

Real Time Pipeline Leak Detection on Shell's North Western Ethylene Pipeline

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ABSTRACT

In the past ten years, a number of pipeline leak detection systems have been implemented on various operational pipelines. Unfortunately the feedback from pipeline operators illustrates that some of these systems have not performed satisfactorily for the following reasons:

- □ They generate frequent nuisance alarms when there is no leak in a pipeline.
- □ They are difficult for users to understand.
- □ They are expensive to maintain.

Consequently, there is a tendency for leak alarms to be neglected and in some cases the systems are switched off completely.

This paper examines the application of state-of-the-art technology (ATMOS PIPE) to the 413 kilometre long North Western Ethylene Pipeline, for Shell UK Limited. Following the technical introduction, the paper addresses the performance of the system over the past two years. Experience on this high pressure ethylene pipeline demonstrates that

- □ It is possible to have a reliable real-time leak detection system.
- □ An effective leak detection system need not be highly complicated.
- □ System maintenance cost can be minimised with the use of new technology.

1 INTRODUCTION

The North Western Ethylene Pipeline was commissioned by Shell in 1992. The pipeline transports high pressure (dense phase) ethylene from Grangemouth in Scotland, via Cumbria and Lancashire, to Stanlow refinery in Ellesmere Port. The cross-country pipeline is 413 kilometres long.

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The smooth operation of such a long and hazardous pipeline demands continuous monitoring. To achieve high integrity, Shell incorporated considerable details during the design of the pipeline and instrumentation system. For example,

- Cathodic protection for the whole pipeline.
- There are 25 block valves along the pipeline that can be operated remotely.
- Pressure and temperature meters are installed both upstream and downstream of the block valves.
- At the inlet and outlet of the pipeline, two sets of flow, pressure, temperature and density meters are installed.
- Two SCADA computers are used. One works as the duty machine and the other as hot standby.
- Redundant telecommunication systems are used so that it is highly unlikely for the SCADA system to lose communication with two consecutive block valves.
- A pipeline leak detection system.
- Regular intelligent pigging.
- Road and aerial surveillance.

In the past ten years, a number of pipeline leak detection systems have been implemented on various operational pipelines. Unfortunately the feedback from pipeline operators illustrates that some of these systems have not performed satisfactorily (1), (2). The main problem with these systems is the generation of frequent nuisance alarms. To overcome this problem, Shell has developed a statistical leak detection system following several years of research and field trials (3). This system is licensed to REL Instrumentation Limited and it is trade marked as ATMOS PIPE.

ATMOS PIPE had been previously applied successfully to a liquid propylene and crude oil pipeline in Shell UK Limited (4), (5). To achieve the same high level of reliability, Shell decided to install ATMOS PIPE on the North Western Ethylene Pipeline.

ATMOS PIPE was implemented on a Personal Computer in December 1997. It gets all the instrument data from the existing SCADA computer at 30 second intervals. After processing the data, the pipeline status (normal or leak) is sent back to the SCADA computer together with the leak rate and location estimates.

Shell performed a Site Acceptance Test in March 1998. ATMOS PIPE has detected a “leak” of 8 ton/hour (0.38 m³/minute) in 15 minutes, with very accurate leak size and location estimates.

During normal pipeline operations, ATMOS PIPE does not generate nuisance alarms, and over the last two years of operation, it has proven to be highly reliable.

2 PIPELINE DESCRIPTION

The lay out of the pipeline is shown in **Figure 1**. The pipeline is 10” diameter, and **413 km** long. The pipeline runs through hilly areas with large elevation changes (**Figure 2**).

There are 25 block valves along the pipeline. The locations of these block valves are shown in **Figure 1**. About half way along the pipeline, at Block Valve 12, an intermediate pump station (IPS) is present. The pumps at the IPS were commissioned in 1998, and are started and stopped to suit operational conditions.

