A Guide to Leak Detection for Aboveground Storage Tanks

PUBLICATION 334
FIRST EDITION, MARCH 1996

STEP
Strategies for Today's Environmental Partnership

American Petroleum Institute

STEP
Strategies for Today's
Environmental Partnership

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- 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.

A Guide to Leak Detection for Aboveground Storage Tanks

Health and Environmental Affairs Department

PUBLICATION 334
FIRST EDITION, MARCH 1996

American Petroleum Institute

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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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Suggested revisions are invited and should be submitted to the director of the Health and Environmental Affairs Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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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 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).

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

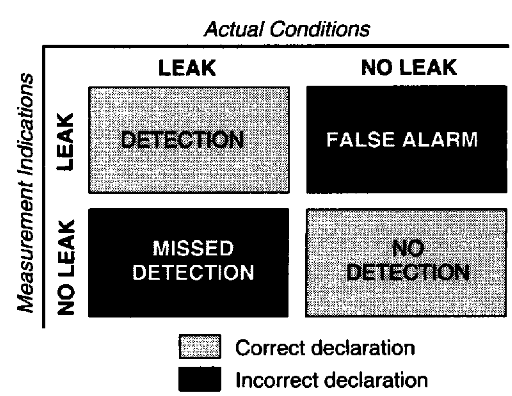
There are many sources of noise. First of all, noise is generated by the measurement system itself. This is typically referred to as system noise, and it defines the accuracy and precision of the measurement system. In addition, noise is present in the environment in which the measurements are made. 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.



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.

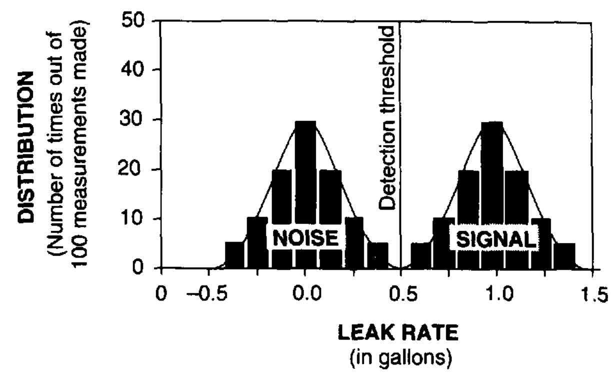
DECLARING A LEAK

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.

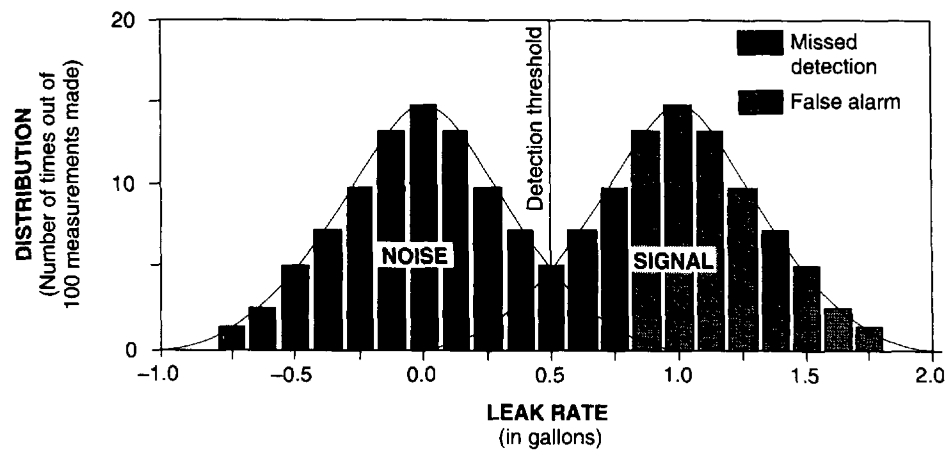
The threshold is closely linked to the P_d and P_{fa}. If the threshold is too high, the probability of detection drops. If it is too low, the probability of false alarm rises. Selection of an appropriate threshold is therefore very important.

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 com-patible 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

	Volumetric/Mass	Acoustic	Soil-Vapor Monitoring	Inventory Control[1]
Measurement Concept	■ 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

	Volumetric/Mass	Acoustic	Soil-Vapor Monitoring	Inventory Control
Demonstration Methods	■ 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	*For level and temperature systems:* ■ A level sensor ■ One or more vertically oriented arrays of temperature sensors *For mass measurement systems:* ■ 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.

Key Features of Four Leak Detection Technologies

Volumetric/Mass	Acoustic	Soil-Vapor Monitoring	Inventory Control
■ Pre-test waiting period ■ Low product level* ■ Long test duration* ■ Test begins and ends at night* ■ External sensors to monitor temperature of tank shell* ■ Known coefficient of thermal expansion of the tank shell ■ Sufficiently precise instrumentation ■ Compensation for thermally induced noise ■ Floating roof not in contact with product* *Additional features for level and temperature systems only:* ■ Internal sensors mounted on a stand resting on the bottom of the tank (not suspended from top of tank)* ■ Internal sensors spaced at vertical intervals of no more than 8 inches ■ Known coefficient of thermal expansion of the product ■ Internal sensors to monitor temperature of product ■ Digital data collection ■ Sampling rate less than 10 minutes ■ Known height-to-volume factor for the tank (strapping table) *Additional features for mass measurement systems only:* ■ Compensation for thermal sensitivity of the instrumentation ■ Known specific gravity of product ■ Pressure measurement made near bottom of tank	■ Digital time series* ■ High data collection threshold* ■ Multipath discrimination ■ Time registration of acoustic events ■ Close spacing of transducers ■ Averaging of data ■ Known signal velocity with regard to the particular product in the tank ■ Known speed of sound in water and sludge layers ■ Backfill must contain air and not be liquid-saturated ■ Pre-test waiting period ■ Presence and extent of sludge layers characterized	■ Backfill is compatible with target substance (substance can propagate easily through backfill) ■ Optimum number of probes ■ Water layer is drained or target substance can penetrate water ■ Background levels of target substance are low	■ Long reconciliation period ■ Frequent measurements of product level ■ Well calibrated instrumentation ■ Accurate calculations

Note: Features marked with an asterisk are not required for all techniques. Those tested by API, however, showed the best results when these features were incorporated.

Volumetric/Mass Technology

Volumetric and mass measurement systems, which are the most commonly used methods of detecting leaks from underground storage tanks, are also applicable to above-ground tanks. The measurement concept is simple. Using suitably precise sensors, these systems quantify the amount of liquid in the tank, the former in terms of level and the latter in terms of mass. If, over a given period of time, this amount decreases, the loss of product is attributed to a leak. For a volumetric/mass test to be accurate and reliable, however, care must be taken to either eliminate or account for any real or apparent changes in volume/mass that are a normal and ongoing part of the tank's dynamics and that as such are unrelated to the changes caused by the leak.

THE NATURE OF THE SIGNAL

When a tank is leaking, the amount of product it contains decreases with time. This is the *signal.* The magnitude of the signal is affected primarily by two variables. One is the depth of product in the tank, which is directly responsible for the head pressure brought to bear on any hole, crack or fissure that might be present. At a given head pressure, the rate of leakage does not change as long as the size of the hole remains the same. As pressure mounts, however, the rate of leakage increases even if the hole size remains the same; the greater the amount of pressure exerted by the fluid against the hole, the faster the rate at which it will escape. In addition, cracks or holes may close as pressure increases. The second variable, then, is the size and shape of the hole. The larger the opening, the less pressure is required to force liquid through it. The shape of the opening—smooth or jagged—determines whether the flow is laminar or turbulent, which can influence the way the leak varies with pressure.

The *ambient noise* consists of temperature-induced fluctuations that can cause the appearance of a change in the amount of product. In volumetric/mass testing, the noise is the sum of the apparent changes in the amount of product in the tank that could be confused with the signal (that is, those changes measured during the course of a test that are not related to the leak). In order for a volumetric or mass test to achieve high performance, it must employ a protocol designed to minimize noise during the data collection portion of the test, or it must use an algorithm that systematically compensates for this noise during the data analysis portion of the test.

Volumetric/mass technology encompasses several different types of systems. Each represents a different way of measuring the signal (which for all these systems is the decrease in the amount of product).

- Volumetric level-and-temperature measurement systems. Using precise sensors, these systems measure the level of liquid in the tank being tested. Because thermal expansion of the product can cause significant changes in level, these systems also employ sensors to monitor the temperature of the liquid. If, during the test period, the volume decreases despite the fact that normally occurring (that is, thermally induced) volume changes have been accounted for, the loss of product is attributed to a leak.

- Mass measurement systems. These systems measure the amount of pressure exerted by the product in the tank. In this way, a large percentage of the noise due to temperature changes in the product is eliminated. (With a level-and-temperature measurement system, these changes must be taken into account.) Mass measurement systems may use a differential-pressure sensor to compare the pressure differential between two readings of the hydrostatic pressure. Gas is passed at a constant rate through a tube immersed in the product. The gas pressure must be high enough to overcome the hydrostatic head exerted by the product against the base of the tube; the back pressure in the tube therefore acts as a measure of the hydrostatic head.

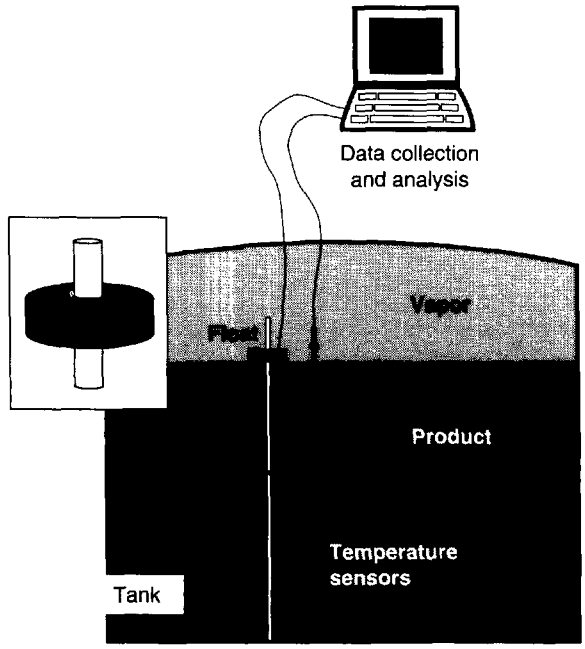
- Mass balancing systems. In mass balancing systems, a differential-pressure sensor measures the difference in head pressure between the product in the tank and a column of product of equal hydrostatic height contained in a vertical tube outside the tank. These mass balancing systems were not studied by API.

