sensornet

Sensornet White Paper

Digital Pipeline Leak Detection Using Fibre Optic Distributed Temperature Sensing (DTS)

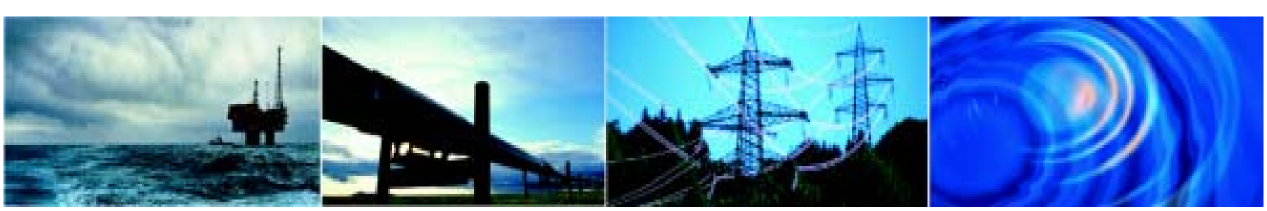


Table of Contents

© Sensornet 2007

1. Introduction

Leak Detection Applications

Sensornet's Digital Pipeline Leak Detection system is an extremely versatile leak detection system that is used to detect both liquid and gaseous leaks in the following industrial applications:

- Gas transmission and distribution
- LNG pipelines and tanks
- Oil transmission and distribution
- Steam pipelines
- Industrial processes (e.g. Ethylene, Ammonia, Sulphur)
- Water pipelines

 © Sensornet 2007

Close the Monitoring Gap

With conventional technology there is a gap between what you believes is occurring along your pipeline and what is actually happening. This information gap can result in a delay in you discovering and locating leaks. Such delays can prove critical and can lead to potentially expensive and hazardous situations. Sensornet's revolutionary technology overcomes the limitations of measurement technologies available today thus closing the monitoring gap and improving system integrity and safety.

Monitoring Gap with Existing Technology	Sensornet Digital Leak Detection Solution
Leaks are not detected until the amount of leakage is large. By this time significant environmental damage may already have occurred.	Sensornet's Digital Leak Detection system is extremely sensitive and able to detect leaks of less than 1 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 1m 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

 © Sensornet 2007

Benefits of Digital Pipeline Leak Detection

Digital Pipeline Leak Detection provides benefits at all levels of the organisation.

Benefits to Asset Manager	Benefits at Operational Level
Improve safety of infrastructure and for personnel	Any leaks will be detected quickly thus minimising risk to operations personnel. The optic signals used for the leak detection are extremely low power and incapable of igniting flammable gases and is suitable for use in hazardous zones
Enhance system reliability through reduced downtime and reduced inspection time	The sensing cable is based on passive sensing cables with a design life of over 30 years and maintenance costs are minimal.
Lower risk of environmental damage	Leaks as small as millilitres can be detected, allowing action to be taken early before these grow to become larger, potentially damaging situations. Additional sensors can be used to monitor the structural integrity of the pipeline, alerting the operator to any movement in the pipeline that could potentially lead to mechanical failure
Improve productivity	System is fully automated and so lowers operating costs with less risk of human error. Can interface with existing SCADA and industrial control system using standard protocols (e.g. OPC, Modbus, electrical relays)

 © Sensornet 2007

2. Return on Investment

The following calculations show that for a major oil pipeline using a Sentinel-DTS based leak detection and monitoring solution can lower the operator's risk profile (including operational, safety and environmental risks) and lead to substantial cost savings.

These calculations 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 of 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 $50 per barrel of oil, a 24 hour loss in production equates to a $7,500,000 USD loss of revenue.

The Sentinel-DTS is able to detect and locate a leak within minutes and so 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% (e.g. from 24 hours to 6 hours). This can result in savings of $5,000,000 per leak.

If we assume that a typical 500km pipeline will leak on average 0.91 times per year over it's lifetime[1] then this will result in an average saving of $4,500,000 USD per year through utilising a DTS based leak detection system which provides detection, location and repair to the leak within a much shorter timeframe.

[1] Based on US Federal Office of Pipeline Safety data –1968-1997. The average pipeline suffers one leak per year per 400 miles.

 © Sensornet 2007

Environmental Savings of Leak Detection System

Environmental costs are very difficult to predict and in cases the damages the operator has had to pay in the result of product spillage from a pipeline have been as high as $4.5mn [2] . With ever increasing environmental sensitivity and awareness these costs are continually increasing. 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.

By detecting and preventing the leak before major environmental damage occurs, the operator can significantly lower the risk profile to major environmental incidents.

Optimisation of Heating Process through DTS

For pipelines that are heated with heat trace, a sensing cable can be directly coupled to the pipeline. The Sentinel-DTS will be able to provide a full temperature profile along the length of the pipeline. 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, firstly it reduces the risks of the temperature dropping below the temperature where the oil can start to solidify (waxy oil or heavy oil), which will lead to increased probability of pipeline blockage. Secondly the additional monitoring of the pipe temperature also increases efficiency (i.e. not heating the cable excessively once the required temperature is achieved) providing a saving on energy costs of the heat trace system and also reducing maintenance schedules.

[2] *Colonial Pipeline November 1997 – United States*

 © Sensornet 2007

3. Principle of Measurement

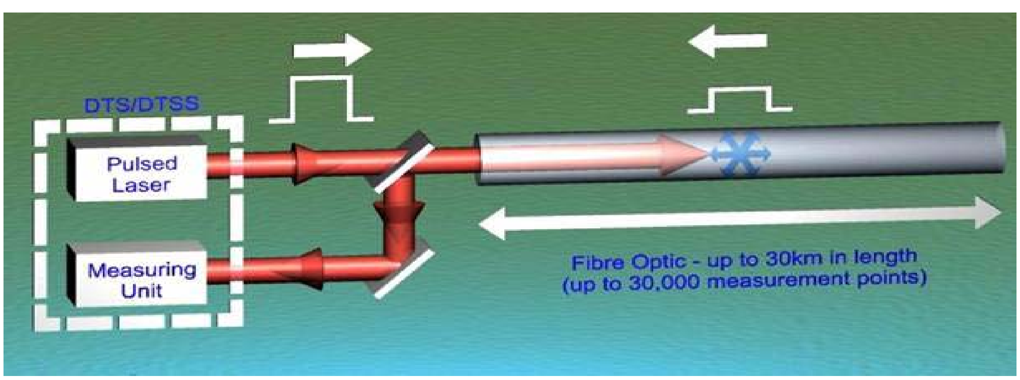
Leak Detection Using Temperature

When a leak occurs from a pipeline, the fluid or gas will contain a temperature signature, which will differ from the surrounding environments. 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 Sentinel 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 m.

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.

Distributed Temperature Sensor (DTS) – Physics of Measurement

The Sentinel DTS is able to take temperature measurements every 1-5m along a fibre optic cable with a coverage of 60km per unit. The DTS illuminates the glass core of the optical fibre with a laser pulse of 10 nanosecond duration (this corresponds to a 1m 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.

