



Preventing Leaks in Large Aboveground Storage Tanks

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Continuing Education

This is the second of two articles on detecting and preventing leaks in large aboveground storage tanks (ASTs). The first covered leak detection fundamentals and the basic causes of leaks ("Where to Find Leaks in Large Aboveground Storage Tanks," April 1999, page 36). This second article deals with leak prevention and advanced leak-detection and monitoring methods.

Old timers would often tell me that "tanks don't leak, because, if they did, the oil would come out on your shoes." Of course, this is not true. Studies and experience show that most leaks go straight down into the ground and ultimately into ground water. So leaks do matter. They can put you or an industry out of business. And your shoes are not very good leak-detection devices, frankly.

Improving bottom integrity

Most of the design effort associated with flat bottom tanks has been directed at the shell and roof (fixed and floating). Relatively little attention has been directed at the bottom, since the tanks have been deemed only as non-pressure containing membranes. Therefore, the design and fabrication requirements for bottom construction have been less stringent than those for the shell and roof.

Near the end of my article in the April issue, I mentioned and illustrated that new tank bottoms sometimes leak because of their design and construction, particularly with regard to welding procedures. I mentioned that:

- The cleanliness of welds is important. Bottom plates are located on the ground and subject to dirt and moisture, which promote porosity and cracks in welds.
- Square corners at the joints where three plates come together or lap patches cannot be easily welded without defects.
- Bottom construction involves the use of fillet welds that cannot be easily examined for tightness. Testing these fillet welds is difficult at best.
- The joining of three plates at the intersection of two seams is a significant problem and is where we have detected most failures. The plates must be welded in a complex and precise procedure in order to be tight.

Today, the American Petroleum Institute's (API's) Pressure Vessel and Tank Subcommittee (PVT) is

considering some steps for improving tank bottom integrity to reduce the probability of leaks. In fact, the API 650 and API 653 Committees are considering the following:

- Recommending two-pass welds on tank bottoms instead of only one.
- Studying vacuum box effectiveness (e.g., vary vacuum pressure and redundant testing).
- Improving welding spacing to prevent having welds too close to one another or overlaid on top of one another.
- Using rounded corners on plates and lap patches.
- Recommending the use of ASME Boiler and Pressure Vessel Code, Section IX welding requirements for tank bottoms.

Preventing corrosion

What can be done to prevent or mitigate corrosion of large ASTs? The answers are not simple, but there are a number of proven methods. Some are discussed next.

Coatings

For internal tank corrosion, bottom coatings have been proven to be very effective. Not only do they reduce interior bottom (topside) pitting, but they also effectively reduce finished fuel contamination and tank cleaning costs. While API standards do not prescribe coatings for finished fuel tanks, API RP 651 gives guidance on how to install coatings when they are used. Chevron coats all finished fuel tanks on the bottom and about two feet up the shell.

Coatings protect those areas that suffer the most aggressive attack by corrosion. Economic analyses, not even considering product purity and product integrity issues, show that coating tank bottoms pays off. Of course, effective coatings also help protect the environment. Not only is this cost effective, but it makes cleaning tanks when they are due for internal inspections much less costly. It also allows for better, more accurate inspections.

External corrosion of tank bottoms presents a different challenge. The underside of tank bottoms cannot be effectively coated. This results from the fact that any underside coating would be burned by the welding of the bottom plates. One measure found to improve tank underside corrosion resistance is using plate that has been “descaled.” “Scale” is iron oxide that results from the mill process. This galvanic corrosion, when the plate is placed in an environment such as the underside of a tank bottom, can significantly accelerate pitting. For this reason, Chevron uses only descaled plate for tank bottoms.

Cathodic protection

Use of cathodic protection to reduce both interior and exterior corrosion is controversial and complex. Industry experience shows that it is very useful for interior corrosion on crude oil tanks when used in conjunction with liners. However, cathodic protection has not been proven universally effective for protecting finished fuel tanks from internal corrosion. Coatings do that job adequately.