- Water-layer monitoring systems. Water-layer monitoring systems measure changes in the amount of the water that may be present at the bottom of the tank. Because water is generally immiscible with the product, it can be measured as a separate entity. These

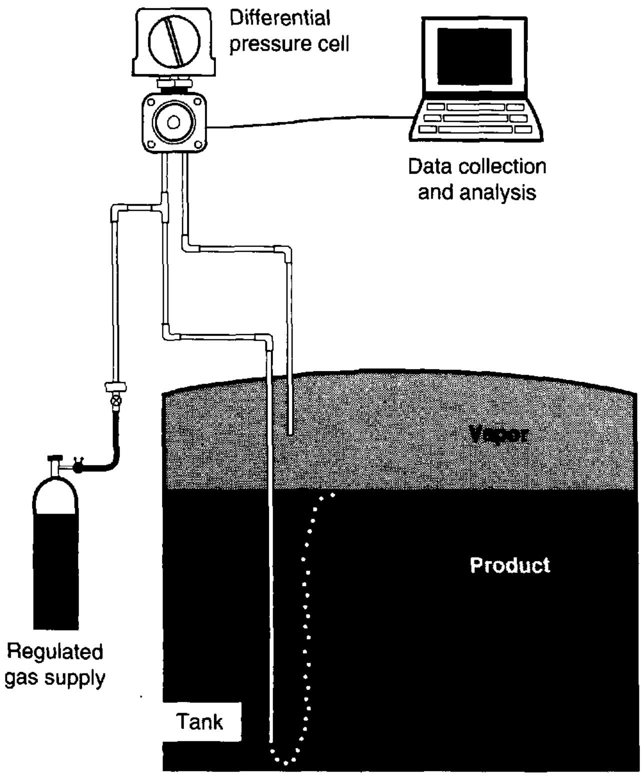
VOLUMETRIC/MASS TECHNOLOGY IN A NUTSHELL

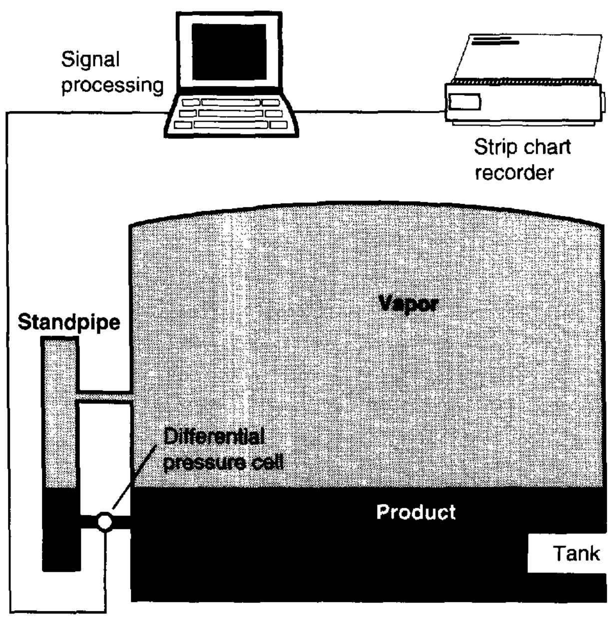
- Measure changes in the amount of product in the tank
- Factor in the changes that normally occur in a non-leaking tank
- Interpret anything beyond the expected changes as a leak

Upper right: an example of a **volumetric level-and-temperature measurement system.** This system monitors the level of product by using a donut-shaped float that rides up and down on the surface of the product along a guide rod. Wires connect the float to a computer. Meanwhile, temperature sensors monitor the horizontal and vertical extent of the product. Data from the temperature sensors are also transmitted.



Left: an example of a **mass measurement system.** This "bubbler" system forces gas into a tube whose outlet is at the bottom of the tank and also into a second (or reference) tube whose outlet is in the vapor space. The differential pressure cell measures the amount of pressure necessary to force air through the tubes, and these readings are input to a computer for analysis. The pressure necessary to force the gas through the tubes is proportional to the pressure exerted by the amount of fluid in the tank, and so can serve as a measure of that fluid. This system is similar to the one used in the API program.





Lower right: an example of a **mass balancing system.** This system compares the hydrostatic pressure in the tank to that in a reference standpipe. The initial level of liquid is the same in both the tank and the standpipe. Any pressure differential between the two is an indication of a leak.

systems have not been studied experimentally in previous API work. The potential advantage of measuring the water layer rather than the product is that the volume of water is small and noise is therefore minimized; at the same time, because product level can be high—and higher pressures induce higher leak rates—the signal is stronger.

SOURCES OF NOISE

All of the above types of systems are subject to the effects of noise. The most important source of noise in a volumetric/mass test on an AST is *temperature.* Because all surfaces of an AST except the floor are exposed to the air, diurnal cycles play a significant role in inducing temperature changes in both the shell and the product. Highs and lows in ambient air temperature, precipitation, and the periodic passage of clouds all can produce measurable effects. Changes in temperature that occur during a test create noise in a number of different ways and thus affect different test methods in different ways. Temperature changes in the product that cause it to expand or contract are perhaps the largest source of noise for level-and-temperature measurement systems.

Major sources of noise in a volumetric/mass test on an AST are:
- ***temperature***
- ***evaporation or condensation***
- ***structural deformation***
- ***floating roof***
- ***leaking valves***

Mass measurement and mass balancing systems are much less susceptible to this source of noise because even as product expands due to an increase in temperature, and level rises, the density of the product decreases, and the head pressure remains constant. Only the thermal expansion of the product below the bubbler tube (the "thermal lift") has an effect on measured mass. For mass systems, the most pronounced source of thermal noise is in the measurement system itself. Differential pressure sensors are very sensitive to temperature changes. Changes in the temperature of the gas bubbler system may also be a source of noise.

Thermal expansion or contraction of the tank shell has a similar effect on all the volumetric/mass measurement systems discussed here. As the tank shell warms or cools, it expands or contracts, changing the diameter of the tank and the level of the product inside it. Because of the nature of this expansion, its effect on test results increases dramatically as the monitored product level increases. Regardless of which type of volumetric/mass system is used, it is important to incorporate temperature compensation routines. The level-and-temperature system tested in the API program showed improved results when product level was low (3 to 5 feet).

Another source of noise is structural deformation of the tank, which occurs in response to the physical pressure exerted by the product. Since a change in product level affects the hydrostatic pressure against the tank floor and walls, product additions and withdrawals (and, to a lesser extent, expansion and contraction of the product) can induce time-dependent structural displacements. The floor deflects downward and the walls bulge outward. The degree of deformation is strongly influenced by the composition of the soil and backfill under the tank floor, with more rigid backfills tending to inhibit displacement of the floor. This kind of deformation is most obvious when product is added or withdrawn just prior to testing. It may continue for many hours. Unlike the thermally induced structural changes described above, the volume changes associated with structural deformation generally decrease with time after the level change, and the noise associated with this phenomenon can be eliminated through the use of waiting periods that allow it to dissipate on its own.

Evaporation and condensation are also sources of noise. The former represents the physical removal of a portion of liquid from the product surface and the latter the return of this liquid. The two are not always in equilibrium. As vapor rises, it can cling to the underside of the roof and to that portion of the walls above the liquid level and it can exit the tank through vents. Vapor clinging to the inside of the tank can then condense and drip back into the extant product. Whatever has been lost through the vents, however, does not return as condensate. Evaporation and condensation are dependent on several external factors, including the pressure and temperature of the vapor, the temperature of the liquid, the surface area of the liquid, and barometric pressure. Higher pressures are generally associated with higher loss rates. Efforts should be made to control these losses, since they are difficult to measure and can easily mask or be confused with a leak.

A tank that has a floating roof may develop vapor pockets (air that becomes trapped between the roof and the surface of the product). Vapor pockets are subject to the influence of both temperature and atmospheric pressure, either of which can cause the volume of trapped air to expand or contract. This results in corresponding changes in the liquid level at the gauging port. These changes, however, are generally so small that vapor pockets can usually be ignored. In volumetric/mass tests, the fact that the roof is resting on the surface presents a much bigger problem than the vapor pockets themselves.

A floating roof resting on the product surface tends to degrade test results, regardless of the type of system used (level and temperature or mass measurement). The roof moves up and down freely along with the product, but only up to a certain point. As the rate of expansion or contraction of the product slows, the frictional forces acting on the roof seals cause the roof to stop moving before the product has stopped expanding or contracting. When the roof stops moving, expanding product is forced into the area around the edge of the roof and into roof openings. Since this area represents only about ten percent of the total surface area of the product, the level changes in the tank are 10 times greater when the roof stops moving than when it is free-floating. This can mean dramatic changes in the height-to-volume ratio over the course of a test and, consequently, significant errors in the test result. In addition, external forces such as wind and rain can affect the way in which the roof interacts with the surface of the product. The way to avoid this kind of noise is to not conduct a test while the roof is in contact with the product. The roof should be propped up on legs, and the level of product should be lowered so that its surface is no longer in contact with the roof. In spite of this potential problem, there are methods (not examined by API) that do conduct tests with floating roofs resting on the product.

Finally, there is the problem of leaking valves. When a valve does not seal tightly, liquid can pass through. Since volumetric/mass systems are looking for a decrease in the amount of product, the escape of liquid through leaking valves can be a source of noise. Valves should be checked prior to testing. Unless it is known with certainty that the valves are tight, valve blinds should be installed.

KEY FEATURES

The features of a volumetric/mass test that are crucial to high performance have been identified as part of a recent research effort by API. Either type of technique level and temperature or mass measurement can be implemented with commercially available measurement systems. The way these systems are used, however, determines the success or failure of the test.