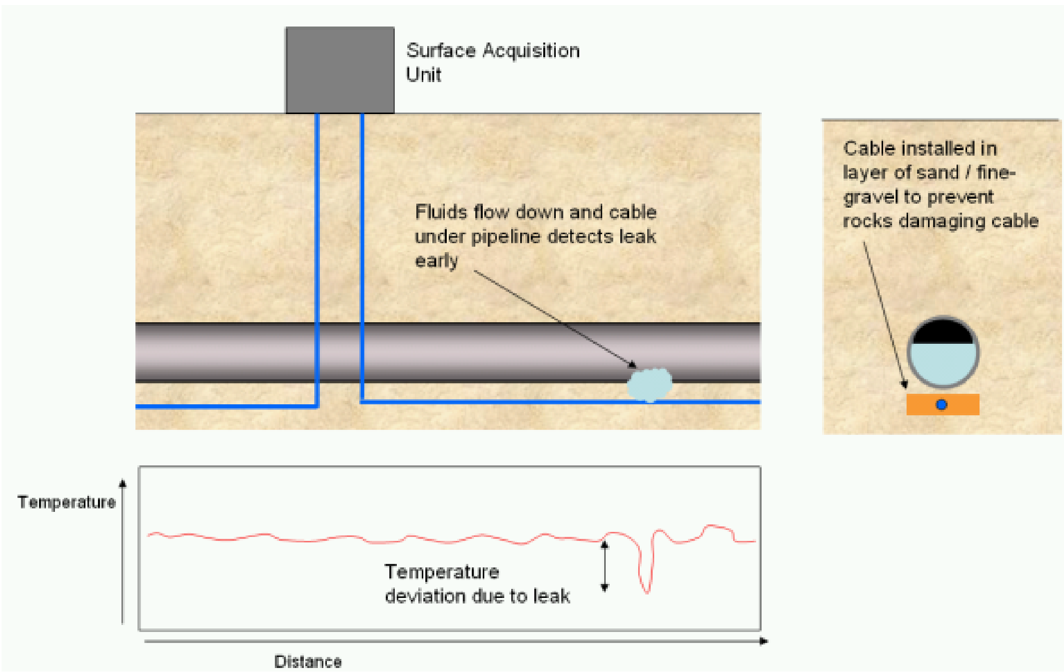


 © Sensornet 2007

Fluid or Gas Detection

The system is based on temperature measurements using distributed fibre optic sensing technology and can be used to detect both liquid and gaseous leaks.

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

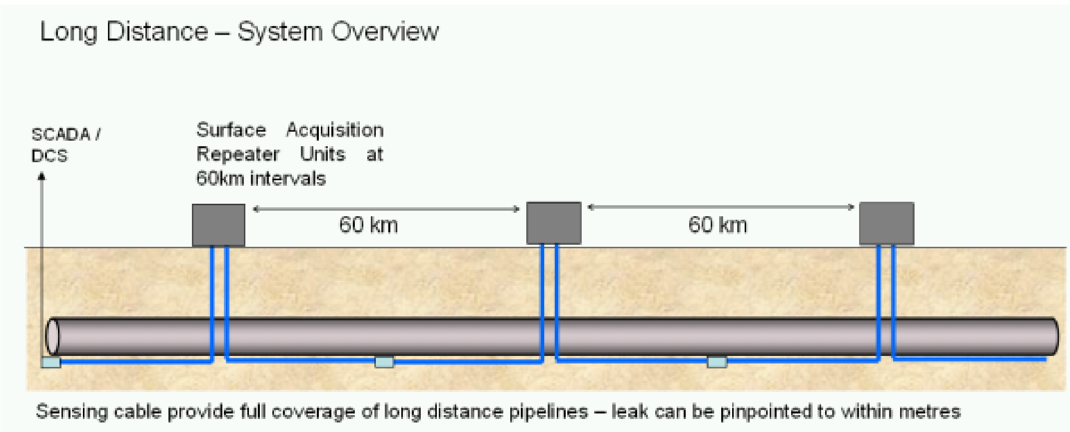


In the effect of liquid leakage (e.g. oil, water.) the temperature change is less pronounced, however the key is in the sensitivity of the system which can detect changes as small as 0.01°C. Using temperature measurements the system cannot only detect leakage but with calibration and advanced interpretation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

 © Sensornet 2007

Full Pipeline Coverage

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



In areas where structural movement is anticipated (e.g. 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 providing a total pipeline integrity solution.

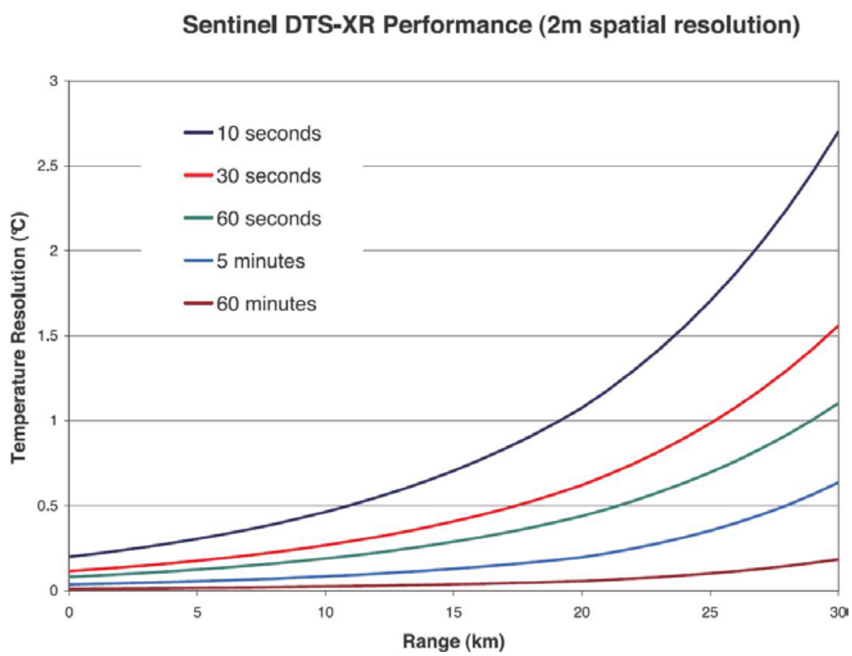
Depending on cable configuration, this system can also be utilised for intruder detection and the precise location of any intrusion can be pinpointed and communicated to the control centre.

 © Sensornet 2007

4. Distributed Temperature Sensing Unit (DTS)

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.

With all DTS systems there is a trade off between temperature resolution, spatial resolution, range and speed of measurement (e.g. 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 30km with a 2m spatial resolution.



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

 © Sensornet 2007

5. System Engineering, Design & 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 effected by ambient temperature changes.
- Installation methodology to minimise disruption to pipe-laying operations
- System integration with operator's control system (e.g. SCADA, DCS)

Sensornet has the full range of engineering expertise from design, through installation to ongoing system maintenance to provide a robust leak detection solution over the lifetime of the pipeline.

Sensing Cable Design

Sensornet has a range of sensing cable designs which are 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°C 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.

