Requalification of LPG tanks in Europe: Verifying the structural integrity by monitoring the pressure test with acoustic emission

Gerald LACKNER¹, Peter TSCHELIESNIG²
¹ TÜV AUSTRIA SERVICES GMBH, Wien, Austria
² AT.Consult e.U., Klosterneuburg, Austria

Contact e-mail:
¹ gerald.lackner@tuv.at - ² office@at-consult.at

Abstract. Requalification of LPG tanks usually requires a set of inspections and tests defined by national regulations or by other applicable rules. To assess the structural integrity of the pressure equipment is the main objective of these activities. Historically the combination of hydrostatic testing and visual inspection (external and/or internal) has been the first widely accepted procedure. Its regular application led to tremendous safety improvements. However, since the end of the 19th century safety considerations have been extended. Degradation by cracks and corrosion as well as manufacturing defects leading to local stress accumulations have to be detected in time in order to prevent failure. Entering into a confined space for an internal inspection is considered to be a high risk activity. Safe disposal of polluted water from the hydrostatic test is a high effort and has a substantial risk regarding environmental pollution. Acoustic emission testing on LPG tanks was developed starting from the late 1980s to offer an alternative to the traditional approach. It allows the detection of corrosion damage, cracks and weld defects activated by the applied test load. On-line monitoring of the pressurisation enables to indicate severe defects while the structural integrity is still given. Thus a pneumatic test instead of a hydrostatic test may be performed. Furthermore it provides information regarding the tank condition usually obtained by internal and external inspection. After the first 1000 tanks had been tested in Austria in 1993, LPG tank testing was applied in Germany, France and other European countries like Czech Republic, Slovakia or Slovenia. In the early 2000s further European countries have updated their national legislation to enable the application of acoustic emission testing like Italy, Portugal and Spain. The standards EN 12817 and EN 12819 addressing requalification of LPG tanks were improved by adding acoustic emission testing for tank requalification. This contribution describes how this kind of LPG tank testing was established in Europe, shows with the help of case studies the capabilities of the method and provides information of latest developments.

Introduction

Is it still safe? To answer this question does bother responsible owners/operators of pressure equipment throughout the service life. When looking at a metallic tank to store liquefied petroleum gas (LPG) one might say that it is not a big deal to give an affirmative answer. Usually those tanks are produced in large quantities by a various number of
manufacturers and installed in almost every corner of European countries. An LPG tank is a mass product and there are proven solutions available to take it into safe operation in almost any environment. The operational conditions are taken into account very well at the time when the owner/operator selects the tank, which is then installed according to the given national and regional regulations. Thus, a properly selected and installed LPG tank is supposed to be safe throughout decades of service life. The answer to the introductory question should be therefore always yes, it is still safe.

From this point of view requalification of LPG tanks after a certain period of operation by in-service inspection and testing seems to be a superfluous activity, which does not change anything regarding the level of safety. However, experience of testing several ten thousand LPG tanks all over Europe does not support the latter. Severe operational conditions, undetected manufacturing defects or undetected failure of protection systems do affect the structural integrity of tanks. This paper shows a selection of examples where in-service inspection and testing prevented severe incidents and thus helped to continue safe service after carrying out corrective measures. And in this regard, acoustic emission testing (AT) has proven to be a very effective testing method to achieve safe and economic LPG tank operation.

From Austria to Europe

TÜV AUSTRIA was among the first inspection and testing organisations in Europe where an expert group was established to apply acoustic emission testing on plant components within an industrial environment. Starting from the 1980s several techniques were developed to test pressure equipment like gas storage spheres, chemical reactors or cylindrical vessels in order to detect degradation processes or consequences thereof. These techniques comprised the detection of various defect types like weld defects, cracks or wall thickness diminution due to corrosion. Leak detection for pressure equipment was a by-product since the presence of leaks made measurements on pressure equipment sometimes impossible. The practical experience gained in those years showed that acoustic emission is capable to assess the structural integrity of pressure equipment. Beside the chemical and petrochemical industry, the LPG industry became aware of acoustic emission testing. The following list highlights the most important drivers for its application:

- Inside inspection is considered to be a high risk activity. Entry into a confined space needs thorough preparation and execution. Serious situations in the course of inside inspections are reported every year. Acoustic emission testing on LPG tanks makes inside inspection unnecessary.
- Water used for hydrostatic testing is considered to be a hazardous waste and has to be disposed at specialised facilities. Furthermore, residual humidity may induce or promote inside corrosion. Acoustic emission testing does not require to empty or to clean the tank. In most cases it is performed with the LPG of the tank under test. After completion of the test, the tank is immediately available for the consumer.
- In the event of an already severely damaged tank, monitoring of the pressurisation with acoustic emission provides on-line information regarding the actual condition of the tank and thus enables the test operator to suspend or even to terminate the test in a safe way in order to prevent a serious situation to evolve.