Some of the features listed below can be classified as protocol measures; others are related to instrumentation, data collection and data analysis. Features that are important for both level and temperature and mass measurement systems are listed first.

- Pre-test waiting period. Before the start of the test, it is recommended that a waiting period of up to 24 hours be observed, during which no product is added to or removed from the tank. This allows inhomogeneities in the product to dissipate (level-and-temperature systems will be affected by thermal inhomogeneities, while mass measurement systems will be affected by inhomogeneities in product density) and any deformation of the tank shell to subside.

- Low product level. The level-and-temperature system tested by API experienced reduced noise at low product levels (3 to 5 feet). As the product level is lowered, however, the leak rate, and therefore the signal, decreases. Mass measurement and other level-and-temperature systems may be employed at normal operating heights. The product level should be adjusted so that the signal-to-noise ratio is optimized. For water-layer monitoring systems, no experimental verification has been made of the optimum level for either the product or the water layer.

- Long test duration. A test has two parts: the data collection period (typically called the "test duration") and the data analysis period. The data collection period of the API-tested volumetric leak detection method is at least 24 hours long and preferably 48 hours. Using multiples of a diurnal cycle (24, 48 or 72 hours) effectively averages out any residual noise that stems from daytime heating and nighttime cooling. Methods not evaluated by API have reported test times as short as one night to four hours.

- Test at night. For the best performance, a test should begin and end at night, when there are no large changes in ambient air temperature and no uneven solar heating of the tank shell. This is equally important for level-and-temperature systems and mass measurement systems, since both are affected by expansion and contraction of the tank shell and by evaporation and condensation of product. There are also different reasons for testing at night that are particular to each approach. A level-and-temperature system is viable since horizontal gradients in the rate of change of product temperature are sufficiently small at night to permit an accurate test. The constant rate of change of ambient air temperature is at night permits more accurate compensation for the thermally sensitive differential-pressure sensor used in a mass measurement system.

- Digital data collection. The data should be collected in digital rather than analog format. Leak detection systems that collect data digitally can take advantage of more sophisticated noise cancellation techniques and analysis algorithms.

- Sampling rate. Digital measurements should be made at intervals of 10 minutes or less.

- External temperature sensors. Some techniques may include an array of sensors mounted on the tank's exterior to compensate for thermally induced changes in the tank shell. These sensors should be mounted on the steel outer wall of the tank, at evenly spaced intervals around its perimeter, and should be shaded from direct sunlight.

- Height-to-volume conversion factor. The factor required for conversion of level or mass changes to volume changes should be known beforehand or should be measured as part of the test. The height-to-volume conversion factor must remain constant during the test; if it does not, the change must be noted and compensated for in the data analysis. Errors in this factor will produce a bias in the test results. It is usually satisfactory to obtain the height-to-volume conversion factor from the tank dimensions or the tank strapping table.

- Known coefficient of thermal expansion of the tank shell. This is the value used to adjust the height-to-volume coefficient, which in turn is used in compensating for thermal changes in the tank shell.

- Sufficiently precise instrumentation. The combined precision of the instrumentation used to measure the rate of change of the thermally compensated volume must be sufficient to sense a leak approximately one-third the size of the smallest leak that can be reliably detected by a test.

- Compensation for thermally induced changes in tank dimension. Accuracy is improved if all thermally induced changes in tank diameter are compensated for in the data analysis. (In methods examined by API, the impact of such changes can also be minimized through the use of a longer test.) Because the leak signal does not have a diurnal period, any diurnal fluctuations remaining in the compensated data are indicative of an error somewhere in the data analysis.

Additional features that are important for high performance and that are particular to level-and-temperature measurement systems are listed below.

- Mounting of sensors. In the method tested by API, the level sensors were mounted on a stand at the bottom of the tank rather than suspended from the top or attached to the sides of the tank. This was done in order to minimize sensor motion due to thermal expansion and contraction of the sensor mounting structure.

- Spacing of sensors. For adequate thermal compensation, the product must be sampled both radially and vertically. An array of temperature sensors with the best precision available (typically 0.001°C) is required. The method tested by API had a vertical spacing between sensors that was no greater than 8 inches. Since most of the temperature changes occur in the upper portion of the product, and strong gradients are present in the lower portion, these two areas warrant more dense sensor spacing (approximately every 4 inches). Increasing the number of vertical sensors should improve test results. Some horizontal sampling of temperature is important, but the maximum horizontal spacing of sensors has not been determined.

- Product's coefficient of thermal expansion. The product's coefficient of thermal expansion must be known or must be measured as part of the test. An error in this coefficient will produce a bias in the test result.

Additional features that are important for high performance and that are particular to mass measurement systems are listed below.

- Compensation for the thermal sensitivity of the instrumentation. Since the primary measurement device, the differential-pressure sensor, is itself subject to the influence of temperature, it can contribute to the noise field. The thermal sensitivity of the DP cell, therefore, must be minimized. Horizontal orientation of the tubes that connect the DP cell to the tank seems to minimize thermal problems, so it is essential that these tubes be installed horizontally. In addition, any air trapped in the tubes and in the DP cell must be purged. It may also be necessary to mount sensors on the body of the DP cell and on the tubes to compensate for changes in ambient air temperature.

- Known specific gravity of product. This value is used to convert pressure measurements to height measurements. Prior knowledge of the specific gravity of the product is required, unless an accurate experimental estimate of the height-to-volume conversion factor has been made as part of the test.

- Pressure measurements made near bottom of tank. The bottom end of the tube should be as close as possible to the bottom of the tank when making pressure measurements. When measurements are made more than a few inches from the tank bottom, the expansion and contraction of the product below the measurement point must be considered. Similarly, the temperature of the product in that part of the tank must be measured and thermal changes taken into account.

DEMONSTRATIONS

The goal of a demonstration test of volumetric/mass technology is to assess the error in the measured flow rate. This can be done under any flow-rate condition while there is no flow, while product is being continuously withdrawn, or even while product is being continuously added as long as the flow rate is known and remains constant during the test. It is important to understand that in a volumetric/mass test the signal is the rate of change of volume rather just a change of volume. If a flow rate is induced as part of the demonstration, it must be continuous throughout the test. At the conclusion of the test, the reported flow rate can be compared to the actual flow rate, and thus the measurement error for that test can be established. This analysis is modified slightly when the object is simply to assess tightness rather than measure leak rate.

Because the primary source of noise in volumetric/mass tests is temperature, weather conditions can play a role in the accuracy of a test. Ideally, weather conditions should be the same during subsequent tests as they are during the demonstration test. Since this is not usually practical, the demonstration can be planned for a time when weather conditions are severe (that is, when the difference between the daily high and low is at a maximum). It can then be assumed that any subsequent tests will be conducted under more benign conditions and that the results will be at least as good as the one obtained in the demonstration.

Finally, it should be noted that the error measured in a demonstration test is merely a single sample of a statistically random error. It is not necessarily the maximum error, minimum error, or even typical (or average) error that can be expected to occur in future tests. It can, however, be used to lend credence to a vendor's performance claims. Thus, a single demonstration test that shows an error greater than the vendor's claimed accuracy does not necessarily invalidate that claim.

Acoustic Technology

Acoustic technology is based on the principle that liquid escaping through a hole or fissure in an AST produces a sound that is detectable. In fact, it has been shown that a leak in the floor of an AST actually produces two different types of sound simultaneously. One type, the "continuous" sound, is similar to the hissing noise that might be expected when liquid escapes from a container under pressure. This sound is created by a combination of turbulent flow through the leak aperture and particulate collisions with the tank floor. The second type is an intermittent popping sound that extends beyond the audible frequency range. Known as "impulsive" sound, it is created by the interaction between the flow field of the leak and air bubbles trapped in the backfill material below the AST floor. Targeting impulsive sound as the desired signal offers a number of advantages. It is the impulsive component that a passive acoustic system tries to detect; the continuous signal, even though its source is the leak itself, is considered noise.

Acoustic systems operate on the principle of detection by location: the basis for identifying a leak is the point of origin of the signal.

The Nature of the Signal

The *signal* in a passive acoustic test, then, is the popping sound associated with the interaction between the flow of liquid through a hole and into the backfill material below the AST floor and air bubbles trapped in this backfill material. Unlike the case in a volumetric test, the magnitude of the impulsive signal may not increase with the size of the leak. (The API program has not fully characterized this phenomenon, since it occurred in tests that were limited to tanks containing water in sludge-free environments. Tests on tanks containing product did not include any bottom leaks.) On the other hand, the frequency of the impulsive signal depends on the backfill material. Very porous backfills that trap a lot of air tend to generate this signal more frequently than less porous backfills. A well-drained sand backfill, for example, may generate many impulsive signals per minute, while a more clay-like backfill may generate only a few over a five-minute period. As the backfill material becomes saturated, either with water or product, to the point where its air content is significantly decreased, the rate of impulsive signals may be reduced completely. Moreover, the API program did not assess the impact of bottom corrosion, liners or sludge on the signal generation mechanism. The extent to which sludge and saturated backfills influence the leak signal in an AST has not been determined.

The *noise* against which the signal must be detected includes many of the common sounds at AST terminals: truck traffic, pump noise and wind, among others. Many of these can be eliminated through the use of electronic filters in the data collection system. If the noise is very loud, however, or very close to the tank being tested, filtering will not suffice and more active noise reduction measures must be taken. Transfers of product into and out of the tank, for example, must be suspended during the course of a test. It may even be necessary to cease operations in adjacent tanks. High wind conditions can also be a problem; sand, rocks and other debris being blown against the side of the tank create high noise levels that can make the signal difficult or impossible to detect. For the most part, noise such as this can be avoided by testing during "quiet" periods.

