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Review of Pipeline Leak Detection Technologies

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ABSTRACT

As pipeline leak detection systems become more widely deployed in the oil, gas, chemical and water industry, the demand for performance improvement increases rapidly. This paper describes the following leak detection technologies and their applicability to different pipelines:

- Real Time Transient Model
- Statistical analysis
- Negative pressure wave and
- Fiber Optics.

After a comparison of these technologies, the following performance figures will be addressed:

- Minimum leak detectable
- Detection time
- Leak location accuracy
- False alarm rate.

To achieve the best available solution and maximum protection of the environment, possible combinations of different technologies are discussed. Future development in leak detection is also addressed.

NOMENCLATURE

DAS	Distributed Acoustic Sensor
DTS	Distributed Temperature Sensor
DVS	Distributed Vibration Sensor
LDS	Leak Detection System
PLC	Programmable Logic Controller
RTTM	Real Time Transient Model
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SPRT	Sequential Probability Ratio Test

INTRODUCTION

Pipelines have been used to transport water, oil and gas for hundreds of years. Usually they serve residential communities, industrial sites and commercial centers reliably and silently. As the pipeline infrastructure ages, more accidents cause fatalities, environmental and property damage [12]. Recent studies by the U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA) [12] indicate that only a small percentage of leaks have been detected and confirmed by pipeline leak detection systems. The same report states that

"It is critical to remember that leak detection systems are Systems and can be usefully broken down into Personnel, Procedures and Technologies. Any implementation that focuses on less than all three of these components will not be optimal."

While leak detection systems cannot reduce the probability of a leak, the optimal implementation of a chosen technology complimented with training and effective operating procedure can help reduce the consequence of the leak significantly. When selecting a leak detection technology it is critical to remember that every pipeline is different and the technology that is best for one pipeline may not serve well on another pipeline.

This paper will focus on the leak detection technologies only. After an overview of the available technologies, the following four technologies will be described in more details:

- Real Time Transient Model
- Statistical analysis
- Negative pressure wave
- Fiber Optics.

The paper will compare the performance of these technologies and their application feasibility to different pipelines. Possible combinations of the technologies to improve the reliability, sensitivity and accuracy are proposed followed by conclusions

TECHNOLOGY DESCRIPTION

Overview of Technologies

Many different technologies are available for detectiong leaks in a pipeline ([3], [4], [6], [7], [8], [9], [10], [11], [13], [14], [15]). Largely they can be divided into two groups ([1], [2], [12]):

- Externally based methods that operate on the non-algorithmic principle of physical detection of an escaping commodity.
- Internally based methods that utilize field sensor outputs to monitor internal pipeline parameters such as: pressure, temperature, viscosity, density, flow rate, product sonic velocity, etc. These inputs are then used for inferring a commodity release by computation.

Figure 1 summarizes the common types of the above two methods. A brief description of each of these methods is given below.
The main externally based methods include:
Fibre optic cable – fibre optic cables laid alongside a pipeline can be used to detect leaks in three different ways: distributed temperature sensing, distributed acoustic (or vibration) sensing and distributed chemical sensing.
Vapour sensing tube – a small diameter perforated tube is laid along a pipeline; gas samples are drawn from the tube and analysed for hydrocarbons by pumping air or nitrogen through the tube.
Liquid sensing cable – buried beneath or adjacent to a pipeline, specific cable types are chosen to reflect changes in electrical properties by contact with hydrocarbon liquid.
Acoustic sensor – based on the fact that any leak generates a sound, acoustic sensors can be attached to and potentially tapped into a pipeline, positioned close to a pipeline, used as aids to human external surveys or within “intelligent pigs” or “smart balls” during routine internal surveys.
Vapour sensor – hydrocarbon gas sensors are used as “electronic noses” at different locations along a pipeline or used as hand carried probes during a routine survey.
Infrared camera – infrared imaging is used to detect hydrocarbon vapour above a pipeline either by permanently mounted cameras or mobile cameras that are handheld, mounted on road vehicles or airborne.

The main internally based methods include:
Volume balance – the measurement imbalance between the incoming and outgoing volume is calculated over different time periods, this imbalance can be compared with a predetermined alarm threshold with or without inventory compensation.
Rate of pressure/flow change – rate of change in pressure and flow are compared to the values under normal operating conditions to infer possible commodity release.
Real time transient model – a pipeline specific hydraulic model is configured and run online based on boundary conditions provided by field instruments at supply, delivery points and pump/compressor stations. Typical field inputs include flow-rate, pressure, temperature, liquid density or gas composition. Leak alarms are generated by comparing measured values with model calculated ones.
Statistical analysis – by applying statistical analysis to different signals from a pipeline, commodity release is inferred. Typical field data used include flow, pressure and temperature.
Negative pressure wave – the pressure wave generated by a leak travels upstream and downstream of the leak location, a commodity release is inferred by analyzing the pressure data sampled at high rate.

