ACOUSTIC EMISSION IN-SERVICE ACTIVE CORROSION MONITORING & ASSESSMENT ON ABOVE GROUND ATMOSPHERIC STORAGE TANK FLOORS

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Motivation - Necessity

Failures of time-based maintenance

- Tanks removed from service, cleaned, sludge dumped, tank inspected......and no repairs required.....

- Tanks inspected though leaks not always prevented ...

- If time based internal inspection worked....... this would not be happening.......
Tank Floors are the only structural part of a tank with no access for inspection during operation

- Access to tank floors for inspection is difficult and costly.
- Leakage is no longer environmentally acceptable.
- Risk of catastrophic failure with severe annular ring damage.
- Cleaning costs can be >$200,000, + environmental waste problem. If no repairs are required these costs are wasted.

Requirements:

- To identify tanks which do NOT yet require internal inspection and repair, this prevents the waste of maintenance resources and protects the environment.
- To determine the relative condition of damaged floors so that a correct priority for internal maintenance may be set.
- To do the above with as little disruption to operations as possible.
Acoustic Emission Tank Floor Testing Overview

- The tank is monitored in service, following conditioning (Valves closed, heaters off, agitators off), for a pre-determined time (6-24 hours in advance of test).

- It is a statistical based Health Monitoring Approach.
Acoustic Sources detected

- Corrosion of steel causes Acoustic Emission (Yuyama, Condello etc).
- Sources detected by sensors on the outside of the tank.
- Spalling of corrosion products.
- Leak noise: (flow interruption, or turbulence).
- External Interference - noise to be filtered:
  
  Roof movement noise, Structural movement, External and pipe-borne noise, Condensation, Particle impacts, Valve leakage.

Shown above: one hour of emission from a tank with very severe corrosion, characteristics of emission change with scaling.
TANKPAC Procedure

- Sensors are attached to the tank wall around the entire circumference.
- The tank is monitored, following conditioning, for a pre-determined time (1-2 hours).
- The data is processed to eliminate unwanted sources of noise.
- The data is evaluated against a database, and using special algorithms for location.
TANKPACT™: CONDITION MONITORING FOR TANK FLOORS

• Tank floor top view with locations of corrosion and/or leak sources
• 3D plots of located corrosion and leak sources
• Separate analysis and grading of the most severe corrosion sites

100% FLOOR INSPECTION & ANNULAR RING

Overall Tank Grading, from A (no damage) to E (severe damage), indicate the general condition of the Floor.
Potential Leak Sites Identified & Graded indicating concentrated sources of severe corrosion or leak.
Combination of Overall Grading with Potential Leak Result in Composite RBI compatible Matrix.
Analysis Tools

Analysis is performed using NOESIS Advanced Acoustic Emission Data Analysis Pattern recognition and Neural Network software. The software is designed to be used in both field or research applications which numerous capabilities, range from advance combination of filters, analysis options, automations to automatic report generation.
Analysis Tools

A large selection of pattern recognition modules are included in the software for the advanced classification interpretation and filtering of data, using various unsupervised and supervised methods or neural networks.
Analysis Tools

Corrosion sources along with color grading can be displayed on 2D or 3D location graphs. The colors are linked with the severity of located corrosion clusters of the tank floor.
Test Recommendations

The internal condition of the tanks, resulted from the large population of conducted tests, is encapsulated in an RBI–like table that separates the classification of the tank floor condition and gives recommendations about the inspection interval. Using this grading system, the maintenance and resources are allocated to where they’re most needed. The table below shows the TANKPAC grading in a risk matrix format.

<table>
<thead>
<tr>
<th>“PLD GRADE”</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
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<tbody>
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<td>I</td>
<td>II</td>
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<table>
<thead>
<tr>
<th>“OVERALL GRADE”</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
</table>

I - No active damage, re-test in 4/5 years.
II - Minor active damage, re-test in 2 years.
III - Active damage re-test in max.1 year*.
IV - Very active damage. Re-test in 0.5 year*.

*or schedule for internal inspection

n/a: Should not occur if standard threshold used
Past Correlation/Validation Tests

TANKPAC “overall” grading vs. repairs required*

Follow-up results versus AE-grades, normalised per AE-grade population of 157 tanks (Shell, Dow-Stade, DSM, PKE, Total and PAL database)

* P. van de Loo/Shell, B. Hermann/Dow, ECNDT 1998
In the following I will try to Compare Apples (AE) with Lemons (MFL) and Oranges (UT) through several case studies !!!

Notes:
MFL sensitivity aprox. 10%-20% of nominal, Weld areas not inspected, annular up to 250mm close to shell not inspected. MFL requires correlation with UT
Manual - contact UT does not detect pin holes or small pitting. Areas close to annular ring require special attention
Welds areas usually inspected visually only for top side corrosion. No testing for bottom side.
Case Study 1 - TANKPAC Comparison w/t Internal Inspection

1st CASE – HEAVY FUEL OIL 46m DIAMETER FIXED ROOF TANK

When reviewing TANKPAC results it appears that a general corrosion state already existed in the whole tank floor. In addition, apart from the generalized state of corrosion indicated by the “C” grade, the presence of localized areas with high AE activity should have signified the importance to re-test in accordance with the recommendation (i.e. 2 years). However no actions were made.

