Field Experience from Fiber Optic Ammonia and LNG Leak Detection Systems Installations

Distributed fiber optic temperature sensing system is a unique tool for the detection and accurate localization of small ammonia or LNG (Liquefied Natural Gas) leaks on pipelines that can reach ten kilometers or more. Such distributed temperature sensing (DTS) systems have the advantage of being easy to deploy over long pipeline sections and have been shown to detect leakage events with good accuracy and reliability. This paper will present the experience gathered from ten ammonia and seven LNG leak detection installations, including examples of real accidental leaks that were detected using the fiber optic system. Reliability and availability data based on the use of the ATTS will also be presented along with information on the rate of undesired alerts and results of a SIL 2 rating analysis. Based on those field experiences, we finally formulate recommendations on the installation of the sensing cable, the alarm settings and the deployment process, to guarantee reliable results while reducing interference with day-to-day plant operations.

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Introduction

Recent developments in distributed optical fiber temperature sensing techniques provide a cost-effective tool that allows monitoring over long distances (up to 80km) with high spatial resolution (typically every meter). Using a limited number of very long sensors it is now possible to monitor the behavior of pipelines with a high measurement speed at a reasonable cost. Unlike electrical and point fiber optic sensors, distributed sensors offer the unique ability to measure temperature along their entire length. This capability allows the measurement of thousands of points using a single transducer. Using this technology, it is possible to detect leaks from liquefied ammonia and LNG pipelines by observing the characteristic temperature drop associated with such leaks. After a comprehensive testing and qualification phase [1, 2, 3] several systems are now permanently installed in real operating leak detection installations.

In this paper we will review the experience gained from those installations and provide recommendations for future similar installations.

Leak Detection with Distributed Fiber Optic Temperature Sensors

The most developed technology of distributed fiber optic sensors is based on Raman scattering as described in more detail in [3].

The typical components of a distributed temperature sensing system are the following:

- Sensing cable to be installed along the pipeline.
- Interrogator.
- Multiplexer to allow multiple fiber optic cables to be measured from one interrogator or to provide interrogation from both ends of the same cable for redundancy.
- Data analysis software for automatic detection of leaks.
- Relay module used to transfer alarm information to other plant control systems (e.g. to initiate automated emergency shutdown sequence).
- SCADA Interface.
- Automated Trip Testing System.
- User graphical interface that shows the exact location of a leak.

Figure 1: Fully redundant leak detection system

A typical rack cabinet containing two fully redundant is shown in Figure 1, while Figure 2 illustrates a typical cable installation. Figure 3 shows the graphical user interface, providing information about pipe route and leak location.

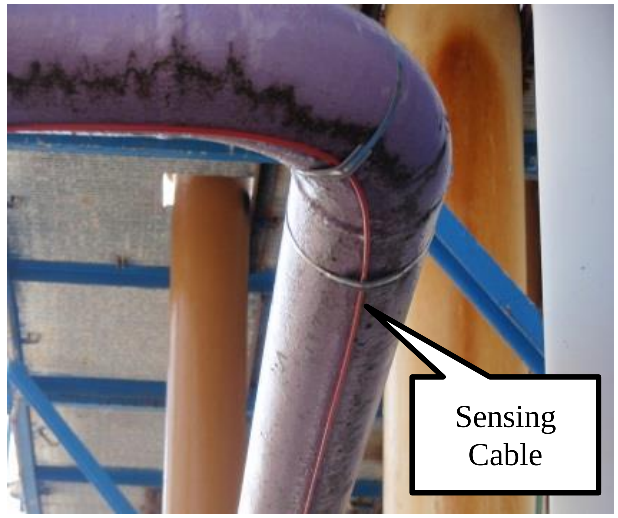

Figure 2: Red cable installation under pipe

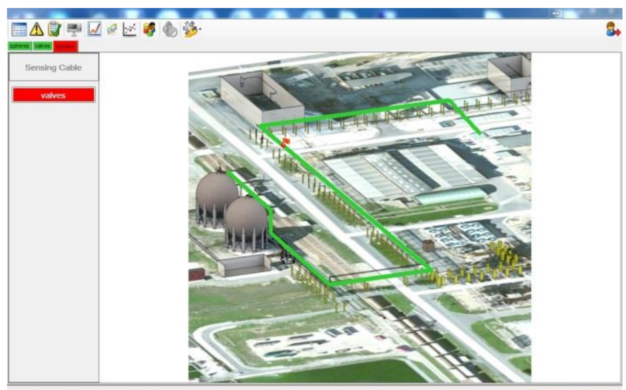

Figure 3: Example of user interface showing location of event, e.g. leak detection

