as a couplant.

Figure 6B shows the guided wave (bulk wave) scanning transducer. This is a manual scanner, but it can easily be automated. Just like the shear wave transducer, the bulk-wave transducer induces a signal into the chime. As can be seen in the photograph, the surface is sand blasted and cleaned as it was for the shear wave transducer.

USING THESE INSPECTION RESULTS IN AN RBI PROGRAM

Maintaining a tank in good operating condition is important for several reasons, including but not limited to, meeting regulatory requirements, maintaining tank availability and preventing leaks. The use of RBI has helped tank operators meet these goals; however, the question remains "how do I know if my program is providing optimal intervals for inspections and if not, how can I determine optimal intervals?" In an RBI program, the Consequences of Failure (CoF) and the Probability of Failure (PoF) are assessed. The CoF is not impacted by non-intrusive inspections, while PoF assessments can be affected. PoF makes assumptions based on past inspections and environmental conditions. Availability and accuracy of inspection data, appropriateness of the testing, and numerous other factors can impact the accuracy of the assessment. In some cases, it may be too conservative because of the lack of accurate historical information, and in others, not conservative enough because of unforeseen changes in the environments, etc. The non-intrusive inspections discussed here help validate the assumptions made in the RBI assessment.

So, how does a tank operator take advantage of these inspections? Consider the following examples. A tank is under an RBI program and according to the inspection schedule he is supposed to perform an assessment of the tank bottom for corrosion. The previous internal inspection showed no corrosion on the tank floor. The non-intrusive inspection techniques described herein have been classified as usually effective and/or highly effective by his RBI program. The operator decides to perform an AE test on the tank floor before deciding on an internal inspection. The results are a composite grade of "I". This indicates little or no active corrosion on the tank floor. The recommendation from this test result is to re-inspect in three to five years. In the Risk Matrix, this tank is classified as a Medium risk tank. Based on the AE test and the prior internal inspections, the RBI program extends the internal inspection for corrosion on the tank floor by three years.

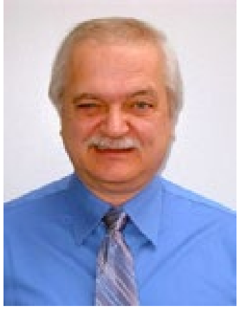
Different scenario: This tank has a Risk Ranking of High. It is not scheduled for an internal inspection for corrosion on the tank floor for two more years, however, because the CP system was inoperative for an extended period of time, the operator decided to perform an AE test on the tank floor. The results of the test were a composite grade of "III". This grade indicates active corrosion is present and the tank should be retested in one year or scheduled for internal inspection. Because of the High Risk Ranking the operator decided to take the tank out of service immediately and perform an internal inspection two years earlier then planned.

In the first example the tank internal inspection was delayed because there was no indication of active corrosion and in the second the internal inspection was moved up because of problems identified by the AE test. These examples show how the non-intrusive inspections can help optimize a RBI program. Opening a tank for internal inspection can be very costly in many cases. Cleaning, waste disposal, preparing for entry, the actual NDT inspection, and the loss of tank availability all contribute to the cost of opening and inspecting a tank. The inspection techniques presented here direct the tank operator to those tanks in most need of attention and allows for tanks in good condition to have their internal inspections extended.

Another use of the non-intrusive inspections is in the planning of a tank opening. Many times the internal conditions of a tank are unknown until the tank is physically entered. Planning for the material, labor, and outage time can be improved through the use of these inspections.

CONCLUSION

The program described herein has been implemented by several companies that operate a large number of tanks. When asked about their results from this program, they were in agreement that significant savings were realized by extending the internal inspections of tanks found to be in good condition. Likewise, tank failures have been averted because problem tanks were identified and taken out of service before a failure occurred. While this second scenario is hard to put a dollar amount on, it is safe to say the savings were extensive.



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