How to Find Leaks in Large Aboveground Storage Tanks

Chevron Products Company's Philip E. Myers shows readers how to find leaks in large ASTs while avoiding a "false positive" result that could needlessly shut down their operations.

Continuing Education
This two-part article (April and May) will help to provide you with the basics to make sound judgments about the use and appropriateness of various tank leak detection technologies for large aboveground petroleum storage tanks (ASTs). In this first article, Philip Myers focuses on the nature and causes of leaks as well as the key concepts involved with leak detection. In May, he will examine the various ways to prevent leaks.

Leak detection fundamentals

A typical authority having jurisdiction (AHJ) over leaking tanks would like to have a leak detection system that is continuous, can detect any size leak (a zero threshold) and is 100 percent reliable. Unfortunately, however, this system does not exist, and it never will. Here's why.

When you investigate leak detection, you soon realize that the smaller the leak size, the less reliable the detection or monitoring equipment. In general, the signal-to-noise ratio plagues leak detection vendors and technologies. To illustrate, assume that you are listening to a speech—the "signal." All sounds other than the speech are "noise."

As the speech becomes lower in volume, there will be a level at which you cannot accurately determine what is said. Also, if the background noise becomes louder, the point will come when you will not be able to accurately determine what is being said. Similarly, the volume of product that leaks from tanks over the typical test period of one or two days is so small, as compared to the tank volume, that the problem of detecting leaks is one of a low signal-to-noise ratio.

Another problem with low signal-to-noise ratios is that of "false positives." In the above example, as the speech becomes lower in volume, the point will come at which the person hearing the speech will probably be filling in or creating words mentally that were not really heard, due to the strain of hearing. These are called false positives. The words that were heard were not really spoken.

Figure 1 illustrates the concept of signal-to-noise and shows how we are really dealing with a statistical process. The distribution on the left is the signal or what we are attempting to measure (the leak). The distribution on the right is noise (anything that interferes with the measurement of the leak). The more separation we can get among the distributions, the less uncertainty there will be. The uncertainty is the overlap between the distributions. This can be more clearly seen in Figure 2.

Figure 2 is a truth table, and it examines all possible outcomes. Since a leak can either exist or not exist—and the leak detection result can be either true or false—the table shows four possible results. Note that two of the results are true or correct and the other two results are incorrect.

Leak detection system performance is measured in terms of probabilities as follows:

Pd = probability of detection
Pf = probability of false alarm

This leads to the identity

Pd + Pf = 1.0

Figure 1: Leak testing, signal noise and threshold levels

Figure 2: Four possible outcomes from leak testing

These basic concepts were worked out for underground storage tanks more than 10 years ago. The EPA required the probability of leak detection for underground tanks to be at least 95 percent, which results in a probability of false alarm of less than five percent. In this case, the signal or leak threshold was set by EPA to be 0.2 gallons per hour. This meant that for every 100 leak tests on tanks that leak at 0.2 gallons per hour, the leak testing methodology would have to be reliable enough to find or detect 95 of the 100 leaking tanks. (Remember that the probabilities of detection and false alarm change drastically as the leak rate threshold level is changed.)

Sometimes local AHJs attempt to apply these same rules to ASTs, but this is a big mistake. For aboveground tanks, the 95 percent level of performance using the same leak detection thresholds is much harder to achieve, if at all possible.

ASTs have a much larger volume-to-leak rate than that of underground storage tanks. In other words, a leak detection system’s performance is based on the size of a leak, relative to the stored volume (i.e., the bigger the tank, the bigger must be the leak rate detection threshold to maintain the same probability of detection or false alarm). Saying this another way, a tank that is 100 times as large as an underground tank, using the same 95 percent probability of detection, should have the leak detection threshold set to 100 times that of the underground tank, given the same types of leak detection tests.

