The challenges and solutions of permanent AE monitoring of an engineering structure

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Abstract
Leakage detection and corrosion screening of aboveground storage tanks is a well-established application of acoustic emission testing. In some countries this type of testing is carried out as replacement of an internal inspection. The reliability of results and prediction of maintenance can be improved, when acoustic emission equipment for leak and corrosion screening is permanently installed. A permanent installation of equipment with the ability to continuously collect and analyse data creates new challenges for hardware and software unknown to a standard inspection process.

In this publication we will focus on challenging aspects of collecting data and intelligently reducing the amount to be analysed. Many factors, such as weather, operating- and environmental conditions, influence the strategy of collecting useful data. Using the example of a prototype permanent monitoring installation for leaks and corrosion detection of an aboveground storage tank we demonstrate an individual solution for this type of task.

Keywords: acoustic emission, leakage testing, chemical and petrochemical, structural health monitoring, corrosion, above ground storage tank (AST)

1. Introduction

Above-ground storage tanks (AST) are important structures for storing liquid chemical and petrochemical products that provide convenient storage management. Storage medium can be crude or refined petrochemical or chemical products which are hazardous to environment and health of workers and neighbouring residents. Corrosiveness of storage medium and environmental conditions have a big influence on the deterioration rate of tanks. Corrosion of tank wall and floor may lead to a leakage of storage medium what causes pollution and health risks. Incuring costs for removing pollution and providing extensive health care for affected people can be tremendous. Unfortunately it is hard to predict with accuracy how rapidly a storage tank deteriorates in service, since the storage medium can be mildly or highly corrosive or changing in corrosiveness over time. As a result, ASTs are inspected in regular intervals whereby national legislation usually governs the length of intervals.

A classical inside inspection is performed visually or using traditional non-destructive testing (NDT) methods (ultrasonic testing, eddy-current testing, etc.) and usually requires that the tank is taken out of service, emptied and decontaminated. A tank is out of operation for a few weeks or even months during an inside inspection.

A tank farm operator wants to reduce the risk of a leakage but at the same time minimize the costs and down time caused by an inspection. An operator usually knows the overall condition of his tanks based on the service history. Additionally, floor corrosion can be effectively prevented by, for example, inside coating and cathodic protection. During normal operation a tank floor should not suffer from serious degradation. But accidents may happen by unforeseeable events.
Naturally a tank operator is opposed to intentions of national governments for establishing dense inspection intervals. On the other hand, national governments have to protect residents and workers from pollution and harm and therefore require dense inspection intervals. Over the past years corrosion screening of AST tank floors by using the Acoustic Emission (AE) testing method has gained increased popularity amongst tank farm operators. AE testing is a non-intrusive testing method. Cost intensive emptying and decontaminating a tank is not necessary. Operational availability of a tank is only minimally affected when inspected by using AE testing. Lackner and Tscheliesnig [1,2,3], Park et al. [4], Takemoto et al. [5], Jomdecha et al. [6] and Baran [7] have shown that active corrosion on a tank floor can be detected and located by the AE-testing method.

The increasing demand for corrosion screening of AST tank floors has cumulated into two standards: ASTM E1930 [8] and EN 15856 [9]. Improvements to the test practice have been suggested by Nakamura [10, 11]. Nowak et al. [12] showed that double bottom storage tanks can also be investigated by the use of AE. The list of publications demonstrates that corrosion screening of AST receives a lot of interest from researchers and tank farm operators.

The AE testing method relies on the fact that an elastic wave, generated by an AE-source, can be picked up by AE-sensors in many meter distance. AE sensors are usually mounted at the outer surface of the tank. The sensor converts the wave into the electrical AE signal which is then conditioned and processed by the AE measurement system. One of the biggest challenges of corrosion screening by using AE is the small fraction of energy that reaches the AE sensor after its passage through the liquid, and the potential presence of undesired background noise. This imposes high requirements on the measurement hardware and the environmental conditions during an AE inspection. To increase the signal to noise ratio, the overall background noise level has to be lowered. Selecting the optimum hardware (30kHz AE-sensors and high gain preamplifiers) is one step to fulfil the high demands of this application. Care has to be taken for avoiding the many potential noise sources inside and outside of the tank. Noise is generated, e.g., by surface movement of the stored product, e.g. due to filling or tapping, by heaters, agitators, spargers inside the tank, by impact, friction, mechanical contact of objects with the storage tank, by a leaking valve, pipe or hose connection, by airborne particles (e.g. sand and rain), and more [8]. In a best case scenario a tank is taken out of service for 24h to 48h, giving the storage medium time to settle down, before it is inspected by the AE testing method. Furthermore all work should be stopped in the vicinity of a tank while it is inspected.

