In-Service Oil Tank Cleaning and Inspection System:

Results of Eight (8) Independent Validations

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1.0 Introduction

The structural integrity of bulk liquid storage tanks has been a major area of concern to the petrochemical industry for a number of years. Although API 653 remains the industry standard relative to tank inspection and maintenance, the frequency of testing and inspection can also be affected by various state and local regulations. The schedule of this inspection process may depend on a number of factors including the age of the tank, its proximity to groundwater, the leak record of the tank, the date of the tank's last integrity test, the construction material of the tank, the product stored, soil conditions, previous corrosion rate calculations, etc.

One of the critical areas of integrity testing is that of the tank bottom. Traditional methods of bottom inspection have required the emptying of the tank's product and a thorough cleaning and degassing prior to the allowance of personnel entry for a floor inspection. There are significant advantages to the tank owner if proper bottom inspection can be completed while the tank is in-service. Robotic technology is now available as a method for acquiring quantitative information for determining the integrity of aboveground storage tank floors while the tank remains on-line and in-service. API 653 allows the use of robotics as an alternative method for assessing the condition of a tank floor as long as certain conditions are met.

The purpose of this paper is to summarize the results of tests at several operating refineries and terminals comparing in-service ultrasonic bottom inspections of tanks to the results of traditional out-of-service inspections. Each tank was inspected using an oil tank inspection system operated by InTANK Services, Inc. The first test was conducted in 1994 and the last test completed in March 2000. All validations were conducted by independent tank inspection organizations or the tank owner's tank inspection staff. All validation inspectors were API-653 certified inspectors.

The objective of the in-service inspections was to quantitatively establish the parameters that would set the next internal inspection. This was achieved by providing the capability of returning to precise locations within the tank over a span of several years in order to compute accurate corrosion rate calculations.

The tank products, size, test locations and test dates are summarized below:

- Tank A: Water, 50 feet, New Jersey, November 1994
- Tank B: Lube Oil, 48 feet, Texas, October 1996
- Tank C: Kerosene, 120 feet, Texas, October 1996
- Tank D: Diesel, 100 feet, Virginia, July 1997
- Tank E: Diesel, 35 feet, Louisiana, April 1997
- Tank F: Diesel, 70, feet, Virginia, April 1998
- Tank G: Lube Oil, 60 feet, Kentucky, February 2000
- Tank H: Water, 117 feet, Texas, March 2000

Each of the following parameters were evaluated by comparing in-service UT floor scanning with out-of-service Magnetic Flux with UT prove-up:

- Overall validity of reported floor condition (i.e. topside vs. bottomside corrosion)
- Accuracy identification of corrosion location
- Nominal floor thickness measurements
- Measurement Reliability (Navigation System Accuracy)
- Floor/Tank Settlement Accuracy

The following operational parameters were evaluated during five of the eight validation inspections:

- Obstacle Avoidance
- Umbilical Handling Capability
- Sludge Removal Efficiency
- Coatings Detection
- Vehicle Handling Ability
- Rig-Up/Rig-Down Efficiency

2.0 Robotic Technology

The remotely controlled system that was used for this validation program is composed of a sludge removal vacuum system, a robotic vehicle with an in-tank navigation system, an eight-transducer array ultrasonic system, a sonar imaging system and a video system. The vehicle has been designed to operate in both fixed and floating roof storage tanks, and is designed to fit through an 18” (45 cm) manway. The system operates in water, No. 2 fuel oil, No. 6 bunker C (heated), lube oil, diesel fuel, jet fuel and similar middle distillates. The system will be operating in light distillates in early 2001.

When deployed inside a tank, the robot can simultaneously vacuum sludge and perform an ultrasonic inspection of the tank floor. The position and orientation of the vehicle are determined in real-time using onboard- and tank external shell-mounted navigation transducers, which enable the vehicle to be mapped on a display of the tank floor plates. Position resolution is on the order of +/- 1.0-inch. During the inspection, vehicle location for each bottom plate thickness measurement is recorded along with the ultrasonic returns from the tank floor. Though some data evaluation is conducted while the vehicle is in the tank, the majority of the data analysis is conducted post-test due to the enormous amount of UT data acquired during a typical 12 hour inspection. In addition to the thickness map of the floor, the UT data analysis software allows for the identification of bottomside and topside corrosion. The vehicle is also capable of detecting tank bottom settlement with onboard pressure transducers. The system is deployed with the tank full of product. Tank blinding is not required.