On external or underside corrosion, cathodic protection has been used with mixed results.

Theoretically, cathodic protection will work if installed properly, but, in reality, there are many obstacles to overcome for it to work right. Unless these systems are installed, tested, maintained and operated by trained and qualified people, they can be totally ineffective and, in fact, can cause accelerated corrosion.

Cathodic protection should not be mandated as a blanket solution but should be individually evaluated and weighed against other alternatives on a site-specific basis. API RP 651 should be consulted when cathodic protection is being considered.

Double bottoms

Although this fact is not well known, the double bottom is an effective corrosion prevention method that significantly increases the tank life. How so? There are several factors that reduce the problem of underside corrosion:

- Adding a double bottom raises the new steel bottom up off the mud and dirt. The elevation generally mitigates the corrosive environment by reducing contact with moisture and salts.
- Concrete in the presence of moisture becomes alkaline. Alkaline water is much less corrosive than acidic water. Measurements from standing water under tank bottoms have been about pH 11 to 12. So the concrete is actually a corrosion inhibitor.
- A double bottom tank has a more uniform foundation, with less likelihood of clay balls or foreign objects. In other words, development of corrosion cells, galvanic corrosion and other problems are less likely when a concrete foundation is used.

Guarding against trauma

Tank problems resulting from hurricanes, earthquakes and other physical traumas can be mitigated (but not eliminated) to acceptable levels of societal risk. The primary mechanism for this is to follow API standards. However, there are gaps between standards and their application that should be noted.

Earthquakes

For the tank itself, but not including the foundation, the most widely used and acceptable practice for ensuring tank adequacy is API Standard 650, Appendix E. However, experience shows that, during earthquakes, it is not only the tank, but also the attached piping and accessories that cause spills, leaks and fires. By ensuring that the attached piping has adequate flexibility and that ladders and platforms are free to move with the tank during uplift, the majority of the risks can be eliminated.

Hurricanes

The wind loads specified in API 650 may or may not be adequate, depending on the geographical location. When there is any doubt, such as for tanks in the south central US, close attention must be given to specifying the required resistance to high winds. To specify this loading reliably, use the latest edition of ANSI/ASCE, Minimum Design Loads for Buildings and Other Structures.

Settlement

Fortunately, settlement has not created a significant number of leaks, but when excess settlement occurs, it can be serious. The rules for the various types of settlement (with the exception of edge-cutting settlement) are generally reliable and accurate for the prevention of settlement-related incidents, as documented in API Standard 653.

The API 653 rules on edge-cutting settlement are, however, inappropriate and should be ignored. They are overly conservative and have had the effect of causing users to re-level tanks that do not require it. Edge-cutting settlement is common in areas such as Alaska. Here, the snowpack load resting on the tank roof (which transmits forces to the shell and bottom), combined with the saturated soil in the Spring, causes the pressure acting under the shell to exceed the soil-bearing pressure. This results in edge-cutting settlement.

The highly distinctive settlement can then be clearly observed, but only from the inside of the tank. Fortunately, informal surveys on the history of leakage or spillage show that edge-cutting settlement does not cause failures of the bottom plates, except in the most severely deformed tanks.

The PVT Subcommittee is revising API 653 to provide new and better rules to address this form of settlement. The proposed revision to Appendix B will provide that any edge-cutting settlement of less than 1H inches does not pose a serious enough risk to warrant being examined. Larger amounts of edge-cutting settlement will be addressed by a graphical method that gives the allowable settlement based on the diameter of the tank and the thickness and fabrication details of the bottom plates.

Traditional monitoring

Traditional tank monitoring for leak detection involves inventory reconciliation: comparing measured inventory with “book” inventory and accounting for variances. While this works reasonably well on small tanks, it is a poor system for detecting relatively small leaks in large storage tanks. Many large tank sites have been contaminated by leaks even though their inventory monitoring systems did not indicate that they had leaks. More advanced leak-detection methods have been developed for large tanks, as discussed in the remainder of this article.

