Analysis of Corrosion Processes and Leaks in Aboveground Storage Tanks with AE Monitoring

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Abstract
Leaks are structural failures especially in old construction of the single-bottom aboveground storage tanks that are mainly caused by corrosion or by weld defects. These damages from the degradation of material and structure are the subject of investigations carried out within the framework of the Research and Development Project of The Polish National Centre for Research and Development entitled "Design, implementation and use of a control system for monitoring activity and leakage of corrosive processes by acoustic emission (AE) of storage tanks for liquid media" - NR15 011410/2010. This paper describes AE experiment, data analysis and evaluation and deals with the AE tests of laboratory corrosion and leaks tests and AE monitoring on storage tanks in operating conditions. AE enables us to monitor the activity of corrosion processes and leaks. The main purpose was to record data with appropriate wide spectrum of frequency domain for different stages of corrosion processes and different kind of leaks. On the storage tanks under various operating conditions, AE background measurements were made. Next AE monitoring tests of storage tank with corrosion and leak sources were conducted. A thorough frequency distribution analysis has identified the main dominant frequency bands for corrosion, leaks and background noise in laboratory and on real storage tanks. These results defined the appropriate frequency ranges for AE monitoring and verification tests were carried out. Data collected during all measurements are used in frequency and AE parameters analysis in order to develop the conditions and criteria of conducting AE monitoring on operating storage tanks regarding condition of the tank bottom. Next stage of the analysis of the data will be pattern recognition analysis to separate the AE signals due to corrosion and leaks from background noise for different conditions measurements.

Keywords: Corrosion and leak detection, AE monitoring of storage tanks

1. Introduction

Environmental protection and the need to meet the legal requirements concerning the maintenance of aboveground tanks intended for storage of dangerous media lead to search for ever more efficient ways to anticipate and detect critical defects in the material of tanks. This applies particularly to non-pressure or low-pressure tanks for hazardous liquid (toxic, corrosive or flammable) stored. For this type of tanks the primary threat is influences of the corrosion on the material, substantially dependent on the aggressiveness of the stored medium and the type of material used and the structural stress levels.

This issue is valid especially for large-capacity tanks with danger of explosion or leakage of aggressive media. Existing methods for surveillance of these type tanks usually react after the occurring damage, but not previously approach and investigate into its critical state. One of the responses to an existing problem may be the protection of the tank leak by building a second bottom. The solution is very costly especially in the case of tanks already in service, often technically risky because of the stress relaxation resulting in cracking of structural material structure outside the protected zone.

Based on these facts, the Research and Development Project of The Polish National Centre for Research and Development was established. The project is entitled "Design, implementation and use of a control system for monitoring activity and leakage of corrosive processes by acoustic emission (AE) of storage tanks for liquid media" - NR15 011410/2010. The project is proposed to solve the problem through the application of AE method to monitor continuously the technical condition of the structure of tank during service. It is proposed that the general solution of the problem through research conducted in the laboratory and research on single real structure and afterwards organization and testing of storage tanks operated in the selected oil storage bases.
2. Laboratory tests

AE enables us to monitor the activity of corrosion processes as well as leaks. Based on this knowledge the corrosion and leak laboratory tests were conducted. The main purpose of the lab measurements was to record data with appropriate wide spectrum of frequency domain for different stages of corrosion processes and different kind of leaks. During laboratory tests were used AMSY6 system with ASIP-2 dual channel AE boards made by Vallen Systeme GmbH. The following types of sensors were used: VS30-SIC, SE45-H, VS75-V, VS75-SIC and wideband type WD. Laboratory testing for leaks using the AE method were conducted for different types of leakage and the rate of the flow. We built a leak test stand (fig. 1) and leakage simulator (fig. 2). In both cases was used inserts with following holes:
- regular vertical hole 1mm $\phi$ (also 3mm $\phi$),
- rough and raw vertical hole with a similar rate of the flow as 1-mm vertical hole in the same condition,
- rough and raw inclined hole with a similar rate of the flow as 1-mm vertical hole in the same condition.

Leak simulator was built in the next sequence after the basic research on test for leaks and development of preliminary results. Building the simulator is aimed for the comparison and verification of leak in the laboratory and in real conditions on the storage tank.