Each of the above methods has its advantages and disadvantages, for example,

- Most of the externally based technologies are able to detect small leaks and locate them accurately but it may not be feasible to retrofit cables or tubes to existing pipelines, sensors and cameras can only detect leaks within the sensing or line of sight distance. Thus most of the externally based methods are used for routine surveynance of pipelines rather than continuous monitoring. A leak may remain undetected until the next survey.
- The internally based technologies can be retrofitted to existing pipelines. With the exception of negative pressure wave, they can use field data provided by SCADA systems. In fact both volume balance and rate of pressure/flow change are usually implemented within a SCADA system. The internally based methods experience different degree of difficulties in coping with transient or slack flow conditions. The location accuracy is usually lower than the externally based technologies and these methods are dependent on the performance of the instrumentation and communications on the pipeline.

Most leak detection technologies are designed around an expectation that there will be egress of the commodity in the event of a pipeline leak. Deepwater pipelines may experience conditions where the hydrostatic pressure of the water is greater than the pipeline pressure. Under these conditions, there will be ingress of water into the pipeline in the event of a leak. This will lead to contamination (or increased water-cut) in the event of small leaks, or blockage of the line due to hydrate formation. Some leak detection technologies can be configured to detect these events as well as the more usual egress of commodity.

Technologies that can be used to monitor pipelines continuously are preferred to minimize the consequences of pipeline leaks, therefore the following continuous monitoring technologies will be described in more details in the following sections:

- Real time transient model
- Statistical analysis
- Negative pressure wave
- Fibre optic cable.

Real Time Transient Model (RTTM)

A Real Time Transient Model (RTTM) is a hydraulic model that simulates fluid flow, pressure and temperature in real time. It is based on the physical laws of conservation of mass, momentum and energy. It requires extensive configuration of pipeline parameters (length, diameter, wall thickness, route topology, pipeline roughness, pumps, valves, equipment location) and commodity properties (accurate bulk modulus value, viscosity, density).

RTTM leak detection is based on the assumption that the fluid behaviour within a pipeline can be modelled accurately. Typically, a RTTM will calculate fluid flow, pressure and temperature for the entire pipeline based on some field data from the SCADA system: flow, pressure, temperature, density at certain receipt and delivery locations, referred to as boundary conditions. An RTTM can be used to detect leaks in several ways, the two most common ones are:

1. Deviation analysis: A set of the measurements taken from the SCADA system are compared with the calculated values from the RTTM. If the difference goes above a predetermined threshold value, a leak alarm is generated.
2. Model compensated volume balance: The RTTM is used to calculate the inventory in real-time. The inventory change is used to correct the volume imbalance. If the compensated imbalance goes above a predetermined threshold value, a leak alarm is generated.

Most commercially available RTTM's are single phase only, usually being able to accommodate only a limited amount of slack flow in liquid lines and liquid drop-out in gas lines. This limited two-phase flow behaviour frequently requires the RTTM LDS to be disabled or significantly de-sensitised during slack or slug flow conditions. Errors on both the instrumentation and model assumptions can affect the sensitivity, reliability and leak location accuracy.

According to the recent study carried out by the DOT in the USA [12], RTTM LDS is the most commonly used CPM method after volume balance and rate of change in pressure/flow. It is applicable to gas and liquid, on-shore and off-shore pipelines. It can be applied to detect ingress for deep sub-sea pipelines and egress caused by leaks and thefts.

For fluids where the properties remain largely unchanged or predictable over the pipeline lifecycle e.g. water, jet fuel, natural gas, and pipelines where good instrumentation is available, it is feasible to maintain an accurate RTTM to deliver good leak detection performance. However for some fluids such as crude oil where the properties vary with the crude batches and no on-line density or viscosity measurement is available, it is very difficult to have an accurate RTTM making it impossible to detect small leaks without false alarms.

RTTM LDS has the following main advantages:

- Relatively cost effective to install as it usually relies on existing measurements and SCADA system. Typically these systems require additional measurement inputs such as density, temperature, viscosity or gas composition.
- Can function with large distances between measurements (flow and pressure sensors).
- Can provide other functions such as pressure profile, look ahead modelling, batch tracking, composition tracking, pig tracking, operation planning.
- Leak size and location are estimated.
- Widely accepted as a mature technology.

The main disadvantages of RTTM LDS are:

- Dependent on the quality of the instrumentation, SCADA and telecommunication system.
- High false alarm rate due to transients, slack flow, measurement errors or incorrect model assumptions.
- Often desensitized during transient operations.
- The model is based on leak-free assumptions, thus the effect of a leak may be "corrected" as instrument errors reducing the sensitivity of the leak detection system.
- Sensitive to fluid properties – especially viscosity and density.
- Requires a lot of data about the pipeline, equipment and fluid that are not always available.
- Complex including a lot of modeling parameters that may change with time, fluid or ambient conditions.
- Requires expertise to deploy, operate and maintain.

Statistical Analysis

Different levels of statistical analysis can be applied to leak detection. At one end, simple low pass filtering is applied to flow or pressure data to reduce the noise level before deciding if an anomaly has occurred. The more comprehensive method compares the probability of a leak with the probability of no-leak.

