Overcoming Corrosion Integrity Management Challenges for Storage Tanks and Associated Pipelines.

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ABSTRACT

Managing corrosion integrity for tanks and associated pipelines is a challenging and costly endeavor. In order to inspect tank floors, the tank's hydrocarbons or chemicals are usually emptied from the tank causing the tank to be out-of-service for an extended period of time. In addition to the monetary costs there is also a significantly increased safety risk.

The associated piping for transferring the hydrocarbons and chemicals in and out of the storage tanks are an additional integrity risk. The delivery lines are not designed for traditional in-line inspection (ILI) tools, often causing expensive modifications prior to ILI inspection. This paper explains how the attributes of "Unpiggable" tools are designed to overcome this challenge.

This paper also explains the attributes of our robotic technology that allows for tank floors to be inspected while the tank is "in-service", thereby overcoming costly delays and increased safety risk.

Finally, this paper highlights a case study associated with the inspection of a tank farm delivery line in 2017. The pipeline was located in a densely populated urban area. As a result, Phillips Petroleum Company had these pipelines on their priority list of pipelines to be inspected. The case study will highlight the associated equipment and technology attributes used to inspect the lines.

Keywords: ROV (remote operated vehicle for in-service tank inspection), ES350 and ES500 (ROV models used by the author's company)

INTRODUCTION

Recent developments in robotic technology have allowed operators to extend the service on above ground storage tanks, in adherence with regulations, before taking the tank out of service. This extends the uptime of tanks and reduces costs and safety risk.
PIGGING THE UNPIGGABLE PIPELINE(S)

When Philips Petroleum Company made a decision to inspect 4 pipelines at the tank farm in Torrance, CA., they determined the pipelines were considered “Unpiggable”. With no pig traps on the line, no space to install temporary traps, and no previous inspection data, there was a risk of having significant problems during the inspection. For this reason, they hired Intero Integrity to inspect the lines utilizing their Piglet fleet of tools.

As the pipelines were located in a densely populated urban area, Phillips Petroleum Company needed a way to inspect the lines without breaking the budget. Of utmost importance the company’s tools were bi-directional, saving significant budget dollars by allowing for a single entry/exit of the inspection tool. The inspection tools are Ultrasonic tools, the most accurate technology for measuring pipeline wall loss.

Prior to mobilizing for the inspection, it is crucial to know the requirements for project. For this reason, a site visit was made and the inspection company provided temporary valves, flow meters, pressure gauges and a temporary pig trap. Two portable pumps and a VAC trucks were provided for pumping the tool in both directions. The tool was launched from the temporary pig trap and was pumped with diesel. Prior to running the smart pig three cleaning tools were run through the pipelines.

The inspections were considered a success by Philips Petroleum Company. Each bi-directional run gave the company not one, but two data sets to evaluate the condition of the pipelines. This is especially useful when there is echo loss due to residual dirt and debris. Having two data sets adds enormous value in the situations.

TANK INSPECTION

Improved electronics over the last several years have enhanced tank floor inspections. Improved ultrasonic (UT) inspection methods address storage tank integrity monitoring and assessment without removing tanks from service. By acquiring large amounts of high-density UT data and evaluating them with readily available analysis tools, inspectors can now provide tank owners and regulators with insight into the integrity of above-ground storage tank (AST) floors not otherwise available.¹

API¹ 653 Requirements for Inspection

In paragraph 6.4.1.2 it states that “All tanks shall have a formal internal inspection conducted at the intervals defined by 6.4.2. The authorized inspector who is responsible for evaluation of a tank must conduct a visual inspection and assure the quality and completeness of the nondestructive examination (NDE) results. If the internal inspection is required solely for the purpose of determining the condition and integrity of the tank bottom, the internal inspection may be accomplished with the tank in-service utilizing various ultrasonic robotic thickness measurement and other on-stream inspection, methods capable of assessing the thickness of the tank bottom, in combination with methods capable of

¹ American Petroleum Industry (API) 1220 L. St. N.W. Washington D.C., 20005-4070
assessing tank bottom integrity as described in 4.4.1. If an in-service inspection is selected, the data and information collected shall be sufficient to evaluate the thickness, corrosion rate, and integrity of the tank bottom and establish the internal inspection interval, based on tank bottom thickness, corrosion rate, and integrity, utilizing the methods included in this standard. An individual, knowledgeable and experienced in relevant inspection methodologies, and the authorized inspector who is responsible for evaluation of a tank must assure the quality and completeness of the in-service NDE."

