EPA 510-K-92-810

REVIEW OF EFFECTIVENESS OF STATIC TANK TESTING

Jairus D. Flora

MIDWEST RESEARCH INSTITUTE

April 1, 1988

1. Introduction

This paper is a review of the document "Analysis of Static Tank Testing as a Leak Detection Technique for Used Oil Tanks at Retail Outlets" (Ref. No. 1). The paper deals with two issues. It first estimates the standard deviation of a stick reading and then uses that value in calculating an average error associated with a static tank test under a variety of scenarios. The error in the measured leak rate that results from the sticking error is computed for two tank sizes (500 and 1000 gallons [gal.]) under a variety of filling conditions and assuming a variety of forms of the static tank test. The paper then recommends a particular form of the static tank test based on consideration of the error in the estimated leak rate and the practicalities of the test.

2. Summary of the Paper

The authors used a simulation to estimate the standard error of leak rate estimates (called the "Effective Leak Rate Error") for a variety of conditions. Table 3-4 in that report (see attachment for tables from the report) contains these estimates together with a 95% confidence interval for the errors.

The "effective leak rate errors" of Table 3-4 were arrived at by considering the volume error induced by the error in the level measurement resulting from manual sticking of the tank. Since the volume for a given error in level depends on the cross sectional area of the tank, an average error was calculated for the tank, assuming a cycle of filling and emptying the tank. A simulation was done resulting in a number of volumes in the tank and associated levels and cross sectional areas. The volume errors corresponding to the assumed stick reading error (of 0.44 inches (in.) for the difference of two readings) were calculated and averaged over the different volumes. Simulations with larger rates of filling the tank resulted in a smaller number of terms in the average, but for the most part, the levels in the faster filling rate simulation would also be in the slower filling rate scenarios, giving the same average error.

Once a standard error in terms of volume was determined for a tank size, then it was scaled to reflect the length of the test. For example, consider model tank 1, scenario 2.a. If the tank had an average volume error of 5.56 gal. corresponding to a static test, that is divided by the time of the test to convert it to an error on the leak rate scale. Thus, an average error of 5.56 gal. is 0.93 gal./h for a 6-h test. If the static test protocol suggests averaging a number of static tests, the leak rate error was reduced by dividing by the square root of n, the number of terms in the average. Thus, continuing the example, if the daily tests are averaged over seven days in a week, the resulting error is divided by the square root of 7 (about 2.64) to give the effective leak rate error (0.93/2.64 = 0.35) gal./h.

It should be noted that the maximum volume error for a given error in level will occur when the tank is half full, since that is the point of maximum cross sectional area. The cross sectional area at the midpoint for a 500-gal. tank (4 feet in diameter and 5.5 feet long) is 3168 square inches, while for a 1000-gal. tank (11 feet long) the area is 6336 sq. in.. Combined with the assumed standard error of level measurement for a single static tank test of 0.44 in., this gives a maximum error of 1394 (cubic inches [cu. in.]) (6.034 gal.) for a 500-gal. tank or 2788 cu. in. (12.068 gal.) for a 1000-gal. tank. These standard errors of volume are then divided by the length of time of the test to convert them to rates and by the square root of the sample size if an average rate is used. Table 1 below presents the maximum volume errors for three tanks (500, 1000, and 2000 gal.), assuming the standard error of the level difference is 0.44 in. The values in the Table 3-4 represent about 85 to 95% of the maximum volume error that would occur when the tank is half full.

Some comments about Table 3-4 are in order. First, it could be simplified. There should be no difference in the errors by filling rates, the slower filling rate merely giving more points and a slightly better estimate of the mean error from the simulation. Consequently, the two filling rates do not add any information. Secondly, all individual tests of the same duration have the same error. That is scenario 1, 4, and 6 in Table 3-4 can be shown mathematically to result in the same mean error. The simulation has verified this, the slight differences (e.g. 0.87 versus 0.83 gal./h) apparently resulting from the randomness in the simulation. Thus, the table could be simplified by deleting 2 scenarios and 2 columns (model tanks).

The table presents an interval stated to be a 95% confidence interval for the leak rate error. This interval is symmetric about the estimated error and appears to be found by taking the error rate plus and minus a value from a statistical distribution (the t or normal) times an estimated standard error for the leak rate. However, the upper end of the intervals in most cases exceeds the error that would occur under the worst case--when the product is at the tank midlevel. For example, Model tank 1, scenario 5.e. the leak rate error at tank midlevel is only 0.0838 gal./h compared to the upper interval point of 0.118 gal./h. For model tank 4, scenario 5.e. the error at midlevel is 0.1676 gal./h, while the upper interval indicates 0.215 gal./h. Apparently the authors did not realize that the distribution of cross section areas is highly skewed and not symmetric so that the normal or t-distribution confidence intervals are not correct. On page 3-12 the paper states that the chi-squared test was used to construct the confidence intervals, referencing the appendix for details. The appendix included did not contain the computational methods or examples. The confidence intervals would not be symmetric if the chi-squared distribution had been used.