No matter what statistics is used and how complex the analysis is, all use field data from a SCADA system or PLC's/RTU's directly. While it is possible to apply statistical analysis to both the volume balance and rate of change in flow/pressure to reduce the false alarm rate, the two main commercially available systems are:

1. Pressure Point Analysis: the pressure data from a measurement point are treated over two moving time windows, each has a different fixed number of samples. The Student-t statistics are used to determine if the average pressure has changed significantly. If the average pressure has decreased with a level of confidence then a leak alarm is generated. This method works effectively if a pipeline is under steady-state operations i.e. the pressure remains nearly constant.

2. Sequential Probability Ratio Test (SPRT): a hypothesis testing method is used to decide between a leak and no-leak scenario. The data used for the sequential probability ratio test is the inventory compensated volume balance. By calculating the ratio of the probability of a leak over the probability of no-leak, it decides if the corrected volume balance has increased with a predetermined probability e.g. 99%. To cover the full range of operating conditions, flow and pressure analysis is carried out to determine if the pipeline is running, shut-in or stopped and if it is under "steady state", "small transient" or "large transient" operations. Different detection time is applied to each of these operations in order to minimize false alarms. Usually accurate leak size estimates are provided by correcting the average corrected volume balance with metering errors. Two leak location options are available based on Time Of Flight (TOF) and pressure interpolation methods respectively. Least Squares algorithm is applied to the pressure interpolation method to minimize the location error.

The performance of the statistical analysis methods varies significantly depending on the technology used. While PPA has been in the market longer, its application has been limited due to its inability to cope with pressure drops caused by transients. Therefore the industry has moved towards SPRT based technology. Successful applications of SPRT type of leak detection have been seen frequently in crude oil, multi-product, slurry, ethylene, LPG, natural gas, hydrogen, carbon monoxide and chlorine pipelines. It is applicable to gas and liquid, on-shore and off-shore pipelines. It can be applied to detect ingress for deep sub-sea pipelines and egress caused by leaks and thefts.

Statistical Analysis LDS has the following main advantages:

- Cost effective to install as it usually relies on existing measurements of flow, pressure and temperature from SCADA systems or PLC's/RTU's.
- Low false alarm rate.
- The SPRT type works effectively under both transient and steady-state operations.
- Can function with large distances between measurements (flow and pressure sensors).
- Leak size and location can be estimated.
- Largely insensitive to fluid properties such as viscosity and density.
- Unaffected by ambient conditions.

The main disadvantages of Statistical Analysis LDS are:

- Dependent on the quality of the flow meters, SCADA and telecommunication system.
- Leak location accuracy is low for small leaks.
- Cannot (normally) discriminate between multiple leaks on one pipeline segment.
- Performance is poorer with large gas networks with limited instrumentation.

Negative Pressure Wave

When a leak occurs in a pipeline, the pressure drops at the release location. This negative pressure wave propagates out from the location of the release in both directions and can be sensed by pressure meters at the ends or along the pipeline. The detection and confirmation of the negative pressure form the basis of this technology. Note that this technology is also (incorrectly) referred to as "acoustic" method.

As the initial pressure drop caused by a leak is short lived, it is necessary to sample the pressure data quickly e.g. 60 times per second. Thus dedicated data acquisition hardware is usually required.

There are two main negative pressure wave technologies in the market:

1. The traditional technology derived in the early 80's were hampered by bandwidth limitations for communications along the pipeline, thus a significant amount of processing was carried out locally. If a local processor detects a pressure drop larger than a preset threshold value, then an alarm event is sent to the master processor. By combining the different events and time stamps, a decision is made by the master processor about the presence of a leak. Since the threshold is often close to the normal noise level, a number of pressure drop events could be sent to the mater processor when no leak is present. It results in either a lot of false alarms or significant desensitization by increasing the threshold.

2. A new system was launched a few years ago. Capitalizing in the significantly improved pressure sensors and communication infra-structure, this technology samples pressure data at high frequencis e.g. 60 Hz and send them all to the central server for thorough analysis. The algorithms filter out noises, arrange the analog 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 operations. It has been subjected to hundreds of tests with both leaks and thefts, including one facilitated by PRCI (Pipeline Research Council International) in 2012. Some very impressive results have been generated in both gas and liquid pipelines.

The response time is in minutes only limited by the propagation time of the pressure wave to the sensors and computer processing time. This is typically governed by the speed of sound in the pipeline. The leak event is a "one-shot" event – i.e. if the event is missed for any reason, there is no opportunity to detect the leak at a later stage although some post leak detection analysis has been incorporated in the modern technology including the use of low cost flow meters. This applies also to existing leaks. Leak location can be very accurate – within meters. Leak size is usually inferred from the observed pressure drop with limited accuracy unless calibration leaks are performed.

This technology suffers from the decay of the pressure wave as it propagates along the pipeline. This leads to a limitation in the maximum distance between pressure sensors that can be monitored by such a system. The recent tests carried out on a 42" natural gas pipeline have demonstrated that it can detect leaks down to 0.3% and the pressure wave is detectable after 140 KM (87 Miles). The decay of the pressure wave in the gas line is much smaller than expected. The longest segment tested on liquid pipelines is 220 KM (137 Miles) between pressure sensors on a multi-product pipeline where theft events were detected.