A small leak in a big tank

Can a very small leak be reliably found in a very large tank? Essentially no. The fundamental problem of leak detection is twofold: (1) to maximize signal-to-noise ratio, and (2) to pick an appropriate threshold signal for which a leak is indicated.

Each test method used has its own peculiar “noise” components. Let’s take an example—volumetric leak detection. This was one type of leak detection described by API in Publication 334 on advanced aboveground tank leak detection methods. The main sources of “noise” in this method are the thermal fluctuations, the product evaporation, instrumentation drift and structural changes that result in changes of measured tank volume.

Contrary to popular belief, large ASTs can develop leaks in a variety of ways at a variety of times

For example, it is not uncommon for liquids to expand several percentage points by volume based on a relatively small temperature change. In a large tank, this could look like a large leak. That is why leak detection vendors and technologies exist. They have figured out how to minimize noise, but cannot totally eliminate it.

Given that there is always noise, the next problem is figuring out how to set a reasonable threshold of detectability that gives a high probability of detection and a low probability of false alarms. The arbitrary requirement that leak detection performance for an aboveground storage tank should be the same as that of an underground storage tank is simply wrong. The performance is less than that of a much smaller underground tank.

As seen from the matrix of possible leak detection outcomes on page 38 (Figure 2), there are two possible errors that can occur resulting from false possible leak detection test results. Either of the two types of erroneous leak detection tests—a false alarm or a missed detection—are serious.

A false alarm results in unnecessary shutdown, cleaning and internal inspection of the tank since the tank was not really leaking. This can cost up to several hundred thousand dollars for just the tank cleaning—not even counting the cost of lost production or capacity due to the tank being out of service. This outcome would probably make the tank owner less likely to rely on leak detection in the future as a deciding factor in repairing suspect tanks.

A missed detection or alarm for a real leak that is undetected by the leak detection system can be bad, and possibly worse, than a false alarm, as the environment can be damaged. Under these conditions, the owner would not take the tank out of service to stop the leak, and the tank would continue to operate, possibly for many years, before the next internal inspection. While the immediate costs to the owner are low, the long-term liabilities could be significant due to the continuing bottom leak.

One company concluded that remediation costs from tank leaks were greater than $100,000 at least 90 percent of the time, and greater than $1 million at least five percent of the time. This does not even take into account the ill will generated when this information is made available to the public and the costs of burdensome regulations that evolve as a result of such leaks.

Causes of leaks

To understand leak detection and prevention, we must understand fundamental mechanisms and causation, including the primary culprit—corrosion.

Corrosion: Corrosion is by far the most aggressive and common cause of tank bottom deterioration and leaks. API Recommended Practices 651[1] and 652[2] address corrosion mechanisms for tank bottoms and are excellent tutorial and resource documents. Here, we will only cover the essential points about corrosion that relate to tank bottoms.

[1]American Petroleum Institute API RP 651 Lining of Aboveground Petroleum Storage Tanks

[2]American Petroleum Institute API RP 652 Cathodic Protection of Aboveground Petroleum Storage Tanks

In the real world, bottom leaks are overwhelmingly more common than shell leaks. It probably goes without saying that leaks from tank roofs are unheard of, except for overfills and seismic activity. Since shell leaks account for practically no leaks or environmental problems, shell corrosion will not be addressed. However, bottom leaks are a significant problem.

Bottoms corrode from both the topside (interior) and the bottom side (exterior). Often, it is the attack from the underside that is of primary concern. Not only is the underside invisible to the inspector during internal inspections, it is often the primary site of bottom deterioration. Let’s examine why.

Corrosion is accelerated by moisture, oxygen and the conductivity of the moisture, which is essentially related to the dissolved salts in the ground moisture. A tank bottom usually has, at some distance in from the outer edge, the worst possible combination of all three elements.

