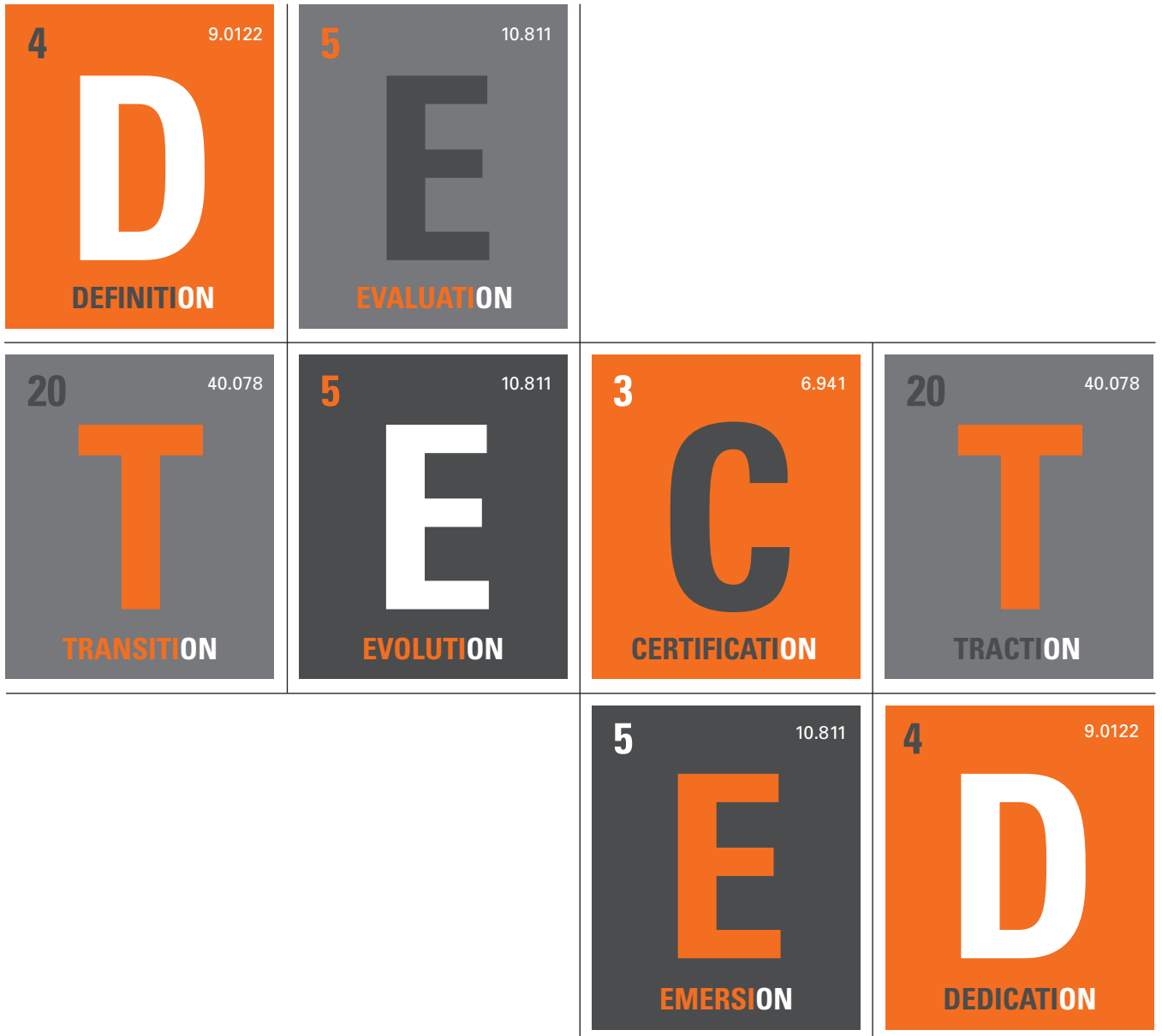




TANK LEAK DETECTION AS A RISK MANAGEMENT TOOL

EXECUTIVE SUMMARY

Storage tanks are an integral part of the infrastructure of the oil industry. Imagine an oil industry without storage; it would be a very different place. All operations would have to happen in real time.