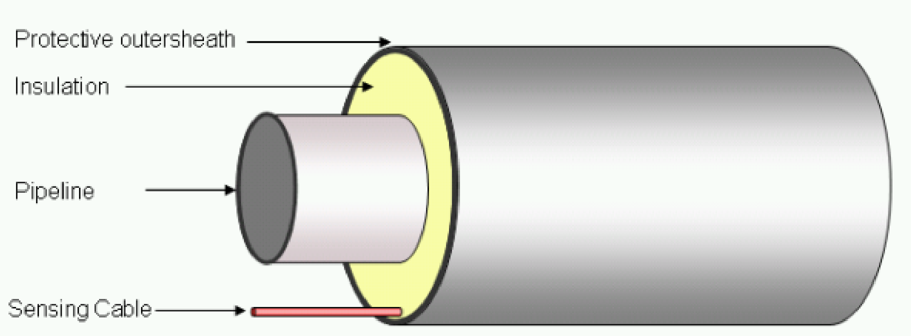
According to operator request, Sensornet can incorporate additional fibres for telecommunications into the design of the cable and thus reducing the need for an additional telecoms cable and reducing overall pipeline.

© Sensornet 2007

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 intelligent alarm software in order to remove false alarms.

Depending on the specific pipeline design (e.g. 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.



Example of Sensing Cable Installed Within Insulation

Safety & Reliability

Sensornet systems are built and designed to the highest standards and safety levels to provide the most safe and reliable system available today. The sensing cable itself is manufactured from only passive components and so if immune to the effects of vibration and EMC interference. Typical design lives of the cable are greater than 30 years. The systems have a laser safety rating of 1M* and the optical power levels are below the EUR 16011 EN (1994) standard and so the sensing cables are suitable for use in hazardous zones. With regards to overall system reliability the Sensornet system is independently certified to Safety Integrity Level 3 (SIL 3).

 © Sensornet 2007

6. Intelligent Automation

The Sensornet leak detection is equipped with automated intelligent 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. 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 zone will be flagged.

The Sensornet leak detection system can be fully integrated into the SCADA/ DCS system typically by using the telecoms fibre optics. At standard Sensornet interfaces using OPC /Modbus protocols or hardwired electrical relays but specific protocols can be customised for specific customer applications.

Intelligent Alarms

The pipeline route is divided into zones and alerts and data will be provided for each section. The 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

Overland vs. Underground Pipelines

The fluctuations in the ambient environment will be greater for the overland pipeline and so will require different alarms which have greater temperature tolerances. This will depend on the configuration of the pipeline (e.g. insulated vs. uninsulated) and the product within the pipeline (i.e. fluid vs gas)

7. Sensornet Reference Tests

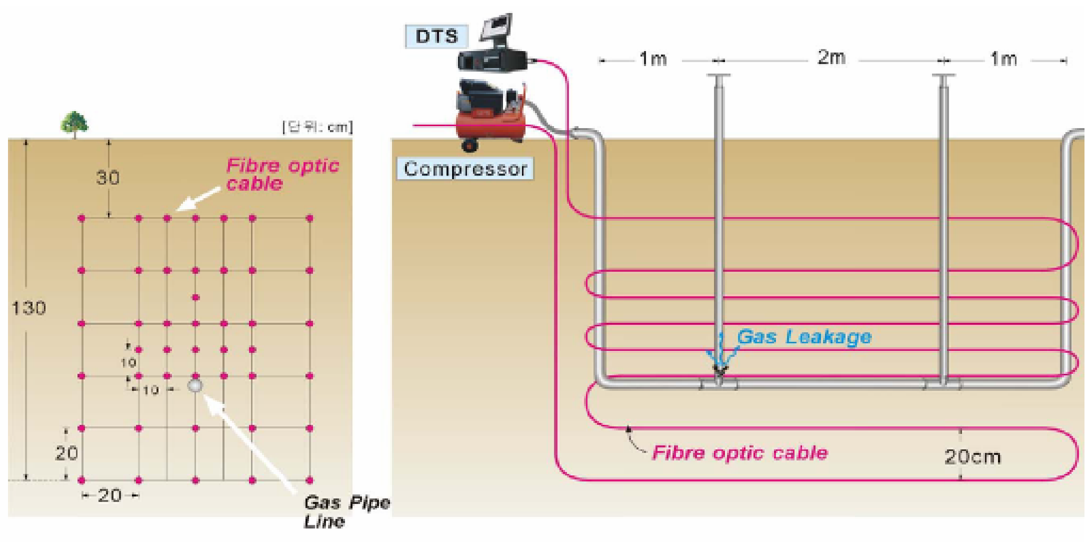
The following reference tests are examples of field deployed approval tests required by the end customer in order to approve the DTS system for use as a leak detection system. In addition to

 © Sensornet 2007

the two tests detailed (Korean Gas Authority, and Federal Energy Regulation Commission (FERC), Sensornet has additionally received independent approval from bodies such as TUV (Technische Überwachungs-Verein).

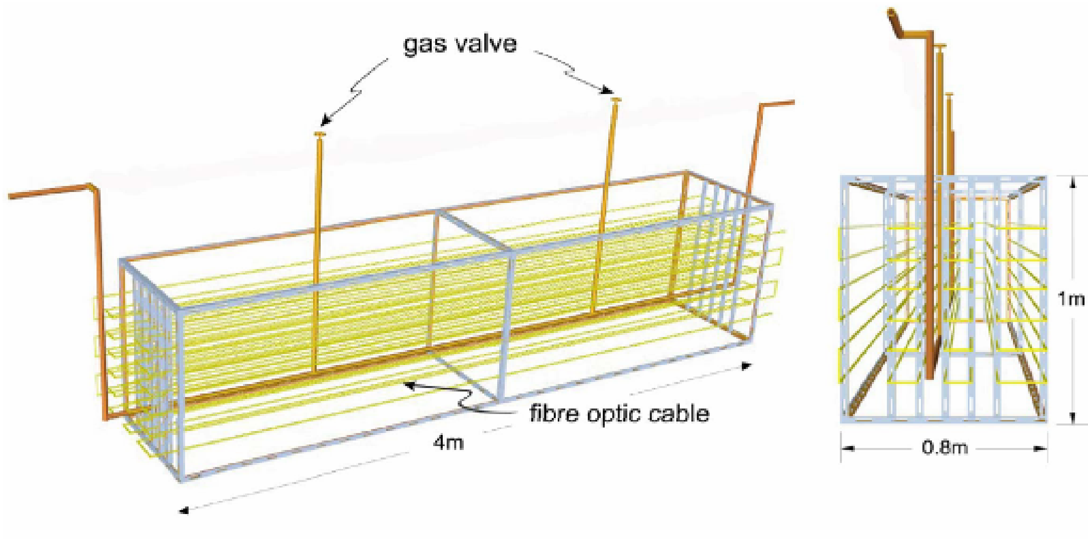
Reference Test 1 – Gas Leakage Detection

This test was carried out in Q2 2006 for the Korean National Gas authority in conjunction with Sensornet's Korean partner company SOAM Consultants Co. The aim of this project was to detect leaks in a gas pipeline using compressed air using the Sentinel DTS. Note with compressed air temperature changes are very small (2°C from ambient conditions). The setup of the system was as shown in the following two images:



