Acoustic Emission Testing of Buried Pressure Vessels
Implementation on a 16000 m3 gas storage unit

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ABSTRACT

Acoustic emission testing of pressure vessels has been applied for decades in France, Europe and worldwide. It allows overall and fast monitoring of large structures, greatly minimizing the time of maintenance and shutdown of plants.
In order to reduce the impact of the presence of large gas storage tanks on the environment and to minimize the risk level, projects of this type are subject to new constraints for several years. These gas storage vessels, cylindrical or spherical, are then covered by either an embankment slope or placed in a sarcophagus filled with sand. The question of periodic control arises fully, since the surface of the pressure equipment is no longer available for inspection. As a compensatory measure to the problem of accessibility, acoustic emission is then possible and appears of great interest.

The experience reported in this article illustrates all stages of acoustic emission implementation on a large industrial project of this type: the building of 4 spherical gas storage vessels of 4,000 m3 each, located in Tunisia. From design, pressure equipments have taken into account the constraints related to the integration of acoustic emission. Indeed, the solution was to use waveguides, allowing the monitoring of inaccessible areas due to the presence of the embankment. From laboratory experimentation until final tests after burying, this technology has been validated. The monitoring of hydraulic pressure test by acoustic emission provided a first acoustic signature of each vessel, which will serve as reference for the future.

This successful project is one of the largest industrial projects in the world if we consider that nearly 400 acoustic emission sensors were needed to control these 4 pressure storage vessels.

1. INTRODUCTION - BACKGROUND

In order to reduce the impact of the presence of large gas storage tanks on the environment, such projects are subject to new constraints for several years. In this case, the 4 spherical tanks of 4000 m3 each are then placed in a sarcophagus filled with sand.
The question of periodic control arises fully, since the surface of the pressure equipment is no more accessible, except by removing the sand, hardly feasible for technical and financial reasons. As a compensatory measure to the problem of accessibility, acoustic emission is the main solution, since it allows a diagnosis of the entire resistant wall of each spherical tank, during hydraulic or pneumatic tests performed at each term of requalification, or when prescribed by the owner.

2. DESCRIPTION OF THE DIFFERENT PHASES OF THE PROJECT

This project, lasting approximately 18 months, required cooperation between the various partners involved in the achievement of the storages: engineering, civil engineering, boilermaker, end-user and safety authorities.
CETIM, as leader of the 'acoustic emission' part, has managed to reconcile the constraints of this technique with all other constraints inherent in such a project.
The steps are described in the following paragraphs.

2.1 The project in brief

The project of building the gas distribution center in La Goulette, a suburb of Tunis, is of great importance for the whole region. It is indeed possible to ensure safely for many decades, a large storage capacity. Anxious to meet current safety requirements, the contractor decided to build 4 spherical tanks in sarcophagus filled with sand, as shown in Figure 1.

