The Evolution of Leak Detection

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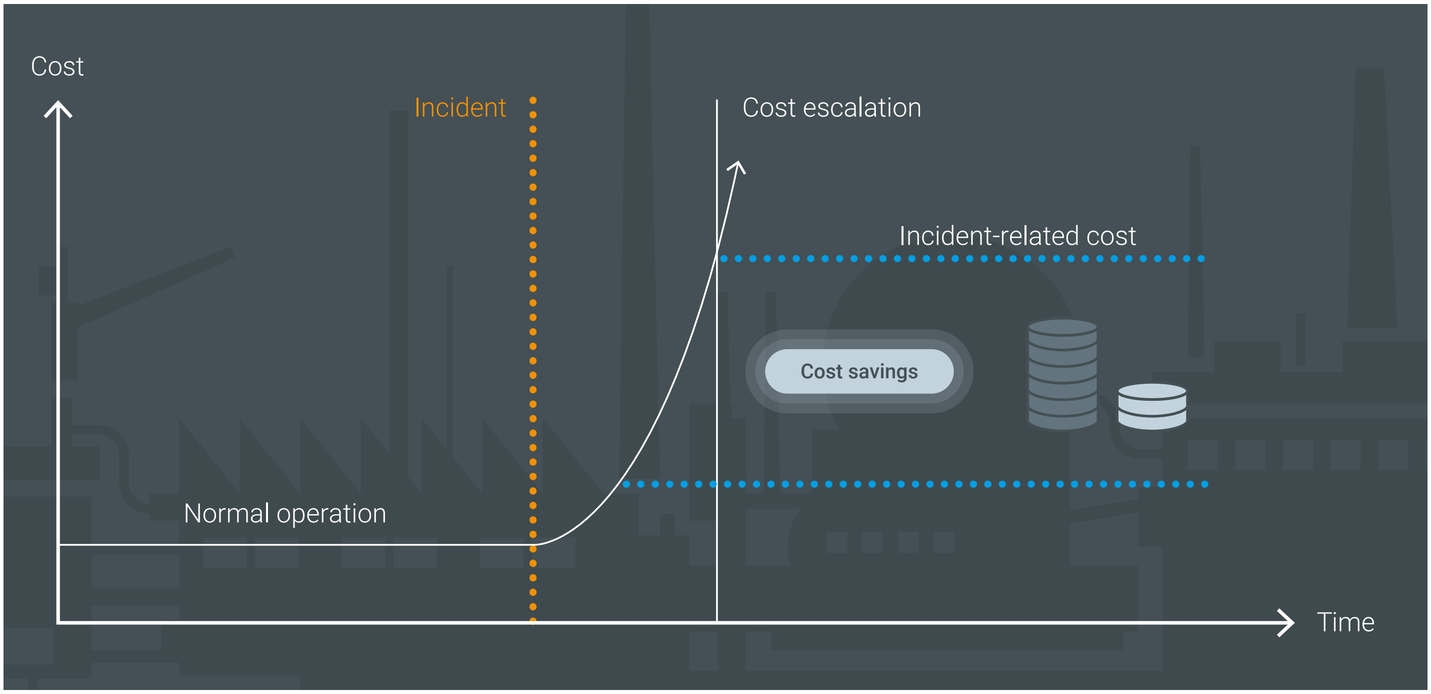
The potential cost of remediation and possible financial penalties due to pipeline leaks has increased, as has the potential damage to the operator's reputation from unfavorable press. However, operators' confidence in commercially available leak detection systems remains low. Many times, staff delay action when an alarm is received from a leak detection system, risking both financial resources and corporate reputation. →