Although most installations are on liquid pipelines, the technology is equally applicable to gas pipelines. Tests on multi-phase pipelines are planned and the results expected in April 2013. Slack flow and slug flow cause some degradation in these systems.

Negative Pressure LDS has the following main advantages:

- Cost effective to install.
- Not sensitive to flow measurement performance.
- Accurate leak location.
- Short detection time for all leak sizes.
- Largely insensitive to fluid properties such as viscosity and density.
- Unaffected by ambient conditions.
- Ability to detect thefts.

The main disadvantages of Negative Pressure LDS are:

- False alarms if not tuned optimally.
- Normally requires custom hardware for high speed sampling and communication.
- Leak size is not a direct calculation.
- May miss a slowly developing leak.
- Pipeline equipment noise can result in higher leak thresholds in some pipelines.

Fiber Optic Cable

Sensing via fiber optics has been a research and development subject for over 40 years [5]. While the principal stimulus for the optical fiber technology was communications, it can be fabricated for sensing and measurements. If fiber optic cables are laid along a pipeline for communications, it can be cost effective to use it as a basic component set to facilitate specialist leak detection technologies.

Fiber optic cables naturally change refractive index when subjected to strain or temperature change. Pulsed laser is used to locate the position of this change in refractive index.

There are three main sensing methods for pipeline leak detection:

1. Distributed Temperature Sensor (DTS): If the commodity release causes sufficient temperature changes in the ambient near a pipeline, the fiber optic

cable can be used to detect the change and alarm a leak. It is important to choose the physical location of the sensor cable with respect to the pipeline; for a gas pipeline a DTS is typically installed above the pipeline, for a liquid pipeline it is typically installed below the pipeline. For a subsea pipeline, the requirements for location are not clear.

2. Distributed Acoustic Sensor (DAS or Distributed Vibration Sensor - DVS): DAS systems monitor for sound (or vibrations) which could be generated by a leak. These systems require a significant amount of processing in order to identify which signals form a part of the ambient noise – i.e. passing traffic, wildlife etc. This technology can also provide pipeline operators with “intrusion” or “third party disturbance” indication when configured to act as vibration sensors.

3. Hydrocarbon Sensing Fiber Optics: The patented covering of the fiber optic sensor changes its refractive index in the presence of hydrocarbons. This change is registered optically by the sensor and converted to a hydrocarbon concentration level.

As the fiber optic cables are laid along a pipeline, they usually have short leak detection time and accurate location. Leak size is estimated from the change in temperature or intensity of the leak sound, so they currently have very limited accuracy.

Generally the fiber optic technologies can be applied to gas, liquid and multi-phase pipelines, but their effectiveness depends on whether the signal to be detected is present in the case of a leak. For example if the crude oil temperature is the same as the ambient temperature, a leak in this pipeline will not generate any temperature change making it impossible for the DTS to work. Thus DTS is more suitable for natural gas pipelines where the Joule Thomson effect will generate a big temperature drop when the gas is released to the ambient.

The technologies should work for both onshore and offshore pipelines. However the expected behaviour in an offshore application is unknown and the installation requirements are not clear currently.

The fiber optic cables have the following main advantages:

- Not sensitive to any fluid property changes.
- Leak location can be very accurate.
- Not affected by pipeline transients.
- Sensitive to small leaks if the leak signal is present e.g. temperature change, hydrocarbon presence or leak sound.
- Fast to alarm a leak.
- Works on gas, liquid as well as multi-phase pipelines.
- Can (possibly) discriminate between multiple leaks on a pipeline.
- DAS can be used for intruder detection.

The main disadvantages of Fiber Optic Cable LDS are:

- False alarms as they are sensitive to all strain, temperature and hydrocarbon changes.
- Very expensive and challenging to retrofit on an existing pipeline where fiber optic cable is not available.
- Requires custom hardware including the optical fibre itself.
- Leak size – not accurate or unknown.
- DTS and hydrocarbon sensing are not applicable to losses caused by thefts.
- DAS or DVS sensitive to all ambient sounds that are not related to leaks, it can be time consuming to commission.
- DTS may not work on most liquid pipelines where the fluid temperature is close to ambient one.
- Very difficult to test on operational pipelines as controlled leaks cannot generate the same temperature, spillage or sound effect as real leaks.

Performance and Application Comparison

The above technologies can be applied to different pipelines. Their cost effectiveness and performance will depend on the application requirements, fluid type, pipeline route, operating conditions, external environment and government regulations.

To help select the technically, operationally and economically feasible technology for each pipeline, some comparisons of the above four technologies are given in this section.

Table 1 summarises the following subjects for comparison:

- LDS Principle: how the LDS works.
- Application Requirements: what are the basic requirements for the LDS to operate.
- Fluid Application: whether it works on gas, liquid and multi-phase, onshore and offshore.

