

An Engineering Evaluation of Volumetric Methods of Leak Detection in Aboveground Storage Tanks

HEALTH AND ENVIRONMENTAL AFFAIRS
API PUBLICATION NUMBER 323
JANUARY 1994



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An Engineering Evaluation of Volumetric Methods of Leak Detection in Aboveground Storage Tanks

Health and Environmental Affairs Department

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AUGUST 1993

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ACKNOWLEDGMENTS

We wish to express our gratitude to the members of the API Storage Tank Task Force and the Work Group for AST Monitoring for their cooperation, their technical support, and their assistance in coordinating this project. We would like to acknowledge the support and encouragement of the chairperson of the Work Group, Mr. James Seebold, and the API staff member monitoring the program, Ms. Dee Gavora. We especially acknowledge the help of Mr. John Collins, of Mobil Oil, who provided technical input to the research and was instrumental in coordinating the field tests at the Mobil Refinery in Beaumont, Texas. Finally, we acknowledge the help of Monique Seibel and Christine Lawson of Vista Research in editing and typesetting this document.

ABSTRACT

There are two approaches to detecting leaks in an aboveground storage tank (AST) by means of the volumetric method. The first is the conventional approach in which measurements of the level and temperature of the product are made with a precision level sensor and a vertical array of temperature sensors. The second is a mass measurement approach which employs a differential pressure sensor to measure the level changes. In a tank with vertical walls, a differential pressure sensor inherently compensates for the level changes produced by thermal expansion and contraction of the product between the pressure port and the product surface.

As part of Phase III of the American Petroleum Institute's (API's) project to develop and evaluate the performance of different technologies for detecting leaks in the floor of ASTs, a controlled experiment was conducted in a 117-ft-diameter tank during late May and early June 1992. The purpose of this experiment was to evaluate the performance of both approaches to volumetric testing. The tank contained a light fuel oil, and data were collected over a continuous 28-day period.

The analytical and experimental results of this project suggest that a volumetric system can be used to detect small leaks in ASTs. Analysis of the level temperature approach indicates that the largest source of volume fluctuations was thermal expansion of the product. It was found that effective compensation for this expansion could be achieved, and leak rates as small as 1.9 gal/h could be reliably detected in a single 24-h test. Furthermore, extending the test period to 48 h would significantly improve leak detection performance, resulting in a detectable rate of about 1.0 gal/h.

While in theory differential pressure systems should achieve a higher level of performance than the level temperature systems, this was not the case. The setup of the differential pressure measurement system is extremely sensitive to air temperature changes, and to a lesser extent, the location of the bottom pressure reading.

Regardless of the approach used, volumetric leak detection tests achieve their highest performance when the level of the product in the tank is low (approximately 3 ft), and the test duration is at least 24 h (48 h if possible), the test is begun and ended at night, and accurate temperature compensation is applied. When the test duration is significantly less than 24 h, it is not possible to accurately compensate for the effects of diurnal temperature changes.

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EXECUTIVE SUMMARY

INTRODUCTION

There are two approaches to detecting leaks from an aboveground storage tank (AST) by means of the volumetric method. The first is the conventional approach in which measurements of the level and temperature of the product are made with a precision level sensor and a vertical array of closely spaced, precision temperature sensors. The second is a mass-measurement approach, which employs a differential-pressure sensor to measure the level changes. In a tank with vertical walls, a differential-pressure sensor inherently compensates for the level changes produced by the thermal expansion and contraction of the product between the pressure port, which is located near the bottom of the tank, and the product surface. Because of the possibility of large horizontal gradients in the rate of change of temperature of the product in an AST (gradients which cannot be accurately measured with a single vertical array) the mass-measurement approach should, in theory, have a performance advantage over the conventional approach.

As part of Phase III of the American Petroleum Institute's (API's) project to develop and evaluate the performance, in actual operational environments, of different technologies for detecting leaks in the floor of ASTs¹, a controlled experiment was conducted in a 117-ft-diameter tank at Mobil's refinery in Beaumont, Texas, during late May and early June 1992. The purpose of this experiment was to evaluate the performance of both approaches to volumetric testing. The tank contained a light fuel oil, and data were collected over a continuous 28-day period. Two vertical arrays of thermistors were placed at two locations inside the tank to determine the magnitude of the horizontal gradients in the rate of change of product temperature. Temperature measurements of the tank's exterior shell were also made.