3.0 In-Service Methodology

Typical deployment operations consist of locating the equipment van and associated utilities adjacent to the tank within the berm area. The deployment process usually requires two crane lifts to the top of the tank. Equipment located at the top of the tank consists of the submersible vehicle and umbilical, pumping systems and in-tank deployment gear. Entry of the vehicle is completed through the roof’s top manway. A 350-foot (107 meters) umbilical is used to support vehicle operation.

While the system is readied for deployment from the top of the tank, the crew locates the tank navigation transducers at their proper locations around the tank. These locations, as well as the position of all tank appurtenances, are entered into a CAD system.

During vehicle deployment, a video record is made by the on-board camera in order to ensure the proper positioning of the vehicle onto the tank bottom. As with most tanks, accurate drawings are not always available. Consequently, special procedures need to be implemented in order to determine the location of various objects within the tank. These objects consist of roof supports, inlet and discharge pipes, sumps, and related internals. Once these objects are annotated into the CAD drawing and the proper position of the vehicle is determined, then the vehicle is ready for floor scanning.

A typical UT run consists of capturing data from all eight transducers every 0.16 of an inch while the vehicle is driven in a straight path for 2 feet. During each individual run, 1,200 ‘A’ scans (Figure 1) are collected and recorded, unless the product and sludge prevent the two foot run, then data are collected with the vehicle is stationery or during very short scan runs. The thickness measurements are then loaded into a spreadsheet where the ‘B’ scan data limits (Figure 2) are checked. Any location with a measured thickness of less than a pre-determined value is highlighted by the program and is then manually reviewed. This review determines the cause of the low thickness measurement. These causes could include actual component thinning, a gate error, a loss of signal, sludge/sediment, and/or if the vehicle ran over a weld seam.

For the particular tanks used for performance validation, between 50,000 and 1.5 million UT readings per tank were taken. These data are taken throughout the tank including the critical zone around the shell.

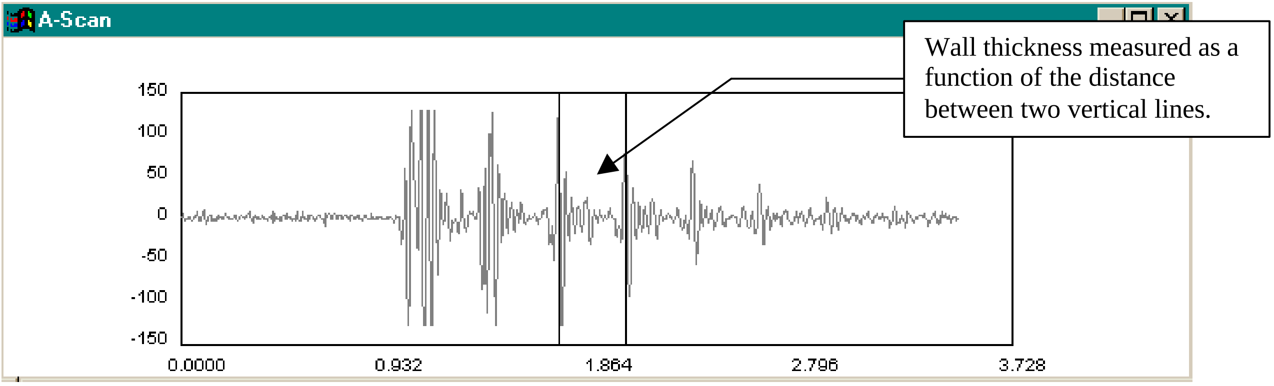
Most of the tanks inspected were found to have sludge at the bottom of the tank that precluded clear video for identifying some of the floor features. Sufficient video was taken, however, to confirm the presence of topside corrosion in some cases and the location of particular in-tank obstacles. Because of the presence of sludge, the material handling system was initiated and was used throughout most tank bottom scanning. Although the vehicle sludge removal system provided a clear path for the vehicle, much of the UT data had to be carefully analyzed off-line in order to acquire proper information regarding the presence of corrosion.