- Reliability: the ability of a LDS to render accurate decisions about the possible existence of a commodity release on a pipeline, while operating within an envelope established by the LDS design.
- Sensitivity: a composite measure of the size of a leak that a LDS is capable of detecting and the time required for the system to issue an alarm in the event that a commodity release of that size should occur.
- Robustness: the ability of a LDS to continue to operate in non-ideal circumstances - loss of measurements, transient operations.
- Leak Location Accuracy: how close the LDS can locate a leak to the actual release site.
- Calculation of Leak Size: the ability of a LDS to estimate the leak size.
- Installation Cost: the cost of installing a LDS initially.
- Maintenance Cost: the ongoing cost of maintaining a LDS.
- Remarks: points of interest that are not covered above.

As can be seen above, none of these technologies is perfect. Figure 2, 3 and 4 illustrate six performance indicators of a leak detection technology:

1. Leak sensitivity and reliability: It is feasible for the fibre optic cable type of systems to detect leaks down to 0.1% within seconds. The negative pressure type can detect leaks within minutes. These two types of systems have the same detection time for all the leak sizes. The statistical systems are more sensitive than RTTM but both types require longer detection time for smaller leaks. While highly sensitive, the fibre optic and negative pressure systems are subject to a high level of false alarms. The most reliable one is the statistical system.

2. Location accuracy and cost: Similar to leak sensitivity, the fiber optic and negative pressure type have the same accuracy for all the leak sizes. The location accuracy changes from tens of meters (fiber optic), to hundreds of meters (negative pressure), thousands of meters (statistical analysis) and ten thousands of meters (RTTM). The installation cost of a fiber optic system is the highest followed by the RTTM, statistical system and negative pressure if no field instruments exist. The cost of RTTM and statistical systems can be reduced if field instruments such as flow meters and pressure sensors are in place.

3. Leak size estimate and robustness: Both the statistical and RTTM systems can provide accurate leak size estimates, but the fiber optic systems cannot tell how big a leak is. The negative pressure systems estimate leak sizes based on pressure drop thus they are only accurate after calibration leak tests. The statistical system is more robust than RTTM and negative pressure but the fiber optic systems are the least robust as no leak detection is available if the cable is cut.

To achieve the best available solution and maximum protection of the environment, possible combinations of different technologies may be considered.

For example, if fiber optic cables are used for DTS, the temperature data may be used for the RTTM to improve the ambient temperature profile. This could improve the temperature modeling. Note that the expected accuracy of DTS is around 1^{O}C (33.8^{o}F).

The negative pressure wave can be used to provide accurate leak locations, faster detection time for sudden leaks while the statistical analysis can compliment it with the high reliability and detection of slowly developing leaks. As both technologies can be retrofitted with relative ease, the redundant solution will improve the overall performance of reliability, sensitivity and accuracy.

In some cases the statistical analysis has already been applied to RTTM, this combination helps to reduce false alarms in the RTTM LDS although it cannot help with the robustness issue.

The above combined solutions may be selected for part of a pipeline e.g. the HCA: high consequence area if the cost of providing two redundant systems is not feasible. To maintain a high availability of the combined solution, it is important that each system should be run independently with information exchanged betweem them only.

FUTURE DEVELOPMENT

Since pipeline leak detection systems are engineering solutions, their performance is largely optimized to individual pipelines. While the LDS technology must be feasible for delivering the desired performance, the successful application of the technologies can only be achieved by close collaboration between the vendors and pipeline operators. This is particularly the case for the internally based technologies where the LDS rely on flow metering, pressure measurements, SCADA and telecommunication system performance. Historically some of the applications have failed to detect leaks because of the following main reasons:

- Lack of ownership, no one is accountable for the performance of the LDS. Some vendors may commit to unrealistic performance figures assuming the real world is perfect, at the end the quality of instruments or pipeline operations are blamed for the failure to deliver such performance targets.

- The field instruments, SCADA or telecommunication systems are often outside the scope of leak detection. The failure of any of them could degrade the performance of an internally based LDS.

- Insufficient training and understanding of the LDS applied to the pipelines. This happens often when personnel changes occur within a pipeline company.

- The high level of false alarms during leak free operations gives pipeline operators low confidence and the tendancy to ignore all the leak alarms.

- Poor service and support of the installed systems.

- Lack of effective leak alarm response procedures.

To help mitigate and minimize the consequence of pipeline leaks, improvement in the above areas will be necessary. In addition, continuous development and testing will be useful in the following areas:

- Testing of the fiber optic cable LDS, identification of their installation requirements, limitations, performance expectations and applicability to different pipelines.

- Further testing of the modern negative pressure wave technology on gas and multi-phase pipelines.

- Minimization of false alarms for all LDS technologies will be essential.

- Improvement in sensivitity for the internally based LDS, in terms of both minimum leak detectable and detection time. It would be ideal to detect leaks below the flow meter accuracy i.e. less than 1% of pipeline throughput.

- Location accuracy can never be high enough. Large reduction in response time, commodity loss, environmental damage and production down time can be achieved if a leak is pinpointed precisely.

- Incorporation and automation of on-line tuning capabilities will make LDS a lot more feasible for the whole life cyle of a pipeline.

- Invention or adaptation of other technologies currently not known to the pipeline industry.