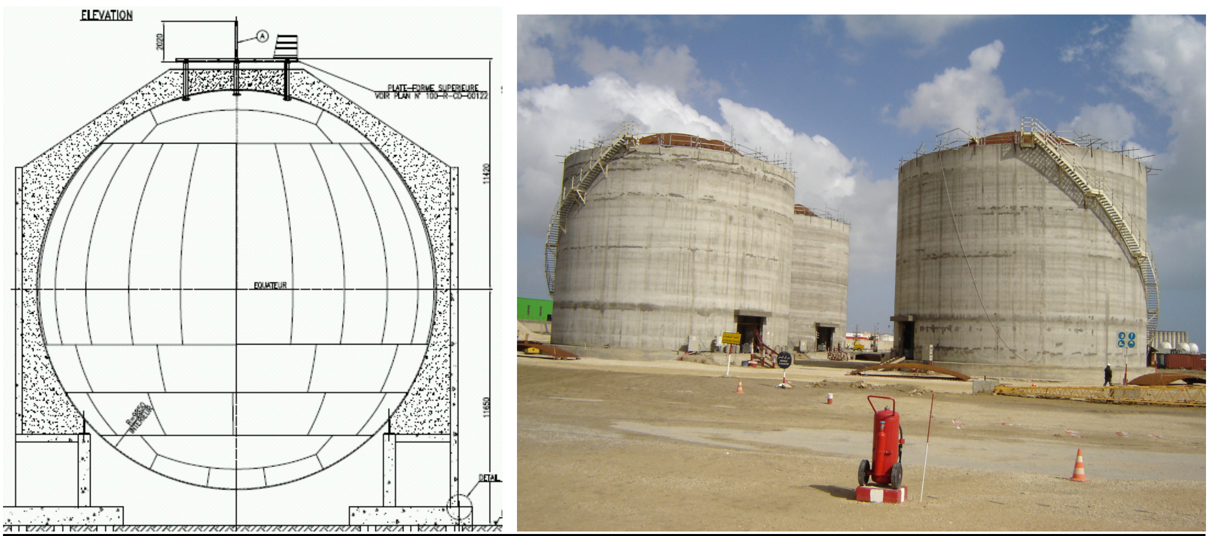


Figure 1: General outline of a 4000 m3 spherical tank under sarcophagus - General view of the 4 sarcophagus during the building

Acoustic emission, a nondestructive testing method based on the detection and analysis of transient elastic waves caused by the stress applied to the structure, requires the use of sensors in physical relation with the wall of the tank.

In this case, the surface of each spherical tank being mainly inaccessible (only the part under the skirt is accessible), the technical solution of using waveguides was chosen. These waveguides, metal rods, acoustically connect the wall of the spherical tank to the sensor, which can then be transported outside the embankment.

2.2. Laboratory tests on a plate / control procedures

In order to quantify the number of waveguides to be used on each spherical tank, acoustic waves attenuation measurements have been carried out on a steel plate similar to that of spherical tanks (same grade, same thickness) covered by the same corrosion-resistant coating. These tests necessitated the building of a sarcophagus, to submit the plate to the contact with the sand.

Thus, these measures are close to the final conditions of the spherical tank under embankment.

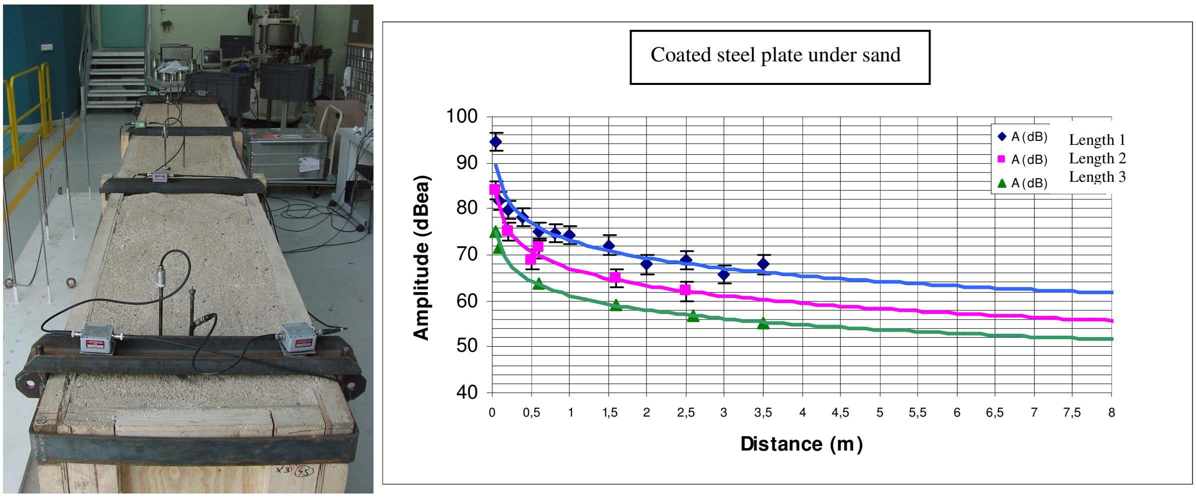


Figure 2: Laboratory tests on a plate in a sarcophagus filled with sand - Result of attenuation measurements

From these attenuation measurements, and taking into account the length of the waveguides required for different depths of burial, a configuration was calculated, which should allow a 100% monitoring 100% of the wall of each spherical tank.

Finally, 98 sensors were implanted in every spherical tank, including 74 requiring the use of waveguides. The length of the waveguides varies from 1 m to 10 m.