As stated in API 653

Initial and subsequent inspection intervals shall be in compliance with the requirements of API 653, paragraphs 6.4.2.1 and 6.4.2.2.

For existing tanks, tank owner/operators shall review the internal inspection interval and be in compliance with this section within 5 years from date of first publication (API 653, Fourth Edition, Addendum 2, January 2012).

6.4.2.1.1 The interval from initial service date until the first internal inspection shall not exceed 10 years unless a tank has one or more of the following (see Table 1 below) leak prevention, detection, corrosion mitigation or containment safeguards listed in Table 6 which are cumulative.

<table>
<thead>
<tr>
<th>Tank Safeguards</th>
<th>Add to Initial Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiberglass-reinforced lining of the product-side of the tank bottom install per API 652</td>
<td>5 years</td>
</tr>
<tr>
<td>Installation of an internal thin-film coating as installed per API 652</td>
<td>2 years</td>
</tr>
<tr>
<td>Cathodic protection of the soil-side of the tank bottom installed, maintained and inspected per API 651</td>
<td>5 years</td>
</tr>
<tr>
<td>Release prevention barrier installed per API 650, Annex 1</td>
<td>10 years</td>
</tr>
<tr>
<td>Bottom corrosion allowance greater than 0.150 in.</td>
<td>(Actual corrosion allowance – 150 mils)/15 mpy</td>
</tr>
</tbody>
</table>

OUT OF SERVICE VS IN-SERVICE INSPECTION

In-service Robotic Inspection of tank floors are now readily accepted by the industry. The cost of taking a tank out of service can be high, including downtime, safety risk, and associated labor and rental costs for transferring of the tank product. Also, in-service tank inspection can assist operators in planning future outage time, material and man power resources. Also, determining tank integrity, through validation of the EVA (Extreme Value Analysis) statistical lifetime assessment, in-service robotic inspection is taking the technological lead in managing tank integrity.

In general, it will not be possible for the ROV to reach/cover 100% of the tank bottom during the inspection. Typical areas that won’t be covered are shown in Figure 2. In principle, areas behind a fixed structure, seen from the manhole through which the ROV has been deployed, cannot be
inspected. These areas are not accessible for the ROV due to size and safety operations procedures.

**DEPLOYMENT AND INSPECTION**

The deployment of the ROV will be carried out through the manhole on the roof of the tank. A specially designed tripod will be used to lower the ROV into the tank and special guidance is required for the umbilical. The length of the control cables is limited, so the control area should be as close to the tank as possible. Special safety precautions shall be applicable to work on the tank roof (fall protection). When the ROV is lowered to the bottom of the tank, it will be maneuvered around in the tank following a pre-determined inspection route (chapter 2.5), as agreed by both parties. The purpose of the inspection plan is to ensure enough coverage of the tank bottom and minimize the risk of the ROV becoming entrapped.

The following list of tank conditions must be confirmed in order to perform a quality and accurate inspection.

- Ultrasonic properties of the existing floor coating must be known or determined. Air gaps/inclusions could influence the measurements.
• Manhole must be free of any obstruction and have a minimum diameter of 20 inches (508 mm) for the ROV
• Product temperature is not higher than 110°F
• Product in the tank is filled to a pre-determined level (based on tank characteristics)
• Floor must be free of any obstruction such as anodes, heating coils etc. Any obstructions should be mapped out in the inspection route plan to determine a safe working area and driving procedure

Extreme Value Analysis (EVA)⁴

Extreme value analysis (EVA) is a statistical tool to estimate the likelihood of the occurrence of extreme values based…observed/measured data. As stated by API 575 (chapter 8.4.4), this is an accepted practice for assessing the minimum remaining metal thickness of the tank bottom. The number of measurements taken for a statistical sampling will depend on the size of the tank and the degree of expected soil-side corrosion. Typically, .2% to 10% of the bottom should be scanned for a representative evaluation used for inspection data know as partial coverage inspection (PCI), where access, cost or other limitations result in an incomplete dataset. In PCI, EVA can be used to estimate the largest defect that can be expected.

