Evaluation of Plasteel Interstitial Monitor For Air and Liquid Leaks

Prepared for:

Plasteel, Inc.

March 17, 1994 Revised
March 24, 2017 Revised
July 20, 2022 Revised
June 12, 2023
Revised August 19, 2024
Revised July 10, 2025
Revised April 3, 2026
Revised April 22, 2026
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Preface

This evaluation was conducted by Ken Wilcox Associates, Inc. Although every effort was made to assure that this testing meets the requirements for Alternative Testing as described by the federal EPA, KWA make no claims that the evaluation will be accepted by any or all regulatory agencies. The test procedures are described in the document "Alternative Test Procedures for Evaluating Leak Detection Methods: Evaluation of Interstitial Vacuum Monitoring Systems."

Questions should be addressed to Mr. Jim Russell, Joor Manufacturing, at (616) 745-0333

H. Kendall Wilcox, President
KEN WILCOX ASSOCIATES, INC.

March 17, 1994

Note for the November 1, 2012 Revision
The only changes to this evaluation were to add an additional tank size to Table 5. And the corresponding table in the Attachments. This additional tank incorporated a 3 inch diameter riser pipe for the monitoring sensor in place of the original 2 inch diameter riser.

Note for the March 24, 2017 Revision

The only changes made to this evaluation were to add two additional tank sizes to table 5 and the corresponding tables in the attachments. This revision was performed by Craig D. Wilcox of Ken Wilcox Associates, Inc.

Note for the July 20, 2022 Revision

The only changes made to this evaluation were the addition of one tank size to table 5 and a correction to the test time on two tanks in the corresponding tables in the attachments. This revision was performed by Craig D. Wilcox of Ken Wilcox Associates, Inc.

Note for the June 12, 2023 Revision

The only change made to this evaluation was the addition of one tank to table 2 and 5. This revision was performed by Craig D. Wilcox of Ken Wilcox Associates, Inc.

Note for the August 13, 2024 Revision

The only change made to this evaluation was the addition of two tanks to table 2 and 5. This revision was performed by Craig D. Wilcox of Ken Wilcox Associates, Inc.

Note for July 10, 2025 Revision

The only change made to this evaluation report was the addition of four tanks to table 2 and 5. This revision was performed by Craig D. Wilcox of Ken Wilcox Associates, Inc.

April 3, 2026 Revision, added additional tanks and corrected some volume/test time errors. April 22, 2026, corrected length error on tank. May 8, 2026 Revision, added a tank

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Background

PLASTEEL, INC.. has developed an interstitial monitoring system for double wall tanks. This report presents the results of an independent evaluation of the vacuum characteristics necessary to detect air or liquid leaks in either the inner or outer wall of the tank.

The Environmental Protection Agency (EPA) requires that leak detectors be tested to determine if they meet certain performance standards. In general, methods are required to detect a leak of 0.1 gal/hr with a probability of detection (P_D) of at least 95% and a probability of false alarm (P_{FA}) of 5% or less. There is no EPA protocol, however, for interstitial monitors such as that developed by the PLASTEEL , Inc. To meet the specialize requirements for the PLASTEEL vacuum system, it has been necessary to use alternative evaluation procedures.

The requirements for alternative protocols are discussed in the introduction to each of the EPA evaluation protocols. The procedures described in this document meet those requirements. The development of this modified protocol was based on the procedures described in the EPA protocols for vapor and nonvolumetric monitors.

The evaluation has been divided into two sections. Section 1 describes methods that are applied to the tank prior to final installation. This method assumes that the tank is empty and that no part of the tank is covered by water. The only possible leaks are air leaks. Section 2 describes the methods necessary to detect a liquid leak. This could be either product through a leak in the inner wall or a water leak through the outer wall if the leak is below the water table.

Volume 1 of this report describes the testing procedures and presents the results of the evaluation. The Alternate EPA Evaluation Forms for the testing described in this report are in Appendix A for air testing and Appendix B for liquid testing. The calculations for determining test times have been described in Appendix C. The raw test data collected during the evaluation are contained in Volume 2. A third volume contains graphs of vacuum vs time for both Composit tanks and Elutron tanks.

The procedures used for the testing of vacuum interstitial monitors are described in detail in the document "Alternative Test Procedures for Evaluating Leak Detection Methods: Evaluation of Interstitial Vacuum Monitoring Systems" developed by KWA, Inc.

Description of Leak Detector and Operational Principles

The leak detection system developed for PLASTEEL Tanks is based on the loss of vacuum in the interstitial space formed between the primary containment vessel and the secondary containment system. Two types of tanks are produced by PLASTEEL; Elutron tanks are a doublewall jacketed tank (primary steel, secondary FRP); and Composit tanks that are constructed of an inner steel tank and an outer steel tank (FRP corrosion resistant laminate is bonded to the exterior of the outer steel tank). A vacuum gauge is used to monitor the interstitial vacuum which must be at 10 ± 1 inches of Hg at the beginning of the test.

The leak detection process is based on the fact that the vacuum cannot be maintained if a leak is present in either the primary or secondary shell. The test time is the time interval required for a 0.1 gal/hr leak to produce a vacuum change from 10" to 5" of Hg under typical operating conditions. This time interval varies according to the volume of the interstitial space which is in turn a function of the tank size. If the vacuum decreases to below 5" of Hg, further investigation to locate the source of the loss of vacuum is required. The test should be repeated after the investigation is complete.

Loss of vacuum can be due to several factors. These include an air leak in either the inner or outer shell, a leak in the fittings of the tank, outgassing of fiberglass materials surrounding the steel inner tank or a liquid leak into the interstitial space. In some instances, very small leaks due to hairline fractures in the fiberglass outer shell may result in a slow loss of vacuum. Although air flow through such breaches will be relatively rapid, liquid flow through these leaks will be extremely slow and will not present any threat to the environment.

It is also evident that the vacuum behavior for air leaks is very different than that produced by a liquid leak. The volatility of the liquid becomes an important factor which is in turn a function of the temperature in the interstitial space. The PLASTEEL vacuum monitoring approach can be used for either air or liquid leaks. The test times for air and liquid leaks vary significantly with less variation between different liquids.

SECTION 1. AIR LEAKS (PRE-INSTALLATION TESTS)

The discussion in Section 1 applies only to tanks that are empty and have not been installed in an environment where water or other liquids are above the bottom of the tank. The only possible leaks under these conditions are air leaks.

The primary factors that will effect the test time for an air leak include the volume of the interstitial space, the size of the leak, and any temperature changes in the interstitial space. Although the effects of each of these variable can be readily calculated, some empirical data was collected to verify the calculated performances. These tests include:

1. Temperature effects on the vacuum level under the test conditions specified by PLASTEEL; and

2. The vacuum decay with an air leak through an orifice that was calibrated to allow a 0.1 gal/hr diesel leak;

Evaluation Methodology

Test Equipment

Because it is difficult to construct and reliably use orifices that are constructed by producing small holes, precision flow controllers were used to produce the leaks described in this evaluation. These consist of a precision needle valve and a variable area float (or a rotameter) so that the flow rates could be monitored during the tests. This made it possible to abort the test if the flow became restricted due to particulate in the fuel or other problems. An electronic pressure transducer and a low cost pressure gauge were used to monitor the vacuum level during the testing. The calculations are based on the output of the electronic pressure transducer.

Calibration of Air Flows

The air leak rates were regulated using a calibrated flowmeter. The flowmeter was initially attached to a reservoir of diesel fuel. The reservoir was then elevated to a height of eight ft. The calibration was conducted by adjusting needle valve until the flow of diesel fuel through the flowmeter was 0.1 gal/hr. The flow of air through this orifice was then measured without further adjustment. This setting was used as the standard for testing the effect of a 0.1 gal/hr leak if the orifice were exposed to air rather than product.

A steel test cell was constructed to test the various parameters of interest. The capacity of this cell was experimentally determined to be 5.0 gallons. This tank could be submerged completely in a temperature bath so that the temperature in the tank could be controlled. The temperature inside the test chamber was monitored using a thermocouple with a resolution of one degree F.

Determination of Temperature Effects on an Interstitial Vacuum

The effects of temperature on an interstitial are easily calculated using the combined gas law

$$\frac{P_1V}{T_1} = \frac{P_2V}{T_2}$$

where P_1 is the initial pressure, P_2 is the final pressure, T_1 and T_2 are the initial and final temperatures, and V is the volume of the interstitial volume. Since the volume is fixed for each tank, the temperature effect is independent of interstitial volume. The reference conditions used for these calculations was set at 10" of Hg at 70 deg F.

In addition to the calculations empirical measurements were conducted by immersing the test cell in a thermostated bath where the temperature could be adjusted from ice water to over 110 deg F. The vacuum was monitored as a function of the temperature. There is a slight difference in the calculated slope vs the measured slope for this data. The source of the variation may be related to residual fumes in the test cell. In any case the conclusions for the evaluation are unchanged.

Measurement of Vacuum Decrease with an Induced Leak

A test was conducted to empirically determine the effects of an air leak on the interstitial vacuum. This involved evacuating the test chamber to 10" of Hg at 70 deg F. The leak was then introduced and the vacuum monitored until vacuum level was below 2" of Hg. The time interval required to reach 5" was obtained from a graphical presentation of the results.

Test Results

Determination of Temperature Effects

Figure 1 is a plot of the effects of temperature changes on the vacuum when the initial vacuum is set at 10" of Hg. at 70 deg F. The temperature was varied from 34 deg F to 110 deg F. As can be seen, temperature changes of over 20 degrees are necessary to change the vacuum by 1" of Hg. To change the vacuum by from 10" to 5" requires a temperature change of 126 deg F. This is clearly outside the range of temperature that can be produced in any environment. It is therefore reasonable to conclude that neither a false alarm nor masking of a 0.1 gal/hr leak can be produced purely by temperature changes in the interstitial space. If a nominal temperature change of 20 deg F does occur, the vacuum will shift down by 1" if the temperature increases or up by 1" if the temperature decreases.