The appendix to the paper describes a study of sticking precision. The appendix does not contain the discussion of methods of calculation mentioned elsewhere in the paper. The study of sticking precision involved repeated sticking of a tank containing gasoline with different individuals, stick materials, with and without fuel-finding paste, and for different residence

Table 1. Maximum Errors for Static Tank Tests

	Tank 1	Tank 2	Tank 3
Capacity	500 gal.	1000 gal.	2000 gal.
Diameter	48 in.	48 in.	64 in.
Length	5.5 ft.	11 ft.	12 ft.
Cross-sectional area at midpoint (square inches)	3168	6336	9216
Volume error for 0.44 in. level error (gal.)	6.034	12.0685	17.554

Test scenario	Leak Rate Error (gal./hr)		
Daily 6 h	1.01	2.01	2.93
Daily 8 h	0.75	1.51	2.19
Daily 12 h	0.50	1.01	1.46
Ave of 7 daily tests			
6 h	0.38	0.76	1.11
8 h	0.29	0.57	0.83
12 h	0.19	0.38	0.55
Ave of 30 daily tests			
6 h	0.18	0.37	0.53
8 h	0.14	0.28	0.40
12 h	0.09	0.18	0.27
Ave of 4 weekly tests			
6 h	0.50	1.01	1.47
8 h	0.38	0.75	1.10
12 h	0.25	0.50	0.73
24 h	0.13	0.25	0.37
36 h	0.08	0.17	0.24
48 h	0.06	0.13	0.18

times of the stick in the product. Table 5-3 of the referenced report contains estimates of the standard deviations of the level reading on the stick for different subsets of the data. (The title should be "Standard Deviation of ... " rather than "Standard Error....") The authors used the value of 0.31 in. for all wood as the standard error in a single stick reading. Since a static tank test requires a stick reading at the start and the end of the test period, the standard error of a single period tank test is 2 times the standard deviation of a single reading or about 0.44 in. This basic value of 0.44 in. has been used by the authors throughout the paper as the standard error in height reading for a single static tank test.

3. Evaluation of the Paper

In summary, the "Effective Leak Rate Errors" presented in Table 3-4 are reasonable estimates for current practice. If special care is taken in the readings these values can be reduced. Also, if two stick readings were taken each time and averaged each time the tank is stuck these errors would be reduced by about 30%. This appears a practical improvement.

The paper assumes that volume changes due to temperature changes can be neglected. This assumption is questionable. Assume that the coefficient of thermal expansion for the product is about 0.0004 per Fahrenheit degree. The largest temperature change observed during the testing on US EPA's National Survey of USTswould correspond to about 0.2 gal./h in the 500- or 1000-gal. tanks, assuming that the same heat flow applied and that the specific heat of the product is the same. During spring warming we have observed a long term trend of product temperature in a half-full 2000-gal. tank rising about 0.05 degree Fahrenheit per hour, which would correspond to an increase in volume of about 0.02 gal./h. Comparing these volume changes to the estimated leak rate errors, the smaller, 0.02 gal./h corresponds to about 25% of the error estimated in the more precise static tank tests. These examples may be extreme, but they suggest that there are conditions under which the effect of temperature is not negligible.

Table 2 is a tabulation of temperature changes that would produce specified volume changes. The volume changes included are small, so that they will be comparable to a leak rate in terms of gallons per hour. Thus, the temperatures in Table 2 should be thought of as changes per hour. Multiplying these by the length of the test will give a temperature change over the test period that could affect the measured leak rate by the amount indicated.

4. Improvements in Static Tank Tests

Generally, it is likely that the temperature effects will not be large relative to the sticking error. However, it would be helpful to check this by making a temperature measurement each time the tank is stuck. Referring to Table 2, and considering the recommended 36 hour test period, if the temperature at the beginning and end differs by less than 4 degrees Fahrenheit, the temperature change per hour will be 0.1 degree Fahrenheit or less and the temperature effect can be ignored. However, temperature changes induce a bias or systematic error that could cumulate over time. Expecting

Table 2. Temperature Change Needed to Produce Volume Changes (Coefficient of Expansion 0.0004)

Volume Change	Product Volume 200	300	400	500	750	1000	1500	2000
	Degrees Fahrenheit							
0.2	2.50	1.67	1.25	1.00	0.67	0.50	0.33	0.25
0.1	1.25	0.83	0.63	0.50	0.33	0.25	0.17	0.13
0.05	0.63	0.42	0.31	0.25	0.17	0.13	0.08	0.06
0.043	0.54	0.36	0.27	0.22	0.14	0.11	0.07	0.05
0.021	0.26	0.18	0.13	0.11	0.07	0.05	0.04	0.03

operators to do a temperature correction may be impractical, but asking that the temperature be measured and the results questioned if a large temperature change is observed should be possible.