CONCLUSIONS

After a brief review of a number of leak detection technologies, this paper discussed the principle and applicability of four main technologies. It showed that there is still a gap between what is available and what is required. Therefore further development and testing are necessary for leak detection technologies to meet the needs of the pipeline industry.

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TABLES

	RTTM	Statistical Analysis	Negative Pressure	Fiber Optic
LDS Principle	Hydraulic simulation and analysis of difference between measured and calculated values	Statistical analysis of volume balance and pressure	Analysis of rarefaction wave generated by a leak	Distributed sensing of temperature, noise/vibration or hydrocarbons
Application Requirements	Measurements of ambient temperature, density or gas composition in addition to flow, pressure, temperature; SCADA and communication	Measurements of flow and pressure; SCADA and communication	Measurements of pressure, dedicated data acquisition equipment and communication	Installation of proprietary fibre optic sensing cable
Fluid Application	For gas and liquid pipelines, onshore and offshore	For gas, liquid and multiphase pipelines, onshore and offshore	For gas, liquid and multiphase pipelines, onshore and offshore	For gas, liquid and multiphase pipelines, mostly onshore
Reliability	Medium, depending on model performance	High, designed to minimize false alarms	Low to medium, depending on tuning and system	Low to medium, depending on environmental factor and leak effect
Sensitivity	Low to Medium due to difficulty in maintaining high accuracy models	Medium	High, detecting small leaks and thefts quickly	Very High, detecting small leaks quickly
Robustness	Medium, loss of function due to missing data, slack flow or transient operations	High, can still detect leaks even if some instruments fail. Works under steady state, transient and shut in conditions	Medium, loss of function if pressure sensors are not available. Works under steady state, transient and shut in conditions	Low, may not detect leaks if cable is cut or if the hole is not located near the cable. Works under steady state, transient and shut in conditions
Leak Location Accuracy	Low	Medium	High, down to 100's of meters	Very high, down to 10's of meters
Calculation of Leak Size	Yes	Yes	Yes, accurate only after leak calibration tests	No
Installation Cost*	High	Medium	Low	Very high if cable is to be installed
Maintenance Cost	High, expert tuning required	Medium	Medium	Medium
Remarks	Suitable for existing and new pipelines if flow, pressure, gas composition/density and ambient temperature measurements are available.	Good track record on both gas and liquid pipelines. Suitable for existing and new pipelines.	Requires pressure sensors only. Suitable for existing and new pipelines.	DAS/DVS can be used for intruder detection. Difficult to test the performance. Difficult to retrofit.

Table 1 – Performance and Application Comparison

*Installation cost has assumed that no field instruments exist on the pipeline. The cost for RTTM and Statistial systems would be reduced if field instruments are already in place.

