Statistical Pipeline Leak Detection Techniques for All Operating Conditions

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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 many 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 various gas and liquid pipelines. Following the technical introduction, the paper addresses the performance of the system under all operating conditions. Experience on different pipelines 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

ATMOS PIPE is a statistical pipeline leak detection system, incorporating advanced pattern recognition functions. It was developed in Shell using advanced statistical techniques to analyse the flow and pressure measurements of a pipeline. Variations generated by operational changes are registered, insuring that a leak alarm is generated only when a unique pattern of changes in flow and pressure exists (Zhang, 1993)

This statistical method does not use mathematical models to calculate flow or pressure in a pipeline but it detects changes in the relationship between flow and pressure using measurement data available. As the system monitors a pipeline continuously it learns about continual changes in the line and flow/pressure instruments.

An optimum sequential analysis technique (Sequential Probability Ratio Test) is applied to detect changes in the overall behaviour of the inlet and outlet flow and pressure. It works based on the observation that although the control and operation may vary from one pipeline to another, the relationship between the pipeline pressure and flow will always change after a leak develops in a pipeline. For example, a leak could cause the pipeline pressure to decrease and also introduce a discrepancy between the inlet and outlet flow-rate. This leak detection system is designed to detect such changes i.e. pattern recognition.

Real-time applications and field tests prove that ATMOS PIPE is superior to conventional leak detection methods. Some examples of applications are given below.

2 THE NORTH WESTERN ETHYLENE PIPELINE

The North Western Ethylene Pipeline was commissioned by Shell UK 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 257 miles (413 kilometres) long.

There are 25 block valves along the pipeline, and there is an intermediate pump station (IPS) about half way along the pipeline, at Block Valve 12. The pumps at the IPS were commissioned in 1998, and are frequently started and stopped to suit operational conditions.

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.

ATMOS PIPE was implemented on a Personal Computer in December 1997. ATMOS PIPE 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.

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.

Shell performed a Site Acceptance Test in March 1998. ATMOS PIPE detected a “leak” of 8 ton/hour (13.4 ft^3/minute) in 15 minutes with very accurate leak size and location estimates. In November 1999, Shell carried out two more site tests:

- The first test was carried out with the intermediate telemetry points at all the odd block valves disconnected to observe the degradation on system performance. ATMOS PIPE detected this leak in 23 minutes and provided an accurate leak size of 7.8 ton/hour (13.1 ft^3/minute) and a leak location of 198 miles (319 kilometres) from the inlet. The actual leak location was 190 miles (305 km). The difference of 14 km occurred because the block valve site nearest to the leak was actually off-line as part of telemetry exercise.
- The second test was the same as above except that all the telemetry points were re-established. ATMOS PIPE has detected the leak in 20 minutes and provided a very accurate leak location of 190 miles (305 km) from the inlet.

Figure 1 shows the site test results on 25 March 1998, including the seven statistical variables “lambda0” to “lambda6” and the threshold value. Leak alarm status and leak size estimate are given in **Figure 2**.

During normal pipeline operations, ATMOS PIPE generates no nuisance alarms, and over the last two years of operation, it has proven to be highly reliable.

