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Chemicals Stored in USTs: Characteristics and Leak Detection

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CHEMICALS STORED IN USTs: CHARACTERISTICS AND LEAK DETECTION

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U. S. Environmental Protection Agency is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document presents an analysis of the characteristics of chemicals stored in underground storage tanks (USTs) and how these characteristics affect the detection of leaks in such tanks. The work reported in this document has application to the UST release detection technical standards in CFR 280 Subpart D.

E. Timothy Oppelt, Director
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ABSTRACT

The regulations issued by the United States Environmental Protection Agency (EPA) in 1988 require, with several exceptions, that the integrity of underground storage tank systems containing petroleum fuels and hazardous chemicals be routinely tested. The regulatory standards for leak detection in tanks containing hazardous chemicals are more stringent than those for tanks containing petroleum motor fuels. This report describes (1) the regulatory standards for leak detection in tanks containing hazardous chemicals, (2) the types of chemicals being stored, (3) the characteristics of the tanks in which these chemicals are stored, (4) the effectiveness of tank tightness tests and automatic tank gauging systems for detection of leaks in tanks containing chemicals other than petroleum, and (5) the approaches to leak detection that are being implemented by tank owners and operators.

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SECTION 1
INTRODUCTION

On 23 September 1989, the United States Environmental Protection Agency (EPA) issued technical standards and corrective action requirements for owners and operators of underground storage tanks (USTs) that are used for petroleum products and hazardous chemical substances [1]. (A hazardous chemical is any substance defined by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [2]). Section 280.42 of the regulation presents the requirements for storing hazardous substances. There are five options for release detection in new tank and pipeline systems used to store hazardous substances. Four of these options require some form of secondary containment and periodic monitoring or leak detection within the secondary containment. The fifth option allows for leak detection without secondary containment safeguards providing that (1) the method or system is at least as effective as the ones allowed for use in petroleum USTs in Section 280.43 (b) through (h) of the regulation, (2) information is provided about the chemical and physical properties of the stored substance, the health risks associated with the substance, the characteristics of the site, and corrective action technologies that can be used in case of a release, and (3) approval from the implementing agency is received before installation and operation of the UST system. Existing USTs do not have to meet these requirements until 1998. Until that date, existing USTs need only meet the requirements for petroleum UST systems given in Section 280.41. After 1998, all existing USTs containing hazardous substances will be subject to the same requirements as new tanks.

Tank tightness test methods and automatic tank gauges (ATGs) are the two most frequently used release detection systems for petroleum USTs. Either one, when used in conjunction with monthly inventory reconciliation, is acceptable as the fifth option and thus will satisfy the requirements delineated in the regulations. (This option should not be used, however, if an accidental release cannot be environmentally tolerated even though detection may be immediate). The release detection requirements for tank tightness tests and ATGs are given in Section 280.43 (c) and (d) of the regulations. Tank tightness tests must be capable of detecting a 0.1-gal/h leak with a probability of detection of 0.95 and a probability of false alarm of 0.05, and ATGs must be capable of detecting a leak of 0.2 gal/h with the same probabilities of detection and false alarm as a tank tightness test. Because an ATG conducts tests more frequently, its performance requirement is not as stringent as that of a tank tightness method.

Over the next eight years, owners and operators of existing hazardous-substance USTs will be using volumetric leak detection systems (for example, tank tightness tests) that were developed primarily for use with petroleum products. As noted above, owners/operators may continue to use these systems after 1998 if the requirements specified in the fifth option are met. It is therefore critical to determine whether volumetric leak detection systems can be relied upon when used on tanks containing non-petroleum chemicals. The performance requirements that were developed for tank tightness tests and ATGs were based on extensive measurements in underground storage tanks containing petroleum motor fuels such as gasoline and diesel [e.g., 3 - 14]. Hazardous substances can differ from these fuels in density, coefficient of thermal expansion, viscosity, and vapor pressure. Moreover, since the list of hazardous substances is extensive, the variability of these properties is expected to extend over a broad range. The effects of these properties on volumetric testing, and therefore on the performance of tank tightness tests and ATGs, have not been fully assessed. Such assessment must be done if the owners and operators of existing hazardous-substance USTs are to have any assurance that they can depend on tank tightness tests and ATGs to guard against accidental releases.

Objectives

The objectives of this project were (1) to identify the chemicals being stored in underground storage tanks and the characteristics of the tank systems used to store these chemicals, (2) to assess the influence of the physical properties of the stored products on the performance of volumetric leak detection systems, and (3) to identify and determine the effectiveness of the approaches to release detection that owners and operators of tanks containing hazardous chemicals are taking to achieve compliance with the regulations.

Report Organization

The work that was done in fulfillment of these objectives is presented in the three technical papers [15-17] included in this report as Appendices A, B, and C. Each paper addresses one of the objectives of the project. The main conclusions and recommendations derived from this work are summarized in Sections 2 and 3 of this report.

The paper included in Appendix A has been accepted for publication in a peer-reviewed journal. This paper presents the results of an analysis of databases containing information on non-petroleum chemicals stored in underground storage tanks. These databases, compiled by 14 states, include the types of chemicals stored in USTs and the characteristics of the USTs themselves. This paper enlarges upon the work described in [18], which gave a comprehensive analysis of the data provided by New York, California, and the Chemical Manufacturers Association (CMA). The important results presented in [18] are also discussed in the paper included in Appendix A.

The paper included in Appendix B has been accepted for publication in the proceedings of the Air & Waste Management Association's 84th annual meeting, held in June 1991. This paper describes an analysis of the performance that could be achieved with volumetric test methods developed for tanks containing motor fuels or hazardous chemicals.

The paper included in Appendix C was published in the proceedings of the 17th annual research symposium sponsored by EPA's Risk Reduction Engineering Laboratory and held in April 1991. This paper summarizes the important aspects of the entire work assignment, including the chemical tank survey presented in Appendix A, the leak detection analysis presented in Appendix B, and the results of a survey of the leak detection practices of tank owners and operators.

SECTION 2
CONCLUSIONS

The main conclusions derived from the surveys and analyses conducted as part of this project are summarized below.

Characteristics of Tanks Containing Non-Petroleum Chemicals

A survey of the registered tanks containing chemicals other than petroleum was conducted and reported in [15]; a copy of the referenced paper is included as Appendix A of this report. The following states participated in the survey: California, Delaware, Florida, Illinois, Indiana, Maine, Massachusetts, Minnesota, Missouri, Montana, New York, Ohio, Texas, Virginia, and Wisconsin. The results of the survey suggest that chemical tanks, containing both hazardous and non-hazardous chemicals, comprise up to 2% of the total national underground tank population. Of the chemical tanks surveyed, approximately 50% were found to contain hazardous substances, while the remaining 50% contained chemicals that are not regulated. The most striking feature to emerge from the survey of chemical tanks is the wide variety of substances that are stored. Analysis of these substances indicates, however, that roughly 80 to 90% of the stored hazardous chemicals are organic solvents, and, of these, the most common are acetone, toluene, xylene, methanol and methyl-ethyl ketone. These five chemicals account for approximately 49% of the tanks containing hazardous materials.

Assessments were made not only of the most commonly stored substances but also of the ranges of tank capacity, age, and construction materials. The average tank capacity was found to be approximately 7,200 gallons, with over 27% of the tanks having capacities of 10,000 gallons or more. The mean age of the tanks was roughly 18 years, and over 86% were fabricated from steel. In view of survey's findings, it can be expected that substantial upgrading of tank installations will occur over the next eight years.

Analysis of the Applicability of Volumetric Leak Detection Systems to Tanks Containing Hazardous Chemicals

The performance of volumetric leak detection systems that could be used to meet the tank tightness testing and the automatic tank gauge release detection option was analyzed [16]. The results, presented here in Appendix B, show that (1) the performance of a volumetric leak detection system is directly proportional to the coefficient of thermal expansion of the stored product, and (2) the waiting period required for the effects of structural deformation to subside is essentially the same for all values of density (even though higher densities produce greater deformation-induced volume changes immediately after any product-level change). When a leak detection system is used with a chemical having a coefficient of thermal expansion lower than that of the product used in the evaluation of the system, the system's performance will be better than it was in the evaluation. Because gasoline has a higher coefficient of thermal expansion than many chemicals, a system evaluated with a gasoline product can be used with such chemicals and still maintain a similar level of performance.

For a large portion of the tank population, internal leak detection methods such as tank tightness tests and ATGs are a viable approach to testing tank integrity. The physical properties of the most commonly stored chemicals are generally similar to those of the unleaded gasoline upon which the quantitative performance standards in the regulations are based. In addition, the size and construction of a majority of chemical tanks closely approximate those from which the data used to support the regulations were developed. Assuming, therefore, that practical details of material compatibility and safety have been addressed, it would seem that only minimal extrapolations of current knowledge are needed before volumetric leak detection systems can be applied to storage tanks containing chemicals.

Currently Used Approaches to Leak Detection

An informal telephone survey of two types of organizations was conducted: those that own and operate tank systems containing hazardous substances and those that provide tank testing services to such organizations [17]. The object of the survey was to determine the type and effectiveness of the leak detection systems and inventory control practices being used to test tank systems. A copy of the referenced paper is included as Appendix C of this report.

Even though a diverse cross section of organizations was contacted, the responses obtained during the telephone survey should not be interpreted quantitatively; the number of organizations was very limited, and the survey was not statistically designed or statistically analyzed. As a consequence, the results should be interpreted cautiously, and the temptation to generalize, particularly about the status of regulatory compliance, should be avoided unless additional data are gathered. The following observations are noteworthy, however, either because the response was overwhelming or because it was ambiguous.

Based on the discussions conducted during the course of the survey, one would tend to conclude that most owners and operators of chemical tanks are actively involved in upgrading their tank systems to minimize the liability associated with any accidental releases. Most organizations said that they were replacing their underground storage tanks with aboveground tanks whenever possible. When this was not possible, tank and piping systems with secondary containment, primarily double-wall tanks and piping, were being used; none of the organizations contacted was considering the use of single-wall tanks or piping in conjunction with the release detection option. What is not clear from the survey is how much time will be required for those organizations currently upgrading their tank systems to complete the process. If the time required for upgrading a tank system exceeds one year, the regulations require that the tank system be tested in the interim by means of methods commonly used on tanks containing petroleum.

None of the organizations contacted used inventory control as a means of leak detection. It also appears that this method of leak detection would be difficult to apply because of the lack of metering devices or the lack of accuracy in the metering devices being used.

The tank testing firms contacted indicated that approximately 5% of their tests were conducted on tanks containing hazardous chemicals, a figure that is slightly higher than the estimated percentage of such tanks in existence in the U.S. This is inconsistent with the response obtained from the 13 tank-owning organizations that responded to the survey. None of these organizations indicated that they were using or planning to use such services; this inconsistency is probably due to the small size of the survey.

SECTION 3
RECOMMENDATIONS

Although the number and volume of underground storage tank systems containing hazardous chemicals is small, it is important to ensure that good leak detection practices are being used---in other words, practices that are in compliance with state and federal regulations.

No attempt was made in this project to assess the status of regulatory compliance by owners and operators of underground storage tank systems containing hazardous chemicals.

The principal recommendation of this project is that a survey be conducted (1) to assess the level of compliance on the part of owners and operators, and (2) to determine whether guidance documents in support of compliance efforts are needed and would be effective.

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APPENDIX A

CHARACTERISTICS OF UNDERGROUND STORAGE TANKS CONTAINING CHEMICALS

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CHARACTERISTICS OF UNDERGROUND STORAGE TANKS CONTAINING CHEMICALS

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ABSTRACT

It is generally acknowledged that a small fraction of the total underground storage tank population is used to store chemicals. The detailed characteristics of these tanks, however, are not well understood. Additional information is required if competent decisions are to be made regarding leak detection, tank upgrading, and tank management practices. In order to obtain more detailed information regarding these tanks, two surveys were conducted over the course of several years. The first survey examined the chemical tank populations in two states, California and New York, along with data from the Chemical Manufacturers Association. The second survey focused on the chemical tank databases for 14 states covering a wide geographical area. Data from these two surveys were then analyzed to determine the primary features of the chemical tank population. The results of these analyses indicate that up to 2% of the total tank population contains non-petroleum chemicals, with roughly half of these tanks, either by number or tank volume, containing hazardous substances. Solvents were found to comprise the single largest fraction of hazardous chemicals. Of these, acetone, toluene, methanol and methyl ethyl ketone were found to be the most commonly stored chemical substances, comprising roughly 60% of hazardous materials stored in tanks, and 34% of all chemical tanks, which contain both hazardous and non-hazardous substances, in the sampled states. Tank age was found to average 18 years, with over 85% of the tanks being fabricated from steel. Roughly 60% of the tanks in the state databases had capacities between 1,000 and 10,000 gallons, with the average tank size from all states being 7,205 gallons. These characteristics suggest that a strong potential exists for corrosion-induced tank leakage, but that conventional tank integrity testing could be applied to detect leakage from a large fraction of the chemical tank population, with no modifications to the leak detection performance requirements.