Every Minute Matters: Early Leak Detection Saves Money



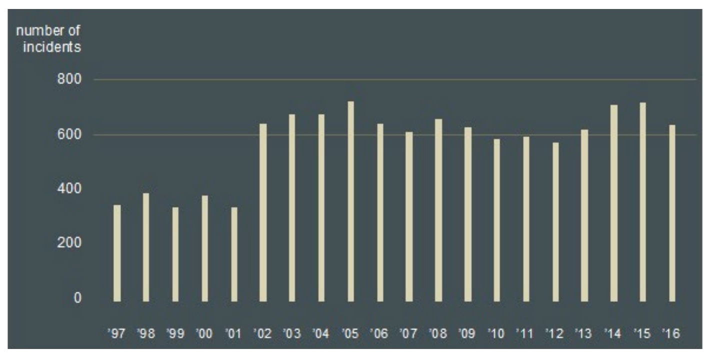
This paper discusses the different methodologies available for leak detection, together with the pros and cons of each. Approaches discussed include external methods that can be buried with the pipeline itself and software methodologies that depend on pressure, flow, and/or temperature readings. Discussion then moves on to the possibility of reducing nuisance alarms by combining methods in a way that covers all phases of a pipeline, and by using one method to validate leaks discovered by another.

Using this methodology, a case can be made that the time has come for automatic leak detection and safety systems. By combining this reduced nuisance alarm methodology with the reliability and logic capability of a SIL 3 rated safety controller, leak detection can become an automatic system that eliminates the operator delay and protects the user's reputation and financial resources while minimizing nuisance trips.

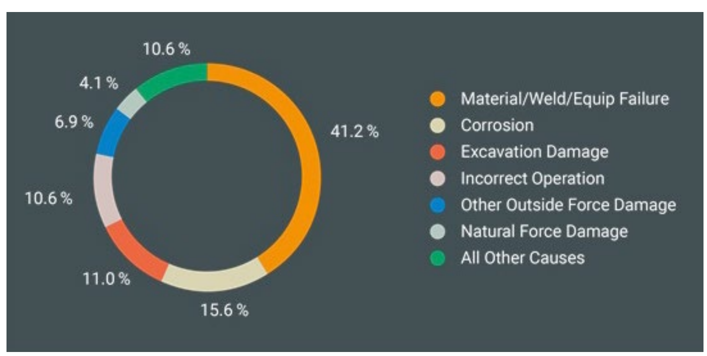
Standards and the Need for Them

Continued improvement of leak detection is necessary because many hundreds of pipeline incidents are reported across the US every year, and these numbers have not seen improvement over the last fifteen years. Specifically, figures from the Pipeline and Hazardous Materials Safety Administration (PHMSA) show that, ever since 2002, the number of pipeline incidents per year has consistently remained above 600 – and closer to 700 in 2005, 2014 and 2015.

US Pipeline Incidents (1997 – 2016)



US Pipeline Incidents by Primary Cause (2016)



The PHMSA figures show that in 2016, material defects were the leading cause of incidents, at 41.2% of the total. Next were corrosion at 15.6% and excavation damage at 11%. These causes supplanted excavation which had been the leading cause in previous years.

In recognition of this, the American Petroleum Institute (API) has released a set of standards to be used as guidelines for the operators to help mitigate the risks and consequences of leaks. These standards can be summarized as below:

- API 1160 – Overall standard to cover all pipeline integrity management
- API 1130 – Design and implementation of leak detection systems
- API 1149 – Theoretical calculations of possible leak detection system performance
- API 1175 – Standard for the selection, operation, maintenance, and continuous improvement of leak detection systems

What to Look For

Many pipeline operators don't know what to look for when shopping for a reliable leak detection system. There is a combination of factors to look at when evaluating the best solution. The primary four factors are summarized below:

- Sensitivity – A combination of the size of a detectable leak and the time required to detect it.
- Reliability – A measure of the system's ability to accurately assess whether a leak exists or not. This encompasses both the ability to identify a leak and the ability to avoid false alarms.
- Accuracy – The ability of a system to estimate leak parameters such as: leak flow rate, total volume lost, and leak location.
- Robustness – The ability of a system to continue to function during unusual hydraulic conditions or when data is compromised.