There are other sources of noise, however, that cannot be eliminated and that, instead, must be accounted for during the analysis of the acoustic data collected during the test. This type of noise includes the condensation of liquid within the tank and the mechanical motion of structures associated with the tank, such as the deployment of a sample bucket or the up-and-down movement of a floating roof. Condensate often accumulates on the underside of the AST's roof. The sound created by a drop of condensate falling onto the product surface is very much like the impulsive signal generated by a leak. The most straightforward way of distinguishing one from the other is to estimate where the sound comes from. A sound originating at the product surface is most likely to be due to condensation, whereas one originating at the tank floor is not likely to be the result of condensation and can probably be attributed to a leak. The sounds produced by the motion of tank structures can be differentiated from the leak signal in much the same way—on the basis of their point of origin.

Acoustic Technology in a Nutshell

- Record the arrival times of an impulsive signal at the transducer over a period of time
- Input arrival times into an algorithm that predicts the most likely origin of the signal
- Plot these on a map of the tank floor
- Interpret clusters of acoustic events as indicative of a leak (as well as of its location)

For this reason, acoustic systems are said to operate on the principle of detection by location. A signal is identified as being due to a leak only if it comes from the tank floor. The test decision (that a leak is or is not present) is based on whether acoustic signals consistent with those produced by a leak are being emitted from one or more locations on the tank floor. Additional information such as the strength, duration, propagation mode, and spectral character of the signal may be used to reject other sources of impulsive noise. The typical output of a passive acoustic system is a map on which the measured location of each acoustic event originating from the AST floor is plotted.

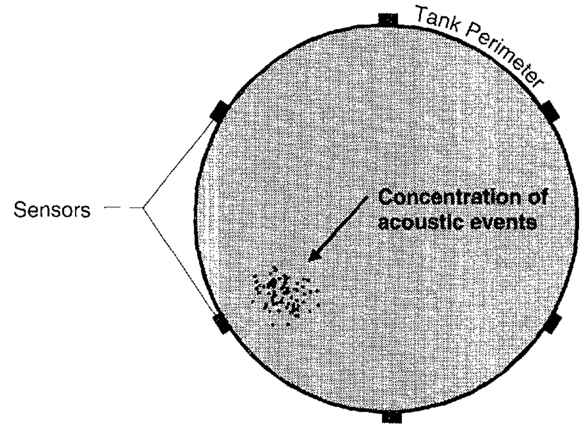
Complicating matters is the fact that each impulsive signal produces echoes. Thus, impulsive sound consists of both a direct signal, which is the wave that originates at the source of the leak (or noise) and travels through the liquid until it makes contact with a sensor, and multipath signals, which are echoes of the original as it bounces off other objects in the tank. (Signals can be reflected, for example, from the walls or other appurtenances in the tank, or from the liquid surface.) Multipath signals, or echoes, are differentiated from the direct signal through their arrival times at the sensor.

The type of sensor used in acoustic testing is a transducer—a device that converts the energy from a sound wave into an electrical signal. Two kinds of transducers are suitable for passive acoustic testing. The first, an accelerometer that is mounted along the outer wall of the tank, has the advantage of being non-intrusive. This can be a highly desirable feature. Non-intrusive methods are easier and less expensive to implement, are easily accessible in case of malfunction, and eliminate the need for contact with a product that may be classified as a hazardous substance. The other type of transducer is a hydrophone that is submerged in the liquid. In both cases an array of transducers is used; accelerometers are positioned at evenly spaced intervals around the circumference of the tank or in clusters along its side, and hydrophones are suspended from the roof of the AST. With either sensor, a test can be conducted in about four hours, so that disruption of normal operations is minimal. Both accelerometers and hydrophones listen for pressure fluctuations that might be caused by a leak through a hole at the bottom of the tank.

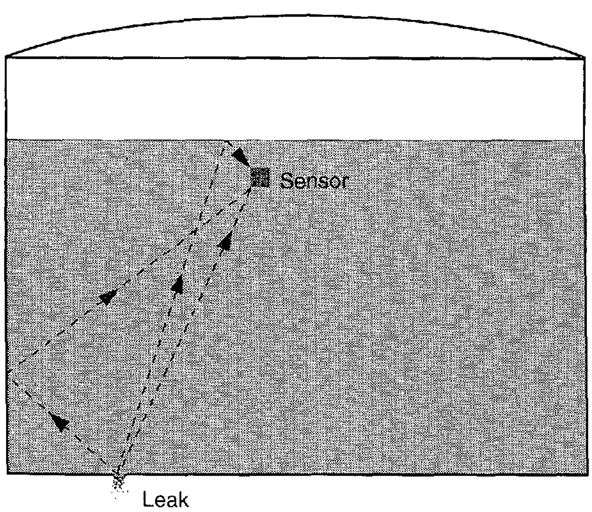
The pressure waves produced at the site of the hole travel outward in a spherical configuration. Each time an impulsive signal emanates from its point of origin, it travels a certain distance, at a known speed over time, before it makes contact with obstacles in its path. When it reaches the sensor, its time of arrival is recorded. Reflections of this signal from other objects will also reach the sensor, but usually with some measurable, if slight, delay. Over a period of time a number of such "acoustic events" are recorded.

The arrival times of each event are fed into an algorithm that predicts the most likely origin of the events, each represented by a single point. All these points are then plotted on a map of the tank floor. Clusters of acoustic events are interpreted as being indicative of a leak. (This process, by its nature, indicates not only the existence of a leak but its location as well.)

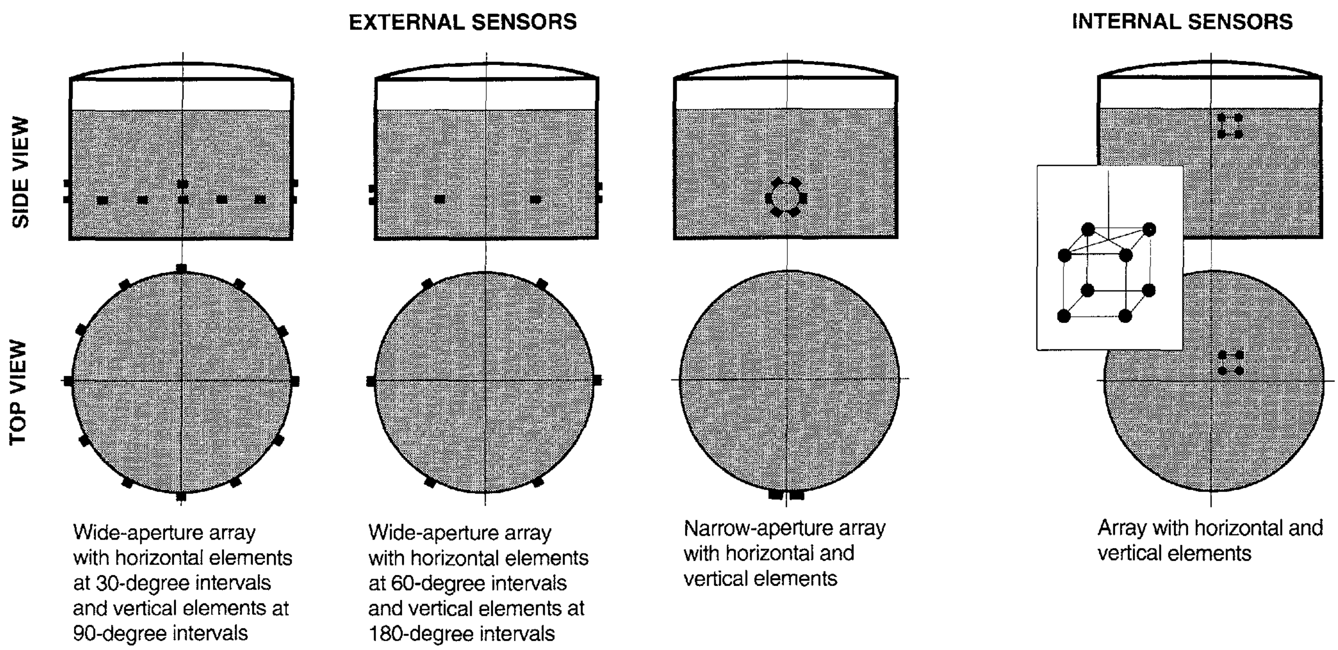
The echo, if undifferentiated from the direct signal, causes errors in the location estimate. These errors are a



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 acoustic transducer picks up multipath signals from the same source. The direct signal is the one that propagates from the hole to the sensor, but echoes of this signal are reflected from the wall of the tank and from the surface of the product. The arrival time of each echo may be slightly different.



source of noise in that they complicate the map, making it more difficult to distinguish clusters of events.

Errors in the location estimate can also be caused by a phenomenon called impulse mixing, which is attributable in part to the standard on/off approach to data collection. Impulse mixing refers to the improper time registration of the data being collected to detect large-amplitude signals. It occurs when the impulsive signal generated by a leak at any point in time and received by one transducer in the array is not the same impulsive signal that is received at one or more of the other transducers. Many types of mixed impulses can occur. Signals from the same leak or from two or more leaks may mix; the direct signal may mix with its multipath echoes; an impulsive signal can mix with external noise; or the noise alone can produce mixed signals. Optimal sensor spacing is one way to address the problem of impulse mixing. Narrow-aperture arrays (those with more closely spaced sensors) and arrays that cover the vertical dimension of the product as well as the horizontal are helpful in minimizing the problem. Adequate data collection and signal processing techniques are also important.

SOURCES OF NOISE

One of the common sources of noise in an acoustic test on an AST is process operations. In the course of normal operations any of a number of phenomena occur on a regular basis. Product flows through the valves, fittings and pipelines connected to the tank. The rate of flow, the number of appurtenances, and the machinery providing the motive force all can influence the amount of noise. An obvious way to minimize the contribution of this type of noise is to cease operations in the tank and in the vicinity of the tank while a test is in progress.

The major sources of noise in an acoustic test on an AST are:
- ***process operations***
- ***structural deformation of the tank due to hydrostatic pressure***
- ***evaporation and condensation***
- ***floating roof***

Another contributor to the noise field is structural deformation of the tank due to changes in hydrostatic pressure. As the product expands (whether due to the addition of new product or as a result of a warming thermal trend) the walls bulge outward and the bottom deflects downward. The opposite happens when the product contracts. Discrete acoustic events arise in response to these phenomena. The preferred approach to dealing with the problem is to wait for structural deformation to subside.