BACKGROUND

The API has completed three phases of a leak detection project for ASTs. The purpose of Phase I was to assess different leak detection technologies in order to determine which had the greatest potential for field application. Phase II addressed in detail two of the methods studied in Phase I: passive-acoustic and volumetric methods. The results of the volumetric experiments indicated that, in order for a test to achieve sufficient compensation for the temperature-induced changes in the product and in the wall needed for high performance, the product should be at lower levels and test duration should be approximately 24, 48 or 72 hours.

¹ Phase III also included an engineering evaluation of passive-acoustic methods of leak detection for ASTs. The results of the acoustic study are provided in a separate API document entitled *An Engineering Evaluation of Acoustic Methods of Leak Detection for Aboveground Storage Tanks*, by Eric G. Eckert and Joseph W. Maresca, Jr.

The objectives of Phase III, which addressed both volumetric and passive-acoustic leak detection technologies, were:

- to determine, in the case of acoustic methods, the nature of the acoustic leak signal resulting from realistic leaks in the floor of an operational AST;
- to determine, in the case of volumetric systems, if differential pressure (mass-measurement) systems have significant advantages over the conventional level and temperature measurement systems;
- to characterize the ambient noise encountered under a wide range of test conditions for both detection technologies;
- to evaluate data collection and signal processing techniques that would allow the detection of the leak signal against the ambient noise;
- to identify any operational issues for implementation of methods based on either technology;
- to demonstrate the capabilities and, if possible, make an estimate of the performance, of both technologies through field tests; and
- to identify, in the case of both volumetric and passive-acoustic technologies, those features of a leak detection test that are necessary for achieving high performance.

CONCLUSIONS

The analytical and experimental results of this project suggest that a volumetric system can be used to detect small leaks in ASTs. Analysis of the float-based system indicated that the largest source of volume fluctuations was thermal expansion of the product. During this project it was found that effective compensation for this expansion, as well as compensation for the thermal expansion of the tank walls, could be achieved. Analysis of the test results suggested that leak rates as small as 1.9 gal/h could be detected in a single 24-h test at a probability of detection (P_D) of 95% and a probability of false alarm (P_{FA}) of 5%. Furthermore, test results suggest that extension of the test period to 48 h would significantly improve leak detection performance, resulting in a detectable rate of about 1.0 gal/h. This high level of performance was achieved in tests begun and ended at night because the horizontal gradients in the rate of change of product temperature were negligible during the night. Both estimates could have been improved with more extensive measurement of the vertical temperature profile of the product, particularly in the upper layers of the product where the greatest rates of temperature change persistently occurred. Some degradation of the performance estimates probably occurred as a result of non-uniform inflow of product from neighboring tanks through leaking isolation valves. This inflow condition was present during the entire 28-day data collection period.

While in theory differential pressure systems should achieve a higher level of performance than temperature and level systems, this was not the case in the field tests conducted as part of this project. We found that the setup of the differential pressure measurement system is extremely sensitive to air temperature changes and, to a lesser extent, the location of the bottom pressure reading. In principle, these setup problems can be eliminated by careful design; in practice, however, as shown by these tests, they are sometimes difficult to avoid. Regardless of the approach used, volumetric leak detection tests achieve their highest performance when the level of product in the tank is low (approximately 3 ft), the test duration is at least 24 h (48 if possible), the test is begun and ended at night, and accurate temperature compensation is made for the thermal expansion and contraction of the instrumentation, the tank shell and the product. When the test duration is significantly less than 24 h, it is not possible to accurately compensate for the effects of diurnal temperature changes.

This document presents the results of these volumetric experiments in two technical papers, which are attached as appendices. The first provides a description of the capabilities of a level-and-temperature leak detection system for use in ASTs. This paper quantifies the sources of ambient noise, describes those features of a leak detection system that are crucial for high performance, and estimates the performance of the volumetric method of testing. The second describes the capabilities of a differential-pressure leak detection system for use in ASTs. This paper focuses on the temperature compensation requirements necessary to achieve high performance with this type of measurement system.