Decay of Vacuum with Leak

The decay rate for a 0.1 gal/hr equivalent leak rate is shown in Figure 2. This graph indicates the time necessary to for the vacuum to decrease from 10" of Hg to any lower vacuum. The time interval from 10" to 5" was the standard used to calculate the test times for other volumes. For the 5.0 gallon test cell, this time was determined to be 8 minutes.

Calculation of Test Times

The time necessary to achieve a vacuum change of 5" of Hg are shown in Table 1 for Composit style tanks and Table 2 for Elutron style tanks. The time intervals were calculated for each interstitial volume from the equation:

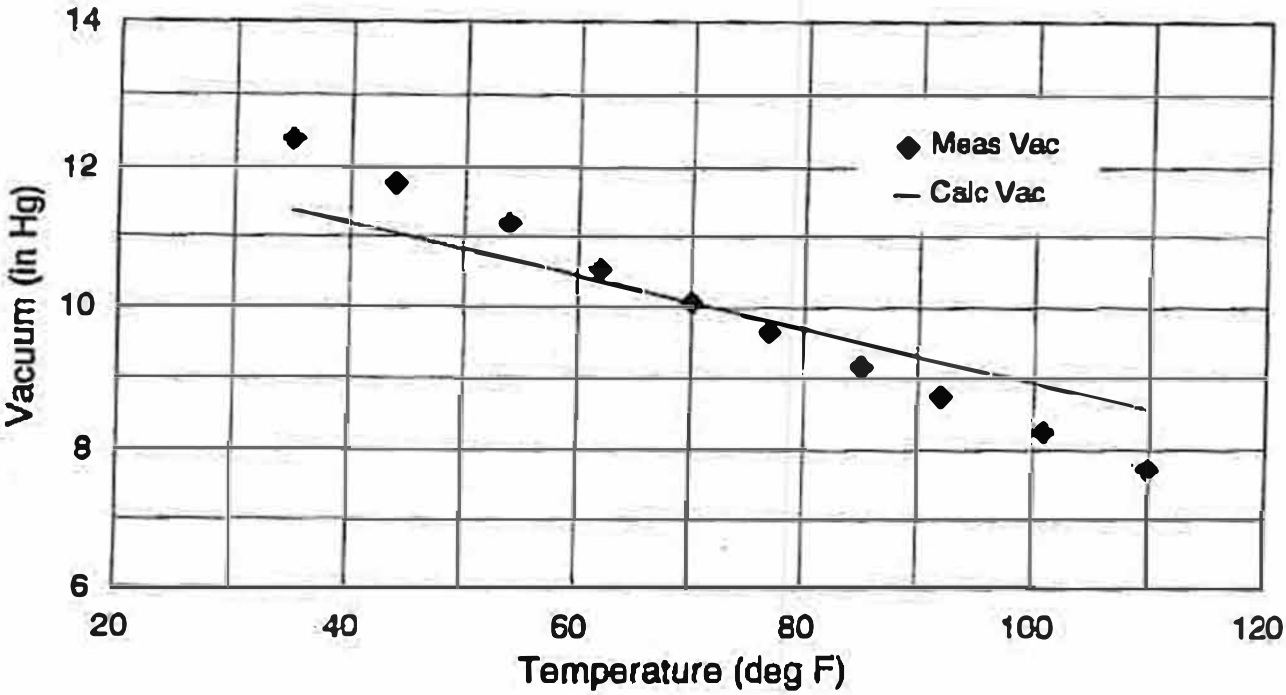

Figure 1. The effects of temperature on a dry interstitial space. Initial vacuum set at 10" Hg at 70 deg F.

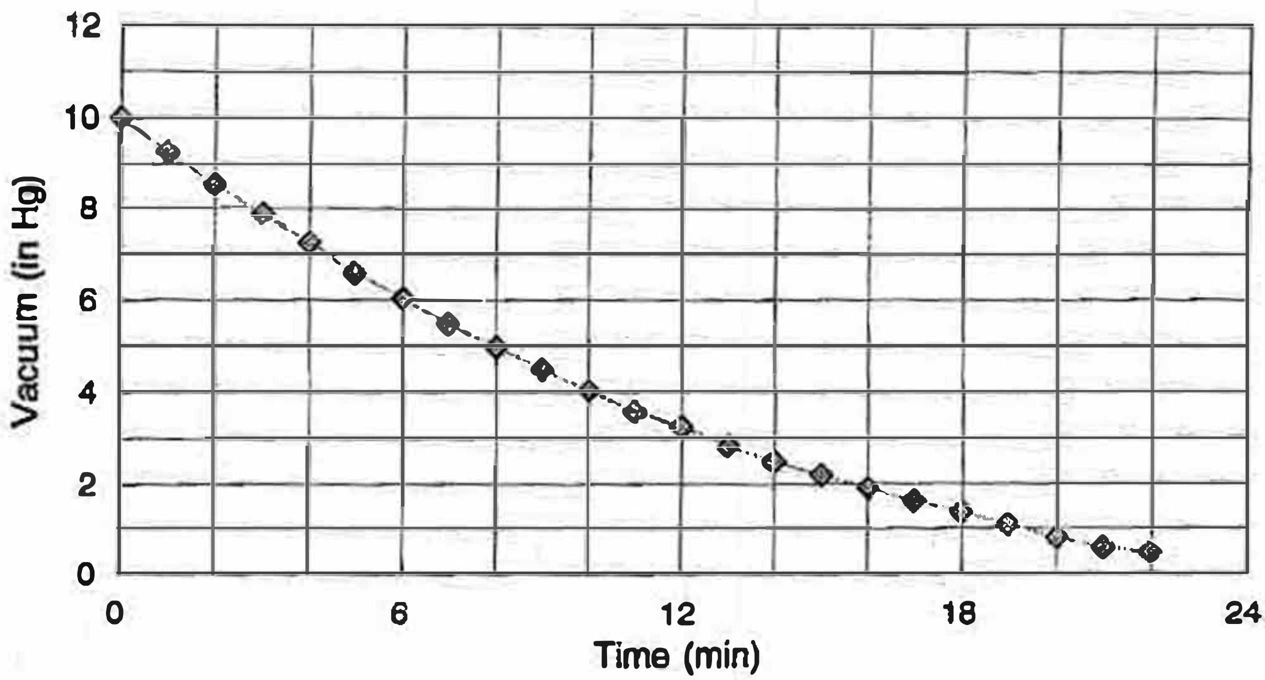

Figure 2. The effects of a 0.1 gal/hr air leak. Initial conditions were 10" Hg at 70 deg F. Volume = 5 gal.

Table 2. Air Leaks - Plasteel Doublewall Jacketed (Elutron) Style Construction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Annular Volume (gal)	Test Time (hrs)
500	48	5-9	3	0.08
1000	64	6-3	4	0.11
2000	94	5-11	5	0.13
3000	94	8-10	6	0.16
4000	94	11-9	7	0.19
5000	94	14-8	8	0.21
6000	94	17-8	9	0.24
6000	96	16-4	9	0.24
8000	114	16-0	10	0.27
10000	114	20-0	13	0.35
12000	114	24-0	15	0.40
12000*	96	32-8	16.6	0.44
15000	114	30-0	17	0.45
15000 - 9k/6k split	120	26	16.3	0.43
15000 - 9k/6k split*	120	26	18.3	0.49
15000 - 7k/8k split	120	26	16.3	0.43
15000 - 7k/8k split*	120	26	18.3	0.49
15000	120	25-8	16.1	0.43
15000*	120	25-8	18.1	0.48
20000	114	39-8	22	0.59
20000 - 12k/8k split*	120	34-4	22.6	0.6
20000 - 16k/4k split*	120	34-4	22.6	0.6
20000 - 15k/5k split*	120	34-4	22.6	0.6
20000 - 15k/5k split	120	34-4	20.6	0.55
20000 - 12k/8k split	120	34-4	20.6	0.55
20000 - 16k/4k split	120	34-4	20.6	0.55
20000	120	34	20.35	0.54
20000	120	34-1	20.4	0.54
20000*	120	34-5.5	22.7	0.61
25000*	120	42-7	28.3	0.75
30000 - 5K/20K/5K split*	120	51-2	32.8	0.87
30000*	120	51-2	32.8	0.87
30000*	126	46-1	31.3	0.83
30000	144	37-1	26	0.69
32000*	126	49-2	33.2	0.89
40000	144	50-0	34	0.91
50000	144	62-0	41	1.09

*These Thirteen tanks have a 3" diameter riser for the sensor. All other tanks have a 2"

$$Test\ Time = \frac{V_{tank}}{V_{cell}} \times t_{cell}$$

where V_{tank} is the volume of the interstitial space for a specific tank, V_{cell} is the volume of the test cell (5 gallons for this evaluation) and t_{cell} is the time necessary for the vacuum to decrease from 10" to 5" in the test cell. The value for t_{cell} is fixed for all of the air tests at 8 minutes.

Discussion

Monitoring the interstitial vacuum presents a sensitive method for determining if the tank integrity is intact prior to installation. Liquid products will flow at extremely slow rates through breaches that produce readily detected air leaks. The ratio of air leaks to liquid leaks is of the order of 25:1, depending primarily on the viscosity of the liquid, the characteristics of the hole, and the backfill material. If the tank passes the air test, the largest product leak that could be present is less than 0.1 gal/hr.

Because of the long test times required by the larger Composit tanks, it may be desirable to reduce the vacuum change for passing the tank. The test times for a vacuum change from 10" to 8" will be only 40% as long as for a full test. Caution should be exercised if shorter tests are conducted.

