



Pipeline Leak Detection and Theft Detection Using Rarefaction Waves

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Abstract:

The paper describes the principles and trial results of a new pipeline leak detection system based on the detection of rarefaction pressure waves associated with a leak. A unique method is used to differentiate leaks from operational changes to avoid false alarms. The method is based on the analyses of three-dimensional pressure maps proven successfully in more than 100 real leak trials on 5 different pipelines carrying water, crude oil, jet fuel and on 2 multi-product multi-batch pipelines. The trials were carried out successfully with the pressure sensors spaced from 3 km to 200 km. Operation conditions include severe transients, steady state, shut-in conditions and slack-flow. The results show sensitivity better than 1% of nominal flow for all the tests, and the detection of very small leaks which are measured in litres.

The system was further developed for use in hydro-testing of buried pipelines. This new application of the technology has proven to be an excellent tool for the detection and location of existing leaks, leaks which were already present before the installation of the LDS system. This feature also works in flowing lines allowing the detection of existing leaks and very slow opening leaks which makes it perfect for the detection of pipeline thefts and for the retrofitting of LDS systems in general.

1 Introduction

The significance of pipeline leak detection has increased over the past 10 years. Public and political intolerance to large leak events have increased the scope and cost of the associated liabilities. This upward trend is likely to continue and in most cases there is a direct relation between the liability cost of a pipeline leak and total volume of the spill.

The total amount of product spilled due to a leak is influenced by many factors, some relate to the pipeline itself, such as throughput or the position of the leak in relation to the elevation profile. Other factors are related to the level of automation and leak detection system. The most important factor affecting the performance of pipeline leak detection are described in the API 1130 standard, one in particular “reliability” has been a major concern for many in the industry.

Many systems with poor reliability are not relied upon, were totally or partially deactivated and many were replaced. The fact is: A Leak Detection System (LDS) with poor reliability is not able to assist the operators to prevent a major leak event. In most cases only the operators can avoid a major leak event, thus they must trust the information given by the LDS.

After 15 years in the market, the statistical pipeline leak detection (SPLD) method had become the most used LDS method with some 400 systems deployed on pipelines around the world. This success is based in great part on its reliability and sensitivity.

Pipelines using LDS systems based on acoustic/negative pressure wave methods have so far been notoriously affected by high false alarms rates. This poor false alarm performance has denied the market the advantages of these methods:

- Fast detection times;
- Accurate leak location;
- High sensitivity (exceeding in some cases LDS systems based on the best flow meters);
- Freedom from dependence on flow meter performance, calibration and availability.

Over the years ATMOSi has developed and tested several different technologies based on the detection of the rarefaction wave originated from the leak. Among these technologies one method – ATMOS Wave showed an infallible ability to differentiate rarefaction waves produced by leaks from pressure signals generated by noise, transient or external interferences. This ability was translated into very low false alarm rate, similar to the one achieved by the SPLD method.

In the last two years ATMOS Wave was tested in 100 real leak trials under different conditions and fluids aiming to determine its operational envelope and confirm its reliability. The trials proved successful and the details are presented in this paper together with a discussion about the method and its sensitivity.

2 Description of the Method

ATMOS Wave is based on the detection of the negative pressure associated with a leak either generated by the onset of the leak or by the pressure instability at the leak position.

To differentiate the negative pressure from other pressure signals the new LDS method examines several aspects of the negative pressure wave front and its propagation through the entire pipeline length. Three comprehensive algorithms filter out noise, arrange the analogue pressure data into a detailed 3-dimensional map that

allows the system to clearly differentiate true leak/theft events from the pressure changes caused by transient operation.

Figure 1 summarises the 3 step process used in ATMOS Wave. The purpose built data acquisition unit – AWAS-3 collect all the analogue pressure data locally and send them to the central location for processing. In the first step the pressure signals are filtered to remove noise. In the second step a dynamic 3-dimensional picture of the moving pressure wave is generated. In the third step the algorithms identify and differentiate the leaks taking into consideration the entire pressure distribution along the pipeline and its dynamic evolution in time.