Post processing of the UT data was completed though the use of a thickness measurement module software package in conjunction with post processing signal detection software. The results suggested the presence of a significant amount of topside corrosion in most of the tanks and some floor thinning. In one case, the suggestion was made to take a tank out-of-service since minimum thickness indications were found below 100 mils (2.5mm). B-scan thickness data and thickness histograms were plotted in all cases. Areas of special interest were manually reviewed with the thickness measurement module and with 2D plotting software. Minimal and nominal thickness readings, as well as corrosion information were recorded in tabular form for later statistical analysis.

All UT data were correlated with the navigation position files and the actual location of all significantly corroded areas and thinning (below a pre-determined threshold) were identified for the out-of-service inspection. In all cases, certain indications were identified for further out-of-service analysis. Many locations were chosen for detailed analysis. Additionally, some tank shell settling was found in certain tanks. Figure 3 presents a plan view of a typical distribution of scans for an in-service floor inspection.

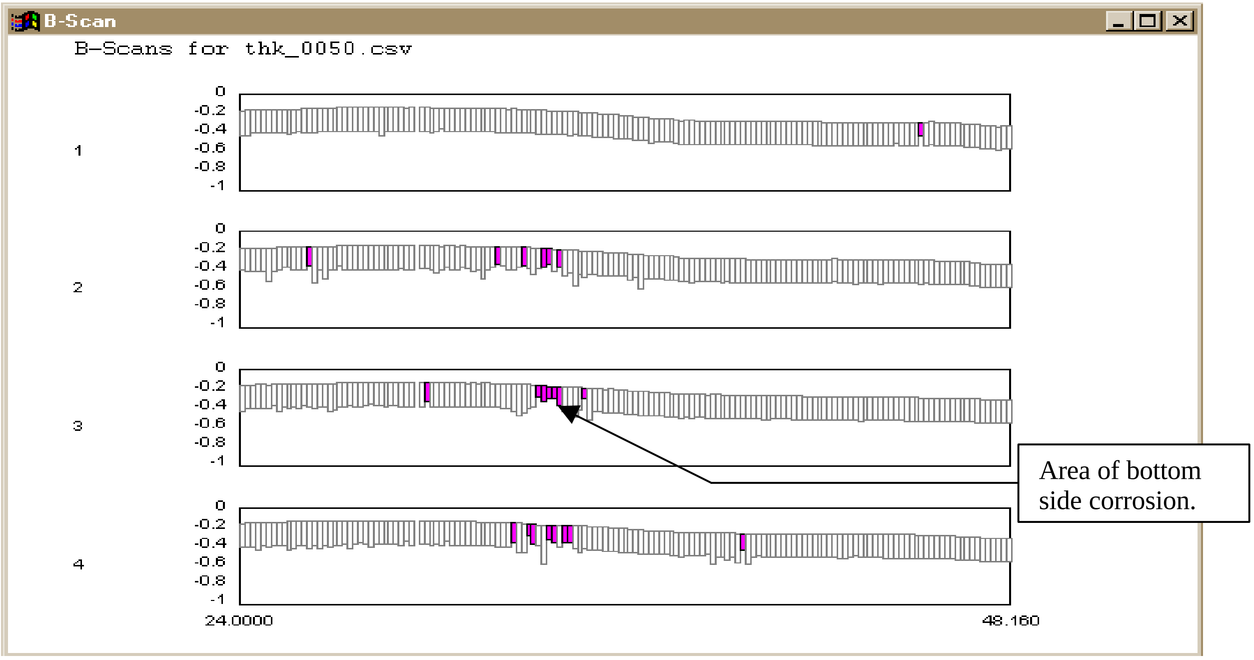
The objective of the in-service inspection is to quantitatively establish the parameters that will set the next internal inspection. Documents such as API 653 typically use the bottom condition, corrosion rate and thinnest remaining steel, as the governing parameters. The robotic in-service inspection described in this paper can provide that data. The minimum remaining metal estimate is provided as a direct result of the inspection and statistical data analysis. The corrosion rate is computed from that information.