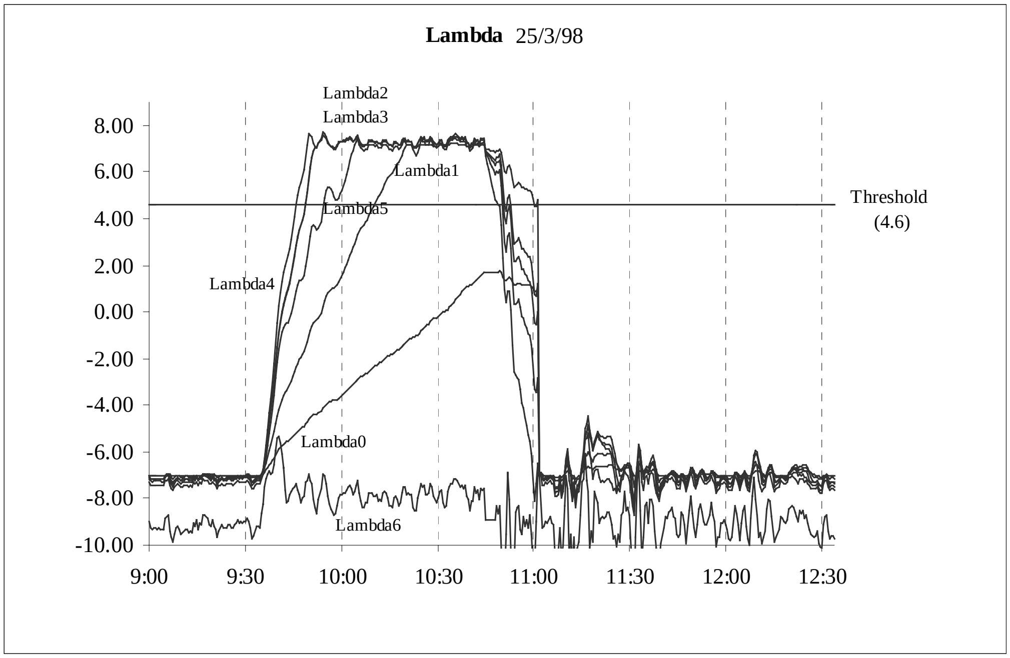

Figure 1 The response of the statistical variables during the SAT

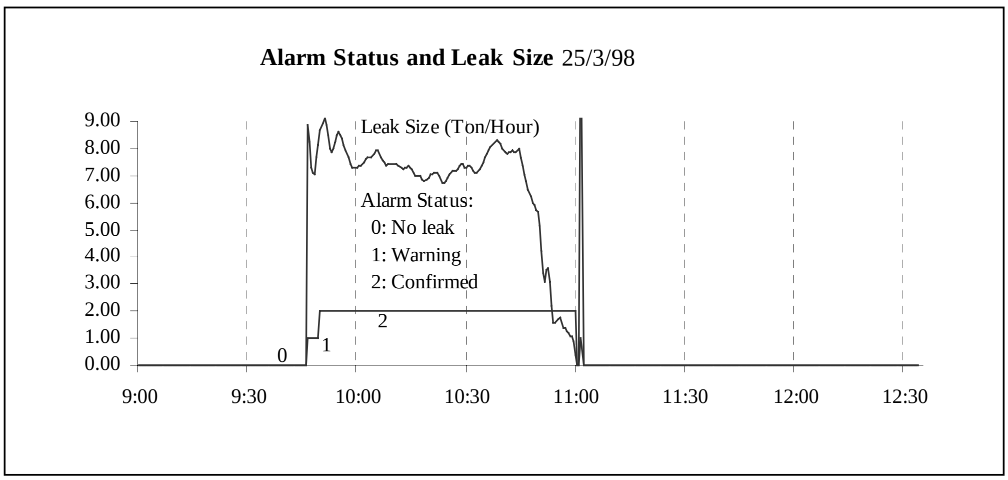

Figure 2 Leak alarm response and leak size estimate during the SAT

3 CRUDE OIL PIPELINE

This pipeline is 14 miles (23 Kilometres) long and has an average internal diameter of 24”. Variations in diameter occur as the wall thickness changes with geographical location.

Most sections of the pipeline are underground, with one section in a tunnel beneath canal locks, and three sections above ground. The pipeline is not insulated and it runs from a tank farm to a refinery.

The pipeline is designed for bi-directional operation, and all plant instruments are bi-directional. Crude oil is pumped in either direction in batches. The length of a batch varies between 4 and 20 hours depending on the delivery available. Between the batch transfers, sometimes there are long periods of shut-in when the pipeline is filled with the last batch of crude. Four pumps are used at the inlet and they are started in sequence.

The crude density changes significantly from heavy Arabian crude to the light North Sea oil. In order to facilitate the heavy crude pumping, the oil is heated to reduce viscous friction or it is mixed with lighter crude.

To achieve a reliable and sensitive leak detection system, the statistical parameters are tuned based on normal operational data over a one-year period. The tuning criteria used are as follows:

1. ATMOS will detect leaks of given sizes within the specified time limits.
2. No false alarm should be generated during the one-year operation period.

Since the system is designed and tuned for this particular pipeline, it learns about its pipeline operation and instrument performance specifically. No assumption has been made about the pipeline, and, once installed, the system continues to learn about the pipeline, e.g. an increase in the friction. This on-line learning capability is very important as pipeline operations always change, and instrument drift can occur over a long time period.

The data validation function of ATMOS is an essential part of the system because in the real world the data collected by the instrumentation system is rarely perfect. For example, **Figure 3** shows the outlet flow measurements over a period of about 17 hours. Towards the end of this data collection period, the outlet flow readings become erratic. Such behaviour had been observed frequently during this period. Following report of this data fault to the client, further investigations were carried out, and the client discovered that the electronics inside the outlet flow-meter were not changed after the inlet flow-meter electronics were updated.