Depending on the type of roof, condensation can be a source of noise. In a tank with a floating roof, which rests on the surface of the product, condensation is not a major problem. In a tank with a fixed roof, however, condensate forms along the exposed interior surfaces (walls and roof). This condensate may slide back down into the extant product along the walls or it may drip from various spots along the underside of the roof. The acoustic frequencies generated by droplets falling onto the surface of the product are similar to those created by the impulsive signal generated by a leak. The way to discriminate between the two is by their location.

Finally, there is the matter of the floating roof. Localized slippage sometimes occurs at points of contact between the tank wall and the perimeter of the floating roof. Impulsive noise emitted by this phenomenon can be erroneously "mapped" into the interior of the AST. That is, a passive acoustic leak detection system may interpret the impulsive noise caused by slippage as the impulsive signal it is looking for. Again, location is the key to differentiating impulsive noise due to slippage from that due to a leak.

Impulsive signals from multiple leaks may add to the complexity of the data analysis. Since the assessment of multiple leaks was beyond the scope of the API program, it was not determined whether this condition could lead to a missed detection.

Rain, wind conditions, plant activity, and vehicular traffic are known to increase acoustic noise. To minimize interference from these sources of noise, it may be necessary to adjust the test schedule. For this reason, several of the tests during the API evaluation were conducted at night.

KEY FEATURES

The features of an acoustic test that are crucial to high performance have been identified as part of a recent research effort by API. The instrumentation used in testing must be capable of detecting the impulsive acoustic signal generated by a leak. Off-the-shelf, frequency-selective transducers appear to be more than adequate for this purpose. For acoustic systems to achieve high performance, however, it is necessary to formulate data collection and signal processing algorithms that will detect this type of signal. The general features of such algorithms are described below.

- Digital time series. The use of digital time series in the data collection was shown, in the API program, to be of potential benefit by reducing the effects of extraneous noise in the data analysis. In the tests conducted as part of this API program, the noise was significantly reduced through the use of digital time series. Nevertheless, conventional methods—although containing more noise—yielded the same test decision in each case. Digital time series of the raw acoustic waveform from each sensor should be made available for the data analysis. Although it would be desirable to collect continuous time histories, this would not be practical, since the quantity of data collected during a normal test is prohibitively large. Continuous time histories are not essential provided that each time series is long enough that the leading edge of the direct signal can be identified, even in the presence of multiple events, multipath reflections, and impulsive acoustic noise. If the duration of a time series is defined as the time it takes for an acoustic signal propagating through the product to travel a distance equal to the diameter of the tank, we can express the duration of the time series in terms of diameter. The time series should be six diameters in duration, four of them prior to the acoustic event that triggers the data acquisition process and two of them after this event.

- High data collection threshold. For the method developed during the API program, a high threshold value for triggering the data collection was the best way to detect the impulsive acoustic signal produced by a leak and to minimize false alarms due to noise fluctuations. A high threshold is practical in acoustic testing because of the high signal-to-noise ratio associated with the impulsive signal.

- Multipath discrimination. The strongest acoustic returns tend to be multipath signals, a fact that may confuse conventional analysis algorithms. A critical requirement for high performance, therefore, is the implementation of an algorithm that distinguishes multipath reflections from the direct signal.

- Time registration of events. The algorithm, whose function is to predict the most likely origin of the signal, must be implemented in such a way that the returns from discrete acoustic events are isolated. This is the best way to ensure that the direct signal is properly time-registered and that no impulse mixing occurs.

- Sensor spacing. Close spacing of the transducers improves the leak detection system's ability to time-register discrete events and to discriminate between direct and multipath signals. As the aperture of the sensor array decreases, however, so does the accuracy of the leak location estimates. The optimal sensor configuration should address both accurate location estimates and proper registration of impulsive events. In order for the algorithm to discriminate between signals originating at the floor of the AST and those originating at the product surface, the array must include at least one sensor that is separated from the others along a vertical plane.

- Averaging. Averaging the data reduces noise and enhances the signal. In both data collection and data analysis, the approach should be to select high-quality events and average them.

- Signal velocity. Since acoustic measurements are highly dependent on characterizations based on time, it is crucial to know the speed at which the acoustic signal propagates through the particular product in the tank. Signal velocity through a given product can be measured at the time of the test. It should be noted that the speed of sound will be different in the sludge and water layers at the bottom of the tank than it is in the product. Failure to identify the presence of these layers and characterize their extent may lead to systematic errors that place real leak signals outside the tank.

- Condition of the backfill. The nature and condition of the backfill influence the leak signal and should, therefore, be assessed. This means characterizing both the design of the backfill and its liquid content of product and water. When the backfill is saturated, no leak signal is produced.

- Pre-test waiting period. To accommodate and minimize noise from tank deformation, a pre-test waiting period must be observed during which time no product is added to or removed from the tank. The pre-test waiting period can be up to 12 hours.

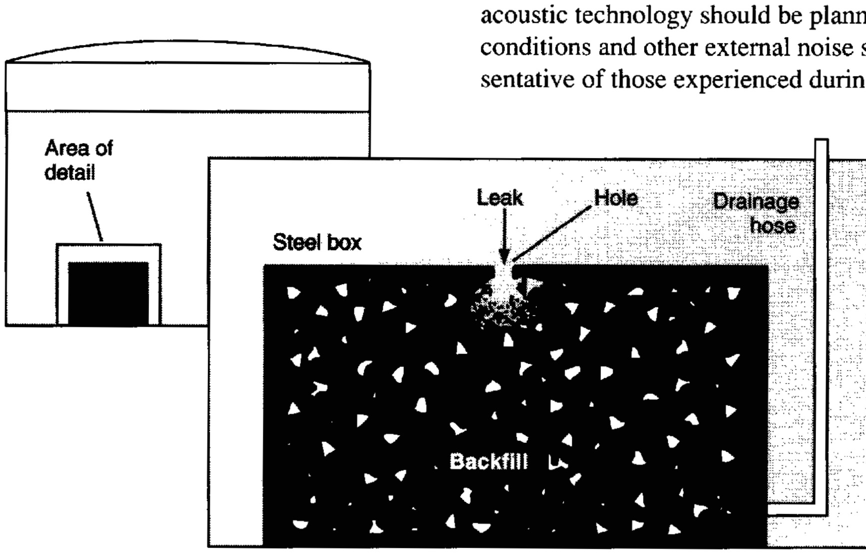
- Identifying the presence of sludge or corrosion of the tank bottom. Sludge may cause attenuation of the leak signal, and corrosion may reduce signal amplitudes by staging the pressure across the leak. These conditions should be considered, even though their effects on tests results have not been quantified.

DEMONSTRATIONS

Unlike demonstration tests of volumetric/mass technology, which can be conducted in the absence of a leak signal, demonstrations of acoustic technology require that a leak signal be present. Ideally, an acoustic demonstration test should be conducted on a leaking tank filled with a product similar to that in the tank that will be tested and draining into a similar backfill. Since most tanks are not leaking, this is almost never practical. The acoustic signal required to detect a leak in an AST can be simulated, however, by placing a steel box filled with the backfill material on the floor of the tank. The box should have a hole in its top so that product can leak into it, and there should be some method of drainage to keep it from filling with product. Tests should be conducted with and without the box in place to verify that the leak signal is detected by the acoustic system; and to assess the amount of noise that gets through the signal processing in the absence of a leak. In larger-diameter tanks, there is greater attenuation of the leak signal as it nears the walls. Sludge at the bottom of the tank may also cause attenuation. Other factors that can influence the signal are corrosion of the tank bottom and the make-up and liquid content of the backfill. Demonstrations should therefore be configured to simulate the worst-case conditions that might be expected.

Floating roofs can generate a significant amount of acoustic noise. If tests are to be conducted on tanks with floating roofs, it is preferable to conduct the demonstration on such a tank. Weather conditions such as wind and rain can also generate enough acoustic noise to have an effect on the test results. All of this should be taken into account when planning a demonstration test of acoustic technology.

As with volumetric/mass methods, demonstrations of acoustic technology should be planned when weather conditions and other external noise sources will be representative of those experienced during actual testing.



A leak simulator for acoustic tests employs a steel box filled with the backfill material and placed on the floor of the tank. A hole at the top of the box allows product to leak into this simulated backfill, while a hose provides drainage so that the box does not fill with liquid.

Soil-Vapor Monitoring Technology

Soil-vapor monitoring techniques, which include tracers and chemical markers, use a different approach to detecting leaks from ASTs. Instead of measuring the contents of the tank, like volumetric/mass and acoustic methods, they focus on the area surrounding it. The operating principle of this technology is that if there is a hole in the tank, and liquid seeps out, certain natural or added chemical components of that liquid can be detected in the soil around the tank. Thus, the discovery of such components outside the tank is indicative of a leak. These components are what constitute the "target" substances that soil-vapor monitoring techniques seek to detect.

The target substance, usually an organic chemical compound, is preferably one that is not already present in the environment. If it is, the soil-vapor monitoring test must be able to quantify increases of the target substance and to identify any such increase as a leak. The substance can be a natural component of the product or it can be added specifically for the purpose of the test. The key is that changes in the concentration of this substance outside the tank must be distinguishable from those that occur naturally. The API program tested a soil-vapor monitoring method using natural chemical markers. The substance must be distributed to that it reaches an acceptable minimum concentration everywhere in the tank.

Soil-vapor monitoring may require that a series of probes be installed under the tank and around its perimeter. The probe is usually a tube, open at both ends and installed radially under the tank. The target substance migrates first through the backfill and then into the open tube; from there it moves freely to the other end of the tube, where it is sampled by an analyzer such as a gas chromatograph, a fiber-optic sensor or a mass spectrometer. If any concentration of the target substance is found, it is considered indicative of a leak. (Methods dependent upon detection of compounds from stored product require additional analysis.) Sometimes a vacuum is applied to one end of the probe, thus establishing a flow of air through it. The target vapor, if present under the tank, is thus aspirated through the probe and then analyzed. If the soil is saturated with either water or product, an aeration probe can be installed through which air is forced in, thus providing something for the aspiration probes to draw upon.