Given the fact that waveguides are welded to the spherical tank, many technical issues have been taken into account:

- Material constituting the waveguides - durability, weldability;
- Form of waveguides (diameter, shape of the ends, minimum radius of curve, ...) that may impact on the propagation of acoustic waves;
- Method of attachment to the spherical tank, welding procedure;
- Protection of waveguides;
- Impact on Cathodic Protection;
- …

All these technical issues have been treated to ensure the durability of each structure and its monitoring system.
For example, the impact of the presence of waveguides on the efficiency of the cathodic protection has been studied, when a sheathing incident would occur. Simulation calculations, performed with the software-CETIM PROCOR can conclude that the impact would be limited in the area of the defect in question, and would only disturb very slightly the overall current cathodic protection [1]. The risk of degradation of the spherical tank would be very low.

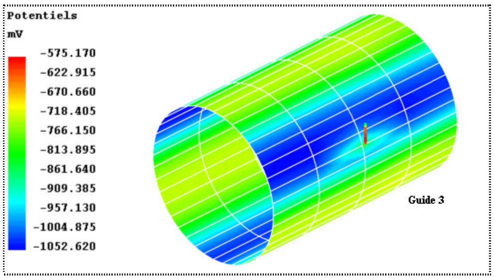


Figure 3: Result of cathodic protection potential calculation, in the presence of waveguide unprotected on a cylindrical pressure equipment (Procor software)

2.3. Acoustic Emission Monitoring of initial hydraulic tests

The initial hydraulic tests of each spherical tank were followed by acoustic emission. For this operation, the waveguides were not in their final configuration. Only the first part of each waveguide was welded to the spherical tank. Beforehand, each weld has been previously checked to ensure the quality of the mechanical link and the absence of defects which could degrade the performance of acoustic waves transmission.

Each test has been conducted in accordance with a control procedure drafted following the recommendations of the AFIAP / GEA Good Practice Guide for Acoustic Emission control of pressure equipment (2004 Edition) and CODAP ® 2000 (pressure vessels construction code and its annexes, in particular acoustic emission (IA.9 and IA.10)).

The acoustic emission monitoring of each hydraulic test requires a lot of tasks :

- Installation of the 98 sensors, wiring,
- Checking the sensitivity of sensors,
- Attenuation measurements under the conditions of hydraulic test,
- Verifying the location,
- Pressurization test,
- Post-test instrumentation checking,
- Analysis of data recorded.

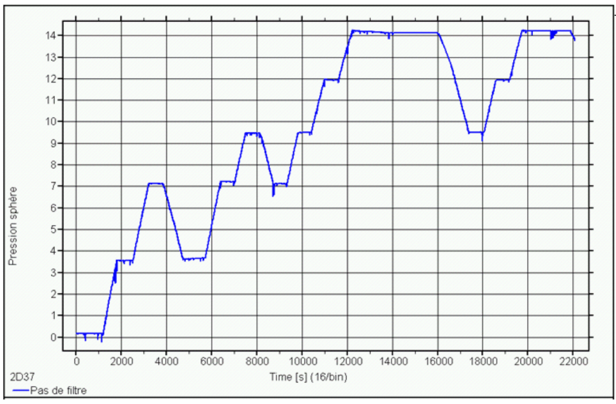
Figure 4: Installation and sensitivity checking of the sensors by a qualified operator – AE System VALLEN AMSY-5 104 channels

The configuration defined by the CETIM, calculated for optimal monitoring in planar location mode, has highlighted during the hydraulic tests, many areas or active regions (acoustic activity is generally important during an initial sollicitation). A detailed analysis of the acoustic behavior of each of these indications, its correlation with the stress applied, supplemented by further investigations conducted after the test have allowed to identify different origins in this activity:

- Friction between different mechanical elements,
- Relaxation of residual stresses present in some welds
- Presence of emissive defects ;

All these information are recorded, and will serve as 'reference image' for future requalification tests.

Overall, the 4 spherical tanks exhibit the same behavior, characterized by areas or regions most emissive located either at the skirt of the spherical tank, or at taps, feet or decks located on the upper cap, either at welds.