1 INTRODUCTION

This report is one of two that summarize Phase III of a research program conducted by the American Petroleum Institute (API) to evaluate the performance of different technologies that can be used to detect leaks in the floors of aboveground storage tanks (ASTs). During Phase I, an analytical assessment of the performance of four leak detection technologies was investigated (Vista Research, Inc., 1989; Maresca and Starr, 1990). The four technologies included: (1) passive-acoustic sensing systems, (2) volumetric systems, especially differential-pressure (or "mass") measurement systems, (3) enhanced inventory reconciliation methods, and (4) tracer methods. During Phase II, field tests were conducted on a 114-ft-diameter AST containing a heavy naphtha for the purpose of making an engineering assessment of the performance of two of these technologies, passive-acoustic sensing systems and volumetric detection systems. The results of the Phase II research program are described in two API final reports and three professional papers (Vista Research, Inc., 1991, 1992; Eckert and Maresca, 1991, 1992). During Phase III, additional field tests were conducted on a pair of ASTs in order to test acoustic and volumetric leak detection strategies that emerged from the Phase II study, and to further evaluate the current state of leak detection technology. To evaluate the performance of the volumetric method, volumetric tests were conducted in a 117-ft-diameter tank containing a light fuel oil. A nearly continuous time series of level and temperature data was collected over a 28-day period. The acoustic tests were conducted in a 40-ft-diameter AST, which contained water and was especially configured to assess the nature of the acoustic signal produced by a hole in the floor of the tank. This report describes the results of the Phase III volumetric tests; the results of the acoustic tests are described in a separate report (Vista Research, Inc., 1993), which consists of brief overview of the work and two detailed technical papers (Vista Research, Inc., 1993).

There are two approaches to detecting leaks from an AST by means of the volumetric method. The first is the conventional approach in which measurements of the level and temperature of the product are made with a precision level sensor and a vertical array of closely spaced, precision temperature sensors. The temperature array is used to estimate the level changes produced by the thermal expansion and contraction of the product so that they can be removed from the measured level changes. The second is a mass-measurement approach, which employs a differential-pressure sensor to measure the level changes. In a tank with vertical walls, a differential-pressure sensor inherently compensates for the level changes produced by the thermal expansion and contraction of the product. Although there are other sources of noise that

affect both approaches, thermal expansion and contraction of the product is the largest. Thus, in ASTs, a mass-measurement system would appear to have a significant performance advantage over the conventional level-and-temperature measurement approach.

The specific objectives of Phase III research in the area of volumetric measurement systems were

- to determine if differential pressure (mass-measurement) systems have significant advantages over the conventional level and temperature measurement systems;
- to characterize the ambient noise that is encountered under a wide range of test conditions and that affects the performance of both types of volumetric leak detection system;
- to identify any operational issues related to the implementation of either type of volumetric system;
- to demonstrate the capabilities and, if possible, make an estimate of the performance of volumetric measurement systems through field tests; and
- to identify those features of a volumetric leak detection test that are required for high performance.

The body of this report consists of a short technical summary of the work. Section 2 summarizes the relevant Phase II results that were further investigated in Phase III. Sections 3 and 4 summarize the important results, conclusions, and recommendations of this experimental program. Section 5 presents those features of a volumetric test that will ensure a high level of performance (both for the mass-measurement and the level-and-temperature approaches). A detailed description of the field tests and analyses are presented in two professional papers, which are attached as appendices to the report.

