WHITEPAPER

RISK BASED INSPECTION METHODOLOGY FOR ATMOSPHERIC STORAGE TANKS

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Reference to part of this report which may lead to misinterpretation is not permissible.

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<th>No.</th>
<th>Date</th>
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<tr>
<td>1</td>
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INTRODUCTION

Atmospheric Storage Tanks (ASTs) are significant and common equipment items in the oil, chemical and transportation industry. Figure 1 shows two common types of tanks, one with a fixed roof and another with a floating roof. ASTs are often used to store very large amounts of inventory, mostly flammable liquids and sometimes toxic liquids. Their content might be kept under atmospheric temperature and pressure but can also sometimes be refrigerated. The hazards from ASTs can be serious given the large amounts of liquid. ASTs can cause serious environmental problems should a liquid leak reach surface or underground waters. Another difficulty with floor leaks is that they go undetected for a long time and can cause serious contamination of the soil or sub-surface water. Rapid floor failure or catastrophic shell failure are rare events but they do occur and they can have very serious consequences. Clean-up of the ground, the groundwater and the surface water are very costly operations that tank owners would obviously wish to avoid.

API 653 [13] is the standard code for inspection, repair, alteration and reconstruction of ASTs. It should be noted that internal examination of the tank, especially of the floor, is difficult and costly. So it is important for operators to identify the tanks that do not require frequent internal inspection and repair and avoid the wastage of maintenance and inspection resources, instead using their resources where it matters: that is when the risk is high and the inspections are useful. This has led tank operators to look for a risk based inspection (RBI) methodology applicable to aboveground storage tanks. EEMUA 159 [16] is a well-known guidance (particularly in Europe) for inspection, maintenance and repair of ASTs and it fully endorses RBI techniques.
It is worth summarizing the reasons that motivated the development of the AST RBI methodology:

- Environmental concerns have increased. There is a large number of tanks with leaking floors and the fear exists of the rare but serious event of tank catastrophic rupture. Costs for environmental clean-up and penalties are increasing.
- Internal inspection of the tanks is costly and difficult. Access to floors is difficult and shell inspection requires complex scaffolding and preparation.
- Backlog of tank inspections. Many tanks are overdue for inspection.
- Inconsistency in regulatory requirements. Inspection intervals vary from country to country and they are even different among US states (inspection intervals varying from 8 to 20 years).
- Prioritization of tank inspections has been largely subjective before the adoption of RBI.

**Risk Based Inspection**

The risk based inspection (RBI) approach had already been well established and widely used in the oil & gas, refining, petrochemical and chemical industries. The essential elements of a “quality” risk based inspection analysis have been documented by the American Petroleum Institute (API) in API RP 580 (2016)[1]. API RP 581 (2016) [2] describes a specific RBI methodology with full details: data tables, algorithms, equations and models. The implementation of the RBI methodologies has been facilitated by commercial software tools such as Synergi Plant RBI Onshore (Topalis, 2007) [3], SYNERGI Plant RBI Offshore (Topalis et al, 2011) [4], API RBI (Panzarella et al, 2009) [5], RISKWISE (Abitt and Speck, 2005) [6] and others. The RBI benefits are well known (API RP 580, 2016) [1] and they can be summarized as follows:

- Risk ranking and prioritization of inspection and maintenance activities
- Optimize spending on maintenance and inspection
- RBI may significantly alter the inspection strategies to become more “efficient”
- RBI may provide substantial cost savings
- RBI may contribute to reducing operational risks or improved understanding of current risks
- Improved communication between operations, inspection and maintenance
- RBI study provides a database for easy future inspection scheduling, updating and risk control
- RBI improves the mechanical integrity system and provides the means to measure the effectiveness of inspection

However, it should be said that any RBI methodology relies on the quality of the input data, the assumptions made, and so on.

Synergi Plant RBI AST implements DNV GL’s methodology for risk based inspection of aboveground storage tanks. The origin of the methodology is the AST Risk Assessment Manual RAM (API, 2002) [8] initially created for the AST committee of API and later encouraged by the RBI committee of API. The initial scope was mainly tank floor thinning. The methodology was later extended to include a quantitative method for shell thinning, as well as susceptibility analysis (supplement analysis) for shell brittle fracture and cracking.