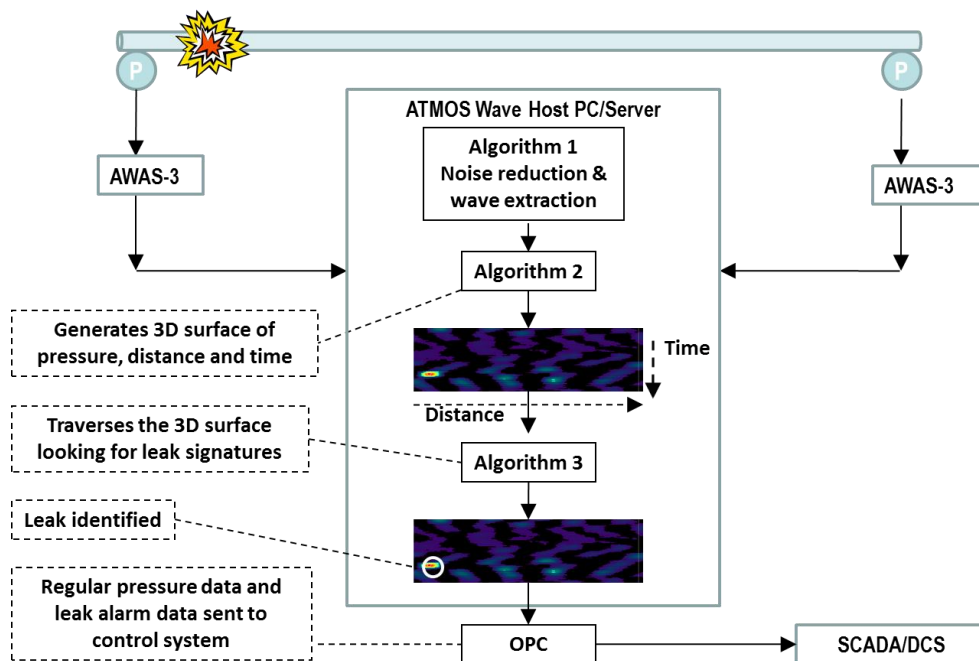


Figure 1 – ATMOS Wave and its 3 step process

Figure 1 shows the following three steps of the algorithm:

- 1) remove process noise from the pressure signals such as pump noise, extract pressure changes involved in a leak
- 2) generate the 3 dimensional probability map
- 3) Analyse the map to identify any leaks in the map, by checking the surrounding map to identify operational change on the pipeline. Calculate leak size, leak position, identify and remove false alarms. Check for leaks generated during slack conditions. Check for build up from low level thefts or leaks < 0.3%.

3 Instrumentation Requirements and Sensitivity Near the Sensors

ATMOS Wave uses high performance off the shelf pressure sensors manufactured by reputable suppliers. The pressure meters are installed to the pipelines in conventional way and connected directly to the data acquisition units (called AWAS). The AWAS units are connected to the available communication system but the meters can also be used to relay manometric pressure directly to the RTUs for process control and monitoring.

Figure 2 shows a basic set-up for installation in one pipeline with one intermediary outlet (or inlet). In this set-up the one pressure meter is used at each inlet and outlet. In this case (similarly to other Acoustic/Negative pressure wave methods), there is a zone near the pressure meters where leaks will not be detected reliably. We call this zone the blind zone. The blind zone using only one pressure sensor is approximately 1% of the distance between pressure meters. For small lines of up to a few kilometres this zone is negligible and for some longer lines it can be quite acceptable on a case by case basis. LDS will cover 98% of the distance between the meters.