■ Installation map of DTS cable for the gas leakage detection test

 © Sensornet 2007



Custom-made structure for installation of DTS cable around gas pipeline

Summary of Procedure

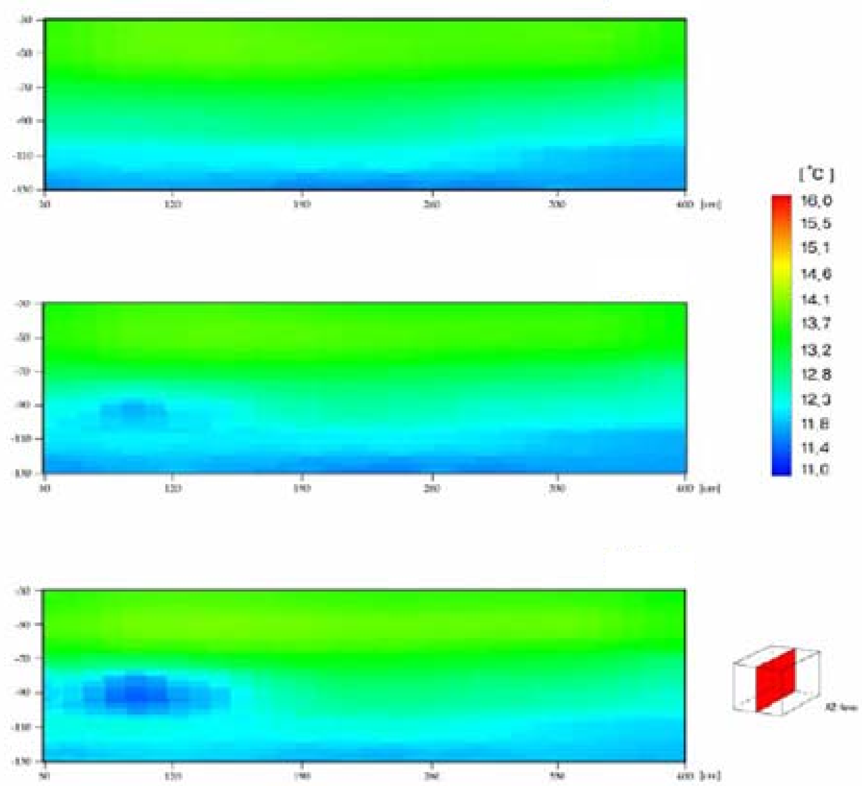
- A Sensornet Sentinel DTS system was used to monitor the temperature thermal response of the system due to gas expansion as a result of a leak occurrence.
- Compressed air was used as the gas contained in the pipeline. As the compressed leaks from the pipeline it cools on expansion – but only be a small amount (2°C)
- A section of pipeline with fibre optic cable installed in close proximity to the pipeline was buried underground. The pipeline contained valves to enable simulation of a leak event – by opening the valve a gas leakage could be created.
- The fibre optic cable was installed as close together as possible to the pipeline to accurately detect a result, using a frame to tie the cable to for easy installation.
- A leak was created by opening a valve (by use of a handle extension to the valve) in the buried pipeline.

The installation procedure is shown in the following diagrams:

 © Sensornet 2007

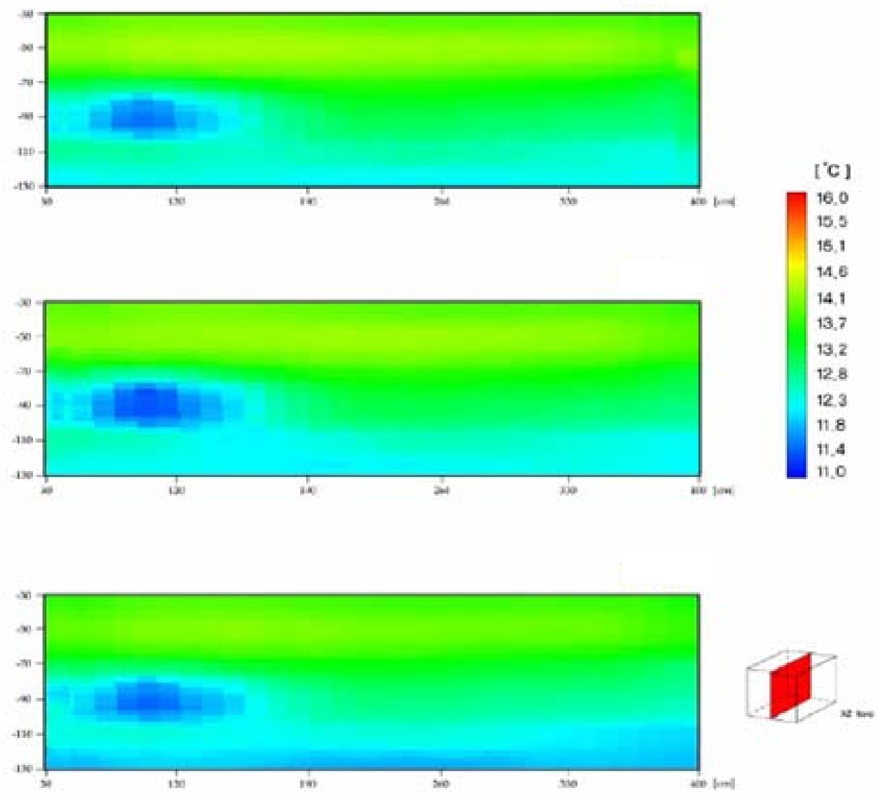
Installation procedure at the testing site

Results



Temperature change of the gas pipeline under its leakage along with time pass at vertical view (120 ℓ/min)

© Sensornet 2007



■ Temperature change of the gas pipeline under its leakage along with time pass at vertical view (120 ℓ/min)

Conclusion

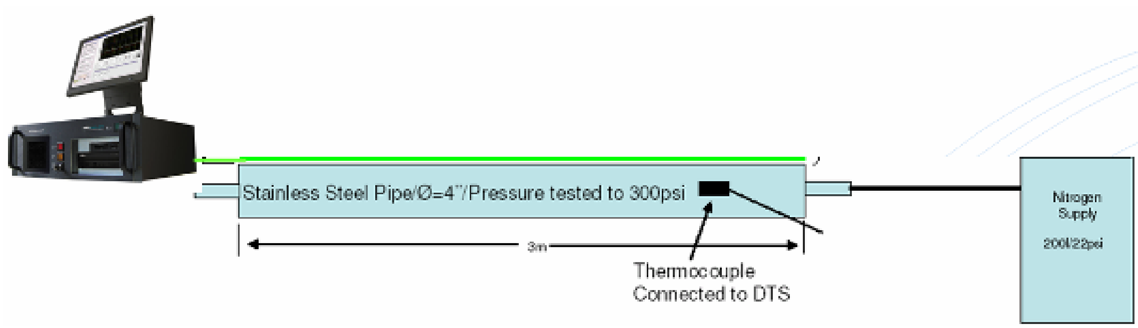
The Sentinel DTS effectively detects leaks using only very small temperature changes occurring due to expansion of gas causing a temperature drop (of approximately 2°C) in the surrounding environment (an area 40cm x 100cm).

 © Sensornet 2007

Reference Test 2 – Liquid Nitrogen

This test was carried out by Sensornet engineers for the US Federal Energy Regulation Commission in July 2006 in order to obtain approval to use the DTS as a leak detection system within an LNG facility. The aim of this project was to measure the response of DTS cables attached to the exterior surface of a pipeline containing liquid nitrogen using the Sentinel DTS.