Figure 2 shows a typical process plant hierarchy and the AST data structure and position in this hierarchy. The tank is part of a process unit involving several more tanks, while the tanks are sub-divided into Floor and Shell. This distinction is because of different failure scenarios for the Floor and the Shell. The Shell is further sub-divided into Courses. Each course may have a different thickness and Point of Failure (PoF).

![Figure 2: Asset Hierarchy for RBI of Atmospheric Storage Tanks](image)

Figure 3 shows how risk is calculated for an equipment item in a quantitative RBI analysis, such as the approach in Synergi Plant RBI AST. This is the product of the probability of failure (PoF) and the consequence of failure (CoF). CoF can be expressed in terms of the environmental/safety consequence effects and the economic effects. On the other hand, PoF is the product of the Generic Failure Frequency (GFF), statistical frequency of failure for a given type of tank, based on API members’ survey (API, 1994) [9] and other sources, and the damage factor (DF).
Figure 3: Calculation of Risk for an equipment item

The reader is also referred to the API codes for ASTs (API 650) [10] and inspection codes (API 651, API 652, API 653, API 12D and API RP 575 [11]-[15].
AST RBI Scenarios, PoF and CoF Models and Inspection Planning

Table 1 shows the liquid release scenarios typically considered in an AST RBI methodology according to the API 581 methodology. These include:

- One floor leak scenario and one floor catastrophic floor rupture (floor to shell region)
- Three shell leak scenarios and one shell catastrophic rupture
- Roof gas leak scenario according to EEMUA 159

Figure 5 shows the six modelled consequence outcomes in order of increasing severity:

- Release inside the dyke
- Release inside the plant fence but outside the dyke
- Release offsite
- Sub-surface soil contamination
- Groundwater contamination
- Surface water contamination

Figure 6 shows the overall methodology for calculating corrosion rates, PoF, CoF, Risk and Inspection planning for the floor and shell:

- Corrosion rates are estimated first, on the product side, soil side and external corrosion
- Damage factor DF and PoF are then calculated
- CoF is then calculated depending on the scenarios and this is followed by risk calculation
- The inspection planning is decided based on the planning targets for DF, Risk or PoF

The RBI methodology calculates the total cost (CoF) as the sum of the environmental cost, equipment damage cost, outage cost and safety cost:

\[ \text{CoF Total Cost} = \text{Environmental Cost} + \text{Equipment Repair Cost} + \text{Outage Cost} + \text{Safety Cost} \]

Equipment damage and safety cost only apply to Shell releases, while floor releases are assumed not to cause safety costs.
Table 1: Release scenarios analysed in the AST RBI methodology

<table>
<thead>
<tr>
<th>Release Failure Scenarios</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Small bottom leak.</td>
<td>One hole size is considered: small leak (0.125&quot; diameter hole).</td>
</tr>
<tr>
<td></td>
<td>This is the main floor failure scenario that is addressed in the RBI methodology, and is focused on bottom corrosion. The Probability can be influenced by inspection.</td>
</tr>
<tr>
<td>Rapid bottom failure.</td>
<td>One scenario, catastrophic failure.</td>
</tr>
<tr>
<td>Instantaneous release of tank contents from failure at the critical zone (Floor-to-Shell region).</td>
<td>Addressed in the RBI methodology through the corrosion model and compliance with recognized design and inspection/maintenance codes. The Probability is only to a limited degree influenced by inspection.</td>
</tr>
<tr>
<td>Small Shell leak.</td>
<td>Three hole size scenarios: 0.125&quot;, 0.5&quot; and 2&quot; diameter hole.</td>
</tr>
<tr>
<td></td>
<td>This is the main Shell failure scenario that is addressed in the RBI methodology, and is focused on Shell corrosion. The Probability can be influenced by inspection.</td>
</tr>
<tr>
<td>Rapid Shell failure.</td>
<td>One scenario, catastrophic failure.</td>
</tr>
<tr>
<td>Instantaneous release of tank contents from brittle fracture or large rupture of the tank Shell.</td>
<td>Addressed in the RBI methodology by screening, and is not influenced by inspection for corrosion.</td>
</tr>
<tr>
<td>Roof leak</td>
<td>Scenario modelled semi-quantitatively according to EEMUA 159</td>
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AST Consequence Analysis
Overview of scenarios

Figure 5: Environmental and economic scenarios
DF and PoF Calculation
- CR, Age, Nominal WT
- Past Inspections
  => DF ‘ar/t’ Modif. Factor
- Generic Failure Frequency
- Condition factors
  - Liner,
  - Maintained to API 653
  - Settlement
  => Probability of Failure (PoF)

Consequence Calculations:
- Clean-up cost
- Fluid Type
- Distance to groundwater
- Estimated time to detect a leak
- Soil type, etc.