Leak Detection 1.0 – the Use of a Single Method

The industry's response to these standards, and to leak detection overall, has been evolutionary. This evolution can be represented as a set of four steps, of which the first – which we can call Leak Detection 1.0 – uses a single method chosen from the many available. It is worth reviewing these alternatives at this point, as they are not only used for 1.0 but also provide the building blocks for the more recent evolutionary stages.

The detection methods must first be classified by whether they are externally or internally based.

External Methods

The external methods discussed are: Acoustic sensors, fiber optic cables, and vapor sensors.

Acoustic sensors are distributed along the pipeline to detect internal noise levels. Any leak produces a low frequency acoustic noise at its location, which the sensors can detect. This method's advantage is its sensitivity to small leaks, while its disadvantages include a high number of false alarms, which can be caused by vehicles driving over the pipeline, changes in valve position, pumps ramping up, or other spurious events. Another disadvantage is that the efficiency and accuracy of this method is dependent on the operator's skill level. Additionally, this method is not efficient for long pipelines, as the high cost is prohibitive.

Fiber optic leak sensing depends on installing a fiber optic cable along the entire pipeline length. This cable monitors continuously for temperature changes caused by pipeline leaks. The method's advantages are high leak location accuracy and theft identification, but it has a high installation cost, leak identification times can be slow, stability over time is unproven, and the entire pipeline must be excavated to install the cable. Additionally, the method does not yield any leak size data which could be an important factor in determining how to deal with the leak.

The last external method uses a **vapor sensor**. A vapor sensing tube, installed along the entire length of the pipeline, contains air moving at a constant speed towards a sensor at the end of the pipeline. During a scan, an electrolysis cell emits a test peak of hydrogen. If vapor from a leak is detected, the system will calculate where the leak is, based on timing differences between the vapor peak and hydrogen peak arrivals at the sensor. Leak location and size accuracy is high, but the installation price is also high. Scanning is only performed once or twice a day rather than continuously, so a leak could become extremely large by the time it is detected.

Neither the fiber optic nor the vapor sensor methods are suitable for brownfield applications, as they both require excavation of the entire pipeline as part of the sensing equipment installation.

Internal Methods

Five internal or computational pipeline monitoring (CPM) methods are available.

The first is a **statistical analysis** method that relies on the pipeline pressure and flow profiles reacting to a leak in a typical manner. These profile reactions can be calculated by using the correlation between inlet and outlet flow as well as inlet and outlet pressure. Unfortunately, without a steady state condition, this correlation does not exist. This means that the method does not work during transient conditions, and leak location tends to be of low accuracy, which only improves as the leak continues. The method does have the advantage of utilizing existing instrumentation.

Real-Time Transient Modelling, or RTTM, uses basic physical laws such as conservation of mass, conservation of momentum, and conservation of energy to create mathematical models of the flow within the pipeline. The pressure and flow profiles are calculated in time steps. When the measured flow deviates from the model, a leak is identified. To design a reliable system with minimal false alarms, the noise level should be continuously inspected to modify the models.

RTTM is very good in transient conditions, and can potentially use existing instrumentation. However, it is very expensive to program, and continuous tuning is required. Training costs for operators that will tune the system must be allowed for, and it is not always possible to obtain all the parameters necessary for programming.

The **volume balance** method is based on the principle of the conservation of mass; what goes in must come out, unless there is a leak. This method is also used in some SCADA systems. The compensated volume balance variant is the best to use in a leak detection system, as this optimizes its functionality. This version of the method accounts for changes in both pressure and temperature. Rising temperatures result in expansion and building pressures cause compression.

This method uses proven technology and algorithms, utilizes existing instrumentation with minimal programming, and remains effective in transient conditions. However, it can only estimate the leak location.

The **pressure drop** method is a simple approach that uses existing instrumentation; during shutdown conditions, a pressure drop indicates a leak. It can detect the smallest of leaks, also known as seepages. However, it can only estimate rather than pinpoint the leak location.

