Evaluation of the Highland Tank Periodic Interstitial Vacuum Test Procedure for Double-Wall Underground Tanks
(Titan®, STI-P3®,ACT-100U® and HighGuard®)

Final Report

Prepared for:
Highland Tank and Manufacturing Company, Inc.

December 20, 2010

Revised March 21, 2023

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One Highland Road
Stoystown, PA 15563**

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Preface

This report presents the results of an independent third-party evaluation of vacuum leak detection system provided for the Highland Tank Models Titan, Sti-P3, ACT-100U and HighGuard double wall underground tanks. These tanks differ primarily in the construction of the outer wall. Both walls of the Sti-P3, ACT-100U and HighGuard listed tanks are constructed of mild carbon steel and have advanced polyurethane coatings applied to the outer shell for corrosion protection. The Sti-P3 tank also has sacrificial anodes as part of its cathodic protection process. The outer wall of the Titan is constructed of polymeric materials that protect the inner metal tank from corrosion and forms the interstitial space.

All tanks are tested by placing a 14" Hg vacuum on the interstice and monitoring for the greatest times shown in Table 1 of this report for a specific volume. If the vacuum decreases are greater than 5" Hg over the test period, the tank is considered to be leaking.

This report is based upon testing previously performed by KWA Associates. This report is also based upon tanks constructed after the effective date of December 20, 2010.

Technical questions regarding this system should be directed to Mr. Charles Frey at the contact points listed below.

Approved.

KEN WILCOX ASSOCIATES, INC

H. Kendall Wilcox, Ph.D., President
May 2, 2018
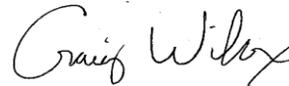
Craig D. Wilcox, Vice President
March 21, 2023

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Executive Summary

The Highland Tank interstitial monitoring method was evaluated for determining liquid leaks into the interstitial space of a double walled tank. The interstice is evacuated to 14" of Hg at the start of the test period. If the vacuum does not decrease more than 5" of Hg over the test period specified for each tank, the tank is considered to be "tight". The test times range from less than one hour for a gasoline leak into the interstice of a 550 gallon tank to 81.3 hours for a diesel leak into the interstice of a 50,000 gallon tank.

Once the tank is installed, the interstice may be monitored using a liquid or vapor sensor installed in a riser that extends into the interstice. In general, the liquid level will reach the threshold of a liquid sensor in less than 4 hours.

Background

The Environmental Protection Agency (EPA) requires that in-tank 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. The regulations for external monitors are much less well defined and there is no EPA protocol, for interstitial testing such as that developed by Highland Tank. To meet the specialized requirements for the Highland Tank system, it has been necessary to develop alternative evaluation procedures for this system. The requirements for alternative protocols are discussed in the introduction to all of the EPA evaluation protocols. The procedures described in this document meet these requirements.

It should be noted that the measurements conducted for this project are based on a limited range of petroleum products. The physical characteristics of fuels vary with geographic location, climates and brands. Physical measurements reported in this document should be taken only as indicative of general behavior and not as absolute values which might apply to other fields.

Description of Leak Detector and Operational Principles

The leak detection system developed by Highland Tank is based on the loss of vacuum in the interstitial space formed between a steel, primary containment vessel and a steel or HDPE secondary containment system that is formed around the outside of the tank. A vacuum gauge is used to monitor the vacuum which must be at least 20" Hg when the tank leaves the factory and 15" Hg when the tank is installed in the ground. (The initial vacuum at the factory may be as high as 27" Hg.) The leak detection process is based on the fact that the vacuum cannot be maintained is a leak is present in either the primary or secondary shell.

The Highland Tank interstitial volumes are relatively small. The tanks are constructed of an inner steel tank, and an HDPE jacket (Titan tank) or secondary steel wall wrapped tightly on the primary tank (Sti-P3, ACT-100U and Highguard). The interstitial spacing between the inner and out wall is 0.018 inches. The tank also consists of a 3" riser that extends through the inner steel wall into the interstitial space. A variety of liquid or vapor sensors may be installed in the riser as an additional means of leak detection.

Loss of vacuum can be due to several factors. These include:

* air leaks in either the inner or outer shell

* product leaks in the inner shell

* water leaks through the secondary containment if the tank is below the water table

In all cases, the resultant loss of vacuum will alert the owner/operator to the presence of a leak. If a leak is present, the vacuum cannot be permanently restored, and in the case of a liquid leak, the interstitial space will contain liquid.