Laboratory leak tests were intended to record AE signals typical for leakage at different rates (0.01-0.10 m$^3$/h) and different shapes of holes. Laboratory tests were performed on the leak test stand (fig. 1), where on the specially designed vessel it is possible to simulate different levels of liquid, as well as different kind of holes. Research with leakage simulator was performed in the following order: in the laboratory test stand in the basin (fig. 3) and on the storage tank in service. All tests were performed in order to collect the measurement data for the widest range for different parameters of leaks.

Laboratory tests of corrosion using the AE method were conducted on the specimens in different stages of material degradation. The specimens were obtained from real storage tanks – material made from carbon steel of normal quality. The specimens were a) without damages with original paint and b) with severe corrosion damages. The specimen size was 200x350mm with thickness 6mm with an open window for corrosion on one side (fig. 3).
The corrosion test stand was rebuilt and modified (fig. 3) for the research purposes in this project. AE measurements of corrosion processes are intended to acquire AE signals typical for various stages of degradation of the specimens, and for different rates of progress of corrosion (0.20-5.00 mm/year). Laboratory tests are performed on the test stand (fig. 3), where in special corrosive environmental conditions (3% NaCl aqueous solution) specimens were undergo corrosion processes. Also here, all tests were performed in order to collect the measurement data for the widest range for different parameters and stages of corrosion.

All initial tests (both corrosion and leak) were performed using the resonant sensors 30, 45 and 75 kHz (VS30-SIC, SE45-H and VS75-V) and broadband sensors (WD). In the next stages, the two types of sensors were selected for the resonant frequencies of 30 and 75 kHz. According to obtained results the range of used frequency filters was changed. Measurement data collected during the tests will be used to parameters and frequency analysis in order to develop guidelines and criteria of conduct by AE measurement and monitoring of bottoms of storage tanks.
3. Tests on a storage tank

For AE testing, we selected one of storage tanks of a refinery (PKN Orlen S.A.), which cooperates with this project. The storage tank is in service and stores diesel oil. In figure 4 is presented storage tank with pipelines, while figure 5 showed the layout of AE sensors together with the accessories of tank. AE monitoring of this storage tank was conducted in order to detect corrosion and/or leak sources. In the next step, AE background monitoring measurements were made on the storage tank for various operating conditions and under different weather conditions.

After a few stages of the leaks laboratory tests, first leak tests were performed on the storage tank using a simulator. The measurements were performed in a variety of operating conditions (e.g., for different levels of stored product) and the environmental conditions. During AE monitoring on the storage tank, we used AMSY6 system with ASIP-2 dual channel AE boards made by Val- len Systeme GmbH. At the beginning we employed the same types of sensors used during lab test, i.e., the resonant frequencies of 30 and 75 kHz.

![Fig. 4 View of tested storage tank together with its and others pipelines](image)

4. Analysis and results

AE measurements during leak tests enables us the detection of leakage and monitoring of their states for different conditions. The most sensitive parameter of AE regarding leak is Root Mean Square voltage or RMS. The RMS value of the signal between two hits (the time period from end of hit detection to next start of hit detection) is continuously evaluated and stored with the next hit as the RMS result. It provides information about the continuous AE signal level below the threshold. In this article we use RMSS parameter, which is the time driven Status Data Sets. RMSS can be used to monitor the background noise, even when there are no hits at all.

Figure 6 shows RMSS vs. time for the background noise on the laboratory tank as reference while in figure 7 is presented an example of leakage for product level simulation, respectively, at 12,5 m and 10,0 m (rate of flow about 40 - 50 dm³/h). In figs. 8 and 9 are presented distribution of hits versus frequency for 1-mm hole and inclined hole for VS30-SIC and VS75-V sensors. Figures 10, 11 and 12 show respectively the same conditions and tests of leaks but for different kind of holes. The RMSS has highest values for most complicated path of leak and opposite lowest values for regular 1-mm hole.
AE measurements during corrosion tests enabled us the detection and monitoring of active corrosion processes. These are long-term tests due to the duration of corrosion processes. All measured data were recorded at several measurement sequences at different stages of the corrosion degradation of the specimens. Figure 13 shows the locations of AE sources on the tested specimen resulting from active corrosion processes, whereas in fig. 14 is presented the same localization in 3D and additional history of location events in time and correlation of amplitude with duration. In figs. 15 and 16 are presented distribution of hits versus frequency in different stage of progress of corrosion degradation for VS30-SIC sensors.
Fig. 7 RMSS for the leak in the laboratory test in tank for 3-mm hole– product level simulation, 12.5 m and 10.0 m, respectively (rate flow about 40 - 50 dm³/h)

