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Real Time Statistical Leak Detection on the RRP Crude Oil Network, Holland

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ABSTRACT

Prior to the year 2000, the RRP crude oil pipeline network in Holland and Germany was monitored using a dynamic leak detection system based on a dynamic model. The system produced some false alarms during normal operation; prompting RRP to investigate what advances had been made in the leak detection field before committing to upgrade the existing system for Y2K compliance. RRP studied the available leak detection systems and decided to install a statistics-based system.

This paper examines the field application of the statistics based leak detection system on the three crude oil pipelines operated by RRP. They are the 177 km Dutch line, the 103 km South line, and the 86 km North line. The results of actual field leak trials are reported. Leak detection systems should maintain high sensitivity with the minimum of false alarms over the long term; thus this paper also outlines the performance of the statistical leak detection system over the last year from the User's perspective. The leak detection experiences documented on this crude oil pipeline network demonstrate that it is possible to have a reliable real-time leak detection system with minimal maintenance costs and without the costs and inconvenience of false alarms.

INTRODUCTION

The crude oil pipelines of the Rotterdam-Rijn Pijpleiding Maatschappij (RRP) have been in operation for over 40 years. One of the pipelines transports crude oil from the Dutch port of Europoort across the Netherlands to Venlo on the Dutch German border, using the 177 kilometer long Dutch line. In Venlo the crude can be temporarily stored or forwarded directly to German refineries at Gelsenkirchen (North line), Godorf and Wesseling (Southline). This can be seen in Fig 1 RRP Overview Diagram.

The North line has two delivery destinations, one at Scholven some 78 kilometers from Venlo, and another at Horst, which is 86 kilometers distant from the inlet, both customers are located in the Gelsenkirchen area.

The South line also has two destinations, one at Godorf, 94 kilometers from Venlo, the other at Wesseling some 103 kilometers from Venlo.

RRP Crude Oil Supervisory and Monitoring System (COSMOS) uses telemetry to control all on the pumping stations, valve stations and delivery points from the central operations control center for crude transportation in Venlo.

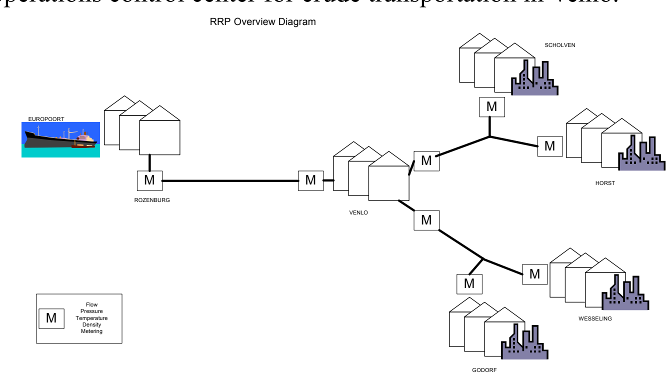

Figure 1 RRP Overview Diagram

Following the installation of a new SCADA system in 1996, RRP also installed a dynamic model type leak detection system that was built and tested offline during 1995. Upon completion of the online tuning of the system, RRP performed a leak test on the Dutch line under steady state conditions with good results. Fine tuning continued on the dynamic system for three years, until the end of 1999, but there were still a couple of false alarms every month when transient states occurred in the pipeline. The system also produced some other nuisance alarms, caused by the physical properties of different crude oils, during normal pipeline operation.

As the dynamic model system (hardware and software) was not Year 2000 compliant, RRP had two options:

a) Upgrade the hardware and software (probably improving performance during transient states) or
b) Install a new leak detection system.

A major concern with most leak detection systems has been the frequent generation of nuisance alarms. RRP investigated the possibilities available and found that Shell had developed a statistical leak detection system, ATMOS PIPE™ that seldom generated false alarms.

ATMOSPIPE™ had performed very well in previous installations and leak tests, including applications on liquid propylene and crude oil pipelines in Shell UK Limited (4) (5), and on the 413 kilometers long North Western Ethylene Pipeline. ATMOSPIPE™ continues to produce virtually no false alarms on any of these applications.

Based on the desire to achieve the same high level of reliability, RRP decided to install and test ATMOSPIPE™ on the Dutch line. If the field trials on the Dutch line were successful, RRP would install ATMOSPIPE™ on the remaining North and South pipelines.

NOMENCLATURE

COSMOS – RRP's Crude Oil Supervisory & Monitoring System
RTU - Remote Telemetry Unit
SAT – Site Acceptance Test
SCADA - Supervisory Control And Data Acquisition)

PIPELINE DESCRIPTION

The Dutch pipeline (Figure 2) is 36" in diameter, and 177 km long. This pipeline runs across the Netherlands from Europoort to Venlo, with a pump station at Rozenburg. It is 5 km from Europoort to Rozenburg, and this section is not covered by the leak detection system, hence the length of the line being monitored is 172 km. There are 9 block valves with pressure measurement along the line including the end valves.