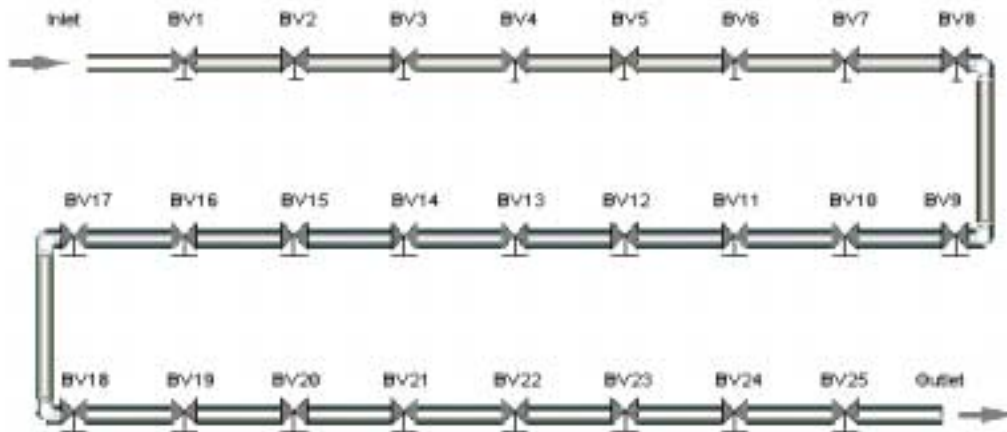


Figure 1 Lay out of the ethylene pipeline

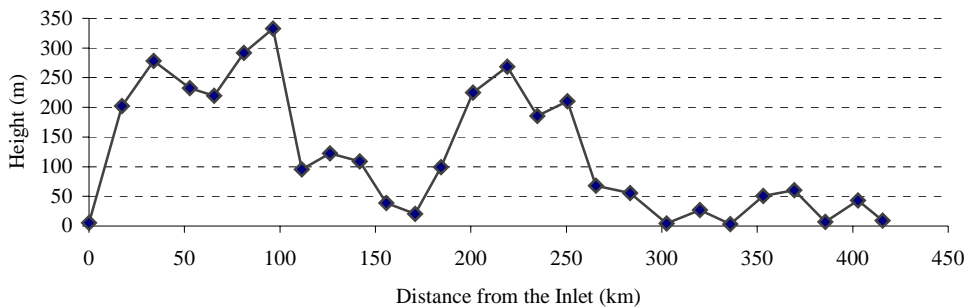


Figure 2 Pipeline elevation profile

Flow, pressure, temperature and density meters are available at the inlet and outlet of the pipeline. Pressure and temperature are measured both upstream and downstream of the block valves. In total there are about 160 measured variables including 25 block valve position indicators. Each of these measurements has a quality status attached, indicating the confidence level in the measurements.

3 IMPLEMENTATION OF ATMOS PIPE

The project was initiated in May 1997. The existing instrumentation system was already collecting all the flow, pressure, temperature, density and valve data. Therefore the only hardware required to install ATMOS PIPE was a Personal Computer. **Figure 3** shows the interface between ATMOS and the instrumentation system.

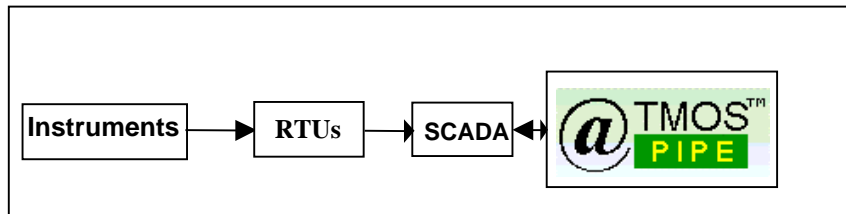


FIGURE 3 THE INTERFACE BETWEEN ATMOS AND THE INSTRUMENTATION SYSTEM
(RTU — Remote Terminal Unit, SCADA — Supervisory Control And Data Acquisition)

In August 1997, the PC was installed on site to collect the operational data. These data were then used to tune the system parameters so that no false alarm was generated under normal operational conditions. Based on the customer's specifications on the leak detection response time and data collected between August and November 1997, ATMOS PIPE was commissioned in December 1997.