FIGURES

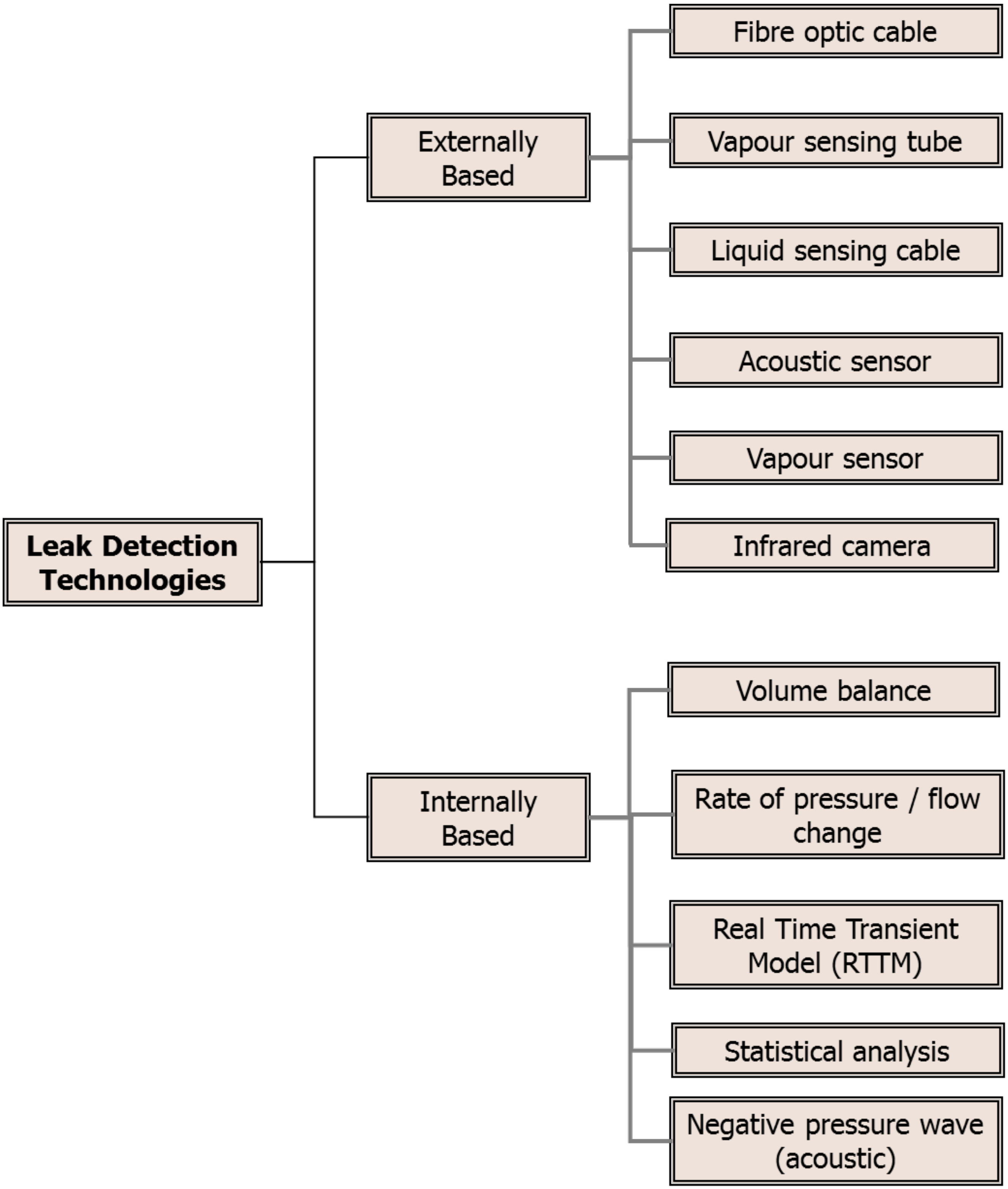

Figure 1 – Overview of Leak Detection Technologies

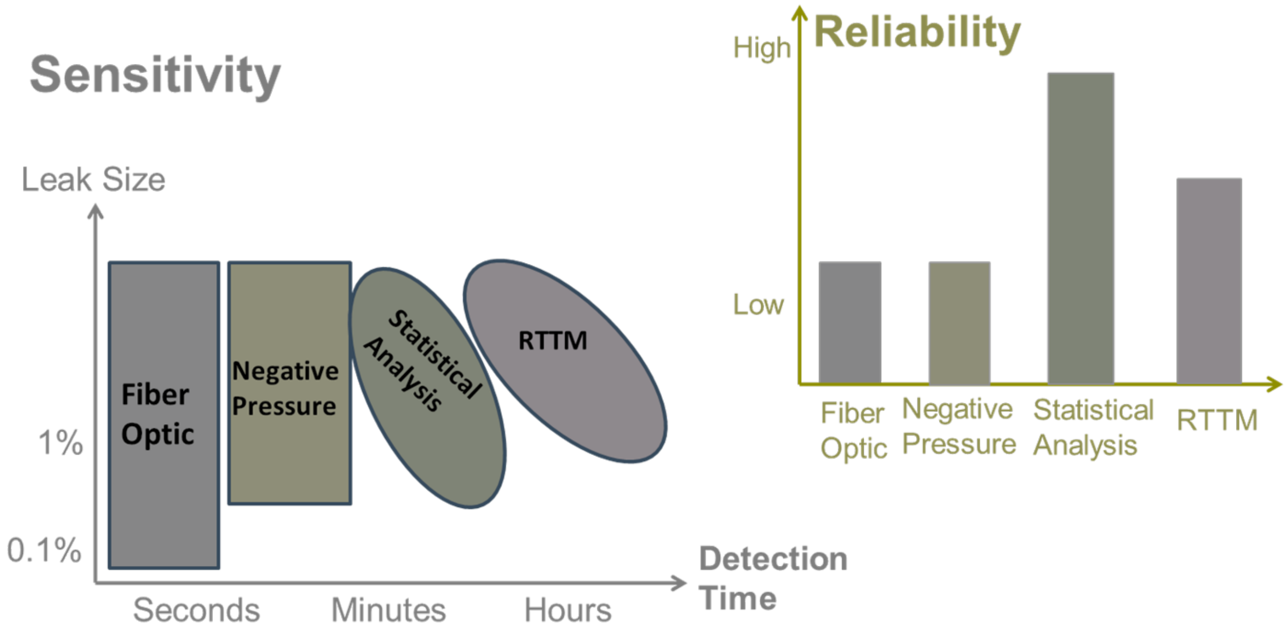

Figure 2 – The Sensitivity and Reliability Comparison

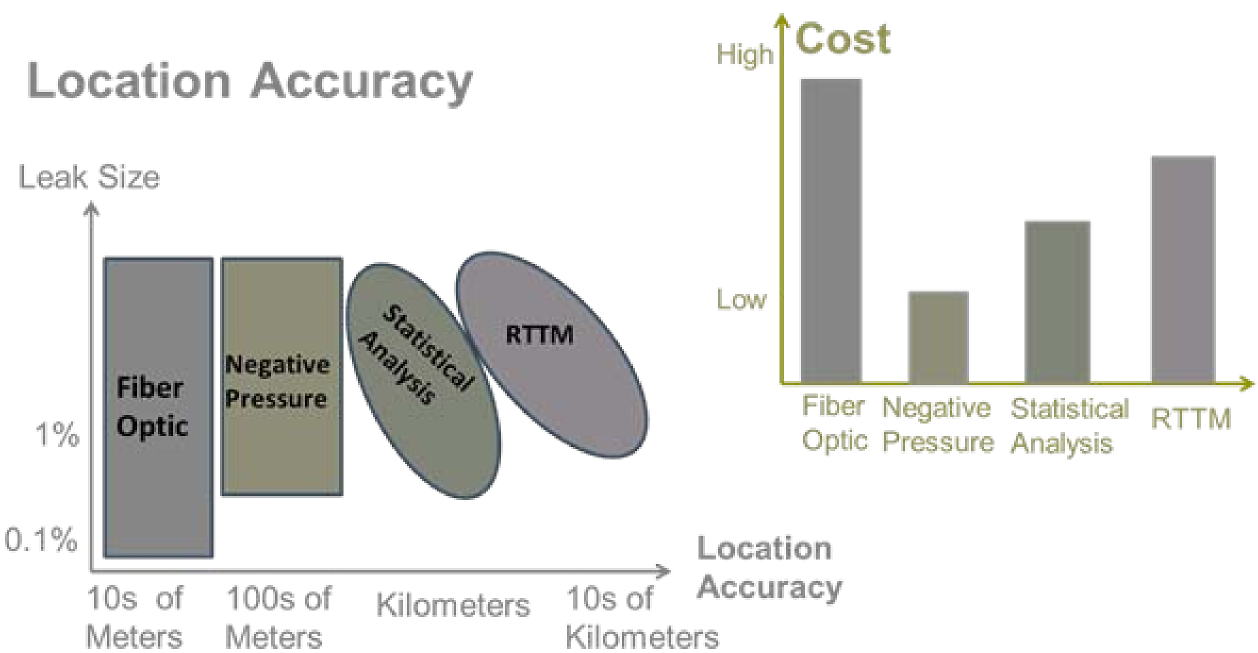

Figure 3 – The Location Accuracy and Installation Cost Comparison