Due to time, internal tank obstructions, and cost, UT inspection of100% of the tank floor is not feasible. Most inspections measure floor thickness over a well-distributed percentage of the floor and then estimate minimum floor thickness using EVA. Some tank owners also use EVA statistics when they evaluate out-of-service floor UT data following MFL scans.

Presuming the inspection plan meets requirements for application of EVA, data need to be collected from only a small percentage of the tank floor. API 575 and API650 agree this method has been validated and that there is no quantifiable difference in determining remaining life for the tank floor inspection as long as the data collected is distributed among all the navigable tank floor plates. Results of field tests and more than 20 independently monitored validation studies demonstrate that a small population sample of the tank floor can provide satisfactory results.

Managing Explosion Risk⁶

When will an explosion occur? The most critical time is when the ROV is being deployed through the vapor zone. The most common types of reactions are between flammable gases, vapors, or dust with oxygen contained in the surrounding air. This is a serious discussion for people working in environments such as in and around above ground storage tanks. Careful consideration must be made to the specifications of the tank and product as well as the design considerations of the tank inspection equipment to eliminate all risks of ignition.

The 3 basic requirements must be met for an explosion to occur in atmosphere air:

1. **Flammable substance** – need to present in sufficient quantity to produce ignitable or explosive mixture.
2. **Oxidizer** – musts be present in sufficient quantity in combination with the flammable substance. Most common is O2.
3. **Source of Ignition** – a spark or high heat must be present.
The presence of these 3 elements make up the sides of an ignition triangle:

![Ignition Triangle Diagram]

<table>
<thead>
<tr>
<th>Flammable Substance</th>
<th>Examples</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammable Gas</td>
<td>Hydrogen, etc.</td>
<td>Often compounds of hydrogen and carbon that require very little to react with atmospheric oxygen</td>
</tr>
<tr>
<td>Flammable Liquids/Vapors</td>
<td>Hydrocarbons such as ether, acetone, lighter fluids, etc.</td>
<td>Even at room temperature, sufficient quantities of the hydrocarbons can evaporate to form a potentially explosive atmosphere at their surface.</td>
</tr>
<tr>
<td>Flammable Solids</td>
<td>Dust, fibers, and flyings</td>
<td>The cumulative nature of dust hazard is the most significant difference between gas/vapor and a dust hazard.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A dust cloud will settle on nearby surfaces if it is not ignited. Unless removed, layers of dust can build up and will serve as fuel for subsequent ignition.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The typical dust explosion starts with the ignition of a small dust cloud resulting in relatively small damages.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure waves of the small initial explosion are the most damaging part of the dust explosions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>These pressure waves release dust layers from surrounding vertical or horizontal surfaces to produce a larger cloud which is ignited by the burning particles of the initial cloud</td>
</tr>
</tbody>
</table>
Oxidizer
Air at normal atmospheric conditions
When the amount of available atmospheric oxygen is more or less in equilibrium with the quantity of flammable material, the effect of an explosion – both temperature and pressure – is most violent

Ignition source
The amount of energy required to cause ignition is dependent upon these factors:
The concentration of the hazardous substance within its specific flammability limits
The explosive characteristics of the particular hazardous substance
The volume of the location in which the hazardous substance is present.

Ignition Sources
(Industrial Electrical Equipment)
Hot Surfaces
Surfaces heated by coils, resistors, lamps, brakes or hot bearings. Hot surface ignition can occur at the Auto-Ignition Temperature (AIT) or spontaneous ignition temperature at which a hazardous substance will spontaneously ignite without further energy
Electrical Sparks
Occurs when circuits are broken or static discharge takes place in low voltage circuits. Arcs are often created through the making and breaking of electrical contacts.
Friction and Impact Sparks
When casings or enclosures are struck

Three principles ensure that electrical equipment does not become a source of ignition. The basic point is to ensure that parts to which a potentially explosive atmosphere has free access do not become hot enough to ignite an explosive mixture.