The main functionality of the system is:

- Collection of flow, pressure, temperature and valve data at 30-second intervals.
- Validation of the above data so that faulty instruments are diagnosed and “bad” data are rejected.
- Detection of leaks under different operational conditions: transient, steady state and shut-in.
- Estimation of leak size and location.
- Record of historical data and events.

To optimise the system performance, the following key features were included (1):

Reliability

There are 160 measured variables from the SCADA system. It is highly probable that one of these measurements is not correct at any specific time. To eliminate errors introduced by such data faults, a comprehensive data validation module is implemented. This operates in three stages:

- Status check. Each measurement has a status variable attached. If the status indicates that the measurement is not “OK” then it will not be used.
- Redundancy check. Since there is sufficient redundancy in the instrumentation system for ATMOS PIPE to compare different readings, a datum will not be used if it is inconsistent with its redundant measurement. For example, if the pressure readings upstream and downstream of a block valve differ by more than the pressure drop over the valve, then both readings will be suspect. Only the pressure that is consistent with the other block valve pressure measurements will be used.
- Independent check. Each data point is validated and it is rejected if it is out of range, does not change at all for a period of time, or the rate of change is too high within a short time period.

Robustness

The instrumentation system consists of field instruments, telecommunication equipment and SCADA computers. A failure in any of this equipment would result in the loss of measurement

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data. ATMOS PIPE was designed so that it will continue monitoring the pipeline as long as the flow measurements at the inlet and outlet are available i.e. even when all the pressure and temperature data from the block valves and inlet and outlet have failed.

To maintain a high reliability level when some of the instruments are not available, the statistical parameters are changed automatically. For example if the measurements from all the even block valves are unavailable, then the system will be desensitised such that the leak detection time will be 10% longer than when all the measurements are available.

Sensitivity

Without loss of reliability, ATMOS PIPE was designed such that the detection time is minimised for various operating conditions and changing instrumentation system scenarios. Three operating modes are included:

- steady state,
- medium operational change,
- large operational change.

Changes in the above operating modes are detected automatically and different sets of statistical parameters are used for each of the modes.

Accuracy

Leak rate and location estimates are provided after a leak alarm is generated. Accurate leak rate estimate is achieved by removing instrument errors using statistical calculations. These calculations are carried out continuously during normal operating conditions. Therefore gradual instrument drifts over a long period of time will be excluded from leak size estimation.

It is difficult to estimate leak location accurately based on instrument readings. The North Western Ethylene Pipeline is particularly hard for a conventional leak detection system because

- the equation of state is not well established for ethylene
- the pipeline elevation varies significantly and it is difficult to measure the elevations accurately (**Figure 2**).

ATMOS PIPE calculates the leak location statistically. Since flow and pressure data are used to calculate the actual pressure profile, no theoretical assumption is made about the equation of state and pipeline elevation data. With the availability of accurate flow and pressure measurements for this pipeline, accurate leak location estimates have been achieved.

4 SITE ACCEPTANCE TEST

Following the installation in December 1997, ATMOS PIPE had worked continuously without generating any false alarms. Shell conducted a Site Acceptance Test in March 1998 to test its performance when a leak occurs.

On the 25 March 1998, a leak of about 8 ton/hour ($0.38 \text{ m}^3/\text{minute}$) was generated by flaring ethylene at Block Valve 2 (34 kilometres from the inlet). ATMOS PIPE generated a leak warning **11 minutes** after the leak and confirmed the leak 4 minutes after the leak warning. At the same

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time, an accurate leak location was given which was **33.8 km** from the inlet. The average leak size estimated was 7.6 ton/hour.

Figure 4 shows the field test results including the seven statistical variables “lambda0” to “lambda6” and the threshold value. Leak alarm status and leak size estimate are given in **Figure 5**. **Figure 6** illustrates the leak location estimate.