(Note that the installation cost has assumed that no field instruments exist on the pipeline. The cost for RTTM and Statistial systems would be reduced if field instruments are already in place)

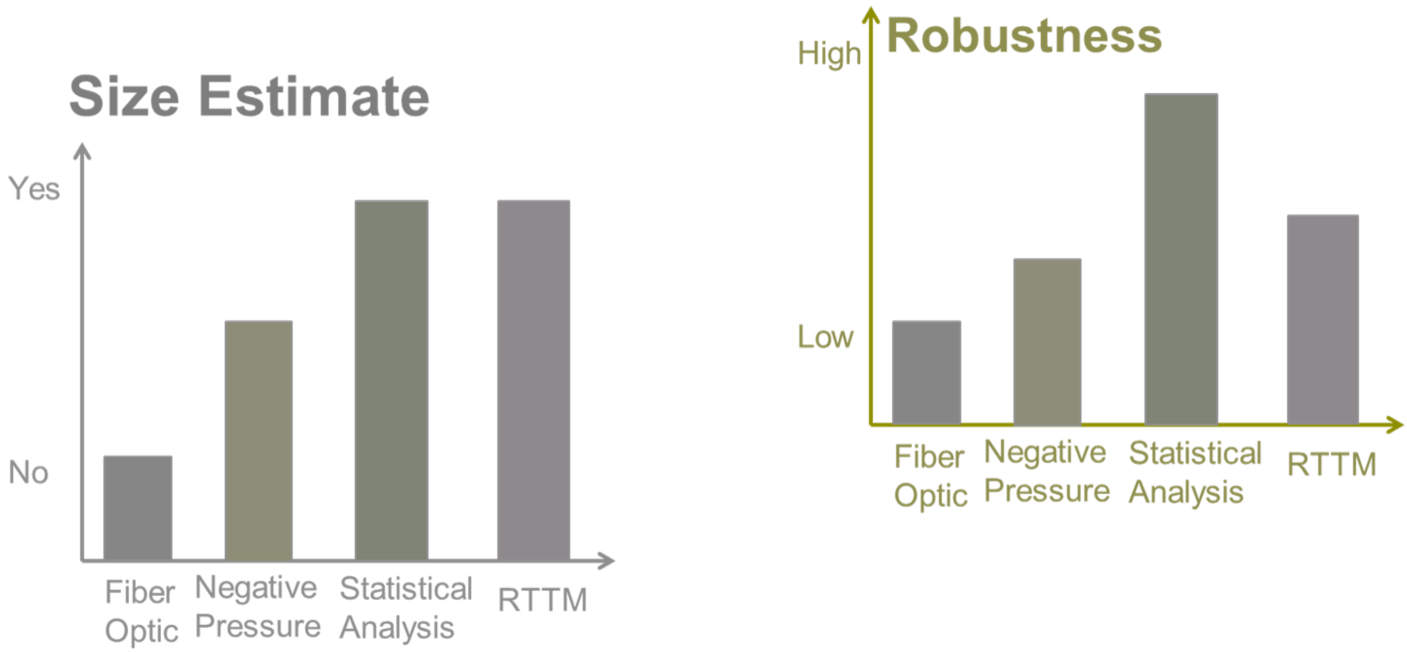

Figure 4 – The Size Estimate and Robustness Comparison