Fig. 8 Distribution of hits versus frequency for 1-mm hole, in tank test with VS30-SIC and VS75-V sensors

Fig. 9 Distribution of hits versus frequency for inclined hole, in tank test with VS30-SIC and VS75-V sensors
Fig. 10 RMSS for the leak in the laboratory test for 1-mm hole – product level simulation in range, respectively 6.0 - 9.0 m (rate flow about 18 - 22 dm$^3$/h)

Fig. 11 RMSS for the leak in the laboratory test for inclined hole – product level simulation in range, respectively 6.0 - 9.0 m (rate flow about 24 - 28 dm$^3$/h)

Fig. 12 RMSS for the leak in the laboratory test for vertical rough hole – product level simulation in range, respectively 6.0 - 9.0 m (rate flow about 18 - 22 dm$^3$/h)
Fig. 13. Location of AE sources on specimen during corrosion test

Fig. 14. Location (3D) of AE sources on specimen during corrosion test
Location events in time and correlation of duration with amplitude

Fig. 15. Distribution of hits versus frequency for corrosion activity for VS30-SIC sensors and the initial stage of corrosion degradation
Numerical analysis was performed using the VisualClass to verify and compare the data from the tests of corrosion and leak. The AE waves generated by leak and by corrosion process sources as recorded AE signals were compared (fig. 17). For the analysis the selected data from all laboratory tests were used.

AE measurements on the real storage tank enabled us to record data for different operating conditions and state of weather. Figure 18 shows RMSS during measurement of background noise on the storage tank for adverse weather conditions and starts of filling up with rate about 100t/h – additionally there is visible RMSS for one of sensors mounted on pipeline at inlet to tank, whereas in fig. 19 is presented RMSS during different weather conditions. In fig. 19a) is very low background noise, in case of b) background was higher due to slight wind and in c) an even higher background because of light rain.
Next AE measurements on storage tank were full monitoring tests for stable operating and weather conditions in order to detect corrosion and/or leak activity. In figure 20 is presented the locations of AE sources in the bottom of the storage tank. This is corrosion activity of old installation inside tank which is in bad condition. When this data were undergoing analysis by classifier built in lab research, the result is such presented in fig. 21. Almost 100% of data were identified as corrosion.

First measurements were made using the leakage simulator inside real storage tanks. Because in this case location of AE source is difficult therefore data filtered was performed for period of leak activity. Obtained data had undergone analysis by the classifier built in lab research and the results are presented in figure 22. For safety reasons and due to operation schedule of production on the storage tank it was impossible to make all planned tests. Remaining tests will be performed soon. For these reasons, leak tests were performed on the tank using leakage simulator only for two low levels of stored product - below 5m. Better result was obtained for higher level of product than lower level. At present there are not yet satisfactory results. Nevertheless, these were only the first tests of this type and afterwards it is expected to get much better effects.
5. Conclusions

Based on the obtained results and on their analysis, the following conclusions can be drawn:

- It is confirmed that the parameter RMS is the most sensitive parameter for leak AE sources,
- It is confirmed that corrosion processes are sources that AE can detect,
- It is possible to simulate leaks in the laboratory in order to collect database for further numerical analysis,
- Acquired during laboratory tests AE signals are very good basis of project database,
- VisualClass analysis of lab data enables us to identify AE sources very well as leak and corrosion - data obtained within laboratory tests undergone analysis in VisualClass application can without problems assign adequate classes with almost 100%,
- A real corrosion damage on storage tank was detected well by AT and identified by new classifier. However it is necessary to develop the classifier beforehand along with AE signals obtained and verified on real objects,
For a full solution of presented problem, it is necessary to perform the planned tests of leaks using the leakage simulator in the storage tank in real conditions.

Fig. 22 Visual Class analysis of AE signals recorded during laboratory tests and tests on real storage tank with used leakage simulator

References