Refining could only take place when a ship was discharging crude oil and another ship was receiving the refined products.

At a terminal, ship discharges could only take place when sufficient road or railcars were available to receive the products. Then imagine the low discharge rate and the time this would take.

The industry would operate at a very much slower pace and on a very much smaller scale without storage facilities, if indeed it could operate at all.

In times of global or regional instabilities, storage tanks also provide a means of securing supply to countries. Termed strategic petroleum reserves, it is estimated that this totals around 4.1 billion barrels globally. This may be in the form of crude oil or refined product.



LOCATI



While the importance of storage tanks is clear, they do need to be in the right place for them to be of use. Easy access to shipping is vital, hence the majority of storage tank farms are built on the coast at a large port.

Furthermore, the terminal must connect seamlessly with the users of the refined products either via pipelines (perhaps to a distribution terminal) or via loading gantries for internal distribution by road and rail. Such locations are relatively unique. The increase in size of ocean-going tankers has further restricted the locations suitable for large storage terminals.

This indicates that there is a vital link in the supply chain with limited potential for growth. This growth (i.e. building new tanks) is further limited by environmental and planning restrictions; society simply does not want more tanks to be built.

The oil industry therefore has a scenario that requires that the current stock of storage tanks must be used at maximum efficiency at all times. However, this is at odds with another requirement: that of safety.

HEALTH AND SAFETY REQUIREMENTS AND ENVIRONMENTAL/ECONOMIC CONSIDERATIONS

All liquids associated with the oil industry, from crude oil to the plethora of refined products, are hazardous to health and to the environment. When even the smallest of releases into the environment is to be avoided, storing them in large quantities only serves to magnify the issue. Storage tank integrity is therefore critical from an environmental point of view. There are also economic considerations: the liquids are valuable, some more so than others and therefore a leak is a financial loss. If a leak does occur then the cost of any clean-up can be significant. On top of that, there may be punitive costs applied plus the impact on the company's reputation. But what can be done to minimise the possibility of a leak from a storage tank?

MANAGING RISK

This starts with the design and build of the storage tank. International codes are available, for example API 650, which give guidance on the matter. The following is an extract from that standard:

1.1.1 This standard covers material, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open-top, welded steel storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressure (internal pressures not exceeding the weight of the roof plates), but a higher internal pressure is permitted when additional requirements are met (see 1.1.10). This standard applies only to tanks whose entire bottom is uniformly supported and to tanks in non-refrigerated service that have a maximum operating temperature of 90°C (200°F) (see 1.1.17).

1.1.2 This standard is designed to provide the petroleum industry with tanks of adequate safety and reasonable economy for use in the storage of petroleum, petroleum products, and other liquid products commonly handled and stored by the various branches of the industry. This standard does not present or establish a fixed series of allowable tank sizes; instead, it is intended to permit the purchaser to select whatever size tank may best meet his needs. This standard is intended to help purchasers and manufacturers in ordering, fabricating, and erecting tanks; it is not intended to prohibit purchasers and manufacturers from purchasing or fabricating tanks that meet specifications other than those contained in this standard.

While testing forms part of this standard, it refers to testing performed during the construction/fabrication process to ensure that the tank is put into service in a fit state, i.e. without leaks and structurally sound. There will be more on this later as many integrity issues relate to tanks when they are first put into service following construction or following major repair work.

Once the tank is in service, what steps can be taken to give confidence that the tank will not leak? Again, standards are available that give guidance as to the recommended checks and tests to be performed. Typically, codes are API 653 and EEMUA 159.

The inspections performed can be classified as follows:

Routine in-service inspection

- The external condition of the tank shall be monitored by close visual inspection from the ground on a routine basis.
- The interval of such inspections shall be consistent with conditions at the particular site, but shall not exceed one month.
- This work shall be performed by competent personnel, but not necessarily an authorised inspector (as defined by the standard).