In some instances, very small leaks in the outer wall or in the fittings of the tank will result in a very slow loss of vacuum. Although air flow through such leaks will be relatively rapid, liquid flow will be extremely slow and will not present any threat to the environment. This slow loss of vacuum may occur over a period of several days or months.

Evaluation Methodology

The data and conclusions for most of the testing conducted for this project were obtained in a laboratory environment using a test cell with a volume of 5.1 gallons. This is approximately the same volume as the interstitial space of a 4,000 gallon tank. This approach assumes that the behavior of the vacuum is not dependent on the shape of the interstitial space. That is, vapors and liquids will flow freely throughout the interstice and the secondary containment is not bonded to the inner wall. Tests for which volume was not a factor (e.g., vapor pressure measurements) were conducted in a smaller test chamber.

The loss of vacuum in the interstitial space will depend on the type of product (or air) that leaks into the interstitial space and the temperature of interstitial environment. Air leaks from the outside of the tank or vapor leaks above the liquid in the tank will reduce the vacuum to zero relatively quickly. The variations in vacuum with liquid leaks are different than those produced by an air or vapor leak. It is important to note these differences when interpreting leak test data. This report describes the testing conducted to determine the characteristics of liquid leaks into the interstice.

The effects of various liquids on the vacuum will depend on the vapor pressure of the liquid which in turn is dependent upon the temperature. Testing has therefore been designed to demonstrate the characteristics of each type of leak using several liquids. These liquids were selected because they represent a range of materials that are likely to be stored in underground tanks.

The following tests were conducted to establish the performance characteristics of interstitial vacuum monitoring.

1.   Measurement of the effect of vapor pressure on the vacuum

2.   The effects of displacement on the vacuum.

3.   Flowmeter characteristics under varying vacuum

4.   Flow of water through cracks in outer wall

Each of these tests is described in this section of the report and the results of each are discussed in the following section.

Vapor Pressure Tests

As the temperature of the interstice increases, the vapor pressure of liquid present in the interstitial space will also increase, resulting in a loss of vacuum. To determine the effects of varying temperatures on the vacuum in the interstitial space, several tests were conducted using water, gasoline and diesel fuel and air. Vapor pressures were measured for gasoline and diesel over the temperature range of 32°F to 120°F. This was accomplished using a small test chamber equipped with a vacuum gauge and a thermocouple to measure the product temperature. The empty test chamber was evacuated to a minimum vacuum of 14" Hg. It was then placed in the temperature bath. Ice was added to bring the temperature to a nominal 32°F . Product was then introduced into the chamber via the valve system at the top of the chamber. Adequate liquid was added to fill the test chamber to approximately 1/3 capacity. The liquid temperature was allowed to stabilize and the temperature and vacuum were recorded.

The temperature was then raised slowly by heating the water in the bath while the bath was stirred vigorously. Temperature and vacuum readings were recorded at regular intervals until the temperature reached a nominal 120°F.

Displacement Tests

Liquids with low vapor pressures will produce little change in vacuum when small amounts of liquid are present in the interstitial space. The vacuum will be reduced, however, as the liquid fills the interstitial space. A series of tests were conducted accordingly to determine the volume of liquid required to reduce the vacuum from 14" of Hg to 9" of Hg.

Volatile liquids will produce an initial large change in vacuum as soon as liquid enters the interstitial space. The vacuum will continue to drop until the test cell atmosphere is saturated. The initial drop will be dependent on temperature. Once the cell atmosphere is saturated, the vacuum will drop slowly as the interstitial space fills with liquid.

Displacement tests were conducted by evacuating the empty test cell to 14" of Hg. The temperature was maintained at a constant value during the addition. Liquid was added incrementally and allowed to stabilize between additions. The vacuum and volume were recorded after each addition. This process was repeated for each liquid.

Calibration of Flowmeter

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 8" of Hg. This corresponds to a new pressure of 4 psi against the orifice. (Four psi represents the pressure against a leak at the bottom of a full tank with a diameter of 8 ft.) The temperature was maintained at approximately 70°F. After the initial rate was established, the vacuum was varied from 20" of Hg to less than 2" of Hg. A graph of the flow rate vs vacuum was then constructed for each liquid.

Water Leaks Through Small Cracks in the Outer Wall

One of the possible sources of loss of vacuum in the interstice is a water leak through the outer containment. This could be a result of damage to the out wall prior to or during installation. While air leaks through these cracks can be large enough to cause loss of vacuum, the flow of water into the interstitial space could be extremely slow.