Advanced monitoring

Advanced tank monitoring methods for large petroleum tanks are outlined in API Publication 334 (A Guide To Leak Detection for Aboveground Tanks). These methods are significantly better than the traditional methods, but still nowhere near to meeting the standards that the federal Environmental Protection Agency (EPA) has set for underground tank monitoring and leak detection. A basic review of the advanced methods follows:

Volumetric measurements

The four principal factors that affect volumetric measurement techniques are:

- product expansion and contraction;
- tank shell expansion and contraction (both thermal- and pressure-induced);
- measurement error associated with the instrumentation; and

- bottom flexures.

Other noise sources (error sources) are thermal gradients, in both the vertical and horizontal directions. The tank is subject to volume changes caused by growth of the shell in the radial direction as a result of thermal changes and internal pressure caused by the liquid in the tank.

Strong winds can deflect the tank shell, causing a variation in liquid level at constant stock volume. The diurnal volumetric changes caused by the thermal changes in the ambient air temperature and by solar radiation all impact attempts to accurately measure leakage.

Even with the best instrumentation, only 90 to 99 percent of the unwanted errors can be removed. Therefore, longer test periods favor more accurate measurements. But longer tests to gain better accuracies are usually not feasible.

To date, there are two basic forms of volumetric leak detection. The level method depends on measuring the drop in liquid level that results from a leak after compensating for thermal expansion of the liquid. The mass-measurement method measures the pressure head caused by the liquid level.

The level method—The basic concept of the level approach is to measure the liquid level accurately, compensate for thermal expansion or contraction and look for a drop in the temperature-compensated level that results from a leak. The liquid temperature is determined using a vertical array of temperature sensors to compensate for vertical thermal gradients. **Figure 1** shows this method.

Mass-measurement method— With these methods, the pressure near the bottom of the tank is measured. The pressure corresponds to the mass above the measuring point and should be independent of liquid level changes caused by thermal expansion. This was thought to be a significant advantage over the temperature-level method. However, testing has shown that the two systems are comparable in accuracy. **Figure 2** shows this method.

Mass measuring systems should not be subject to the thermal variations that the level measuring systems are subject to. However, the transducers used to measure pressure are significantly affected by the sensor's temperature. The sensitivity of the differential pressure cell sensor to thermal ambient temperature changes is three to five times greater than the uncompensated volume changes measured by the level sensor.

Mass measuring systems also do not compensate for any thermally induced product changes below the lowest pressure sensing port. While this problem may be eliminated by design, in practice, this remains the limiting factor for the accuracy of pressure measurements. However, the vendor community has been addressing these problems by installation of climate-controlled enclosures for the sensors. Improvements in the capabilities of mass-measurement systems are expected.

By keeping the liquid level low and making measurements at night, when the horizontal thermal gradients are low, the level-and-temperature method (according to API testing) is approximately

equal to the mass-measuring method. The primary disadvantage of either method is the 24 to 48-hour out-of-service “stilling period” required to conduct the test. Also, complete isolation of the tank by “blinding” all flanges is required to obtain reliable test results.

In spite of these problems, the API testing indicated that leaks as low as 1.9 gallons per hour could be detected in a 117-foot diameter tank with a probability of detection at 95 percent, conducted using a 24-hour test. The detectable leak rate was reduced to 1.0 gallons per hour for a 48-hour test.

Acoustic emissions

As applied to aboveground tanks, acoustic emission leak detection technology is listening for the characteristic noises created by a leak from the bottom of a tank. The passive acoustic system operates essentially by detection and location of noise signals that are consistent with the types of signals emitted from tank bottom leaks. **(See Figure 3.)**



Figure 1: Volumetric-Level Method The system monitors level of product. Wires connect the float to a computer. Temperature sensors monitor the horizontal and vertical extent of the product. Data from the temperature sensors are also transmitted electronically to the computer.



