FIELD TESTING OF FLAT BOTTOMED STORAGE TANKS WITH ACOUSTIC EMISSION – A REVIEW ON THE GAINED EXPERIENCE

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KEYWORDS

Corrosion and leakage testing, aboveground storage tank (AST), tank floor

ABSTRACT

A new testing technique for corrosion and leakage testing of the flat bottoms of atmospheric, aboveground storage tanks (AST) with acoustic emission (AE) was developed in the frame of an EC funded project [1]. Frequency domain based pattern recognition is used to identify the source mechanism of the found AE sources located at the tank floor. The basics of the applied method and the testing technique itself are outlined as well as results of performed tests are given together with statistical numbers regarding the grading of tested tank floors. Conventional non-destructive testing (NDT) of tank floors relies mainly on visual testing and wall thickness measurements and therefore reflects the past service periods of the tank in total. On the other hand AE enables to monitor the active processes taking place at the time of test on the tank floor at conditions similar to normal tank service. The combination of both leads to a complementary view of the tank floor condition, taking advantage of both approaches: determination of the total degradation of the tank floor and monitoring of the actual degradation processes taking place under current service conditions.

INTRODUCTION

More than 200 tanks have been tested at refineries, chemical sites and tank farms since the testing technique was introduced into the maintenance and inspection market. Where available, results obtained with other NDT methods are compared with AE test results. In order to be able to combine the information from different NDT techniques a precise knowledge of the service conditions, current as well as previous, of all performed maintenance actions and of all preparation works in order to clean the tank for inside inspection is necessary. Compared to an AE test, which occupies the tank with the stock product for only one or two days, the cleaning procedure and the inside inspection leads to a downtime of the tank for weeks or even months. This underlines the increase in tank availability and the benefit related to employing AE corrosion and leakage testing of ASTs.

In many countries the duration of the service period till to the next inside inspection is restricted to a few years. Then the tank has to be put out of service and very often the inside inspection is carried out to confirm again a good floor condition. This procedure is still questioned by many tank operators, who know the overall conditions of their tanks according to documented service histories very well. Floor degradation due to corrosion, especially general corrosion, can be prevented quite effective by appropriate measures, e.g. inside coating and cathodic protection. So if the service conditions are kept well inside the known boundaries of safe operation, the tank floor should not suffer from serious degradation.

But still unforeseen situations might occur, which lead to more severe types of corrosion with higher corrosion rates than expected. This could be the case at areas on the tank floor where the inside coating has been damaged or due to contamination of the stock product with corrosive agents accumulating at the tank floor. Thus, the time driven inside inspection intervals may detect the onset of corrosion only by accident, more likely the present corrosion damage may just be documented in order to repair the affected floor areas.

In contrary acoustic emission testing (AT) enables to indicate tanks with active corrosion processes and does nearly not interfere with tank operation. AT is therefore a valuable maintenance and inspection tool supporting the tank operator to prevent serious damage in time. Optimal conditions for this kind of monitoring are given, when it starts after the tank has been put back into service after an inside inspection. At that occasion the current status of the tank floor is usually estimated precisely by floor scanning techniques, hence it follows that an early measurement with AE gives an ideal reference for future repetition tests. A tank history built up in such a way may be exploited by prolonging substantially the service period till to the next intrusive tank maintenance activities. The costs of preparing the tank for inside inspection may reach easily some 100.000 Euro, therefore significant savings may be gained by using non-intrusive AT.

TESTING TECHNIQUE

The sources of costs due to corrosion are manifold and the economic costs of corrosion are obviously enormous [2]. Beside direct costs also indirect costs, e.g. plant downtime or loss of product, are important factors. The presented testing technique enables to detect and to locate active corrosion processes at the tank floor and, in case of an already penetrated floor, to detect and to locate active leakage. Thus, it is a useful maintenance tool to handle tank floor degradation economically. Acoustic emission is in general limited to the detection of active defects. But this limitation turns out to be a strength, since this NDT method indicates only defects, which have an impact on tank floor degradation (progressive loss of wall thickness) or on tank safety (actual loss of product). Figure 1 shows a typical example of an AST for crude oil.

