

A Guide to Leak Detection for Aboveground Storage Tanks

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- To commit to reduce overall emissions and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.



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Health and Environmental Affairs Department

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FOREWORD

This document is intended to provide the reader with a background in leak detection technologies for aboveground storage tanks in petroleum service. This document was developed by Vista Research, Inc. under the guidance of the API Leak Detection Workgroup and the API Storage Tank Task Force. The document incorporates information on leak detection technologies from API's research and from the experience of workgroup members. While an attempt has been made to discuss the main types of leak detection methods, the reader should recognize that there may be other forms of leak detection not discussed in this publication. The reader should also be cautioned that claims made by leak detection vendors should be carefully evaluated and that API does not endorse any of the leak detection technologies discussed in this publication.

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A Guide to Leak Detection for Aboveground Storage Tanks

Introduction

Aboveground storage tanks (ASTs) are widely used in the U.S. petroleum industry. These tanks are usually clustered in large terminal facilities, and store a variety of products, both crude and refined. The type of AST addressed in this booklet is a vertically oriented cylinder ("shell") constructed of welded or riveted steel plates. It may have a fixed roof or one that floats on the product surface and moves up and down as product is added or withdrawn. The bottom of the AST is in contact with the soil or with a backfill material such as sand or gravel that provides a buffer between the tank and the soil underneath it.

This booklet examines many of the known AST leak detection technologies in their generic forms. Its purpose is to demonstrate not only how to select a workable leak detection method but also how to select the technology that is best suited to a particular application. It is also intended as a tool for understanding the uncertainties associated with advanced leak detection technologies.

One other type of AST leak detection methodology is where specific tank bottom and foundation designs are used. As these undertank leak detection designs are covered in detail in API Standard 650, they are not discussed in this document. This method of leak detection dealing with tank bottom and foundation designs can only be installed at the time of tank construction or during a major renovation. However, the leak detection methods described in this report can typically be installed on most tanks during normal operations.

Leak detection as envisioned in this booklet is a tool that has the potential to supplement the regular internal and external inspections that are standard in the industry. Leak detection in ASTs is also regulated by some state and local authorities. All of the leak detection methods discussed in this booklet can provide results on a periodic basis, and some can accommodate continuous monitoring.

AST owners have three important tasks when implementing a leak detection program: (1) to select a type of leak detection technology or technologies, (2) to select specific systems based on those technologies, and (3) to develop a strategy for using those systems. Managers, operators and engineers are urged to explore a range of options before making these decisions.

WHO SHOULD READ THIS BOOKLET?

This booklet addresses a varied audience: terminal managers, tank owners and operators, and engineers involved in implementing recommendations on leak detection practices.

What can each of these readers expect to gain from this booklet?

- A basic understanding of each of the different technologies that will ensure some level of effectiveness when systems based on these technologies are applied at a given site. Each technology is described in terms of "key features" that effectively constitute a checklist against which comparisons of different systems can be based; "demonstration" techniques for verifying systems on site are also offered.
- An awareness of site-specific characteristics that may affect the performance of a given technology.
- Information on how to select a technology or combination of technologies that best suits the needs of a particular site.
- An improved ability to estimate the impact of testing on facility operations in terms of cost and time.
- Greater confidence in interpreting the results of vendor-supplied evaluations.

A NOTE OF CAUTION

It must be understood that none of the techniques discussed in this booklet will detect a leak without fail 100 percent of the time and that each will occasionally produce false alarms. Furthermore, not all the technologies examined in this booklet have been tested. Claims made by vendors of leak detection services and equipment must be carefully evaluated, and whatever technology is selected must be appropriate for the site where it will be used.

The scope of this report is limited to the description of several leak detection methods. Tank design, liners, cathodic protection, inspection, and operations are described in API Standards 650, 651, 652, 653, and 2610.

The Statistical Nature of the Testing Process

Testing a tank for leaks is an example of the classical statistical problem of finding a signal in a background of noise. A *signal* is a discrete and measurable event produced by a leak, whereas *noise* is any process or phenomenon unrelated to a leak that can mask or be mistaken for the leak.

In this report, the concepts of signal and noise are described qualitatively for each technology. It is recognized that not all AST leak detection methods will have equivalent performance. The out-come of an AST leak detection test depends upon a combination of parameters, including tank design, connections to piping and other tanks, weather, soil or backfill conditions, stored product, and environmental noise. Quantifying the performance of each method with respect to these parameters is beyond the scope of this report. All of the technologies described in

A reliable system must be able to differentiate between signal and noise.

this booklet, however, are considerably more sensitive than the conventional method of handgauging the tank (that is, taking a manual reading with a tape measure).