Recently, improvements to the results of tank floor corrosion screening by the use of AE have been proposed. One of the drawbacks of an AE inspection is that its result is based on a short measurement, which represents a snapshot in time. Result of an inspection can be biased into a certain direction, if the corrosion state at the time of inspection differs from the average state the tank was in the past. The reliability of results can be improved, when data over a longer period of time is analysed.

Permanently installed AE-measurement devices are under discussion for improving the reliability of corrosion screening results. When data is collected continuously the whole history of a tank can be taken into consideration when analysing its state with respect to active corrosion or leakage. Upcoming problems are detected when they happen and not during an inspection at a later point in time. Davies [13], Nakasa [14], Allevato [15] and others have shown that the AE method is very suitable for a continuous monitoring task. The advantages of using AE for continuous monitoring applications are very clear. No other non-destructive evaluation methodology could provide information about AE-sources such as active corrosion and leakage.
on inaccessible sites of a monitoring object under normal operating conditions, cost effectively for 24 hours a day, 7 days a week. This favourable characteristic of AE has found its way into standards such as ASTM E1139 [16] and ASME Boiler and Pressure Vessel Code, Section V, Article 13 [17].

2. Challenges of permanent AE-monitoring

The challenges and requirements arising out of a permanent installation for continuous monitoring are manifold. The surroundings of a storage tank are usually rated as explosion hazardous area whereby it is usually characterised as an area in which an explosive atmosphere is not likely to occur in normal operation and if it occurs it will exist only for a short time. While the risk of an explosion can be controlled very well during a short time interval of an inspection, a permanent installation of AE-sensors needs to address this safety issue with an appropriate design of AE-sensors. Hence AE-sensors are required that can be safely installed in an explosion hazardous area. Such AE-sensors are certified according to ATEX or NEC.

When AE-sensors are mounted permanently they may not be accessible easily. Replacing or remounting AE-sensors can cause a lot of effort. On the other hand environmental conditions such as rain, humidity, temperature, etc. may still be able to attack the mounting mechanism and the AE-sensor leading to a degradation of the mounting mechanism over time. Mounting of an AE-sensor can be done by compression- or bonding mount method [18]. Neither the compressive force nor the adhesive force or the characteristics of the adhesive should change over time while the AE-sensors are in operation. Otherwise a systematic error is introduced which cannot be controlled and negatively influences reliability of analysis results. This long term stability requirement is unique for a permanent installation and is not found as such in case of inspections.

Recording data 24 hours a day, 7 days a week using the data acquisition tools for AE inspection can produce very large amounts of data. Meaningful processing of data in real time can become difficult if not impossible. Analysing, storing and archiving such amounts of data require new approaches in real time data reduction and data management.

A permanent installation for continuous monitoring is recommended by the advantage to deliver more reliable results compared to an inspection. While a tank can be taken out of service for the avoidance of acoustic noise during an AE-inspection, other ways to reduce noise or to separate noise from interesting AE data must be found and developed for a continuous monitoring solution.

3. A strategy for measurement and analysis of data

Two goals shall be achieved with the prototype continuous monitoring installation. These are to detect and inform about (i) leakage and (ii) increased activity of corrosion. A strategy for a meaningful measurement and data analysis has to be worked out considering that potential noise sources exist. Since these noise sources cannot be controlled they have to be assessed and the results of this assessment have to be considered during the analysis of the acquired acoustic emission data.

Based on the above consideration the analysis process is laid out to consider three data sources: (i) data from the AST measuring station, (ii) data from a weather station and (iii) data from the acoustic emission measuring system. Only the information buried in acoustic emission data is
suitable to achieve the goal of detecting leakage and changes in corrosion rate. Taking data from measuring- and weather station into consideration lets one identify suitable time periods for acoustic emission data analysis.

The AST measuring station delivers information about the operation and status of a tank. It informs about noise sources such as pump operation, filling, tapping, etc. as well as fill-level, product composition and -temperature. Especially the fill-level has a direct impact on the detectability of a leak. The energetic content of acoustic emission generated by a leak increases with increasing pressure difference at the position of the leak. The surrounding is usually at atmospheric pressure, which is approximately 101kPa and changes only slightly with weather. The pressure inside the tank is characterised by the hydrostatic pressure. The hydrostatic pressure at the bottom of the tank increases with the fill-level and the specific weight of the storage medium. A higher fill-level causes a higher hydrostatic pressure at the tank bottom and in case of a leak a higher differential pressure. A higher difference pressure causes a higher energetic content of acoustic emission generated by a leak. Hence a high fill-level makes the restrictions on background ambient noise less sever and favourable acoustic emission data analysis periods can be found more frequently.

The weather station provides detailed information about the weather conditions. Lowest environmental noise levels occur in good and stable weather condition, that is no rain, no wind and stable temperature. Weather data provides information that helps to identify time periods in which acquired acoustic emission data is suitable for analysis. Even if such conditions exist for only some minutes per 24h, results will become increasingly reliable the longer the measurement system is installed and able to acquire data.