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Introduction

Federal underground storage tank regulations promulgated on 23 September 1988 (40 CFR 280,281) establish a broad range of minimum requirements for the design, installation, operation and testing of a large fraction of tanks in the United States containing both petroleum fuels and other hazardous chemicals (as defined by CERCLA, 40 CFR 302) [1,2]. These regulations are designed to help the underground tank community control and minimize the adverse environmental impact caused by leakage of product from the tank. Quantitative leak detection performance standards are included in these regulations. These standards were developed through an extensive theoretical and experimental test program conducted at the U.S. EPA's Underground Storage Tank Test Apparatus in Edison, New Jersey, on 8,000-gal tanks containing unleaded regular gasoline.

The federal regulations, as noted above, apply to petroleum substances as well as to a wide variety of chemicals having a broad distribution of chemical and physical properties. Specific information has not yet been assembled to characterize the features of the chemical tank population, or potential impact of these features on leak detection performance. Technically, since a large portion of the federal standards are based on data for a single, particular petroleum product, the influence of varying chemical composition on the ability of leak detection methods to satisfy the mandated performance standards needs to be addressed. The primary objective of this study is to develop, in sufficient detail, the characteristics of the tank population in which leak detection could be employed. With this information, a focused analysis of leak detection practices in underground chemical tanks can be made, and areas of potential alteration or improvement to the leak detection performance standards can be identified, if required. This paper describes the results of two chemical tank surveys. The first survey, conducted in 1987, was limited in scope, and relied on data from California, New York, and the Chemical Manufacturers Association [3]. A second survey, conducted in 1990, utilized the information from chemical tank databases in 14 states. Where possible, efforts were made to draw comparisons between the two data sets in an effort to gain an understanding of the characteristics of the chemical tank population.

Approach

As the first step in assessing the impact of underground chemical storage tanks on leak detection practices and performance, the basic characteristics of the tank population were identified. This was accomplished by means of two surveys conducted over the course of several years. The first survey utilized data from the two most populous states, California and New York, and on a national level, data from the Chemical Manufacturers Association (CMA). CMA data were used because, at the time of the survey, the registration of tanks in compliance with the Resource Conservation and Recovery Act (RCRA) amendments had not been fully implemented. The second survey used the chemical tank databases compiled by 14 different states distributed over a wide geographic area (Delaware, Florida, Illinois, Indiana, Maine, Massachusetts, Minnesota, New York, Ohio, Texas, Virginia, and Wisconsin). In selecting these states, efforts were made to obtain representative national coverage while simultaneously examining the more populous industrial states, which might be expected to have large numbers of chemical tanks. New York was again included in the second survey so that changes in its tank population since the earlier survey might be identified. For each state, information regarding stored substances was compiled. (This included CERCLA name and/or CAS number, tank capacity, material of construction, and tank age.) The information collected from this second survey was based primarily on the responses to the national underground tank registration requirements, which were instituted in 1984 as part of the amendments to the RCRA. The resulting data were then organized and sorted so that the basic characteristics of the sample population could be quantified.

Chemical Distribution

Previous studies suggest that, of the total number of underground tanks installed in the United States, approximately 95% are used to store petroleum products. The remaining 5%, comprising non-petroleum tanks, are devoted to the storage of a vast array of hazardous and non-hazardous chemicals. The initial survey of data from California, New York, and the Chemical Manufacturers Association indicated that non-hazardous chemicals comprised roughly 44 to 46% of the non-petroleum tank population. Of the remaining non-petroleum tanks, 3,766 (2.25%) of a total population of 166,973 tanks in California were found to contain CERCLA chemicals, while 792 (1.07%) of the 73,819 registered tanks in New York were considered hazardous.

Based upon the more recent data obtained from the survey of 14 states, the proportion of hazardous to non-hazardous tanks in the sampled non-petroleum tank population appears to be similar to that in the earlier survey. These data are summarized by state in Table 1. As would be expected, the relative proportion of hazardous and non-hazardous tanks in each of the sampled states exhibits a degree of variability. However, compilation of the aggregate proportions for all 14 states indicates that the hazardous fraction, by both number of tanks and by tank volume, is approximately 51.1% and 53.1%, respectively, compared to the earlier range of 44 to 46%.

Approximately half of the non-petroleum tanks are used to store hazardous chemicals as defined by CERCLA. Since this group of substances poses a significant environmental hazard, basic information regarding the primary characteristics of the tank population can be useful in helping to guide leak detection strategies. In addition, classification of this group of tanks can provide a useful means of comparing the data obtained from the tank surveys. This comparison can then be used to help identify any trends that may be developing in the management of this class of tanks.

In order to facilitate the analysis, the hazardous chemicals from the initial survey were classified into organic and inorganic compounds, and particular emphasis was then placed on characterizing the organic tank population. The organics were found to comprise approximately 81% of the CERCLA tanks in the databases. Organic compounds were classified as solvents, monomers, or miscellaneous compounds. Solvents include ketones/aldehydes, alcohols,

Table 1. Percentage of Hazardous vs. Non-Hazardous Chemicals Stored in Registered Non-Petroleum Tanks

	% by Number of Tanks			% by Volume	
State	**Number**	**% Haz**	**% Non-Haz**	**% Haz**	**% Non-Haz**
Delaware	18	78.9	21.1	97.0	3.0
Florida	404	28.2	71.8	30.4	69.6
Illinois	2862	72.0	28.0	68.1	31.9
Indiana	506	100.0	*	100.0	*
Massachusetts	66	49.0	51.0	54.8	45.2
Maine	667	28.8	71.2	22.6	77.4
Minnesota	406	24.9	75.1	28.9	71.1
Missouri	734	33.0	67.0	47.4	52.6
Montana	76	100.0	*	100.0	*
New York	936	100.0	*	100.0	*
Ohio	795	35.6	64.4	43.6	56.4
Texas	692	57.4	42.6	57.1	42.9
Virginia	896	34.2	65.8	42.7	57.3
Wisconsin	598	44.8	55.2	49.5	50.5

* An asterisk denotes that only hazardous, non-petroleum chemicals were reported in the database for that state.

aromatic hydrocarbons, esters/ethers, chlorinated hydrocarbons, and aliphatic hydrocarbons. Monomers include intermediates important to many manufacturing processes, including styrene, acrolein, vinyl esters, and ethylene and propylene oxides. Miscellaneous chemicals include various amines, organic acids, anhydrides, phenols, and other less common substances. The results of this classification of the data from California, New York, and CMA are shown in Table 2.

Table 2. Summary of Organic CERCLA Substances Stored in Underground Tanks (source: [3])

	California Data		New York Data		CMA Data	
Chemical Groups	**% by Tank Number***	**% by Tank Volume***	**% by Tank Number***	**% by Tank Volume***	**% by Tank Number***	**% by Tank Volume***
Solvents	87.1	81.9	91.4	90.0	78.3	72.3
Monomers	3.6	6.2	2.8	1.6	13.3	22.2
Miscellaneous	7.4	7.0	6.0	8.0	8.8	5.0
Pesticides	1.4	4.2	--	--	--	-

* Due to rounding, the total percentages may not sum to 100.

Inspection of these data indicates that, in terms of both capacity and number of tanks, solvents comprise the largest single fraction of the CERCLA tank population. Based upon this finding, additional sorting and classification was performed to characterize the solvent tank population, and to identify the most commonly stored substances. The results of this analysis are summarized in Table 3. While the CMA database suggested that the number of tanks containing acrolein, ethylene oxide, and styrene was fairly large (approxmately 2.5%), these chemicals were not included in Table 3, because their contributions to the New York and California databases were very small.

Table 3. Summary of the Most Commonly Stored Organic CERCLA Solvents (source: [3])

	California Data		New York Data		CMA Data	
Chemical	**% by Tank Number***	**% by Tank Volume***	**% by Tank Number***	**% by Tank Volume***	**% by Tank Number***	**% by Tank Volume***
Acetone	22.8	18.0	12.0	18.3	17.8	19.1
Toluene	13.3	14.2	22.4	21.1	13.1	16.9
Xylene	8.1	6.3	15.5	11.7	5.6	3.4
Methanol	6.6	5.5	11.5	8.5	15.8	14.9
Methyl- Ethyl Ketone	10.3	9.6	9.0	7.0	3.8	1.6
Methylene Chloride	2.8	2.1	1.4	0.7	8.5	7.6
TOTALS	63.9	55.7	71.8	67.3	64.6	63.5

* Percentages apply only to the CERCLA chemical tank populations in the initial survey.

These data suggest that a large fraction of the CERCLA organic chemical tank population is comprised of only a few predominant substances. In all three databases, the most commonly stored substances were found to be the same in four of five cases. The only difference that was found was in the case of methylene chloride and methyl-ethyl ketone; the former was more prevalent in the CMA data, while the latter was more common in the two state databases.

In order to provide a comparison with the more recent data collected from the 14 state databases, a similar analysis was made to identify the most commonly stored chemicals. The results of this analysis are given in Table 4.

In examining these data, two characteristics are notable. First, except for methanol and methyl ethyl ketone, the most commonly stored chemicals are the same in both surveys. The relative ranking of the most common chemicals by number of tanks or by storage capacity is slightly different in the two surveys. These differences depend upon the data survey analyzed, or

Table 4. Summary of the Most Commonly Stored Chemical Substances Based on Data from 14 States

Chemical	% by Tank Number*	% by Tank Volume*
Toluene	5.6	9.2
Acetone	3.9	4.2
Methanol	3.8	3.3
Methyl-Ethyl Ketone	3.7	2.9
Mineral Spirits	3.1	---
Xylene	---	2.5
TOTALS	20.1	22.1

* The data are reported as a fraction of the total number (or volume) of all hazardous and non-hazardous tanks.

whether the classification is based upon the number of tanks or on the storage capacity. Regardless of the data set examined, acetone, toluene, methanol, xylene, and methyl ethyl ketone are found to be prevalent in each survey.

Second, considering the broad range of chemicals, both hazardous and non-hazardous, the five most common chemicals comprise a significant fraction of the total chemical tank population. The initial survey indicated that as much as 81% of the chemicals stored in hazardous tanks was devoted to organic substances. Of that organic portion, 60% was comprised of the five most common substances. After the fraction of inorganic tanks has been accounted for, the five most common organics are estimated to comprise 49% of the total population of CERCLA (i.e., hazardous) tanks. The more recent survey of 14 states, extrapolated to the national level, suggests that this dominance is diminishing slightly. The results of this later survey indicate that only 40% of the hazardous chemical tank population is accounted for by the five most common solvents.

Tank Distribution

The initial survey indicated that tank capacities ranged from as little as 2,000 gallons to more than 20,000 gallons. The mean tank capacity in both the California and New York data was 6,000 gallons, while in the CMA data it was 15,000 gallons.

The range of tank sizes in the second survey, as well as the number of tanks in different size ranges, are summarized in Table 5. To generate this table, five different ranges for tank capacity were developed and the data then sorted by tank capacity. The results indicate that the average tank size in all surveyed states for which data were available ranged between 3,409 and 12,400 gallons. The aggregate average tank size was found to be 7,205 gallons. The largest size reported for an individual tank (found in Delaware) was 430,000 gallons.

Table 5. Summary of Tank Size Distributions Compiled from the 14 State Databases and Expressed as a Fraction of the Number of Tanks in Each State

	Range of Tank Capacities (Gallons)					
State	**< 1,000**	**1,000-<4,000**	**4,000-<10,000**	**10,000-<20,000**	**>20,000**	**Average Volume**
Delaware	5.6	16.7	27.8	22.2	27.8	101293
Florida	27.7	39.9	22.0	7.4	0.5	3409
Illinois	7.1	29.2	33.6	19.8	5.9	6826
Indiana*	4.3	16.0	26.5	19.8	29.6	11525
Maine	6.2	26.2	36.9	24.6	6.2	8226
Massachusetts	15.5	32.1	28.7	19.7	4.0	6132
Minnesota	15.3	34.5	23.9	18.2	7.1	6211
Missouri	10.1	28.7	31.9	21.0	8.3	9144
Montana*	44.7	23.7	19.7	3.9	7.9	12400
New York*	12.8	22.3	30.8	23.5	10.6	8957
Ohio	6.6	33.8	37.9	18.1	3.6	5546
Texas	11.3	28.0	28.9	19.7	6.8	6952
Virginia	15.8	29.4	28.7	17.0	6.9	6534
Wisconsin	8.4	30.4	37.6	19.7	3.8	6350
TOTAL	11.3	29.6	31.9	19.6	7.6	7205

* Totals for New York, Indiana, and Montana are based on CERCLA chemicals only.

It is clear from these data that the majority of the tanks exhibit capacities of 20,000 gallons or less. In addition, over 70% of the tanks have capacities less than or equal to 10,000 gallons, with the two largest groups comprising the range between 1,000 and 10,000 gallons. With the exception of Delaware, the average tank volume for most states was generally found to be between 6,000 and 9,000 gallons. The data for Delaware are comprised of only 18 tanks, four of which have capacities of 430,000 gallons each, resulting in an extremely biased average tank volume.