Figure 1: AST for crude oil

Using AT enables to focus maintenance on tanks, which show indications of severe corrosion or even leakage. It has to be stated, and this will be underlined by statistics later on in this paper, that the majority of tanks are in good condition when continuously well maintained. These tanks should be kept in operation and the floor condition should be monitored further on. The test result states the condition of the tank floor regarding the defects under consideration in terms of grades, the applied grading system is given in table 1.

Table 1: Grading system for AE testing on ASTs

Grade	Description	Recommended service period duration
I	No active sources	5 years
II	Low active corrosion	3 years
III	Medium active corrosion	1 year
IV	Leakage and/or high active corrosion	--

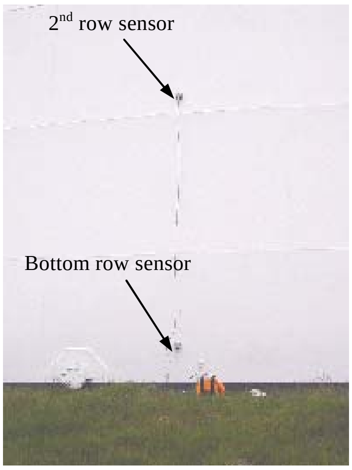
The recommended maximum duration of the following service period is with respect to the service condition present at the time of test. And it is communicated very clear to the responsible contact person on-site, that the conditions set by the tank operator in order to prepare the tank for the test have to be as close as possible to usual service conditions. So if the service conditions are kept like they were before the test, then a prediction for the floor condition is possible. Hence it follows that after a change in service conditions the tank floor grading is not valid any more and a repetition test is necessary to assess the new service conditions. If the tank floor is assigned to grade IV, then an inside inspection in order to verify the indications found with AT is recommended.

The preparation works for AT start with the determination of the tank properties (construction details, storage product, etc.). For this purpose we usually send out a questionnaire together with basic information regarding our testing technique. After evaluating the filled in statements of the responsible contact person on-site, all necessary resources have to be allocated. Our testing personnel is certified for AT according to EN 473 and the used combinations of measuring systems AMSY-5, Vallen-Systeme are state-of-the-art. Figure 2 shows a system set-up within a testing van, which is positioned nearby the tank.

Figure 2: Combination of AMSY-5 measuring systems for AST corrosion and leakage testing

It is also communicated very clear before each test to the responsible customer representative that every AE measurement is affected by noise of different origin (mechanical, electrical, etc.). Much noise data can be identified by software procedures and therefore it can be filtered and does not flaw the test result. But the most important part in preparing a tank on-site is simply to avoid noise so that it is not picked up by the AE sensors. If appropriate measures are taken before the test, e.g. elimination of noise sources or avoiding noisy time periods, then the noise content is already limited to a low extend and the noise rejection algorithms need not to be stressed till to their very limits. Thus, the reliability of the test result increases, which is of major importance, especially if costly follow-up actions are recommended.

The standard arrangement requires an AE sensor at least after every 15 m along the circumference in a height of approximately 1 m. The bottom row of sensors enables to locate AE events within the horizontal cross-section of the tank (2-d location). The considered path of sound wave propagation (see figure 3) from the source at the tank floor to the AE sensor on the tank shell is via the liquid stock product, therefore the location uses the speed of sound of the liquid stock product. This arrangement is suitable in case AE events originating at other parts than the floor (e.g. a floating roof) can be ruled out. In every other case we strongly recommend a sensor arrangement in two rows of sensors. With the help of these additional sensors in a height of approximately 3 to 5 m above the floor and exactly above the sensors near the bottom, it is possible to reject AE events from upper regions of the tank from evaluation and increases the reliability of the floor grading additionally. An example for AE sensors mounted onto the tank shell may be seen in figure 3 left.