Acoustic emission data analysis is split into a two stages process. In the first stage an analysis of acoustic emission data should answer the questions whether leaks are present or not. Since a leak is capable of producing continuous acoustic emission that can predominate AE from active corrosion it is logical to schedule leak detection prior to active corrosion detection. The second stage of an analysis is only executed if no leaks are detected. Only then is the state of active corrosion assessed.

Each analysis stage requires its own acoustic emission data acquisition mode. By default the acoustic emission measurement system is in a so called “leak detection” mode. It switches into “active corrosion screening” mode if the leak detection mode does not indicate any leak and the data from both, the AST measuring station and the weather station indicate good acoustic emission measurement conditions. Leakage is assumed to cause a more or less continuous signal, corrosion is thought to cause burst like acoustic emission. In leak detection mode only acoustic emission feature data is required. For detecting active corrosion, acoustic emission feature data and waveform data is required. Acoustic emission feature data occupies only small disk space but storage of waveform data can consume a lot of disk space. So defining and executing two acquisition modes is also beneficial for an economical usage of computer resources. When favourable conditions for active corrosion screening are detected the measurement system switches in between the two acquisition modes automatically. Favourable data acquisition conditions are additionally flagged with start- and stop-flags. These flags allow easy identification of periods that have been or need to be analysed. Furthermore only data from such periods is exported and archived to even further reduce the amount of data to be stored.

4. Measurement Setup
The prototype installation uses an AMSY-6 acoustic emission measurement system [19] of manufacturer Vallen Systeme. An AMSY-6 acoustic emission measurement system consists of a master box containing a number of parallel acoustic emission signal processors, to which acoustic emission preamplifiers and sensors are connected. The Vallen AE-Suite software for acquisition and analysis of AE data runs on an external PC, connected to the AMSY-6 via USB. A schematic block diagram of the measurement setup is shown in figure 1.

In order to address the safety aspect of installing electrical equipment in an explosion hazardous area, intrinsically safe AE sensors model ISAS3-030 and signal isolators model SISO3 of the ISAFE3 AE-sensor system [20] of Vallen Systeme are used. ISAS3-030 has an integrated preamplifier, a 30kHz resonance and is suitable for a frequency range of 20 kHz to 70 kHz. In previous studies [1, 6, 7] it has been confirmed that active corrosion is best detected in a frequency range from 20 kHz to 50 kHz. This frequency range is also suitable for leakage detection.

The SISO3 signal isolator is necessary to achieve galvanic isolation of the electronic circuit in the explosion hazardous area and to limit the electrical power, voltage, current and pulse energy delivered to the sensor in the hazardous area. The SISO3 units are located in the non-hazardous area nearby the AMSY-6.

Figure 1. Schematic block diagram of the measurement setup

Four AE-sensors are mounted in one ring on the tank hull that has a circumference of 100m. 4 sensors are sufficient to detect a leak by increased RMS noise status at the sensor nearest to the leak. Using 4 sensors only is sufficient for zone location of AE from active corrosion. For the mounting mechanism, magnetic holders were chosen. The flexibility of being able to access, remount and replace an AE-sensor easily was more important for the prototype installation than the requirement of a reliable and permanent holding mechanism. Stability of mounting was checked in regular intervals by the use of the automatic sensor test routine.

AMSY-6 hardware is controlled by the acquisition module of Vallen AE-Suite software. The same module stores the acquired data to hard disk drive of the PC. Data are analysed using the VisualAE module of Vallen AE-Suite software.
For leak detection the most important parameter for analysis is the RMS-value of background noise. For corrosion detection, the features burst signal peak amplitude, burst signal energy and ring down counts are considered. A future goal is to use characteristics of frequency content of burst signals from waveform data for AE-source analysis as well. Waveform data is optionally stored by the signal processors in addition to the feature data.

Weather data is acquired by a wireless weather station of model Wireless Vantage Pro [21]. Data from the weather station is transmitted wireless to a data logger and subsequently stored to a hard disk drive. This data is included into data analysis via a special interface of VisualAE.

Data from AST measuring station, most importantly the fill level and some other operating conditions are transmitted by wire and stored on PC. During the prototype installation period, it was not possible to include data from measuring station automatically into VisualAE because of interface restrictions.

5. Results

The prototype installation had been running for a year. Since the end of this test phase no more data is generated. Currently results and findings are evaluated and requirements for hardware and software as well as analysis are revised. Nevertheless the test phase produced some remarkable results that will be summarized in the following text.

Data generation rate per day was several hundred MB of acoustic emission feature data. Out of this data an automatic routine still identified a few hundred MB of data suitable for analysis. Automatic selection process of analysis periods was based on weather data only since measuring station data could not be included in this process.