The implication of this tank size distribution for leak detection should be carefully considered. Based upon the experimental data used to support the development of the national regulations, it is expected that, qualitatively, as the tank capacity is increased beyond 10,000 gallons, it will become increasingly more challenging to conduct precision tests. Fortunately, the majority of tanks in the surveyed states have capacities of 10,000 gallons or less. This characteristic, coupled with the chemical and physical properties of the most commonly stored chemicals, suggests that a significant portion of the hazardous chemicals may be addressed by volumetric tests, which have performed satisfactorily in detecting leaks of petroleum motor fuels. As a consequence, the impact of tank size on the feasibility of conducting internal (i.e., volumetric) tests of these tanks should be minimal. For larger tank capacities, issues associated with appropriate scaling of volumetric leak detection performance would need to be addressed before employing this type of test. For the near term, however, volumetric testing would probably be a preferred leak detection approach, since interstitial monitoring, which could be used to detect product leakage through the primary tank wall, would be limited to the small fraction of installed double-walled tanks. The suitability of exterior monitoring for the current tank population cannot be assessed from the current data.

Tank Construction

Data from both surveys indicate that the primary material of construction for underground tanks containing hazardous substances is carbon steel. In the initial survey, summarized in Table 6, New York and CMA data indicated that the fraction of steel tanks in the entire population was 86.4% and 87.7%, respectively. Painting was the predominant method of corrosion protection for these tanks. The majority of these tanks utilized single-walled construction, with New York reporting that 54.9% and CMA that 38.4% of tanks were painted for corrosion resistance. Of particular note in this survey was the large number of tanks in which corrosion protection was not employed or the type of protection was unknown. In New York, 41.3% of the tanks exhibited this characteristic, while for the CMA, the fraction was 42.9%.

Table 6. Summary of Tank Construction Materials (source: [3])

Construction	New York Data % by Tank Number	CMA Data % by Tank Number
Steel	90.3	93.7
Fiberglass/Plastic	3.4	0.7
Other	6.3	5.6

In the more recent survey, summarized in Table 7, the distribution of steel tanks was found to support these earlier findings. In addition, significant portions of the installed tanks in some of the states are of unknown construction, with as many as 22.3% of the tanks in Florida fitting this category.

Table 7. Summary of Tank Construction Materials Compiled from 14 State Databases

State	Steel	Fiberglass Reinforced Plastic	Other	Unknown
Delaware	77.8	0.0	5.5	16.7
Florida	62.9	9.2	5.7	22.3
Illinois	89.4	4.2	2.6	3.8
Indiana*	---	---	---	---
Maine	72.7	15.2	10.6	1.5
Massachusetts	90.3	5.4	3.0	1.3
Minnesota*	---	---	---	---
Missouri	83.4	7.2	6.1	3.3
Montana	85.5	---	---	---
New York	83.9	12.3	3.8	0.0
Ohio	94.1	2.1	1.5	2.3
Texas*	---	---	---	---
Virginia	86.5	5.9	5.1	2.6
Wisconsin	79.3	9.4	7.2	4.2
TOTAL	86.1	6.2	3.9	3.8

* Materials were not reported for Indiana, Minnesota, and Texas. Only steel tanks were reported for Montana. Values reported are percentages of the total tank populations in each state.

Age Distribution

Inspection of the tank age distribution derived from the two surveys can yield some insights into the likelihood of potential problems, as well as an early indication of developing trends in tank construction practices. Data from the original survey suggest that, while the tank ages ranged from new to 60 years old, the mean tank age for both New York and the CMA (national) data was approximately 18 years. While no information was developed regarding the distribution of ages in this survey, the average age, coupled with the large fraction of marginally protected (if at all) steel tanks, suggest that there exists strong potential for tank leakage due to corrosion. The extent of this potential threat is somewhat site-specific and dependent upon numerous other factors, including tank maintenance practices, electrical properties of the local backfill, and local water-table levels.

The more recent study of the 14 sampled states yields a tank age distribution summarized in Table 8. As can be seen in this table, the mean age of all tanks containing chemical substances is 18.3 years, with nearly 40% of the tanks being over 20 years old. According to this survey, the average age of those tanks in New York whose age was known was 17.9 years in 1990. This suggests that, in spite of the upgrading requirements in the federal underground tank regulations, large scale improvements to the chemical tank population have not yet been widely implemented.

Table 8. Summary of Tank Age Distributions Compiled from 14 State Databases and Expressed as a Percentage of the Number of Chemical Tanks in Each State

	Range of Tank Age (Years)				
State	**0 to 4**	**5 to 9**	**10 to 14**	**15 to 19**	**>= 20**
Delaware	22.2	5.6	5.6	0.0	66.7
Florida	3.5	31.4	18.7	11.0	35.4
Illinois	2.6	12.1	22.9	18.2	44.2
Indiana	6.9	15.2	20.6	16.8	40.5
Maine	9.1	14.1	13.9	16.2	46.7
Massachusetts	1.8	14.0	43.9	17.5	22.8
Minnesota	3.0	23.0	22.2	10.0	41.8
Missouri	3.3	20.9	23.0	16.0	36.8
Montana	2.7	4.0	4.0	2.7	86.7
New York	14.8	15.2	20.0	14.2	35.8
Ohio	1.5	15.8	20.4	21.5	40.8
Texas	6.2	21.3	26.1	17.9	28.4
Virginia	2.1	19.1	21.6	21.1	36.0
Wisconsin	4.3	13.8	24.9	25.6	31.5
AVERAGE	4.9	16.2	21.6	17.6	39.7

Conclusions

Based upon the currently available information, the chemical tank population, although comprising only 1 to 2% of the total national underground tank population, appears to pose a substantial environmental hazard. Of the chemical tanks surveyed, approximately 50% were found to contain hazardous chemicals, while the remaining 50% contain chemicals that are not regulated.

The most striking feature of the surveyed chemical tank population is the wide variety of substances that are stored. Analysis of these substances indicates that roughly 80 to 90% of the hazardous chemicals are organic solvents. Of these, the most common constituents are acetone, toluene, methanol and methyl ethyl ketone, comprising between 44 to 49% of the number of surveyed CERCLA tanks.

In addition to assessments of the most commonly stored substances, assessments were made of the range of tank capacities, ages, and materials of construction. Based upon these analyses, the mean tank age was found to be roughly 18 years, with over 86% of the tanks fabricated from steel. The average tank capacity was found to be roughly 7200 gallons, with over 60% of the tanks having capacities between 1,000 to 10,000 gallons. In view of these findings, substantial upgrading of tank installations can be expected to occur over the next 8 years, as tank owners comply with the national regulations.

Internal leak detection appears to offer one viable approach to testing the integrity of a large fraction of the tank population. The physical properties of the most commonly stored chemicals are generally similar to those of the unleaded gasoline upon which the quantitative performance standards in the regulations are based. In addition, the size and construction of a majority of the chemical tanks closely approximate those from which supporting data for the regulations were developed. As a consequence, assuming practical details of material compatibility and safety have been addressed, only minimal extrapolations of current knowledge should be needed in order to conduct tank integrity tests.

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Appendix

PARTIAL LIST OF CHEMICALS STORED IN UST

Partial List of Chemicals Stored in UST

	CERCLA	NON-CERLA
Ketones/Aldehydes	Acetone Methyl ethyl ketone Methyl iso butyl ketone Cyclohexanone Formaldehyde	
Alcohols	Methanol n-Butanol iso-Butanol	Ethanol n-Propanol iso-Propanol Tridecyl alcohol 2-Ethyl hexanol 2-Methoxy ethanol 2-Ethoxy ethanol Methyl amyl alcohol Strearyl alcohol
Esters/Ethers/Glycols	Ethyl acetate n-Butyl acetate iso-Butyl acetate Dioctyl phthalate Ethyl ether	Ethylhexyl acetate n-Propyl acetate Trioctyl phthalate Cellosolve acetate Sodium octyl acetate Sodium phenyl acetate Methly ether Propylene glycol-methyl ether Ethylene glycol Propylene glycol
Aromatic Hydrocarbons	Benzene Toluene Xylene	1-Propyl toluene
Chlorinated Hydrocarbons	Methyl chloride Methylene chloride 1,1,1, Trichloromethane Carbon tetrachloride Ethylene dichloride	Trichloromonofluoromethane
Monomers	Stryrene Propylene oxide Vinyl acetate Methyl methacrylate Ethyl acrylate	Butyl acrylate
Miscellaneous Chemicals	Acetic acid Propionic acid Adipic acid Phenol Tetrahydrofuran Furfural Hydrazine Monomethyl amine Toluene di-iso cyanide Acetic anhydride Allyl chloride Phosgene Carbon disulfide	Methyl cellosolve Ethyl cellosolve Butyl cellosolve Naphthol Perchloroethylene-hydroflouric acid Hexyl cellosolve Sodium silicate 1-Nitropropane

(continued)

Partial List of Chemicals Stored in UST (continued)

	CERCLA	NON-CERLA
Inorganic Chemicals	Sodium hydroxide Potassium hydroxide Hydrochloric acid Sodium hypochlorite Sodium cyanide Ammonium thiosulfate Ferric chloride Ferrous chloride Chromic acid Chlorine Zinc Chromium Phosphorus Ammonium hydroxide Nitric acid Sulfuric acid Phosphoric acid Ammonium sulfide Ferrous sulfate Hydrogen cyanide	Potassium fluoride Calcium mitrate

APPENDIX B

VOLUMETRIC LEAK DETECTION IN UNDERGROUND STORAGE TANKS CONTAINING CHEMICALS

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Volumetric Leak Detection in Underground Storage Tanks Containing Chemicals

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Abstract

Volumetric tank tightness test methods are most commonly used to detect small leaks in underground storage tanks containing petroleum products. The performance of most of these leak detection systems has been evaluated on 30,000- or 38,000-L (8,000- or 10,000-gal) tanks containing gasoline or diesel products. These same systems can be used to test underground storage tanks containing other chemicals provided that the equipment is not damaged by the chemicals contained in the tank. The performance achieved by these testing systems depends on the chemical properties of the product in the tank. Two analyses based on mathematical models of volumetric leak detection systems were done. The purpose was to determine if significant differences in performance should be expected when such systems are used to test tanks containing liquids other than petroleum. The first analysis, covering the range of chemicals stored in underground tanks, addressed errors in temperature compensation as a function of the coefficient of thermal expansion. The second analysis dealt with the waiting period required for the volume changes due to structural deformation of the tank to subside, and examined this waiting period as a function of the density of the stored product. It was assumed in both analyses that the hypothetical volumetric leak detection system used an array of five equally spaced thermistors each having a precision better than 0.001°C/h (0.002°F/h), and a level sensor having a precision better than 40 ml/h (0.01 gal/h). For the purpose of the analysis, the tank was partitioned into five layers of equal thickness, each layer centered on a thermistor; the thermally induced volume changes in each layer were then summed, giving an estimate of the thermally induced volume changes in the tank as a whole. The analyses suggest that the performance of a volumetric leak detection system is directly proportional to the coefficient of thermal expansion of the stored product and that the waiting period required for the effects of deformation to become neglible is nearly independent of the chemical stored in the tank. Because gasoline has a higher coefficient of thermal expansion than many chemicals, most volumetric leak detection systems designed to test tanks containing gasoline products can also be used to test tanks containing the most commonly stored chemical products, without sacrificing performance.

1 Introduction

Only a small fraction of the total underground storage tank population is used to store chemicals. An analysis of a database of chemical storage tanks in 14 states indicates that approximately 2% of the total tank population contains non-petroleum chemicals, with roughly half of these tanks, either by number or tank volume, containing hazardous substances [1]. Solvents were found to comprise the single largest fraction of hazardous chemicals. Of these, acetone, toluene, methanol and methyl-ethyl ketone were found to be the most commonly stored chemical substances, comprising roughly 60% of the hazardous materials stored in tanks and 34% of all chemical tanks in the sampled states. Tank age was found to average 18 years, with over 85% of the tanks being fabricated from steel. Roughly 60% of the tanks in the state databases had capacities between 3,800 and 38,000 L (1,000 and 10,000 gal), with the average tank size from all states being 27,275 L (7,205 gal). These characteristics, which are more thoroughly described in [1], suggest that a strong potential exists for corrosion-induced tank leakage.

Detection of leakage from underground chemical tanks poses many of the same challenges encountered in testing petroleum storage tanks. Many of the procedural requirements identified in previous work for testing petroleum tanks can be expected to be applicable to chemical tanks as well [2-10]. Currently available data suggest that a large fraction of the chemical tank population utilizes single-walled steel construction. The release detection standards in the federal regulations for tanks containing hazardous chemicals are more stringent than for tanks containing petroleum products and require that all existing tanks be upgraded to meet these standards by 22 December 1998 [11]; all new tanks must also meet these standards. While the regulations strongly encourage the replacement of single-wall tanks with tanks that are secondarily contained, the regulations permit the use of single-wall tanks with leak detection provided that approval from the regulatory agency is obtained. Until upgrading is fully implemented, however, volumetric tank tightness testing can be expected to play an important role in the detection of leaks from chemical tanks. While permitted by regulation, the role of volumetric testing after 1998 is expected to be small, because most tanks will be secondarily contained and methods applicable to the "interstitial" space will be used.

