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# Inspection and Evaluation of Lined Aboveground Storage Tank Bottoms in the Petroleum Industry

*Linings can complicate the inspection of tank bottoms. Here is an approach to surveying the complete surface of lined petroleum storage tank bottoms through the intact protective material.*

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**A** comprehensive inspection of aboveground storage tank (AST) bottoms, often with surface areas of several thousand square feet, can be a long and tedious task. Determining the integrity of the substrate can be complicated by the presence of protective coatings and linings. To adequately inspect lined tank bottoms without removing sections of the lining, inspectors need some type of technique for surveying the complete surface of the tank bottom through the intact protective material. This will allow detection of defects on the inaccessible soil side of the bottom as well as the lined, invisible product side. In addition to locating the corrosion, this technique must be able to differentiate corrosion originating on the soil side of the plate from corrosion originating on the product side. This task must be accomplished quickly and cost effectively.

This article briefly describes tank linings and traditional approaches to inspecting lined tanks. It then describes a relatively new approach to inspecting lined petroleum storage tank bottoms: the use of combined magnetic flux leakage (MFL) and eddy current (EC) testing.

## **Protective Linings**

Since the early 1970s, the use of protective linings on new and existing AST bottoms has been increasing. Such linings help mitigate product-side corrosion caused by water, salts, and sulfur compounds that are present in some petroleum products. Such linings are especially important when dealing with petroleum fractions known to have high internal corrosion rates such as sour crude oil, No. 6 fuel oil, or



Fig. 1 - Currently available MFL/EC unit  
Figures 1 and 2 courtesy of Magnetic Analysis Corporation (Mt. Vernon, NY)



Fig. 2 - Currently available MFL/EC unit

catalytic cracker feed stocks. In other instances, tanks are lined only to maintain product purity, as is the case with some jet fuel tanks.

The American Petroleum Institute (API) Recommended Practice 652, *Lining of Aboveground Storage Tank Bottoms*<sup>1</sup>, divides such systems into 2 general categories: thin film and thick film systems. Thin film (20 mils, 0.51 mm or less) linings are typically applied to new tank bottoms or to tanks with minor internal corrosion. Thick film (greater than 20 mils, 0.51 mm) linings can be used on both new and old tank bottoms and are typically glass reinforced with the glass in the form of flakes, fibers, or mats. For older tanks that have signs of severe product-side corrosion, or combinations of product-side and soil-side corrosion, reinforced linings of up to 120 mils (3.0 mm) may be applied.

Many ASTs that had thick-film fiberglass-reinforced linings installed 10 to 15 years ago are now due for inspection and evaluation. Typically, the linings were installed because the tank bottoms already showed significant levels of product-side corrosion. At times, the linings were installed as an attempt to mitigate the effects of soil-side corrosion as well. These linings, in particular, present a challenge to an AST inspector.

### Traditional AST Bottom Inspections

Traditional inspections of AST bottoms generally include a combination of several nondestructive testing (NDT) techniques, including visual inspection, ultrasonic testing (UT), magnetic particle testing (MT), and vacuum box inspections. Such traditional techniques are limited when inspecting AST bottoms because they typically are methods that sample only localized areas of the tank bottom. With lined AST bottoms, the limitations are increased. Of the NDT techniques mentioned above, all but ultrasonic testing is typically ineffective on lined

ASTs. Even UT, which has the ability to penetrate linings, may be ineffective if the lining on the tank bottom has begun to disbond or delaminate, or if it contains air bubbles or voids. All of these defects can cause a false reflection of the UT signal, thus giving a false reading. For most conventional UT equipment, accurate measurement of the steel plate is also difficult once the lining thickness is greater than about 80 mils (2.0 mm).

In the past, the decision of how to maintain a tank bottom was often based on a one-time internal inspection of a small percentage (less than 0.1 percent) of the total tank bottom. Replacement of tank bottoms and environmental risks due to leak-

ing tanks are important and potentially expensive issues. The decision should not be based on a limited, random assessment of a tank bottom. A technique that allows nearly 100 percent of the bottom to be inspected is required. MFL allows such an inspection to be accomplished.

### Magnetic Flux Leakage

Inspection of tank bottoms utilizing MFL, also known as magnetic flux exclusion (MFE), provides a technique for inspecting over 95 percent of the tank bottom, whether lined or unlined. MFL units are typically self-contained mobile units (about

## Where To Go from Here: Tips on Inspection and Evaluation

The following recommendations are based on my company's experience with the inspection and evaluation of lined ASTs.