Risk Calculation
- PoF × CoF
  - Floor
  - Shell
  => Risk Exposure ($/Yr)

Inspection Planning
Criteria for Inspection Target
- Damage Factor
- Risk target
- PoF target
  => Recommended inspection time for
- Floor and Shell

Determine Corrosion Rate:
- **Soil side CR – Calculated**
  - Base CR
  - Adjustment factors
    - Soil resistivity
    - Tank pad quality
    - CP, etc.
- **Product side CR – Calculated**
  - Base CR
  - Adjustment factors
    - Coating
    - Water draw, etc.
- **External CR – Calculated**
  - Base CR
  - Adjustment factors
    - Climate
    - Coating, etc.
- **Measured CR – Inspection**
  => Use Calc., Measured or Expert

Figure 6: Overview of the floor and shell RBI methodology
### Results

The AST RBI methodology produces risk results for a set of tanks (floor & shell risk matrices, executive summaries) but it also produces a detailed risk profile and inspection plan for each tank (equipment summary sheet). This can answer questions about what, when and how to inspect (what technique/effectiveness & coverage). This is shown in Figure 7.

If one or more risk targets are set, the inspection time will be determined by the intersection between the risk curve (function of time) and the “target” line. Figure 8 shows a real case study where the RBI suggested date is later than the old regulation inspection date and the date determined by API 653. But this is not always the case and RBI can sometimes suggest an earlier date depending on the tank risk.

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Figure 7: Risk Matrix, Executive summary and AST summary reports
CONCLUSION

A risk-based inspection (RBI) methodology for aboveground storage tanks has been presented in this paper. The objective of this work is to allow management of the inspections of atmospheric storage tanks in the most efficient way, while at the same time minimizing accident risks. This RBI methodology is an evolution of an approach and mathematical models developed for DNV GL, the American Petroleum Institute (API) and EEMUA 159. The methodology assesses damage mechanism potential, degradation rates, probability of failure (PoF), consequence of failure (CoF) in terms of environmental damage and financial loss, safety loss, risk and inspection intervals and techniques. The scope includes assessment of the tank floor for soil-side external corrosion and product-side internal corrosion and the tank shell courses for atmospheric corrosion and internal thinning as well as the roof. It also includes preliminary assessment for shell brittle fracture and cracking. The data are structured according to an asset hierarchy including Plant, Production Unit, Process Unit, Tag, Part and Inspection levels.

This methodology can help the process and tank farm industry to address the issues currently affecting ASTs, particularly leaks, difficulty in conducting internal tank inspections and inconsistent regulations or subjective methods to set inspection intervals.
ABOUT THE AUTHOR
Panos Topalis is a chemical engineer and holds a PhD in Process Simulation and Thermodynamics from Institut National Polytechnique de Toulouse. He has conducted numerous risk assessments both offshore and onshore and has developed consequence analysis software for Phast software. Panos has been product manager of RBI software in DNV GL since 2000 and has responsibility for development, direction, training, advanced technical support and business development.

NOMENCLATURE
API American Petroleum Institute
AST Aboveground Storage Tank
CMMS Computerized Maintenance Management Systems
CR Corrosion Rate
CoF Consequence of failure
DF Damage Factor
DNV Det Norske Veritas
GUI Graphical User Interface
EEMUA Engineering Equipment & Materials Users Association
ERP Enterprise Resource Planning
GFF Generic Failure Frequency
FRP Fibre-reinforced plastic
PLL Potential Loss of Life
PoF Probability of Failure
RAM Risk Assessment Manual
RBI Risk Based Inspection
RPB Release Prevention Barrier
REFERENCES


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