The volumetric leak detection systems developed to test underground storage tanks containing petroleum products should be applicable to tanks containing other chemicals provided that the chemicals in question do not damage the equipment. Most of these systems were designed to meet the EPA regulatory standards [11], which means that they must be able to detect leaks as small as 380 ml/h (0.1 gal/h) with a probability of detection (P_D) of 0.95 (95%) or better and to keep the probability of false alarm (P_{FA}) less than or equal to 0.05 (5%). The performance achieved by these systems depends on the chemical properties of the product in the tank. Performance has, in most cases, been determined through an evaluation based on a single, specific, stored product. Volumetric leak detection systems were developed specifically to test storage tanks containing petroleum fuels, and any estimates of their performance, therefore, have been based on this class of liquids. Most performance evaluations of such systems have been conducted in 30,000- or 38,000-L (8,000- or 10,000-gal) tanks containing either gasoline or diesel fuels. If the tank contains a chemical that differs, in density, viscosity, or coefficient of thermal expansion, from the product used in the evaluation of a given leak detection system, the performance of that system on the chemical tank will be different from what it was on the petroleum tank.

The chemical properties of the stored product affect the magnitude of the ambient noise field and thus the performance of the leak detection system. Among the more important sources of ambient noise are the volume changes produced by fluctuations in product temperature and by the structural deformation of the tank-backfill-soil system. Both types of volume changes can be affected by the kinematic viscosity, surface tension, density, and coefficient of thermal expansion of the product. Kinematic viscosity (dynamic viscosity divided by density) and surface tension affect the rate of flow through a hole at a given pressure head even if the leak is as small as 380 ml/h. However, since the signal is reported in terms of flow rate and not hole size, the influence of viscosity on the magnitude of the signal does not enter into the performance calculations. The density affects the pressure differential between the product in the tank and the backfill and soil system supporting the tank walls, and, as a consequence, is an important factor in determining how long it takes for the time-dependent volume changes due to structural deformation to subside. The coefficient of thermal expansion of the product affects the magnitude of the thermally induced volume changes and therefore the accuracy of temperature compensation. When a tank is partially filled, the product may exists in two states, liquid and vapor. In a test conducted on such a tank, the vapor pressure affects the magnitude of the volume changes due to evaporation or condensation at the vapor/liquid or vapor/wall interface. When a test is conducted on an overfilled tank, the vapor pressure affects the volume changes due to the expansion or contraction of any pockets of trapped vapor.

This paper investigates the influence of the viscosity, density, and coefficient of thermal expansion of the stored product on the performance of volumetric leak detection systems used to test tanks containing the chemicals identified in [1]. The signal and noise models developed for petroleum-based testing systems are used to investigate (1) the effect of the coefficient of thermal expansion on the magnitude of the thermally induced volume changes and (2) the effect of density on the magnitude of the deformation-induced volume changes. Aspects of the vapor pressure are not discussed in this paper.

2 Chemical Properties of the Stored Product

A wide variety of chemicals are stored in underground tanks. Table 1 lists some of the most commonly stored hazardous chemicals and presents baseline values for those properties of the listed chemicals that affect volumetric tests (i.e., density, coefficient of thermal expansion, and dynamic viscosity). To expand the range of baseline values, ethylene glycol and carbon tetrachloride, which have higher densities (and in the case of the former, a higher viscosity as well), have been added to the list in Table 1. Also included are typical values for water and the two most common petroleum fuels, gasoline and diesel. The chemical properties of the petroleum fuels provide a basis for comparison and a reference point for material discussed later in this paper.

Table 1. Summary of the Physical Properties of Selected Chemical Substances at a Temperature of 20°C. (Typical properties of diesel and unleaded gasoline at 20°C are included for comparison.)

Stored Product	Density (g/ml)	Coefficient of Expansion (/°C)	Viscosity (cp)
Acetone	0.790	0.001423	0.32
Toluene	0.867	0.00109	0.59
Xylene	0.880	0.000968	0.81
Methanol	0.791	0.00120	0.60
Ethylene Glycol	1.120	0.00065	19.9
Carbon Tetrachloride	1.595	0.00118	0.969
Water	1.000	0.0001	0.44
Diesel	*0.800*	*0.000792*	*2.50*
Gasoline	*0.743*	*0.001251*	*0.63*

3 Temperature Compensation

In volumetric testing, the most important physical property to be considered is the coefficient of thermal expansion (C_e) of the stored fluid. Temperature fluctuations in the fluid cause it to expand and contract, a phenomenon that is manifested as apparent changes in volume. Virtually all volumetric leak detection systems attempt to compensate for these changes by estimating what portion of the total volume change is due to thermal activity and then subtracting this portion from the total in order to obtain the actual volume change (the change due to the leak alone). Therefore, the coefficient of thermal expansion is of direct importance to the accuracy of the test.

The performance of a leak detection system is expressed in terms of the P_{FA} and the P_D against a specific leak rate [2-7]. Estimates of performance are made from the histogram of the noise and the signal-plus-noise. The noise is compiled from a large number of tests on one or more nonleaking tanks over a wide range of ambient temperature conditions. In the present study, the temperature database that had been compiled from the wide range of temperature conditions generated in the 30,000-L (8,000-gal) steel and fiberglass tanks at EPA's UST Test Apparatus in previous studies [2-7] was used to estimate the performance of the model leak detection system with different stored chemicals. This database, even though it is based on unleaded gasoline (the product in the EPA tanks at the time of the previous work), was the only option because it is the only one of its kind in existence; there are no similar temperature databases for other chemicals. Unleaded gasoline has a coefficient of thermal expansion of 0.00125/°C, and it was assumed in the performance estimates made as part of the present study that all the liquids examined exhibit temperature changes identical to those seen in gasoline. (This may not be true if the thermal diffusivity of a chemical differs sufficiently from that of gasoline.) The effect of the coefficient of thermal expansion was determined directly from this database and a model of a volumetric leak detection system having sufficient performance to meet the EPA regulatory standard for a tightness test.

The performance estimate made in this study was derived according to the following procedure.

- It was assumed that the volumetric leak detection system used five evenly spaced, volumetrically weighted thermistors for temperature compensation and that the pressure head remained nearly constant during a leak detection test.
- A test conducted with this leak detection system was initiated 12 h after product had been added (whether in the form of a delivery or topping). For the tanks at the UST Test Apparatus, this waiting period was sufficiently long that deformation had become negligible and that the performance of the system was controlled mainly by the accuracy of the temperature compensation.
- The length of this test was 1 h.
- The precision of both the thermistors and the level sensor was more than sufficient to keep the total instrumentation uncertainty less than 40 ml/h (0.01 gal/h); each thermistor had a precision better than 0.001°C (0.002°F).
- Temperature data from each thermistor were sampled once per minute; data from the level sensor were sampled once per second and averaged to one sample per minute.
- The tank was partitioned into five layers of equal thickness, each layer centered about a thermistor, and the thermally induced volume changes in each layer were calculated and summed to obtain the thermally induced volume change in the tank as a whole.

- The temperature-compensated-volume time series was generated by subtracting the thermally induced volume changes measured by the thermistor array from the volume changes measured by a level sensor.

- The temperature-compensated volume rate was estimated by fitting a least-squares line to the temperature-compensated-volume time series.

The effect of the coefficient on the cumulative frequency distribution of the noise can be seen in Table 2 and Figure 1. Each cumulative frequency distribution was compiled from the temperature-compensated-volume rates from 321 tests simulated with the leak detection system described above. Given the variety of chemicals found in underground storage tanks, there can be a wide range of values for the coefficient of thermal expansion. Three values of the coefficient were selected here in an attempt to encompass as much of this range as possible. The middle curve in Figure 1 shows the cumulative frequency distribution of the test results when the product was gasoline (0.00125/°C). As can be seen in Table 2, increasing the value of the coefficient of thermal expansion from half that of gasoline to twice that of gasoline results in a corresponding increase in the standard deviation of the temperature-compensated-volume-rate histogram. Thus, the performance of a volumetric system is directly proportional to the value of the coefficient. The impact of this increase can best be appreciated if we calculate its effect on the detectable leak rate at a P_D of 0.95 and a P_{FA} of 0.05. The results of these calculations are given in Table 2. It should be noted that the detectable rates given in Table 2 assume that thermal expansion is the only noise source present, and that performance has not been degraded by insufficient sensor resolution or by improper test procedures.

Table 2. Variation in Detectable Leak Rate for Selected Coefficients of Thermal Expansion (It is assumed that the compensated-volume-rate histogram has a normal distribution.)

Coefficient (/°C)	Standard Deviation (ml/h)	Threshold (ml/h)	Probability of False Alarm	Probability of Detection	Leak Rate (ml/h)
0.00062	34	-55	0.05	0.95	111
0.00125	68	-112	0.05	0.95	223
0.00250	136	-223	0.05	0.95	446

It is evident from Table 2 that, as the coefficient of thermal expansion increases, the detectable leak rate at a given value of P_D increases by the same amount. This occurs because the normal model used to characterize the histograms of the noise and signal-plus-noise is completely described by the standard deviation (i.e., there is no bias and the mean of the noise histogram is 0 ml/h), and the relationship between the coefficient and the standard deviation of the compensated-volume-rate histogram is linear. Based upon this observation, we can expect

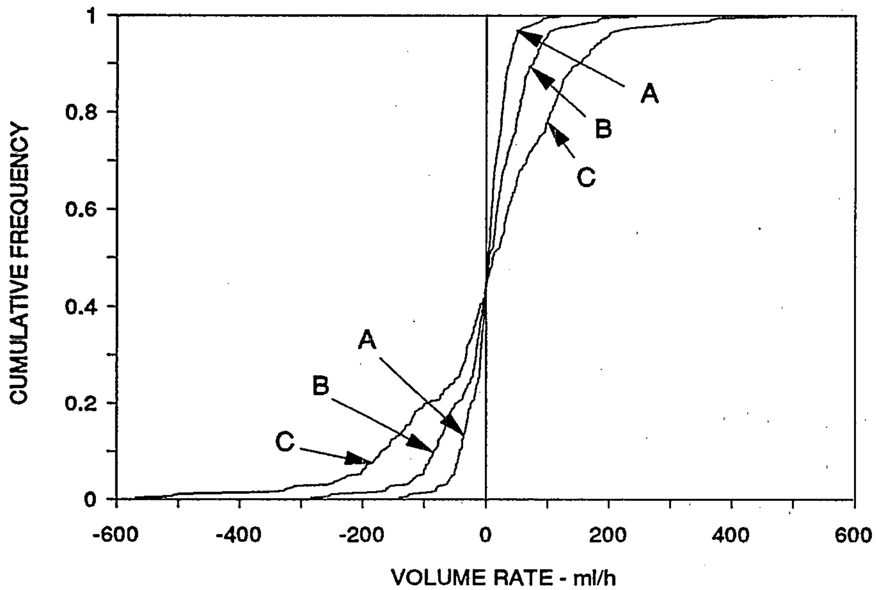

Figure 1. Cumulative frequency distributions for three coefficients of thermal expansion generated from temperature-compensated-volume-rate histograms, given a leak detection system employing five volumetrically weighted, evenly spaced thermistors. Curves A, B, and C show coefficients of 0.00062/°C, 0.00125/°C, and 0.0025/°C, respectively.

that the performance of a given volumetric leak detection system will be proportional to the coefficient of thermal expansion of the stored product. As a result, appropriate adjustments to the threshold value (the basis for declaring a leak) will be necessary if a system's performance is to be maintained at levels comparable to those obtained when that system was evaluated.

A typical example of the need for such threshold adjustments can be seen if we examine the threshold required to maintain a P_{FA} of 0.05 in the case of a volumetric leak detection system that was evaluated on a tank containing gasoline (C_e=0.001251 /°C) but is now used on tanks containing other chemical products. When the coefficient is half that of gasoline, using a threshold of 112 ml/h results in a P_{FA} of 0.0005, much better than what is required to meet the minimum EPA performance requirements; but when the coefficient increases by a factor of 2 over what it is for gasoline, the P_{FA} can be as high as 0.21. Thus, when the coefficient is greater than that of the product used in the evaluation, it may be necessary to increase the threshold to satisfy the performance requirements specified in the EPA regulation; such an adjustment will not be possible if the performance just barely meets the EPA standards.

Similar behavior can be expected in the case of the probability of detection and the detectable leak rate. In this case, using a fixed threshold while the coefficient increases beyond that of gasoline will increase the detectable leak rate while maintaining a constant P_D. Conversely, maintaining the detectable leak rate at a fixed value yields a lesser P_D as the coefficient increases.

It is clear from the data shown in Table 2 that a leak detection system cannot be applied indiscriminately to a fluid other than that used in the performance evaluation of that system. Such an application should be undertaken with appropriate caution if regulatory standards are to be maintained. This is particulary true when the coefficients are greater by a factor of 2 or more than those in the evaluation, for example, when a system evaluated with diesel fuel (C_e = 0.000792/°C) is to be used with another petroleum fuel such as gasoline (C_e = 0.00125/°C) or with a chemical product such as acetone (C_e = 0.00142/°C).

The most commonly used leak detection threshold is 0.05 gal/h. Table 3 presents the P_D and P_{FA} against a 380-ml/h (0.1-gal/h) leak; a normal model is used to estimate performance. A normal model usually does not describe the tails of the cumulative frequency distributions well, and it generally results in better performance estimates than the leak detection system would realize in actual operation. Estimates of performance using the empirically derived cumulative frequency distributions are presented in Table 4. In the case of the two smaller coefficients, the performance estimates made with the normal model suggest better performance than would actually be achieved. This is important because very few chemicals have a coefficient as high as gasoline (the second coefficient shown in Table 4). In the case of the highest coeffficient, the performance estimates made with the normal model are about the same as those made with the empirical model.