2 BACKGROUND

A methodology for testing ASTs for small leaks with a volumetric test method was developed in the Phase II field tests. Volumetric measurements were made in a 114-ft-diameter AST containing a heavy naphtha. Two three-day data sets were collected, one in which the tank was filled to a level of 17 ft and the other to a level of 10 ft. Estimates of the magnitude of the important sources of ambient noise were made at each level. The results of the field tests indicated that compensation for thermally induced volume changes is essential for the detection of small leaks. Changes in the temperature of the product, in response to diurnal cycles, were found to be the largest source of volume fluctuation. These were difficult to measure with sufficient accuracy for effective compensation when only a *single* vertical array of thermistors was used. The reason for the insufficiency of the single array was that the rate of change of temperature differed at various locations along the horizontal axis of the tank. The volume changes induced by the thermal expansion and contraction of the wall were found to be much smaller, but because they were still large in comparison to a small leak, compensation was required if robust detection performance was to be achieved. The peak-to-peak variation of the thermally induced product volume changes over a 24-h diurnal period was sometimes over 1,000 gal. The results also indicated that test durations of at least one or more diurnal cycles (i.e., at least 24 h) are required in order that there be (1) a high level of compensation for diurnally induced thermal changes and (2) sufficient time that the volume changes induced by small leaks in a large tank can be sensed. The Phase II results also indicated that, for a high degree of performance, volumetric tests must be performed when product level is lower than 10 ft. Volume changes due to evaporation and condensation, also controlled by large diurnal changes in air temperature, were identified in the Phase II tests but could not be quantified. Because it cannot be easily compensated for, evaporation/condensation as a source of noise will ultimately be the limiting factor in performance.

The Phase II experimental work suggested that a mass-measurement (or differential-pressure) system would perform better than a level-and-temperature measurement system because it is not affected by large thermally induced changes in the volume of product. A level-and-temperature system is subject to errors in thermal compensation because of horizontal gradients in the rate of change of temperature that are difficult to account for. This error is expected to be much greater than (1) any error due to the low-level measurement precision of most differential-pressure (DP) sensors; (2) any error due to the thermal sensitivity of such a DP sensor; or (3) any error due to the inability of a DP measurement system to compensate for the thermally induced volume changes that occur below the lowest pressure port. Whether or not sufficient performance could be achieved with a mass-measurement system still depends on the magnitude of the other errors

and sources of noise that affect both types of volumetric measurement systems equally, for example, thermal expansion and contraction of the tank walls, evaporation and condensation, etc. The test methodology developed in Phase II was based on two simple points: use a long test duration that approximately covers integral multiples of a diurnal cycle (24, 48, or 72 h), and conduct a test when the level of product is low (approximately 3 ft).

3 SUMMARY OF RESULTS

The Phase III field tests were designed to evaluate the performance of volumetric methods designed for testing ASTs with diameters of approximately 100 ft. The experiment design focused on mass-measurement systems, because the Phase II results suggested that such systems had performance advantages over the conventional level-and-temperature measurement systems in terms of compensation for thermally induced diurnal changes in the volume of product. The data collected by the level-and-temperature system was intended mainly for use as diagnostic information for the mass-measurement system. As it turned out, however, the level-and-temperature measurements also proved adequate for use in a leak detection test; furthermore, they provided the basis for most of the conclusions drawn in this phase of the work.

An estimate of the performance of both types of volumetric method was made from the 28-day data set collected during experiments on a 117-ft-diameter AST. The experiments took place in late May and early June at the same refinery used in Phase II. The tests were conducted at about the same time of year, and the tank was of similar size and type as that used in Phase II. The main differences were in the type of product and the level of product. The light fuel oil used in the Phase III tests was less volatile than the heavy naphtha used in the Phase II tests, and product levels were lower during Phase II.

Two vertical arrays of thermistors were placed at two locations inside the tank to determine the magnitude of the horizontal gradients. Additional temperature measurements were made on the tank exterior to estimate thermally induced changes in the tank walls. Precision level measurements were made with an electromagnetic sensor provided by Vista Research and with two differential-pressure sensors. Vista Research also provided the various thermistor arrays.

All data were collected at a nominal product level of 37.5 in. This low level helped to minimize the volume fluctuations associated with expansion and contraction of both the product and the tank wall. During the entire test period, volume fluctuations exhibited strong diurnal influence, with peak-to-peak volume changes of as much as 150 gal occurring over a 24-h period; the thermally induced volume changes of the product accounted for approximately 90% of the total thermally induced volume changes. While the rate of change of volume could be as high as 30 gal/h over a 4-h period, it was generally less than 10 gal/h over a 24-h period. Since even the best methods of temperature compensation can remove only 90 to 99% of the unwanted noise fluctuations, long tests are essential for accurate compensation. Other sources of volume change during these experiments, such as evaporation and condensation of the product, which are also thermally driven, appeared to be extremely small.