Figure 2: Volumetric-Mass Method A “bubbler” system forces air or gas into a tube. Its outlet is at the bottom of the tank and also into a second (or reference) tube with an outlet in the vapor space. The differential pressure cell measures the amount of pressure needed to force air through the tubes, and these readings are entered into a computer for analysis.



Figure 3: Acoustic Emissions Impulsive acoustic events that exceed a certain threshold are plotted on a map of the tank floor. A concentration of these events indicates not only the existence of a leak but also its location.

The problem is that the intensity of the leaking noise signal is so low, compared to other ambient noises, it is almost drowned out. The leak signal is barely detectable and decays rapidly with distance. In addition, multiple reflection paths confuse the location of the leak signal.

However, the development of sophisticated algorithms and signal processing has allowed this technique to be considered feasible. Information such as duration, propagation mode and spectral characteristics can be used to reject noise contamination of the signals.

Because acoustic emission technology is sophisticated and not well-understood, there are numerous problems in its successful implementation and use. This method can have a significant probability of false alarms. Several companies offer leak-detection systems based on passive acoustic emission. However, very little technical information has been published about the performance characteristics of these systems, the nature of the signals produced or the probability of false detection.

Types of leak signals — When a tank bottom leaks, there are two distinct types of noise created. First is the persistent leak signal produced by the turbulent flow through the hole in the tank bottom. This signal accompanies all tank floor leaks.

The second type of noise is the impulsive leak signal produced by air bubbles collapsing in the backfill under the hole. The response of sensors to these noises is similar, whether the sensors are placed in the liquid itself or on the exterior wall of the tank.

The impulsive leak signal is greater in magnitude than the persistent signal and is therefore easier to detect. However, the impulsive signal only occurs when air is entrained into the leak flow field beneath the tank. This means that the soil beneath the tank must be relatively well-drained. If the area beneath the leaking tank floor is saturated, there is no signal. The probability that impulsive leak signals will occur when tanks leak is not known.

The persistent leak signal depends on soil conditions under the tank and the flow rate of the leak. The signal is created by the flowing turbulence of the liquid through the hole in the bottom plate. The signal's characteristics are altered by the conditions beneath the tank. Multipath reflections of signals inside of vertical cylindrical tanks can be stronger than the direct-path signal itself, thus masking the signal. Under such conditions, the ability to discern the persistent leak signal may be a limiting factor in this type of leak detection.

Noise generated in typical processing plants, such as traffic, leaking valves, control valve flows and piping noise, can mask the acoustic leak signal. However, most of the noise is confined to a frequency below 10kHz. The persistent leak signal may be detectable above the ambient noise levels if the signals are above 10kHz.

The impulsive signal is about 10 to 20 times larger than the average background noise. Most background noise can be avoided by careful selection of the measurement period, sensor location, data collection and signal processing.

For reading impulsive leak signals, multiple sensors spaced at various locations allow computation of the time it takes for the impulse to traverse the distance from the leak to the sensor. By using this computation, the estimated location of the leak signal can be determined. Various signal processing methods and algorithms are used to filter out or correct for multiple reflections.

False signals — Some potentially false signals can come from the following sources:

- Impulsive signals seemingly from the floor can come from such other sources as roof drains, pivoted float arms and roof supports.
- Impulsive signals can be generated by condensation dripping onto the product surface.
- Impulsive signals can be generated by floating roof movement.
- Impulsive signals can come from high winds.
- Impulsive signals can come from thermal excitation of the tank shell.

The potential for false signals is also affected by other factors. For example, data collection and analysis have a significant impact on the potential for false acoustic leak signals. Also, it is critical to

identify the propagation mode for signals received to locate the source of the signal.

One company recently examined 345 tanks using the acoustic emission leak-detection method. Twenty-one of the tanks were indicated to be leaking, and 19 of the 21 were internally inspected. Of those 19 suspects, 16 actually had leaks. This gives a probability of detection of 0.84 and a probability of false alarm of 0.16.