Table 3. Estimates, Made with a Normal Model, of the P_{FA} and the P_D against a Leak Rate of 380 ml/h (0.1 gal/h) Using a Threshold of 190 ml/h (0.05 gal/h)

Model	Coefficient (/°C)	Standard Deviation (ml/h)	Threshold (ml/h)	Probability of False Alarm	Probability of Detection	Leak Rate (ml/h)
Normal	0.00062	34	-190	< 0.0000001	> 0.9999999	380
Normal	0.00125	68	-190	0.0026	0.9974	380
Normal	0.00250	136	-190	0.080	0.920	380

Table 4. Estimates, Made with the Empirically Determined Cumulative Frequency Distribution, of the P_{FA} and the P_D against a Leak Rate of 380 ml/h (0.1 gal/h) Using a Threshold of 190 ml/h (0.05 gal/h)

Model	Coefficient (/°C)	Standard Deviation (ml/h)	Threshold (ml/h)	Probability of False Alarm	Probability of Detection	Leak Rate (ml/h)
Data CFD	0.00062	33.7	190	<< 0.003	>> 0.997	380
Data CFD	0.00125	67.8	190	0.015	0.994	380
Data CFD	0.00250	135.6	190	0.074	0.949	380

4 Structural Deformation

In the temperature-compensated histogram in Section 3, the bias of the leak detection system was equal to 0.0 ml/h. Under actual conditions, this may not be the case. One of the primary sources of bias in a test result is the residual structural deformation of the tank in response to a change in product level. Previous work conducted in support of the initial EPA evaluation of volumetric test methods [2-10] identified the basic exponential characteristics of this phenomenon, and recommended that a waiting period be adopted as part of a leak detection system's test protocol. This waiting period minimizes the detrimental effect of structural deformation on a system's performance. In the EPA work, unleaded gasoline was the fluid used in evaluating leak detection systems. In the present study, therefore, an assessment was made as to whether varying the density of the product would have a significant effect on the response of the tank in terms of structural deformation.

Any time that the level of the product in the tank is raised or lowered, the potential exists for the tank to expand or contract due to the concomitant pressure change. A comprehensive discussion of the volume changes produced by tank deformation is presented in [2,6,8]. In the works cited, models were developed, and validated through experiments, to predict the magnitude of the volume changes produced by two different measurement methods: (1) when the product is maintained at a constant pressure head and the volume changes are measured directly and (2) when the product level is allowed to change freely during a test and volume changes are measured in a 10-cm (4-in.) -diameter fill tube. These models showed that the latter method can lead to highly erroneous measurements of the volume changes, whether these changes are produced by the leak or whether they are produced by any one or more of the sources of noise.

Since deformation is primarily pressure-driven (hydrostatic pressure changes cause the tank's end walls to deflect until a new state of equilibrium is attained), calculations were made to examine the effects of different fluid densities on the deformation response of the tank. In each of these calculations, three different densities were used: 0.743, 1.00, and 1.20 g/ml. The smallest of these values is representative of a typical gasoline and approximates the values of a large number of organic chemicals. The other two values expand the range of gravities that may be encountered and cover a large fraction of the substances identified in the chemical tank survey [1]. The deformation response of the tank to an instantaneous level change of 100 cm was calculated for each density and for both measurement methods described in the preceding paragraph. The elasticity constant and the time constant used in the analysis were those of the steel tank at the EPA's UST Test Apparatus (120 cm^2 and 3 h, respectively). Choosing these three values, even though they result in a high degree of deformation, afforded direct comparisons to the earlier work [2-10].

It was assumed in the calculations that there was a leak of -380 ml/h and that a level change of 100 cm took place. Figure 2 shows the results of these calculations when product level (in a 10-cm (4-in.) -diameter fill tube) was allowed to vary, and Figure 3 when a constant product level was maintained. Figures 4 and 5 show the results of the same calculations, but with two differences. First, part (a) of both figures shows, for comparison purposes, a leak of 0 ml/h, and part (b) shows the -380-ml/h leak; second, in both part (a) and part (b) the data collection begins at a point *4 h after* the level change. This is done not only to show the curves in more detail but also because most leak detection systems, in order to minimize the effects of temperature inhomogeneities when product is added to or removed from the tank, specify a waiting period before the test is begun. Most systems wait at least 4 to 6 h after any delivery of product and at least 3 h after topping, regardless of the magnitude of the deformation changes.

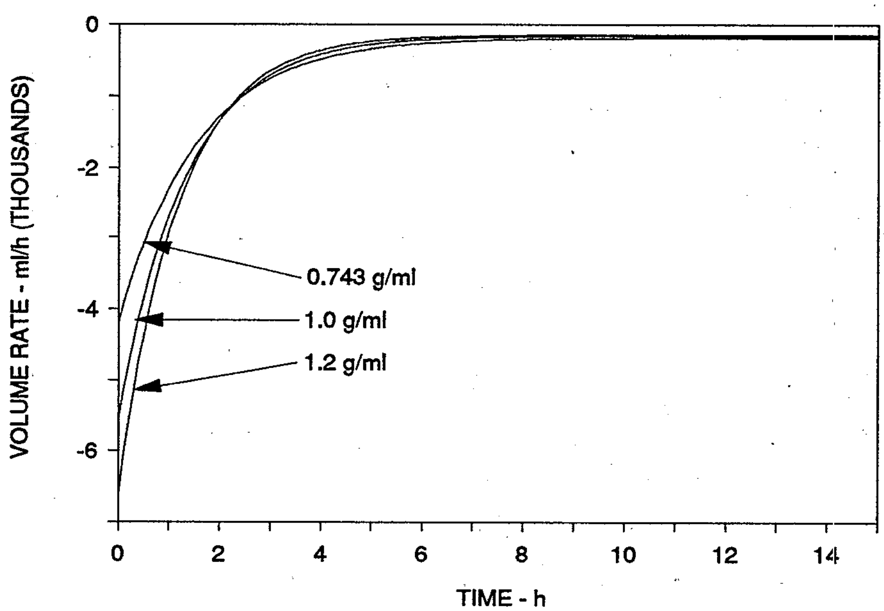

Figure 2. Typical deformation behavior for a *non-constant-level* volumetric test of a tank with a -380 ml/h leak. It is assumed that the structural properties of the tank are the same as those of the steel tank at the UST Test Apparatus.

Figure 2 indicates that, as fluid density increases, an increase of 100 cm in product level at the beginning of a test results in an initially larger rate of change in volume in cases when product level is allowed to vary. This is due to greater pressures induced by the greater fluid densities. Because the fluid is not maintained at a constant level, these early rapid volume changes create height changes that are sufficiently large to reduce the rate of change of volume.

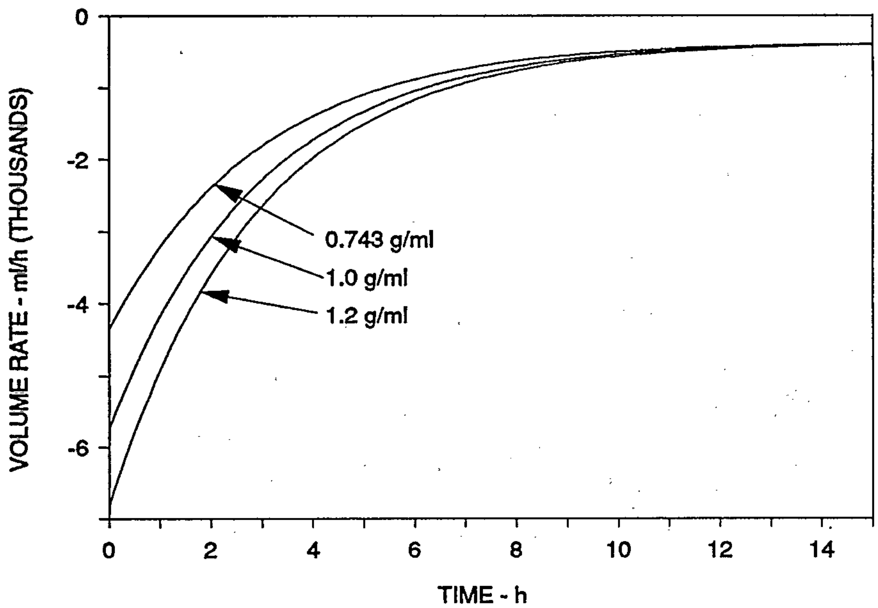

Figure 3. Typical deformation behavior for a *constant-level* volumetric test of a tank with a -380 ml/h leak. It is assumed that the structural properties of the tank are the same as those of the steel tank at the UST Test Apparatus.

This results in a volume-rate crossover approximately 2 h after the initial change in product level. After this time, the rate of change of volume is higher than it would have been in a constant-level test, even when the fluid is less dense, until a state of equilibrium is reached and all rates of change approach a common value. As was the case in earlier studies of this phenomenon [2,6,8], when there is a leak (or any other volume change not associated with deformation), the measured volume change will be only a fraction of the true volume change unless the product is maintained at a constant level. The magnitude of this error varies according to the density of the fluid, with higher densities tending to result in greater errors. This is best illustrated in Figure 4b. The error in measuring the leak rate ranges from 49% for the least dense fluid to 61% for the most dense fluid.

In volumetric testing the preferred practice is to maintain a constant product level throughout the duration of a test and measure the volume of product that must be added or removed at periodic intervals to keep the level constant. Figure 3 shows the rate of change of volume when the product is maintained at a constant level. When the level is constant, fluid density has no effect on the test if the waiting period is sufficiently long for the volume changes due to deformation to subside. Although the tank generally behaves similarly whether product level is allowed to vary or whether it is kept constant, there is one major difference, which occurs after the initial step change in product level. A higher fluid density results in a corresponding increase in the rate of change of the volume of the tank itself, without any tendency for the rates to cross over as in non-constant-level tests. In addition, the equilibrium volume rates (attained after approximately 5 time constants of the tank) approach the true volume rates, rather than only a fraction of those rates, as happens in non-constant-level tests. While this simplifies the interpretation of the volumetric measurements, it does not obviate the need for a waiting period appropriate to minimize the bias. As shown in Figure 5b, after 15 h, the rate of change of volume approaches -380 ml/h, the flow rate due to the leak. If a test is begun before the deformation has subsided, large errors in measuring the leak rate will occur, and the higher the density of the product, the greater these errors will be.

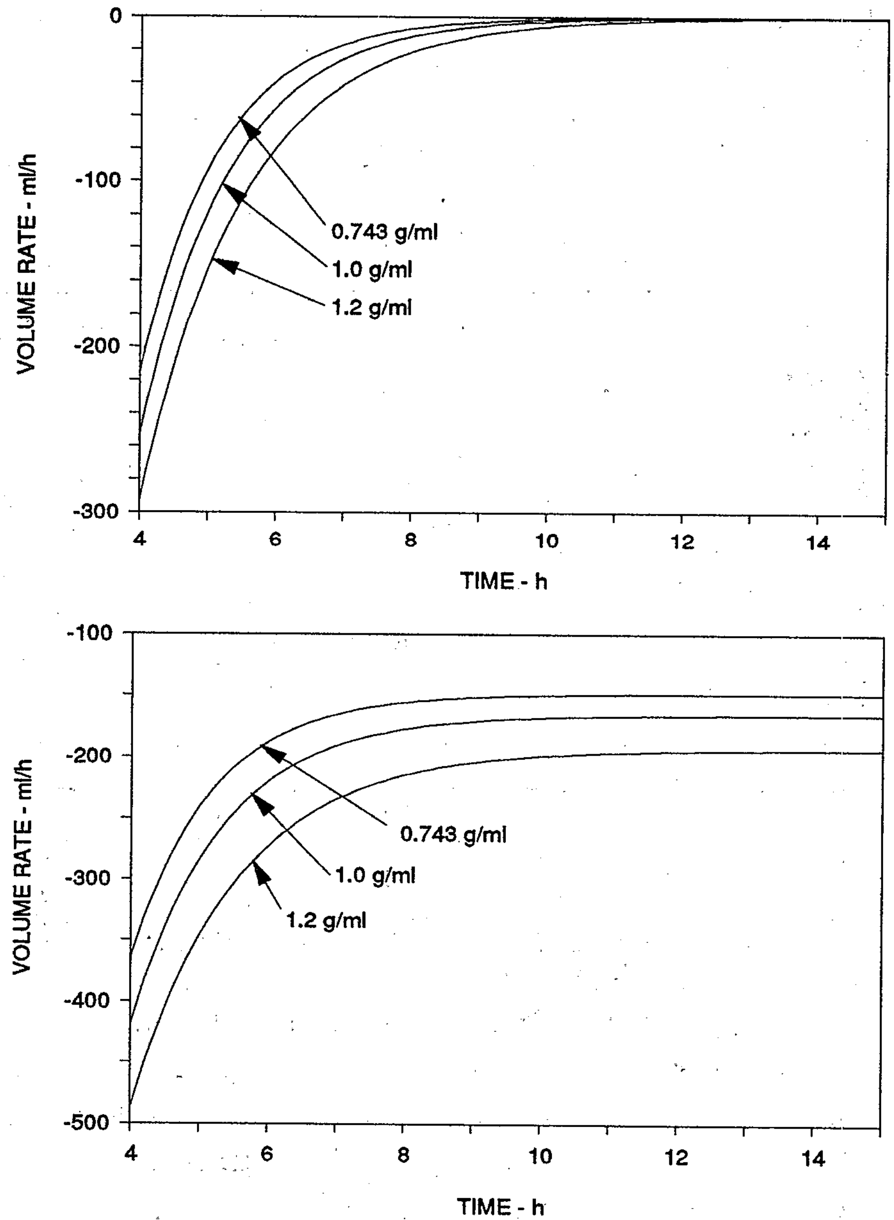

Figure 4. Typical deformation behavior during a *non-constant-level* volumetric test of (a) a nonleaking tank (top) and (b) a tank that has a leak of 380 ml/h (bottom). It is assumed that the structural properties of the tank are the same as those of the steel tank at the UST Test Apparatus.