The basic principle of pipeline leak detection through the use of distributed fiber optic sensing relies on a simple concept - when a leak occurs at a specific location along the pipeline, the temperature distribution around the pipeline changes. In the case of Ammonia and LNG, we observe a rapid and localized drop of temperature

Automated Trip Testing System

One of the most effective tools to insure an high level of availability is the addition of an automated testing system. The ATTS (Automated Trip Testing System) is a device, fully independent from the data acquisition system, which can create an artificial leakage along the sensing cable and verify the correct response of the alert system (see Figure 4). Every hour, the ATTS automatically cools or heats 1m section of optical fiber at a rate similar to the one observed in the case of real leakage and observes the signal coming from the relay module to verify alarm triggering. A PLC (Programmable Logic Controller) is used to verify that for each testing cycle initiated by the ATTS, a corresponding alert is raised by the DTS. This configuration allows a higher level of self-diagnostic capability and insures that any issue in the system is rapidly detected.

This system configuration, including DTS, Multiplexer, sensing cable, relay module, leak detection software and ATTS, has received a SIL 2 certification with the following parameters:

Safety Integrity	SIL 2
"hazardous" failure rate (revealed)	$7.73\ 10^{-6}$ per hour
"hazardous" failure rate (unrevealed)	$0.12\ 10^{-6}$ per hour
"safe" failure rate (revealed)	$0.47\ 10^{-6}$ per hour
"safe" failure rate (unrevealed)	0
Diagnostic Coverage	98%
Safe Failure Fraction	>98%

The failure rate was evaluated in respect of the following failure modes:

- In response to a valid temperature condition at the fiber cable, failure to deliver a loop disconnect output (open relay)
- Despite no valid temperature condition, deliver a loop disconnect output (open relay)

The rating assumes that the user can recognize the hourly "healthy" signal generated by the ATTS, by means of some logic function and to provide and act on a positive alarm in the event of no diagnostic signal. Thus, all failures within the ATTS, and those within the MUX, can only result in loss of hourly diagnostic function which, in itself, should be treated as a revealed failure. Failures not revealed by the use of ATTS are assumed to be revealed by an annual proof test which also covers the diagnostic features.

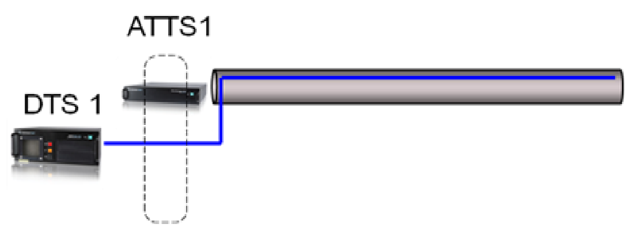

Figure 4: Example of simple leak detection system with additional self-testing capability

The overall integrity claim, which derives from the very high diagnostic coverage obtained, supports this safety-integrity assessment. As a consequence, both the unit and the simulated-based diagnostic unit must be subjected to the annual periodic proof test.

Field Installations

The leak detection system described in the previous chapters has been installed in a number of plants in Europe, as illustrated in the following tables.

Ammonia pipelines

Plant	Country	Year of install.	Approx. length of pipe	System configuration
Yara Ravenna	Italy	2006	5 km	2 x basic
Yara Le Havre	France	2010	10 km	2 x fully redundant
Yara Montoir	France	2013	2 km	1 x fully redundant
Yara Pardies	France	2013	1.5 km	1 x basic + ATTS
Yara Ambès	France	2014	2 km	1 x fully redundant
Borealis Grandpuits	France	2013	2.5 km	1 x fully redundant
Borealis Ottmarsheim	France	2010 pilot project	0.4 km	1 x basic (pilot test)
TOTAL			**23 km**	**14 systems**