If the operator would take two stick readings and use the average level each time the level is determined, a substantial reduction in the error would be obtained. This would reduce the standard error of the difference from the assumed 0.44 in. to 0.31 in.. This would reduce the errors of the leak rates by about 30% and would make the procedure better. (Requiring three readings and an average each time would reduce the error from 0.44 in. to 0.254 in. and the average of four readings each time would reduce it to 0.22 in..)

5. Implications of the Error Rates for Method Performance

If the "Effective Leak Rate Errors" are used as representing the error associated with a static tank test, the test performance can be calculated. Since the errors result from reading errors on the stick, they will generally follow a normal distribution closely. Assuming the normal distribution for the errors, there are two approaches that can be taken in determining the performance of the method. The first is to calculate the threshold leak rate that would correspond to a 1% false alarm rate and then determine the probability of detection of specified leak rates, particularly 0.2 gal./h. The second is to specify the decision threshold as 0.1 gal./h (midway between zero and the performnce standard of 0.2 gal./h) and calculate the probabilities of false alarm and of detection. A third consideration is that the procedure will be repeated periodically, generally monthly, so that performance will improve over time.

Let L denote the leak rate to be detected, let C denote the critical measured value for declaring the tank to be leaking, and let R denote the measured rate. Then the probability of a false alarm is given by

$$P(FA) = P(R < C|0),$$

where the value after the vertical bar denotes the true leak rate (zero if a false alarm occurs). Note that, following the usual convention, leak rates are represented as negative numbers since they correspond to volume reductions or losses from the tank. Using the assumption of the normal distribution for the measuring errors, and using s to denote the standard error of the measurement, we have

$$P(FA) = P(R/s < C/s|0)$$

$$= D\ (C/s),$$

where D denotes the standard normal distribution value. The probability of detecting a leak of size L is the probability that the measured leak rate, R, is less than the threshold, C, when the true leak rate is L. This probability is given by

$$P(D) = P(R < C|L)$$

$$= P[(R-L)/s < (C-L)/s|L]$$

$$= D\{(C-L)/s\}.$$

Taking weekly 36-hour static tests, averaged over four weeks each month, the estimated standard error is 0.08 gal./h for a 500-gal. tank and 0.16 gal./h for a 1000-gal. tank. We will use these values to illustrate the results.

First we set the probability of a false alarm to be 0.01. This corresponds to the tabled value of -2.326 from the normal distribution. Solving for the threshold, C, gives

$$C/s = -2.326,$$

or

$$C = -2.326\ s.$$

Substituting the values of the standard error, the threshold for declaring a leak would be a measured leak rate of -0.186 gal./h or more for a 500-gal. tank and -0.372 gal./h or more for a 1000-gal. tank, with the negative sign denoting that the rate represents a volume loss (flow out of the tank). Substituting these values for C one can determine the probability of detecting a leak of -0.2 gal./h in a single month as

$$P(D|L=-.2) = D\{(C + .2)/s\}$$

$$= \begin{cases} D\{0.175\} & \text{for the 500-gal. tank} \\ D\{-1.075\} & \text{for the 1000-gal. tank.} \end{cases}$$

The tabulated values of the normal distribution give the probability of detection of a leak rate of -0.2 gal./h as 0.57 for the 500-gal. tank and 0.14 for the 1000-gal. tank.

If we set C = -0.1 gal./h as the threshold for declaring a leak, then the symmetry of the normal distribution will make the probability of the two error types (false alarm and missed detection of a leak rate of -0.2 gal./h) equal. Substituting into the formulas gives

$P(FA) = 0.11$
$P(D) = 0.89$

for a 500-gal. tank and

$P(FA) = 0.27$
$P(D) = 0.73$

for a 1000-gal. tank.

6. Modifications to Improve Performance

If the average of two stick readings were used throughout, the standard error of level measurement would be reduced from 0.44 in. to 0.31 in.. This would have the effect of changing the thresholds, C, for a probability of false alarm of 0.01 to -0.133 gal./h for a 500-gal. tank and to -0.263 for a 1000 gal. tank. The probabilities of detecting a leak of -0.2 gal./h would then become 0.88 and 0.29, respectively.

If the fixed threshold of -0.1 gal./h were used with this reduced standard error, the probability of a false alarm for a 500-gal. tank would be reduced to 0.04 and the probability of detecting a leak of -0.2 gal./h would increase to 0.96. The corresponding numbers for a 1000-gal. tank would be a false alarm rate of 0.19 and a probability of detection of 0.81.