Using magnetic holders appears to be a viable solution for mounting acoustic emission sensors. The mounting condition was automatically checked in regular intervals and no degradation due to environmental influences had been found. Nevertheless an incident had been identified when a person unintentionally moved an acoustic emission sensor. Besides this incident, acoustic emission sensors need not be re-mounted in a period of one year.

The diagram in figure 2 shows how weather station data was combined with acoustic emission data. Depicted is the average of the RMS measured in µV over time measured in hours (in green). The average of RMS refers to the average over all channels in a time period of 6 minutes (corresponds to 0.1h). The RMS is a measure for the overall noise. The overall noise includes unwanted noise from environmental processes such as noise from rain, agitators and heaters as well as wanted noise from active corrosion and from a leak if existent. The horizontal axis shows the time in hours whereby the time refers to the measurement time. In this case the measurement started on Friday, 18th of October at 14:57. At this point of time there was probably a switch of data files because the old file reached a predefined limit. When this happened a new data file was started automatically. The measurement ended approximately 115h later. The right hand vertical axis shows the scale for a rain indicator (red curve). Whenever there is an increase rain has fallen and was measured as deci litre per square meter. When the indicator is constant, e.g. a horizontal line, then no rain has fallen, which is interpreted as good weather condition for acoustic emission data analysis.
At $t \approx 2$ h the red line increases sharply, indicating a short period of heavy rain. A sharp increase of the green RMS curve from 3 to 10 µV coincides with that event. At about $t \approx 17$ h a second short period of rain was measured. This had no visible effect on the RMS of the measured AE channel. A product removal started at $t \approx 48$ h and lasted until $t \approx 63$ h. During that time period the fill level changed from 12m to 1m. There is a slow increase of RMS starting at $t \approx 53$ h that is later on superposed by noise from a rain event. At $t \approx 56$ h the rain indicator shows a 4 hour lasting period of rain. After the rain RMS slowly decreases, which may be related to settling of storage product after rain or may be caused by product removal. The rise in RMS at $t = 69$ h corresponds with filling of the tank lasting about 9 hours. The short spikes in the green curve were caused by taking samples from tank and other changes in operating condition. These events have been correlated by hand from data of the AST measurement station. An automatic correlation of tank operation with AE data will be realized later. The fact that the RMS returned to the initial 3 µV level indicates that no leak exists.

Figure 2 shows that phases of good conditions for meaningful AE data analysis, that is when the RMS stays at its minimum, accumulate to about 50 hours or 42% of the measurement period.

Analysis of acoustic emission data showed some active corrosion on the tank floor. This finding was expected and confirmed the condition of the tank derived from regular inspection results and the service history of the tank. Active corrosion did not substantially change over the course of the prototype installation period of one year. The status of tank floor degradation did not change in the monitoring period.

Leaks on the tank floor have not been detected by the use of acoustic emission analysis. However, it happened from time to time that tank was filled or tapped while evaluation of weather station data indicated a good data analysis period. In some of these cases acoustic emission data analysis indicated leaks. The structure borne noise that was picked up and automatically misinterpreted as leak was generated by: (a) valves that have been opened and (b) valves that were not shut tight after tapping or filling process. This misinterpretation will be solved by implementing the automatic correlation of data from AST measuring station with AE data.

It can be concluded with high certainty that the tank floor has not a leak.
6. Conclusion

Running the prototype installation for one year showed that the goals set at the beginning of this project can be achieved. It was important to show that active corrosion can be detected with the installation and that tank need not be specially treated as it is needed for a scheduled AE inspection. The second goal of detecting leakage was confirmed indirectly. Since there was no leak on tank floor, installation could not detect it. However, similar noise sources were detected unintentionally, when valves were opened or did not shut tight. In such cases storage medium leaked through valves. AE from this leaking process was detected by the installation. The goal will be to disregard such noise sources by implementing the automatic correlation of data from the AST measuring station with AE data in a final stage of the application. The fact that RMS measurement and weather data correlate trustworthy can be taken as an evidence that the implementation of the automatic correlation of data from AST measurement station with AE data can solve the effect that a leaking valve is indicated as a leakage in the tank’s bottom or wall.

Acoustic emission sensor mounting mechanism fulfilled its task of providing a stable and good coupling of the sensor’s sensitive surface to the surface of the object under test. The mechanism can be improved insofar, that even unintentional contact does not have an influence on mounting condition.

The data generation rate and total amount of data acquired for analysis is huge. Only a small percentage of the data is important, means there is a high potential for sharpening the indication of leak or active corrosion and reduce the required amount of data for analysis.

As with respect to the tank, expected active corrosion was confirmed by the installation. A leak was not found. The tank appears to be in good condition and its status did not change during the prototype installation phase.

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