External inspection

- Visual external inspection to be performed by an authorised inspector at least every 5 years or less if the shell plate corrosion rate dictates otherwise.

Ultrasonic thickness inspection

- External ultrasonic thickness testing of the tank shell used to determine rate of uniform general corrosion while the tank is in service.
- Inspection intervals can vary dependent upon whether the corrosion rate is known or not. When it is not, the maximum interval should be 5 years. When it is then the interval is determined by calculation based on current shell thickness, minimum allowable shell thickness and the known corrosion rate. If this figure is greater than 15 years then a maximum of 15 years between inspections should be adopted.

Cathodic protection surveys

- Where exterior tank bottom corrosion is controlled by a cathodic protection system, periodic surveys of the system shall be conducted in accordance with API RP 651. This work shall be performed by a competent person.

Internal inspection

The purpose of the internal inspection is as follows:

- Ensure that the bottom is not severely corroded and leaking.
- Gather plate thickness data.
- Identify and evaluate tank bottom settlement.

HOW OFTEN?

The frequency of internal inspections is dependent upon knowledge of plate corrosion rates. Where this information is available, either through previous internal inspections or is anticipated based on tanks in similar service, a simple calculation can be performed to ensure a minimum plate thickness is not reached over a known period of time. Notwithstanding this, the standard indicates that the internal inspection interval should not exceed 20 years.

When corrosion rates are not known and similar service experience is not available an internal inspection should be performed to determine bottom plate thickness. This should be performed within 10 years of the tank being put into service.

In practice, it is this 10-year period that has been adopted as the target for internal inspection intervals by many organisations. In some countries legislation is in place that requires tanks to be taken out of service for an internal inspection and re-calibrated on their tenth anniversary. In the UK such legislation is not in place, but an operator must have in place a documented maintenance plan/policy that sets out what actions will be taken, and when, to ensure that the facility (which includes the storage tanks) is operated in a safe manner and the potential for

contamination of the environment is minimised. This document can be subject to review by the Environment Agency and may be included in any licence granted for the operation of the facility.

GOING INSIDE

Many operators write into their maintenance policy that tanks will be subject to an internal inspection every 10 years, thereby meeting requirements as set out by the API document.

But what happens if the tank cannot be taken out of service at this time?

The act of tank entry raises a number of issues: operational, financial, and health and safety – all giving good reasons for not entering a tank unless it is absolutely necessary. For example, entering a tank that has contained hydrocarbon liquids or indeed other hazardous liquids has significant health and safety implications.

The tank is an enclosed space and the stored products are hazardous to health. Strict controls are required to minimise potentially life-threatening risks to those entering the tank. Therefore, many operators have looked for alternative means of ensuring the integrity of their tanks, without the need for entry unless absolutely necessary (i.e. if work needs to be done) and have adopted what is termed as an RBI (risk-based inspection) approach.

Section 6.4.3 of API 653 outlines RBI. Operators use this to justify not entering their tanks. However, this may be considered somewhat weak by regulators as it does not provide positive proof that the tank is tight. In order to demonstrate the conclusions reached concerning the integrity of the tank, based on the various factors considered in their risk-based analysis, operators should ideally include a precision leak test as a final check. The precision leak test will document and confirm that their tank is not leaking, supporting that their actions have been sufficient.



EXTRACT FROM API 653

6.4.3 Alternative Internal Inspection Interval

As an alternative to the procedures in 6.4.2, an owner-operator may establish the internal inspection interval using risk-based inspection (RBI) procedures. Combining the assessment of the likelihood of tank leakage or failure and the consequence of tank leakage or failure is the essential element of RBI. A RBI assessment may increase or decrease the internal inspection intervals obtained using the procedures of 6.4.2.1. The RBI process may be used to establish as acceptable the risk of a minimum bottom plate thickness at the next inspection interval independent of the values in Table 6-1. The RBI assessment may also increase or decrease the 20-year inspection interval described in 6.4.2.1. The initial RBI assessment shall be reviewed and approved by an authorised inspector and an engineer(s), knowledgeable and experienced in tank design (including tank foundations) and corrosion. The RBI assessment shall be subsequently reviewed and approved by an authorised inspector and an engineer(s), knowledgeable and experienced in tank design (including tank foundations) and corrosion, at intervals not to exceed 10 years, or more often if warranted by changes in service.