The **negative pressure wave** method works on the principle that as a leak occurs, it generates a negative pressure wave of a known velocity both upstream and downstream of the leak. The leak location can be calculated by comparing the arrival times of the negative wave at each transmitter.

The method utilizes existing instrumentation to provide extreme leak sensitivity and excellent leak location accuracy, with a reduction in false alarms.

Method	Pros	Cons
Acoustic Sensor	• Sensitivity	• Nuisance Alarms • High Cost
Fiber Optic	• Location Accuracy	• High Cost • No Leak Size Data
Vapor Sensor	• Accurate Size and Location Data	• High Cost • Not Real Time
Statistical Analysis	• Uses Existing Instrumentation	• Works Only in Steady State Conditions • Low Accuracy Location Data
Real Time Transient Modeling	• Uses Existing Instrumentation	• High Programming, Training, and Maintenance Costs • Require Constant Tuning
Volume Balance	• Uses Existing Instrumentation • Effective in Transient Conditions	• Only Estimates Leak Location
Pressure Drop	• Uses Existing Instrumentation • Can Detect Small Leaks	• Only Effective during Shutdown
Negative Pressure Wave	• Uses Existing Instrumentation • Sensitive to Small Leaks • Good Leak Location • Reduced False Alarms	

Leak Detection 2.0 – the Use of Multiple Methods

With the above ‘building block’ detection methods in mind, we can consider Leak Detection 2.0. Leak Detection 2.0 is the use of multiple leak detection methods simultaneously to provide comprehensive coverage during all pipeline stages and identify and locate leaks accurately. HIMA’s approach is a combination of the best three internal leak detection methods: Enhanced pressure wave, compensated volume balance, and pressure drop method. By applying these methodologies simultaneously, system availability can be assured for all phases of the pipeline, while false alarms are reduced significantly.

This approach reduces programming costs for the pipeline operator. Additionally, the system requires little, if any, tuning to compensate for changes in the physical properties of the pipeline, such as corrosion or debris buildup.

Comprehensive Leak Detection Coverage

Pipeline Status	Leak Type: Burst	Leak Type: Leak	Leak Type: Seepage
Shutdown	EPW PDM	PDM EPW	PDM
Steady State	EPW VBL(A,R)	VBL(A,R) EPW	
Transient	VBL(A) EPW	VBL(A)	

EPW: Enhanced Pressure Wave

PDM: Pressure Drop Method

VBL: Volume Balance (Absolute, Relative)

HIMA’s FLOWorX leak detection solution combines the best three internal leak detection methods.

Leak Detection 3.0 – a Standalone Rupture Detection System

The next evolutionary phase, Leak Detection 3.0, introduces the concept of Emergency Shutdown (ESD) action as well as monitoring. It concerns detection of ruptures, which, by definition, are more serious than leaks and must be handled accordingly. Typically, a leak is classified as a rupture if it reaches or exceeds around 30% of the pipeline flow rate, although the precise value is defined by each pipeline operator’s individual risk analysis.

Rupture detection systems were created as standalone systems operating independently of the leak detection implementation, and designed to shut down a pipeline in the event of a rupture. The leak percentage threshold at which the system reacts can be raised or lowered as necessary.

In any case, immediate reaction to a rupture is vital to minimize spills and environmental damage. These systems are used particularly in environmentally sensitive areas where a delayed response can be damaging to the environment and the operator’s reputation.

HIMA has developed a HIMax FLOWorX RDS solution which exerts valve control directly from a rupture detection algorithm. It can be set to detect a rupture of a specified volume and flow rate. When detected changes in pipeline pressure and flow exceed a defined level, the system reacts automatically to isolate the damaged pipeline segment.

The system can work in pair mode, with two independent control units sharing process data over a dedicated communications link, or as standalone units. The paired configuration significantly improves performance and can detect smaller ruptures. It is recommended for high-consequence areas with proximity of housing, water reservoirs, rivers or other sensitive features, where even a small release can be dangerous to human health or the environment.