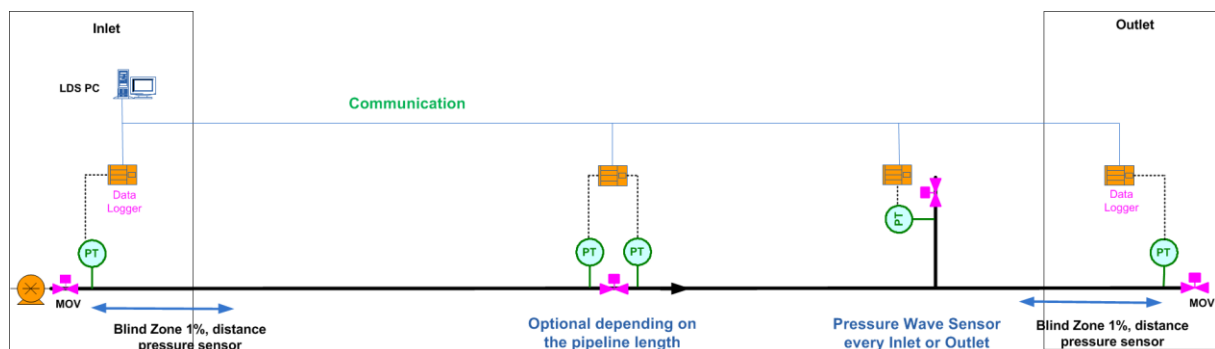


Figure 2: Set-up using one pressure meter at each inlet/outlet.

Fortunately it is possible to reduce the blind zone to a negligible value by using two pressure sensors at each inlet and outlet or by connecting the flow meter also to the AWAS. Figures 3 and 4 describe these two possibilities.

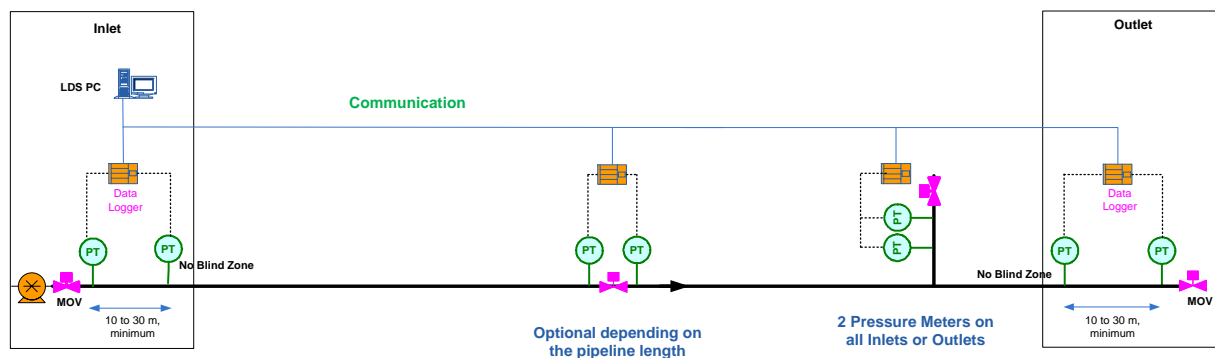


Figure 3: Set-up using two pressure meters on each inlet/outlet.

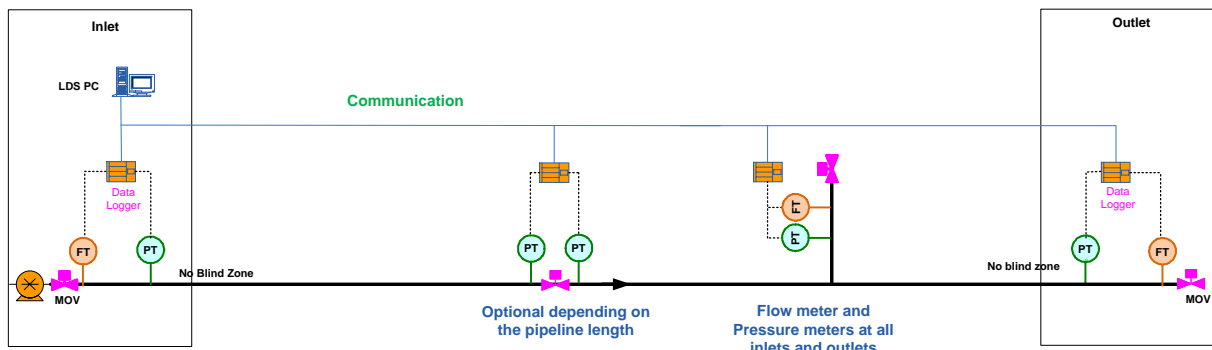


Figure 4: Set-up using one pressure meter and one flow meter on each inlet/outlet.