- The inspection of lined ASTs should be completed by inspectors certified to API 653<sup>1</sup> and experienced with lined storage tanks. The inspection of these tanks requires a different set of skills that must be acquired through experience.
- The use of combined MFL with EC testing should be considered for all lined ASTs, but especially those with known corrosion conditions. If MFL is used without EC, it is recommended that portions of the lining be removed to verify the results.
- If severe soil-side corrosion is detected, it is not recommended that a lining, even a reinforced system, be relied upon to prevent leaks. While a reinforced lining can bridge a small hole in a tank bottom, over time, the hole can grow to such a

size that the lining could fail and a large leak could develop without warning.

- If a tank owner takes the API credit for a lining on a tank bottom and assumes an internal corrosion rate ( $S_{p,r}$ ) of zero or reduce the MRT to 0.050 in. (1.3 mm) as allowed by API 653, we recommend the following:
  - For new lining systems, the guidelines found in SSPC-PA 1<sup>2</sup> and NACE 6F 164<sup>3</sup> should be followed as a minimum. The lining should be inspected during the application and upon completion of the work. Inspectors should be NACE certified.
  - For existing lining systems, before the tank is returned to service, the lining should be inspected by NACE-certified personnel according to API 652.<sup>4</sup> Any defects found should then be repaired to API 652 and NACE RP0184.<sup>5</sup> ○

### References

1. *API Standard 653*, Tank Inspection, Repair, Alteration, and Reconstruction (Washington, DC: American Petroleum Institute, 1995).
2. *SSPC-PA 1, Shop, Field, and Maintenance Painting, in Systems and Specifications, Vol. 2*, Steel Structures Painting Manual (Pittsburgh, PA: SSPC, 1991).
3. *NACE 6F 164*, Curing of Interior Tank Linings (Houston, TX: NACE International).
4. *API Recommended Practice 652*, Lining of Aboveground Storage Tank Bottoms (Washington, DC: American Petroleum Institute, 1991).
5. *NACE RP0184*, Repair of Lining Systems (Houston, TX: NACE International, 1991).

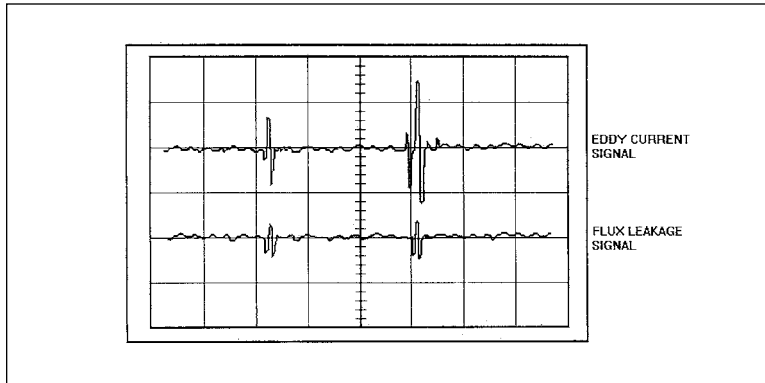


Fig. 3 - Schematic of signals caused by product-side (internal) corrosion pits  
*Figures 3-8 courtesy of the author*

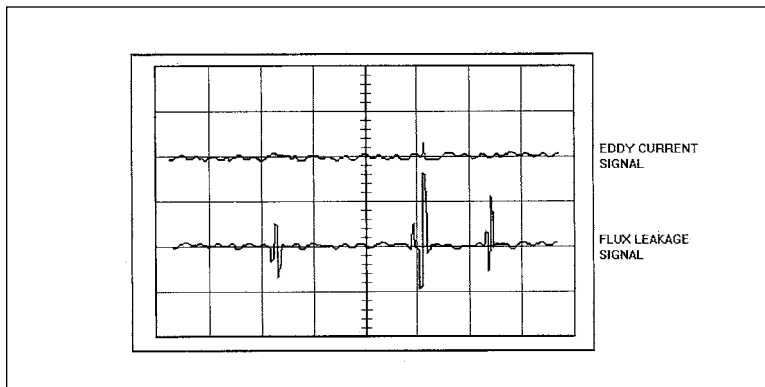


Fig. 4 - Schematic of signal caused by soil-side (external) corrosion pits

the size of a lawnmower) that are designed to detect product-side and soil-side corrosion in the steel bottom plates. Figures 1 and 2 show examples of currently available MFL units.