Voie	N1S /zone	N2S /Zone	N3S/Zone (En bleu : Palier de 10 minutes, dont pris en compte [2 min; 10 min]; En rouge : Paliers de 30 minutes dont pris en compte [2 min; 10 min]													Act.	Int.	Rf	Classe Finale
			3,56 Bars n°1	7,12 Bars n°1	3,56 Bars n°2	7,12 Bars n°2	9,50 Bars n°1	7,12 Bars N°3	9,5 Bars n°2	11,97 Bars n°1	14,25 Bars n°1	9,50 Bars n°3	11,97 Bars n°2	14,25 Bars n°2	Classe Interm.				
1	610	18		8		1	13		13	18	20	1		11	2	2	1	>1	2
2	610	10	1	13		4	11	1	7	11	13	1		8	2	2	1	>1	2
3	830	31	5	6	1	5	17		9	23	21	2		13	2	2	1	>1	2
4	760	31		4		2	11		10	14	15	3	4	11	2	2	1	>1	2
5	195	6	1	1			6		2	5	7			2	2	2	1	>1	2
6	310	5					2		3	15	10			12	2	2	1	>1	2
7	255	9	1	1		1	3		3	8	9			1	2	2	1	>1	2
8	260	10		2		2	1		4	11	6			7	2	2	1	>1	2
9	505	16	1	5		2	5		5	11	16			14	2	2	2	>1	2
10	570	22		3		4	10	1	8	20	13			12	2	2	1	>1	2
11	230	7		1			2		3	4	7			7	2	2	1	>1	2
12	610	21		4		2	13		5	15	35			19	2	2	1	>1	2
13	690	45	7	13		7	13	2	9	21	25		1	13	2	2	1	>1	2
14	165	11	4	2			2		2	5	6	1		8	2	1	1	>1	1
15	160	8				3	1			5	10	2		4	2	2	1	>1	2
16	130	7		3			5		1	5	9	1	1	3	2	1	1	>1	1
17	280	16	2	5		2	5		4	10	7		1	3	2	2	1	>1	2
18	1295	29	8	8	2	12	16	1	14	46	45	2	1	28	3	3	1	0,99	3
19	550	15		5	3	4	11	2	6	11	12	4	4	12	2	3	2	>1	2
20	500	8		4		2	13	2	7	13	9		1	9	2	2	1	>1	2
21	350	10	1	3		5	6		6	12	9			2	2	2	1	>1	2
22	400	50	2	5			18	5	9	24	21	2	3	8	2	1	1	>1	1
23	515	26	3	10	1	9	12	5	9	21	22	1	1	7	2	2	2	>1	2
24	620	30	2	13	3	9	11	3	10	13	26	2	3	14	2	3	2	>1	2