What methods do we use to design tank inspection systems? This depends on the individual characteristics of tank and its product. For example, a water storage tank with no residual hydrocarbons or chemicals will require less design safety features than with a gasoline tank. The checkmarks below identify the design safety features used by our E350 and E500 robots.

<table>
<thead>
<tr>
<th>No.</th>
<th>Principles</th>
<th>Protection Method</th>
</tr>
</thead>
</table>
| 1   | Confine explosion
Explosive mixtures can penetrate the electrical equipment and be ignited. Measures are taken to ensure that the explosion cannot spread to the surrounding atmosphere | Explosion-proof enclosure✔ Dust ignition-proof enclosure✔ Conduit and cable seals✔ |
<table>
<thead>
<tr>
<th></th>
<th><strong>Isolate the hazard</strong></th>
<th><strong>Limit the energy</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The equipment is provided with an enclosure that prevents the ingress of a potentially explosive mixture and/or contact with sources of ignition arising from the functioning of the equipment.</td>
<td>Potentially explosive mixtures can penetrate the enclosure but must not be ignited. Sparks and raised temperatures must only occur within certain limits.</td>
</tr>
<tr>
<td></td>
<td>Pressurization and purging ✔️</td>
<td>Intrinsic safety ✔️</td>
</tr>
<tr>
<td></td>
<td>Oil immersion ✔️</td>
<td>Pneumatics</td>
</tr>
<tr>
<td></td>
<td>Hermetic sealing</td>
<td>Fiber optics</td>
</tr>
<tr>
<td></td>
<td>Encapsultation (potting)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Restricted breathing ✔️</td>
<td></td>
</tr>
</tbody>
</table>

**Photo 1. ES350 ROV**

In July 2017 Intero Integrity performed its first in-service inspection in the USA with the E350 Robot. This was a feasibility study conducted on an aboveground 3.3 million-gallon fuel storage tank, and was the culmination of two years of planning by the Defense Logistics Agency, Fleet Logistics Center (FLC) Jacksonville. This was a hugely successful project as the robot was able to detect elevation changes on the tank floor, thereby identifying ground erosion. Moreover, the corrosion anomalies on the tank floor that were detected and sized were within .1% accuracy from the subsequent manual UT sizing.

Today, we are pleased to announce the second US success of our remotely operated E350 robot. This project was commissioned by the Tennessee Valley Authority (TVA), located in...
Gallatin, Tennessee. The tank’s dimension are 138’ in diameter x 48’ tall and stores no. 2 diesel fuel.

TVA had a regulatory requirement to inspect this tank. The minimum cost to perform an out-of-service inspection of the tank floor would be significant. Intero Integrity charged significantly less and completed the entire project in 3 days. For this project we utilized a crew comprising technicians from both our Houston and Netherlands facilities.

Photo 2: Lifting Intero Integrity’s E350 Robot and floaters onto Tank roof

CONCLUSION

Out of service tank inspection is a costly, inefficient way to manage tank floor integrity. Periodic out of service inspections are still needed but improvements in tank robotics has now allowed for in-service risk-based inspections. Other benefit of this technology is it allows tank operators to minimize safety risk and optimize rehabilitation planning and maintenance.
1. B. Judkins, C. Palacios (2009); “Improved Methods Broaden In-Service Tank Inspection”, Oil and Gas Journal, 08/10/2009

2. API 653, Fifth Edition, November 2014

3. API 653, 6.4.2.1.1 Table 6.1

4. Extreme value analysis (EVA) of inspection data and its uncertainties, D. Benstock and F. Cegel; NDT & E International, Volume 87, April 2017


6. ExxonMobil Research and engineering; Krynicki, J., Babin, B., and Lok, J., Presentation by ExxonMobil Research and Engineering, “Onstream Inspection of Atmospheric Storage Tank Bottoms; API Singapore, March 6-8 2012

7. Class/Division Hazardous Location; Allen-Bradley Quality; Publication 800-WP003A EN – P, October 2001