There are many sources of noise. First of all, noise is generated by the measurement system itself. This is typically referred to as system noise, and it defines the accuracy and precision of the measurement system. In addition, noise is present in the environment in which the measurements are made. This is typically referred to as ambient noise, and it can take many forms depending on the type of measurement being made. Ambient noise may also include that generated by operational practice (for example, the opening and closing of valves or the flow of liquid through pipes connected to the tank).

Leak detection systems, regardless of which technology they are based on, measure a combination of both signal and noise. Reliable detection can only be accomplished when the signal can be distinguished from the noise.

In order to evaluate the effectiveness of a leak detection system, it is first necessary to determine the amount of residual noise. The noise associated with an AST leak detection method is the noise that is measured when there is no leak. A large number of tests must be conducted on one or more non-leaking tanks over a wide range of environmental conditions. This procedure will yield a measure of the noise that can be expected in a typical AST when a given leak detection system is used and, thus, an estimate of the magnitude of the signal (or leak rate) that can be reliably detected above this level of noise. In some cases, measures can be taken to reduce the noise; however, reliable detection usually requires a detailed understanding

of the sources of noise so that ancillary measurements can be used to effectively remove some of the noise from the data collected during a test. The noise left in the data after this removal can be significantly less than the original ambient noise, depending on the effectiveness of the noise removal techniques. In most cases, characterizing the effectiveness of a leak detection system comes down to characterizing the effectiveness of the noise removal techniques.

THE CONCEPT OF PERFORMANCE

The concept of performance as a way to measure the effectiveness or reliability of a leak detection system evolved from research on underground storage tanks (USTs). Although performance measures for AST leak detection are yet to be implemented, many of the same general concepts are expected to be applicable. Performance is defined in terms of the *probability of detection*, or P_d , which is the likelihood that a test will detect a real leak, and the *probability of false alarm*, or P_{fa} , which is the likelihood that a test will declare the presence of a leak when none exists. A related issue is the *probability of missed detection*, or P_{md} , which is the likelihood that a test will not find a leak that does exist.

		Actual Conditions	
		LEAK	NO LEAK
Measurement Indications	LEAK	DETECTION	FALSE ALARM
	NO LEAK	MISSED DETECTION	NO DETECTION

 Correct declaration
 Incorrect declaration

The matrix above shows the possible outcomes of a leak detection test. When the measurements match actual conditions, the result is a correct test decision—either the detection of an actual leak or the confirmation that none exists. If the measurements do not match actual conditions, the test decision is incorrect—either a missed detection or a false alarm. A reliable leak detection system generates tests that have a high probability of detection (or non-detection when there is no leak) and low probabilities of false alarm and missed detection.

DECLARING A LEAK

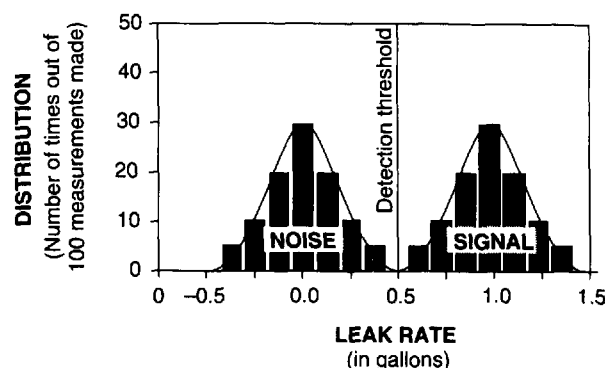
The basis for declaring a leak is the *threshold*. Test results that fall within the threshold are considered noise, whereas those that exceed it are considered indicative of a leak.

The threshold must be set at a value greater than the noise output of the leak detection system and less than the size of the leak that the system will reliably detect. The threshold is thus a value that depends on the amplitudes of the signal and noise as well as the precision of the measurement system.

The threshold is closely linked to the P_d and P_{fa} . If the threshold is too high, the probability of detection drops. If it is too low, the probability of false alarm rises. Selection of an appropriate threshold is therefore very important.

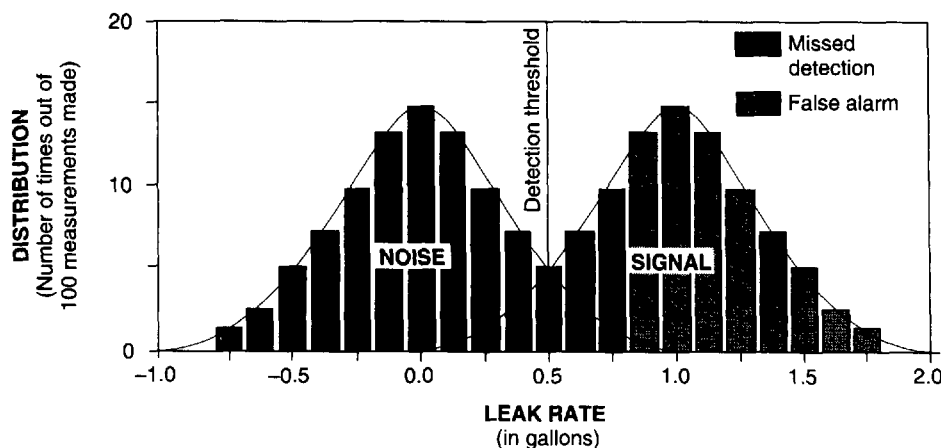
Consider the histogram at the top right of the page, representing an ideal situation in which there is no overlap between signal and noise. It is obvious where to set the threshold.