TANKPAC™ Results (2008) five years before internal inspection, graded as “C”, along with indications of very persistent localized AE activity
Case Study 1 - TANKPAC Comparison w/t Internal Inspection

1st CASE – HEAVY FUEL OIL 46m DIAMETER FIXED ROOF TANK

The specific tank was opened for maintenance and inspected internally with **MFL five years after the AE test**, on 2014. MFL scan was performed and holes were found on most of the areas where TANKPAC™ had revealed high AE activity five years ago. In addition, it appears that the corrosion areas increased within the five years’ time between the two different inspections.

142 of the 171 main plates had top side corrosion, 14 had bottom side corrosion and more than 100 holes were found. 23 of the 25 annular ring plates had bottom side corrosion.

Earlier prioritization might have resulted in significant maintenance cost reduction due to the fewer repairs that would have been needed and downtime of the tank.
Case Study 2 - TANKPAC Comparison w/t Internal Inspection

2nd CASE – CRUDE OIL 85m DIAMETER FLOATING ROOF TANK

The MFL equipment coverage was up to 200mm from the annular ring area. The area that could not be covered with MFL was inspected with ultrasound (UT). In this case, it was found that the annular ring was suffering from a bottom side corrosion and high thickness losses. The tank floor was found to have both top and bottom side general corrosion as it is shown in both MFL and TANKPAC™ results.

Overall, extensive repairs were performed in this tank. In addition, the cost of having it out of service, was the most important fact in this case, since this large capacity tank had remained out of service for nearly a year.
Case Study 2 - TANKPAC Comparison w/t Internal Inspection

2nd CASE – CRUDE OIL 85m DIAMETER FLOATING ROOF TANK

The TANKPAC results showed a highly active tank with most of the AE activity to take place around the annular ring of the tank. The tank grade was given as D, with a re-test recommendation in maximum 1 year or to be scheduled for internal inspection. However, as in the previous case, no actions were taken.

TANKPAC™ Results (2009) three years before internal inspection. Graded as D, with a re-test recommendation in max 1 year or to be scheduled for internal inspection.
Case Study 3 - TANKPAC Comparison w/t Internal Inspection

3rd CASE – CRUDE OIL 85.4m DIAMETER FLOATING ROOF TANK

TANKPAC Inspection Results. Graded: “D”, PLD:”2”, Composite:”II” (re-test in 2 years). (high activity at the annular ring on 2003)

Automated UT Inspection Results (extensive local corrosion found on the annular ring on 2006)
Case Study 4 - TANKPAC Comparison w/t Internal Inspection

4th CASE – DIESEL 17m DIAMETER FIXED ROOF TANK


Automated UT Inspection Results on 2006. Thin areas in certain plates (small plates), not representative of corrosion damage. Possible ‘bad’ material at construction.
Statistics of MGH Data Base

Since 1997, a large population of tanks were tested by Mistras Group Hellas using TANKPAC™ technology. The pie charts below show a representative percentage of the products that are handled. The classification of the tanks based on the product that is stored, will be given considering whether the product is “light” (processed / final product) or “heavy” (crude, “thick” products etc.).

Population 383 Tanks, 496 Tests, 25 Untestable, 15 Countries
Statistics - Effect of Composite Grading

Heavy Product Tanks

Heavy Product Overall Grading

Heavy Product PLD Grading

Heavy Product Composite Grading

Overall Grading

PLD Grading

Composite Grading

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Statistics - Effect of Composite Grading

Light Product Tanks

Overall Grading

- "A" 25%
- "B" 39%
- "C" 26%
- "D" 9%
- "E" 1%

PLD Grading

- "1" 53%
- "2" 29%
- "3" 16%
- "4" 1%
- "5" 1%

Composite Grading

- "I" 58%
- "II" 32%
- "III" 10%
- "IV" 0%
Statistics - Effect of Composite Grading

All Tanks

All Products Tanks Overall Grading

Overall Grading

Potential Leak Grading

Composite Grading

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## Grade Variation Over Time

<table>
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<tr>
<th>Tank</th>
<th>Year</th>
<th>Dia.</th>
<th>Product</th>
<th>Roof Type</th>
<th>Year Built</th>
<th>Overall</th>
<th>PLD</th>
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Conclusions

Time difference between AE test and Internal Inspection and the limitations of each inspection method does not permit 1-1 comparison between the different inspection techniques.

Nevertheless, comparison of TANKPAC™ AE testing results with follow-up off-line floor inspection clearly demonstrates the ability of the method to identify the overall state of floor corrosion and early stage damage, as well as to pin-point areas on the early stage of damage development, with reasonable accuracy considering that no access is available to the internal side of the tank.

Furthermore, if we are to assume that, in any given time, about 20% or so of the assets will be in the worst condition, then TANKPAC replies to the question: which 20%?
TANKPAC™ is a maintenance planning tool

• Significant money savings: No money wasted for opening of good tanks.
• Maintenance prioritisation: The most severely damaged tanks are programmed for internal inspection first.
• Prevention of environmental losses: Early identification of potential leaks.
• Very fast, low-cost inspection with minimal interruption of operations
• TANKPAC™ fits perfectly into an RBI program (risk based inspection).
• PROCEDURE Approved & Operators Qualified by SAUDI ARAMCO