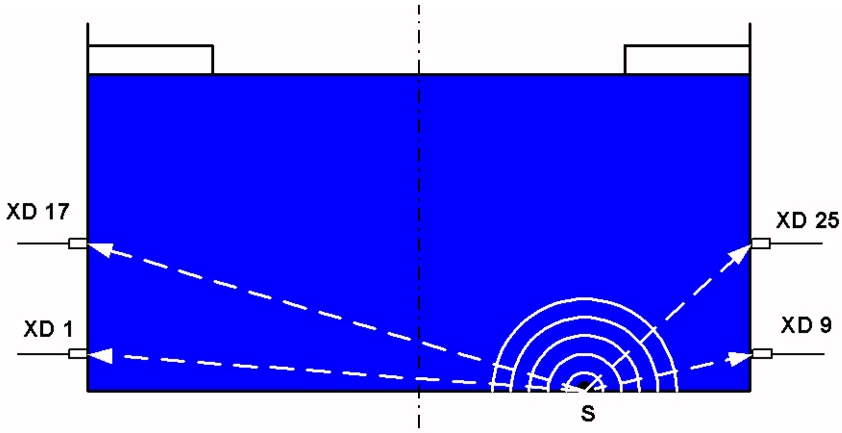


Figure 3: AE sensors mounted onto the tank shell, path of wave propagation

Once an AE source is detected at the tank floor, it is important to state the source mechanism in order to grade the tank floor properly. Source mechanism identification involves essentially the three following aspects

1. data acquisition and preprocessing,
2. data representation and
3. decision making,

which lead to the design of a pattern recognition system [3]. For choosing the best way of data representation one has to take into account, that a tank floor covers an area up to some 1.000 square metres. Thus, the distance from the source at the tank floor to the sensor at the tank shell may vary within a wide range and so do AE signal parameters like signal peak amplitude, signal duration, signal energy etc. accordingly. The applied testing technique takes advantage of the waveforms, which are acquired and stored in parallel to the other AE signal parameters. From the waveform data the frequency response of the sound waves may be calculated and used for data representation. Figure 4 shows a typical AE signal waveform together with its frequency response. Sound wave propagation in liquids is free of frequency dispersion; thus, the frequency response is independent of the distance from the source to the sensor. Furthermore, the attenuation of the concerned frequency bandwidth around 30 kHz may be regarded to be uniformly. Hence it follows that the frequency response of the AE signal does not depend on the distance from the source to the AE sensor. A classifier was designed with the help of a reference data base comprising signal waveforms with well known source mechanisms. This tool is then applied on unknown data in order to decide whether the found AE source is related to corrosion or to leakage. If the source mechanism turns out to be leakage, then the tank floor is of 'grade IV' and it is recommended to open the tank as soon as possible. If corrosion is detected, then the test result may vary from 'grade II' to 'grade IV' according the source activity. Moreover, in a second classification step the found corrosion source is assigned either to well-established corrosion, which is indicated by the presence of a layer of corrosion product, or to the onset of corrosion, when a scaling layer is about to develop. In case no active source is detected, then the tank is free of any active defect and therefore from the AE point of view it may be operated for another five years without any further maintenance.

