ACOUSTIC EMISSION TESTING ON FLAT-BOTTOMED STORAGE TANKS: HOW TO CONDENSE ACQUIRED DATA TO A RELIABLE STATEMENT REGARDING FLOOR CONDITION

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Abstract

Acoustic emission testing on flat-bottomed storage tanks is a beneficial method for tank operators to obtain information about possible corrosion or even leakage of the floor without opening the tank. Within a research project funded by the European Commission (SMT4-CT97-2177), a new testing technique was developed. It is based on specially designed measuring equipment as well as on sensor arrangement in combination with suitable location algorithms and on frequency analysis of the waveforms. After successful completion of the research project, the method is now in its introduction phase on the European market. Many tanks have been tested in refineries and tank farms. The new technique is described, including the outlines of AE testing, evaluation principle, data treatment, test examples and final report.

Keywords: Acoustic emission testing, storage tank, corrosion, leakage, maintenance.

1. Introduction

To have the necessary storage capacity available is of vital importance for every tank operator. One main task of the maintenance department is to take proper actions for ensuring the availability of the tanks. There are different methods to estimate the duration of a service period for a certain tank, most of which are based on experience. The common link between the experience-based methods is that they do not take into account the actual tank condition. Knowing the actual tank condition would enable the maintenance department to point out the tanks, which have to be repaired while leaving the others in operation. That would give an economic advantage by opening only tanks in bad condition for inside inspection and appropriate repair.

Tank degradation is mainly caused by corrosion. Physical and chemical conversions take place at the boundary area between the liquid storage product and the floor sheet. These processes are non-ideal. Therefore, some parts of the process energy are transformed into acoustic emission (AE) and may be detected with an appropriate measuring system. Within a research program funded by the European Commission (project identification: SMT4-CT97-2177, project partners: TÜV Austria/ENEL, Italy/Vallen-Systeme and Dow, Germany/Shell, Netherlands), a measuring system for detecting active corrosion and active leakage was developed. It was shown by laboratory and on-site measurements that AE signals contain information to obtain the actual tank condition [1-3].

Based on these results a suitable AE testing technique was developed. It consists of two parts:
1. Testing procedure to set up and to perform the measurement.
2. Evaluation procedure to process the acquired data and to grade the tank floor.

The tested tank floor is assigned to one out of four possible grades given in Table 1. The recommended duration of the following service period after the AE test is with reference to the service conditions given before and at the test. If the tested tank is grade IV, it is recommended to open the tank in order to clarify the indications found with AE. Costs for opening a tank and preparation for inside inspection differ according to the size and the storage product. In any event, significant expenses have to be spent. A loss of storage capacity for weeks or months might have a serious effect on production facilities. Therefore, a negative test result has to be as reliable as possible. However, a positive result has to be of highest confidence as well, because unexpected problems are even worse than an expected shut-down of a tank.

### Table 1: Grading system for AE testing on flat-bottomed storage tanks.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Recommended service period duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>No active sources</td>
<td>5 years</td>
</tr>
<tr>
<td>II</td>
<td>Low active corrosion</td>
<td>3 years</td>
</tr>
<tr>
<td>III</td>
<td>Medium active corrosion</td>
<td>1 year</td>
</tr>
<tr>
<td>IV</td>
<td>Leaks and/or high active corrosion</td>
<td>--</td>
</tr>
</tbody>
</table>

2. **The AE Equipment**

As an example for the standard sensor arrangement, 24 sensors have to be applied on a 100-m diameter tank, equally distributed along the circumference and at a level of 1 m above the tank floor. The used sensor is the VS30-V of Vallen-Systeme, which has a flat response especially within the used bandwidth centring at 30 kHz. The sensitivity of each measuring channel is checked with the Hsu-Nielsen source before the test. The AE system is an AMSY 4 of Vallen-Systeme, which is capable of acquiring AE data and waveform data simultaneously for each channel. It has an internal pulsing unit, which sends on request an electric pulse to a sensor. That electric pulse is transferred into an acoustical pulse by the sensor. The other sensors may detect the emitted pulse after transmission through the liquid stock product and along the metallic tank shell. The AE system measures the time period for travelling from the emitting to the receiving sensor and that gives together with the distance between emitter and receiver the speed of sound.

The software for data acquisition, visualisation and frequency analysis are also provided by Vallen-Systeme. With VisualAE™ 2D and 3D plots may be produced to show the tank floor activity. With VisualClass™ classifier, files for analysing waveform data were created in order to identify the source mechanism, as shown in Figs. 1a and 1b. That may be either leakage or corrosion. If corrosion is given, further analysis assigns the corrosion process to either the onset of corrosion or to an already established 'old' corrosion indicated by the presence of a scaling layer.