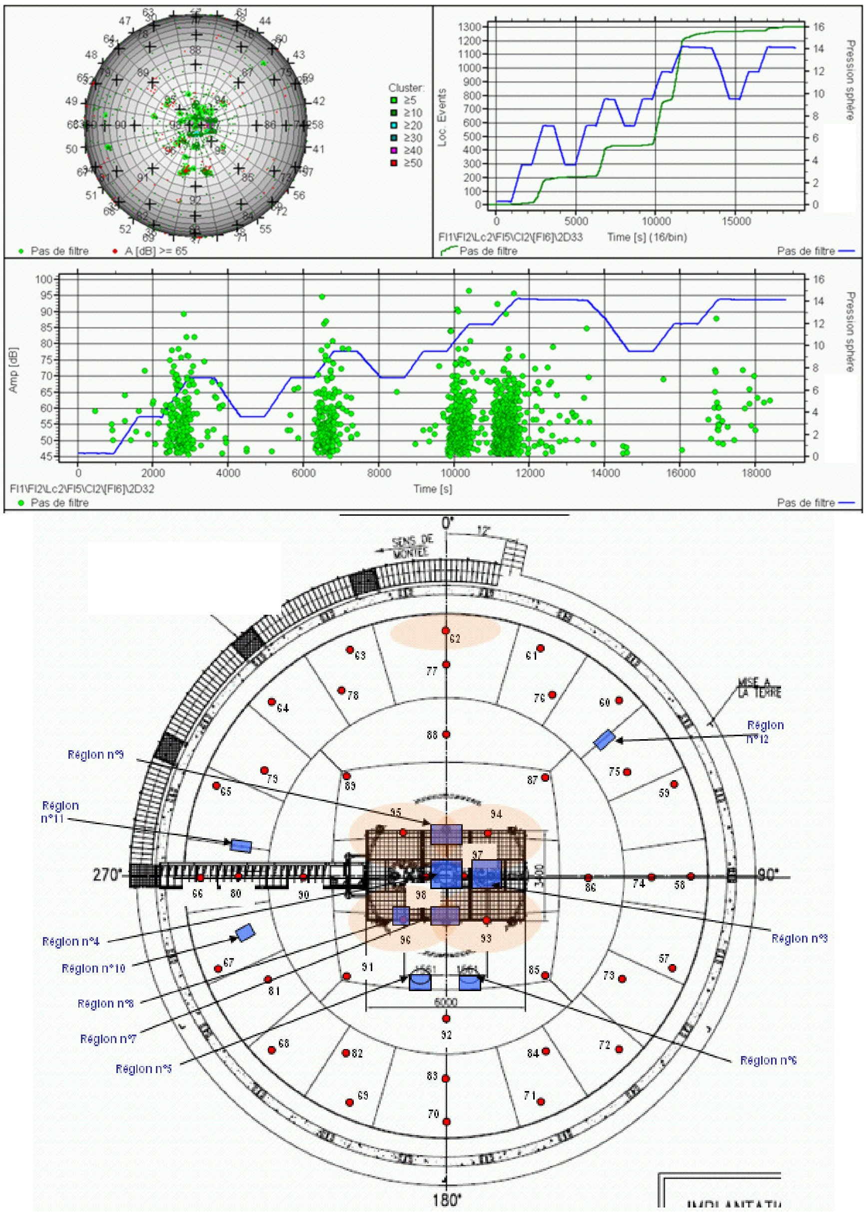


__Figure 5: Results of an initial hydraulic test followed by acoustic emission__

o Pressure cycle applied to the spherical tank o zonal analysis table (partially)
o Analysis of acoustic activity shown on the upper half of a spherical tank
o Schematic summary of the acoustic activity on the upper half of a spherical tank

2.4. Checking the waveguides extension operation before silting

The initial hydrostatic test passed successfully, the next step is to extend the waveguides, so they are in their final configuration before the silting of the spherical tanks. This requires expertise and methodology, since it involves welding, protecting and securing waveguides.

To validate this, the acoustic continuity between the wall of the spherical tank and the end of the waveguide is verified using a portable measuring device (PDA based acquisition system), developed by CETIM for this application, according to a specific procedure. This measure is always based on the detection of Hsu-Nielsen sources, generated on the wall of the spherical tank.

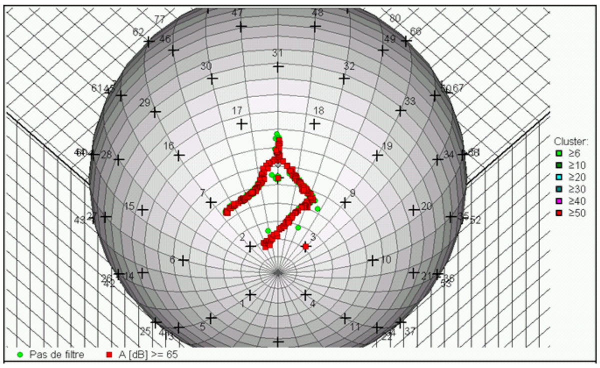
Figure 6: Final installation of waveguides - This operation is performed throughout the phase of silting of each spherical tank; On the right of the picture, the wall of the spherical tank; on the left, the concrete wall, on which are attached waveguides

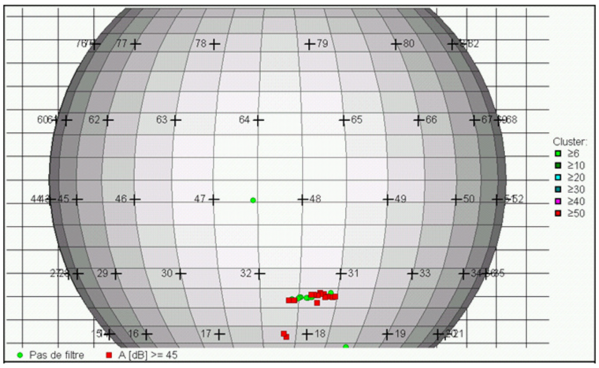
This operation, which follows the phase of silting of each spherical tank (because the waveguides are welded as and as the sand level rises), requires responsiveness and availability of technicians to adjust their schedule. It is however essential to verify that the waveguides ensure their function of transmitting acoustic waves from the wall of the equipment to their end.