Graphs of vacuum vs time for each PLASTEEL tank have been prepared for air leaks through an orifice calibrated to allow a 0.1 gal/hr liquid leak as discussed in the section on "Calibration of Air Flows" (see page 2). The graphed line traces the experimental/calculated vacuum level-to-time relationship resulting from a precise 0.1 gal/hr leak rate. These graphs are contained in Section 1 of Volume 3 and may be used to compare the observed vacuum behavior with the calculated vacuum behavior for any time interval.

If the level of vacuum observed on the gauge is found (on a graph in Section 1, Volume 3) to be at a point above the graphed line, a leak rate less than 0.1 gal/hr is one of the possible test conclusions. If the level of vacuum observed on the gauge is located at a point below the graphed line, a leak rate greater than 0.1 gal/hr is a possible conclusion.

As mentioned on page 2 of this report, several possible causes must be considered when loss of vacuum is experienced during the test time period. Very short test times should be avoided.

SECTION 2. LIQUID LEAKS (POST INSTALLATION TESTS)

The discussion in this section applies to leaks that are below the water table or the product level. In these cases, liquid will leak into the interstitial space. The behavior of the vacuum under these conditions is significantly different than for air leaks. These situations could occur after tank installation and product has been delivered to the tank or if ballast has been added to the tank during installation. Three liquids most expected to be encountered were tested: water, gasoline, and diesel fuel.

Evaluation Methodology

The evaluation of this system included theoretical calculations of the expected behavior of small leaks. Empirical data was collected to verify the performance of the test method.

To determine the test times required to detect liquid leaks of 0.1 gal/hr, it was necessary to empirically determine the vacuum/leak behavior for water, gasoline, and diesel fuel under the same conditions of vacuum and temperature as are expected during actual field tests. These tests were conducted on a 5.0 gallon test cell. The basic data was then scaled linearly to determine the test times for each of the PLASTEEL tanks.

There are several factors that will effect the detection of a liquid leak. The most important of these include:

1. The type of product and;

2. The temperature effects on the vapor pressure of the liquid.

Several types of tests were conducted to identify these effects. Each is discussed in detail below.

Test Equipment

The equipment used to evaluate the effects of liquid leaks is the same as that described in Section 1. The controlled testing was conducted using a vacuum chamber with a volume of 5 gallons. The chamber was constructed of ¼" thick steel and was equipped with a vacuum gauge, a valve to the orifice, a valve to the vacuum pump and an internal thermocouple.

Calibration of Liquid Flowmeters

Liquid flow rates were calibrated for each of the liquids considered during the evaluation. The flowmeter was attached to the vacuum chamber and the flow rate was set to 0.1 gal/hr with a vacuum of 10" of Hg. The temperature was maintained at approximately 70 deg F. After the initial rate was established there were no further changes in the needle valve setting. The vacuum was then reduced from at regular intervals from 10" of Hg to less than 2" of Hg . A graph of the flow rate vs vacuum was constructed for each liquid. This information was used in the calculation of the test times for an initial leak of 0.10 gal/hr.

Vacuum vs Cumulative Volume of Product in the Interstitial Space

For low volatility liquids, (e.g., diesel fuel and water) the vacuum will decrease as the interstitial space is filled with liquid. The behavior of the vacuum is largely determined by the volume of product that has leaked into the interstitial space. The vacuum will decrease to zero when the interstitial space is approximately ⅓ full of liquid.

For volatile liquids, (e.g., gasoline or chemical solvents) the vacuum is affected by volatilization of the liquid as well as the total volume of liquid that has been added to the tank. The volatility is dependent on temperature as well so that the times required for the vacuum to decrease from 10" of Hg to 5" of Hg may vary significantly as the temperature changes.

These tests were conducted by evacuating the test cell to 10" of Hg under temperature controlled conditions. The reference temperature used was 70 deg F. Liquid was added incrementally to the cell until the vacuum decreased to below 2" of Hg. The resulting vacuum vs volume added to the test cell was graphed to determine the volume required to decrease the vacuum from 10" to 5". This process was repeated for each liquid.

Vacuum vs Temperature

Since the volatility of gasoline is a function of temperature, a series of tests were conducted to measure the effects of temperature on the interstitial vacuum when gasoline is present. The test cell was evacuated to 29.9" of Hg. Approximately 900 ml of gasoline was added to the test cell and the temperature was lowered to approximately 34 deg F by immersing the test cell in an ice bath. The temperature was then slowly raised at discreet increments until the vacuum in the test cell decreased to zero. This process was repeated for diesel fuel over the temperature range of 34 deg to 110 deg F.

Calculation of Test Times

The time for the vacuum to decrease from 10" of Hg of 5" of Hg was calculated from the flow rate calibration and the behavior of the vacuum with each liquid. The flow rates were estimated for each 1" increment in vacuum. The volume required to decrease the vacuum by 1" was obtained from the graphs of vacuum vs cumulative volume. These two pieces of information were used to estimate the decay time for a 0.1 gal/hr leak in the 5 gallon test cell. The time estimate for the test cell was extrapolated linearly to the interstitial volumes for each of the PLASTEEL tanks. The details for this calculation are provided in Appendix C.

Test Results

Calibration of Liquid Flowmeters

Calibration curves for the three water, gasoline, and diesel are shown in Figures 3, 4, and 5. The average flow rates for 1" intervals are tabulated in Table 3 for each of the liquids. Each flow rate was initialized at 0.1 gal/hr with the vacuum set at 10" of Hg and a nominal temperature at 70 deg F. This means that the needle valve setting is different for each liquid. As can be seen from inspection, the three curves are nearly identical in behavior over the vacuum range from 10" of Hg to 5" of Hg. Since the flow rate of liquids is a function of pressure, this behavior is consistent with theoretical expectations.

The leak rates for each one inch vacuum interval were taken from the calibration curves. These have been tabulated in Table 3 for each liquid. The rates were used in the calculation of the test times.

Vacuum vs Cumulative Volume of Product in the Interstitial Space

The vacuum vs volume of product added to the test chamber is shown in Figure 6 for gasoline, water, and diesel fuel. Because neither water nor diesel fuel is particularly volatile at 70 deg F, the decrease in vacuum is largely due to displacement of the air that is present in the tank at a vacuum of 10" of Hg. (The absolute pressure at 10" of Hg is 0.67 atm.) As can be seen, the vacuum approaches zero when the liquid added to the tank is about ⅓ that of the interstitial volume.

For more volatile liquids such as gasoline, the total pressure in the tank is the sum of the pressure produced by the air in the tank (approximately 0.67 atm at 10" of Hg) and the vapor pressure of the liquid. At 70 deg F, the vapor pressure of gasoline (Reid vapor pressure of 10) is over 10" of Hg. As soon as sufficient gasoline has been added to the test cell, the cell atmosphere will be saturated and the vacuum will drop to zero. For the particular blend of fuel used in this evaluation, the vacuum drops to zero after approximately 0.25 gallons of gasoline have been added to the test cell. This is only about 5% of the total cell volume. Less gasoline