Throughout the entire test period, the mean inventory in the tank was found to increase linearly at about 2.8 gal/h. It is suspected that this increase, which was measured with the level-and-temperature system, is due to inflow from neighboring tanks through leaking isolation valves. Because the inflow appeared to be relatively uniform over the 28-day period, it was possible to make estimates of performance under these conditions. No independent measurement of the flow rate was made, however, and so it cannot be determined whether day-to-day non-uniformities in this inflow degraded the performance estimates. Some degradation probably occurred.

The temperature-and-level measurements were made by a float-based system. Analysis of these measurements indicated that the largest single source of volume fluctuations was thermal expansion of the product. When compensation was made for this expansion, as well as that caused by thermal growth of the tank walls, it was possible, in a single 24-h test, to detect leaks as small as 1.9 gal/h with a probability of detection (P_D) of 95% and a probability of false alarm (P_{FA}) of 5%. When the test period was extended to 48 h, with no alteration of the thermal compensation scheme, leak detection performance improved significantly, resulting in a detectable leak of about 1.0 gal/h. The high performance achieved by the temperature-and-level measurement approach was due to the fact that all tests were begun and ended at night, when horizontal gradients in the rate of change of product temperature (and shell temperature as well) were negligible. The estimates of leak rate were made from only one of the two vertical arrays; both arrays gave approximately the same results in tests beginning and ending at night. Better performance would have been achieved if there had been more temperature sensors on the array; more sensors would have provided a more extensive measurement of the vertical temperature profile of the product, particularly near the surface where most of the temperature changes occurred. The high performance achieved with the temperature-and-level measurement system was unexpected; this measurement approach is viable for leak detection in ASTs provided that tests are begun and ended at night and that product level is very low.

In examining the mass-measurement approach, two different implementations of the differential-pressure system were used. In each case the sensor was extremely sensitive to changes in ambient air temperature; this was the result of having to use vertical tubes to connect the sensor to the tank. The volume changes measured by the DP cell were three to five times greater than the uncompensated volume changes measured by the level sensor, a fact that could be attributed to the thermal sensitivity of the tube geometry. A number of temperature compensation schemes for the DP cell were therefore devised. These schemes used temperature data obtained from thermistors attached directly to the tubes. While some of the schemes worked for short data seg-

ments, they were not universally applicable. In principle, this thermal sensitivity could be minimized by using only horizontal tube connections between the differential pressure sensor and the tank. We do not know whether or not this is sufficient to avoid the thermal sensitivity observed during these tests. Some limited data were collected with a differential pressure sensor configured with only horizontal tube connections, but residual thermal fluctuations still occurred. We believe, however, that when the differential pressure system is properly implemented, it should be possible to obtain performance similar to or perhaps better than that of the level-and-temperature measurement system.

A differential-pressure system does not compensate for any thermally induced product changes below the lowest pressure port, a source of error that is not present in level measurement systems. The peak-to-peak volume changes over a diurnal period that were produced by thermal expansion and contraction of the product in this bottom layer were as large as 30 gal during these tests. This means that hourly rates as high as 1 gal/h could occur during test periods significantly shorter than one diurnal fluctuation period. Fortunately, these changes were small when measured over a complete diurnal period (i.e., 24 h)---less than 10% of the peak-to-peak gross product volume changes (i.e., approximately 0.04 gal/h). The same shell-mounted temperature sensors were used to compensate for changes in volume induced by the thermal expansion and contraction of the tank walls.

4 CONCLUSIONS AND RECOMMENDATIONS

The main conclusion of Phase III volumetric tests is that accurate and reliable detection of small leaks in ASTs is possible. Leaks as small as, or perhaps even smaller than, 1 gal/h should be detectable with a P_D of 95% or greater and a P_{FA} of 5% or less. In addition, the important features of a volumetric leak detection test with high performance have been identified and validated.