It is possible to combine the set ups above to suit specific project characteristics, constraints and/or requirements.

4 Field Trials Summary

4.1 Short pipelines.

2.7km, Crude Oil Pipeline

Atmos Wave pressure sensors were connected to each end of the crude oil unloading pipe. 16 leaks were generated over 2 days without Atmos staff being present. All 16 leaks were correctly identified. The system was run continuously during all loading and tanker changeover conditions with no false alarms generated.

4.2 Medium Length pipelines.

12.4 km, 6" Jet Fuel Pipeline

Distance between sensors: 12.4 km

All leaks from 0.8% to 2.6% of nominal flow were detected within one minute. Leak volumes as small as 4 litres were sufficient for the system to alarm. Most of the leaks lasted for less than 15 seconds.

Location accuracy varied from +/-30meters to +/- 300 meters for these very short duration leaks.

19km, 8" Crude oil pipeline

Distance between sensors: 19 km

All leaks from 0.1% (shut-in leaks) to 6.8% of nominal flow were detected within 3 minutes.

Location accuracy varied from +/- 90m to +/- 400 m,

4.3 Long pipelines

80 km Multi-batch Multi-product Pipeline

Distance between sensors: 80 km

All leaks between 1% to 4% were detected in 2.5 to 6 minutes .

One existing leak of approx. 0.5% was detected within 15 minutes.

Location accuracy: +/- 250 m to +/- 400 m

150km, 12" Jet Fuel Pipeline

Distance between sensors: 150 km

All leaks between 1% to 10% were detected in 2.5 to 5 minutes including during slack conditions.

Location Accuracy: +/- 150 to +/- 400 m

Location Accuracy during slack +/- 800 m

180 km, 12" dia Multi-batch Multi-product Pipeline

All leaks between 1% to 4% were detected within 4 to 8 minutes

Pre-Existing leaks were detected in 15 minutes.

Distance between sensors: 180 km

Location accuracy: +/- 250 m to +/- 2,000 m

2 off 125 km, 78" Water Pipelines

Distance between sensors: 30 km

Leak trials are on-going, and complete results will be available by the end of March.

4.4 Thefts from pipelines

Atmos wave is able to identify three persistent theft points where <0.3% was being extracted from an 80km pipeline believed by the customer to be leak free.

The system has been used on a pipeline with real thefts and has identified the tapping position to within +/- 250 meters over a length of 220km.

5 Discussion on Sensitivity and LDS Performance

The system sensitivity relies on the leak signal to noise ratio and therefore the sensitivity can vary from segments to segments. The main controlling factors, namely the intensity of the signal and the level of noise are affected by many different factors, the more relevant ones are summarised in the following section.

5.1 Strength of the leak signal

The magnitude of the pressure wave due to the leak near the leak location is affected by the following main factors:

1. The pressure difference between the internal part of the pipe and the external environment. Within the same pipeline, this factor is associated with the position of the leak in relation to the pump or source. The closer you are from the pipeline inlet, the higher the signal. Deep offshore pipelines can experience significant external pressure, and this must be taken into account.
2. The leak hole size and associated leak rate. The signals will be higher for larger leak diameters.
3. Velocity of opening the leak. This dynamic effect can be quite significant with reference to the negative pressure peak at the onset of the leak, and it must be considered in pipeline theft. There is some controversy about the leak opening velocity of a real leak. We believe that both cases can occur either fast (by a crack opening or by popping of large corrosion pits) or slow (by increasing hole size due to corrosion or by controlled theft).

