Digital pipeline leak detection

Using fibre-optic distributed temperature sensing (DTS)

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With conventional pipeline leak detection methods there is a gap between what you believe is occurring along your pipeline and what is actually happening. This information gap can result in a delay in you discovering and locating leaks.

Delays in detecting pipeline leaks can prove critical and can lead to potentially expensive and hazardous situations. Digital leak detection technology overcomes the limitations of measurement technologies available today, thus closing the monitoring gap and improving system integrity and safety. A summary of the benefits of digital leak detection versus existing technology is shown in Table 1.

Benefits of digital leak detection

Digital leak detection systems provide benefits at all levels of the organisation, including:

- improvement of safety of infrastructure and for personnel;
- enhancement of system reliability through reduced downtime and reduced inspection time;
- lower risk of environmental damage; and
- improvement of productivity.

Return on investment

The following calculations for a major oil pipeline using a Sentinel-DTS-based leak detection and monitoring solution incorporate figures for utilising the Sentinel-DTS both as a leak detection system and as a monitoring system (for pipelines using heat trace).

Operational savings with a leak detection system

For a major pipeline the daily production and transport can be in the region of 150,000 barrels of crude per day. Therefore, using the figure of $90 per barrel of oil, a 24 hour loss in production equates to a $US13,500,000 loss of revenue.

A digital leak detection system, such as the Sensornet Sentinel-DTS, is able to detect and locate a leak within minutes, therefore, in the event that a leak does occur, it can be repaired very quickly, minimising production downtime. If we conservatively estimate that down time due to leak detection, location and repair is reduced by 75% (eg from 24 hours to six hours) then this can result in savings of over $10,000,000 per leak.

If we assume that a typical 500 km pipeline will leak on average 0.91 times per year over its lifetime[1] then this will result in an average saving of $US9,000,000 per year through utilising a DTS-based leak detection system which provides detection, location and repair to the leak within a much shorter time frame.

Environmental savings with a leak detection system

Environmental costs are very difficult to predict and, in some cases, the damages the operator has had to pay as a result of product spillage from a pipeline have been as high as $4.5 million.[2] With ever increasing environmental sensitivity and awareness these costs are continually expanding. Additionally, with growing media exposure, the potential damage to the corporate image and public perception of the company in the event of a major leakage can be immeasurable.

Monitoring gap with existing technology	Digital leak detection technology
Leaks are not detected until the amount of leakage is large. By this time significant environmental damage may already have occurred.	Digital leak detection systems are extremely sensitive and able to detect leaks of less than one litre. With regular updates, you will be notified while the leak is still manageable.
Even when conventional systems know there is a leak, they are not able to find the location, leading to further delays and further expenses due to loss of product.	Leaks can be pinpointed to within 1 m with this technology. This rapid location minimises response time and any potential excavation expenses in order to find and repair the leak.
Certain leak detection and inspection systems are used on an intermittent basis. If a leak occurs in between inspections, this will not be detected.	This technology is a permanent monitoring solution and continuously monitors at all points along the pipe at all times, providing complete pipeline integrity.

***Table 1:** Digital pipeline leak detection versus existing technology.*

Optimisation of the heating process through DTS

For pipelines that are heated with heat trace, a sensing cable can be directly coupled to the pipeline. A full temperature profile along the length of the pipeline can be produced. Accurately monitoring the temperature profile along the pipeline allows the operator to control the process and ensure that it is as close to the desired temperature as possible.

This has two benefits. First, it reduces the risks of the temperature dropping below the temperature where the oil can start to solidify, which will lead to increased probability of pipeline blockage. Second, the additional monitoring of the pipe temperature also increases efficiency and provides a saving on energy costs for the heat trace system and reduced maintenance schedules.