Chemical markers

In this method a highly unique chemical can be injected into the tank that is otherwise not present in normal petroleum liquids. These markers, or tracers, then spread throughout the liquid. By sampling vapors from the underside of the tank (if a leak exists), the detection of the chemical marker in the sampled vapors indicates the existence of a leak.

This method is highly accurate and perhaps has the best probability of detection. But since the vapors under the tank must be monitored, it is necessary to install sampling tubes. While this technique is feasible for small tanks, it becomes prohibitively costly at diameters exceeding 60 to 100 feet (on existing installations). Tracer Research Corporation, located in Tucson, AZ, has perfected this technique and can be consulted for further details [(520) 888-9400].

Release prevention barriers

The release prevention barrier (RPB) is the simplest but most effective of all leak-detection systems for large ASTs. It may simply be a plastic liner underneath the tank bottom.

The double bottom is a subset of the RPB. The double bottom works extremely well for retrofits, whereas a simple sheet liner buried beneath a newly constructed tank is entirely adequate. API Standard 650, Appendix I addresses the basic requirements for constructing double bottom systems.

RPBs are very simple to understand; they block the downward flow of leaks and divert them to the perimeter, where the leak really does come out on your shoes. In all cases that I am aware of, leak detection that has been accomplished by viewing the leak at the perimeter has effectively prevented environmental damage.

The RPB detects extremely small leaks. In one case, leaks occurred in a new double bottom. Six years later, the very small leaks appeared as a staining at the leak-detection bottoms. The double bottom has some important leak detection characteristics:

- It is passive (i.e., it has no moving parts and does not depend on power supplies or any other maintenance or support).
- It has essentially a zero threshold leak rate—it will detect smaller leaks than any other type of leak-detection system.
- It has essentially a 100 percent probability of detection. Unlike other leak-detection systems it will not miss any leaks.

It must be understood that there are many ways to construct a double bottom tank. The foregoing

discussions of double bottoms assume the use of a concrete spacer and 80 mil high density polyethylene (HDPE) liner. Concrete construction, in addition to the other advantages already cited, reduces the probability of creating serious problems when using granular filler material. Remember, however, that the concept of a liner could include a reinforced concrete mat, a plastic liner, a double bottom tank, or other similar ideas. It is the concept of using an RPB that catches and diverts the leak that is important—much more so than the details of how the system is constructed.

Answers to questions of PE&T's Pop Quiz on large ASTs and leak detection.

1. (c)

Bottom construction uses fillet welds because they are the only practical way of building tank bottoms for the vast majority of applications. However, these are the most difficult types of welds to examine for tightness to leaks.

2. (a)

Coatings are not used on the underside of tank bottoms because the welding process would destroy them.

3 (d)

All of the above. While a (internal coatings) and b (cathodic protection) are universally recognized corrosion prevention measures, the double bottom, if constructed according to Chevron specifications, does reduce corrosion (1) by reducing water and contamination, changing the alkalinity of any residual water under the tank bottom and (2) by elevating the tank bottom, improving the ability of the water to drain away from the tank.

4. (d)

API 650 Appendix E is used for this purpose.

5. (b)

Volumetric testing measures the change in volume of a tank by compensating for thermal expansion of the liquid. An alternative form of volumetric testing is the mass method where the pressure head of the liquid is measured.

6. (b)

The impulsive leak signal is the characteristic sound emitted by a leaking tank. It is this sound that allows us to perform acoustic leak detection.

7. (d)

All of the above are sources of potential false alarms.

8. (a)

No downtime is required. The double bottom tank operates reliably and passively over time.

9. (d)

The double bottom is an effective corrosion prevention method that significantly increases the tank

life in a variety of ways.

10. (b)

Cathodic protection has not been proven universally effective for protecting finished fuel tanks from internal corrosion. Coatings do that job adequately.

¹ A complete discussion of this topic may be found in the book Aboveground Storage Tanks by Philip Myer and Robert Ferry.

Glossary

1. Ambient air temperature –

The average, everyday temperature and the temperature that a tank tends to become if liquid is stored in it for a long time.