If the duration of the test is extended, an improvement in the size of the leak that can be detected can be obtained. Extending the time of the leak test decreases the leak rate that can be detected in proportion to the length of the test. Extending the time from 36 to 48 hours reduces the size of the detectable leak by a factor of 36/48 = 0.75. Extending the time from 36 to 56 hours would reduce the size of the detectable leak by 36/56 = 0.643.

If both of these modifications (2 stick readings and longer tests) are performed, the performance of the method is improved. For example, with a 48-hour test in a 500-gallon tank, the standard error is reduced to 0.042 gal./h. This, in turn, implies a threshold of 0.099 gal./h for declaring a leak with a 1% false alarm rate and means that a leak rate of 0.197 gal./h could be detected with probability 99%. Table 3 summarizes the performance that would be expected from this modification for tank sizes of 500, 1000, and 2000 gallons and for tests with a duration of 36, 48, and 56 hours. Note that a test of 56 hours could be done by not adding product to the tank from Friday evening until Monday morning. (With a tank used to hold used oil, this may be a reasonable time period, as the oil is usually accumulated in a drum and dumped periodically.) It should be emphasized that the detectable leaks in Table 3 are the result of a monthly average of 4 weekly tests and that duplicate stick readings are used at the beginning and end of each test.

Table 4 is a tabulation of performance information for a variety of standard (steel) tank sizes. The tank lists the nominal volume of the tank as well as its dimensions (length and diameter) in inches. Using the change in level that corresponds to the 1% false alarm rate at the threshold (approximately 0.75 in., assuming duplicate stick readings at the beginning and end of each static test), the average volume change that corresponds to the threshold for a single test is tabulated. This average was estimated as 85% of the maximum volume that would occur when the tank was half full. The next column in the table is the average volume changes that would be detected with 99% probability for a single test. The last two columns are the 1% false alarm thresholds and the volumes detectable with 99% probability for the monthly test that averages 4 weekly tests.

Table 5 is a tabulation of performance similar to Table 4. In Table 5 the volume changes detectable with 99% probably in the monthly (4 week average) tests have been converted to leak rates for three test durations: 36, 48, and 56 hours. As can be seen, only the 500 and 550 gallon tanks can achieve detection of 0.2 gal./h leak rates with probability of 99% and a false alarm rate of 1%.

As a result of somewhat disappointing performance of the static tank test for tank sizes larger than 550 gallons, another modification to the test was evaluated. Rather than require owners and operators to perform the static test every week and average the results monthly, one could require that the test be done with the tank at a specific percent of capacity, for example, 95%. This has several advantages. First, it ensures that the test checks

TABLE 3

STANDARD ERRORS, THRESHOLDS, AND DETECTABLE LEAK RATE (gal/h) FOR 4 WEEKLY TESTS AVERAGED[a]

	TEST DURATION (HOURS)		
	36	48	56
500 gal. Tank			
Standard Error	0.057	0.042	0.036
Threshold at 1%	0.132	0.099	0.085
Leak Detectable at 99%	0.264	0.197	0.170
1,000 gal. Tank			
Standard Error	0.107	0.082	0.069
Threshold at 1%	0.249	0.191	0.160
Leak Detectable at 99%	0.498	0.382	0.320
2,000 gal. Tank			
Standard Error	0.146	0.109	0.094
Threshold at 1%	0.340	0.254	0.219
Leak Detectable at 99%	0.679	0.507	0.437

[a] Assuming duplicate stick readings.

TABLE 4

TANK SIZES AND THRESHOLD VOLUMES

NOMINAL VOLUME (gal.)	TANK DIMENSIONS DIAM. (IN.)	TANK DIMENSIONS LENGTH (IN.)	AVERAGE 1% FALSE ALARM VOL. CHANGE THRESHOLD (gal.) (SINGLE TEST)	AVERAGE VOL. DETECTED WITH 99% PROB. (gal.) (SINGLE TEST)	AVERAGE 1% FALSE ALARM VOL. CHANGE THRESHOLD (gal.) (MONTHLY)[a]	AVERAGE VOL. DETECTED WITH 99% PROB. (gal.) (MONTHLY)[a]
500	48	66	8.7	17.5	4.4	8.7
550	48	72	9.5	19.1	4.8	9.5
1,000	48	128	17.0	33.9	8.5	17.0
1,000	64	73	12.9	25.8	6.4	12.9
2,000	64	144	25.4	50.9	12.7	25.4
3,000	64	216	38.2	76.3	19.1	38.2
4,000	64	288	50.9	101.7	25.4	50.9
5,000	96	160	42.4	84.8	21.2	42.4
6,000	96	192	50.9	101.7	25.4	50.9
8,000	96	256	67.8	135.6	33.9	67.8
10,000	96	320	84.8	169.6	42.4	84.8
12,000	96	384	101.7	203.5	50.9	101.7

[a] 4 test average.