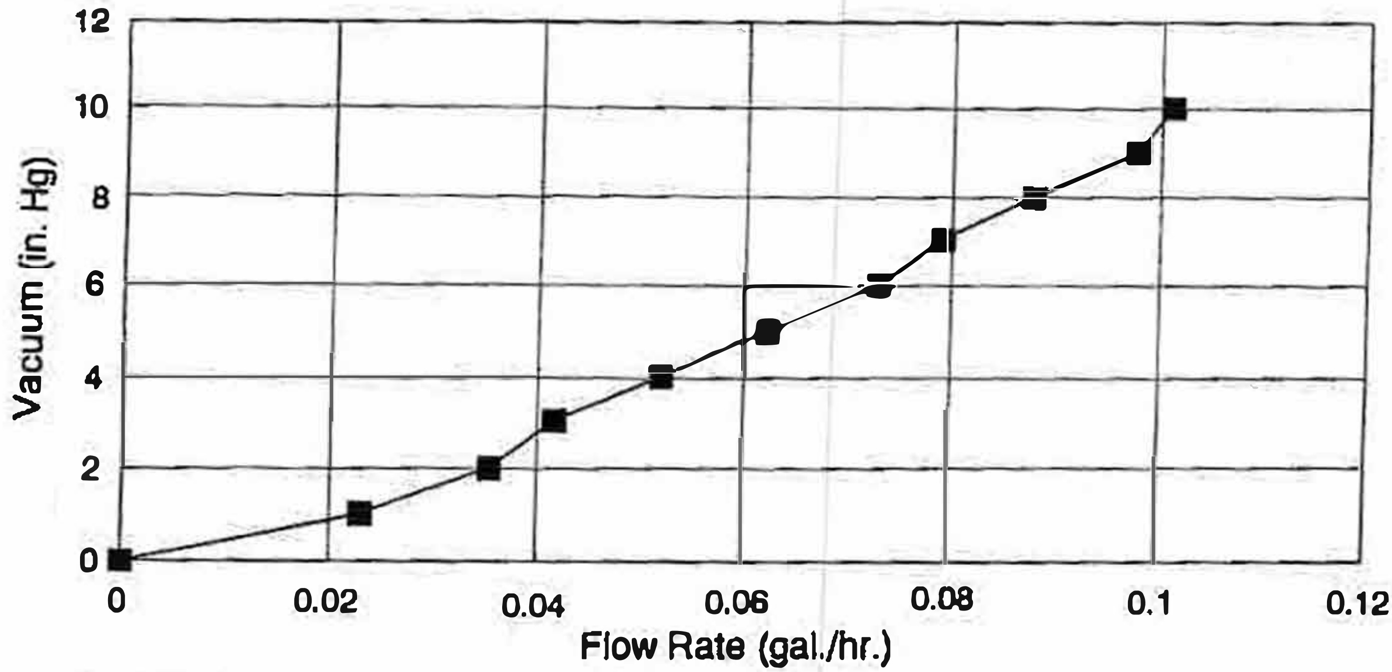

Figure 3. Calibration of Flow Meter for Water Calibration

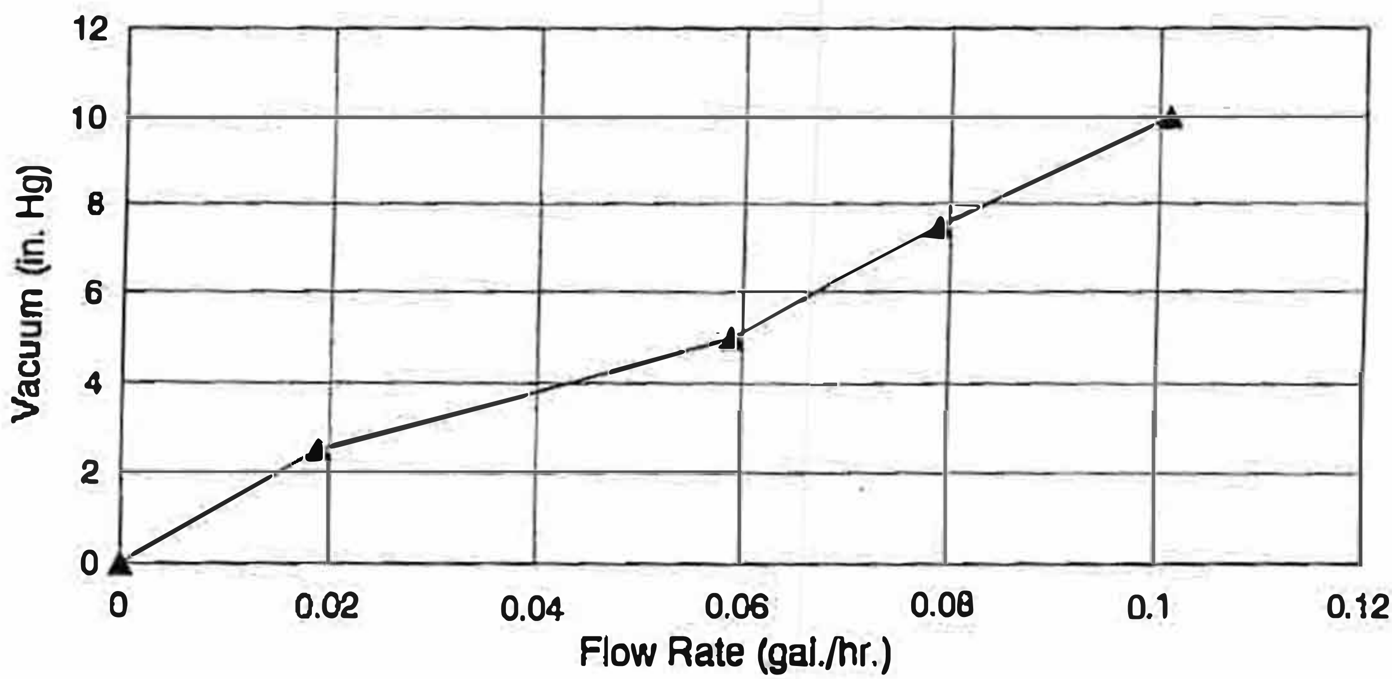

Figure 4 . Calibration of Flow Meter for Unleaded Gasoline

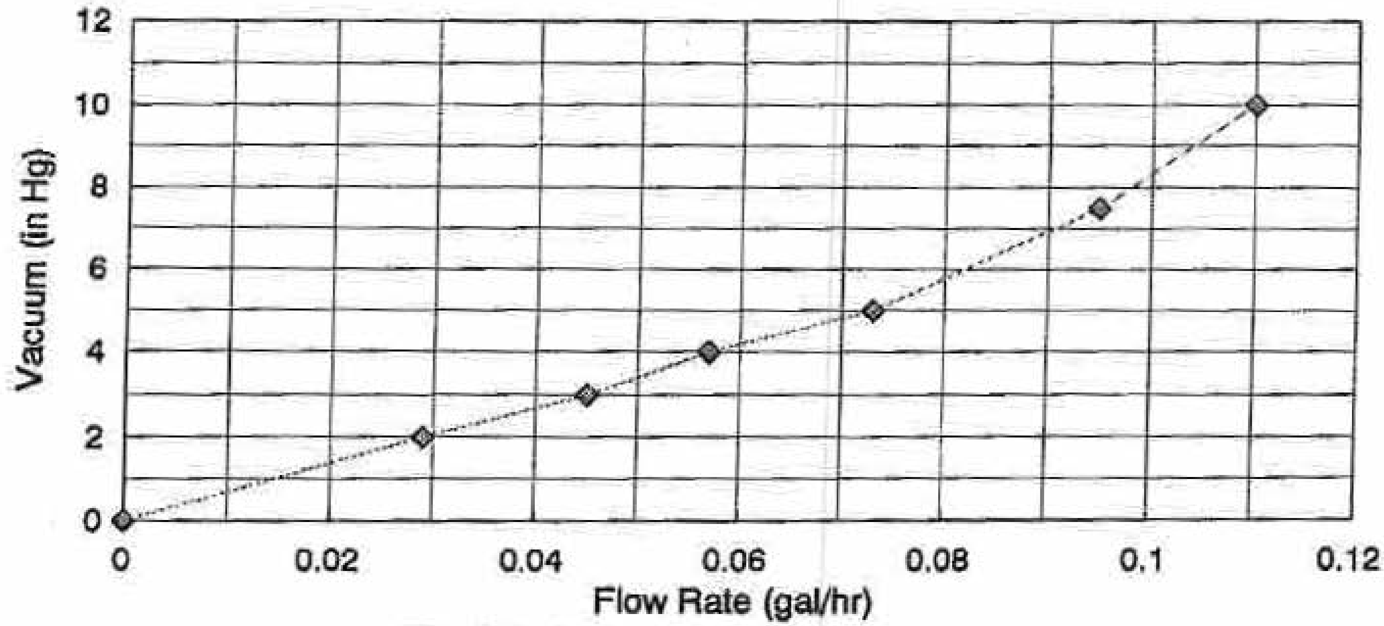

Figure 5. Calibration of Flow Meter for Diesel

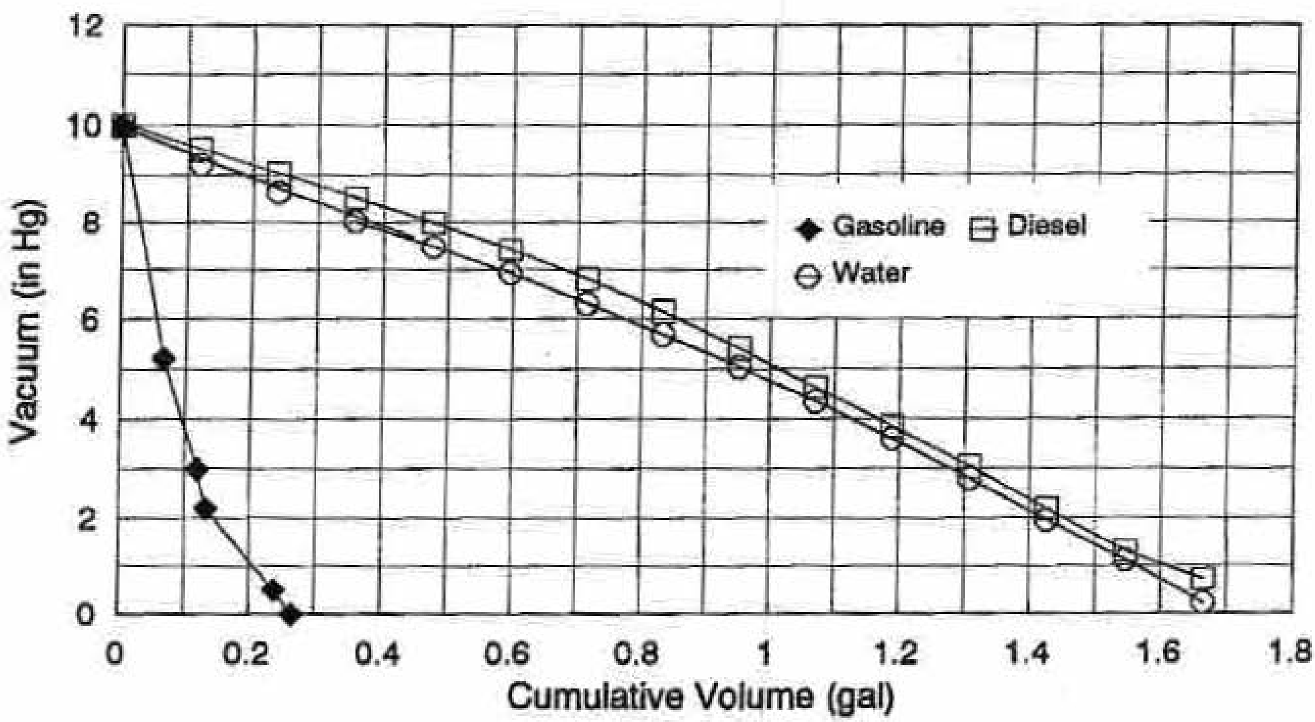

Figure 6. Vacuum vs volume of product added to interstitial space. Test cell volume = 5.0 gallons