4.2 LNG pipelines and tanks

Plant	Country	Year of install.	Approx. length of pipe	System configuration
LNG plant pipe	USA	2006	undisclosed	Ad-hoc
LNG Jetty pipe	USA	2007	2 km	Ad-hoc
LNG pipe	USA	2008	undisclosed	Ad-hoc
Grain Terminal LNG pipeline	UK	2008	4.5 km	1 x fully redundant
LNG transfer hose monitoring	France	2009	2 km	Ad-hoc
LNG tank	France	2015	1 km	1 x basic
LNG transfer line	France	2016	4 km	1 x basic + ATTS
TOTAL				**7 systems**

Learnings

For confidentiality reasons, the return of experience described in the following chapters will not make reference to a specific site, but rather summarize the lessons learned across all projects.

Detected leaks

Fortunately, none of the instrumented plants has suffered any major ammonia or LNG leak since installing the fiber optic detection system. There have been however two cases where a minor leak was detected.

The first instance concerned a very small leak from a bolted joint that was discovered during the commissioning of one of the systems. The leak was correctly identified by the system and was later confirmed by visual inspection. This leak was well below the minimum leak rate that requires immediate action.

A second occurrence concerned a coupling to a transportation vessel that leaked during an ammonia transfer operation. Also in this case the leak was correctly identified by the system and an alert was generated. The ammonia transfer was stopped and resumed after fixing the issue. Figure 5 shows the temperature evolution at the location of the leak. It is possible to observe how the temperature dropped from an initial value of about 20 °C (ambient temperature) to about -40 °C due to the leak. The location of the leak can be clearly identified at meter 887, but a larger section of cable is affected by the cooling effect of the ammonia evaporation cloud.

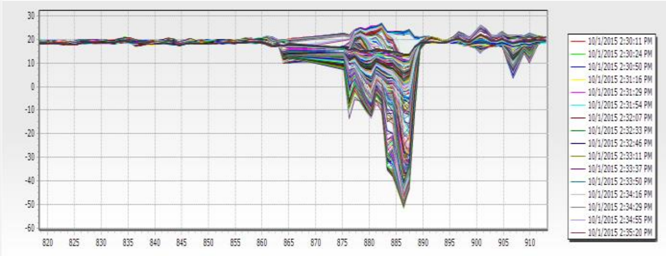

Figure 5: Temperature distribution along the sensing cable during a leak

The time evolution of the temperature at the leak location can be observed in Figure 6.

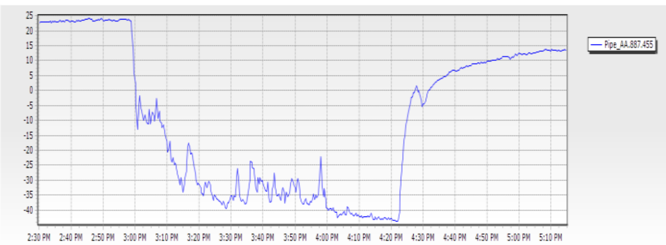

Figure 6: Temperature evolution at the location of the detected leak

Availability

Availability data from the sites were evaluated to quantify the reliability of the different components of the leak detection system. At the time of writing, the 14 systems that are in operation have added up 34 years of operation, with an average of 2.4 years per system. The recorded mean time between failures (MTBF) of the individual sensing components was evaluated to 8 years. The failure and/or maintenance of the individual sensing components (interrogator, ATTS, server) have prevented operation of the 34 systems for a total of 0.9 years, corresponding to an uptime of 97%. Considering only redundant system the uptime was 99% (with at least one of the two redundant systems available).

ATTS data

Figure 7 shows an illustration of temperature recording at the location of the cooling zone as a function of time. It can be observed that with an hourly frequency the apparition of the cooling peak is easily observable.

