LEAK DETECTION AND LOCATION
FOR GAS TRANSMISSION PIPELINES

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ABSTRACT
For legal, economic or safety reasons, gas transmission companies must look for leaks. The most widely used leak detection method is a planned survey of the network. It can be a simple visual inspection of the pipe's environment. It can also be done with hand held gas detectors or aboard vehicles. New methods are being developed to improve productivity. The most promising are those based on the absorption of methane in the infrared which can be airborne. The first one is based on lidars that scan the pipe and measure the backscattered light. New lasers will permit great sensitivity for gas detection. The other is a camera measuring the absorption of the light emitted by the ground.

On-line detection exists, but it is seldom used nowadays. The rare onshore applications use the data collected by SCADA systems that are processed by more or less sophisticated statistical methods. For off-shore applications, many systems are currently used: acoustic gates, echography or hydrophones. Promising new developments by many companies are under way. The first that has shown good results is based on the vibratory waves emitted by a leak. Acoustic waves can also be used.

PREAMBLE
In most European countries, leak detection for transmission networks of gas has more to do with regulations than with economical reasons or even with safety. Almost every accident of the past decades was due to external interferences, such as construction work. No life could have been saved had a leak detection system been in place because the casualties took place in the first minutes.

On average, 10 incidents resulting in gas leaks occur each year in France. Seventy percents of the damage are caused by excavation equipment.
Nonetheless, it is important to have on hand methods for detecting and locating leaks should it be necessary to authorize transmission pipelines in sensitive zones or should changes in regulations occur. Some of the methods that were developed for gas distribution can be used. But for the Gaz de France transmission network, a leak detection system would completely fulfill the needs only if it was coupled to a system able to detect incoming digger before the leak actually happened1.

LEAK SURVEY

Except for those provoked by external aggression and very few others, most leaks are very small. Thus a planned survey of the network is usually enough.

Classic

Visual Survey, It is often a simple visual inspection of the pipeline's environment. It can be done by air or by a team walking along the pipeline. Its main aim is to verify that no new building or tree can deteriorate the pipe. But it can also discover leaks that have dried up the soil by their effect on the vegetation.

Survey with Gas Detectors, It can also be done by a hand held gas detector or aboard a vehicle. For many pipelines, walking would consume too much time. Moreover, Flame Ionization Detectors in leak survey vehicles are often too sensitive to shock to be used along transmission lines. Gaz de France is developing a new optical vehicle that should be able to survey transmission networks.

New ways

But new methods are being developed to improve productivity. The most promising are those based on the absorption of methane in infrared and which can be airborne.

What has been done. The first is based on lidars that scan the pipe and measure the backscattered light. The first trials of those methods, for example by the American Gas Research Institute (GRI), using pulsed lasers weren't really successful. But new lasers will permit considerable sensitivity for gas detection. The main disadvantage is the price of the device.

The other is a camera measuring the absorption of the light emitted by the ground by a methane cloud. This method is less sensitive but also less expensive. That technique works well with propane and butane.

What could be done in the near future. Thanks to the works of Defence contractors both in Europe and America, cameras with better optics and signal processing offering good sensitivity have been developed. They can detect a few ppm2 of gases. Gaz de France is

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1 Another paper, "Technics for Preventing Accidental Damages to Transmission Pipelines" tells you more about the subject when it is not related to leak detection.
2 Parts per million
testing cameras to survey its GNL terminals. If the results are good enough, they could be used on a plane to survey the transmission grid.

"REAL TIME" LEAK DETECTION

"Real Time" in this case is fast enough for detection time to be lesser than intervention time. It is seldom used nowadays because not many transmission lines are equipped with the motorized shut-off valves needed to take full advantage of a fast response.

Off-Shore

Off-Shore is different because of the size of the investments and the risks taken. Following the Piper-Alpha disaster, many companies started leak detection project. Many systems are currently used:

- Acoustic gates. They work like garage gates. An acoustic beam is created between two points. It detects gas bubbles that cross the beam. Its range is limited by the curving of sound waves in water.
- Echography is slightly different from the previous method. It is basically a sonar locating gas bubbles. Its range is also limited.
- Listening to the sound of bubbles is the simplest way of detecting gas leaks but requires a large number of hydrophones (more than one per 100m (100 yards)).

Nowadays, none of those techniques appear simple and cheap enough to be used widely. Furthermore, the physical principles are typical of submarine conditions and cannot be extended to onshore applications.

What has been done onshore

The rare onshore applications use the data collected by the SCADA systems that are processed by more or less sophisticated statistical methods. These systems give good results for liquids but are less efficient for gas. Only leaks of at least a few percents of gas flow are detected, and the leaks are detected within response times of several minutes.

Moreover, when you are interested in detecting small leaks, you can get a lot of false alarms. A few pipelines in France which used this leak detection technique decided to shut it off.

What can work

A few techniques have shown good results even for small leaks. Some of them can be used to prevent third party damages as well.