Table 3. Data for Calculation of Vacuum Decay Times for the 5 Gal Test Cell

UL Fuel at 70 deg F
Initial Leak rate at 0.1 gal/hr

Start Pressure (psig)	End Pressure (psig)	Vacuum Change (psi)	Initial Volume (gal)	End Volume (gal)	Incremental Volume (gal)	Measured Flow Rate (gal/hr)	Time Interval (min)	Cum Time (min)
10	9	1	0.000	0.015	0.015	0.095	9.5	9.5
9	8	1	0.015	0.028	0.013	0.086	8.7	18.2
8	7	1	0.028	0.040	0.013	0.077	9.7	27.9
7	6	1	0.040	0.055	0.015	0.067	13.4	41.4
6	5	1	0.055	0.070	0.015	0.058	15.5	56.9
5	4	1	0.070	0.093	0.023	0.048	28.1	85.0
4	3	1	0.093	0.115	0.023	0.039	34.6	119.6
3	2	1	0.115	0.145	0.030	0.029	62.1	181.7
2	1	1	0.145	0.195	0.050	0.020	150.0	331.7
1	0	1	0.195	0.265	0.070	0.010	420.0	751.7

Water at 70 deg F
Initial Leak rate at 0.1 gal/hr

Start Pressure (psig)	End Pressure (psig)	Vacuum Change (psi)	Initial Volume (gal)	End Volume (gal)	Incremental Volume (gal)	Measured Flow Rate (gal/hr)	Time Interval (min)	Cum Time (min)
10	9	1	0.00	0.16	0.156	0.100	94	94
9	8	1	0.16	0.36	0.208	0.097	129	222
8	7	1	0.36	0.57	0.208	0.088	142	364
7	6	1	0.57	0.76	0.188	0.079	143	507
6	5	1	0.76	0.95	0.188	0.073	155	662
5	4	1	0.95	1.11	0.162	0.062	157	819
4	3	1	1.11	1.26	0.149	0.051	176	994
3	2	1	1.26	1.40	0.143	0.041	209	1203
2	1	1	1.40	1.53	0.130	0.035	223	1426
1	0	1	1.53	1.66	0.130	0.022	354	1780

Diesel at 70 deg F
Initial Leak rate at 0.1 gal/hr

Start Pressure (psig)	End Pressure (psig)	Vacuum Change (psi)	Initial Volume (gal)	End Volume (gal)	Incremental Volume (gal)	Measured Flow Rate (gal/hr)	Time Interval (min)	Cum Time (min)
10	9	1	0	0.24	0.24	0.111	130	130
9	8	1	0.24	0.48	0.24	0.108	133	263
8	7	1	0.48	0.675	0.195	0.104	113	376
7	6	1	0.675	0.85	0.175	0.095	111	486
6	5	1	0.85	1.025	0.175	0.085	124	610
5	4	1	1.025	1.175	0.15	0.073	123	733
4	3	1	1.175	1.32	0.145	0.057	153	886
3	2	1	1.32	1.45	0.13	0.045	173	1059
2	1	1	1.45	1.6	0.15	0.029	310	1369
1	0	1	1.6	1.8	0.2	0.01	1200	2569

will be required if the temperature is above 70 deg F and more fuel will be required for colder temperatures.

It should be noted that different blends of gasoline will have different vapor pressure curves. These can vary considerably from summer to winter. The fuel used in this evaluation was obtained from a commercial service station in October.

The volumes required to reduce the vacuum for each one inch interval from 10" Hg to 5" Hg are also tabulated in Table 3. This information was also used in the calculation of the test times.

Vacuum vs Temperature

The exact process of vaporization of liquid into an interstitial space is complex. This situation is additionally complicated by the fact that the volatility of fuels changes seasonally and regionally. Fortunately, a qualitative understanding of the process is reasonably straight forward. Empirical tests were conducted to verify the general type of behavior for gasoline and diesel fuel.

Figures 7 and 8 demonstrate the effect of temperature on the vapor pressure of gasoline and diesel fuel over the temperature range of 34 deg F to 110 deg F. For gasoline (Fig. 8) the vapor pressure reaches 10" of Hg at around 60 deg F and atmospheric pressure at around 85 deg F. The implications of this are that at temperatures above 60 deg F, the entry of very small amounts of gasoline (approximately 5% of the interstitial volume) into the interstitial space will decrease the vacuum to near zero. The is because the sum of the pressure of air present in the tank at 10" of Hg and the vapor pressure of the fuel reach atmospheric pressure. This is consistent with the test results described in the "Vacuum vs Cumulative Volume" section of this report.

Figure 8 shows that the effect of temperature on diesel fuel is much less pronounced. The decrease in vacuum over the same temperature is only around 2.5 " of Hg. A temperature change of about 25 deg F is required to produce a 1" change in vacuum. Changes of this magnitude will not occur for a buried tank. The effects of temperature on the test results will be negligible under normal test conditions.

Figures 9, 10 and 11 show the effects of temperature on the vacuum under test conditions when gasoline is added to the interstitial space. At 100 deg F, virtually all of the gasoline will be vaporized. Only 200 ml of product are required to reduce the vacuum to zero. At 35 deg F approximately 3000 ml of fuel are required to achieve the same result.