After an effective RBI assessment is conducted, the results can be used to establish a tank inspection strategy and better define the most appropriate inspection methods, appropriate frequency for internal, external and on-stream inspections, and prevention and mitigation steps to reduce the likelihood and consequence of a tank leak or failure.

Factors that should be considered in tank RBI assessments include, but are not limited to, the following:

Likelihood Factors:

- Original thickness, weld type, and age of bottom plates.

- Analysis methods used to determine the product-side, soil-side and external corrosion rates for both shell and bottom and the accuracy of the methods used.
- Inspection history, including tank failure data.
- Soil resistivity.
- Type and quality of tank pad/cushion.
- Water drainage from bund area.
- Type/effectiveness of cathodic protection system and maintenance history.
- Operating temperatures.
- Effects on internal corrosion rates due to product in service.
- Internal coating/lining/liner type, age and condition.
- Use of steam coils and water draw off details.
- Quality of tank maintenance, including previous repairs and alterations.
- Design codes and standards and the details utilised in the tank construction, repair and alteration (including tank bottoms).
- Materials of construction.
- Effectiveness of inspection methods and quality of data.
- Functional failures, e.g. floating roof seals, roof drain systems, etc.
- Settlement data.
- Tank bottom details (single, double, Release Prevention Barrier (RPB, internal reinforced linings, etc.)

Consequence Factors:

- Product type and volume.
- Mode of failure, e.g. slow leak to the environment, tank bottom rupture or tank shell brittle fracture.
- Dike containment capabilities (volume and leak tightness).
- Identification of environmental receptors such as wetlands, surface waters, ground waters, drinking water aquifers, and bedrock.

- Distance to environmental receptors.
- Effectiveness of leak detection systems and time to detection.
- Mobility of the product in the environment, including for releases to soil, product viscosity and soil permeability.
- Sensitivity characteristics of the environmental receptors to the product.
- Cost to remediate potential contamination.
- Cost to clean tank and repair.
- Loss of use.
- Impact on public safety and health.

More qualitative approaches may be applicable that do not involve all of the factors listed above. In these cases, conservative assumptions must be used and conservative results should be expected. A case study may be necessary to validate the approach.

The results of the RBI assessment are to be used to establish a tank inspection strategy that defines the most appropriate inspection methods, appropriate frequency for internal, external and on-stream inspections, and prevention and mitigation steps to reduce the likelihood and consequence of tank leakage or failure.

By including a precision leak test, this would confirm that the procedures put in place are working and that deferment of the internal inspection is justified.

The key is that the maintenance plan provides sufficient detail of the approach to be adopted.

The advantages to a risk-based inspection approach are clear. By moving away from a strict calendar-based inspection programme this more flexible approach allows an operator to maximise utilisation of the tank assets to meet operational needs. It also encourages a more focused approach to maintenance spend, targeting those tanks that are most in need of maintenance rather than those that have reached a certain age, but may be completely serviceable.

HOW TO



LEAK



TEST

The next section considers various options for performing leak tests to verify the RBI findings. Obviously, if the tank is fitted with a permanent leak detection system or has a double bottom with interstitial monitoring then these should be capable of providing the verification required. However, many tanks have only a single bottom and do not have any permanent leak monitor systems in place. This section considers what techniques are available in such circumstances.

Clearly, for the test to provide this confirmation it must be suitable for the application and ideally have had its performance verified by an independent third party.

An immediate response is that the automatic gauging system used for stock determination can be used during quiet periods to act as a leak detection system. On the face of it this seems a sensible approach, utilising equipment already installed on the tank and providing constant feedback of level measurement to a central control room. They are normally calibrated before installation and typically thereafter on a regular basis. Indeed, many systems are marketed as having leak detection built in to their functionality. However, on closer examination, does it really provide the level of discrimination required to confirm that a tank is tight?