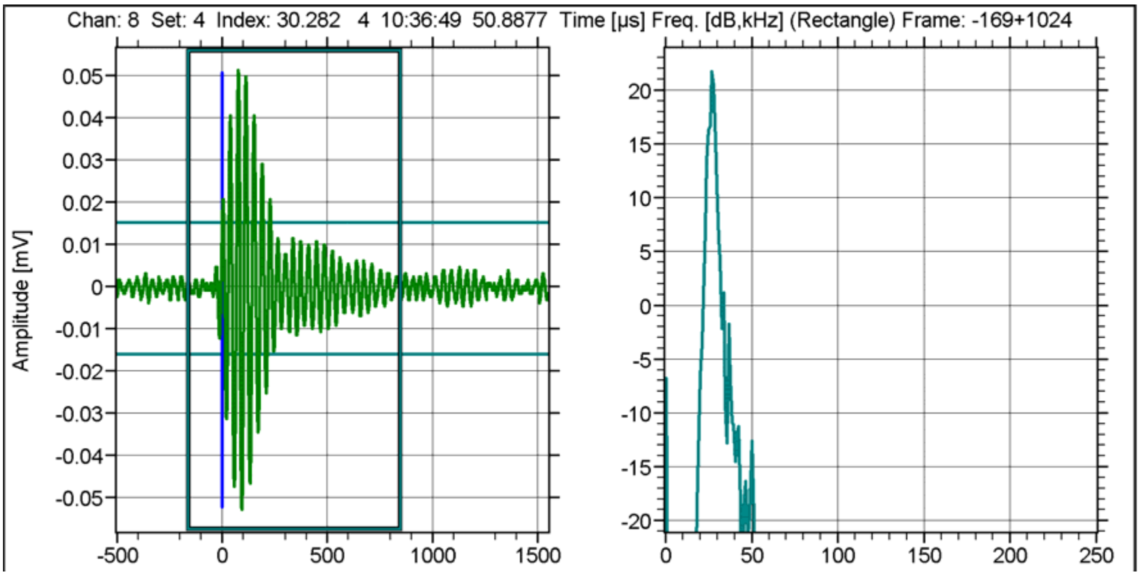


Figure 4: AE signal waveform and its frequency response

STATISTICS OF THE PERFORMED TESTS

More than 200 tanks have been tested using the described testing technique in the past years since its introduction into the maintenance and inspection market mainly in Germany, Austria and Italy. The diameter range of the tested ASTs (fixed roof or floating roof) is from 4,5 m (product tank of a chemical plant) to 98 m (crude oil tank of a pipeline tank farm). The stock product had been at ambient temperature as well as at elevated temperatures (80 °C maximum surface temperature at the sensor position) with tank shells thermal isolated or not. Figure 5 shows the distribution according the stock product, grouped into the three main categories. Distillates like naphtha, gasoline, gas oil or fuel oil have been assigned to ‘refinery products’, whereas chemicals like acetone, trichloroethylene, propylene oxide and also caustic soda have been added to ‘products’.

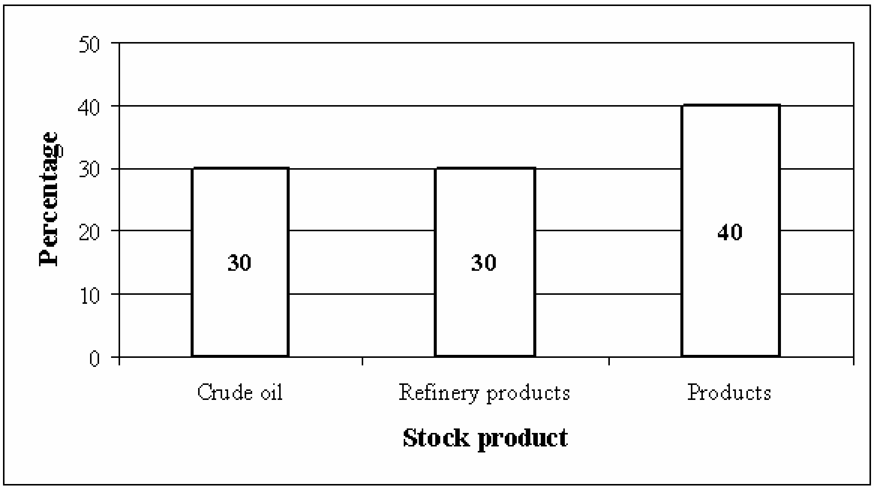


Figure 5: Stock product distribution of tested ASTs (total of 218 tanks)

Altogether the applicability of the testing technique covers a broad variety of stock products, which are used frequently in different industries and the respective ASTs have been tested already with AE successfully. Figure 6 gives a distribution of the test results according the four different grades from table 1.

One can take from this distribution, that the majority of tanks (52 %) is assigned to 'grade I', indicating the best floor condition. This underlines the experience of many tank operators that the time driven inside inspection intervals lead to costly openings of tanks being still in good condition. By integrating AT into the regular maintenance and inspection programme it is possible to indicate these tanks in order to have their service period prolonged for some further years of safe operation till to the next inside inspection.