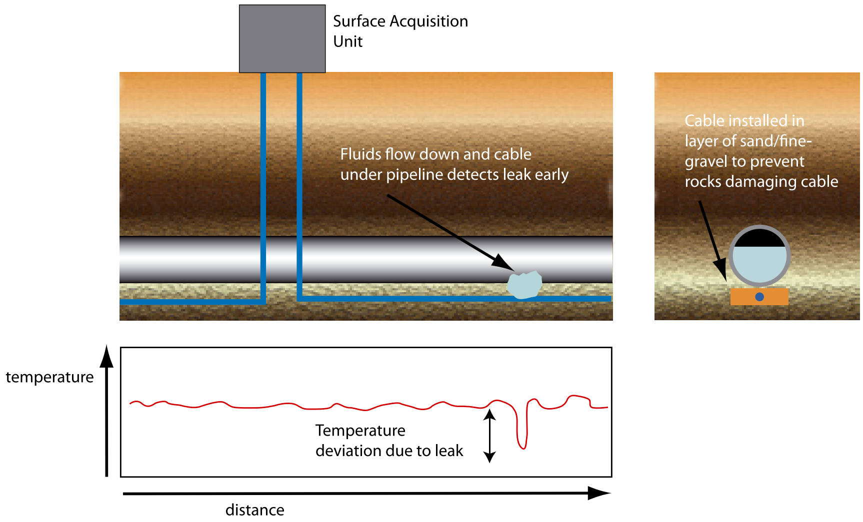

Figure 2: *Detection of fluid or gas leakage.*

Principle of measurement

Leak detection using temperature

When a leak occurs from a pipeline, the fluid or gas will contain a temperature signature which will differ from the surrounding environment. In some cases, the temperature changes can be very small (in the case of water leakage in dams) and in other cases the temperature difference can be substantial (in the case of liquid natural gas, -120 to -160°C, or, for Ethylene, -110°C). By detecting the temperature change of the surroundings, the distributed temperature sensor can not only detect the presence of a leak, but can also pinpoint the location of the leak to within 1 to 5 metres.

Depending on system configuration, the amount of the leak and flow velocity can actually be quantified to levels as low as 0.05 L/s.

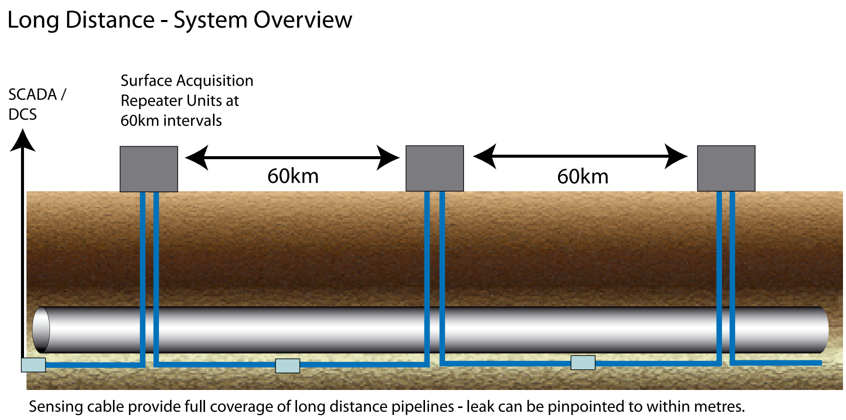

Figure 3: *Long-distance pipeline sensing system.*

DTS — physics of measurement

The system is based on temperature measurements using distributed fibre-optic sensing technology and can be used to detect both liquid and gaseous leaks. The optic fibre temperature sensor is able to take temperature measurements every 1-5 m along a fibre-optic cable with coverage of 60 km per unit. The DTS illuminates the glass core of an optical fibre with a laser pulse of 10 nanoseconds' duration (this corresponds to a 1 m pulse.) As the optical pulse propagates down the fibre, it undergoes scattering even in the absence of impurities and structural defects. Part of this scattered radiation is known as Raman scattering. Because this vibrational energy is a well-defined function of temperature, the ratio of the signals is also. It is this ratio, in conjunction with the time of flight of an optical pulse, which is used to determine the temperature of the fibre at a given point.

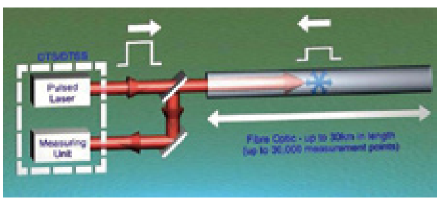

Figure 1: *DTS physics of measurement.*

Fluid or gas detection

In the event of a gaseous leak, the temperature drop due to the expansion (Joules Thompson effect) is instantaneous and can be considerable (it can be more than -100°C). The system provides measurements from every 10 seconds and such rapid detection is essential in the case of potentially explosive gases.

In the effect of liquid leakage (eg oil, water) the temperature change is less pronounced, however, the key is in the sensitivity of the system which can detect changes as small as 0.01°C. Using temperature measurements the system can not only detect leakage but, with calibration and advanced interpretation algorithms, it can quantify leaks down to millilitre accuracy.

Full pipeline coverage

The leak detection cable is installed along the length of the pipeline and takes measurements every 1 m along the cable length. The system can be used on long-distance pipelines with repeater stations situated every 60 km along the pipeline, thus providing full coverage of the pipeline with the ability to pinpoint the leak to within 1 m.

In areas where structural movement is anticipated (eg subsidence, tectonic movement, landslides), structural integrity sensors can also be integrated into the system. This system is very sensitive and can detect very small strains (less than 10 micro strain), thus detecting any movements in the surrounding environment before this causes potential mechanical damage to the pipeline. This combined system provides a total pipeline integrity solution.