The magnitude of the same pressure wave near the sensor, is affected by the attenuation of the pressure wave as it travels through the pipe. The following main factors control the peak height at the sensor location:

1. Distance between the sensor and the leak position,
2. Pipeline diameter,
3. Other variables like density and viscosity of the product,
4. Presence of interfaces in the fluid. This is the case where the pressure wave is attenuated as it passes through an interface like in multi-batch multiproduct pipelines, or slack-sections.

5.2 Background Noise

There are different sources of noise including pumps, wells, industrial processes and other sources which have their origin outside the length of pipe being monitored. The

magnitude of the noise coming from these sources is project specific and is affected by numerous factors that cannot be easily predicted. Fortunately these noises can be processed and filtered to a great extent.

Noises within the pipeline segment being monitored can originate from restrictions, pig traps, motor operated valves, mechanical load on the external wall of the pipe or from surfaces connected to the pipe and other sources. Fortunately these can be differentiated and even used to detect third party interference.

5.3 Sensitivity and Signal to Noise Ratio

If one considers the factors above in order to predict sensitivity it is easy to appreciate that sensitivity can vary significantly from pipeline to pipeline and from segments to segments within the same pipeline.

Segments monitored by sensors away from the noise sources and close to the leak will be more sensitive. On the other hand, segments monitored by sensors near the noise source and away from the leak will be less sensitive. However one must consider that the strength of the initial signal will also vary due to the variation in pressure. The signal will be stronger near the pumps where the pressure and noise are higher and weaker at the outlet where the pressure and noise level are lower.

5.4 LDS Performance

While the discussion above is relevant it is not practical to predict the performance of the system on each position of the pipe. The same rationale would apply to location accuracy and detection time.

To avoid endless discussions on the expected performance for a specific application we choose to quote the expected performance system on its worst case for sensitivity in conjunction with an expected range for location accuracy and detection time. This performance is in line with current industry practices and ATMOS Wave often exceed these performance expectations:

Minimum detectable leak: 1% of nominal flow

Leak location accuracy: +/- 100 to +/- 400 meters

Detection Time: 1 to 6 minutes.

In specific segments located a few kilometres away from the pumps, the sensitivity and general performance can be substantially increased by placing intermediary sensors near this region. In these cases the performance can be estimated as:

Minimum detectable leak: 0.3 to 0.5% of nominal flow

Leak location accuracy: +/- 100 to +/- 200 meters

Detection Time: 1 to 2 minutes.

6 Summary of the System Capabilities and Characteristics

- ATMOS Wave is a pipeline leak detection system based on the negative pressure wave method in compliance with API 1130 (Sept 2007).
- Very low false alarm rate
- Maximum distance between sensors is approximately 200 km.
- Detection of existing leaks
- Detection time from 1 to 8 minutes, combined with sensitivity less than 1% of nominal flow for single phase liquids, results in a very small release before a confirmed alarm.
- Leak location typically within ± 100 to ± 400 metres depending on operational conditions during the leak for lines slack free.
- Based on high performance, off the shelf pressure sensors that can relay manometric pressure.
- AWAS-3 incorporates local data storage for up to 4 hours to mitigate the effects of communication failures.
- Detection of slow opening leaks.
- Detection of end of “leaks”, which is very useful to identify theft events.
- Leak detection under all operating conditions.
- No reduction of minimum detectable leak size under transient conditions in liquid pipelines.
- Even more sensitive during shut in (or static line) leak detection & location capability.
- Field proven reliability and sensitivity for liquids. Trials and pilot projects are scheduled for gas pipelines.

7 Conclusions

ATMOS Wave combines a unique group of features and capabilities in one system that set itself apart from existing acoustic/negative pressure wave technologies.

The system combines the ability to space pressure sensors up to 200 km apart, the detection of pre-existing leaks (either in flow lines or shut-in conditions) and the detection of slow opening leaks with or without the help of flow meters.

The system’s performance is field proven. After extensive laboratory tests, several systems were installed and tested addressing a wide range of pipeline applications.

Feedback from experienced end users has been very positive, stressing that the very important performance characteristics have been successfully tested such as low false alarm, detection during all operating conditions, high sensitivity, fast detection times and accurate leak location.