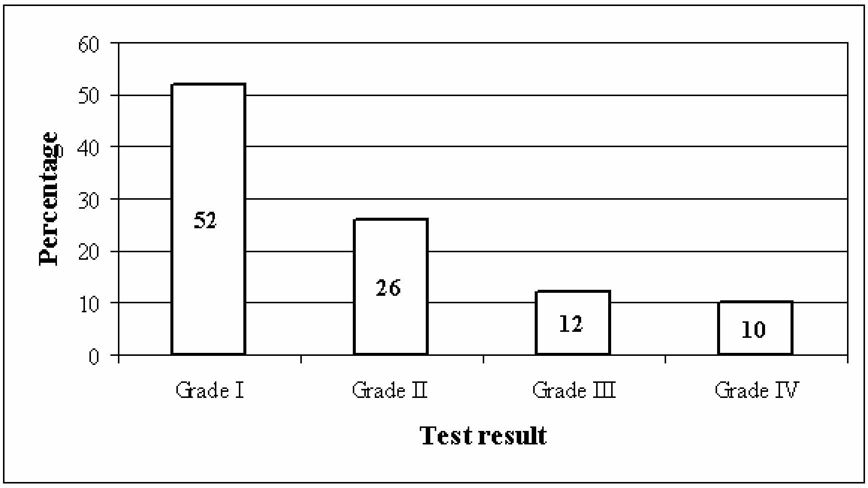


Figure 6: Result distribution of tested ASTs (total of 218 tanks)

The reliability of our testing technique has been proven twofold: by safe tank operation for the recommended service period and by many follow-up inspections. Since AT results in a statement regarding active defects at conditions present during the test, it is complementary to the result of an inside inspection, which aims on the estimation of the total tank floor degradation. This has to be kept in mind when comparing both kind of testing. One has to have a very detailed knowledge of the tank service history and also the actions performed in order to clean the tank have to be considered when finally assessing the floor condition in comparison to the AT result. As an example we experienced one case where the inside coating has been removed by the cleaning procedure due to insufficient bonding at an area of already established corrosion damage. Since the tank floor had been assigned to 'grade I', it appeared at first glance that this defect has not been detected. After studying the tank history it was found well documented, that the inside coating was applied onto the given corrosion damage after grit-blasting but without repair. Finally it turned out that the AT result was true, it represented the actual tank floor condition present before the tank cleaning procedure. Of course also the result of the inside inspection was true as a matter of fact, it showed the total tank floor degradation. This case should just underline that the beneficial combination of both results requires sometimes a precise knowledge of the tank history and of the preparation activities before entering the tank. In the majority of experienced cases this detailed discussion could be dropped due to congruent results: a tank floor in good condition.

According to figure 6 quite a number of ASTs in rather bad condition have been tested. Tank floors have been found with severe general corrosion as well as tank floors with localized forms of corrosion and leaking tanks. As one may have already assumed, also at other end of the grading system some indications have to be clarified first before taking further actions. Since AT is capable of detecting active corrosion, it does detect sacrificial anodes within the tank. Together with the tank operator we could identify the found corrosion indications to be at locations were sacrificial anodes had been placed. At another site a serious corrosion source was detected not on the tank floor but at the floating roof. Since a sensor arrangement in two rows like show in figure 3 had been applied, the found corrosion source could be assigned definitely to the floating roof. There a weld had already been penetrated and product was found on the sheets. Floating roof corrosion causes AE indications and therefore flaws the grading of the tank floor if not properly identified. With the help of two rows of sensors, this can be done quite simple and effective. In general every indication for a serious defect is first analysed regarding other possible causes to avoid costly false calls. Figure 7 shows both kinds of evaluation for the roof corrosion example, without and with the help of the second row sensors. The horizontal cross-section of the tank is shown in the x-y plane together with the sensor positions and identifications of the bottom row, whereas in the vertical direction the number of located AE events within the reference area per hour is given. It can be seen easily that the indication (red column on the left) disappears when taking advantage of the improved sensor arrangement (right).