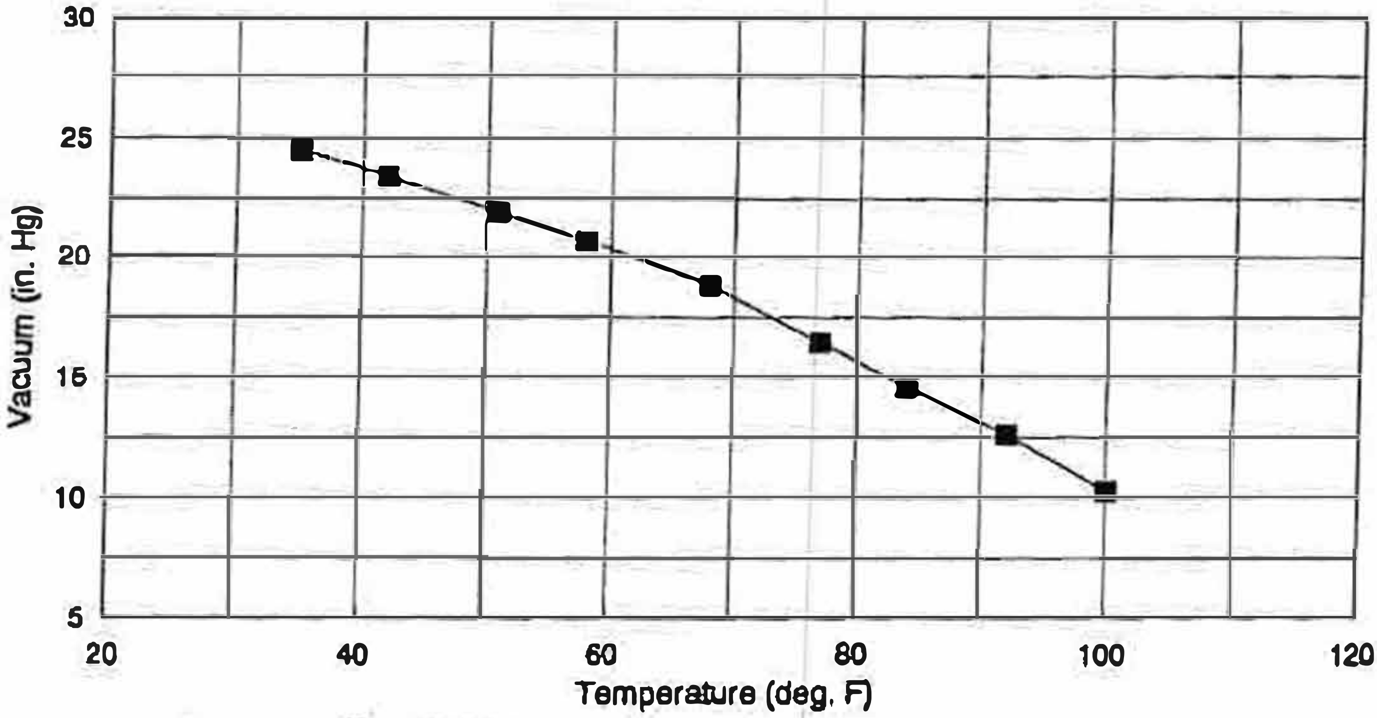

Figure 7. Temperature vs. Vacuum for Unleaded Fuel

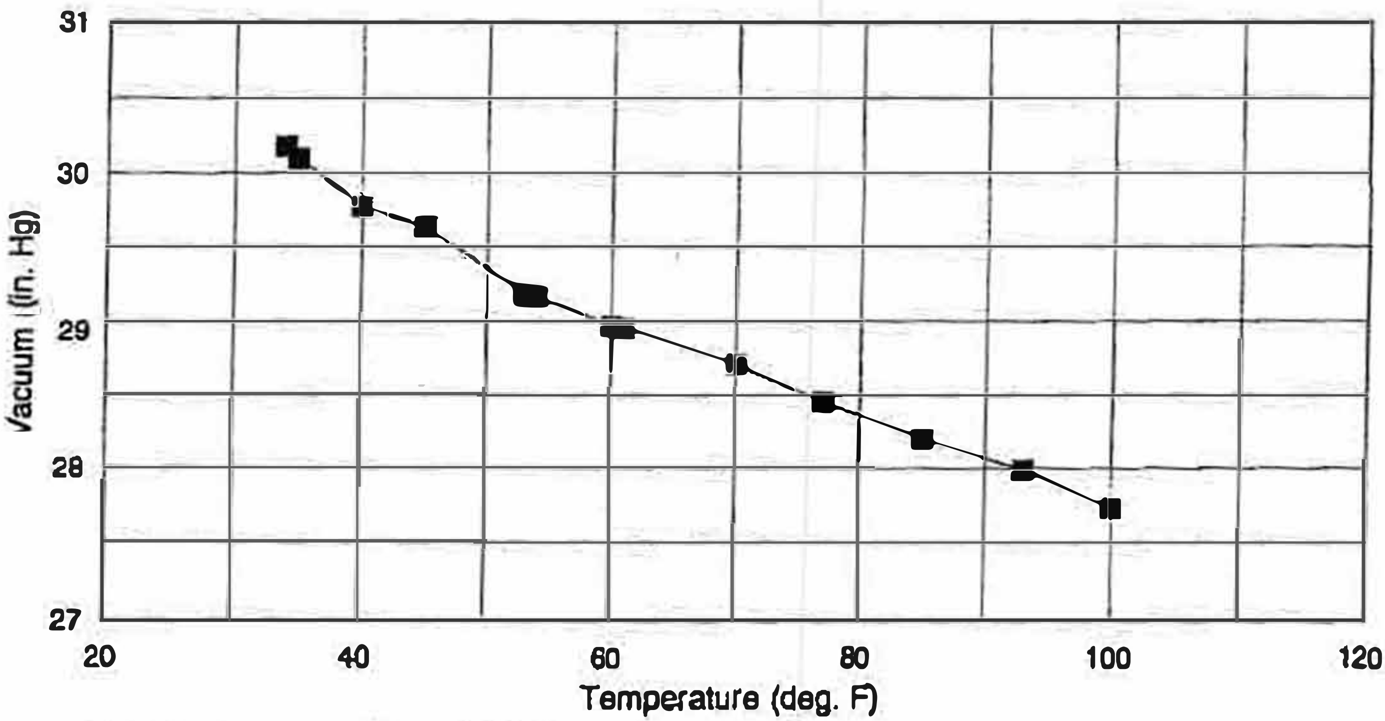

Figure 8. Temperature vs. Vacuum for Diesel.

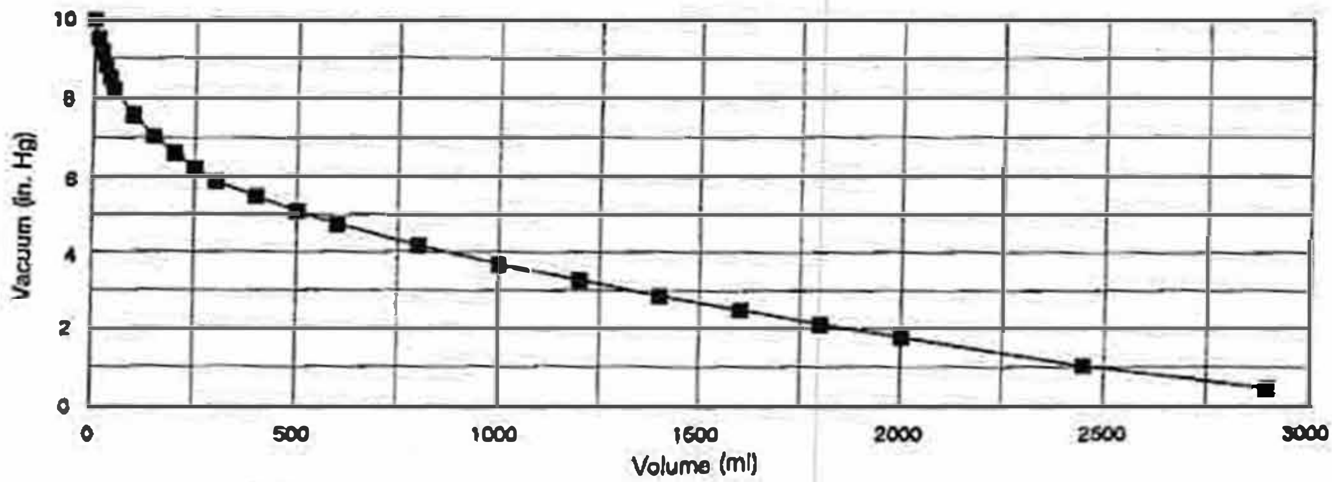

Figure 9. Unleaded Fuel at 35 deg. F

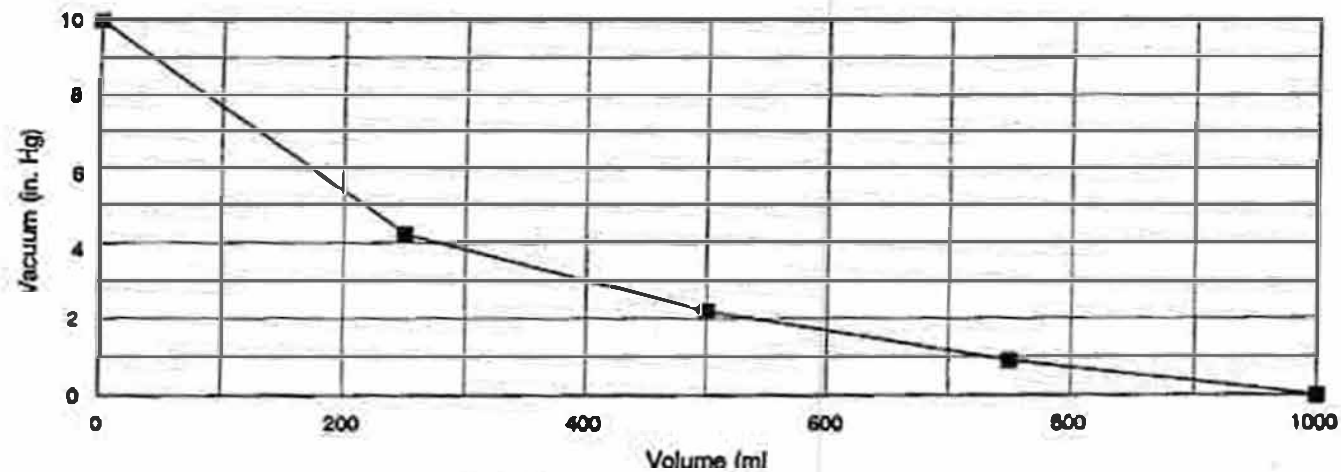

Figure 10. Unleaded Fuel at 70 deg. F

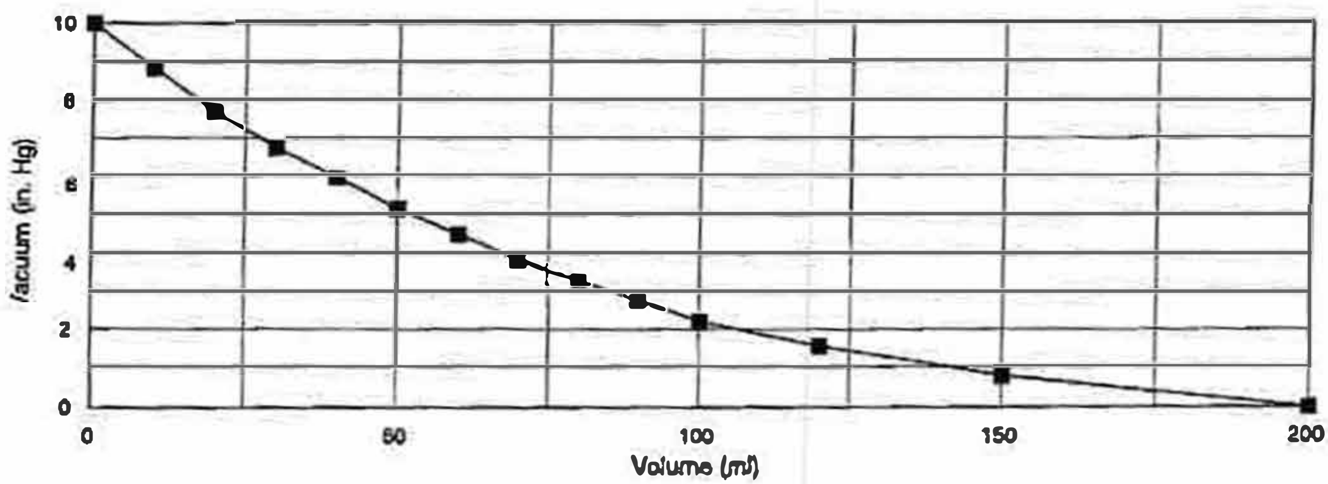

Figure 11. Unleaded Fuel at 100 deg. F.

The information from this testing can be used to estimate the effects of temperature on the leak test times. For nonvolatile compounds, the temperature effects are minimal For more volatile products, the effects can be significant.

Calculation of Test Times

The calculation of test times is based on the flow rate at each vacuum level and the volume required to produce each vacuum level change. These calculations were conducted for each liquid tested. For example, the volume of water required to reduce the vacuum from 10" Hg to 9" Hg was determined to be 1.66 gallons for the 5 gal test cell. The average flow rate obtained from the water calibration curve for the vacuum change from 10" to 9" was determined to be 0.097 gal/hr. Using this information, the time for a 0.1 gal/hr leak to change the vacuum from 10" Hg to 9" Hg is calculated to be 93.5 minutes. This calculation was conducted for one inch intervals from 10" Hg to 5" Hg. The sum of time from 10" Hg to 5" Hg is then the test time for a 5 gallon interstice. For water, the test time for a 5 gallon interstice was 1780 minutes. For Diesel fuel, the test time was determined to be 2569 minutes and for gasoline 752 minutes.

The test times for other interstitial volumes were obtained from a linear extrapolation of the test times for the 5 gallon test cell to the interstitial volume of each tank using the equation

$$Test\ Time = \frac{V_{tank}}{V_{cell}} \times t_{cell}$$

The results of this extrapolation are shown in Table 4 for the Composit style tanks and Table 5 for the Elutron style tanks. The test times for the largest tanks are relatively long, particularly for the larger Composit style tanks. This makes it difficult to distinguish between a slow air leak and a larger liquid leak for diesel or water. The test times can be reduced to 40% of the tabulated times if the vacuum change is limited to 2" of Hg rather than 5" of Hg. There would be some increased risk, however, of either a false alarm or a missed detection if this practice is followed.