Current level gauging systems claim a best measurement capability of $\pm 0.5\text{mm}$. If we consider a tank of diameter 30m the surface area of the tank is 707m^2 . A level change of 0.5mm equates to a volume of 354 litres. It is only once a volume change of this magnitude or greater has occurred that a leak could be identified with some confidence. Remember as well that throughout the test period the tank contents and the shell will be subject to thermal gains and losses.

As the system measures level directly, changes in liquid temperature will impact directly on level, perhaps triggering false leaks or masking real leaks. Based on the above, it is suggested that the use of existing level gauges does not give the

confidence required to determine whether a tank is leaking or not, except in situations when the leak is very large.

An alternative is the use of acoustic emissions. This technology uses an array of transducers located at intervals around the tank that listen for the noises created by active corrosion and potentially for the noise created by leaking liquid. Careful interpretation of the received signals against a database of known responses enables the operator to map the complete tank floor and highlight the level of active corrosion taking place. This is extremely useful as it provides the owner (and specifically those charged with maintaining the tanks) with details of where corrosion activity is high and logically where there is a greater likelihood of a leak path being present. For the test to take place there must be product in the tank, but it must be static. As the technology monitors sound the test area must be acoustically quiet during the test period (this could be a number of hours) otherwise the low-level noise generated by the active corrosion is swamped by extraneous noise potentially masking an actual occurrence.

While not strictly a leak test it does provide information that can be used to verify the assumptions made from the RBI. For example, if RBI points to high rates of corrosion and this is supported by acoustic testing then the tank is a prime candidate for early internal inspection. If RBI suggests little corrosion and this is corroborated by acoustic testing, then the tank can remain in service with increased confidence.

However, acoustic emission is a qualitative test; monitoring one parameter (sound) and from that, predicting another parameter (corrosion activity) in conjunction with a database of known responses. A better approach would be to apply a quantitative approach to tank leak determination through precision, mass-based testing.

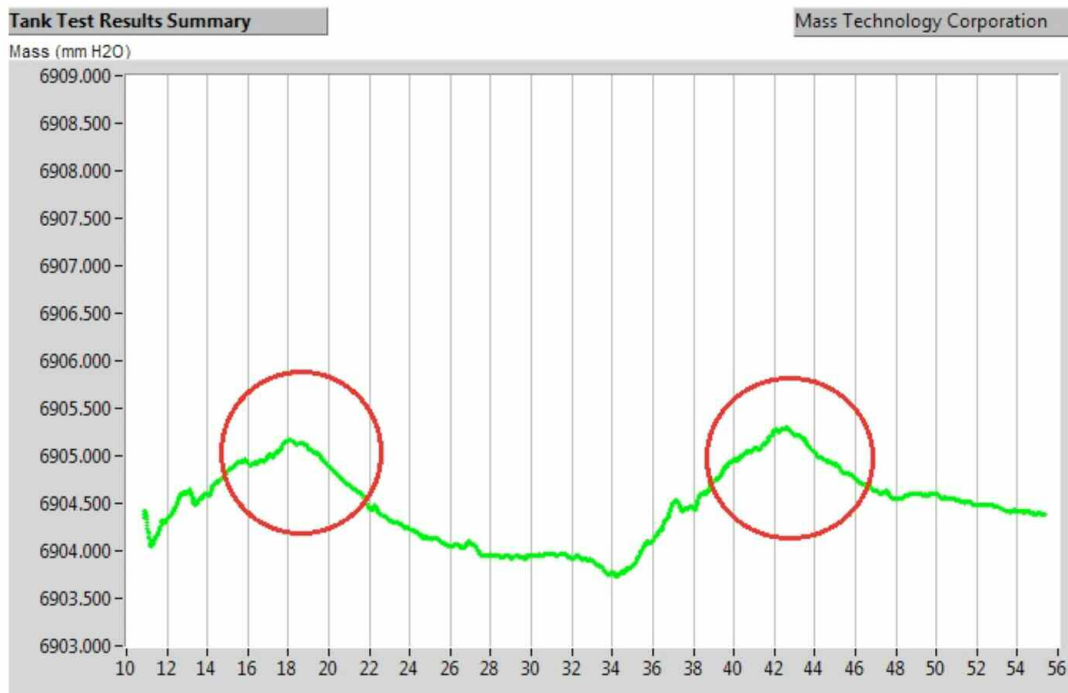
A mass-based technique monitors the pressure head generated by the column of liquid in the tank over a period of time. The basic equation that is applied by the technique is:

$$p = \rho * g * h$$

where,

- p is the pressure generated by the column of liquid
- ρ is the density of the liquid in the tank
- g is the constant term, acceleration due to gravity
- h is the height of the liquid column

Changes in liquid temperature result in a change in density and therefore a change in volume. If the liquid is constrained within a tank then any change in volume will manifest itself as a change in level, yet there is no physical loss or gain of liquid by the system. With a leak detection system based on level measurement, even small temperature fluctuations are sufficient to mask any leaks that may be present. By monitoring pressure rather than level, the impact of changing liquid temperature is neatly eliminated. Considering the above equation, as temperature changes the density of the liquid also changes.



Schematic data plot showing diurnal effects – circled in red. Courtesy of Mass Technology Corporation.

Within a fixed container the corresponding change in volume of the liquid will result in a change in the height of the column. However, since the changes in density and liquid height are inversely proportional the net result in pressure change is zero.

However, the shell of the tank containing the liquid is not immune from temperature changes. A good example is the effect of solar radiation on the tank: as the sun rises in the morning the effect is to warm the tank shell causing the steel to expand and increase the capacity of the tank. This causes the liquid level to fall resulting in the pressure falling (assuming there has been no change in the density of the liquid). This will continue through the day, but as the sun begins to set and the heat goes out of the day, the tank shell cools and contracts.

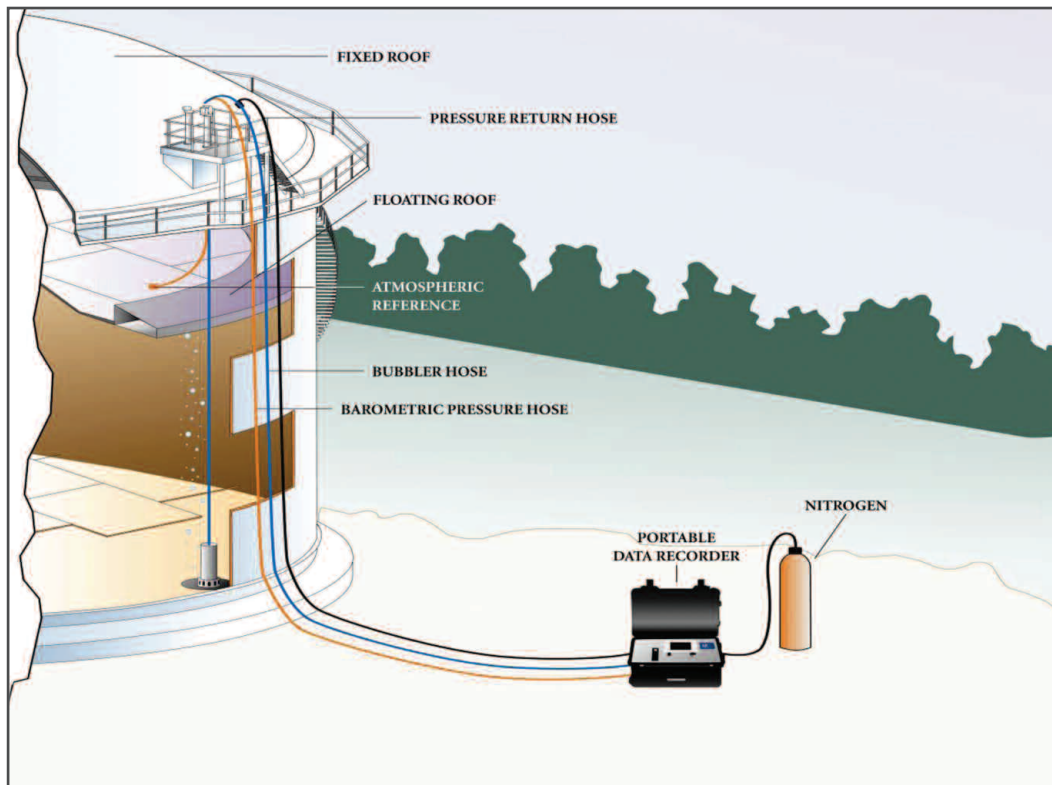
The capacity of the tank reduces and the level rises. This rise in level results in a corresponding increase in pressure. The diurnal effects are marked in red on the data plot above.