OTC73A

TABLE 5

TANK SIZE, THRESHOLDS, AND DETECTABLE LEAK RATES

TANK SIZE NOMIAL VOLUME (gal.)	DIMENSIONS DIAM. (in.)	DIMENSIONS LENGTH (in.)	AVERAGE 1% FALSE ALARM VOL. CHANGE THRESHOLD[a] (gal.)	LEAK RATES DETECTABLE WITH 99% PROBABILITY (gal./h)[b] TEST DURATION (HOURS) 36	48	56
500	48	66	4.4	0.243	0.182	0.156
550	48	72	4.8	0.265	0.199	0.170
1,000	48	128	8.5	0.471	0.353	0.303
1,000	64	73	6.4	0.358	0.269	0.230
2,000	64	144	12.7	0.706	0.530	0.454
3,000	64	216	19.1	1.060	0.795	0.681
4,000	64	288	25.4	1.413	1.060	0.908
5,000	96	160	21.2	1.177	0.883	0.757
6,000	96	192	25.4	1.413	1.060	0.908
8,000	96	256	33.9	1.884	1.413	1.211
10,000	96	320	42.4	2.355	1.766	1.514
12,000	96	384	50.9	2.826	2.119	1.817

a 4 Weeks Average (gal.)
b Value from last column of Table 4 divided by test duration.

nearly all of the tank for possible holes. Second, it will result in a much smaller surface area for the product during the test, and, as a result, the level change will correspond to a smaller volume change, increasing the performance of the test. Third, it should reduce the burden of testing on the owner and operator, since they will now be required to test only each time the tank reaches 95% capacity, or, at most once a month.

Tables 6A-6C contain information about the static tank test when performed at 95% of the capacity of the tanks. The three standard tank diameters (for steel tanks) of 48, 64, and 96 in. are included. In addition, the standard tank lengths and nominal volumes are included for tanks from 500 up to 12,000 gal. For each tank diameter, the distance from the bottom of the tank that corresponds to 95% of the capacity has been calculated. Thus, an owner or operator would be required to allow the used oil tank to reach this level and then test. Following the test, the oil could be pumped out.

Assuming that duplicate stick readings are used at the beginning and end of each test, the standard error of the difference in height is 0.31 in. The static tank test indicates a possible leak if the product height drops more than 3/4 inch from start to finish (the actual number is 0.31 x 2.326 = 0.721 in. for a 1% false alarm rate, but three-fourths of an inch is a practical field number). In the first section of the table, for each tank diameter the standard error of the height differences, the height difference threshold, and the difference detectable with probability of 99% have been converted to gal. This conversion results from multiplying the height times the cross sectional area of the tank at the 95% capacity level and expressing the resulting volume in gal.

Tables 6A-6C also present the volume change that can be detected with 99% probability in terms of the equivalent leak rate for tests of different durations. The durations range from 12 hours to 56 hours, corresponding to durations from overnight to over a weekend from Friday evening until Monday morning. The results are not restricted to used oil, but are valid for any product.

The results in Tables 6A-6C do not include any temperature correction. The convention followed is that an increase in volume requires use of water-finding paste and action if water is found. A decrease in volume signals a leak. Temperature changes could cause a false alarm or a missed detection. However, incorporating a temperature correction would substantially complicate the static tank test.

Calculations show that the cross sectional area of a tank at 95% of capacity is about 59% of the maximum cross sectional area of the tank. As a result, requiring that the static tank test be performed when a tank is filled to 95% of capacity reduces the volume error by only a factor of 0.59 (i.e. to about 60% of the maximum volume error when the tank is half full). As can be seen in Table 6, a leak rate of 0.2 gal./h is detectable with 99% probability only for tanks of about 550 gal. or less. Thus, the performance of the single static test at 95% capacity is about the same as the average performance of the average of four weekly tests of the same duration (see Table 5). It should be noted that the weekly tests use an average error that is about 85% of the maximum error when the tank is half full. The test at 95% capacity has a fixed error size.

TABLE 6A

PERFORMANCE OF MONTHLY STATIC TANK TEST AT 95% OF CAPACITY FOR VARIOUS TANKS AND TEST DURATIONS

TANK DIAMETER (in.)		TANK LENGTH (in.) 66	72	128
		NOMINAL VOLUME (gal.)		
		500	550	1,000
48 (43.4)[a]	Standard Error	2.515	2.743	4.877
	1% Threshold (gal)	5.849	6.381	11.344
	99% Detection (gal)	11.698	12.762	22.688
	Leak Rates Detectable with 99% Probability (gal/h):			
	12-hour test	0.975	1.063	1.891
	24-hour test	0.487	0.532	0.945
	36-hour test	0.325	0.354	0.630
	48-hour test	0.244	0.266	0.473
	56-hour test	0.209	0.228	0.405

a Value in parenthesis is the distance from tank bottom for 95% capacity.