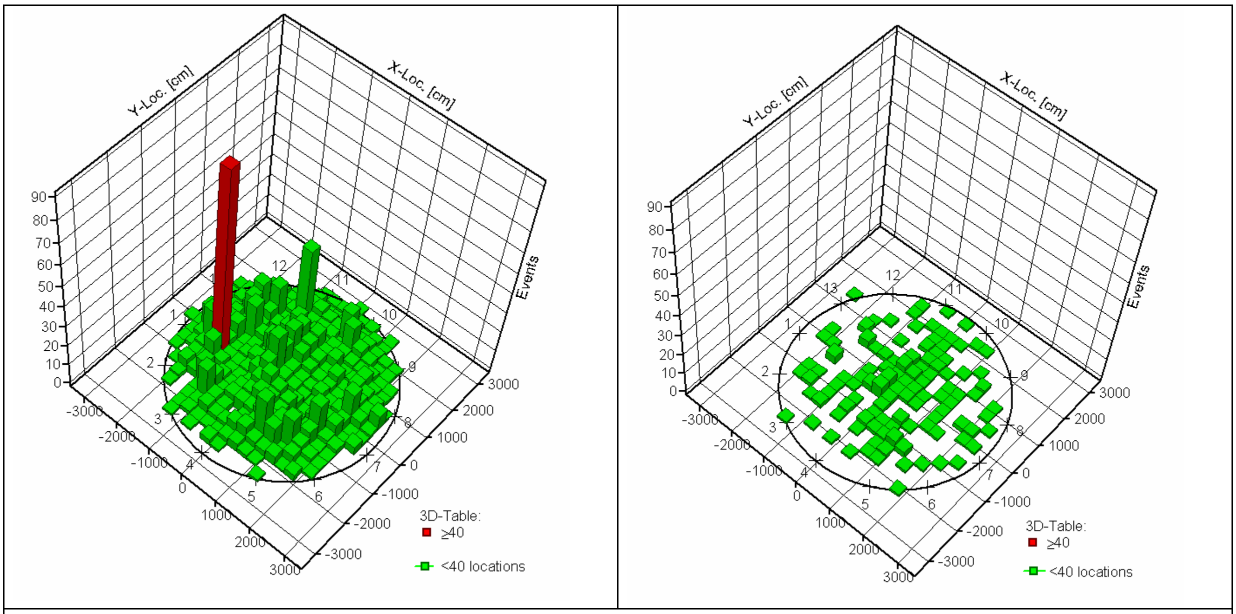


Figure 7: 3-d diagram of location result without and with two rows of sensors

CONCLUSION

Non-intrusive tank floor testing with acoustic emission (AE) is able to detect active corrosion (progressive loss of wall thickness) and active leakage (actual loss of product). The testing covers 100 % of the tank floor as well as bottom side and top side of the floor sheets. Integrated into the regular maintenance and inspection programme it is a valuable tool to separate tanks in good condition, capable for some further years of safe operation, from tanks in bad condition, which should be opened for inside inspection and repair.

The application of the presented testing technique enables to open tanks based on the tank floor condition and not on a time driven schedule. Thus, maintenance may be focused on tanks, which show an indication of a severe defect.

The regulations for tank operation are not the same in all European countries. There are different restrictions for the duration of the service period till to the next inside inspection. To receive an official approval for prolonging a service period requires from the tank operator to convince the responsible authority, which has already led to first successful results.

Corrosion testing with AE is not restricted to ASTs. A new research project funded by the European Commission (EVG1-CT-2002-00067) has been started to test ship tanks, especially those of crude oil tankers, for active corrosion [4]. It has already been shown, that this application is feasible despite of the harsh environment present on sea. Ongoing research activities together with the experience from hundreds of tests ensure continuous improvements, so that AT is able to strengthen its position for supporting economical and safe plant operation.

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