Distributed temperature sensing performance

One of the essential factors to consider when designing a leak detection system is the performance of the DTS system itself. The system must have a temperature resolution fine enough to be able to detect the temperature change. As a rough guideline, in order to measure a leak for fluids, the temperature resolution should be better than 1°C (although in certain scenarios this needs to be finer than 0.1°C) and, for gaseous leaks, a resolution of 1 to 5°C can be acceptable.

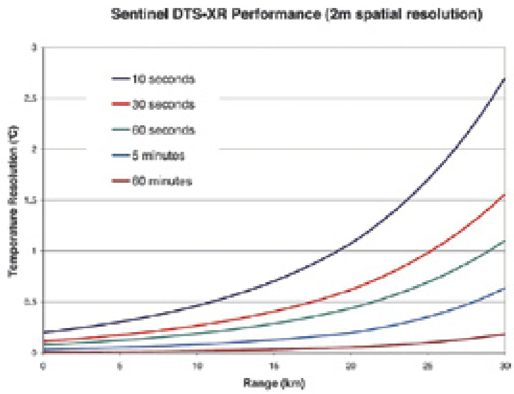

Figure 4: *Temperature resolution versus measuring time.*

With all DTS systems there is a trade-off between temperature resolution, spatial resolution, range and speed of measurement. The more time you allow the DTS to acquire data, the better the temperature resolution. Therefore, in order to define the performance of a system, temperature resolution, spatial resolution, range and measurement time should all be quoted.

The following graph illustrates the temperature resolution achieved for the Sentinel DTS-XR at ranges up to 30 km with a 2 m spatial resolution.

For example, with a measurement time of 10 seconds at 30 km, the temperature resolution is 2.5°C (the blue curve). For the same measurement time at 15 km, the resolution is 0.7°C. If the measurement time is increased to 1 minute (the green curve), the corresponding temperature resolutions are 1°C at 30 km and 0.25°C at 15 km.

System engineering, design and installation

In order to design an effective fibre-optic-based leak detection system there are a number of factors that must be taken into account, including:

- Design of the sensing cable to maximise thermal response while offering sufficient protection to the sensing fibre.
- Positioning of the sensing cable so that is will measure the thermal effects of leak without being affected by ambient temperature changes.
- Installation methodology to minimise disruption to pipe-laying operations.
- System integration with the operator's control system (eg SCADA, DCS).

Sensing cable design

The sensing cable must be designed to provide the balance between achieving rapid thermal response while also providing maximum protection to the sensing fibre in the harshest of environments. According to the specific operating range, the cables can be designed to operate from as low as -196 to 700°C.

The cable contains no moving parts and is immune to mechanical vibrations and EMC interference, making it ideal for use in industrial sensing applications. Depending on the operating conditions, that cable can be designed with a 30-year design life.

Additional fibres for telecommunications can also be incorporated into the design of the cable, thus reducing the need for an additional telecoms cable and reducing overall pipeline cost.

Positioning of sensing cable

It is essential that, when designing the system, the sensing cable is positioned such that it will come into thermal contact with the effluent in the event of a leak. Additionally, any changes due to ambient temperature transients must be accounted for when configuring the intelligent alarms. In certain scenarios (for buried and insulated pipelines), the sensing cable can be isolated from the ambient thermal environment. However, in cases of overhead or un-insulated pipelines, any changes due to ambient temperature will be filtered using algorithms in the alarm software in order to remove false alarms.

Depending on the specific pipeline design (eg insulated pipeline, pipe-in-pipe design) it is possible to incorporate the sensing cable into the construction of the pipeline. In order for a successful installation it is essential that the design engineers for the fibre-optic leak detection system work closely with the pipeline manufactures at the design stage and also with the installation crew on site during installation.

Intelligent automation

The leak detection system is equipped with automated alarm algorithms which are calibrated to the particular operating conditions. These algorithms are based on a combination of absolute temperature changes, rate of change and deviation from average conditions.

The pipeline route is divided into zones and alerts and data will be provided for each section. For example, the Sensornet Sentinel DTS has the ability to define up to 500 zones for alarming. These zones can be defined from one measurement point to the entire range of the fibre. The following types of alarms can be defined:

- Temperature exceeds value
- Temperature lower than value
- Temperature exceeds rate of change
- One point exceeds average value in zone
- Fibre break

Using this combination of algorithms, the sensitivity of the system can be optimised while eliminating false alarms. The cable can be zoned for operator convenience and, in the event of an alarm, both the specific zones will be flagged.

Sensornet
www.sensornet.co.uk

References

1. Based on US Federal Office of Pipeline Safety data — 1968–1997. The average pipeline suffers one leak per year per 400 miles.
2. Colonial Pipeline November 1997 — United States.