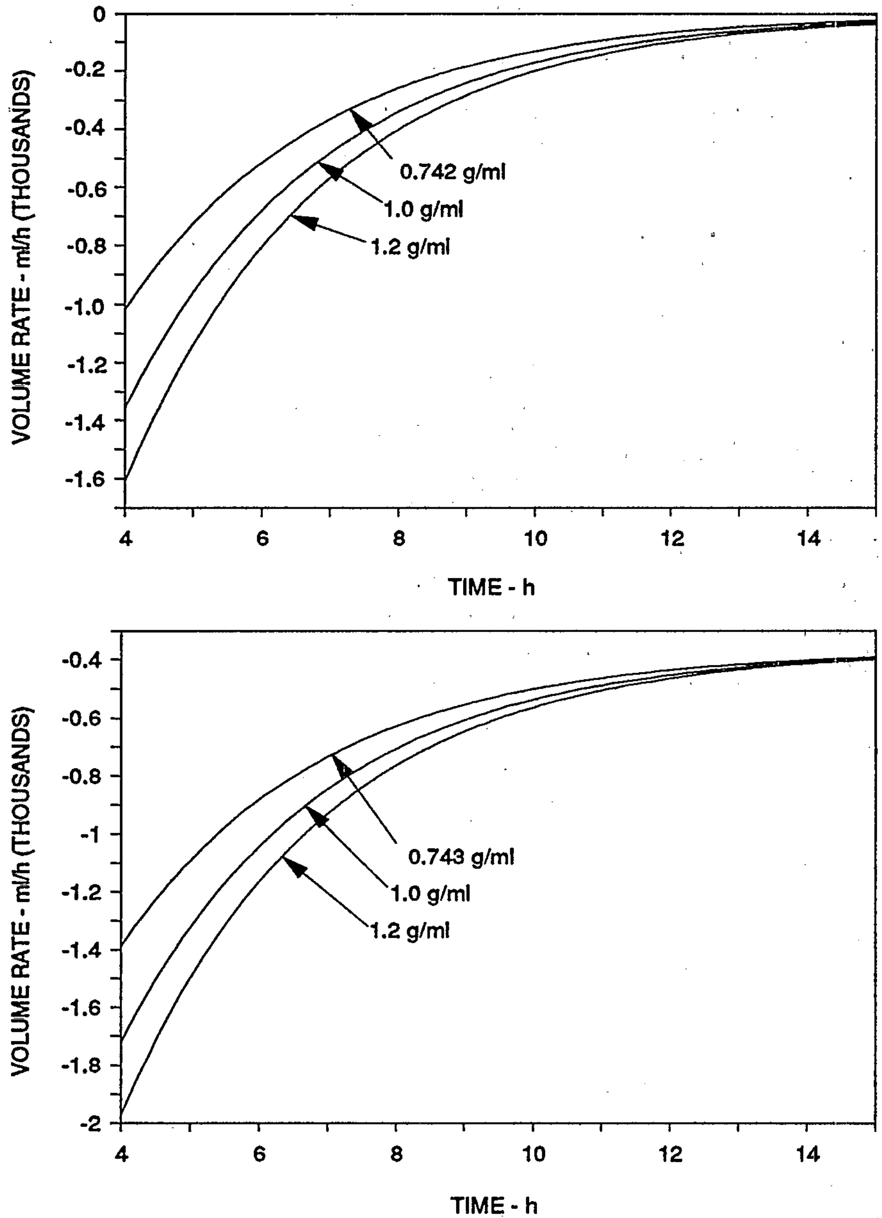

Figure 5. Typical deformation behavior during a *constant-level* volumetric test of (a) a nonleaking tank (top) and (b) a tank that has a leak of 380 ml/h (bottom). It is assumed that the structural properties of the tank are the same as those of the steel tank at the UST Test Apparatus.

Although density affects the rate of the volume change due to deformation in both constant-level and non-constant-level tests, it does not have a significant effect on the performance of a properly executed volumetric test. By this we mean one that includes a waiting period that is sufficient to allow the rate of change to reach a state of equilibrium. If such a waiting period is observed, the effect of the volume changes is so small that it is completely negligible, especially in the case of a constant-level test. Initial work suggests that, for tanks similar to those at the UST Test Apparatus, the bias due to deformation can be reduced if a waiting period of at least 12 to 18 h is observed after any change in product level preparatory to a constant-level test. As reported in [2,6,8], variable-level tests lead to erroneous results and should not be used unless the cross-sectional area of the container in which the level measurements are made is very much larger than that of the fill tube, for example, in the case of a tank that is partially filled.

5 Summary

The analyses reported here show that (1) the performance of a volumetric leak detection system is directly proportional to the coefficient of thermal expansion of the product in the tank and (2) the waiting period required for the effects of structural deformation to subside is essentially the same for all values of density (even though higher densities produce greater deformation-induced volume changes immediately after any product-level change). When a leak detection system is used with a chemical product having a coefficient of thermal expansion higher than that of the product used in the evaluation of the system, the system's performance will be lower than it was in the evaluation. If the performance achieved in the evaluation barely meets the minimum standards established by the EPA, it is possible that the leak detection system will not be in compliance when used with chemicals having higher coefficients of thermal expansion. Even if the leak detection system exceeds the minimum performance standards, it is possible that it will not meet the P_{FA} or P_D requirement; however, if a system has achieved high performance during the evaluation, judiciously changing the detection threshold can make it possible for the leak detection system to meet the requirements. Because gasoline has a higher coefficient of thermal expansion than many other chemicals, a system evaluated with a gasoline product can be used with such chemicals and still maintain a similar level of performance. Nevertheless, even if the system was evaluated with a diesel product (which has an even higher coefficient than gasoline) care must be exercised when applying the system to a chemical product.

These analyses did not examine volume changes due to evaporation and condensation, or those due to trapped vapor; the former may be an important source of error in tests conducted on underfilled tanks, and the latter an important source of error in tests conducted on overfilled tanks.

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APPENDIX C

INDUSTRY SURVEY OF THE LEAK DETECTION PRACTICES ASSOCIATED WITH UNDERGROUND STORAGE TANKS CONTAINING HAZARDOUS CHEMICALS

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UNDERGROUND STORAGE TANKS CONTAINING HAZARDOUS CHEMICALS

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ABSTRACT

The regulations issued by the United States Environmental Protection Agency (EPA) in 1988 require, with several exceptions, that underground storage tank systems containing petroleum fuels and hazardous chemicals be routinely tested for releases. This paper summarizes the release detection regulations for tank systems containing chemicals and gives a preliminary assessment of the approaches to release detection currently being used. To make this assessment, detailed discussions were conducted with providers and manufacturers of leak detection equipment and testing services, owners or operators of different types of chemical storage tank systems, and state and local regulators. While these discussions were limited to a small percentage of each type of organization, certain observations are sufficiently distinctive and important that they are reported for further investigation and evaluation. To make it clearer why certain approaches are being used, this paper also summarizes the types of chemicals being stored, the effectiveness of several leak detection testing systems, and the number and characteristics of the tank systems being used to store these products.

This paper has been reviewed in accordance with the U. S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

Federal underground storage tank regulations promulgated on September 23, 1988, establish a broad range of minimum requirements for the design, installation, operation and testing of a large fraction of tank systems in the United States. These regulations cover tank systems containing petroleum fuels as well as those containing other hazardous chemicals [1,2]. They are designed to help the underground storage tank community control and minimize the adverse environmental impact caused by leakage of product from a tank or its associated piping. The regulatory standards for leak detection in tank systems containing hazardous chemicals are more stringent than for those containing petroleum motor fuels. This paper describes (1) the regulatory standards for leak detection in tank systems containing hazardous chemicals, (2) the types of chemicals being stored, (3) the types of containers in which these chemicals are stored, (4) the effectiveness of tank tightness tests and automatic tank gauging systems for detection of leaks in tanks containing chemicals other than petroleum, and (5) the approaches to leak detection being implemented by tank owners and operators. Items (2) through (4) have been described in detail elsewhere [3-5]. The data used to develop the conclusions for items (2) and (3) are tabulated differently in this paper than in [4]. The main focus of this paper is on the fifth item, specifically, the results of a preliminary survey of manufacturers of leak detection equipment for chemical tank systems, owners and operators of these systems, and state and federal regulators.

REGULATORY STANDARDS

The federal regulatory standards for release detection in underground storage tanks issued by the EPA on September 23, 1988 [1] require that tank systems containing petroleum products and hazardous chemicals be tested periodically for releases. (A hazardous chemical is any substance defined by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [2].) The regulations for testing underground storage tanks containing hazardous substances are similar to those for tank systems containing petroleum products. During the first 10 years after the issuance of the regulations, all existing tank and pipeline systems containing hazardous substances must meet the requirements specified for tank systems containing petroleum products. After 10 years, all existing tank and pipeline systems must be upgraded, if necessary, to meet a more stringent set of requirements. These requirements emphasize the use of either double-wall tanks and piping or tanks and piping with secondary containment, both with interstitial monitoring to detect a leak in the inner wall of the system. These options are described in Section 280.42 (a) - (d) of the regulations [1]. If the tank system is new or has been upgraded, single-wall tanks and piping are permitted provided that owners and operators meet the following three criteria.

- Use any one of the release detection methods for tanks specified in Sections 280.43 (b) - (h) of the regulations or demonstrate to the implementing agency that an alternative method is at least as stringent. These include internal methods such as tank tightness testing systems, automatic tank gauging systems, and manual tank gauging for tanks 7,600 L (2,000 gal) or less, as well as external methods such as groundwater- and vapor-monitoring systems.
- Provide information to the implementing agency about health risks, effectiveness of corrective action, properties of the stored substance and characteristics of the site. If the health risks associated with the release of the chemical substance being stored are no higher than those associated with the release of a petroleum product, and there exist effective methods to clean up a release, then a single-wall tank system with release detection would be appropriate.

- Obtain approval from the implementing agency.

Although for some types of stored chemicals the single-wall tank system may be a highly effective way to satisfy the regulations, this option is treated as a variance. The onus is on the owner or operator to demonstrate to the implementing agency that the chemical substance will not be any worse than petroleum if accidentally released.

During the 10-year period between 1988 and 1998, the EPA regulations allow tank owners/operators to use either internal or external systems to test for releases. All systems attached to or inserted into the tank, piping, or interstitial space of double-wall tanks or piping are considered internal systems. Internal systems must meet a specific performance standard: they must have a capability to detect a leak of specific size with a probability of detection (P_D) of 95% and a probability of false alarm (P_{FA}) of 5%. No performance standards are specified for external systems, but specific requirements about conducting tests with such systems are given.

During this 10-year period, the regulations allow three general approaches to release detection, any of which might be practically pursued. The first two approaches use internal release detection systems and the third uses external monitoring systems. The first and most popular approach is to conduct an annual tank or line tightness test to detect small releases and to use more frequent monitoring by another method to detect large releases. All tank and line tightness tests must be performed at least once per year and must be able to detect leaks of 0.38 L/h (0.1 gal/h). In all cases where annual tightness tests are used, the regulations require an additional form of leak detection in which tests on tanks are conducted at least monthly and those on pressurized lines at least hourly; this ensures the detection of excessively large releases. For tanks, daily inventory records must be reconciled monthly. For pressurized lines, leaks of 11.4 L/h (3 gal/h) must be reliably detected; this is usually accomplished by means of a mechanical line leak detector. The second approach is to install an automatic tank gauge or automatic line leak detector that is capable of detecting leaks of 0.76 L/h (0.2 gal/h); all monitoring tests must be done at least once per month. As with the tank and line tightness testing approach, this option also requires that there be a system for detecting large leaks. The tank gauge can be used to satisfy the inventory control requirements, and most automatic line leak detectors are designed so as to be able to satisfy the 11.4-L/h (3-gal/h) hourly test for pressurized piping. Interestingly, if the tank gauge is used to satisfy the ***Other*** option in the EPA regulations rather than the ***Automatic Tank Gauge*** option, inventory control is not required; however, owners or operators who use this option do so because of the potential for better and more accurate control of inventory. The third approach is to install an external monitoring system that can detect the presence of the stored chemical in or on the groundwater or in the backfill and soil surrounding the tank system. Among other things, the success of external systems depends on the sensitivity of the sensor, the ability of the sensor to distinguish the stored chemical from other chemicals (i.e., its specificity), the ambient background noise level of the stored chemical, the migration properties of the chemical, and the sampling network. In many instances both internal and external methods are used in conjunction as a way to increase the probability of detection.