2.5. Validation tests in the final configuration

The sanding operation being completed, each structure is covered with a wall of concrete slabs.
On the periphery of the structure, the ends of the waveguides remain accessible in order to install acoustic emission sensors for periodic inspection. CETIM has developed special sensors for this application, integrating a holding device on the head of the waveguides.
In order to validate the waveguides-based control system, a final series of tests aimed to verify by experiment the ability to detect a potentially emissive source on the structure in its final configuration.
To do this, Hsu-Nielsen sources of acoustic emission were generated inside a spherical tank, in the accessible parts, that is to say from the bottom to a level higher of about 3.5 m than the skirt and in the top part.
Analysis of data from such a configuration control requires a post-treatment if one wishes to interpret signals correctly, and if you want to locate the original source by triangulation or by area. Indeed, the propagation of acoustic waves in waveguides induces different 'delay' depending on the length of the waveguide. In the first to have used waveguides on this type of structures, CETIM has been at the origin of the development (by VALLEN) in 2003, of a specific software correcting the data recorded by post-treatment.

Figure 7:
Intervention by a CETIM technician for the placement of sensors and their verification
View of several waveguides ends;





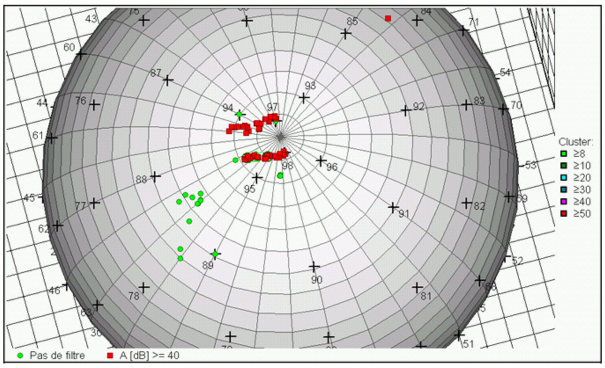


Figure 8:
Results of localization obtained using the acoustic emission system in its final configuration (sensors placed at the end of waveguides)
Top left: lower cap
Top right: Weld located above the skirt
Left : upper cap

After correction of the data and analysis, we have established the following conclusions:
The acoustic emission monitoring system allows complete coverage of the spherical tanks in planar location under certain acquisition requirements. The use of waveguides can also provide the system performance stability over time, since no degradation should intervene, thanks to the design of all elements in place, and recommendations made to the end-user of the vessels.

CONCLUSIONS

Subject to new environmental constraints for several years, large tanks of gas or other hazardous materials must be protected, usually by a bank completely covering the equipment or a sarcophagus in which it is placed. Consequently, the resistant wall of this type of equipment is no more accessible for periodic inspections.
As a compensatory measure to the problem of accessibility, acoustic emission is the main solution, since, as a global method of control, it allows a 100% diagnosis of the structure during hydraulic or pneumatic pressure tests, performed at each term of requalification, or as prescribed by the owner.
The example developed in this article illustrates all the stages of implementation of the acoustic emission technique, from laboratory study to final qualification tests.
This project is remarkable for its size, as these 4 spherical storage tanks of 4000 m3 each, required the implementation of nearly 400 acoustic emission measurement channels. This is one of the largest projects of this kind conducted by the CETIM, in collaboration with all stakeholders in this project over a period of 18 months for acoustic emission part.
It is important to note that, besides the fact that the system put in place aims to ensure the diagnosis of spherical tanks for the upcoming requalification terms, acoustic emission has been an additional means of control during the initial hydraulic tests, to obtain a reference signature of each device.
With his many experiences in such applications, CETIM has demonstrated that this technology, if it is under control, can be integrated without major obstacles to industrial projects of this type, or more widely to monitor any inaccessible structures.

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[1]. Developpement and use of NDE Methods on pressure equipment : Industrial Experience in applying acoustic emission, M.Mediouni, J. Catty, C. Herve and M. Cherfaoui, ECNDT 2006, Berlin, September 2006.