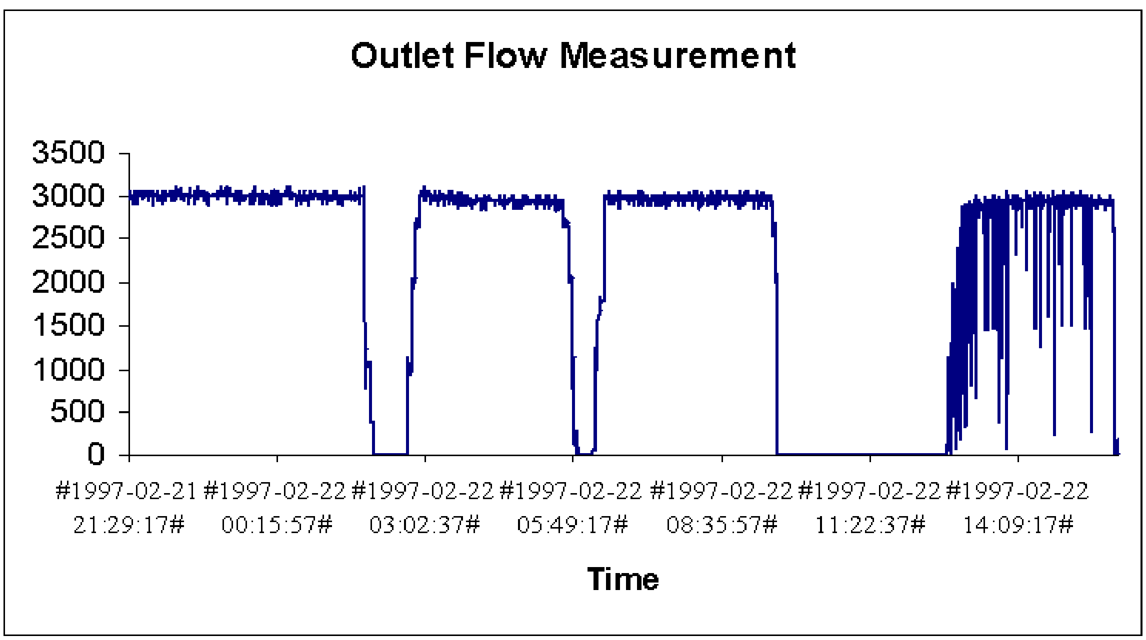

Figure 3 Outlet Flow Follows Inlet Flow Changes with More Noises

In general typical data faults detected are:

- out of range data,
- excessively noisy data,

- outliers (sudden increase in the rate of change),
- frozen data (no change at all for a certain time period)

When ATMOS identifies any of the above data faults, it will inform the operators of the fault type so that corrective actions can be taken. In the meantime, it continues the monitoring of the pipeline. However the leak detection response time is expected to increase as the system will be running in the "degraded" mode.

4 LIQUID PROPYLENE PIPELINE

A 4" diameter, 37 kilometre long liquid propylene pipeline runs through a hilly area. The initial leak detection system was implemented in 1991. Pipeline operational changes take place continuously as a result of upstream plant variations. However, no false alarm is generated by such operational changes or discrepancy between the instruments. Over the past 9 years of operation, a number of changes have been introduced in both the plant and pipeline operation, including throughput increase by maximising the upstream plant production and the introduction of pigging, but the system runs satisfactorily without any modification or false alarm.

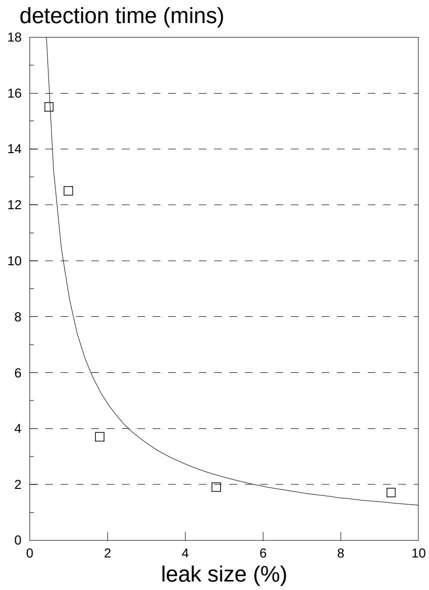

Figure 4 - Leak detection time against leak size for propylene pipeline

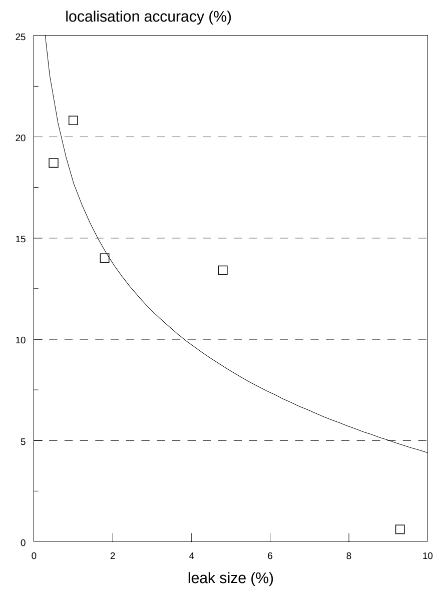

Figure 5 - Localisation accuracy against leak size for propylene pipeline

Leaks with sizes from 0.5% to 9.3% were generated during field tests. The tests show that as the leak size increases, both the detection time and localisation error decrease exponentially (**Figure 4** and **Figure 5**).

5 COMPARISON WITH OTHER TECHNOLOGIES

Different leak detection technologies can be used to meet the application requirement (Zhang 1997). 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
- ATMOS PIPE.

Depending on the design and implementation of a particular technology, the performance of a leak detection system varies significantly. Even the best technology may not work, if it is engineered poorly. Therefore, only a general comparison of performance is provided 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.

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. 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 Incorporated.

6 CONCLUSIONS

ATMOS PIPE is state-of-the-art leak detection technology. Its applications to both gas and liquid pipelines prove that it has minimum false alarms during normal pipeline operating conditions and it is cost effective to maintain.

The field tests show that it can detect leaks quickly and provide good leak size and location estimates. The statistical characteristics provide it with a self-tuning capability that allows it to monitor a pipeline system for its entire life cycle at minimum costs.

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