The anticipated performance advantage of the mass-measurement approach over the level-and-temperature approach was not realized. It was found that horizontal gradients in the rate of change of temperature of the product were negligible during the night; it was therefore possible to achieve accurate temperature compensation with a single vertical array of temperature sensors as long as a test was conducted entirely during night-time hours. This discovery, which makes the level-and-temperature approach feasible, is a surprising and important finding, and one which should be verified under a wider range of conditions, both for the tank and the product. The reason for the high performance of the level-and-temperature approach was the fact that product level was low. If the horizontal gradients are large, a differential-pressure system should in theory achieve a higher level of performance than a level-and-temperature system. If, however, the horizontal gradients are small (as they were in these tests) the two should perform more or less equally. This turned out not to be the case. The DP system's performance was not as good as that of the level-and-temperature system. We found that because of the way the DP system is set up it is extremely sensitive to ambient changes in air temperature and (to a lesser extent in these tests) is influenced by the position of the bottom tube of the DP sensor along the vertical axis of the tank. In principle, these setup problems can be eliminated by careful design, but in practice, as was our experience during these tests, they are sometimes difficult to avoid. Further work is required before these implementation issues can be understood.

Regardless of the approach used, volumetric leak detection tests achieve their highest performance when the level of product in the tank is low (approximately 3 ft), the test duration is at least 24 h (48 h, if possible), a test is begun and ended at night, and the thermal expansion and contraction of the instrumentation, tank shell, and product are accurately compensated for. When a test is significantly shorter than 24 h, it is not possible to achieve a high level of performance because it is not possible to compensate adequately for thermally induced changes in the volume of product that are the result of the diurnal temperature cycle. To allow thermal

inhomogeneities to dissipate, as well as for any deformation of the tank shell to subside, it is necessary to include as part of the *pre-test* protocol a waiting period of at least 24 h, during which time no product is added to or removed from the tank.

In general, the performance of both the mass-measurement and level-and-temperature approaches will decrease (1) as the diameter of the tank increases, (2) as the level of product in the tank increases and (3) when the tank contains more volatile products than the one used in these experiments, such that evaporation or condensation becomes an important noise source. Tests at higher product levels, although not optimal for performance, may be possible in smaller ASTs. Additional modeling and experimental data will be necessary to determine when or if this is possible.

The success achieved with the volumetric leak detection method is critically important, because until now, the accepted procedure for determining whether or not an AST is leaking has been to take the tank *out of service*, drain it, and inspect the tank floor. This process is not only expensive and time-consuming but also poses environmental risks connected with the transfer and temporary storage of product. Volumetric methods represent a way to test a large AST for leaks before it is taken out of service. Since testing may take several days, and since product may have to be removed from the tank, a volumetric test is most efficiently used when another type of test has already suggested the possibility of a leak or when product level is low enough that no liquid has to be removed and temporarily stored elsewhere.

Three recommendations are made as part of API's Phase III effort. The first is to demonstrate that the data collection and analysis approach developed in the Phase III field tests works by using this approach to perform leak detection tests on a variety of operational ASTs whose integrity has been or will be checked by tank inspection procedures. The data obtained in the Phases II and III tests are limited in that they represent only one type and size of tank, two products, and one season of the year. Less than a month's worth of experimental data were collected with the test procedures outlined here, and these data are limited to ASTs in the same geographic location and under the same climatic conditions. While the data collection and analysis methods developed as part of Phase III are based on sound experimental evidence, these methods have not yet been evaluated over a wide enough set of conditions to be definitive. In addition, there are some implementation issues yet to be resolved, namely, the issue of horizontal gradients with regard to the level-and-temperature approach and that of the set-up geometry of the DP sensor with regard to the mass-measurement approach.

The second recommendation is to develop and validate a *standard test procedure* for evaluating the performance of leak detection methods in terms of probability of detection (P_D) and probability of false alarm (P_{FA}). The advantages of standardized evaluation procedures, in terms of both technology transfer and performance estimation, have been successfully demonstrated and implemented as part of the EPA's underground storage tank (UST) program. The development and implementation of a standard test procedure for ASTs is particularly important because it is an extremely effective means of technology transfer; it almost ensures that industry will integrate the important findings of this research into its leak detection systems, because by doing so industry can achieve the highest performance possible when evaluating these systems. Such procedures also ensure that all leak detection systems have a minimum level of performance and that the performance of one system can be compared to that of any other system.