THE NATURE OF THE SIGNAL

In soil-vapor monitoring the *signal* is the concentration of the target substance in the vapor collected through diffusion or aspiration. Larger leaks will produce larger concentrations of the target substance in the backfill. This method, however, is not intended to measure the size of the leak. Rather, it confirms the presence or absence of a leak above a specific threshold. *Noise,* in this context, is any process or phenomenon that can alter the measured concentration of the substance in the collected vapor.

SOURCES OF NOISE

The mechanisms that produce noise in soil-vapor monitoring techniques are quite different from those that affect volumetric and acoustic tests, except in the realm of instrument calibrations and calculations.

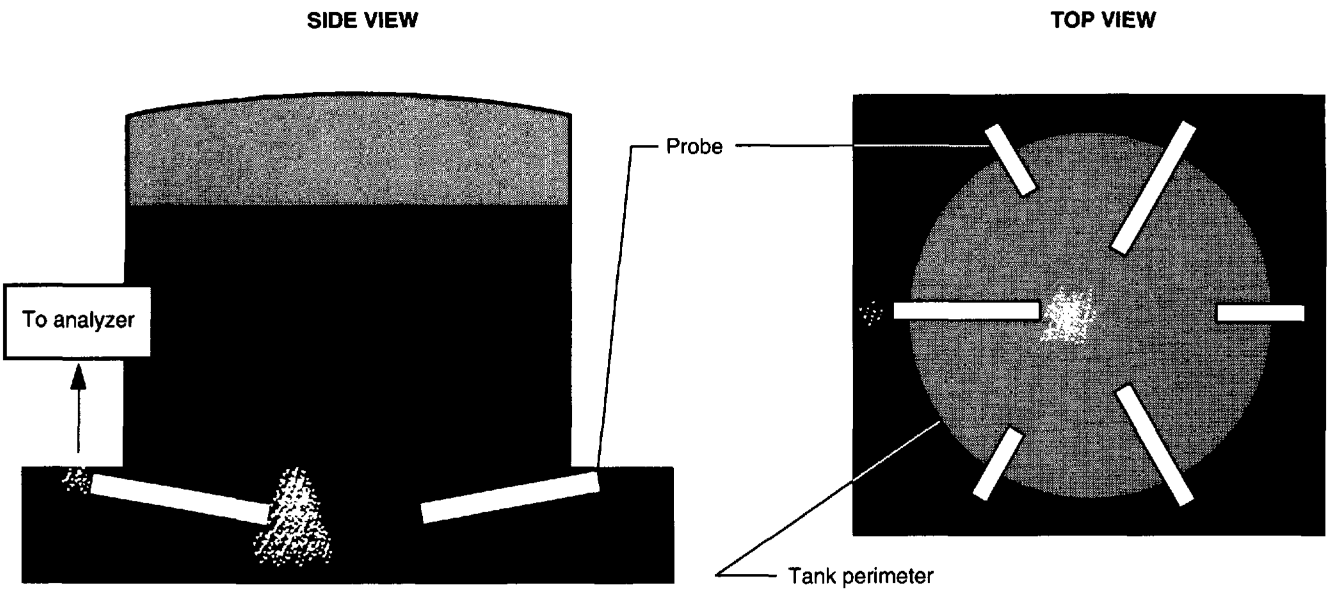
One source of noise is uneven distribution of the target substance within the tank. Uniform mixing of an added chemical marker is not critical. Experience has shown that adding a marker through the aperture normally used for filling the tank is usually adequate. In addition, circulating the product by means of existing pumps and piping is usually sufficient to ensure that uneven distribution is not a problem. If there is a layer of water or sediment at the bottom of the tank, however, the substance may fail to diffuse in this layer at the same rate as in the product, or, if the target substance is immiscible with water, it may not reach the probes at all, even if there is a leak. Hydrocarbons, for example, will not penetrate the water layer, but chemical marker techniques typically use heavier compounds that will. It is prudent, therefore, either to drain any extant water or to ensure that the compound selected as a target is heavy enough to penetrate water.

Noise is also generated by obtruding compounds that are similar to the target substance and can interfere in the analysis. For this reason it is very important that the chemical marker have unique and readily identifiable properties—a distinct signature so that ensures the marker cannot be confused with other compounds in the tank or the tank environment.

The target substance itself may be a source of noise if there are any trace levels of it left in the soil or backfill. It

SOIL-VAPOR MONITORING TECHNOLOGY IN A NUTSHELL

- Add a chemical marker to the product (or identify a component of the product that will serve as a marker)
- Take samples of vapor from the soil under the tank
- Analyze this vapor for the presence of the chemical marker



Top and side views of an AST illustrate a commonly used configuration for probes.

is important to gauge the background levels of the target substance before proceeding with a test. Unless the tank's history can be documented and a record of what products may have leaked into the soil in the past can be established, some uncertainty about the background levels of various compounds is to be expected.

The hydrogeology of the soil—its permeability and moisture content—plays another important role. The permeability of the soil and backfill affects the rate at which the target substance travels, with low-permeability soils and backfills retarding its spread. Because this is a very site-specific problem, it is important that the backfill and soil at a given site be well characterized. Using a more stable substance as the target can mitigate the effects of a soil with low permeability, as can increasing the duration of the tests.

KEY FEATURES

Soil-vapor monitoring is considered capable of detecting small leaks from ASTs provided that tests are properly conducted and certain conditions are satisfied. Below are the key issues that all systems based on soil-vapor monitoring technology should address.

- Compatibility of the target substance with the backfill. Some backfills provide a poor environment for the diffusion of target substances. The selection of this technology as a means of leak detection should be based on the diffusive characteristics of the backfill and the time it takes for the target vapor to decay.

- Optimum number of probes. The optimum number of probes is dependent not only on the diffusion-related selection criteria noted above, but also on the diameter of the tank. The larger the tank, the more probes are needed to cover the area defined by its perimeter. It is important to select a number sufficient for the task yet not overly ambitious.

- Neutralization of the effects of a water layer. The bottoms of ASTs may contain a layer of water as a result of environmental conditions such as rainfall and condensation. If the target substance is immiscible with water, it will not find its way into the backfill, even if the tank is leaking. There are two solutions. The preferred one is to use a target substance that penetrates water. The other is to use a test protocol that calls for the removal of any existing water layer prior to testing.

- Minimal background levels of the target substance. Unless information on the tank's history is available, it is not possible to document the types of product that may have leaked into the soil in the past. Thus, even if the target substance has a unique signature in the context of the present contents of the tank, there may be trace levels of it in the environment. To ensure that any such residue is low, soil samples should be taken before the target substance is added to the tank as part of the test protocol.

DEMONSTRATIONS

A demonstration test of soil-vapor monitoring technology requires that a signal be present. The objectives of the soil-vapor monitoring demonstration are to characterize the amount of the target substance that is present in the backfill when the tank is not leaking; and to verify that when the substance is present in the backfill it is mobile enough to reach the probes in a reasonable amount of time.

To verify the first objective, probes must be installed under a tank that is known to be free of leaks, or, if the target substance is an additive, under a tank (leaking or not) that has not previously contained this additive. When the integrity of the tank is not known, and the target substance is a component of the stored product, it is necessary to conduct a more detailed analysis that will identify the tank as being leak-free. Then a test must be conducted. To verify the second objective, realistic quantities of the target substance must be injected into the backfill through one of the existing probes or through an additional probe installed for this purpose. Clearly, the first test should show no signs of the target substance. The second test should show levels above the detection threshold within the standard test period.

The most important source of error in soil-vapor monitoring tests relates to the condition of the backfill material. The tank used in the demonstration test should have the same backfill as other tanks that will be tested. The number of probes per square foot of tank floor should also be similar.

Inventory Control Technology

Using inventory control technology as a means of leak detection has been a common practice for some time. Inventory control employs some measurements that are similar to those used in volumetric/mass testing. The principle of operation, however, is completely different, because it is based on arithmetical accounting. The procedure requires that detailed records be kept of all product deliveries, withdrawals, and resident quantities over a given period of time. (A flow meter is used to measure the amounts added and withdrawn.) At the same time, the amount of liquid in the tank is carefully monitored by means of a tank gauge. Theoretically, if the tank is not leaking, the net gain (or loss) of product as measured by the tank gauge should equal the net inflow (or outflow) as measured by the flow meter. Any discrepancy between these two measurements is indicative of a leak. The rate of leakage is obtained by dividing the residual volume (the discrepancy) by the reconciliation period (the period of time over which records were kept and measurements were made). This technology was not specifically tested as a part of the API program.

The Nature of the Signal

As is the case in volumetric/mass testing, the *signal* is that change in the amount of fluid which is due to a leak. Again, as in volumetric/mass testing, this change must exceed those caused by sources other than a leak. The *noise,* then, is defined as any change in the amount of product, as measured during the reconciliation period, that is not caused by a leak.

Sources of Noise

Inventory control is based on the premise that noise can be filtered out by means of repeated measurements, made frequently over a long period of time. Thus, if the reconciliation period is sufficiently long, time-dependent noise can be ruled out as a source of error. The primary concern then becomes the type of noise that is independent of time. This includes not only ambient noise but also that due to operational practice.