In reality, what happens is that there is a combination of the two effects in operation throughout the testing process. Tank shell dynamics can be partially corrected for, but much better that their impact is minimised and this is achieved, to a large degree, by only analysing data gathered during the night-time period, which should be more stable.

But how is the pressure monitored? The system used by SGS utilises a differential pressure (DP) transmitter located outside the tank in a portable control unit. The head pressure of the liquid in the tank is transferred to the

high-pressure side of the DP transmitter using a "nitrogen bubbler" system, similar to that previously used for tank level gauging. The low-pressure side of the DP transmitter connects to an open hose located in the vapour space above the liquid, the barometric pressure.

Temperature probes are used to monitor both liquid and air temperature throughout the test. All data from the various transmitters are input to a control unit for data logging purposes and subsequent analysis. This analysis is performed off-line using bespoke software.



Schematic of the Compact Bubbler Leak Detection System. Courtesy of Mass Technology Corporation.

The performance of the system has been determined through independent evaluation in the USA by Ken Wilcox Associates, who performed a series of tests on behalf of the US Environmental Protection Agency. The evaluation programme determined the threshold of detection for the system and the testing protocol required to achieve that level of performance.

The threshold of detection if expressed in terms of level change is constant regardless of tank diameter and equates to approximately 0.004mm per hour. For a mass-based system, the detection threshold (expressed volumetrically) varies directly with tank diameter. For a tank of 30m diameter, the threshold of detection is less than 3 litres per hour.

Recalling the example provided earlier of a potential detection threshold for a standard level gauging system in a similar size tank, the precision mass-based approach is two orders of magnitude better. Test duration is also

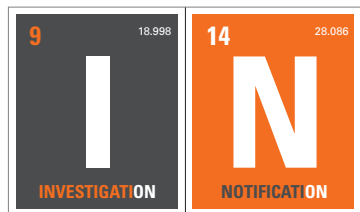
related directly to tank diameter with tanks up to 9m in diameter requiring a 24-hour test, and up to 120 hours for tanks with diameters in excess of 67m.

A key requirement for this technique to provide a conclusive result is for all tank penetrations to be adequately isolated. Experience shows that single isolation using the tank-side valve is not adequate. Either the penetration should be physically blinded or a double block and bleed arrangement needs to be in place and monitored during the test. The system will indicate if there is loss of liquid from the tank, but it cannot differentiate between liquid lost through a hole in the tank floor and liquid passing through a nominally closed valve.

External floating roofs also create a potential problem if rain occurs during the test. Rain collecting on the roof increases its weight, which is registered by the system as an increase in liquid head pressure. Any real loss of liquid is masked until the roof attains the same operating conditions as it was in at the start of the test. For the test to be conclusive it may need to be extended in order to capture enough valid data for analysis.

Clearly, all techniques have their limitations. But provided those limitations are known and understood useful information can be generated, whether from acoustic emissions or by precision mass monitoring, which can be used in conjunction with data from the RBI process.

CALENDAR-BASED INTERNAL



INSPECTIONS

Returning to the calendar-based approach, what happens when a tank programmed to be taken out of service as required by the operator's own maintenance plan cannot be released, for whatever reason?