A detailed, technical discussion of MFL is beyond the scope of this paper. For those who wish a more complete, technical description, references 2, 3, and 4 should be consulted. The following provides a brief description of the technique.

The technique is based on the use of electromagnets to completely saturate the bottom plates with a magnetic field. Sensors attached to the scanner monitor the magnetic field at the surface of the bottom plates. Corrosion alters the pattern of the magnetic field by causing a leakage field that is detected by the sensors.

Under normal conditions, pitting as shallow as 70 mils (1.8 mm) can typically be detected in  $\frac{3}{8}$ -inch (9.5-millimeter) bottom plate. Scanning rates vary and depend on the general condition of the tank bottom and the number of indications that are found. As a basic guideline, an 80-foot (24-meter) diameter tank bottom can be in-

spected in one, 8-hour day. MFL scanning techniques typically can detect corrosion accurately on both sides of an unlined AST bottom plate.

There is, however, an important limitation of this technique. Although MFL alone can detect corrosion on the plates, it cannot determine the origin of the corrosion. That is, MFL cannot distinguish or differentiate corrosion originating at the soil side from corrosion originating at the product side.

For unlined AST bottoms, this limitation is not usually problematic because for these structures, visual inspection of the unlined product side can usually confirm the corrosion's origin. If the product side of the unlined substrate does not manifest corrosion and pitting, then the corrosion detected by the MFL generally has its origin on the soil side of the bottom plate.

The limitation of MFL is most problematic when an AST bottom is lined; visual inspection of the product side to determine the corrosion's origin is no longer possible without actually removing the lining. If the AST had been lined when new,

Fig. 5 - Illustration of tank floor having both internal and external corrosion lying under a fiberglass reinforced lining. Internal (product-side) corrosion pits correspond to fluctuations in eddy current signal in Fig. 6 below. External (soil-side) corrosion pit corresponds to middle fluctuation of flux leakage signal in Fig. 6 below.

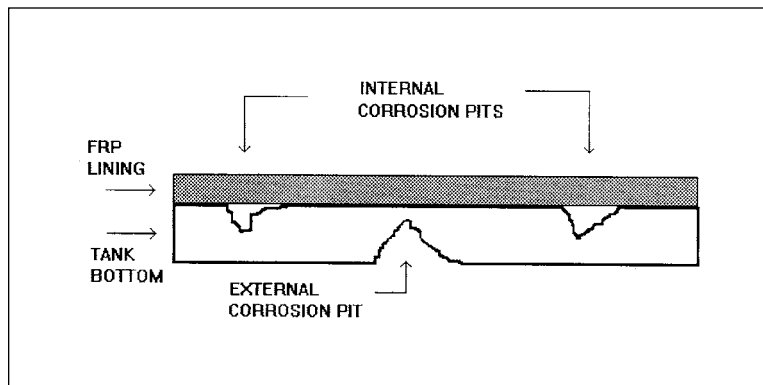
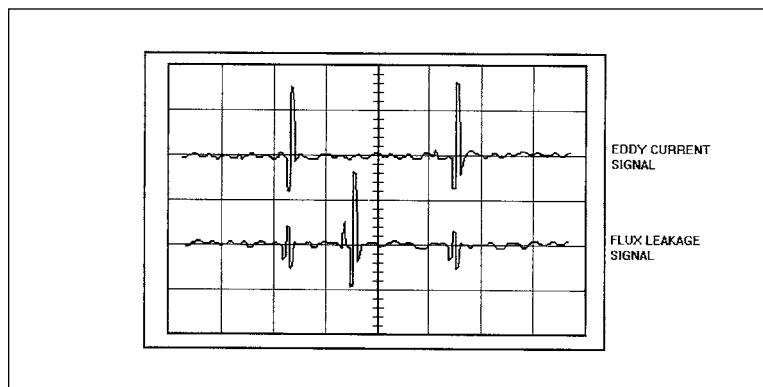


Fig. 6 - Schematic showing eddy current and flux leakage signals representing corrosion condition shown above



the difficulty is not as great because any corrosion indicated by the MFL unit can be assumed to be from the soil side unless the lining itself is deteriorating. This assumption is generally valid because if a lining installed at the time of tank construction is intact several years later at an inspection, then the lining is still providing an effective barrier between the product stored and the substrate.