2. Ambient noise level –

The background interference present in all measuring systems that tends to obscure the measurement and lead to inaccuracies of measurement.

3. Blinding –

Closing off of the end of a pipe through the use of bolted plates.

4. Bottom plates –

The steel plates that form the bottom of a tank. They are usually about six to 10 feet wide and up to 40 feet long. They are typically 3/8 inch thick.

5. Descaled plate –

Bottom plates that have had the factory mill scale removed to improve the corrosion resistance of the plates to soil-side corrosion attack.

6. Diurnal volumetric changes –

Even with no liquid entering or leaving the tank, the fluctuation of the liquid level will move in response to its temperature change on a daily basis that tracks the outside ambient temperature. This results from the well known expansion and contraction of liquids when heated or cooled.

7. Edge-cutting settlement –

One of several forms of settlement addressed in Appendix B of API 653 that covers tank settlement.

Edge-cutting settlement results when the load at the tank shell is so great that it causes the bottom plates under the shell to be pushed into the soil.

This is more likely to occur in the Spring in locations where the heavy snow load on the tank roof adds to the pressure at the tank bottom near the shell and when the soil is soft as in the springtime during snow melt. API 653 addresses edge-cutting settlement, but the formulas are currently too stringent and are overly conservative. A task group has been formed that is revising the Appendix to provide a more reasonable method of determining what acceptable edge-cutting settlement is.

8. Fillet welds –

Welds that join plates, which are lapped on one another (as opposed to butted up against one another). The lap welds are triangular in shape and, for bottom plates in tanks, are on the topside only. These welds are difficult to make in tank bottoms without defects. Therefore, testing is important.

9. Finished fuel –

Fuel for motor, aviation and other applications including gasolines, diesels and jet fuels.

10. Horizontal thermal gradient –

In a tank, the temperature variations that can occur on a horizontal plane across the diameter of the tank.

11. Mass measurement –

This measurement makes use of pressure measured at the bottom of a tank to determine if a leak is occurring in a tank.

12. Missed detection rate –

The false result of a leak-detection test stating that there is no leak when, in fact, there is a leak.

13. One- and two-pass welds –

If only one weld is made, this is a single-pass weld. If the welder comes back and welds on top of his first weld a second time, this is a two-pass weld.

14. Passive system –

These are systems known for reliability because they do not require any foreign power supply, air supply or any other source that must be relied upon. The only thing that passive systems require are the forces of nature such as gravity.

15. Pressure head –

The pressure exerted by a column of liquid due to gravity.

16. Probability of false alarm –

The chance of a leak-detection system indicating a leak when there is none.

17. Release prevention barrier –

A barrier to a leak under a tank. The RPB can be a plastic sheet, a double bottom tank, a reinforced concrete mat or other constructions that are passive and divert the leak to the perimeter of the tank, where it can be visually observed.

18. Soil bearing pressure –

The ability of the foundation soil to withstand the forces of the tank resting on it without undue settlement or deformation.

19. Stilling period –

When leak tests are conducted, it is necessary to stop flowing liquid into or out of the tank. It is also necessary to ensure that no energy input, such as by mixing, is allowed to occur in the tank so that the liquid is quiescent.

20. Temperature-compensated volume –

The volume that would be in the tank if the temperature were changed to a standard value, such as 60 degrees F.

21. Vacuum box –

A steel box with a glass window that allows for evacuating the air on a portion of a tank bottom weld. When the vacuum is applied, the soap solution that is painted over the weld starts to emit bubbles if there is a leak. This is the primary method of testing bottom plate weld seams.

22. Vertical thermal gradients –

If you were to measure the liquid temperature at one foot intervals vertically from the bottom to the top of the tank, the temperature would form a curve called a vertical thermal gradient. It can vary by as much as five to 10 degrees F.

23. Volumetric measurement –

A method to detect leaks by attempting to see if the temperature-compensated volume is constant after the tank has been stilled.

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