The test compared the response of different fibre optic temperature sensing cables placed inside an HDPE duct which was placed in direct contact with the cold pipeline. The system setup is shown in the following diagrams:

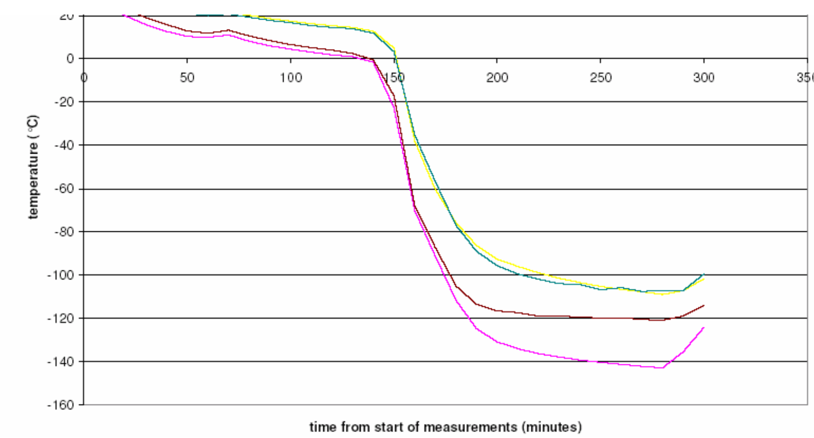


 © Sensornet 2007

Summary of Test

- A Sensornet Sentinel DTS system was used to monitor the low temperature thermal response of the system.
- The pipeline was a 3m long section of 4" steel tubing which was exposed to liquid nitrogen flow on the inside of the pipeline. The pipe was surrounded by 50cm of soil in all directions.
- Three different sensing cable types were used. One of these was an HDPE duct was strapped to the side of the pipeline which contained several different types of fibres to measure the temperature response of these fibres.
- Liquid nitrogen (-196°C) was pumped through a pipeline at a rate of approximately 3L/min. (To start with the flow rate was too low, therefore it was increased to 3L/min for a period of 50 minutes, as seen on the graph below between 150 – 200 minutes after the start of the test).

Results



Conclusion

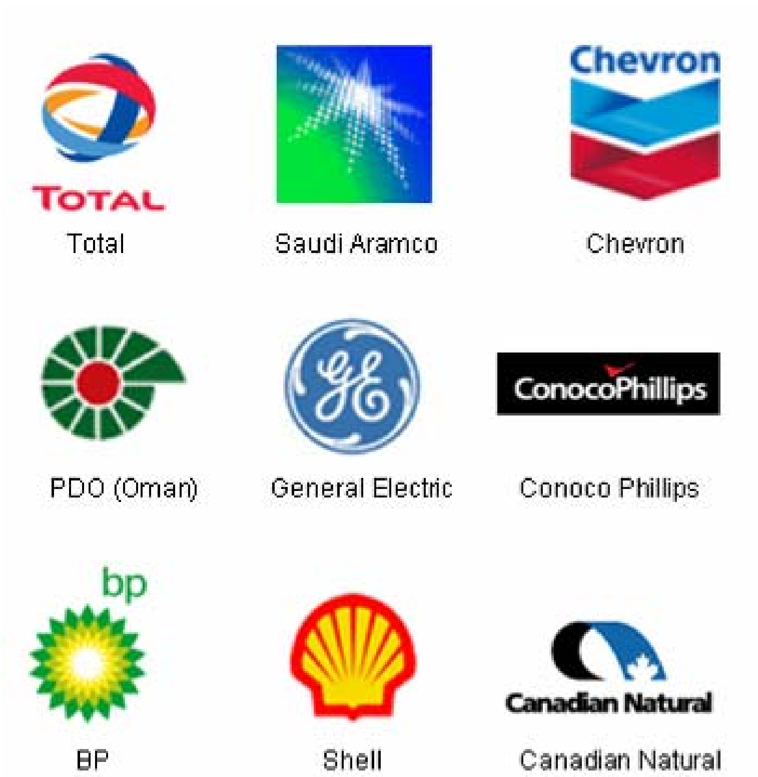
This test concluded that all of the cables tested, including the cable in the HDPE duct successfully showed differing rates of cooling (as seen by the slope of the curves above). Despite being insulated from the cold environment of the pipeline, the fibres in the duct experienced a very strong thermal response.

 © Sensornet 2007

8. Sensornet Leak Detection Sample Customers

Sensornet has worked on numerous commercial projects, across a range of industries with some of the largest global blue chip companies. These companies work in industries where safety and quality control are of the utmost importance and thus these companies work to procedures of the highest standard. Sensornet always aims to meet or exceed these standards and has developed its own rigorous safety and quality control procedures.

Below is a sample of some of the customers who Sensornet has worked with.



In addition to the 25+ dam seepage monitoring applications that Sensornet has carried out (see additional attachment for details), below are some examples of additional leak detection projects, which Sensornet has supplied the instrumentation.

© Sensornet 2007

9. Case Studies

The following case studies are examples of commercial installations where Sensornet has installed leak detection systems in industrial process/pipelines environments.

Case Study - Leak Detection Monitoring for Ethylene Pipeline

Sensornet Ltd installed and commissioned a Distributed Temperature Sensing system to monitor a 57km Ethylene Pipeline in northern Germany. This installation was monitored using a single Sentinel DTS-XR system, which is able to detect a leak in realtime and pinpoint the location to within a few metres.

Client Requirements

The Ethylene supply pipeline runs between the processing sites in Northern Germany. The pipe route operates at a 100bar pressure capacity and passes near residential areas. The integrity of the Ethylene pipeline is not only crucial to the operator's productivity but also to the local community and ecology and any leak from such a pipeline presents a potential environmental and safety hazard. According to German regulations such a pipeline must be monitored by a comprehensive leak detection system which also must be approved by the TUV (Technische Überwachungs-Verein).. The TUV is one of the global leaders in independent safety and quality assessment for industrial solutions and operates to the highest standard.

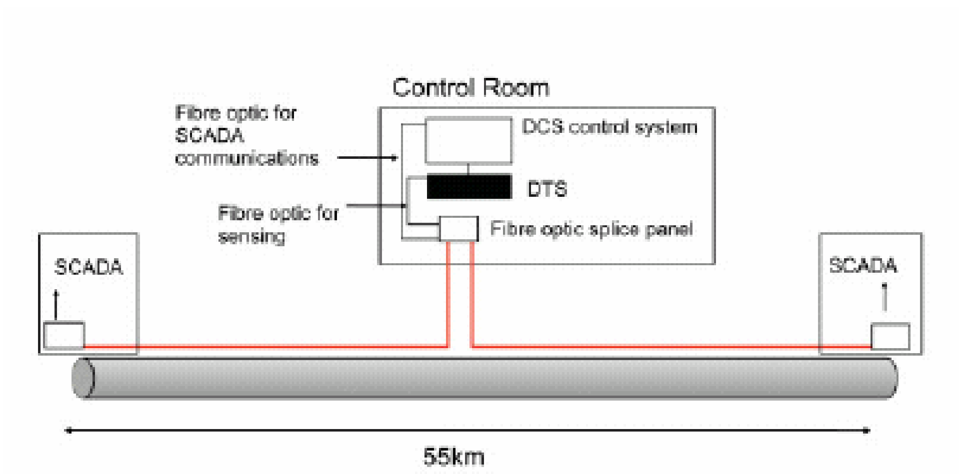
 © Sensornet 2007

Application

The sub ground pipeline was installed complete with a Singlemode fibre optic cable for the entire route, with a control station in the middle of the route. The multicore cable was utilised for data, telecoms and the Distributed Temperature Sensor system. The control station was therefore a natural choice for the deployment of the HMI and DTS equipment and the placement of the stations divided the cable routes into 26 and 31km runs. For this project a long range, Singlemode DTS-XR system was utilised (Sensornet also offers systems based on Multimode fibre which can cover > 60km).