Graphs of vacuum vs time for each PLASTEEL tank have been prepared for liquid leaks for water, gasoline, and diesel fuel. The graphed line traces the experimental/calculated vacuum level-to-time relationship resulting from a precise 0.1 gal/hr liquid leak. These graphs are contained in Section 1 of Volume 3 and may be used to compare the observed vacuum behavior with the calculated vacuum behavior for any time interval.

Plasteel Interstitial Monitor

Table 4. Gas, Diesel, Water Leaks - Plasteel Doublewall Composite Style Contruction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Annular Volume (gal)	Test Time (hrs)		
				Gas	Diesel	Water
500	48	6-1	38	7.21	77.22	83.79
1000	64	6-8	91	17.26	184.92	200.66
2000	94	6-3	182	34.51	369.94	401.32
3000	94	9-2	210	39.82	426.73	463.06
4000	94	12-1	237	44.94	481.6	522.59
5000	94	15-0	265	50.25	538.5	584.34
6000	94	18-0	293	55.56	595.39	646.08
8000	114	16-4	368	69.78	747.8	811.46
10000	114	20-4	414	78.5	841.27	912.89
12000	114	24-3	459	87.03	932.72	1012.11
15000	114	30-4	528	100.12	1072.93	1164.26
20000	114	40-4	640	121.35	1300.52	1411.23
30000	144	37-7	1281	242.9	2603.18	2824.66
40000	144	50-6	1579	299.4	3208.63	3481.76
50000	144	62-6	1863	362.99	3785.73	4107.99

Table 5. Gas, Diesel, Water Leaks - Plasteel Doublewall Jacketed (Elutron) Style Construction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Riser Size (in)	Annular Volume (gal)	Test Time (hrs)		
					Gas	Diesel	Water
500	48	5-9	2	3	0.57	6.10	6.62
1000	64	6-3	2	4	0.76	8.13	8.82
2000	94	5-11	2	5	0.95	10.17	11.03
3000	94	8-10	2	6	1.14	12.20	13.23
4000	94	11-9	2	7	1.33	14.23	15.44
5000	94	14-8	2	8	1.52	16.26	17.64
6000	94	17-8	2	9	1.71	18.30	19.85
6000	96	16-4	2	9	1.71	18.30	19.85
8000	114	16-0	2	10	1.9	20.33	22.05
10000	114	20-0	2	13	2.47	26.43	28.67
12000	114	24-0	2	15	2.85	30.50	33.08
12000*	96	32-8	3	16.6	3.15	33.75	36.61
15000	114	30-0	2	17	3.23	34.56	37.49
15000 - 9k/6k split	120	26	2	16.3	3.1	33.17	35.98
15000 - 9k/6k split*	120	26	3	18.3	3.48	37.24	40.39
15000 - 7k/8k split	120	26	2	16.3	3.1	33.17	35.98
15000 - 7k/8k split*	120	26	3	18.3	3.48	37.24	40.39
15000	120	25-8	2	16.1	3.06	32.74	35.52
15000*	120	25-8	3	18.1	3.44	36.81	39.93
20000	114	39-8	2	22	4.18	44.73	48.51
20000 - 12k/8k split*	120	34-4	3	22.6	4.29	45.90	49.79
20000 - 16k/4k split*	120	34-4	3	22.6	4.29	45.90	49.79
20000 - 15k/5k split*	120	34-4	3	22.6	4.29	45.90	49.79
20000 - 15k/5k split	120	34-4	2	20.6	3.91	41.84	45.38
20000 - 12k/8k split	120	34-4	2	20.6	3.91	41.84	45.38
20000 - 16k/4k split	120	34-4	2	20.6	3.91	41.84	45.38
20000	120	34	2	20.35	3.87	41.41	44.92
20000	120	34-1	2	20.4	3.88	41.52	45.03
20000*	120	34-5.5	3	22.7	4.22	46.17	50.06
25000*	120	42-7	3	28.3	5.38	57.57	62.44
30000 - 5K/20K/5K split*	120	51-2	3	32.8	6.23	66.66	72.31
30000*	120	51-2	3	32.8	6.23	66.66	72.31
30000*	126	46-1	3	31.3	5.95	63.67	69.06
30000	144	37-1	2	26	4.94	52.86	57.34
32000*	126	49-2	3	33.2	6.31	67.52	73.24
40000	144	50-0	2	34	6.46	69.12	74.98
50000	144	62-0	2	41	7.79	83.35	90.41

*These Thirteen tanks have a 3" diameter riser for the sensor. All other tanks have a 2"

If the level of vacuum observed on the gauge is found (on a graph in Section 2, Volume 3) to be at a point above the graphed line, a leak rate less than 0.1 gal/hr is one of the possible test conclusions. If the level of vacuum observed on the gauge is located at a point below the graphed line, a leak rate treater than 0.1 gal/hr is a possible conclusion.

As mentioned on page 2 of this report, several possible causes must be considered when loss of vacuum is experienced during the test time period. Very short test times should be avoided.

Discussion of Liquid Leak Detection

The interpretation of the test data from an operating tank is complicated when several possible leak combinations are possible. It is certain that a rapid decrease in vacuum (less than a few days) indicates that a leak is present. Either air or gasoline could produce this effect, particularly if the temperature of the tank is above 60 deg F.

For low volatility liquids, the method is less sensitive, particularly for larger tanks. For these tanks, the testing is similar to that for an annual precision test. A slower decrease in vacuum over many days or months could be either a very small air leak (too small to be detected by other conventional volumetric methods) or a somewhat larger diesel or water leak. Part of the methodology to deal with this question involves restoring the vacuum on the tank to 10" of Hg and carefully monitoring the vacuum behavior. If the vacuum decays at an even more rapid rate, a leak is indicated. This is because as the interstitial space fills with liquid, the additional volume of liquid required to decrease the vacuum is decreased.

Additional measures that can be taken if a leak is suspected include a determination of whether or not there is liquid in the interstitial space. This would, of course, require that the vacuum be broken and some type of monitoring or sampling of the interstice be conducted.

For large tanks where the test times are days to months in duration, the observed vacuum can be compared with the calculated vacuum graphs in Volume 2. A consistent decrease in vacuum greater than that indicated for the calculated curve could be indicative of a leak. Personnel responsible for interpretation of the vacuum test data may want to investigate further if such vacuum behavior is observed.

Appendix A - Alternative EPA Evaluation Forms
Pre-Installation Air Leak Tests

Results of U.S. EPA Alternative Evaluation

Interstitial Monitoring Method

This form documents the performance of the interstitial monitor described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA'S requirements for alternative protocols. The full evaluation report also includes a report describing the method and a description of the evaluation procedures, and a summary of the test data. The results forms were modified from the Vapor-Phase Out-of-Tank Product Detectors. The evaluation procedures are included in Attachment A of this report.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name PLASTEEL, INC.

Version Interstitial Vacuum Installation Test - Air Leaks

Vendor PLASTEEL, INC.

1189 Industrial Avenue

Escondido, CA 92029 Phone (619) 745-0333 Fax (619) 746-9515

Detector output type: (x) Quantitative ( ) Qualitative

Detector Operating Principle: loss of vacuum over time

Detector Sampling Frequency: ( ) Intermittent (x) Continuous

Evaluation Results

The detector described above was tested for its ability to detect losses in vacuum over a period of time. The following parameters were determined:

Accuracy - Ability of the detector to respond to small leaks.

Detection Time - Length of time required to detect a leak of known size.

Lower Detection Limit - Smallest leak which could be readily detected.

Ambient Conditions - Effects of temperature and product type on behavior of the leak detector.

Criteria for Declaring a Leak

The tank is declared to be tight when the vacuum remains above 5" of Hg for longer than the times specificed in Tables 1 and 2 for each tank. The vacuum prior to the test must be 10"±1" of Hg.

Interstitial Tightness Testing Method PLASTEEL, INC.

Version Interstitial Vacuum Installation Test - Air Leaks

Compiled Evaluation Results

Two styles of tanks were evaluated: Plasteel Doublewall Jacketed (Elutron) Style construction; and Plasteel Doublewall Composit Style construction. Tank sizes range from 500 gallons to 50,000 gallons. Interstitial volumes range from three gallons to 1,863 gallons. Test times to detect an air leak through an orifice equivalent to a 0.1 gal/h diesel fuel leak are shown in Tables 1 and 2 for the two construction styles.

Accuracy - System has a probability of detection of 100% for leaks of 0.1 gal/hr or greater when all of the testing criteria are met. The false alarm rate for a tight tank is <5%. It is impossible to maintain a steady vacuum if a leak is present.

Specificity - This test procedure is intended to detect small air or vapor leaks.

Lower Detection Limit - Est 0.05 gal/hr with an extended test time

> Safety disclaimer: This test procedure only addresses the issue of the method's ability to detect leaks. It does not test the equipment for safety hazards.

Certification of Results

I certify that the interstitial monitor was installed and operated according to the vendor's instructions. I also certify that the evaluation was performed using methods which meet the requirements of the Alternative EPA test procedures as they are applied to interstitial monitors and that the results presented above are those obtained during the evaluation.