With this information, the tank operator can estimate how much longer the tank can remain in-service before a bottom leak. Some codes and regulations may specify a non-zero minimum remaining bottom metal thickness for operations. In either case, the operator can use the in-service data to make an informed, quantitative decision regarding the appropriate schedule for the out-of-service inspection and repair.



Wall thickness measured as a function of the distance between two vertical lines.

Figure 1. Example of an A scan plot showing the front and rear walls from which thickness measurements are derived.



Area of bottom side corrosion.

Figure 2. Example of a B-scan plot showing the ultrasonic thickness readings from four transducers. Primarily bottomside pitting is shown.

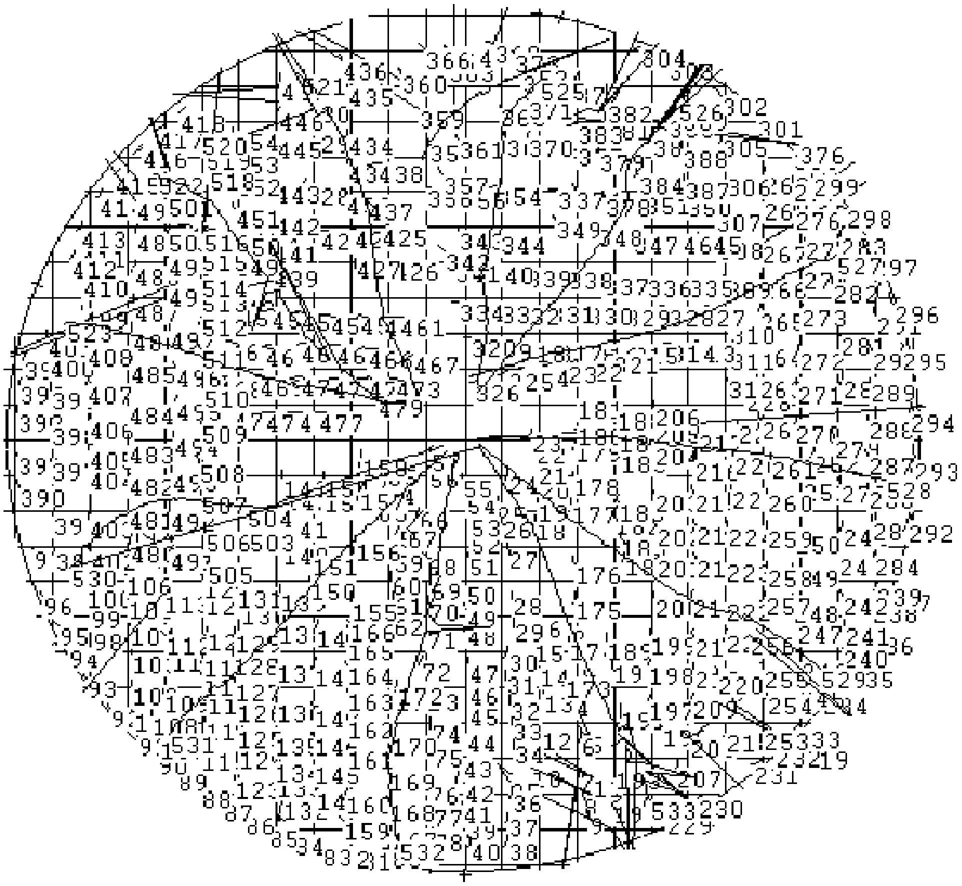


Figure 3. Plan view of a typical distribution of scans for an in-service floor inspection.

4.0 Out-Of-Service Methodology

All out-of-service inspections were conducted with the tank emptied of all products and cleaned. The inspections were conducted following the in-service test. On two occasions, the inspections were conducted prior to the in-service inspections. This was the case for Tank A where the target pits were pre-formed and for Tank E. Most out-of-service inspections consisted of full magnetic flux leakage floor scans with UT prove-up. Third party certified inspectors conducted the validation inspections and full reports were provided directly to the tank owner. Under no circumstances did any InTANK representatives have access to the out-of-service results prior to their submittal to the tank owner.