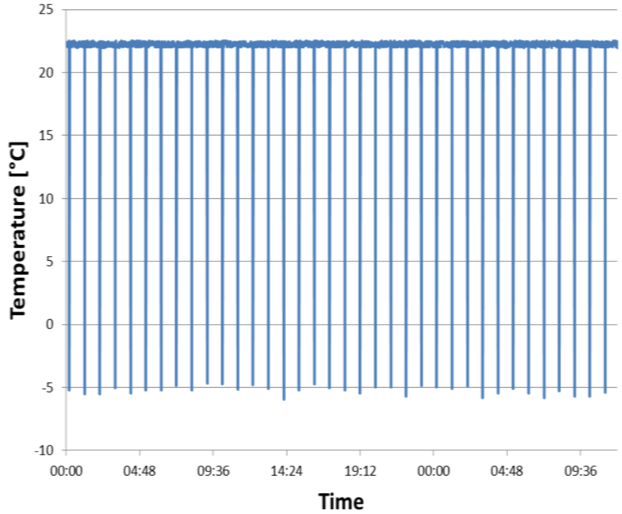

Figure 7: Example of ATTS temperature recording at the cooling location

Once hundreds or thousands simulated leakage events are generated, it becomes possible to calculate the probability of answer on demand (% of successful detections) and generate statistics on the reaction time (average and maximum delay). For example, a confidence level of 2 requires that 99% of the simulated leaks are correctly detected.

The data from the installed ATTS systems corroborates the availability data presented in the previous paragraph, respectively 97% for individual detection systems and 99% for redundant systems. When the systems were in service, the ATTS triggered an alert in 99.9% of the tests, demonstrating the high reliability of the ATTS device itself. Those results confirm experimentally the high availability expected from a SIL 2 certified system compliance.

False alerts

There have been no reported cases of false alerts, where an alarm was triggered without a corresponding temperature drop. There have, however, been numerous cases of false positives where unforeseen circumstances have triggered a "true" alert that did however not correspond to a real ammonia leak. The main causes of such false positives were the following:

- Trigger levels: temperature changes that would trigger an alert were initially set too aggressively and have generated false positive due to temperature variation induced by normal plant operation or weather conditions. After an observation period, the trigger levels were re-assessed and optimized to eliminate such false positives.
- Singular points: at some locations, extreme temperature changes were recorded due to external events. Examples include nearby fast cooling devices or vapor blows that would heat and cool the sensing cables. Those localized points were easily spotted by observing how false positives cumulated at the same location. It was then easy to correct those points by physically shielding the cable from the disturbance or adjusting the trigger levels of those isolated points.

Other encountered issues

The main obstacles that were encountered on the path to a successful deployment of ammonia leak monitoring system were organizational rather than technical. One common challenge in many sites concerned the transfer of system ownership from the project team to the operational team. In some cases this transfer did not occur with a sufficient training of the final operators. That caused misunderstandings on the way the system works and result in false expectations and the system sometimes became “orphan” since nobody was really taking ownership of it. In such cases it is possible that alerts generated by real leaks or warnings about failed components gets un-noticed. To avoid such misunderstandings, it is recommended to involve the production and maintenance teams from the beginning of the project and carry out in-depth training of all shifts to make sure the system functionality is properly understood.

In some other cases the opposite problem arose, when the system was transferred too soon to exploitation, before the initial false positives were completely eradicated, causing a general mistrust in the system that had to be reversed later on. In general, most safety systems that have no direct benefit on the day-to-day plant activities need to strike the right balance between staying out of the way of normal exploitation and not becoming forgotten and abandoned.

In two other sites, damage to the cable was caused by insufficient training of the maintenance personnel. They simply did not know how to handle the sensing cable if they need to service components supervised by the ammonia leak detection system. An early involvement of the maintenance staff is therefore highly recommended. At another site, the maintenance team was able to inform us about the most usual maintenance interventions that can affect the pipe and ancillary devices. It was then possible to install some extra length of cable at those locations to allow displacing the sensor and easing future maintenance.

Conclusions

The large number of field deployments of fiber optic based ammonia and LNG leak detection system has allowed learning valuable lessons on the technical and organizational sides. It was possible to improve the reliability and availability of the systems by implementing automated self-testing capabilities. The data gathered by the 14 systems currently in operation show an availability of 97%. All cases of non-availability were quickly identified so that they can be corrected rapidly or alternative safety measures could be implemented. The system is SIL 2 certified.

By monitoring false positives and understanding what operational or environmental condition would trigger unwanted alerts, it was possible to improve the leak detection algorithms and standard thresholds so that only real ammonia or LNG leaks would trigger alerts.

Finally, the process for deploying a system to a new site is improved by involving the right project and site team and by making sure that the system is finally owned by the people using it daily. Only one real leak of significant (although very small) size was recorded and correctly set off an alert.

Acknowledgements

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