The third recommendation is to encourage the continuation of applied R & D by other organizations, especially the federal government, as a way to improve the performance of these technologies and to extend their application over a wider population of tanks. Three areas of further technology development are recommended for volumetric methods: (1) characterize the noise environment over a wider range of tank and tank testing conditions, (2) evaluate the performance of volumetric leak detection systems (both mass-measurement and level-and-temperature-measurement systems) over a wider range of tank types and testing conditions, and (3) develop better methods of temperature compensation for each approach. It is especially important to determine the magnitude of the horizontal temperature gradients and the evaporation and condensation in tanks as a function of the type of product stored. It is also important to examine the thermal sensitivity of different setup configurations for the DP system and to develop compensation methods that minimize the noise contribution from the instrumentation. While the goals of each of these three recommendations seem somewhat unrelated, addressing any one of them will offer significant input to the other two.

While not a specific recommendation, the importance of technology transfer cannot be overemphasized, because it must be recognized that it is expensive and time-consuming for industry to implement some of the features that have been identified as being important for achieving high performance with a volumetric system. This is typically accomplished by the publication and presentation of technical results. Even more important, perhaps, is direct communication with the intended users (in this case, the commercial vendors and the owners of ASTs) for review and comment of the test plan before and the test results after each set of field tests. While publication and direct interaction with the user community has been actively and vigorously pursued by

API, it may not be sufficient to effect the necessary technology transfer. In our opinion, the most effective method of insuring technology transfer involves the implementation of the second recommendation, the development of a standard test procedure.

5 IMPORTANT FEATURES OF A VOLUMETRIC METHOD WITH HIGH PERFORMANCE

The features of a volumetric test that are crucial to high performance have been identified. The design of a volumetric test must carefully address the diurnal temperature fluctuations observed in the volume data that are controlled by the ambient air temperature. Let us first examine the general features (those that are important to both the mass-measurement and the level-and-temperature approach). These "general" features apply to tests conducted on ASTs having diameters of approximately 100 ft. Important features particular to one approach or the other are described later. Note that either approach can be implemented with commercially available, off-the-shelf measurement systems.

- **Waiting Period.** Before starting a test, it is necessary to observe a waiting period of at least 24 h, during which time no product is added to or removed from the tank. This allows thermal inhomogeneities in the product to dissipate and any deformation of the tank shell to subside. (The waiting period is an established part of the protocol for testing USTs; because of the continuous nature of the data in the experiments described here, the importance of the waiting period was not verified independently as part of the current work.)
- **Low Product Level.** Product level should be low enough to optimize the signal-to-noise ratio. Good performance was achieved when the product level was at approximately 3 ft. This minimized the overall thermally induced volume changes and resulted in horizontal gradients at night that were small enough to be negligible.
- **Long Test Duration.** The duration of the data collection period during a leak detection test should be at least 24 h and preferably 48 h. Test durations that are whole multiples of a diurnal cycle should be used unless it is demonstrated a slightly longer or shorter duration will yield better temperature compensation. This would be the case if, for example, differences in temperature (whether of the ambient air, the shell, or the product) were less over a period of 22 or 26 h than over the full 24 h.
- **Test at Night.** For best performance, a test should begin and end at night, when there are no large changes in ambient air temperature and no sunlight heating the tank perimeter unevenly. Testing at night is equally important to both measurement approaches, since both are affected by expansion of the tank shell and by evaporation and condensation. There are also *different* reasons for testing at night that are particular to each approach. The fact that horizontal gradients in the rate of change of product temperature are sufficiently small at night means that a level-and-temperature system is a viable tool in leak detection; and the fact that the rate of change of the ambient air temperature is constant at night permits more accurate compensation of the thermally sensitive differential pressure sensor used in a mass-measurement system.