More commonly, ASTs that already have product-side corrosion are later lined to extend the life of the steel bottom. When the linings are in good condition and the tanks are due for inspection, the effective use of MFL may be difficult if not impossible. This is because the MFL alone cannot distinguish product-side corrosion that occurred before lining from soil-side corrosion that occurred after lining.

The lining, or more commonly, sections of it, must be removed to identify the origin of corrosion detected through MFL, but this procedure is expensive and time-consuming for the owner. Therefore, a new technology needed to be developed not only to detect the corrosion but to deter-

mine the corrosion's origin (soil side vs. product side). The technique developed for this task is actually a combination of 2 electromagnetic techniques, the previously mentioned MFL combined with EC testing.

### Combined Magnetic Flux Leakage/Eddy Current Inspection

Until recently, AST bottoms have been scanned using either MFL or some variation of EC testing. A proprietary technology allows simultaneous MFL and EC testing of AST bottoms.

This new technology combines the best features from both techniques into a complete bottom scan. One of the major advantages of this combination is that it allows soil-side and product-side corrosion to be differentiated on-line during the inspection. Dual displays show the eddy current/product-side corrosion separate from the main MFL signal.

Figure 3 shows the response from 2 product-side corrosion pits. Note the large

**Table 1**  
**Minimum Remaining Thicknesses (MRTs)**

Minimum Bottom Plate Thickness at Next Inspection	Tank Bottom/Foundation Design
0.10 in. [2.5 mm]	Tank bottom/foundation design with no means for detection and containment of a bottom leak
0.05 in. [1.3 mm]	Tank bottom/foundation design with means to provide detection and containment of a bottom leak
0.05 in. [1.3 mm]	Applied tank bottom reinforced lining, >50 mils [1.3 mm] thick

*From API Standard 653, Tank Inspection, Repair, Alteration, and Reconstruction, Second Edition, December 1995. Reprinted courtesy of the American Petroleum Institute.*

signals from the product-side eddy current trace and the smaller signals on the flux leakage trace. Figure 4 shows the response from 3 soil-side corrosion pits. The signals here are large responses on the flux leakage trace and a flat line signal on the top-side EC trace. The traces will both be flat if there is no corrosion.

This ability to differentiate the origin of corrosion is essential when the AST has a lining that results in the product-side of the bottom not being visible. This differentiation of corrosion allows inspections to be done more accurately and with higher scanning rates.

Figures 5 and 6 illustrate how this combined technique can be used to detect and differentiate corrosion under a thick film lining system. During the inspection, the inspector looks for a signal typical of the one shown in Fig. 6.

This technique has been used successfully in inspections of lined AST bottoms in refineries, bulk storage terminals, and chemical plants over the past 3 years. Figures 7 and 8 show examples of corrosion identified through a protective lining by a MFL/EC unit.

Once the substrate has been inspected and the presence as well as origin of the corrosion has been determined, the extent of active corrosion, if there is any, must be calculated so the service interval of the tank can be estimated.

MFL/EC gives only a qualitative assessment of the presence and origin of corrosion on an AST bottom with an intact lining. UT can be used to measure the depth of corrosion pitting so that the corrosion rate can be calculated. The next section explains a method for evaluating the inspection data and establishing a service interval for a lined storage tank. API 653<sup>5</sup> recognizes that lined ASTs have unique properties compared to unlined ASTs and, as such, should be evaluated differently.

### Evaluation—Tank Bottom Service Interval

All tank bottoms have a certain useful service interval. In this context, the service interval is the time period until the tank has to be next taken out of service for cleaning, inspection, and maintenance. The majority of ASTs in the petroleum industry are constructed using steel bottom plate ranging in thickness from  $\frac{1}{4}$  in. (6.4 mm) to  $\frac{3}{8}$  in. (9.5 mm). Due to corrosion, both internal and external, the service interval of a tank bottom is limited. Tanks owners have a keen interest in extending the service interval of their tanks. The cost of cleaning large diameter storage tanks can easily reach tens of thousands of dollars. In addition, the temporary loss of storage volume or plant operating issues (in the case of an oil refin-

Fig. 9 - API equations for establishing the service interval of an AST bottom.