One option is for the operator to do nothing, keep the tank in service and hope that the tank integrity will not be compromised until it can be taken out of service for an internal inspection.

Is this really a viable option? Without the ongoing information gathered as part of an RBI programme what level of confidence does the operator have in making a decision to keep the tank in service?

Such a scenario, which one suspects is not an isolated occurrence, would be improved by performing a precision leak detection test. While the operator is still beyond their own maintenance policy, it at least demonstrates that efforts have been made to assess the tank before extending its service life. Clearly, if the tank is shown to be leaking then its life cannot be extended and it should be taken out of service immediately.

Even when the operator is able to meet their own maintenance programme there is a place for a precision leak test. Performing an internal inspection on a storage tank is not an easy task. The environment is difficult and there can be a very large area to examine.

A source in the USA found that around 7% of new/repared tanks are identified as leaking when hydro-tested (see section below). Therefore it is reasonable to conclude that a percentage of all tanks subject to internal inspection will be returned to service with a leak path that has been missed.

Below is an extract from API 653:

5.2.1 In all reported incidents of tank failure due to brittle fracture, failure occurred either shortly after erection during hydrostatic testing or on the first filling in cold weather, after a change to lower temperature service, or after a repair/alteration.

Tanks could continue to leak for many more months or years until the loss of liquid is identified.

When a tank is entered the greatest possible care and professionalism is taken when performing the inspection, but it is a difficult environment and if no leaks are found then it is generally concluded that the tank was fine before it was taken out of service. But that may not be the case.

By performing a precision leak detection test prior to the tank being taken out of service the operator will know whether the tank is tight and they are not expecting to find any potential leak paths or that it is leaking at a rate of x litres per hour. Knowing that the tank is leaking before the internal inspection commences means that they are expecting to find a leak path or paths. The work would continue until leak paths are found.

As a colleague says: "Trying to find a leak in a tank is like looking for a needle in a haystack. Precision leak testing tells you that there is a needle in the haystack!"

NEW AND REPAIRED TANKS

Before a new or repaired tank is put into service it is subject to a hydro-test. While this is primarily a test of the structural integrity of the tank many operators also use it as a means of confirming that the tank is tight, before returning it to service.

But how valid is a hydro-test as a means of detecting small leaks from a tank? In many instances the decision as to whether the tank is leaking or not is based on level changes during the test period. How the level is monitored may be as rudimentary as checking the position of the floating roof (if one is fitted). A level gauging system may be used, but we have already seen that this method of leak detection will only identify major leaks of several hundred litres per hour. Some operators utilise fluorescent chemicals in the water and check around the base of the tank using fluorescent lights. This is neither scientific nor likely to identify a leak unless it occurs in a visible area.

Is a leak test strictly necessary as surely the tank was inspected before it was returned to service? Data shows that approximately 7% of tanks subjected to a leak test leak while under hydro-test. How many of these would have been identified without a precision leak detection test? Consider the financial and environmental impacts of returning a leaking tank to service.

By performing a precision leak test it gives the operator the confidence to return the tank to service; remember it could be many years before the tank is subjected to an internal inspection and the leak found.



SUMMARY

The integrity of storage tanks is a pressing issue for all parties concerned. More so now than ever before, operators are being pushed to prove the integrity of their storage tanks to reduce the risk to the environment as well as gaining greater control over their assets.

All the methods discussed in this paper serve a common purpose within our industry. The advantages of using precise methodology such as a precision mass-monitoring system are clear and can anyone afford not to understand exactly what is happening in their tanks?

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SOURCES

This white paper acknowledges the following sources:

- API 650 – Load Combinations.
- API 653 – Tank Inspection, Repair, Alteration and Reconstruction, Fourth Edition.
- API RP 651 – Cathodic Protection of Above Ground Storage Tanks.
- EEMUA 159 – Best Practice Inspection of Above Ground Storage Tanks.

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WHEN YOU NEED TO BE SURE