- **Digital Data Collection/Sampling Rate.** All data should be collected digitally at a sampling interval between 1 and 10 min. This permits the development and application of a variety of the more complex noise cancellation and data analysis algorithms.
- **External Temperature Sensors.** To permit compensation for thermally induced changes in the tank shell, a horizontal array of 6 external temperature sensors is recommended. These should be mounted on the outer steel wall and around the perimeter of the AST; they should be shaded from direct sunlight. When the data processing algorithm uses only the data from the beginning and end of a test initiated at night, fewer temperature sensors may suffice.
- **Known Coefficient of Thermal Expansion and Known Height-to-Volume Conversion Factor.** The coefficients required for temperature compensation and for conversion of level changes to volume changes should be known beforehand or should be measured as part of the test. A different set of constants will be required for each measurement approach. Errors in these constants will produce a bias in the test results that might be large enough to suggest the presence of a leak.
- **Sufficient Instrumentation Precision.** The "combined" precision of the level-and-temperature instrumentation used to measure the rate of change of the thermally compensated volume, regardless of approach, must be sufficient to sense a leak approximately one-third the size of the smallest leak to be detected reliably. A low-precision level sensor, for example, can be improved by increasing the test time. A method for estimating the minimum duration of a test conducted with a level sensor having a given precision is discussed by Starr and Maresca (Vista Research, Inc., 1989; Maresca and Starr, 1990). A method for estimating the minimum duration of a test conducted with a temperature sensor having a given precision is presented in the same works.
- **Compensation for Thermally Induced Volume Changes.** All thermally induced volume fluctuations need to be compensated for, or they must be minimized by means of a long test. Because the leak signal does not have a diurnal period, any diurnal fluctuations remaining in the compensated volume data are indicative of an error.

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

- A single array of closely spaced temperature sensors with a precision of 0.001°C is required in order that thermally induced changes in the product can be compensated for. It should be possible to position this array at any location in the tank if a test is begun and ended at night. The temperature sensors should be located at closely spaced intervals (e.g., 8- to 12-in., or closer); since most of the temperature changes occur in the upper portion of the product, and strong gradients are present in the lower portion, it is recommended that sensors be spaced more densely in the upper and lower layers of product (e.g., 4 in., or closer).

- The coefficient of thermal expansion of the product and steel shell, the volume of product in the tank, and the height-to-volume conversion factor must be known before a test is conducted. The coefficient of thermal expansion should be experimentally determined as part of the test procedure.

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

- The thermal sensitivity of the instrumentation must be minimized as part of the setup. It is essential that all tubes used to connect the DP sensor to the tank be horizontal and that all trapped air be completely removed from the tubes and the sensor. Additional temperature sensors attached to the body of the DP sensor and to the connecting tubes might be required to compensate for changes in ambient air temperature. Since we were unable to develop a compensation algorithm during the course of this analysis that could be universally applied to all of the differential pressure data, we cannot state with certainty that additional thermal problems will not occur when the pressure connections are made with horizontal tubes. The data obtained from a system configured with horizontal tubes suggest that thermal fluctuations still persist, even after thermal compensation.
- The coefficient of thermal expansion of the steel shell, the specific gravity of the product, and the height-to-volume conversion factor are required. If an accurate experimental estimate of the height-to-volume conversion factor is made during a test, then the specific gravity does not have to be known.

There are several ways to determine whether a signal is a false alarm or a real leak signal. The first step is to simply repeat the volumetric test. Previous analysis has shown that two or more tests will reduce the possibility of a false alarm. Since these tests are not totally independent, the performance improvement achieved by repeat testing may be only a factor of two or three. If, after a test has been repeated one or two more times, a leak is still suspected, another approach can be used. In this approach, a test based on a completely different technology, such as acoustics, is then conducted. This approach can be very effective because the mechanism generating the leak signal, and the noise interfering with it, are very different in an acoustic test than they are in a volumetric test. It is unlikely that the same false alarm mechanism will affect both methods similarly. Another effective approach is to drop a hydrophone over the purported leak and listen for the strong return of the continuous signal. The presence of a signal can be determined by comparing this acoustic return to the return obtained at one or more different locations in the tank where the leak signal is not present. This approach works because the strength of the