OTC73A

TABLE 6B

PERFORMANCE OF MONTHLY STATIC TANK TEST AT 95% OF CAPACITY FOR VARIOUS TANKS AND TEST DURATIONS

TANK DIAMETER (in.)		TANK LENGTH (in.) 73	144	216	288
		NOMINAL VOLUME (gal.)			
		1,000	2,000	3,000	4,000
64 (57.8)[a]	Standard Error	3.709	7.316	10.973	14.631
	1% Threshold (gal)	8.626	17.016	25.524	34.032
	99% Detection (gal)	17.252	34.032	51.048	68.064
	Leak Rates Detectable with 99% Probability (gal/h):				
	12-hour test	1.438	2.836	4.254	5.672
	24-hour test	0.719	1.418	2.127	2.836
	36-hour test	0.479	0.945	1.418	1.891
	48-hour test	0.359	0.709	1.063	1.418
	56-hour test	0.308	0.608	0.912	1.215

a Value in parenthesis is the distance from tank bottom for 95% capacity.

OTC73A

TABLE 6C

PERFORMANCE OF MONTHLY STATIC TANK TEST AT 95% OF CAPACITY FOR VARIOUS TANKS AND TEST DURATIONS

TANK DIAMETER (in.)		TANK LENGTH (in.) 160	192	256	320	384
		NOMINAL VOLUME (gal.)				
		5,000	6,000	8,000	10,000	12,000
96 (86.7)[a]						
	Standard Error	12.19	14.63	19.51	24.39	29.26
	1% Threshold (gal)	28.36	34.03	45.38	56.72	68.06
	99% Detection (gal)	56.72	68.06	90.75	113.44	136.13
	Leak Rates Detectable with 99% Probability (gal/h):					
	12-hour test	4.727	5.672	7.563	9.453	11.344
	24-hour test	2.363	2.836	3.781	4.727	5.672
	36-hour test	1.576	1.891	2.521	3.151	3.781
	48-hour test	1.182	1.418	1.891	2.363	2.836
	56-hour test	1.013	1.215	1.621	2.026	2.431

[a] Value in parenthesis is the distance from tank bottom for 95% capacity.

One can obtain somewhat better performance by averaging the four weekly tests. However, the single test at 95% capacity may be preferred by some in that it requires less testing for about the same preformance. It may be easier to comply with than the averaging of four weekly tests.

One could improve the performance by increasing the level of product in the tank when the test is to be done. Requiring the test at 99% of capacity would reduce the size of the detectable leak rates by a factor of 0.6 for the numbers in Table 6. This would require product levels of at least 46.6 in. in a 48-in. diameter tank, 61.9 in. in a 64-in. diameter tank, and 92.8 in. in a 96-in. diameter tank. From a practical standpoint, requiring any higher levels would almost amount to requiring that the product be brought into the fill pipe for testing. This would probably require monitoring to ensure that temperature changes did not influence the test and to ensure that expansion did not cause an overflow.

In summary, either the weekly static test averaged over four weeks with a duration of 48 hours or longer or a single test of 56 hours duration when the product levels is at least 95% of capacity will give a detection level of about 0.2 gal./h in small (550 gal. or less) tanks. Operators could be given the option of which they prefer to use. Static tank tests in larger tanks do not reach the 0.2 gal./h leak rate detectable with 99% probability for tests of reasonable duration. Requiring that the test be done at 95% capacity and averaged over 4 weeks would extend the size of tanks up to 1,000 gal., and almost up to 2,000 gal. if a 56-hour test is used. Requiring the test level to be 99% of capacity would result in about a 40% improvement (reduce the detectable leak by a factor of 0.6), but may not be practical.

7. Suggested Operating Protocol

The following is suggested at a practical operating procedure for using a static tank test as a leak detection method for used oil tanks.

1. Take a stick reading on a tank and write down the depth of the product.
2. Wipe off the stick, take a second stick reading, and write down the depth of the product.
3. Add these two depths and divide by two to find an average depth.
4. Convert this average depth of product to gallons using the tank chart. Record the volume and the time of the stick readings.
5. After the set period (e.g., 48 hours) has elapsed, stick the tank again and record the depth of the product.
6. Wipe off the stick, stick the tank a second time, and record the depth of the product.
7. Add these two depths and divide by two to obtain an average reading.
8. Convert this depth to volume by using the tank chart and record the volume and time at the end of the static test period.