STORAGE OF HAZARDOUS CHEMICALS

Two surveys were conducted to estimate (1) the number of tanks storing hazardous chemicals, (2) the types of stored chemicals by tank number and capacity, and (3) the characteristics of the tanks by capacity, construction material, and age. A detailed description of these surveys can be found in [3,4].

The states participating in the program provided databases from their underground storage tank registration programs[1] for compilation and analysis; a total of 16 state databases were used in the analysis. The first survey, conducted in 1987, used data from the two largest states in terms of population, California and New York [3]. In the second survey, conducted in 1990, chemical tank data from New York and 13 other states were analyzed [4]. In selecting these states, efforts were made to obtain representative national coverage while simultaneously examining the more populous industrial states, which might be expected to have large numbers of chemical tanks. The 14 states included in the 1990 survey were Delaware, Florida, Illinois, Indiana, Maine, Massachusetts, Minnesota, New York, Missouri, Montana, Ohio, Texas, Virginia, and Wisconsin. New York was included in the second survey so that changes in its tank population since the earlier survey might be identified. Tables 1 through 5 summarize the results of the survey.

TYPES OF CHEMICALS STORED

Solvents were found to comprise the single largest fraction of hazardous chemicals, comprising over 85% of the total. Table 1 presents the distribution of the most commonly stored chemicals by the number of tanks storing the chemical and by the total volume of product being stored. The 1987 data from New York and California are based only on the population of tanks containing *hazardous* chemicals, while the 1990 data from the 14 state databases are based on the population of all chemical tanks; the 1990 tabulation includes tanks containing *both*

1 In 1984, as part of the amendments to the Resources Conservation and Recovery Act (RCRA), each state was required to register all underground storage tanks.

hazardous and nonhazardous chemicals. As illustrated in Table 1, acetone, toluene, xylene, methanol and methyl-ethyl ketone were found to be the most commonly stored chemical substances. The 1987 survey indicated that these five substances accounted for as much as 60% of all stored organic chemicals. After the fraction of tanks containing nonhazardous chemicals is removed from the 1990 databases, it can be shown that the five most common organics comprise 49% of all tanks containing hazardous chemicals, a figure that is slightly less than the estimate made from the survey of the two large states in 1987.

TABLE 1. SUMMARY OF THE MOST COMMONLY STORED ORGANIC CERCLA SOLVENTS

	1987 California Data		1987 New York Data		1990 Data (14 States)	
Chemical	**% by Tank Number**	**% by Tank Volume**	**% by Tank Number**	**% by Tank Volume**	**% by Tank Number**	**% by Tank Volume**
Acetone	22.8	18.0	12.0	18.3	3.9	4.2
Toluene	13.3	14.2	22.4	21.1	5.6	9.2
Xylene	8.1	6.3	15.5	11.7	---	2.5
Methanol	6.6	5.5	11.5	8.5	3.8	3.3
Methyl-Ethyl Ketone	10.3	9.6	9.0	7.0	3.7	2.9
TOTALS	61.1	53.6	70.4	66.6	17.0	22.1

CHARACTERISTICS OF THE TANKS STORING CHEMICALS

Tables 2 through 5 give information about the characteristics of the tanks used to store chemicals. The characteristics tabulated are the number of tanks, the capacities of the tanks, the construction materials, and the ages of the tanks. Table 2 presents the total number of tanks compiled in the 1990 survey that contain hazardous substances. The 5,529 tanks containing hazardous chemicals represent approximately 57% of the 9,656 registered tanks containing products other than petroleum. The remaining statistics in the table (i.e., minimum, maximum, mean, and standard deviation) are based on a tabulation of the number of hazardous-substance tanks registered in each state. The mean number of tanks containing hazardous substances in each state is 395. The large standard deviation, the large difference between the mean and the median value, and the large spread between the states with the minimum and maximum number of tanks indicate that the number of tanks per state is quite variable. In comparison to the number of petroleum tanks, the number of tanks containing hazardous chemicals is only a very small fraction of the total underground storage tank population. Based on these data, the number of tanks containing hazardous materials throughout the United States should be between 1 to 2%

of the total tank population, whether calculated by number or by tank volume. The tabulation indicates that Illinois has more than twice the number of hazardous-substance tanks than any of the other states surveyed [4].

TABLE 2. SUMMARY OF THE NUMBER OF TANKS CONTAINING HAZARDOUS CHEMICALS COMPILED FROM 14 STATE DATABASES*

Statistics	Number of Tanks
Total for 14 States	5,529
Minimum	14
Maximum	2,060
Median	255
Mean per State	395
Standard Deviation	516

*The total number of registered tanks containing non-petroleum chemicals was 9,656.

Table 3 summarizes the capacities of the storage tanks containing hazardous substances, including the average volume of product. The percentage of tanks in each category (denoted in the first row across in Table 3) is based on the entire population of tanks containing hazardous chemicals. The statistics in the remaining rows, both percentages and average volumes, were computed from the average percentages and average volumes reported for each state. It is interesting to note that the states having the minimum, maximum, and median values vary considerably with tank capacity. Roughly 60% of the tanks in the state databases had capacities between 3,800 and 38,000 L (1,000 and 10,000 gal), with the average size of a tank (based on data from all states) being 7,205 gallons. Over 27% of the tanks are larger than 38,000 L (10,000 gal).

TABLE 3. SUMMARY OF TANK SIZE DISTRIBUTIONS COMPILED FROM THE 14 STATE DATABASES AND EXPRESSED AS A PERCENTAGE OF THE NUMBER OF TANKS IN EACH STATE

	Range of Tank Capacities (Gallons)					
Statistical Parameters	**< 1,000**	**1,000- <4,000**	**4,000- <10,000**	**10,000- <20,000**	**>20,000**	**Average Volume**
Total*	11.3	29.6	31.9	19.6	7.6	7,205**
Minimum	4.3	16.0	19.7	3.9	0.5	3,409
Maximum	44.7	39.9	37.6	24.6	29.6	101,293
Median	12.2	29.0	28.8	19.7	7.0	6,889
Mean*	13.7	27.9	29.6	18.2	9.2	7,555**
Standard Deviation	10.8	6.6	5.6	5.7	8.6	2,460

* Totals for New York, Indiana, and Montana are based on CERCLA chemicals only.

** Does not include the Delaware data because one of the tanks in that state has a capacity of 430,000 gal, and inclusion of these data would result in a misleading statistical estimate.

Table 4 summarizes the types of materials from which chemical tanks are constructed; the total is broken down according to the percentage of tanks constructed from steel, fiberglass-reinforced plastic, and "other" materials. As was the case for tank size (Table 3), the percentage of tanks in each category (denoted in the the first row across in Table 4) is based on the entire population of tanks. The data indicate that 86% of the tanks are fabricated from steel and approximately 6% from fiberglass; about 4% are constructed of material(s) other than steel or fiberglass, and for another 4%, the construction material is not known.

TABLE 4. SUMMARY OF TANK CONSTRUCTION MATERIALS COMPILED FROM LISTING OF REGISTERED TANKS IN THE 14 STATE DATABASES AND EXPRESSED AS A PERCENTAGE OF THE NUMBER OF TANKS IN EACH STATE*

	Type of Construction Material*			
Statistical Parameters	**Steel**	**Fiberglass**	**Other**	**Unknown**
Total	86.1	6.2	3.9	3.8
Minimum	62.9	0.0	1.5	0.0
Maximum	94.1	15.2	10.6	22.3
Median	83.9	6.6	5.6	2.6
Mean	82.4	7.1	5.1	6.4
Standard Deviation	8.9	4.6	2.6	7.6

* Materials were not reported for Indiana, Minnesota, and Texas. Only steel tanks were reported for Montana. Values reported are percentages of the total tank populations in each state.

Table 5 summarizes the age of the tanks. The average percentages are based on the entire tank population. The remaining statistics are based upon the percentages reported for each state. Tank age was found to average 18 years, with approximately 40% of the tanks being more than 20 years old.

TABLE 5. SUMMARY OF TANK AGE DISTRIBUTIONS COMPILED FROM 14 STATE DATABASES AND EXPRESSED AS A PERCENTAGE OF THE NUMBER OF CHEMICAL TANKS IN EACH STATE

	Range of Tank Age (Years)				
Statistical Parameters	**0 to 4**	**5 to 9**	**10 to 14**	**15 to 19**	**≥ 20**
Average	4.9	16.2	21.6	17.6	39.7
Minimum	1.5	4.0	4.0	0.0	22.8
Maximum	22.2	23.0	26.1	25.6	86.7
Median	3.4	15.2	21.1	17.1	38.7
Mean	6.0	16.1	20.6	14.9	42.4
Standard Deviation	5.9	7.0	9.4	7.0	16.3

CONSEQUENCES FOR RELEASE DETECTION

The results of these tabulations suggest that there is a strong potential for leakage from tanks containing hazardous substances. The statistics suggest that the tanks are generally old, made of steel, and fairly large. One would speculate that because the average age of these steel tanks is 18 years, many are unprotected by rust-resistant coatings and are highly susceptible to corrosion. As noted in the next section, the analysis performed in [5] suggests that most tank tightness and automatic tank gauging systems (which are internal leak detection systems) should be able to test these tanks effectively. Most of these leak detection systems were evaluated on 30,000- or 38,000-L (8,000- or 10,000-gal) tanks, which is consistent with the average capacity of tanks containing hazardous chemicals. Successful testing of chemical tanks should be possible, especially because their number is relatively small, approximately 1 to 2% of the total underground storage tank population. Moreover, a very small number of chemicals (five) accounts for roughly half of the hazardous substances being stored. External methods of leak detection can also be used provided that the leak detection system in question has the necessary specificity.

VOLUMETRIC TANK TIGHTNESS TESTING

The same types of leak detection and monitoring systems used for testing tanks and pipeline systems containing petroleum products should be applicable to those containing non-petroleum chemicals provided that the sensors and equipment are compatible with the particular stored chemical and can be installed and used safely. The performance of these leak detection systems has, in most cases, been determined through an evaluation based on a single, specific, stored product. Volumetric leak detection systems, such as tank tightness testing systems and automatic tank gauges, were developed specifically to test storage tanks containing petroleum fuels, and any estimates of their performance, therefore, have been based on this class of liquids. Most performance evaluations of such systems have been conducted in 30,000- or 38,000-L (8,000- or 10,000-gal) tanks containing either gasoline or diesel fuels. If the tank contains a chemical that differs, in density, viscosity, or coefficient of thermal expansion, from the product used in the evaluation of a given leak detection system, the performance of that system when used to test a tank containing a non-petroleum product will be different from what it was on the petroleum tank.

An analysis was made of the performance of tank tightness systems (and tank gauging systems) when applied to tanks containing chemicals other than petroleum fuels [5]. Since petroleum was the stored product in most evaluations of tightness testing systems, the analysis attempted to determine the impact of liquids with viscosities, densities, and thermal properties different from petroleum products. The influence of the viscosity, the density, and the coefficient of thermal expansion on performance was investigated for the range of chemicals identified in the 14 state databases. The analysis examined the two most important sources of noise: thermal expansion or contraction of the product stored in the tank and the structural deformation of the tank resulting from any level or pressure changes before or during a test. Methods of compensating for thermal expansion/contraction and structural deformation were also investigated.

The analysis showed that (1) the performance of a volumetric leak detection system is directly proportional to the coefficient of thermal expansion of the product in the tank and (2) the waiting period required for the effects of structural deformation to subside is essentially the same for all values of density (even though higher densities produce greater deformation-induced volume changes immediately after any product-level change). When a leak detection system is used with a chemical product having a coefficient of thermal expansion higher than that of the product used in the evaluation of the system, the system's performance will be lower than it was in the evaluation. If the performance achieved in the evaluation barely meets the minimum standards established by the EPA, it is possible that the leak detection system will not meet the standard when used with chemicals having higher coefficients of thermal expansion. Even if the leak detection system exceeds the minimum performance standards, it is possible that it will not meet the P_{FA} or P_D requirement; however, if a system has achieved high performance during the evaluation, judiciously changing the detection threshold can make it possible for the leak detection system to meet the requirements. Because gasoline has a higher coefficient of thermal expansion than many other chemicals, a system evaluated with a gasoline product can be used with such chemicals and still maintain a similar level of performance.

This analysis did not examine volume changes due to evaporation and condensation, or those due to trapped vapor; the former may be an important source of error in tests conducted on underfilled tanks, and the latter an important source of error in tests conducted on overfilled tanks.

CURRENTLY USED APPROACHES TO LEAK DETECTION

An informal survey of the owners and operators of chemical tanks, manufacturers of tank tightness testing and automatic tank gauging systems, and state and local environmental regulators was conducted by telephone to determine

- what methods of leak detection are being used for underground storage tanks (i.e., tanks and associated pipelines) storing hazardous substances,
- the basic characteristics of the chemical tank population to which these methods are applicable, and
- what inventory practices are being followed by owners/operators of underground storage tanks containing hazardous substances.