When it rains, there is a great deal of moisture outside the tank, and this moisture is reduced as one moves inward toward the center. At the same time, the oxygen level is at its normal ambient concentration at the outside edge of the tank, but it reduces down as one moves toward the inner part of the tank to essentially anaerobic conditions. Third, the salinity (chemical salts concentrations) may vary radially inward under the tank bottom. What we have is a condition of varying oxygen, salinity and moisture as we move inward. **Figure 3** illustrates this principle.

Most experienced API 653 inspectors say there is a band of pitting that is several feet wide and most severe at usually about 10 to 15 feet in from the edge of the tank. (This, of course, is a generality, and there are many exceptions.)

Also, there is the subject of topside corrosion. Most petroleum tanks have a layer of water that either condenses from the petroleum, comes from rain or is pumped into the tank as a contaminant. This water can be very corrosive because it sits on the bottom for an indefinite period. Crude oil tanks are an example of tanks with severe, interior corrosion from the layers of the water on the bottom. Finished fuel tanks do not usually have severe corrosion as they are often coated to prevent pitting at the bottom.

Figure 3: Typical underside corrosion

Useful tank life: One key point to understand is how the useful tank bottom life is estimated. This estimation is important for leak detection because if the useful life is not calculated correctly, a leak can develop before anticipated. API 653 gives guidance for this (**see Figure 4**). This estimation essentially has a safety factor of 0.1 inch to account for uncertainty in corrosion rates. So if a tank bottom is 0.25 inches thick—less the safety factor of 0.1 inch—we have a permissible working thickness of 0.15 inches.

Although corrosion rates are highly site-specific, an average value of 0.01 inches per year can be used for purposes of discussion. Dividing the working thickness (0.15 inch) by the corrosion rate (0.01 inch per year) gives a lifespan of 15 years. Based on surveys and averages, this is the typical average lifespan of a tank bottom. This can vary, however. And, if any hard decisions are to be made based on corrosion rates, the site-specific corrosion rates must be determined; and these could be substantially different from our example.

API 653 requires, as it should, that this calculation be done site specifically and for each tank. Notice that the calculation includes a safety factor of 0.1 inch, which is substantial. API 653 also gives credit to those tanks that use a thick film liner inside the tank or that use a leak detection system, lowering the safety factor to 0.05 inch.

Figure 4: Determining useful tank bottom life

Difference in life span: The typical cushion or foundation for a single-bottom tank is compacted native soil or sand. A double-bottom tank uses a concrete cushion or spacer. The use of the concrete cushion significantly reduces an underside corrosion attack and is the primary reason that the double bottom has a life approximately 40 percent or more or longer than its single bottom counterpart. The corrosion is reduced due to two major reasons:

• The concrete cushion forms a uniform, alkaline surface, creating a corrosion inhibiting effect.
• The bottom is raised out of the moist or wet areas and can drain more effectively due to its higher elevation and more uniform profile.

Figure 5 shows the details of a double-bottom tank. API calls a barrier, such as the plastic liner shown in the drawing, a “release prevention barrier” (RPB). As far as the details go, a minimum thickness 80 mil polyethylene (HDPE) liner is placed on the old bottom.

Figure 5: Details of a double-bottom tank

Sometimes, a geosynthetic fabric is placed under the liner to protect it from old bottoms, which are rough enough to cut the liner. Next, a spacer is used to separate the new bottom from the old bottom. Some people use sand, but this requires cathodic protection and care in handling the plates.

Chevron uses concrete, which works better than sand. Concrete functions as a corrosion inhibitor, does not rely on a cathodic protection system to work and provides a good hard bottom surface that allows for accurate control of the tank bottom slope. This makes for good water removal, which reduces corrosion, and gives customers a cleaner product. It also serves to speed up and improve construction of the tank bottom.

After the concrete is poured and sloped to the proper point, the new bottom is welded on top of the concrete spacer, just as it would be for a new tank installation. Last, the shell slot is sealed by the proper welding techniques, and the tank is just about as good as new.