9. If the depth at the end of the period is more then 3/4 inch greater than that at the start period, wipe off the stick, apply water-finding paste to the lower end, and re-stick the tank.

10. If the water-finding paste indicates that water is present, the increase in level could be cause by water coming into the tank. Unless an alternative source for the water is identified, this should be regarded as evidence that the tanks may have a hole in it, allowing water to come in.

11. If the depth at the end of the period is more than 3/4 inch less than that at the start of the period, this is evidence that product has been lost from the tank, and the tank may be leaking.

12. If the depth at the beginning and end of the static tank test period does not change by more than 3/4 in. in either direction, subtract the volume at the end of the period from that recorded at the start of the period.

13. At the end of each four-week period, add the four differences in volumes corresponding to the weekly static tests. Divide this sum by four.

14. For a 500-gal. tank (nominal size) and a 48-hour test, if the average volume change indicates a loss of more than 4.75 gal. per weekly test, the tanks fails the static tank test.

The next to last column in Table 4 provides volume thresholds for other tank sizes. Table 3 gives the leak rate detectable with 99% probability for some tank sizes and test durations. These should be used in determining the appropriate duration of the static tank test.

The above protocol may be modified to improve the performance of the static tank test by requiring the level in the tank to be at 95% of tank capacity. The modification required ensures that the depth of the product in the tank is high enough before beginning the static test.

If the diameter of the tank is 48 in., the product level must be at least 43.3 in.

If the diameter of the tank is 64 in., the product level in the tank must be at lest 57.75 in.

If the diameter of the tank is 96 in., the product level must be at least 86.65 in.

After ensuring that the required level of product has been met, refer to Table 6 to determine an appropriate test duration for the tank size and the required detectable leak rate.

When the minimum product level has been determined at the test duration set, proceed as before in steps 1 through 11 above.

With this modification (testing at 95% of capacity), there is no need to average weekly tests. Thus, the test is concluded and passed if the level change is less than 0.75 in. in magnitude. If not, refer to steps 9, 10, and 11 above for the appropriate conclusion. Note that the difference in volume obtained by subtracting the product volume corresponding to the second stick reading from that corresponding to the first stick reading divided by the duration of the test gives the estimated leak rate (a negative sign indicating loss of product and a positive sign a gain of product).

8. Effect of Monthly Tests

The recommended method is a 36-hour static leak test conducted weekly, and averaged over four weeks each month. This test would be performed each month to determine whether there was evidence of a leak.

Repeating the leak detection test monthly will ensure that a leak will not remain undetected over a long period. Even if the probability of missing a small leak is fairly high for a single test, if that is repeated each month, then the probability of missing the leak for several months is much reduced. If the probability of missing a leak of fixed size any one month is denoted by P, and independent tests are done each month, the probability of missing the leak each month for n months is P raised to the n-th power.

If the error in failing to detect a leak results from random errors in measurement, then repeating the detection monthly will make it unlikely that the leak will be missed for very long. The number of monthly tests required to achieve a low probability of failure to detect the leak at least once can be calculated. If a power of 0.99 is desired, then the probability of missing the leak would be 0.01. The number of monthly tests required is given by

$$n = \log(0.01)/\log(P),$$

where P is the constant probability of missing the leak each month. For example, if P is 0.5, which would be the probability of missing a leak just at the threshold for declaring a leak, one has less than a 1% chance of missing the leak for each of 7 consecutive months.

The probability of detecting a leak increases with the size of the leak. This fact, coupled with the monthly testing, means that even a small leak can be detected with specified power over a number of months. That is, with monthly testing, it is unlikely that even a small leak will be missed perpetually.

Reference

Shareef, G. S. and Dickerman, J. C., "Analysis of Static Tank Testing as a Leak Detection Technique for Used Oil Tanks at Retail Outlets." American Petroleum Institute, February 1987.

TABLE 3-1. MODEL TANK PARAMETERS

Model Tank No.	Nominal Tank Capacity (gal)	Actual Tank Capacity (gal)	Fill Rate (gal/month)	Length (ft)	Diameter (ft)
1	500	517	200	5.5	4
2	500	517	400	5.5	4
3	1,000	1,036	200	11	4
4	1,000	1,036	400	11	4