A special test apparatus was designed to test the effects of water leaks through small cracks in the out shell. The test apparatus consisted of a steel plate (inner wall) with a sheet of outer wall bounded around the out edges of the plate so that an interstice similar to that for a Highland Tank was created. Twelve small star cracks were produced in the out wall to simulate possible damage to the tank. A vacuum was then applied to the interstice to determine that air would in fact flow through the cracks. The vacuum vs time was monitored until the vacuum disappeared. The volume of the interstice was also estimated by creating a vacuum followed by quickly allowing water to fill the interstice.

The interstice was then connected to a water column that could be elevated to a height of 12 ft. The water flow rate through the cracks was measured at a different water head pressures to determine the behavior of the cracked outer wall material.

Calculation of Test Times

The time necessary to achieve a vacuum change of 5" of Hg was calculated for the interstitial volume for each tank using the equation

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

where V_{tank} is the volume of the interstitial space for the largest tank (32.3 gallons), V_{cell} is the volume of the test cell (5.1 gallons for this evaluation) and t_{cell} is the time necessary for the vacuum to decrease from 14" to 9" in the test cell. When the leak rate is 0.1 gal/hr at a temperature of 70°F, the value for t_{cell} is fixed at 1.0 hrs for gasoline, 12.1 hrs for water and 12.4 hrs for diesel fuel.

Test Results

Vapor Pressure Tests

The results of the vapor pressure tests are shown in Figure 1 for water, gasoline and diesel fuel. For water and diesel fuel, the initial vacuum in the test chamber prior to addition of product was nominally 27" of Hg. For unleaded fuel, two levels of initial vacuum were tested 27" and 22" (designated as "low P" on the graph).

In each case, the initial vacuum drops very rapidly as the first few ml of liquid enter the test chamber. More volatile liquids, such as gasoline, produce a large drop, while less volatile materials such as diesel fuel, produce much less initial loss of vacuum.

As the temperature of the test chamber increases, the vapor pressure of any liquid present will also increase, resulting in an increasing loss of vacuum in the interstitial space. For low volatility liquids, the decrease in vacuum is small. For both water and diesel fuel, the decrease in vacuum was approximately 2" Hg over the entire temperature range. Temperature will not be a significant factor for these liquids.

For gasoline, the vapor pressure increases much more rapidly as the temperature rises. For this reason, a gasoline leak will be much more readily detected. The initial decrease in vacuum will be rapid and should be easily identified by tank operators if consistent records are kept. The initial drop will be dependent on the temperature of the environment. At 32°F, the nominal drop was from 27" to 18" and from 22" to 9" for the low pressure test. At 60°F, the nominal increase will be from 27" to 14" or from 22" to 5". At temperatures around 100°F, the vacuum will decrease to near zero. At temperatures above 100°F, the interstitial space will be pressurized.

Displacement Tests

The second factor that caused a decrease in vacuum if the displacement process that occurs when liquid is added to the test chamber. This displacement process effective decreases the volume of the test chamber by the volume of liquid that is added.

The time required to detect a leak for nonvolatile liquids will depend directly on the volume of the interstitial space and the size of the leak. At an initial vacuum of 27", approximately 10% of the air at atmospheric pressure is still present in the interstitial space. When the liquid volume reaches approximately 90% of the total volume, the vacuum in the interstitial space will be reduced to near zero. For an initial vacuum of 15" Hg, approximately 50% of the air at atmospheric pressure is still present in the interstitial space. The vacuum will be reduced to near zero when the total volume of liquid added is approximately 50% of the interstitial volume.

This behavior is illustrated in Figure 2 for water and gasoline. The vacuum changes only very slowly as water is added to the test chamber. When the volume of water reaches approximately 75% of the chamber volume, the decrease in vacuum is rapid until the vacuum reaches zero.

For volatile liquids, the behavior of the vacuum is dependent on temperature. At low temperatures, the behavior is similar to that for nonvolatile liquids. At higher temperatures, the vacuum initially decreases rapidly followed by a slow decrease until the interstitial space is approximately 75% full. At 75% capacity, the decrease is again rapid. This behavior is also illustrated in Figure 2 for gasoline.

The behavior of the vacuum under the test conditions of 14" of Hg is shown in Figure 3. At 70°F, the volume of liquid required to decrease the vacuum from 14" to 9" is approximately 1 gallon for both water and diesel fuel and 0.075 gallons for gasoline.

Calibration of Flowmeter

The results of the calibration of the orifice at different vacuum levels is shown in Figure 4. Under the test conditions of this evaluation, the variation in leak rate with vacuum is expected to be linear and uniform for all liquids. The line represents the theoretical variation assuming that the leak rate is a direct function of the vacuum level. The theoretical curve was used for the calculations.