5.0 Results

Table 1 and Table 2 summarize the results of the field trials, including comparison to out-of-service inspections, where applicable. The comparison of results was accomplished by surveying the tank with traditional survey instruments (Tank B and C) or with the use of measuring tapes. Multiple tapes were set to their corrosion locations identified by the robot and the coordinates were measured from fixed reference targets within the tank such as manways, nozzles and similar appurtenances. Coupons were cut in certain areas to confirm soil side corrosion.

In one tank, the out-of-service results confirmed widespread deep product side corrosion. Several inches of water identified during the inspection probably contributed to the corrosion. The corrosion damage in this instance required full replacement of the bottom. In another case, limited soilside corrosion and scattered product side corrosion was found. A side-by-side comparison was made between observed product side corrosion and specific results reported by the out-of-service inspection at 9 specific locations. Locations were chosen both where the in-service inspection identified areas of specific corrosion and areas where no definitive metal loss was measured. These locations were physically identified in the tank using surveying methods. To within the accuracy of physical alignment, there was good correlation between the in-service and out-of-service measurements.

In another tank, the in-service testing similarly showed limited product side corrosion and widely scattered soilside corrosion. Data were collected in a large data set. Within each data run, the maximum pit depth was identified. From these areas pit depths greater than 0.2-inch (5mm) were noted. After those three deepest pit data points, the next deepest pit actually measured during the in-service inspection was 0.15-inch (3.75mm). These results correlated with the out-of-service results.

In another tank, a full API 653 internal inspection was conducted immediately before the robotic inspection. No floor repairs were made. This internal inspection included a full magnetic flux leakage floor scan with UT follow-up. The product side showed no signs of corrosion. Modest scattered soilside corrosion was found with the floor scanner. The in-service testing similarly showed limited product side corrosion and widely scattered soilside corrosion. Data were collected in a total of 191, 1-foot (.3 meter) data sets. Within each of these areas, the maximum pit depth was identified. Approximately 180 data sets had a maxima pit depth under .03-inch (.75mm). An extreme value analysis (EVA) was conducted on these data. The results showed that the EVA predicted a range of between 0.05–0.06-inch (1.3mm-1.5mm). Considering the nominal plate thickness of 0.25-inch (6.3mm), the maximum EVA pit depth estimate of 0.06-inch (1.5mm) would have correctly confirmed no immediate need for tank entry by predicting minimum bottom thickness of 0.17-inch (4.25mm).

Table 1. In-Service tank inspections compared to out-of-service results.