Leak Detection 4.0 – the First Hybrid Solution

HIMA has developed and created Leak Detection 4.0 with the world’s first hybrid solution. This is an innovative approach that integrates a leak detection system using the multiple detection methodologies of 2.0, and a SIL 3 safety system with ESD capability. Detection is implemented using FLOWorX LDS while safety is provided by the HIMax SIL 3 ESD system. Unlike traditional systems, which detect leaks but take no action, the hybrid solution is geared towards safety.

The package is available as a complete pipeline management automation solution to help pipeline operators to improve their safety. It can continuously monitor pipelines, shut them down automatically in hazard situations, and prevent or significantly reduce damage. It is a non-PC-based system that includes all

HIMA's traditional PC-based leak detection system capabilities – leak detection and location, pressure monitoring and rupture detection – integrated into a HIMax SIL 3 PLC.

Flow control is implemented within the hardware, while HIMA's secure Ethernet protocol – SafeEthernet – delivers pressure and temperature readings to the user's location. The HIMax systems themselves are also connected by SafeEthernet. As such, each can monitor the entire pipeline's condition. If a leak occurs, HIMax will automatically regulate the flow, or, if necessary, cut it off entirely. This SafeEthernet connectivity also allows for controlled shutdown of the pipeline. It may be necessary to take actions upstream or downstream from a leak to ensure maximum protection. The Hybrid Leak Detection 4.0 solution can implement a managed shutdown without operator action, protecting people, the environment, and the operator's reputation.

HIMA has implemented this hybrid solution using their XMR technology that combines SIL 3 safety technology with a scalable, fault-tolerant architecture. This helps prevent false alarms, and allows unlimited alterations, modifications, extensions, improvements and even mandatory proof tests while the plant is in operation.

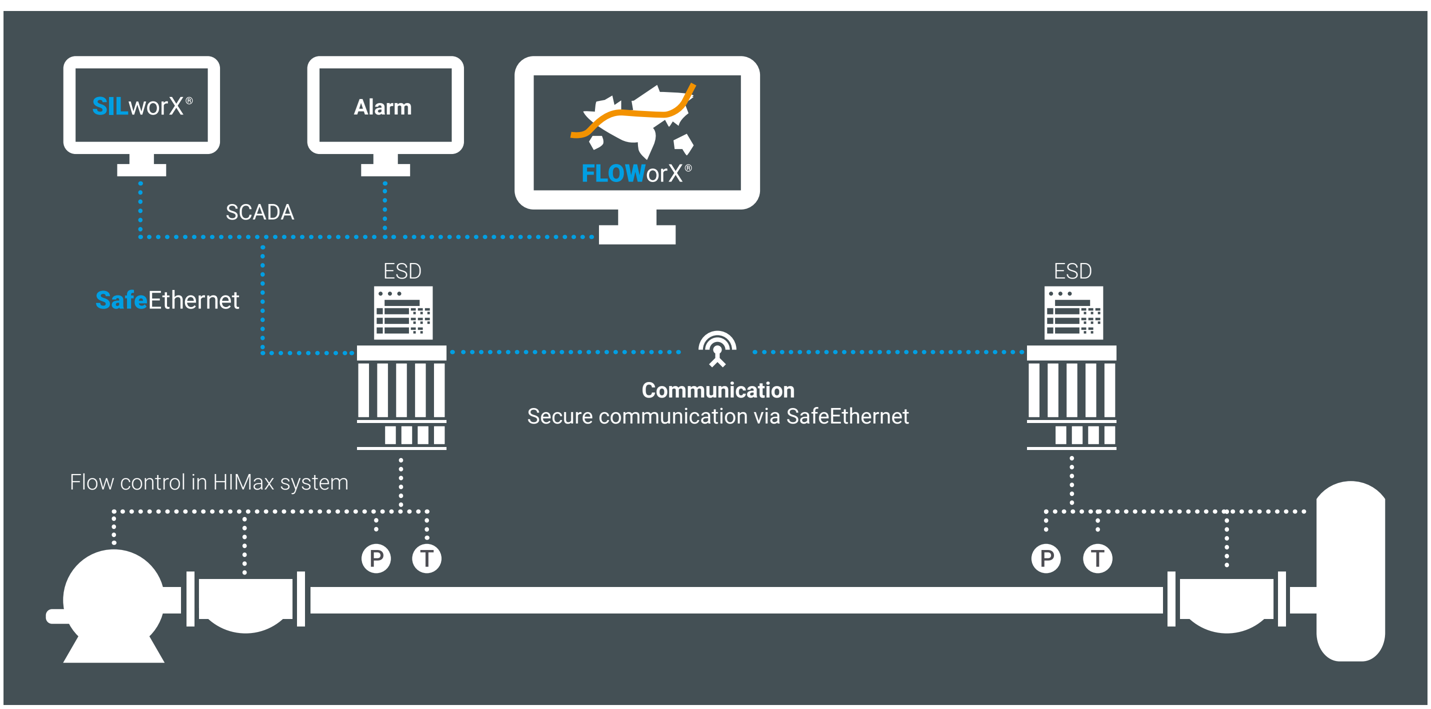
The SIL 3 controller's performance and multitasking capabilities allow the operator to carry out other safety related functions in addition to the leak detection and shutdown. Successful installation and maintenance of the hybrid safety control system itself is also assured. Along with the automation components necessary for control, regulation, and monitoring of gas and liquid pipelines, the new integrated hybrid solution includes customer support and service.