As shown in **Figure 4**, at time **9:35:00** Lambda0, Lambda1, Lambda2, Lambda3, Lambda4 and Lambda5 started to increase indicating the initial leak size was between 5.0 and 12.5 t/h. At time **9:46:30**, Lambda4 was 5.0 which was greater than the threshold value of 4.6. Therefore a leak warning was generated (Alarm status changed from 0 to 1) i.e. in 11.5 minutes Lambda4 increased from -7.0 to 5.0. A leak alarm was generated at time **9:50:00** (**Figure 5**, alarm status changed from 1 to 2), the leak size estimate was 8.69 t/h and location 33.8 Km from the inlet.

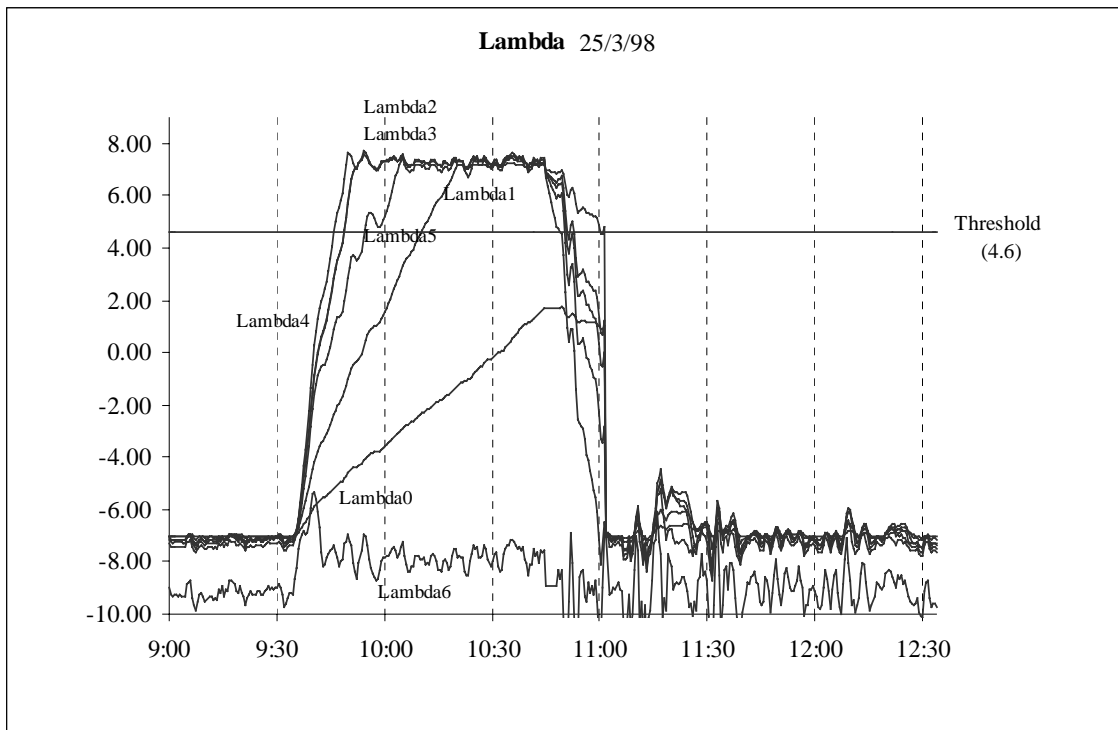


Figure 4 The response of the statistical variables during the SAT

From time 9:50:00 to 10:45:00, the leak size estimate varied between 6.7 and 9.1 t/h and the average is **7.6 t/h** (**Figure 5**). The leak location estimate stayed around 33.8 Km (**Figure 6**).

The leak alarm was cleared (alarm status from 2 to 0) at time 11:00:00 but went back to 1 (leak warning) for one sample before settling back to 0 at time 11:02:00 (**Figure 5**).

Following the successful leak test, Shell has accepted the system and it has been running satisfactorily since the site acceptance test.