Because of the reduced corrosion, the life of the average tank bottom is extended from 25 to more than 35 to 50 years. The average life used here is conservatively, based on refined fuel tankage. It is much shorter than this for other kinds of tanks, and this makes the use of double bottoms even more cogent.

Notice here that we are talking about population average lives, not specific tanks. For example, if you talk about human lifespan variations of different countries you speak of average lifespan. However, you can always find someone from population A whose lifespan is longer than someone in population B. At the same time, you may find many individuals in population B who have outlived those in population A. The basic idea of increased lifespan for tanks using the double bottoms, contrasted with those with single bottoms, is similar to the example above and is illustrated by **Figure 6.** An economic analysis comparing the total cost of ownership of a double bottom versus that of a single bottom shows that the after-tax rate of return on the double bottom tank improves a company's economic position.

Figure 6: Average tank life span

New construction: It is commonly believed that tank leaks only occur after long periods of in-service operation and are due to corrosion. In fact, leaks represent failures of the tank bottom or shell, and can occur at any time. Like electronic components, bottoms and shells are influenced by a failure rate that looks like a bathtub curve. **(See Figure 7.)**

In other words, initial failures can occur when or, soon after, tanks are put into service. Once in service without leaks, the tank will operate for a long time until corrosion holes come through the bottom or shell. Then, the failure rate will start to increase as the age of the tank has reached the point where corrosion is perforating the walls or bottom. This failure rate tends to be a normal distribution, with the "average life" being the peak of the normal distribution curve.

The "infant mortality syndrome" is not just speculation. We have recorded data on our double bottom program with the following results: In the last 49 tank bottoms installed over the last few years, we had at least three suspected leaks. However, only one of them was confirmed as an actual leak and the other two were either self-sealed or a false detection. These "leaks" were all found during hydrostatic testing, and they were all small except for one leak, which was over 0.2 gph.

Figure 7 Infant mortality syndrome "bathtub curve"

Taking all things into consideration, we feel that there is at least a one percent chance that a new tank bottom will leak due to the infant mortality syndrome. These leaks would not necessarily be discovered without a double bottom, because they are too small for detection by any other leak detection method.

Another point to consider is that this one percent applies even in the case in which extraordinary measures have been taken to make a good bottom. Specifically, Chevron has written procedures that attempt to reduce the leakage rate to zero. For instance, Chevron uses two pass welds. (API only requires single pass welds.) Chevron also has procedures that require a vacuum box test to be performed on all bottom welds at least twice. (API only requires a single test.) Chevron requires special provisions be applied to tank bottom weld spacing, fabrication and welding that are not required by API standards.

It is important to realize that most of these leaks occur at a low rate, and because of this they would not be detectable by any means except a double bottom. Whether they are significant environmental degraders, when compared to other kinds of tank leaks and spills, however, is debatable. **Figure 8** depicts some of the reasons that new tank bottoms leak. Note that in this regard, the double bottom has proven to be a superior leak detection system that exceeds the performance capability of those advanced methods currently available for tank leak detection. Such methods include acoustic emission, volumetric measurments or trace gas testing.More will be covered about this in the next article.

Physical trauma: Leaks, spills and environmental damage can result from physical trauma to a tank including sudden impact or deformation. This trauma can be induced by external forces (e.g., wind, earthquake, and snow loads), or internal action (e.g., sinking floating roofs, landing of floating roofs or floating suctions). Many such traumas are possible. Fortunately, in all but the most severe instances, welded steel tanks have sufficient ductility and strength that cracking or rupture is relatively rare.

Since we are focusing on the issues related to leak detection, we will say no more about this topic other than this: a tank built to the requirements of API standards is generally sufficient to prevent problems associated with these kinds of events.

However, if more tank users properly implemented the overfill prevention methodologies outlined in API Standard 2350, the number of tank overfills could be drastically reduced.

Figure 8 Why new tank bottoms sometimes leak

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