H. Kendall Wilcox, President (printed name)	Ken Wilcox Associates, Inc. (organization performing evaluation)
H. Kendall Wilcox (signature)	Independence, MO 64055 (city, state. zip)
January 6, 1994 (date)	(816) 795-7997 (phone number)

Plasteel Interstitial Monitor

Table 1. Air Leaks - Plasteel Doublewall Composite Style Contruction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Annular Volume (gal)	Test Time (hrs)
500	48	6-1	38	1.01
1000	64	6-8	91	2.43
2000	94	6-3	182	4.85
3000	94	9-2	210	5.6
4000	94	12-1	237	6.32
5000	94	15-0	265	7.07
6000	94	18-0	293	7.81
8000	114	16-4	368	9.81
10000	114	20-4	414	11.04
12000	114	24-3	459	12.24
15000	114	30-4	528	14.08
20000	114	40-4	640	17.07
30000	144	37-7	1281	34.16
40000	144	50-6	1579	42.11
50000	144	62-6	1863	49.68

Table 2. Air Leaks - Plasteel Doublewall Jacketed (Elutron) Style Construction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Annular Volume (gal)	Test Time (hrs)
500	48	5-9	3	0.08
1000	64	6-3	4	0.11
2000	94	5-11	5	0.13
3000	94	8-10	6	0.16
4000	94	11-9	7	0.19
5000	94	14-8	8	0.21
6000	94	17-8	9	0.24
6000	96	16-4	9	0.24
8000	114	16-0	10	0.27
10000	114	20-0	13	0.35
12000	114	24-0	15	0.40
12000*	96	32-8	16.6	0.44
15000	114	30-0	17	0.45
15000 - 9k/6k split	120	26	16.3	0.43
15000 - 9k/6k split*	120	26	18.3	0.49
15000 - 7k/8k split	120	26	16.3	0.43
15000 - 7k/8k split*	120	26	18.3	0.49
15000	120	25-8	16.1	0.43
15000*	120	25-8	18.1	0.48
20000	114	39-8	22	0.59
20000 - 12k/8k split*	120	34-4	22.6	0.6
20000 - 16k/4k split*	120	34-4	22.6	0.6
20000 - 15k/5k split*	120	34-4	22.6	0.6
20000 - 15k/5k split	120	34-4	20.6	0.55
20000 - 12k/8k split	120	34-4	20.6	0.55
20000 - 16k/4k split	120	34-4	20.6	0.55
20000	120	34	20.35	0.54
20000	120	34-1	20.4	0.54
20000*	120	34-5.5	22.7	0.61
25000*	120	42-7	28.3	0.75
30000 - 5K/20K/5K split*	120	51-2	32.8	0.87
30000*	120	51-2	32.8	0.87
30000*	126	46-1	31.3	0.83
30000	144	37-1	26	0.69
32000*	126	49-2	33.2	0.89
40000	144	50-0	34	0.91
50000	144	62-0	41	1.09

*These Thirteen tanks have a 3" diameter riser for the sensor. All other tanks have a 2"

Appendix C
Calculation of Test times

Appendix B - Alternative EPA Evaluation Forms
Post-Installation Liquid Leak Tests

Results of U.S. EPA Alternative Evaluation

Interstitial Monitoring Method

This form documents the performance of the interstitial monitor described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA'S requirements for alternative protocols. The full evaluation report also includes a report describing the method and a description of the evaluation procedures, and a summary of the test data. The results forms were modified from the Vapor-Phase Out-of-Tank Product Detectors. The evaluation procedures are included in Attachment A of this report.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name PLASTEEL, INC.

Version Interstitial Vacuum Test - Liquid Leaks

Vendor PLASTEEL, INC.

1189 Industrial Avenue

Escondido, CA 92029 Phone (619) 745-0333 Fax (619) 746-9515

Detector output type: (x) Quantitative ( ) Qualitative

Detector Operating Principle: loss of vacuum over time

Detector Sampling Frequency: ( ) Intermittent (x) Continuous

Evaluation Results

The detector described above was tested for its ability to detect losses in vacuum over a period of time. The following parameters were determined:

Accuracy - Ability of the detector to respond to small leaks.

Detection Time - Length of time required to detect a leak of known size.

Lower Detection Limit - Smallest leak which could be readily detected.

Ambient Conditions - Effects of temperature and product type on behavior of the leak detector.

Criteria for Declaring a Leak

The tank is declared to be tight when the vacuum remains above 5" of Hg for longer than the times specificed in Tables 1 and 2 for each tank. The vacuum prior to the test must be 10"±1" of Hg.

Interstitial Tightness Testing Method PLASTEEL, INC.

Version Interstitial Vacuum Test - Liquid Leaks

Compiled Evaluation Results

Two styles of tanks were evaluated: Plasteel Doublewall Jacketed (Elutron) Style construction; and Plasteel Doublewall Composit Style construction. Tank sizes range from 500 gallons to 50,000 gallons. Interstitial volumes range from three gallons to 1,863 gallons. Test times to detect a 0.1 gal/hr liquid leak are shown in Table 1 for the Elutron style construction and in Table 2 for the Composit style.

Accuracy - System has a probability of detection of 100% for leaks of 0.1 gal/hr or greater when all of the testing criteria are met. The false alarm rate for a tight tank is <5%. It is impossible to maintain a steady vacuum if a leak is present.

Specificity - This test procedure is intended to detect liquid product or water leaks.

Lower Detection Limit - Est 0.05 gal/hr with an extended test time

> Safety disclaimer: This test procedure only addresses the issue of the method's ability to detect leaks. It does not test the equipment for safety hazards.

Certification of Results

I certify that the interstitial monitor was installed and operated according to the vendor's instructions. I also certify that the evaluation was performed using methods which meet the requirements of the Alternative EPA test procedures as they are applied to interstitial monitors and that the results presented above are those obtained during the evaluation.

H. Kendall Wilcox, President
(printed name)

H. Kendall Wilcox
(signature)

January 6, 1994
(date)

Ken Wilcox Associates, Inc.
(organization performing evaluation)

Independence, MO 64055
(city, state, zip)

(816) 795-7997
(phone number)

Plasteel Interstitial Monitor

Table 4. Gas, Diesel, Water Leaks - Plasteel Doublewall Composite Style Contruction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Annular Volume (gal)	Test Time (hrs)		
				Gas	Diesel	Water
500	48	6-1	38	7.21	77.22	83.79
1000	64	6-8	91	17.26	184.92	200.66
2000	94	6-3	182	34.51	369.94	401.32
3000	94	9-2	210	39.82	426.73	463.06
4000	94	12-1	237	44.94	481.6	522.59
5000	94	15-0	265	50.25	538.5	584.34
6000	94	18-0	293	55.56	595.39	646.08
8000	114	16-4	368	69.78	747.8	811.46
10000	114	20-4	414	78.5	841.27	912.89
12000	114	24-3	459	87.03	932.72	1012.11
15000	114	30-4	528	100.12	1072.93	1164.26
20000	114	40-4	640	121.35	1300.52	1411.23
30000	144	37-7	1281	242.9	2603.18	2824.66
40000	144	50-6	1579	299.4	3208.63	3481.76
50000	144	62-6	1863	362.99	3785.73	4107.99

Table 5. Gas, Diesel, Water Leaks - Plasteel Doublewall Jacketed (Elutron) Style Construction

Tank Capacity Capacity (gal)	Tank Diameter (in)	Tank Length (ft-in)	Riser Size (in)	Annular Volume (gal)	Test Time (hrs)		
					Gas	Diesel	Water
500	48	5-9	2	3	0.57	6.10	6.62
1000	64	6-3	2	4	0.76	8.13	8.82
2000	94	5-11	2	5	0.95	10.17	11.03
3000	94	8-10	2	6	1.14	12.20	13.23
4000	94	11-9	2	7	1.33	14.23	15.44
5000	94	14-8	2	8	1.52	16.26	17.64
6000	94	17-8	2	9	1.71	18.30	19.85
6000	96	16-4	2	9	1.71	18.30	19.85
8000	114	16-0	2	10	1.9	20.33	22.05
10000	114	20-0	2	13	2.47	26.43	28.67
12000	114	24-0	2	15	2.85	30.50	33.08
12000*	96	32-8	3	16.6	3.15	33.75	36.61
15000	114	30-0	2	17	3.23	34.56	37.49
15000 - 9k/6k split	120	26	2	16.3	3.1	33.17	35.98
15000 - 9k/6k split*	120	26	3	18.3	3.48	37.24	40.39
15000 - 7k/8k split	120	26	2	16.3	3.1	33.17	35.98
15000 - 7k/8k split*	120	26	3	18.3	3.48	37.24	40.39
15000	120	25-8	2	16.1	3.06	32.74	35.52
15000*	120	25-8	3	18.1	3.44	36.81	39.93
20000	114	39-8	2	22	4.18	44.73	48.51
20000 - 12k/8k split*	120	34-4	3	22.6	4.29	45.90	49.79
20000 - 16k/4k split*	120	34-4	3	22.6	4.29	45.90	49.79
20000 - 15k/5k split*	120	34-4	3	22.6	4.29	45.90	49.79
20000 - 15k/5k split	120	34-4	2	20.6	3.91	41.84	45.38
20000 - 12k/8k split	120	34-4	2	20.6	3.91	41.84	45.38
20000 - 16k/4k split	120	34-4	2	20.6	3.91	41.84	45.38
20000	120	34	2	20.35	3.87	41.41	44.92
20000	120	34-1	2	20.4	3.88	41.52	45.03
20000*	120	34-5.5	3	22.7	4.22	46.17	50.06
25000*	120	42-7	3	28.3	5.38	57.57	62.44
30000 - 5K/20K/5K split*	120	51-2	3	32.8	6.23	66.66	72.31
30000*	120	51-2	3	32.8	6.23	66.66	72.31
30000*	126	46-1	3	31.3	5.95	63.67	69.06
30000	144	37-1	2	26	4.94	52.86	57.34
32000*	126	49-2	3	33.2	6.31	67.52	73.24
40000	144	50-0	2	34	6.46	69.12	74.98
50000	144	62-0	2	41	7.79	83.35	90.41

*These Thirteen tanks have a 3" diameter riser for the sensor. All other tanks have a 2"