The Monitoring Gap

The biggest issue for the client using existing technology was that it was not possible to pinpoint the location of the leak. Prior to using the Sensornet Digital Leak Detection system, the operator used a leak detection algorithm based on mass flow rate. This mass flow system monitors the physical parameters of the flow input and output and estimates if there is a leak in the system based on a computational algorithm. An additional issue is that this algorithm needs to be fined tuned over a period of 3-6 months and is very complex. Therefore, in addition to the mass flow system the operator must also commission a helicopter to fly the length of the pipeline on a regular basis to provide a visual inspection which is an expensive undertaking.



 © Sensornet 2007

The Sensornet Solution

The Sensornet solution is based on detecting the temperature changes in the environment in the event that there is a leak in the pipeline. Should a leak occur the Ethylene will cool to -110°C and revert to its natural gaseous form. The Sentinel DTS is able to detect such a temperature change and pinpoint the location to within metres. Using Sensornet's intelligent alarms software, the route was divided into specific zones with intelligent algorithms utilised to take into account transient temperature changes and minimise false alarms. As the monitoring station was a remote site, ensuring full capability with the existing SCADA system was a priority. This not only meant using the singlemode fibre infrastructure that was specified for the data acquisition network, but also integrating the DTS reporting and alert functions with the third party HMI. Sensornet provided this interface via a standards based Ethernet OPC server.

Substantial Benefits

The Sensornet Digital Leak Detection system provides protection over the entire length of the pipeline and is a non-intrusive detection system. In the event of a leak, this can be detected in real time and the location pinpointed to within a few metres. The response team can therefore react instantly and can be at the location of the leak without delay thus minimising the potential environmental and safety hazards. This sentiment was echoed by representatives of the TUV who independently approved and accredited the Sensornet Sentinel DTS system.

Measurable Performance

The Sentinel DTS-XR offers the most advanced performance available today. Measurement time can be from 10 seconds and temperature changes smaller than 0.1°C can be detected. For a 60km pipeline measurement points can be taken every 2m, providing over 100,000 points along the entire length of the pipeline, thus providing the operator with total integrity over the entire length of the pipeline.

 © Sensornet 2007

Case Study – Ammonia Plant (Italy)

System description	Leak Detection System for Ammonia Plant
Location	Ravenna, Italy
Commissioning date	February to April 2006
DTS system used	Sentinel DTS-SR
Route length	5km of DTS sensing cable
Measurement time	10 seconds
Operating temperature range	-30°C to +50°C
System interface	Alerts provided through electrical relay switches

General Description

This European based operator is the world's leading supplier of plant nutrients in the form of mineral fertilizers .The Ravenna site is located on 23 ha near the North East coastline of Italy, The site has the following production units: three nitric acid plants, one nitrate fertilizer plant, one ammonium nitrate solution plant, and one NPK plant. Ammonia is supplied by pipeline from the Ferrara plant.

The operator required a leak detection system for their ammonia plant for the pipeline network. The temperature of the ammonia within the pipelines is -30°C and so in the event of a leakage there will be a substantial temperature drop. The DTS was deemed a suitable technology for such a leak detection system. The system was configured to a 10 second measurement time and the alerts integrated into the control system using the Sentinel DTS alarm software and electrical relay interface module.

 © Sensornet 2007

Ammonia Facility

Sample of Instrumented Tank

 © Sensornet 2007

Case Study – LNG Pipeline Leak Detection (USA)

System description	Leak Detection System for LNG plant
Location	Freeport, Texas
Installation	Q1/Q2, 2006
Commissioning date	Q2 2006
DTS system used	Sentinel DTS-MR and DTSS
Route length	8km of DTS sensing cable
Measurement time	10 seconds
Operating temperature range	-160°C to +50°C
System interface	Alerts provided through electrical relay switches

General Description

A US LNG operator commissioned a leak detection system for their LNG plant, configured in such a way as to detect escaping liquid LNG from the main "VIP" transportation line in the event of an inner pipe breach by means of detection fibre being buried adjacent to the 2" exhaust pipe and by returning internally within the 2" exhaust pipe to detect escaping LNG in the event of a valve failure.

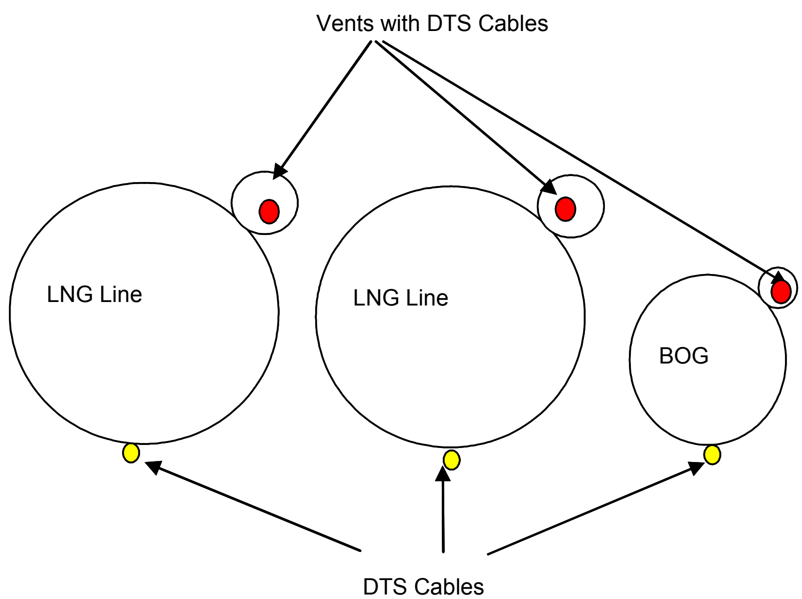
Additionally sensing cables were also installed buried underneath the pipelines within a levee. These cables contained both temperature and strain sensors. The temperature sensing cables will be used as a leak detection system and the strain sensing cables will monitor if there is any subsidence along the length of the pipeline and will act as an early warning system to detect any structural deformations.

The cable will be installed in two phases. Firstly the strain cable will be built into the Levee prior to the installation of the pipeline. Then when the pipeline is installed the DTS cable will be installed both under the pipeline and on the pipeline vents. The installation will be carried out by an approved Sensornet installation team. The total sensing cable route for the DTS will be 8km and 4.5km for the strain sensing cable.