In reality there is generally some degree of overlap between signal and noise, as shown in the second histogram (below). In this case, the signal is anything over 0.0, but anything from 0.0 to 1.0 might also be noise. If we set the threshold at 0.0, so as to include the entire signal



amplitude, about half of what we detect will be a false alarm. On the other hand, if we set the threshold at 1.0, so as to eliminate all the noise, we will miss approximately half of the signals. Typically we compromise, opting for the minimum possibilities of both missed detection and false alarm. This is best done, in this instance, by setting the threshold at 0.5.

To do a true statistical evaluation of any given system requires a great number of tests conducted under controlled conditions. Since none of the technologies has been evaluated in this way, no numerical values for minimum detectable leak rates, thresholds, or probabilities of detection and false alarm have been established.



Leak Detection Technologies Suitable for Aboveground Storage Tanks

The American Petroleum Institute (API) has examined many leak detection systems either designed specifically for use on ASTs or having potential applicability to them. Internal detection methods (such as volumetric/mass systems, acoustic techniques and inventory control) are those which monitor the contents of the tank, and infer the presence of a leak from changes in the amount of liquid or from pressure fluctuations occurring in this liquid. External detection methods (such as soil-vapor monitoring and chemical markers) monitor the area surrounding the tank for evidence of a leak, in the form of some chemical component of the liquid (either naturally occurring or added specifically for this purpose) that can be detected in the soil.

There are four broad classes of technology suited to ASTs—volumetric/mass, acoustic, soil-vapor monitoring, and inventory control—each represented by many variations on a single measurement concept.

The leak detection systems examined by API, both internal and external, can be divided into four broad classes: volumetric/mass, acoustic, soil-vapor monitoring and inventory control. Each of these is based on a different measurement concept; in each the nature of the signal is different; and each is affected by different sources of noise. Most importantly, there are certain characteristics that are

crucial to each technology in terms of its performance and reliability. Through recent API research, these characteristics—called *key features*—have been identified.

Understanding the differences between the classes of technology, especially in terms of signal and noise, is the key to selecting the most appropriate leak detection system for a given application. When combined with a thorough familiarity with site-specific characteristics, this understanding enables a terminal operator to choose a technology compatible with the prevailing sources of noise, or to choose a combination of technologies wherein one technology offsets the shortcomings of the other.

Equipped with the list of key features for each technology, and with information on how to conduct demonstrations of different types of systems, the terminal operator is better prepared to evaluate the claims made by vendors of leak detection systems.

DEMONSTRATIONS

One way of verifying that a leak detection system works as intended is to conduct a “demonstration” test with that system. In any demonstration test, it is important that certain criteria be met. First, depending on the technology, it may be necessary to confirm tank integrity (although some methods can be successfully demonstrated even in the presence of a leak in the tank bottom or an associated pipeline). Second, it is necessary to generate a leak signal similar to that made by an actual leak. Third, the tank used in the demonstration must be representative of those on which the leak detection system will be used. “Representativeness” is defined by the specific sources of noise that will affect the test. For example, if a floating roof can be a significant source of noise for the type of system to be demonstrated, and the system will be used on tanks with floating roofs, the demonstration should be conducted on a tank with a floating roof. Fourth, other sources of noise typical during an actual test should be present during the demonstration. Finally, it is critical that the protocol used in conducting the demonstration test be the one that is followed during subsequent tests.

A QUICK OVERVIEW

The following charts offer a concise summary of the different technologies, allowing readers to make comparisons at a glance. The first chart displays the general characteristics of each technology, and the second gives their respective key features.

Each technology is described in terms of:

- the nature of the signal this technology seeks;
- the sources of noise affecting measurements;
- the key features that any leak detection system based on this technology should include; and
- demonstration techniques for verifying that a leak detection system works as intended.

Detailed information is available from primary sources listed in this report's bibliography.