The breakthrough in Austria was achieved in 1993, when the first testing campaign with more than 1000 tank tests had been completed successfully. It was shown that a large number of tanks from different manufacturers at various sites across the country can be
handled with a standardised procedure by skilled test operators using a pressurisation unit based on LPG. In 1996 another milestone was reached in terms of test data evaluation, the Cluster Evaluation Factor (CEF) was introduced to the test procedure. CEF is a powerful tool for acoustic emission source severity grading and tank classification. It was developed based on the experience gained during the performance of two test series in France, where we have been invited to support the investigation of issues related to stress corrosion cracking on the circumferential welds (joggle joints) of LPG tanks near the 6 o’clock position. The algorithm to calculate the value of CEF combines in an advantageous way several parameters of the measuring data and thus it allows assessing the tank condition in a straightforward way. It is one major feature of our testing technique and supports the broad application of LPG tank testing using acoustic emission in Europe and abroad.

Once established in Austria, several other countries became aware of the – at that time – new and innovative solution. Initial testing routes were performed in Germany in 1997 and 1998 in order to deal with the same issue of stress corrosion cracking as already experienced in France. Those defects had evolved already quite substantially so that some tanks became leaky, e.g. while refilling. The lesson learned during this period was to apply a measuring set-up needed to focus the data analysis on events caused by sound wave emission originating from a physically plausible source anywhere at the loadbearing shell of the tank and to improve the on-line data analysis [1]. The test operator needs to obtain the value of CEF in a very effective way in order to reduce the reaction time in case of severe indications. This set the demand for an automatic CEF calculation from the measuring data for on-line analysis, which was not available at that time.

Over the years TÜV AUSTRIA concluded many cooperation agreements with companies dealing with the requalification of LPG tanks, especially in neighbouring countries like Czech Republic, Slovakia or Slovenia. The package consisting mainly of the testing procedure, the design of the mobile testing laboratory including the pressurisation unit and the data analysis based on CEF was licensed to our cooperation partners so that they could perform – after sufficient training – LPG tank testing independently. The experience gained by testing tanks outside Austria with our technique supported very well its further improvement. It enabled us to apply it without major changes on a broad variety of different tank designs resulting from specific regional technical requirements.

The wide acceptance of acoustic emission for testing of pressure equipment led to its implementation into European standards devoted to the requalification of LPG tanks. Starting from 2002, the standards EN12817 for tanks with a capacity of up to 13 m$^3$ and EN12819 for tanks with a capacity of more than 13 m$^3$ were issued and became a reference for authorities in many European countries. According to these standards the owner/operator has several options how to carry out the tank requalification properly, with acoustic emission testing being one option among others. Many European countries adapted their national legislation in order to follow the state of the art described by these standards.

Another step forward in our testing technique was possible when acoustic emission equipment provider Vallen Systeme implemented a so-called embedded code processor in VisualAE, the measuring data processing and visualisation software. When dealing with already severely damaged tanks in France and Germany as already described above, it has been identified that the reaction time of the test operator is a crucial element for safe tank pressurisation. Vallen Systeme started this development in 2004 and was able to issue the first version of VisualAE with the option to add-on the CEF calculation algorithm in 2006. To obtain the value of CEF automatically on-line during testing became the key feature of the TÜV AUSTRIA procedure [2].

One of the first countries beside Austria to introduce acoustic emission testing into its legal system was Italy in 2005. Tests on underground installations of LPG tanks up to 13 m$^3$ are carried out since then by approved testing and inspection organisations under the
supervision of the national institute for occupational safety ISPESL (now part of INAIL, the national institute for work accident insurance). The Italian expert group at INAIL has developed the testing procedure for this activity to be applied. TÜV AUSTRIA has been active in Italy from the very beginning, first by a cooperation and later on by a partnership with Blu Solutions. Since the Italian LPG tank population is very large, about ten thousand tests per year on tanks up 13 m³ are performed by TÜV AUSTRIA Italia - Blu Solutions as a testing organisation together with the inspection organisation ICEPI.