In today's digital world, it is important to note that the HIMax system offers enhanced protection from cyber threats. Unlike traditional systems that rely on open channel communications, it offers security of vital plant data with an Achilles certified ISA secure design. This capability is not only highly desirable but also likely to become essential if cybersecurity becomes mandatory.

Conclusion

Pipeline operators should consider the different possibilities and chose the right one for their pipeline because every pipeline is different. A leak detection system should include more than one method! For environmentally-sensitive areas a rupture detection system makes sense. Leak Detection 4.0 for pipeline management offers pipeline operators considerable benefits. Uninterrupted operation and maximum availability are assured, while the system complies with current and upcoming global safety standards according to SIL 3. The system also ensures maximum functional safety and extremely high reliability by automatically shutting down any affected areas during critical situations. As a result, it cuts pipeline operating costs, significantly reduces false alarms, and increases the profitability of installations.

The New Hybrid Solution, Leak Detection and Safety in One System



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About HIMA

The HIMA Group is the world's leading independent provider of smart safety solutions for industrial applications. With more than 35,000 installed TÜV-certified safety systems worldwide, HIMA qualifies as the technology leader in this sector. Its expert engineers develop customized solutions that help increase safety, cybersecurity, and profitability of plants and factories in the digital age.

For over 45 years, HIMA has been a trusted partner to the world's largest oil, gas, chemical, and energy-producing companies. These rely on HIMA solutions, services and consultancy for uninterrupted plant operation and protection of assets, people, and the environment. HIMA's offering includes smart safety solutions that help increase safety and uptime by turning data into business-relevant information. HIMA also provides comprehensive solutions for the efficient control and monitoring of turbomachinery (TMC), burners and boilers (BMC), and pipelines (PMC). In the global rail industry, HIMA's CENELEC-certified SIL 4 COTS safety controllers are leading the way to increased safety, security, and profitability.

Founded in 1908, the family-owned company operates from over 50 locations worldwide with its headquarters in Brühl, Germany. With a workforce of approximately 800 employees, HIMA generated a turnover of approximately €126 million in 2016. For more information, please visit: **www.hima.com**

HIMA has operated in the Americas since the early 1980s. Its headquarters for the Americas is located in Houston, Texas.

Discover more at **www.hima-americas.com**

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