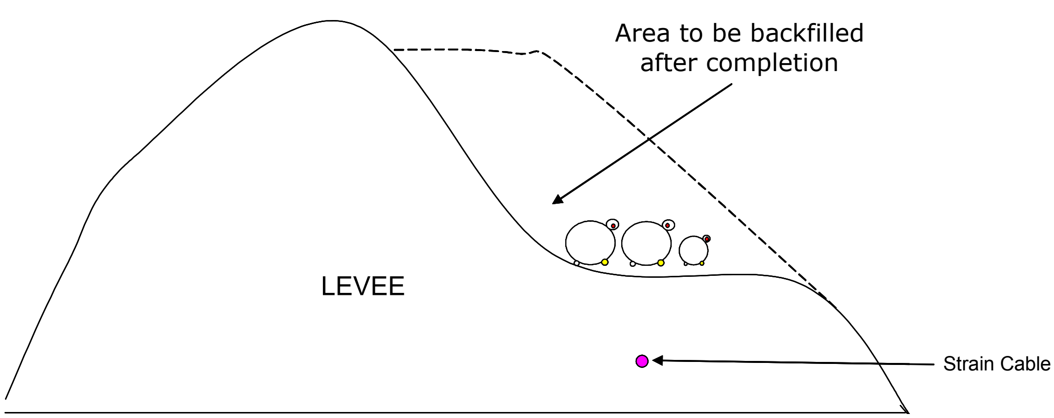
 © Sensornet 2007

The leak detection system will provide updates every 10 seconds and will be integrated into the control system using the Sentinel DTS alarm software and the electrical relay interface module. The strain measurements will be provided as a service on an ongoing basis (it is anticipated that this will be on a 6 monthly basis).

Configuration of DTS Sensing Cables

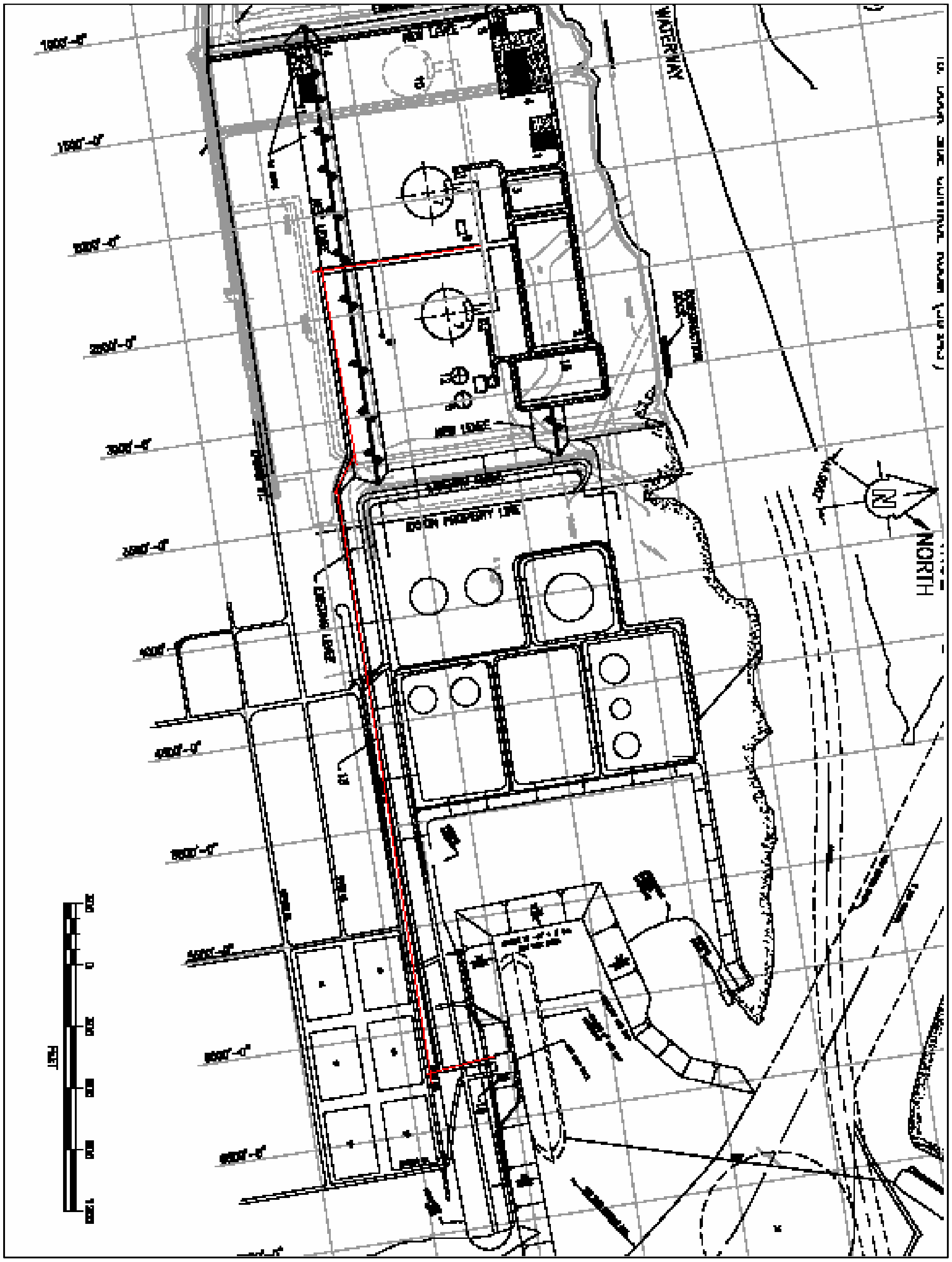


Configuration of DTSS Strain Sensing Cables



 © Sensornet 2007

Installation Site Diagram



Case Study – Shell Refinery Pipeline Leak Detection

Sensornet carried out an installation of the Sentinel DTS as leakage detection system on a product pipeline at a European refinery and petrochemical complex for Shell Global Solutions. The results proved the ability of the Sentinel distributed temperature sensor (DTS) – to monitor temperature variances with a high degree of resolution, and to not only detect simulated leaks but also to predict where such a pipeline failure might occur.

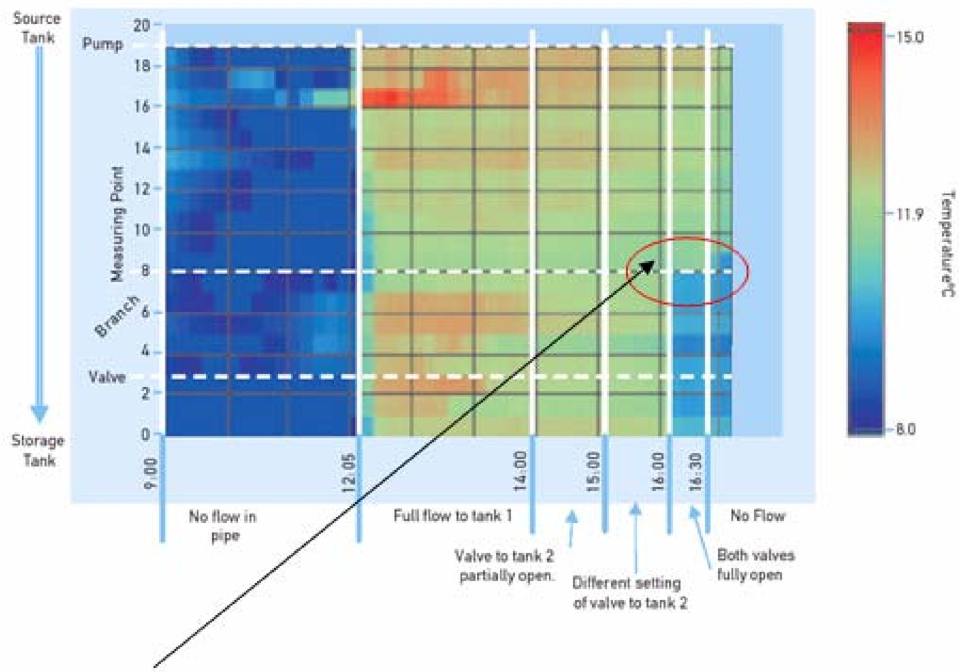
Sensornet systems can both detect a pipeline leak and determine where pipeline failure might occur.