From API Standard 653, Tank Inspection, Repair, Alteration, and Reconstruction, Second Edition, December 1995. Reprinted courtesy of the American Petroleum Institute.

$$MRT_1 = T_o - GC_a - SIP_a - UP_m (SIP_r + UP_r + GC_r) O_r$$

$$MRT_2 = T_o - GC_a - SIP_m - UP_a (SIP_r + UP_r + GC_r) O_r$$

Where:

$MRT_1, MRT_2$  = minimum remaining thickness at the end of the in-service period of operation, in inches ( $MRT_1$  represents minimum remaining thickness due to average internal pitting and maximum external pitting.  $MRT_2$  represents minimum remaining thickness due to maximum internal pitting and average external pitting.)

$T_o$  = original plate thickness, in inches.

$SIP_a$  = average depth of internal (product-side) pitting, in inches, measured from the original thickness.

$SIP_m$  = maximum depth of internal (product-side) pitting remaining in the bottom plates after repairs are completed, in inches, measured from the original thickness.

$UP_a$  = average depth of underside (soil-side) pitting, in inches.

$UP_m$  = maximum depth of underside (soil-side) pitting, in inches.

$SIP_r$  = maximum internal pitting rate, inches per year;  $SIP_r = 0$  if the tank bottom is internally lined (see API RP 652).

$UP_r$  = maximum underside pitting rate, in inches per year;  $UP_r = 0$  if tank bottom is cathodically protected (see API RP 651).

$O_r$  = anticipated in-service period of operation (normally 10 years).

$GC_a$  = average depth of generally corroded area, in inches.

$GC_r$  = maximum rate of general corrosion, in inches per year.

ery) can be extremely costly. Added to these factors are the risk of environmental damage caused by leaking tanks and the high cost of environmental cleanup.

Until recently, estimating the service interval of storage tank bottoms had been based on such factors as visual observations, operating history, and general experience with similar tanks. In 1991, API issued the first edition of Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*.<sup>5</sup> This standard covers all aspects of tank inspection and includes a section on how to determine the service interval of an AST bottom. The API approach is to gather data through an internal inspection and calculate corrosion rates, provide limits on minimum bottom thickness, and establish the schedule for the next internal inspection. As one way to establish the service life of an AST bottom, API presented the equations shown in Fig. 9.\*

\*In addition to this deterministic method from API, probabilistic methods using statistics have been employed with good results.

Based on the equations in Fig. 9, the minimum remaining thickness (MRT) at the end of the anticipated service period ( $O_r$ ) can be calculated. This minimum thickness is used to establish the service life of the tank bottom. The MRTs established by API are shown in Table 1.

API Standard 653 recognizes the protective capacity of tank bottom lining systems and allows certain assumptions or credits to be made. These assumptions or credits cannot be made for unlined tanks. When determining the internal inspection frequency for a storage tank, the internal corrosion rate ( $SIP_r$ ) of a tank with an internal lining can be assumed to be zero. This assumption can be made provided that the lining is in acceptable condition and suitable for the intended service. This assumption is valid for either thin or thick film linings.

If the AST has a reinforced lining thicker than 50 mils (1.3 mm), then API 653 allows the MRT at the end of an inspection interval to be reduced from 0.10 in. to 0.05 in. (2.5 mm to 1.3 mm), as shown in Table 1. This reduction is due



Fig. 7 - Numerous holes found by MFL/EC in lined tank bottom. (Note: Wooden stakes inserted into holes as location markers.)



Fig. 8 - Detail showing holes verified by removal of the tank bottom lining

in part to the ability of a reinforced lining to provide sufficient strength to bridge a small hole that may unexpectedly develop when the tank is in service.<sup>1</sup> For details on the above, please refer to API 653, Section 2.4.<sup>5</sup>

Both the reduced internal corrosion rate ( $S_{cP_r}$ ) and the MRT allowance will have a significant effect on the service interval of an AST. Even if an AST has been subject to significant corrosion, the service interval may reach the API maximum of 20 years with adequate repair and the installation of a proper lining system.

## Summary

The inspection and evaluation of AST bottoms can be the most difficult part of an overall tank inspection project. This is in part because the soil side of the bottom plate is typically inaccessible to visual inspection. Lined tank bottoms present further difficulties in that the product side in these tanks is also not visible. To compound matters, tanks are usually lined because significant product-side corrosion has already occurred.

Through a combination of MFL and EC testing, the condition of a lined tank can be accurately assessed. Combined MFL/EC inspection allows tank bottom corrosion to be detected and soil-side

corrosion differentiated from product-side corrosion.

Using the data from the MFL/EC inspection, the evaluation of lined tanks can be completed in such a way as to maximize the service interval of the tanks without sacrificing safety or reliability. **JPCL**

## References

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