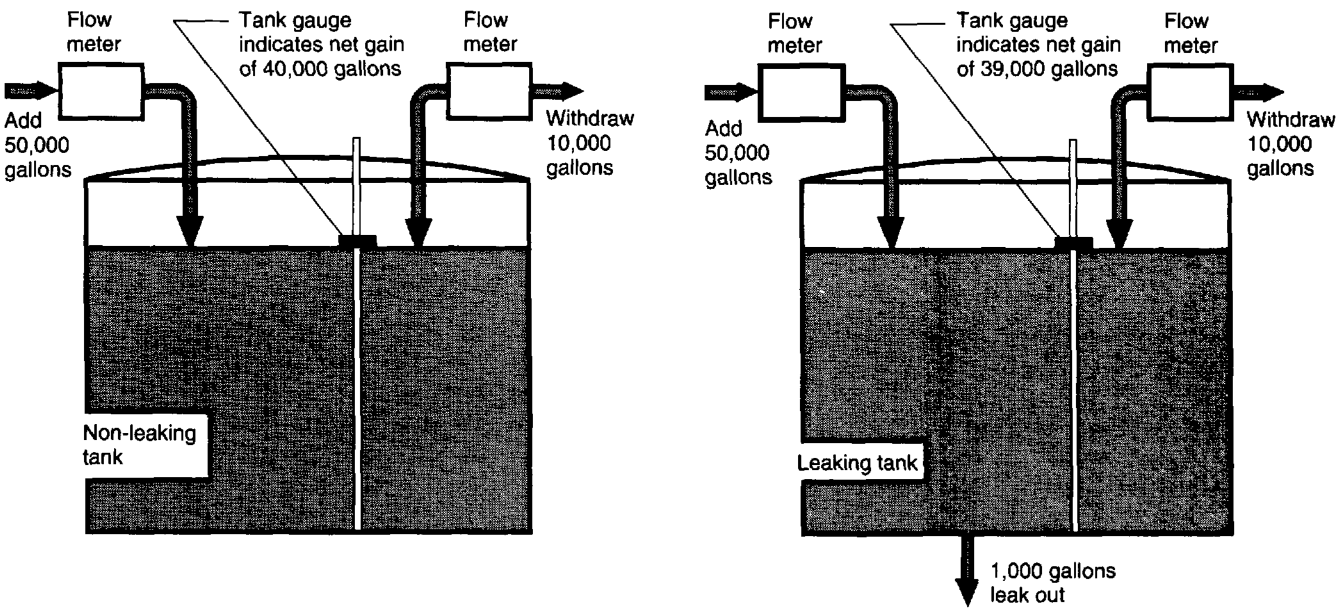
The two basic measurements required in inventory control are the amount of product added to or removed from the tank and the level/mass of the extant product. (Typically, these measurements are associated with custody transfers, and volumetric measurements are therefore likely to be converted to mass equivalents.) The amount added or removed can be obtained by means of a flow meter, which measures the product as it is added or withdrawn, or by means of a tank gauge. Although the tank gauge's primary function is to monitor the level of the extant liquid for reconciliation purposes, a level measurement made immediately after a delivery or withdrawal of product can serve as an estimate of the amount added or removed. Measurements made with either instrument, however, are subject to error. Generally, the accuracy of the meter determines the error, which, it can be assumed, will be a percentage of the quantity delivered or withdrawn. Careful calibration of the meter can reduce these errors. If the tank gauge is used as a meter substitute as well as for making level measurements, tank gauge errors will have a dual impact. A tank gauge error can be systematic or random. If, for example, the height-to-volume coefficient is wrong (if expansion or contraction is such that the tank strapping tables are no longer accurate), this is a system-wide error that affects all data collected; on the other hand, one incorrect reading of level among many represents a random error. Both metering and tank gauge errors can be minimized through the use of instruments that have good resolution and precision and that are well calibrated.

Another source of noise in inventory control is evaporation, which is always manifested as a loss of product and which is thus very difficult to distinguish from a true leak. Efforts should be made to either control or account for these losses.

Lastly, there is the noise produced by expansion and contraction of the product. Since these two phenomena are dependent on temperature, the ideal way to eliminate the errors they cause would be to make sure that product is at the same mean temperature each time a level measurement is made. Since this is not possible, the best alternative is to make many measurements over a period of a month or more and then to average them. The assumption is that temperature fluctuations can be averaged out over time to produce a result similar to one obtained in the "ideal" way.

Inventory Control Technology in a Nutshell

- Maintain a detailed record of product deliveries and withdrawals over a given period
- Over the same period, measure the level of product with a tank gauge
- Compare net inflow or outflow to net gain or loss
- Any discrepancy between the two is indicative of a leak



The figure on the left shows a non-leaking tank to which 50,000 gallons has been added and 10,000 gallons withdrawn. Thus, according to the flow meters, there was a net addition of 40,000 gallons. The tank gauge also indicates a net gain of 40,000 gallons, in agreement with the measurements made by the flow meters. The figure on the right shows a leaking tank to which the same amounts have been added and withdrawn. In this case, however, the tank gauge indicates a net gain of only 39,000 gallons. The discrepancy of 1,000 gallons is due to the leak. These figures are for illustrative purposes only; no inventory control method was tested as part of the API program.

KEY FEATURES

Inventory control can be used effectively as a means of leak detection if the following key features are incorporated.

- Long reconciliation period. The length of time over which measurements are made is typically several weeks.
- Frequent measurements of product level. At a minimum, a level measurement should be made each time a product transfer occurs. This usually means at least several times per day.
- Well-calibrated instrumentation.
- Accurate calculations.

DEMONSTRATIONS

In order to demonstrate an inventory reconciliation system, it is necessary only to apply it to a tank and pipeline system that is known to be free of leaks. The discrepancy in the inventory records at the end of the prescribed test period is then indicative of the error in the system.

Devising the Best Testing Strategy for a Particular Site

Having noted the key features of the various technologies and how to conduct demonstrations that verify their effectiveness, the reader by now will have some idea of what constitutes an acceptable leak detection system. Most systems that fit into the four classes of leak detection technology described here are viable options when they are used correctly, when the instrumentation employed is well maintained and calibrated, and when they are applied in the proper context.

The matter of context is a very important one. With so many options available, how does one choose the best system for a specific application? Depending on the site-specific variables, a technology that works well at one tank facility may not be well suited for another. Before making a choice, one should be thoroughly familiar with the site, should weigh operational and cost considerations, and should be able to assess vendors claims in a realistic way.

Familiarity with the Site

The terminal operator, manager or site engineer should have a thorough knowledge of a number of site-specific features. First among these are the tanks themselves. How large is each tank in terms of diameter and capacity? What is it made of? How is it constructed? Does it have a floating roof? What kind of access is available for installing instrumentation? How is the tank situated? For example, is it built into a hillside so that one side of it is exposed to sunlight to a greater degree than the other?

The second aspect of site-specificity is the product (or products) contained in the tanks. Is the product compatible with the type of instrumentation that will be used? Will it damage or corrode instruments made of certain materials? Is it hazardous to the extent that installing the instruments would present a danger to workers?

The ambient environment is also an important factor in deciding what types of systems may be applicable. What are the prevailing weather conditions? Is there a preponderance of sunny days, or is the climate rainy? What is the yearly range of temperatures? Are there cycles of freezing and thawing that affect either the ground or any of the tank's appurtenances? What is the diurnal range of temperatures during a given season? Is it enough to cause errors? Is there much traffic in the area (air, rail or road-way)? Does the traffic peak and ebb in a way that could affect test results?

A final consideration is the composition of the backfill material under the tank and the soil around the backfill. What is the porosity of the backfill and the soil? Are they permeable? Has the backfill been oiled? Is the soil saturated with water?

All of the factors noted above contribute in different ways to the different types of noise that selectively affect various technologies. When the operator is familiar with the specific characteristics of the site, matching this site with an appropriate technology becomes easier.

Operational Considerations

In addition to the physical aspects of the site, there are a number of operational aspects to consider. It is almost always desirable to minimize the down-time associated with testing, since any disruption of operations translates quickly into lost revenues. Therefore, the question of how long the tank must remain out of service for testing is an important one.

Another consideration is the instrumentation. How much and what type of instrumentation does this system require? Is it easily available? What level of precision is required? Must the instrumentation be placed inside the tank? If so, is it compatible with the type of product being stored and with operations at this facility?

Does the leak detection system require that valve blinds be installed in pipelines connected to the tank? If not, do the valves in question seal tightly enough to prevent noise (in the form of leaks across a valve) that would compromise the test results?

Finally, there is the question of product level. The optimum product level during a leak detection test is the one that will produce the strongest leak signal. That condition typically occurs when the product is at maximum level. Cases have been reported, however, in which the pressure due to a high product level reduced the leak rate by causing the hole or crack to close up.

Cost Considerations

If there were a leak detection system that worked without fail and that never generated a false alarm, there would be no debate about which one to select. The only cost involved would be the price of the test itself. There would be no hidden costs such as those associated with false alarms and missed detections. No leak detection system is 100 percent effective, however, and compromises must be made. The terminal operator, manager, or site engineer must find the best balance between environmental and cost considerations.

The costs of a leak detection test consist not only of the vendor's fee (for conducting the test) but also of the incidental costs associated with preparations and down-time.

Vendors fees, which can vary considerably, are not discussed here. One can get an idea of the incidental costs associated with a certain technology, however, by consulting "General Characteristics of Four Leak Detection Technologies" on pages 5 and 6 (specifically information on operational requirements and total amount of time required), and also by reading about the particulars of each technology (pages 8 through 23).

The cost of a test can be minimal in comparison to other cost considerations, all of which must be carefully evaluated. The revenue lost as a result of shutting down tank operations during a test may be minor in comparison to what would be lost if the facility had to be closed in order to clean up a leak that had gone undetected, or if the facility had to absorb the costs associated with trying to verify the presence of a leak when none exists. There is also the issue of fines associated with uncontrolled releases or noncompliance with regulations. Weighing the probability of detection against the probability of false alarm is an important part of selecting a leak detection system.

ASSESSMENT OF VENDORS' CLAIMS

One of the most important keys to the judicious selection of a leak detection system is the ability to assess the credibility of vendors' claims. A good place to start is by checking that a leak detection system has the requisite key features. These, as the reader will recall, are described as part of the sections on each of the four technologies. In addition, the charts on pages 5 through 7 condense the relevant information into a convenient tabular format. Once it has been determined that a system possesses these key features, the terminal operator must check whether the type of noise present at the facility will interfere with the performance of the system. If the system is compatible with the facility in terms of noise, it can be considered a good match. Because actual circumstances are never ideal, however, it is likely that compatibility will exist only to a certain degree.

As part of the assessment of a vendor's claims, a tank operator or outside agency may request a demonstration of the proposed technology. Any third-party testing or demonstration procedures must be acceptable to both the assessor and the vendor.