General Characteristics of Four Leak Detection Technologies

Measurement Concept	General Characteristics of Four Leak Detection Technologies			
	Volumetric/Mass	Acoustic	Soil-Vapor Monitoring	Inventory Control ¹
	■ Measure changes in the amount of liquid in terms of either level or mass.² ■ Account for normal changes in measured level or mass (those that occur in a non-leaking tank). ■ Interpret any measurement that exceeds the expected range of changes as a leak.	■ Measure the acoustic energy generated by a fluid as it passes through an orifice (a small hole, crack or fissure in the tank). ■ Plot all acoustic "events" on a map of the tank floor. ■ Interpret clusters of acoustic events as the likely location of a leak.	■ Use a compound in the tank that can contact the bottom and migrate through the backfill. ■ Monitor the backfill and the surrounding soil for signs of this "chemical marker." ■ Interpret specific concentrations of the chemical marker found outside the tank as a leak.	■ Keep a detailed record of additions and withdrawals of product over a given period. ■ Over the same period, monitor the level or mass of the liquid.² ■ Compare the two measurements. ■ Interpret any discrepancy between them as a leak.
Signal	A change in volume or mass that exceeds what is expected in a non-leaking tank.	A cluster of acoustic events as "mapped" on the tank floor.	An increase in the concentration of the chemical marker found outside the tank.	A discrepancy between two different kinds of measurements of the amount of product.
Sources of Noise	■ Temperature fluctuations ■ Evaporation and condensation ■ Structural deformation ■ Variable tank geometry (for example, floating roof) ■ Leaking valves	■ Process operations ■ Water layer or sludge ■ Structural deformation ■ Condensation ■ Multiple leaks ■ Floating roof ■ Composition and liquid concentration in backfill ■ Weather (rain or wind) ■ Ambient noise ■ Leaking valves	■ Insufficient target substance within the tank ■ Obtruding compounds that interfere with the detection of the target substance ■ Hydrogeology of the area ■ Natural presence of the chemical marker outside the tank	■ Metering error ■ Tank gauge error ■ Temperature fluctuations ■ Evaporation or condensation ■ Structural deformation ■ Variable tank geometry (for example, floating roof) ■ Leaking valves

Notes:

1. No inventory control methods were tested in the API program.
2. Level is converted to volume by means of the height-to-volume conversion factor (strapping charts). Mass, imputed from the hydrostatic pressure of the column of liquid in the tank, is converted to volume by means of the height-to-volume conversion factor and the specific gravity of the product.



General Characteristics of Four Leak Detection Technologies—continued

Demonstration Methods	Volumetric/Mass		Acoustic		Soil-Vapor Monitoring		Inventory Control	
	Impressed leak		Acoustic leak simulator		Injection of test marker into backfill		Tests on tanks known to be free of leaks	
Operational Requirements	■ Suspend normal operations. ■ Install valve blinds (or make sure that closed valves are leak-tight) ■ Deploy instrumentation if not permanently installed. ■ Adjust product level to a depth between 3 and 5 feet.³ ■ Wait up to 24 hours before starting the test, depending on conditions.		■ Suspend normal operations. ■ Deploy instrumentation if not permanently installed. (Mount accelerometers around the circumference of the tank or submerge hydrophones in the liquid.) ■ Night testing may be preferable. ■ In some cases, restrict transfers of product in adjacent tanks. ■ Wait up to 12 hours before starting test.		■ Install probes in the soil under the tank (a one-time operation). ■ If adding a chemical marker to the product (rather than targeting one of its natural components), make sure a sufficient amount of the substance is distributed. ■ The tank can remain in service throughout the procedure.		■ The tank can remain in service throughout the procedure.	
Total Amount of Time Required	For the procedure tested by API, 48 to 72 hours, including waiting period. Other procedures (not tested by API) report test times as short as 4 hours to one night, but performance may not be the same.		4 to 16 hours.		Anywhere from several hours to several weeks, depending on the permeability of the backfill or soil and the speed at which the target substance propagates through it. (The use of aspiration probes speeds the process.)		Measurements are usually made over a period of several days to several weeks.	
Minimum Instrumentation	<i>For level and temperature systems:</i> ■ A level sensor ■ One or more vertically oriented arrays of temperature sensors <i>For mass measurement systems:</i> ■ A differential pressure sensor ("DP cell") ■ A sensor that measures the temperature of the DP cell ■ A regulated supply of gas (not required for mass balancing)		An array of accelerometers (mounted externally) or an array of hydrophones (suspended in the liquid)		■ Probes installed under the tank. ■ If the aspiration technique is used, a vacuum device to create air flow in the probes. ■ A gas chromatograph, mass spectrometer, or fiber-optic sensor to analyze and sort concentrations of the target vapor in the air that migrates or is aspirated through the probe. (Samples can be sent to a central facility or lab for analysis.)		■ A tank gauge or level sensor to make the primary measurement. ■ Flow meters to measure how much liquid is added to and removed from the tank. (If flow meters are not available, specific measurements made with the level gauge may be substituted.)	

3. Product level adjustment is not required for all techniques. The API test program included a method with product at normal operating height.