Enquiries from all over Europe indicate that our testing service is considered to be beneficial for our clients of the LPG industry. In 2008 we have been invited to qualify the TÜV AUSTRIA testing procedure on real tank samples at a Turkish LPG company near to Istanbul. We have passed this qualification process to the full satisfaction of the client and have received a long term contract for performing acoustic emission tests. The volume of the order was about 1000 tanks per year and it was handled by the TÜV AUSTRIA Turk after having built-up mobile testing laboratories and after completing the required training for the Turkish test operators. It was the initial start for a widespread application of acoustic emission on LPG tanks in Turkey.

QTEC, an inspection and testing company from Portugal, has signed an agreement in 2009 for testing underground tanks in cooperation with TÜV AUSTRIA. Within a few months the preparation for field testing has been finished: A mobile testing laboratory has been purchased from Blu Solutions, the Portuguese test operators were trained in Austria as well as on-site on Portuguese tanks and the authorisation to provide the testing service on underground tanks was obtained. The progress in Portugal achieved by QTEC was recognised in Spain, and one year later in 2010 the testing service was rendered on the whole Iberian Peninsula after passing the qualification process defined by the client successfully. The required level 2 certification of the personnel in acoustic emission testing according to ISO 9712 was obtained in Italy. After the initial period QTEC is performing the tests independently with their own personnel. The successful cooperation was extended to a partnership and QTEC became in 2012 part of the TÜV AUSTRIA Group, which is engaged in acoustic emission testing on LPG tanks in many European countries as shown in figure 1.

![Fig. 1. LPG tank testing in Europe with acoustic emission by TÜV AUSTRIA Group. Austria (AT) 1993, Germany (DE) 1997, Switzerland (CH) 2004, Italy (IT) 2005, Turkey (TR) 2009, Portugal (PT) 2010, Spain (ES) 2011.](image-url)
Enquiries from all over the world regarding collaboration in acoustic emission testing on LPG tanks give evidence that there are still countries relying on a traditional approach for requalification. We are able to proof our high level of competence by many examples of practical experience in defect detection and moreover by demonstrating the testing technique on samples provided by clients as part of their internal qualification process.

Case Study – Above Ground Tank with Corrosion

One candidate tank with several corrosion effects on the cylindrical shell was presented to us at a workshop in order to demonstrate the capabilities of our testing technique. The tank with a capacity of 2450 litre was equipped with several sensors as indicated in figure 2. Linear location was applied with two sensors of VS75-SIC of Vallen Systeme near to the intersection of the circumferential weld and the longitudinal weld at each end. The design pressure of the tank was 2 MPa (20 bar) and it was filled with water. The aim was to perform a hydrostatic test monitored with acoustic emission.

**Fig. 2.** Demonstration test on an above ground LPG tank (2450 litre), photo of the tested tank with corroded area near to sensor XD1 on the top, graphs on the bottom show CEF and pressure vs. time (1st row left), CEF of located events vs. position along the cylinder lengths (1st row right), maximum amplitude and energy of located events vs. time (2nd row left), waveform and frequency content of an event located at the area of corrosion (2nd row right)
The data confirmed very clear already at a pressure of about 1.5 MPa (15 bar) that there is a rather severe source of acoustic emission near to sensor XD1, which confirmed the findings obtained by visual inspection. The tank was taken up to 1.8 MPa (18 bar) until the pressurisation was stopped at a value of CEF above 2.8 and thus the tank had failed the acoustic emission test. After completion of the final pressure hold period the tank was subject to hydrostatic testing with a maximum test pressure of 3 MPa (30 bar). In contrary to the acoustic emission test, the tank has passed the hydrostatic test: no leak, no plastic deformation. The representatives of the client were satisfied by this result. They had the opportunity to see how such a test had to be set-up, what the important boundary conditions for its successful performance were and how on-line data evaluation resulted in the final grading of the tank.

Case Study – Above Ground Tank with Leak in Cylindrical Shell (Parent Metal)

On a regular field testing route the test operator came to an above ground tank as shown in figure 3. He applied the usual test set-up procedure and then started with the pressurisation by feeding LPG liquid phase from the tank under test to the mobile laboratory, where it was evaporated in the heat exchanger and fed through the filling valve back to the gas phase.