Fiber Optic Sensors. Many kinds of fiber optic sensors have been developed in recent years. Theoretical papers and a few experiments have shown that it was possible to detect leaks with a temperature sensor. Although distributed temperature sensors have been commercialized for some time, we don't know of any installed systems. Gaz de France demonstrated the technical feasibility of such a fiber for detecting leaks in a GNL terminal, but the system has not yet been installed.
Acoustic and vibration sensors also permit gas leak detection. However, they are neither as simple to use nor as robust as temperature sensors. Either the fiber is often coiled, or external devices are needed at any point where you need a measurement. The physical principles are discussed later on.

The last sort of fiber optic sensors was developed by Gaz de France for distribution networks (technical galleries, high rise buildings...). The sensor is sensitive to methane and to higher hydrocarbons and can detect concentrations in the LEL\(^3\) range. The fiber is a bus system of sensors supporting a finite number (less than 250) of distributed points of measurement on distances up to a few tens of kilometers. The optical sheath of a fiber is locally and partially replaced by a polymer. This sensor relies on the principle that the refractive index of some polymers varies in the presence of gas. Unlike most other extrinsic sensors, the sensitive part is quite compact. The system is interrogated by OTDR\(^4\).

As shown on the diagram, when no gas is present the light pass through the coupling device undisturbed. The presence of gas allows some light to pass from one fiber to the other one terminated by a mirror. The time between light emission and reception gives the position of the leak.

However, this method has a few drawbacks. The interrogating device is quite expensive, but the same reflectometer can be used for several fibers by multiplexing the optical signal.

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3 Lower Explosive Limit.  
4 Optical Time domain Reflectometry.
and thus adding to the length of pipe thereby controlled. An efficient way to realize many sensors has still to be found.

**Vibratory Methods.** Due to problems encountered with existing methods, especially for small leaks, many companies have developed leak detection methods based upon entirely different physical principles. The first which has shown good results is based on the vibratory waves emitted by a leak and transmitted to the pipe walls. Those methods can also reliably pinpoint leaks with good precision. A few systems have been installed with seemingly good results.

However, its major drawback is due to its limited range. The attenuation of the signal is important and at least two sensors are needed per kilometer (three per mile). This method could be interesting for Gaz de France only if we can prove that it is able to detect approaching construction work that would be potentially hazardous to the pipe’s health. No work has been done yet on this subject.

**Acoustic Methods.** Acoustic methods are closely related to the former. They are based on the sound emitted by a leak directly into the fluid. The most widely used was developed for water companies in the 1970s. The acoustic waves are propagated at a known speed. They are therefore well adapted to the development of a method which pinpoints the leak from the extremities of the leaky section by correlating the signal of two microphones.
Leak detection applications have been installed to check the security of water pipelines in France for some years. For gas, this method has been tested by METRAVIB on a Gaz de France network. Leaks of 6mm (1/4") in diameter were detected and located on a 6km (4 miles) section of a transmission pipeline. Previous trials of this method had shown that it was able to detect leaks on distances of up to 20km (12 miles). Theoretically, the farther apart you are, the bigger the leak must be in order to be detected.

Gaz de France tested acoustic correlation for distribution networks. We installed microphones on the customer connections and listened to the gas pipes. The results obtained from a simulated leak facility were less good than numeric simulations but remained usable. Test campaigns on operations on urban gas networks have nonetheless shown that the method was very sensitive to parasite noises, especially to the noise produced at a precise location. The problem would be the same for urban transmission networks.

A collaboration between Gaz de France and METRAVIB RDS has been created in an effort to overcome these difficulties. Theoretical studies have been carried out to come up with a method especially designed to solve this problem by using the characteristics of the acoustic waves produced by a gas leak more thoroughly. The results obtained allow the location of up to two noise sources transmitting into a pipe between two microphones. More generally, leak detection with this method is less sensitive to ambient noise and thus distance between microphones can be increased.

This method needs only two sensors for several miles, but requires a bigger bandwidth to transmit information. It is currently used by Gaz de France to locate leaks on its distribution network. Leaks which should occur in a slip-lined network or under concrete pavement are usually very difficult to locate. It is therefore worthwhile for Gaz de France to use a method that is independent of subsoil geometry and which can be used on every type of network as a complement to standard pinpointing techniques.

It could be used for transmission in France if it can detect approaching construction work or for surveying sensitive parts of the network. However, this method is more likely to be used by Gaz de France in countries where leaks are more frequent and have bigger financial consequences.

CONCLUSION

Several methods for detecting leaks have been investigated, and some of them ready to use or simple declination of existing solutions. For leak detection alone, the benefits would be
small for the Gaz de France transmission network. Most leak consequences are either too quick or too small to justify a leak detection application.

However, if leak detection can also help to prevent external damage by a third party, the interest would be huge. Much additional work is needed to confirm the possibilities. Interest in the outcome makes it worth the effort.

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