COMBINING TECHNOLOGIES EFFECTIVELY

Because each technology is based upon a different principle of operation, each is affected by different sources of noise. The kind of noise that adversely affects the performance of one system has no impact on another system based on a different technology. It would seem practical, then, to combine systems in such a way that the limitations of one are offset by the advantages of another. Using more than one technology in a specific application is a good way to boost the overall effectiveness of a testing strategy.

Individually, each of the four technologies described in this booklet has the potential for greater sensitivity than conventional hand gauging. When they are combined effectively, based on site-specific characteristics, this potential increases. Consider, for example, this hypothetical scenario. A regularly scheduled acoustic test indicates a leak near a roof-support leg resting on the tank floor. Before draining the tank to conduct an inspection, however, the terminal operator wants to verify that there really is a leak. If, for example, the acoustic system has been "fooled" into thinking a leak exists due to some slight motion of the roof-support leg, he needs a test that will not be influenced by the presence of this structure. Therefore, he decides to conduct a soil-vapor monitoring test. If the acoustic system has been "fooled" once, it could be fooled repeatedly; thus, using soil-vapor monitoring would be more effective in reducing false alarms than conducting repeated tests with the acoustic system. The key is that each system be independent (that is, that neither system be subject to the same errors as the other).

USING MULTIPLE TESTS

This is not to say that repeated tests with the same technology are never useful. If a suspected noise source can be identified and eliminated, conducting another test with the same system may be advisable. For example, if it is known that there was operator error in a test that indicates a leak, it would be worthwhile to repeat the test. Or, if a volumetric test conducted on a very hot day indicates a leak, it would be legitimate to suspect that the extreme temperature contributed to a testing error.

All of the technologies described in this booklet have a high probability of identifying a leak. The possibility of finding a leak is increased by the use of test protocols that minimize noise and employ back-up measures to confirm the test's response to the leak signal. Consistent with the procedures for testing underground storage tanks, it is common practice for AST operators to accept a single test result indicating that the tank is not leaking (that is, one in which the leak signal is less than the detection threshold).

Glossary

Accelerometer: An instrument that measures acceleration or a gravitational force capable of imparting acceleration; in the context of this booklet, the specific measurement made by the accelerometer is the speed of a sound wave generated by an acoustic event. Accelerometers are mounted around the external perimeter of a tank.

Acoustic: Pertaining to sound; in the context of this booklet, pertaining specifically to the propagation of sound waves caused by pressure fluctuations.

Acoustic signal: A transient elastic wave generated by a rapid release of energy due to some structural alteration in a solid material; for example, the wave produced in a fluid-filled tank as liquid escapes through a small hole in the bottom.

Algorithm: A set of mathematical steps devised for the solution of a specific problem.

Ambient noise: The level of noise normally present in the environment. (See "noise.")

Aspiration probe: A means of monitoring the soil around and under a tank using tubes that have been installed under the tank. A vacuum system is set up so that air flows through the tubes in a given direction, and samples of this air are taken to determine the presence of specific compounds.

Backfill: The material under and around the bottom of a tank, usually sand or gravel, that forms a porous boundary between the tank and the surrounding soil. The backfill provides a relatively even surface for the bottom of an AST.

Bias: The difference between the expected or predicted value of a given parameter and its true or actual value.

Chemical marker: A compound added to the product in a tank and used as the target substance in a soil-vapor monitoring test. (See also "tracer.")

Coefficient of thermal expansion: The change in volume of a solid, liquid or gas due to a rise in temperature.

Detection criterion: A predetermined set of characteristics used to distinguish the leak signal from noise. (See also "threshold.")

Differential pressure sensor: A device for measuring the difference in pressure between two locations or points.

DP cell: See "differential pressure sensor."

False alarm: A term denoting that a leak detection test has indicated a leak when in reality none exists. (See also "missed detection.")

Floating roof: A type of AST roof that rests on the surface of the liquid in the tank, moving up and down as product is added or removed.

Gas chromatograph: An instrument that detects the presence of volatile compounds. It can be used to determine the distribution of vapor concentrations and adsorption isotherms.

Height-to-volume factor: The relationship between the level (that is, height) of fluid in a tank and the volume of that fluid; usually expressed in tank strapping tables as barrels per foot.

Histogram: A graphical representation of a frequency distribution by means of contiguous vertical rectangles whose widths represent the class intervals of a variable and whose heights are proportional to the corresponding frequencies of this variable.

Hydrophone: A device that, when submerged in a liquid, receives sound waves and converts them into electrical impulses.

Hydrostatic head: The amount of pressure, measured in pounds per square inch (psi), exerted by a liquid.

Hydrostatic pressure: See "hydrostatic head."

Inventory control: A method of monitoring tank integrity by keeping detailed records of all additions and withdrawals of liquid while at the same time making accurate and regular measurements of the level of liquid in the tank. Over a given period, the change in level should reflect the amount of liquid added or withdrawn. Discrepancies between the two are interpreted as being indicative of a leak.

Inventory reconciliation: See "inventory control."

Leak: An unplanned or uncontrolled loss of product through a hole, crack or fissure in a tank.

Leak detection method: (As opposed to a "leak detection system") an approach, usually having a certain protocol, to conducting a leak detection test. Different systems can be based on the same method.

Leak rate: The quantification of a leak in terms of the amount of liquid that escapes during a given time; usually expressed in gallons per hour.

Leak detection system: (As opposed to a "leak detection method") a device, usually associated with a specific manufacturer, for conducting leak detection tests.

Leak detection test: The exercise of a set of steps to determine the integrity of a tank. A test can involve the use of some physical device, or leak detection system, which is based on certain operational principles (that is, a leak detection method).

Level: See "product level."

Mass: As used in this booklet, synonymous with weight.

Mass measurement: A method of leak detection based on measurements of the pressure exerted by the liquid in a tank.

Measurement system: In the context of this booklet, a term used synonymously with "leak detection system," because the latter relies on some type of measurement in order to detect a leak.

Missed detection: A term denoting that a leak detection test has failed to identify an existing leak. (See also "false alarm.")

Multiple-test strategy: An approach in which the declaration of a leak is based on more than one test. For example, if Test #1 indicates a leak, Test #2 must be conducted and must also indicate a leak before a tank is taken out of service.

Noise: Any process or phenomenon unrelated to a leak that interferes with the detection of a signal generated by that leak. Background levels of noise are present in every type of leak detection test. (See also "signal" and "signal-plus-noise.")

P_d: See "probability of detection."

P_{fa}: See "probability of false alarm."

P_{md}: See "probability of missed detection."

Performance: The reliability of a method or system in detecting leaks, usually expressed in terms of probability of detection and probability of false alarm at a given leak rate.

Probability of detection: The likelihood that a test will detect an existing leak; expressed as a percentage; inversely related to the probability of false alarm.

Probability of false alarm: The likelihood that a test will find a leak where none exists; expressed as a percentage; inversely related to the probability of detection.

Probability of missed detection: The likelihood that a test will not find a leak even though one exists; expressed as a percentage.

Probe: A means of monitoring the soil around and under a tank using tubes that have been installed under the tank. Air migrates through the tubes to an outlet point, where samples of this air are taken to determine the presence of specific compounds.

Product: The liquid contents of a tank, for example, a petroleum product.

Product level: The height of the product, measured in inches or feet from the bottom of the tank.

Reconciliation period: When inventory control techniques are used as a means of leak detection, the amount of time over which measurements of level and inflow and outflow are made. (A leak is suspected when measurements made by a tank gauge do not reconcile with those made by a flow meter.)

Release: In this booklet, a term used synonymously with "leak."

Residual Noise: Noise that is still present in the data after noise cancellation or compensation algorithms have been applied.

Shell: See "tank shell."

Signal: An identifiable phenomenon that is produced by and is indicative of a leak. The nature of the signal is a function of the leak detection method being used; depending on the method, the signal can be, for example, an acoustic wave, a fluctuation in product level, a concentration of a certain chemical compound, or a number of other phenomena.

Signal-plus-noise: A value represented by the linear addition of the amplitude of the signal to the amplitude of the noise.

Soil-vapor monitoring: A method of leak detection in which a chemical compound that is not found in the environment, but that is either added to or naturally present in the product, serves as a target for detection, the principle being that any concentrations of this vapor found outside the tank are indicative of a leak. (See also "probe" and "aspiration probe.")

Standard deviation: A statistic used as a measure of the dispersion of the distribution of a variable.

Structural deformation: The physical changes that a tank undergoes when it is filled with product, or when product is withdrawn. The tank shell, for example, bulges outward when product is added, and the floor deflects downward, causing a drop in product level that is not indicative of fluid loss but that can be mistaken for such.

System noise: The noise produced by a leak detection system's instrumentation, for example, level gauges or differential-pressure sensors; usually associated with the accuracy of the measurement system. (See also "threshold.")

Tank shell: The sides of an AST, as opposed to the tank bottom and tank roof.

Thermal expansion or contraction (of shell or product): A temperature-induced change in the volume of product in the tank or the dimensions of the tank shell itself. One can influence the other, and both are influenced by ambient air temperature.

Threshold: A predetermined value that is the basis for declaring a leak. Data points that fall within the threshold setting are considered noise, whereas those that exceed the threshold are considered indicative of a leak. (See also "system noise" and "detection criterion.")

Time series: A measurement of the amplitude of a signal at regular intervals in time.

Tracer: An organic chemical compound (usually a gas such as nitrogen or helium) used as the target substance in a soil-vapor monitoring test. A tracer can be a substance that occurs naturally in the product or one that has been added to it, as long as it is not present in the environment outside the tank.

Transducer: A device that converts an input signal based on one kind of energy into an output signal based on another kind; in the context of this booklet, a device that converts sound waves into electrical signals.

Volume: The quantity of liquid contained in a tank, usually expressed in gallons.

Volumetric: A method of leak detection based on measurements of the level of liquid in a tank which are then converted to volume. Measurements that exceed the fluctuation levels considered normal for a non-leaking tank are indicative of a leak.

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