One can take from Fig. 1 that the source mechanism is given in x-direction. The classifier file was created by using well-known and reliable training data sets. Then, independently acquired test data given at the y-axis were classified and the resulting assignment percentages given in z-direction.
were obtained. Due to the fact that the method is based on statistical methods it is very unlikely to get a 100% assignment. The identified source mechanism is indicated by the maximum assignment percentage. The source mechanism was identified properly for every test data set in Fig. 1.

3. The Test Set-Up

Today’s AE systems offer many features to filter the acquired data in order to eliminate noise as well as signals related to effects different from corrosion and/or leakage of the tank floor. There are possibilities for data filtering of each AE channel independently using criteria derived from combinations of various AE signal parameters. Optimised sensor arrangements in combination with appropriate location algorithms enable to focus on sources located on the tank floor by rejecting AE events with origins on the floating roof or drops falling from the fixed roof onto the liquid.

All these AE system capabilities may lead to the conclusion that the data treatment during the evaluation procedure is the most important part of the testing technique. But this is definitely not the case. The key to a successful test is always a proper set-up. The better the raw data of the test, the easier and more reliable is the data reduction down to the tank-floor condition representing located AE data. Following this straightforward concept, no measurement shall be taken during and shortly after periods of rain and/or strong wind. Furthermore, it is the aim before every test to identify and eliminate noise sources at and in the surrounding of the tank. The next step to avoid too much noise within the raw data is to find the best suited testing period. Very often this is during night; therefore a working permission covering 24 hours a day has to be provided. The AE sensors have to be applied onto the metallic surface of the tank shell; therefore small areas of the coating have to be removed at the sensor positions. The benefit of all these efforts is to be able to test the tank with the lowest possible threshold and with the highest possible sensitivity of the measuring channels. It has to be stressed that at the time being no data treatment is able to convert bad raw data into useful data.

To perform the test after a proper set-up is the easiest task of the testing technique. During the test the boundary conditions of the measurement have to be observed and remarks have to be writ
ten into the measuring file to identify periods of disturbance. These periods are rejected from evaluation and do not add to the minimum data recording time of 60 minutes. That gives up to 650 MB data (AE data and waveform data) for one measurement, which has to be stored on CD-R afterwards.

4. The Evaluation Principle

At the beginning of the research works, the demands for the testing technique were defined. Source mechanism identification was one of the main demands of the industrial partners. One possible approach was to use AE parameters like signal duration or peak amplitude for this purpose. One weak point of this approach was that the dependence of these parameters on the distance between source and sensor had to be estimated somehow. Since the frequency content of the emitted sound wave may be regarded as nearly unaltered starting from the source to the sensor on the tank shell, the partners have chosen another approach for source identification: the frequency-domain-based pattern recognition. Therefore, the evaluation of the test focuses on source location. This is again a straightforward concept. One can keep the link between the active source of the tank floor and its visualisation by location plots. Figure 2 shows as an example a 55-m diameter crude oil tank (floating roof) with a high active source near sensors 1 and 2.

![Fig. 2. Tank floor activity, 3D view of located AE events, 55 m diameter, floating roof.](image-url)
The evaluation results in the location (coordinates) of the sources and their activity (low, medium, high). Moreover, it is obtained by frequency-content analysis of the acquired waveforms, if the sound waves were emitted by corrosion or leakage sources. In case of a corrosion source the presence of a scaling layer will be examined in another evaluation step. If a scaling layer is indicated, the source is assigned to an already established long-term corrosion process. If no scaling layer is indicated, then the source is identified as the onset of corrosion, which does affect the tank floor condition less than ‘old’ corrosion. But of course, if the activity is high, it has to be taken into account, lest this source might turn into a serious defect soon.

5. Measuring Data Treatment

Before the location result is ready for activity and frequency analysis, the measuring data has to be filtered in order to reject noise data or other signals not related to corrosion and/or leakage of the tank floor. Figure 3 shows the different stages of data reduction.

The first filtering step is applied to the raw data in order to get rid of spike signals. These signals are characterised by a very short rise time and are acquired in large numbers due to the fact that the measuring threshold is set very low. As already mentioned above, every test shall be performed with the lowest possible threshold. One consequence is that the test sensitivity is at its maximum; on the other hand, many acquired signals are related to arbitrarily occurring spikes of the background noise. Since these signals are without any significant source location potential, they are rejected from further evaluation. The remaining data is called filtered data.