Water Leaks Through Small Cracks in the Outer Wall

The results of these tests are shown graphically in Figures 5 and 6. The volume of the test cell was determined to be 68 ml. Figure 5 shows the effects of vacuum on the air leak through the test cell. The time required for the vacuum to drop from 14" of Hg to 9" of Hg was only 15 seconds. This corresponds to an air leak rate of 1.8 gal/hr.

When water is applied against these cracks, the leak rate as a function of head pressure is show in Figure 6. These results indicate that water will flow through these cracks at a rate of less than 0.001 gal/hr under the test conditions.

Calculation of Test Times

The calculated test times for liquid leaks into the interstice is shown in Table 1 for tanks up to 50,000 gallons. The test times are provided for water, gasoline and diesel fuel for leak rates of 0.1 gal/hr and 0.05 gal/hr.

If a liquid sensor is located within the riser with a threshold of 1", an alarm will occur within 4 to 5 hours for the largest tanks. The interstitial vacuum will be at approximately 13.5" of Hg for diesel or water. The vacuum for gasoline will decrease to around 10" of Hg.

Table 1

Table 1		
Tank Size		Vacuum Hold Time
Diameter	Volume	
(in)	(gal)	(Hours)
48	550	5
48	1000	8
64	1000	7
64	1500	8
64	2000	10
64	3000	14
64	4000	19
72	4000	17
72	5000	20
72	6000	24
84	4000	15
96	4000	14
96	5000	17
96	6000	19
96	8000	25
96	10000	30
96	12000	35
96	15000	43
120	8000	23
120	10000	27
120	12000	32
120	15000	37
120	20000	48
126	10000	25
126	12000	29
126	15000	35
126	20000	45
120	24000	51
120	25000	51
126	25000	52
126	30000	58
144	30000	55
144	40000	68
144	50000	82

Intermediate volumes shall have a vacuum hold time equivalent to the next higher volume of the same diameter

Discussion and Conclusions

The Highland Tank monitoring method included a position-sensitive liquid leak sensor installed in the lowest point of the interstitial monitor tube, which will monitor for liquid leaks through both the primary and secondary tank walls when installed in accordance with Highland Tank's Interstitial Leak Detection Sensor Installation instructions.

While higher blends of ethanol in gasoline were not specifically tested, this report has stated that the more volatile liquids, such as ethanol, will produce larger and faster changes of vacuum in the interstitial space. Therefore, we conclude that ethanol blends of gasoline, up to and including E85, can be stored in these double wall tanks, and the testing protocol should follow the periodic testing procedures and test times noted for gasoline.

Periodic vacuum testing as required by the NC DENR will be performed as outlined in Highland Tank's Periodic Interstitial Test Procedure before start-up, six to twelve months after startup, and every three years thereafter.

Test Procedure

1. The vacuum shall be a minimum of 14" of Hg at the start.

2. The test period for each tank shall be that stated in Table 1.

3. Vacuum decreases of less than 5" of Hg during test period indicate that the tank is right. Record vacuum change, if any, in the space provided on installation checklist.

4. A vacuum decrease of more than 5" of Hg during test period required further investigation.

5. If further investigation is required, the tank manufacturer shall be contacted. After investigation is complete, this test shall be repeated.

6. This test procedure meets the EPA requirements for tightness testing of operating underground storage tanks containing product.

APPENDIX - ALTERNATIVE EPA EVALUATION FORMS

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   Highland Tank & Mfg. Co.

Version _____

Vendor   Highland Tank & Mfg. Co.

      One Highland Road

      Stoystown, PA 15563

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 decreases less than 5" of Hg over the test times

specified in Table l. The vacuum prior to the test must be a minimum of 14" of Hg.

Compiled Evaluation Results

Tank sizes range from 500 gallons to 50,000 gallons. Interstitial volumes range from 1.8 gallons to 32.3 gallons. Test times to detect 0.05 gal/hr and 0.1 gal/hr liquid leaks are shown in Table 1 for water, gasoline, gasoline/ethanol blends up to and including E85 and diesel fuel(including bio-diesel).

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 0.01 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	Ken Wilcox Associates, INC
(Printed Name)	(Organization Performing Evaluation)

H. Kendall Wilcox

(Signature)	Grain Valley, MO 64029
	(City, State, Zip)

Craig Wilcox

Craig D. Wilcox, Vice President	
(Printed Name)	(Signature)