Attachment

TABLE 3-4. EFFECTIVE LEAK RATE ERROR*

STATIC TANK TEST SCENARIO	MODEL TANK 1 500 gal 200 gal/mo	MODEL TANK 2 500 gal 400 gal/mo	MODEL TANK 3 1,000 gal 200 gal/mo	MODEL TANK 4 1,000 gal 400 gal/mo
1. Individual Daily Tests				
a. 6-hr	0.870 (0.724 - 1.016)	0.890 (0.676 - 1.103)	1.740 (1.534 - 1.945)	1.760 (1.464 - 2.055)
b. 8-hr	0.650 (0.541 - 0.759)	0.670 (0.509 - 0.830)	1.310 (1.155 - 1.464)	1.320 (1.098 - 1.541)
c. 12-hr	0.440 (0.366 - 0.513)	0.440 (0.334 - 0.545)	0.870 (0.767 - 0.972)	0.880 (0.732 - 1.027)
2. Daily Tests Averaged 7 Days				
a. 6-hr	0.350 (0.183 - 0.517)	0.350 (0.266 - 0.434)	0.665 (0.448 - 0.882)	0.686 (0.570 - 0.801)
b. 8-hr	0.280 (0.146 - 0.413)	0.266 (0.202 - 0.329)	0.497 (0.334 - 0.659)	0.511 (0.425 - 0.596)
c. 12-hr	0.210 (0.110 - 0.310)	0.175 (0.133 - 0.217)	0.336 (0.226 - 0.445)	0.343 (0.285 - 0.400)
3. Daily Tests Averaged 30 Days				
a. 6-hr	0.180 (0.074 - 0.285)	0.180 (0.064 - 0.296)	0.330 (0.199 - 0.460)	0.360 (0.204 - 0.515)
b. 8-hr	0.120 (0.049 - 0.190)	0.150 (0.053 - 0.246)	0.240 (0.144 - 0.335)	0.270 (0.153 - 0.386)
c. 12-hr	0.090 (0.037 - 0.142)	0.090 (0.032 - 0.148)	0.180 (0.108 - 0.251)	0.180 (0.102 - 0.257)
4. Individual Tests Made Once/Week				
a. 6-hr	0.850 (0.444 - 1.256)	0.880 (0.669 - 1.091)	1.720 (1.159 - 2.282)	1.760 (1.464 - 2.055)
b. 8-hr	0.640 (0.334 - 0.945)	0.660 (0.502 - 0.818)	1.290 (0.869 - 1.711)	1.320 (1.098 - 1.541)
c. 12-hr	0.420 (0.219 - 0.620)	0.440 (0.334 - 0.545)	0.860 (0.579 - 1.141)	0.880 (0.732 - 1.027)
5. Once/Week Tests Averaged 4 Weeks				
a. 6-hr	0.468 (0.244 - 0.691)	0.496 (0.245 - 0.741)	0.916 (0.478 - 1.353)	0.964 (0.631 - 1.296)
b. 8-hr	0.352 (0.184 - 0.520)	0.360 (0.177 - 0.542)	0.688 (0.359 - 1.016)	0.724 (0.474 - 0.913)
c. 12-hr	0.236 (0.123 - 0.348)	0.240 (0.118 - 0.361)	0.460 (0.240 - 0.679)	0.484 (0.317 - 0.650)
d. 24-hr	0.120 (0.063 - 0.177)	0.124 (0.061 - 0.186)	0.232 (0.121 - 0.342)	0.240 (0.157 - 0.322)
e. 36-hr	0.080 (0.042 - 0.118)	0.084 (0.414 - 0.126)	0.152 (0.079 - 0.224)	0.160 (0.104 - 0.215)
f. 48-hr	0.060 (0.031 - 0.088)	0.060 (0.030 - 0.090)	0.116 (0.060 - 0.171)	0.120 (0.078 - 0.161)
6. Once/Month Individual Tests				
a. 6-hr	0.830 (0.342 - 1.318)	0.860 (0.304 - 1.415)	1.700 (1.026 - 2.373)	1.740 (0.990 - 2.489)
b. 8-hr	0.630 (0.260 - 1.000)	0.640 (0.227 - 1.053)	1.280 (0.773 - 1.786)	1.310 (0.745 - 1.874)
c. 12-hr	0.420 (0.173 - 0.666)	0.430 (0.152 - 0.707)	0.850 (0.513 - 1.187)	0.810 (0.495 - 1.245)

*Results presented in gal/hr and designate the effective leak rate error followed by the 95% confidence level in parentheses.

RADIAN

TABLE 5-3. STANDARD ERROR OF MANUAL GAUGING RESULTS FOR DIFFERENT SUBDIVISIONS OF THE DATA

Data Set	Standard Error (Inches)
All data	0.30
Fiberglass	0.25
Wood	0.31
Fiberglass, no paste	0.20
Fiberglass, paste	0.27
Wood, no paste	0.36
Wood, paste	0.25

Jerry's Analysis of Stcht gauging for 1000 gallon tanks

Maximum Standard deviation for stick reading on 1000 gallon tanks to achieve 0.2 gph at 95/5 36 hour tests, 4 / Month (averaged)

	50% full	85% full
48" x 128"	0.1644 inches	0.1936
64" x 73"	0.216 inches	0.254