The second filtering step is aimed at noise signals. These are AE signals, which are not related to corrosion or leakage sources. It was shown by laboratory tests that AE activity due to corrosion or leakage is evolving steadily in time without any sudden activity steps. Hence, it follows that every sudden step in AE activity indicates noise interference. One example of this noise interference during on-site tests is floating roof movement caused by gusts. Besides wind, electronic noise interference may lead to such a fluctuation in AE activity. In any case, noise shall not have an influence on the grading of the tank floor and those data has to be rejected from further evaluation. The remaining data after this step is called extracted AE data.
The final step of the data reduction process is the application of the location algorithm. It analyses the extracted AE data for hit sequences (AE events) with proper differences in arrival time. The main parameters of the calculations are the speed of sound, the size of the tank and of course the sensor positions. An AE event turns into a located AE event, if the algorithm finds correspondence of the measured arrival time differences with values derived from a certain location within the tank. The remaining data after this filtering step, the located AE data, are represented in Fig. 3 by the centre area of the disk.

At this stage one can be sure that the data is cleared from spikes, noise and signals, which cannot be combined to one single sound wave emitting physical event within the tank floor area. Figure 4 shows the extent of data reduction for some tank floors of different conditions according to the described filtering steps.

It can be taken from Fig. 4 that the raw data contain only a few locatable AE data in the range of some percents (3 % for ‘no active sources’ to 9 % for ‘extensive corrosion’). But still the located AE data are not necessarily representing the actual tank floor condition regarding corrosion and/or leakage. In some cases further considerations are required.

6. Examples of Tested Tanks

Assuming a highly active corrosion source is located within a tank like that shown in Fig. 2, then the recommendation for tank maintenance according the grading system given in Table 1 would be to open the tank as soon as possible. Before presenting this kind of result to the tank operator
other possibilities for corrosion within the tank should be taken into account. One potential source of corrosion influencing the test result is the floating roof. An inspection of the roof can solve this problem only partly; much better is to use a sensor arrangement consisting of two rows of sensors. Figure 5 shows the same floating roof tank like Fig. 2 but the measurement was evaluated with the help of the applied second row sensors.

The first row sensors are applied at a height of 1 m above the tank bottom as usual, and the second row sensors are mounted above the bottom row sensors in a vertical distance of 2 m to 4 m. The value depends on the filling height and the tank size. With this set-up AE events from above may be identified easily and reliably by using the second row sensors to guard the bottom row. It can be taken from Fig. 5 that no active source is remaining after this final evaluation step, the located AE source in Fig. 2 was identified as defect of the weld between two roof sheets.

![Fig. 5. Tank floor activity, 3D view of located AE events, 55-m diameter, floating roof, evaluation with two rows of sensors to reject AE events from the roof.](image)

Another application of the second row of sensors is for identifying drops falling on the liquid product inside a fixed roof tank. This might occur if the gaseous phase of the product condenses at cold parts of the roof structure. Some drops interfering the measurement may be identified manually; for large numbers of drops more efficient methods have to be used in order to finish evaluation within a reasonable period of time. Figure 6a shows the tank floor activity of a test interfered by...
drops obtained by the bottom row only. Figure 6b shows the same tank but evaluated with the help of two rows of sensors, and no active source is remaining.

Fig. 6. Test interfered by drops, evaluation using a) one row and b) two rows of sensors.

The feasibility of the application of this special sensor arrangement is limited only by the increase of the background noise caused by countless drops. The corrosion or leakage signals would be drowned by noise signals without any chance to get them by a threshold depended AE system. But for the time being this is the same for all other noise sources, which cannot be eliminated.

7. Conclusion

Acoustic emission tests are suited for obtaining the actual tank floor condition of flat-bottomed storage tanks regarding active corrosion and/or active leakage. The presented testing technique focuses on location of AE sources and the identification of the source mechanism, either leakage or corrosion, by frequency-content analysis of the gathered waveforms. If corrosion is detected, further analysis results in distinguishing the onset of corrosion (no scaling layer) from already established long-term corrosion (presence of a scaling layer).

Several demands have to be fulfilled to obtain a test result, which represents the actual tank floor condition. One important part is to filter the raw data of the performed measurement subsequently in different steps. The strongest filter criterion is given by the location algorithm. It was shown that the raw data of the measurement contains from 3 to 9 % locatable AE data depending on the tank floor condition and the boundary conditions of the measurement. It follows that the location algorithm and the parameters to be set for its application have to be well known and well chosen. The standard sensor arrangement is able to locate within a horizontal plane and does not give any information about the position of the source origin in vertical direction. With a second row of sensors the location algorithm used is capable of rejecting AE events located above the sensor arrangement.
Meanwhile more than 100 tanks have been tested with this testing technique within the EU. The database and the knowledge of the given tank populations increase steadily. This again enables further improvements of the testing as well as the evaluation procedures, which shall lead to a broad acceptance of AE testing.

References