A questionnaire was prepared as a guideline to stimulate discussion. The questionnaire, included in the appendix, was designed to shed some light on what methods of leak detection are being applied to single-wall tanks between 1988 and 1998. The responses were given in confidence, and, as a result, the organizations discussing their environmental programs will not be disclosed by name. They are identified only by size and by a general description of the type of business they conduct. The organizations contacted ranged from small enterprises to large, well-known, Fortune 500 companies. The organizations that were interviewed were located in New York, California and Illinois.

Two surveys were planned, one to address leak detection practices and the other to address inventory practices. In the initial survey, tank tightness testers and organizations that store chemicals were contacted to determine (1) which methods of leak detection are being used and (2) user perceptions as to the effectiveness of these methods. The second survey was designed to address the inventory practices of tank owners/operators and to collect 30 to 90 days of inventory records for analysis. As a check on the owners' responses, a brief discussion of inventory practices in the chemical industry was held with a major inventory/statistical inventory management service.

After the survey taker had contacted only a few organizations using tanks to store chemicals, it became clear that these organizations were either in the process of or had completed upgrading their systems to meet the regulatory standards required by 1998. As a consequence, the emphasis of the questions shifted from the technical details of the types of leak detection methods being used and the procedures followed for inventory reconciliation in single-wall tanks, and turned instead to the upgrading approaches. Instead of two separate surveys, only one was actually conducted.

RESULTS OF DISCUSSIONS WITH TANK TESTERS

Three tank tightness testing services that are well known in the leak detection industry were asked whether they were capable of testing tanks containing chemicals other than petroleum and whether they had actually tested such tanks. At the time of the survey, all three companies had systems that conducted tests on overfilled tanks, and one had the ability to test partially filled tanks. (At present, all three firms have the capability to test partially filled tanks.)

All three said that they did test tanks containing chemicals. The only constraint on testing was that the temperature and level (volume) measurement systems inserted into the tank had to be compatible with the stored chemical. In general, such equipment was constructed of stainless steel and Teflon. All three firms indicated that up to 5% of their services involved testing tanks containing products other than petroleum. They all indicated that the performance of their systems was the same regardless of whether a tank contained petroleum or other chemicals. This response is consistent with our estimate of the number of tanks containing chemicals and our previous knowledge of this industry. None of the organizations manufacturing automatic tank gauges was contacted directly as part of this survey because, based on previous discussions with several automatic tank gauge manufacturers, it was expected that they would give the same general response as the tank tightness testing services. Automatic tank gauges are particularly suited for meeting regulatory requirements in tanks containing chemicals because tests can be conducted routinely and automatically without adding product to the tank.

RESULTS OF DISCUSSIONS WITH TANK OWNERS AND OPERATORS

The survey taker contacted a total of 19 organizations that use chemicals in their operations and that own the tanks in which these chemicals are stored. He obtained responses from 13. The level of response varied considerably, as shown in Table 6, which summarizes the important aspects of the survey. Six of the firms, which are denoted by an asterisk, responded in sufficient detail to address all the questions prepared for the survey. A triple dash means that the organization did not respond to the question or did not know how to respond to the question.

In general, most firms had fewer than 50 tanks containing chemicals, and the median age of these tanks was approximately 20 years. Two of the firms did not indicate the number or age of their tanks because they were in the process of replacing all their single-wall tanks with aboveground tanks, double-wall tanks, or tanks with secondary containment. In all cases the tanks were used to store chemicals used in company operations. About half of the firms responded to the question of removal and disposal of the chemicals after the process had been completed. Waste chemicals were either reclaimed or stored in drums for removal.

None of the firms contacted indicated that they have had their tanks tested with a volumetric tank tightness testing system; one firm had its tanks tested with an air test, but this method was discontinued because of inaccuracy and other problems. (Air tests are no longer recommended, nor are they commonly used.) None of the companies contacted were using or planning to use automatic tank gauges for monitoring or inventory control purposes.

TABLE 6. SUMMARY OF IMPORTANT RESPONSES TO THE SURVEY

Company Product	Company Size	No. of Tanks	Mean Age	Was inventory control used?	Were tanks being replaced?	Were double-wall tanks being used?	Were aboveground tanks being used?	Were single-wall tanks with secondary containment being used?
Finishing*	Small	23	25+	Yes	Yes	Yes	---	---
Adhesives/Glues*	Medium	21	20	No	Yes	Yes	---	---
General Chemicals*	Large	17	20	Yes	Yes	Yes	When Possible	---
Adhesives/Glues*	Large	53	15-40	No	Yes	Yes	When Possible	---
Printing*	Medium	24	10	Yes	Yes	---	Yes	---
Computers*	Large	---	---	No	Yes	---	When Possible	Single-wall/ vaulted
Chemicals	Small	11	15-	No	Yes	---	Yes	---
Cleaning Chemicals	Medium	21	20	No	Yes	---	---	---
Adhesives	Medium	24	25+	---	Yes	---	When Possible	---
General Chemicals	Large	13	---	---	Yes	---	Yes	---
Tank Farm	Medium	19	---	---	Yes	---	When Possible	---
Finishes/Paints	Medium	215	---	---	Yes	---	Yes	---
Computers	Large	---	---	No	Yes	---	Yes	---

* Firms that answered all survey questions in detail.

Only three of the firms indicated that they kept inventory records, but these were for accounting and scheduling purposes only. These firms did not use inventory control data for leak detection. Based on the discussions with these three organizations, it was determined that the data being routinely obtained could not be used for inventory reconciliation either because there was no meter used to indicate the volume of material removed from the storage tank or the accuracy of this meter was inadequate for such an application.

All of the organizations contacted were replacing or planning to replace their single-wall tanks with either aboveground tanks or double-wall tanks with interstitial monitors. It was clear that the use of aboveground tanks was overwhelmingly preferred. The use of aboveground tanks permits visual inspection for leaks and facilitates maintenance; aboveground tanks also minimize the cleanup costs associated with an accidental leak.

SUMMARY

Even though a diverse cross section of organizations was contacted, the responses obtained during the telephone survey should not be interpreted quantitatively; the number of organizations was very limited, and the survey was not statistically designed or statistically analyzed. As a consequence, the results should be interpreted cautiously, and the temptation to generalize, particularly about the status of regulatory compliance, should be avoided unless additional data are gathered. The following observations are noteworthy, however, either because the response was overwhelming or because it was ambiguous.

First, there is a strong tendency for owners/operators of tank systems to be planning ways to comply with the "upgraded standards" specified for 1998. There appears to be an emphasis on replacement of single-wall tank systems with (1) double-wall tanks and pipes equipped with interstitial monitors (and in some cases combined with external monitors also) or (2) tank systems mounted completely above ground so that visual inspection is possible. This emphasis on meeting the upgraded standards has occurred, we believe, because of the potential for serious environmental damage, the high clean-up costs, and the large liability associated with chemical contamination of the soil and groundwater. Concern may also stem from the fact that tanks containing chemicals are old (averaging 18 years) and constructed of steel (86%). What is not clear from the survey is how much time will be required for those organizations currently upgrading their tank systems to complete the process. If the time required for upgrading a tank system exceeds one year, the regulations require that the tank system be tested by means of methods commonly used on tanks containing petroleum.

Second, none of the organizations contacted used inventory control as a means of leak detection. It also appears that this method of leak detection would be difficult to apply because of the lack of metering devices or the lack of accuracy in the metering devices being used. This observation was independently verified by a company that is heavily involved in analyzing inventory control data for owners or operators of chemical and petroleum tank systems.

Third, the tank testing firms contacted indicated that approximately 5% of their tests were conducted on tanks containing hazardous chemicals, a figure that is slightly higher than the estimated percentage of such tanks in existence in the U.S. This is inconsistent with the response obtained from the 13 tank-owning organizations that responded to the survey. None of these organizations indicated that they used such services. In addition, the tank testing firms did not know whether the owners and operators of the tanks they tested employed monthly inventory reconciliation. (Inventory reconciliation is required by the regulations when the only form of leak detection is an annual tightness test.) The contradictory responses offered by the testing firms and the owners and operators of tank systems containing chemicals suggest that the owners/operators who responded to the survey may not be representative of the entire chemical tank community.

Fourth, additional information is required before any assessment can be made of release detection practices in effect now and during the next eight years (the time allowed for owners/operators of chemical storage tanks to upgrade their systems in anticipation of the 1998 EPA deadline).

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Appendix

QUESTIONNAIRES
USED TO ASSESS LEAK DETECTION PRACTICES
IN UNDERGROUND STORAGE TANKS
CONTAINING HAZARDOUS CHEMICALS

(1) EPA Chemical Tank Leak Detection and Inventory Control Practices Questionnaire

(2) Leak Detection Manufacturer Questionnaire

EPA Chemical Tank Leak Detection and Inventory Control Practices Questionnaire

Company Name: ________________________________

Address: ________________________________

____

____

Contact: ____________________________

Telephone: ____________________________

FAX: ____________________________

Leak Detection

1. What types of leak detection practices are currently employed by your company on underground tanks containing chemicals? Please check the appropriate response(s).

   ( ) Tank tightness tests
   ( ) Automatic tank gauges
   ( ) Interstitial monitors (for double-wall tanks only)
   ( ) External monitoring wells
   ( ) Inventory record analysis
   ( ) Other (Specify) ________________________________
   ( ) None

2. What type of construction is employed on your underground chemical tanks?

   ( ) Single-wall steel
   ( ) Double-wall steel
   ( ) Single-wall reinforced plastic
   ( ) Double-wall reinforced plastic
   ( ) Other (Specify) ________________________________

3a. What type of construction is employed on the underground piping connected to the underground tanks?

   ( ) Single-wall steel
   ( ) Single-wall steel
   ( ) Double-wall steel
   ( ) Single-wall reinforced plastic
   ( ) Double-wall reinforced plastic
   ( ) Other (Specify) ________________

3b. What is the average length (approximate) of the pipeline from the tank to the metering point?

4. Are all of your chemical tanks subjected to leak testing? If not, which ones are excluded? Why?

5. Are any special precautions or procedures required in order to conduct a test? Please describe them briefly.

6. Which test methods or procedures have been utilized in the past for testing underground chemical tanks?

Inventory Control

1. Are inventory records maintained for each underground chemical tank?

2. How many tank measurements are made each day?

   ( ) One
   ( ) Two
   ( ) More than two (Specify number) ____________________
   ( ) One per shift
   ( ) Other (Specify) ____________________

3. Is a standard procedure (such as API Publication 1621) followed in implementing inventory control? Describe the procedure, or identify its source.

4. How long are inventory records saved?

5. How are product levels measured in the tanks?

   ( ) Manually via stick measurements
   ( ) Automatically via automatic tank gages
   ( ) Other (Specify) ______________________________

6. Are product levels measured after additions and withdrawals?

7. How are the product levels in the tank converted to volumes?

   ( ) Tank Chart
   ( ) Calibration Volume
   ( ) Other (Specify) ______________________________

8. What is the source of product deliveries to the underground tanks?

   ( ) Truck
   ( ) Rail Car
   ( ) Pipeline
   ( ) Manufacturing Process on Site
   ( ) Other

9. Are flow meters used to measure product additions and withdrawals? If yes, what is the accuracy of the meters?

10. How frequently are the inventory records reconciled?

   ( ) Daily
   ( ) Weekly
   ( ) Monthly
   ( ) Other (specify) ______________________________

11. Have any leaks identified by the reconciliation procedure been confirmed by an independent precision test or by excavation?

Leak Detection Manufacturer Questionnaire

Note: These questions are intended to obtain basic background information from manufacturers of leak detection test methods for underground storage tanks containing chemicals, i.e., fluids other than petroleum motor fuels.

Company Name: ______________________________

Address: ______________________________

____

____

Contact: ______________________________

Telephone: ______________________________

FAX: ______________________________

1. What stored fluid(s) was the test method designed for?

2. What are the primary measurements made during the test? (Example: pressure, level, temperature, etc.)

3. What tank level must be established in order to conduct a test?

4. Can double-wall tanks be successfully tested with the method?

5. Has a performance evaluation been prepared for the test method? If yes, which organization conducted it?

6. What fluid was used to conduct the performance evaluation?

7. Does the leak detection performance of the test method change for different stored chemicals? If yes, how much?

8. Are there any chemicals or classes of chemicals for which tests cannot be conducted? Which ones?

9. How many chemical tanks have been tested with the method?

10. Are any special precautions or procedures required to test tanks containing chemicals? Please describe them briefly.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The regulations issued by the United States Environmental Protection Agency (EPA) in 1988 require, with several exceptions, that the integrity of underground storage tank systems containing petroleum fuels and hazardous chemicals be routinely tested. The regulatory standards for leak detection in tanks containing hazardous chemicals are more stringent than for those containing petroleum motor fuels. This report describes (1) the regulatory standards for leak detection in tanks containing hazardous chemicals, (2) the types of chemicals being stored, (3) the characteristics of the tanks in which these chemicals are stored, (4) the effectiveness of tank tightness tests and automatic tank gauging systems for detection of leaks in tanks containing chemicals other than petroleum, and (5) the approaches to leak detection that are being implemented by tank owners and operators.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
	USTs, Chemicals, Leak Detection, Tank Characteristics, Chemical USTs	

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