![Field test on an above ground LPG tank (2300 litre), photo of the tested tank on the top, graphs on the bottom show CEF and pressure vs. time (1st row left), CEF of located events vs. position along the cylinder lengths (1st row right), maximum amplitude and energy of located events vs. time (2nd row left), waveform and frequency content of an event located near to sensor XD1 (2nd row right)](image)
He saw that the value of CEF increased rather quickly and was alarmed. On the other hand side he realised that the background noise (given by the measuring parameter RMS-status) was rising with increasing load (see figure 4) and this led him to the conclusion that there might be leakage at the tank fittings. This was confirmed at the first pressure hold where after closing the gas flow to the tank the RMS-status did not reduce, as it is supposed to do in case the increase of noise is caused by the gas flow to the tank from the pressurisation unit. He continued the test till to 1,75 MPa (17.5 bar) and performed the final pressure hold phase. The tank was graded preliminary by class C, the tank has failed the test. Then the follow-up to clarify the found indications was done. For this reason soapy water was applied to check the fittings for leakage. Unexpectedly the nozzles and valves did not show any indication for loss of gas phase. Suddenly the test operator saw that bubbles indicating a leak showed up not at the tank fittings but below at some vertical distance. The photos given in figure 4 document these findings. The owner/operator was informed immediately. The tank was taken out of service and replaced by a new one. It was the first time that such kind of defect has been seen in the field and the test result prevented an unsafe situation, which most likely would have evolved in time.

Fig. 4. Field test on an above ground LPG tank (2300 litre) with leakage of tank shell, graph on the top shows background noise level of both measuring channels (red for channel 1, green for channel 2) and pressure (blue) vs. time, photos at bottom document leak of parent metal at area right below the tank fittings.
Conclusion and Outlook

There are many other case studies available taken from practical field experience, where defects were detected under regular testing conditions. All of them highlight the contribution of acoustic emission testing to raise the level of safety in LPG tank operation. The main advantage of acoustic emission testing compared to hydrostatic testing is that in case of the latter the result is binary, either passed or not passed with no further information. The result of an acoustic emission test is finally a passed or not passed too. However, it gives additional information regarding the condition of the test object as shown in table 1 below.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
<th>Further actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Minor source</td>
<td>No actions required, found indication(s) are non-relevant for safe service. Documentation for future tests only.</td>
</tr>
<tr>
<td>B</td>
<td>Active source</td>
<td>Further NDT is recommended to clarify the cause for the found indication(s) and to continue with safe service. One option among others is to retest with acoustic emission.</td>
</tr>
<tr>
<td>C</td>
<td>Very active source</td>
<td>Other NDT shall be applied as soon as possible. Tank regarded as severely degraded unless there is evidence that the found indication(s) have no impact on safe service.</td>
</tr>
</tbody>
</table>

Similar to a traffic light, class A and C represent the green (passed) and the red (failed) light. Class B represents the yellow light and is supposed to guide the attention to the tank under test and to perform further maintenance actions. The statistical numbers of past years show, that tanks tested with class C represent in numbers only some tanks taken from a representative sample of 1000 tanks. In case of class B this gives already some 10 tanks per 1000 tanks tested. The condition of those class B tanks may degrade further in time, if the reason for the indication(s) is not clarified and further degradation not prevented. Consequently acoustic emission helps to focus maintenance resources on tanks, which do need it. Hydrostatic testing cannot offer this support to the owner/operator responsible for safe operation.

The total number of acoustic emission tests performed on LPG tanks with a capacity of less than 13 m³ by TÜV AUSTRIA Group has resulted in 2014 in more than 15000. This proofs that this testing method became the standard test method in many countries. Furthermore, quite a lot of tanks have been tested with a capacity of more than 13 m³ during the last years. More than 400 items were tested annually in 2012, 2013 and 2014.

The testing technology is applicable to very large tanks with several hundred cubic meters. In this regard a reference has been set by TÜV AUSTRIA in Italy. The largest cylindrical LPG tank tested in 2014 was a mounded cylindrical tank with a capacity of 2000 m³ using an innovative methodology to access the tank shell developed by Blu Solutions [3].

References