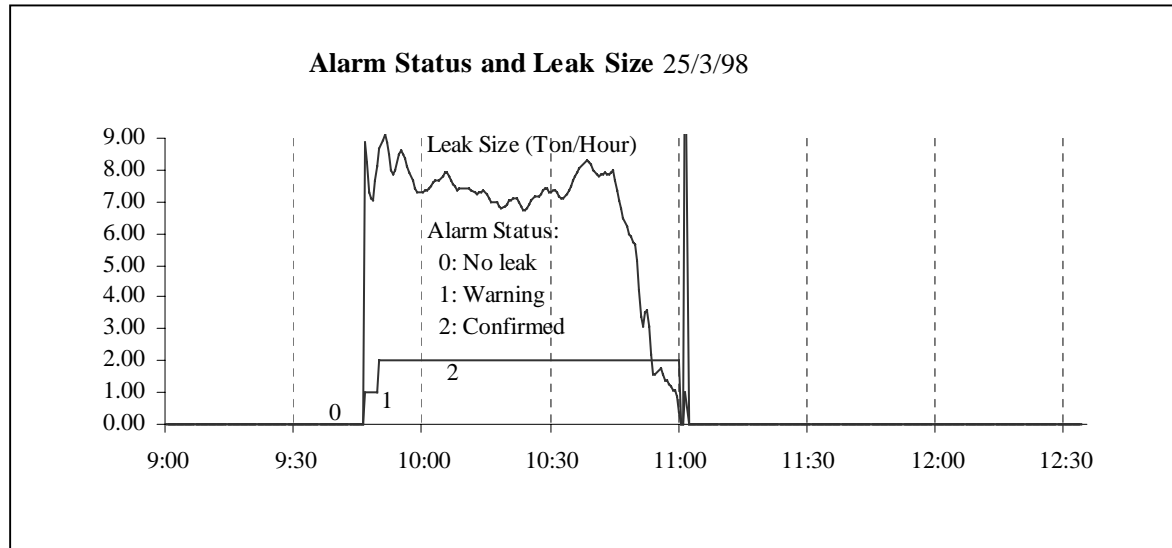


Figure 5 Leak alarm response and leak size estimate during the SAT

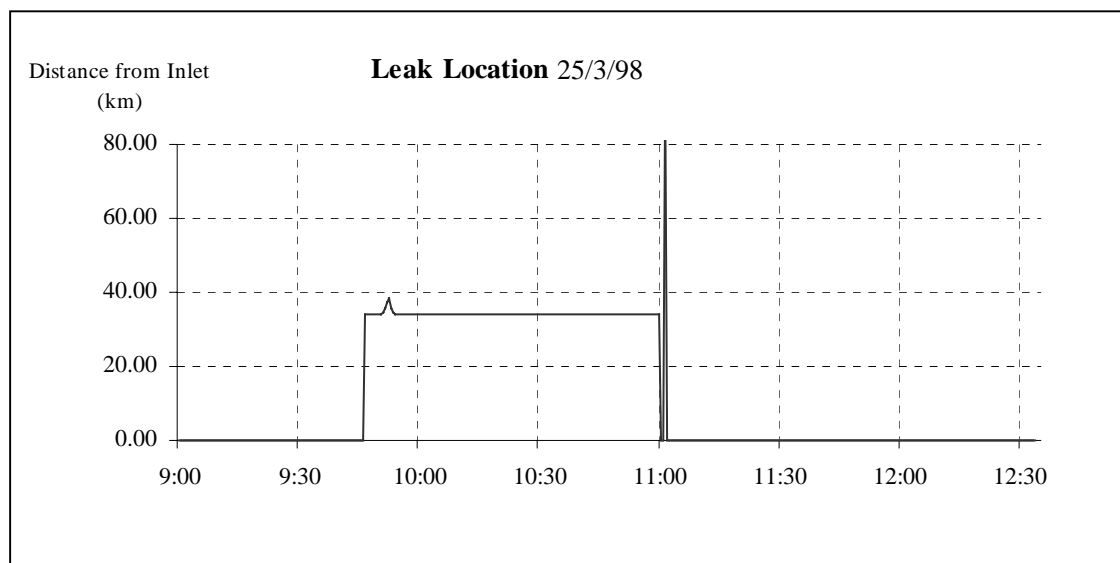


Figure 6 Leak location estimate during the SAT

5 SYSTEM PERFORMANCE DURING NORMAL OPERATIONS

ATMOS PIPE has been monitoring the North Western Ethylene Pipeline since December 1997. Significant operational changes have occurred during this period, for example:

- The IPS pump was commissioned at the middle of the pipeline so that one or two pumps can be started and stopped when required.
- Pigging has been carried out for the whole pipeline length.
- The pipeline was in a shut-in condition for a short period of time when no flow is pumped into or out of the pipeline.
- Partial loss of instrument data due to power failure caused by lightning or other events.

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ATMOS PIPE has experienced the above changes without loss of functionality or reliability. In 1998, for example, only one leak alarm was generated due to IPS pump shut down and ATMOS did not recognise the change quickly enough. This type of alarm will not occur again as the IPS status is now sent to ATMOS to inform it of any changes immediately.

In addition to leak detection, ATMOS PIPE has been used to provide instrument monitoring. Both on-line and off-line analysis can be carried out for each individual instrument so that its performance is assessed and additional information is provided for maintenance and support. Other value-added services provided by ATMOS PIPE include:

- Flow discrepancy analysis between the inlet and outlet,
- Inventory tracking and survivability analysis,
- Pig tracking,
- Management information.

Although ATMOS PIPE was installed back in 1997 it is fully year 2000 compliant. There was no additional cost to the customer for Y2K tests. The overall maintenance cost is also low compared with conventional systems.

6 COMPARISON WITH OTHER TECHNOLOGIES

Different leak detection technologies can be used to meet the application requirements (4). For the continuous monitoring of a pipeline, the following software-based methods are available:

- Volume or mass balance
- Rate of change in flow or pressure
- Hydraulic modelling
- Pressure point analysis
- Statistical analysis (ATMOS PIPE).

Depending on the design and implementation of a particular technology, the performance of a leak detection system varies significantly. The best technology may not work if it is engineered poorly. Therefore only a general comparison of performance is given in Table 1 and no particular reference is made to any commercial products.

Table 1 Comparison of different methods

Method	Reliability	Robustness	Sensitivity	Accuracy
Mass balance	Medium	High	Medium	Medium*
Rate of change	Medium	High	Medium	N/A ^{&}
Hydraulic modelling	Medium	Low	High	Medium
Pressure point analysis	Medium	High	Medium	N/A ^{&}
ATMOS PIPE	High	High	High	Medium

* Leak location is not estimated by mass balance method.

& Leak size and location are not estimated.

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As shown in Table 1, most of the above methods are robust since they can monitor a pipeline continuously even when some instruments fail. However, a common shortcoming of these methods is that they either do not provide a leak location estimate or cannot pinpoint a leak accurately. Although ATMOS PIPE located the leak accurately during the site acceptance test on the North Western Ethylene Pipeline, it is because the leak was at a block valve where pressure measurements were available. For most applications, it is not feasible for any of these methods to pinpoint a leak with no error. The main reason is that these methods work based on measurements given by field instruments that are not 100% accurate. To improve the leak location accuracy, continuous research and development have been carried out at REL Instrumentation Limited.

7 CONCLUSIONS

ATMOS PIPE is state-of-the-art leak detection technology. Its application to the North Western Ethylene Pipeline proves that it has minimum false alarms during normal pipeline operating conditions and it is cost effective to maintain.

The Site Acceptance Test shows that it detected an 8 ton/hour (0.38 m³/minute) leak in 15 minutes with accurate leak rate and location estimates. The statistical characteristics provide it with a self-tuning capability allowing it to monitor the pipeline for its entire life cycle at minimum costs.

Following the successful application to the North Western Ethylene Pipeline, Shell has installed ATMOS PIPE on both the Runcorn to Stanlow and Stanlow to Montell ethylene pipelines. Recent applications to other gas and liquid pipelines have further proven that it is possible to have a robust and reliable but simple leak detection system.

Acknowledgement

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