The system was put through a leak detection simulation on the refinery pipeline where, for two days in November weather, the system proved their ability to detect small variations in temperature under a variety of operating conditions.

Throughout the testing, the DTS showed a temperature resolution of better than 0.1ºC with rapid, one-minute measurements and was even able to capture the thermal signature of the fluid as it moved down the pipe.

In this test a major leak condition was simulated in which the flow downstream from the leak was significantly less than upstream of the leak. It was anticipated that the DTS would be able to detect a different temperature signature downstream from the leak in comparison with the upstream temperature signature.

 © Sensornet 2007



Leak Simulation started at this point.

As can be seen in the diagram the point of leakage can clearly be identified. From the data you can see 3 clear flow zones from the temperature profile that varies over time.

Zone 1 9:00 to 16:00 – No flow

In this period the fluid has reached thermal equilibrium with the surroundings and the pipeline is at a temperature of approximately 8°C

Zone 2 12:05 to 16:00 – Steady flow

In this period the pipeline warms according to the temperature of the petroleum inside the pipeline. This varies from 12° to 15°C.

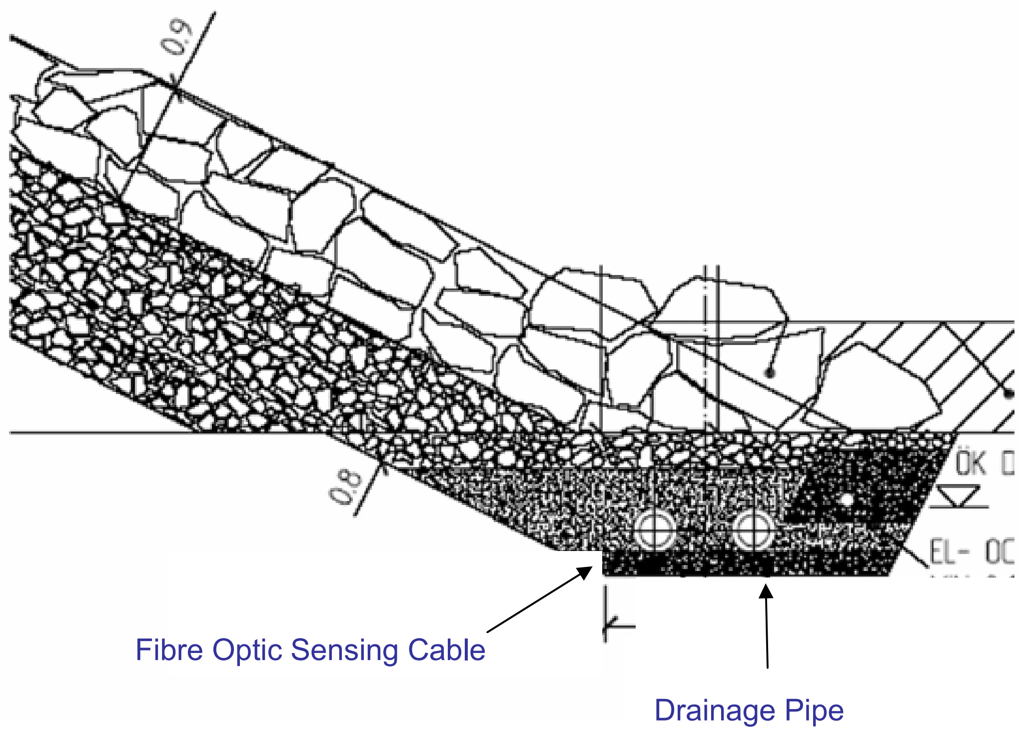
Zone 3 16:00 to 16:30 – Leak simulation

In this period a leak was simulated and the flow downstream (between measurement points 0-8) was significantly less than the flow upstream (measurement points 8-20). It can be seen that in the lower flow zone the temperature drops due to the fact that there is less thermal mass of liquid and therefore the temperature of the pipeline returns to equilibrium.

 © Sensornet 2007

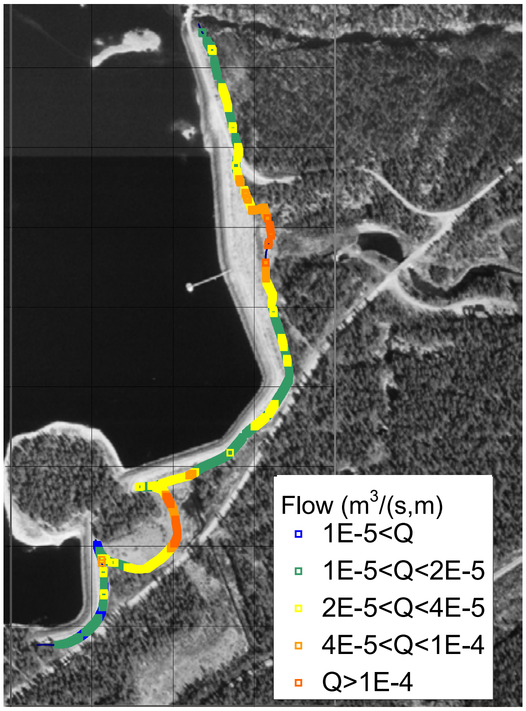
Case Study – Drainage Pipeline Seepage Detection

This Swedish installation is 1300m long and the fibre optic sensing cable was installed along the downstream toe of the dam just upstream of the drainage system, in order to monitor the seepage flow. The main purpose of this installation is to complement the conventional seepage monitoring system. The detail of the cable installation at the toe of dam is shown in the image below:



By applying an especially developed version of the HydroResearch DamTemp software, the seepage flow was evaluated for each metre along the length of the fibre. The flow was generally in the order of $10^{-5}m^3/s,m$ as seen in the figure below. The total seepage flow passing the fibre was estimated to be 20l/s, of which about 12l/s passes through the natural headland outcrop. This result agrees well with the measured flow rates, varying within a typical annual range of 1.5 to 15l/s. These results are shown on the following image – which displays the result from seepage evaluation from one measurement at the Vässinkoski dam.

 © Sensornet 2007



Based on this initial measurement it was concluded that the seepage flow in the dam was normal and no major water-leakage was detected. This also agrees with results obtained from surveillance of the dam and from conventional seepage flow measurements.

Conclusions

The experience gained from the installations in Sweden show the potential of this monitoring technology, and installation of optical fibre is now almost a standard at re-construction works on embankment dams. The seepage monitoring capability is similar to conventional methods, but has a much higher spatial resolution. Small seepage flow changes, as a result of internal erosion, can be detected and located at a very early stage.

© Sensornet 2007