Tank ID	Tank	Actual Conditions	In-Service Results
A	Refinery (Water Tank) 50' diameter (165 meters)	**Topside:** minimal product side. Localized corrosion targets. **Bottomside:** no bottom corrosion. **Inspection Method:** visual	**Topside:** Localized targets found and sized. **Bottomside:** no soil side corrosion found.
B	Refinery (Lube Oil) 48' diameter (158 meters)	**Topside:** severe widespread corrosion. **Bottomside:** local bottom corrosion. **Inspection Method:** visual and coupons.	**Topside:** severe top corrosion identified but not possible to quantify. **Bottomside:** Severe localized pitting identified and confirmed via coupons.
C	Refinery (Kerosene) 120' diameter (37 meters) 4% Coverage	**Topside:** significant widespread corrosion (but not 100% - many areas with no damage); limited visual; identified through holes. **Bottomside:** experience/coupons suggest limited corrosion. **Inspection Method:** limited visual, UT, coupons, history	**Topside:** good local correlation between in-service and manual data. Globally, the topside EVA 4% sample predicted hole through. **Bottomside:** No significant corrosion identified.
D	Terminal 100' diameter (30 meters) 17% Coverage	**Topside:** No corrosion found **Bottomside:** 50+ areas less than .180 inch (4.6 mm) for repair. Area deeper than .200 found **Inspection Method:** visual and scanner with UT prove-up.	**Topside:** Limited product side corrosion found **Bottomside:** Widely scattered soil side found. Three areas of pit depth greater than .200 inch (5 mm) found
E	Refinery 35' diameter (10.6 meters) 30% Coverage (346,185 UT Readings)	**Topside:** No product side corrosion found **Bottomside:** Limited soil side corrosion found. Maximum pit depth of .065 inch (1.6 mm) found. **Inspection Method:** visual and scanner with UT prove-up.	**Topside:** Limited product side corrosion found **Bottomside:** Widely scattered soil side found. Pit depths in the range of 0.05 – 0.06 inch (1.3 – 2.0 mm) found.
F	Terminal (Kerosene) 70' diameter (21.2 meters) 10% Coverage (445,200 UT Readings)	**Topside:** Limited topside corrosion **Bottomside:** limited corrosion found. Near holes discovered. **Inspection Method:** visual and scanner with UT prove-up.	**Topside:** Limited topside corrosion **Bottomside:** Isolated, randomly distributed bottomside pitting. Average nominal floor thickness was .315. Maximum soil side pit depth was 0.199 (remaining wall thickness of .116). The next closest pit depth was approximately 0.166. Lamination found.
G	Refinery (Lube Oil) 60' diameter (18.2 meters) (156,000 UT readings)	**Topside:** No product side pitting found (Subsequent inspection confirmed some pitting in areas located by robot). **Bottomside:** No soil side corrosion found. **Inspection Method:** visual and MFL scanner with UT prove-up.	**Topside:** Some isolated pitting found. The average nominal floor thickness during the inspection was 0.248. A minimum thickness of 0.140 was found. **Bottomside:** Limited soil side corrosion found.
H	Refinery (Water) 117' diameter (35.4 meters) (55,200 UT readings)	**Topside:** Scattered product side corrosion confirmed under coating. Two plate sizes confirmed. **Bottomside:** Scattered soil side pitting confirmed. **Inspection Method:** visual and UT (flaw detector) prove-up.	**Topside:** Epoxy coating identified. Scattered product side corrosion found. Two plate sizes discovered. The average nominal floor thickness was 0.292. Minimum value recorded was 0.182 **Bottomside:** Scattered soil side pitting identified. Seven of the 46 UT runs contained corrosion

Table 2. Summary of Field Tests

	Tank A	Tank B	Tank C	Tank D	Tank E	Tank F	Tank G	Tank H
Diameter, feet	50	48	120	100	35	70	60	117
Product	Water	Lube Oil	Kerosene	Diesel	Diesel	Diesel	Lube Oil	Water
Product side corrosion	Minimal	Extensive	Scattered, through-holes	Limited	Limited	Limited	Limited	Scattered
Sludge	Minimal	Considerable	Considerable	Moderate	Moderate	Considerable	Moderate	Minimal
Soilside corrosion	None	Significant	Limited	Widely scattered	Limited	Moderate	None	Scattered
Comments	Targets Found	Water detected	Water detected	Identified lamination	2 Plate Sizes	Near Holes	Areas missed by MFL	Coatings 2 plate sizes
Minimum thickness measured, mils	125	"thin"	125	Less than 50	195	116	140	182
EVA minimum thickness estimate, mils	N/A	N/A	10	Less than 40	190	N/A	N/A	N/A
# of areas used in EVA	N/A	N/A	38	661 and fewer	191 and fewer	N/A	N/A	N/A
Percent of floor scanned	N/A	10	4	17	30	10	4	4
Type of inspection	Visual	Visual, coupons	Visual, spot UT	100% MFL/UT	100% MFL/UT	UT	100% MFL/UT	Visual/UT
Product side corrosion	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot
Soilside corrosion	N/A	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot	Agree with robot
Comments	Coupons confirm robotic inspection	Coupons confirm robotic inspection	Verified robotic at 9 specific points	Verified robotic at 30 specific points	Verified robotic at 10 specific points	Verified robotic at 10 specific points	Verified robotic at 10 specific points	Verified robotic at 10 specific points