The South pipeline (Figure 3) is 24" in diameter. The first outlet, Godorf, is 94 km from Venlo, and the other outlet, Wesseling, is 103 km from the Venlo inlet. There are 12 block valves with pressure measurement along the line including the end valves.

The North pipeline (Figure 4) is 86 Km long. The first section (48 km) from Venlo to Welmen is 24" in diameter. The remainder of the pipeline from Welmen through Scholven to Horst is 16" in diameter. The Scholven outlet is located 78 km from Venlo. There are 11 block valves with pressure measurement along the line including the end valves.

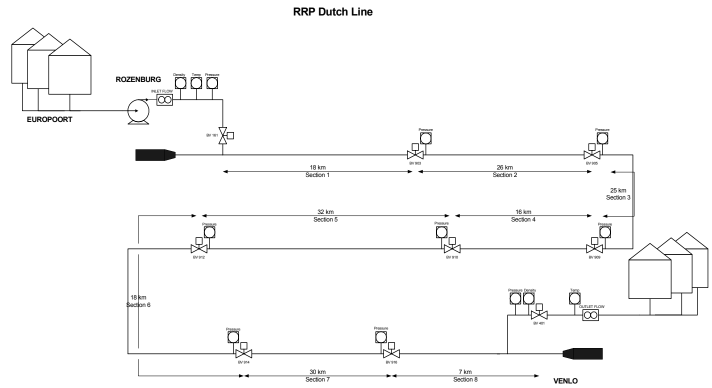

Figure 2 Layout of the Dutch pipeline

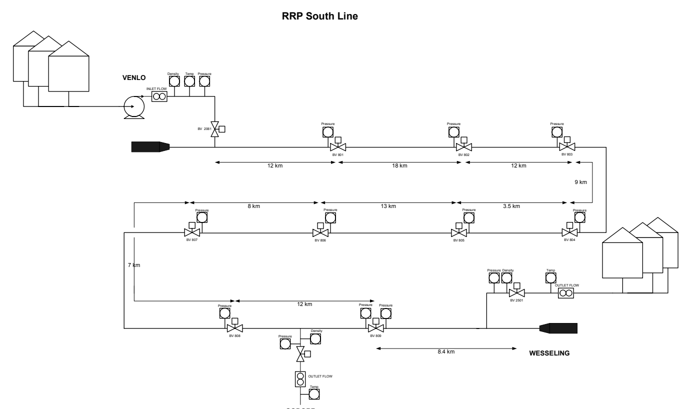

Figure 3 Layout of the South pipeline

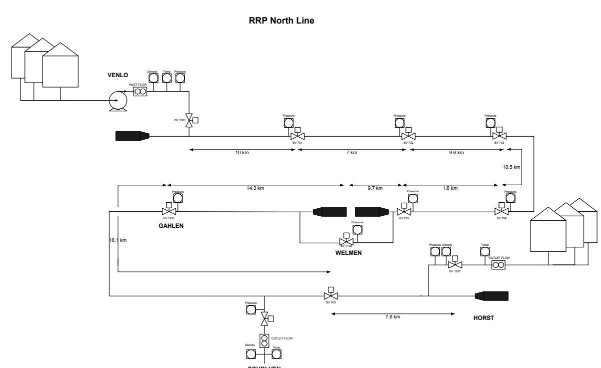

Figure 4 Layout of the North pipeline

Flow, pressure, temperature and density meters are available at the inlets and outlets of the three pipelines. Pressure is measured at all of the block valves. In total there are approximately 300 measured variables including block valve position indicators, pump status signals and pig switch signals. Each of these measurements has a quality status attached, indicating the confidence level in the measurements. All the measurements are sent back to the control center at Venlo.

The smooth operation of such a pipeline demands continuous monitoring. To achieve high integrity, RRP uses a high level of instrumentation and employs detailed integrity systems. For example:

- There are block valves along the pipeline that can be operated remotely.
- Pressure meters are installed at the block valves, most are upstream but some block valves do have downstream measurements.
- At the inlet and outlet of the pipelines, flow, pressure, temperature and density meters are installed.
- Two SCADA computers are used. One works as the online machine and the other as hot standby.
- Pipeline leak detection systems (in addition to the Computational Pipeline Monitoring CPM system), such as flow balance and negative wave for steady state operation.
- The performance of all instrumentation is checked frequently.
- RRP performs internal and external corrosion monitoring (incl. intelligent pigging) regularly.
- RRP frequently cleans the pipelines using pigs provided with discs and brushes
- RRP performs road and aerial surveillance.

IMPLEMENTATION

The project to install the statistical leak detection system, ATMOSPIPE™, began in 1999. The existing instrumentation system already collected all the flow, pressure, temperature, density and valve data, therefore a Desktop Computer was the only additional hardware required to install ATMOS PIPE™. **Figure 5** shows the interface between ATMOSPIPE™ and the RRP instrumentation system.

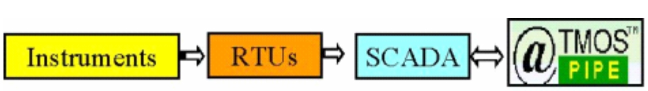

Figure 5 The interface between ATMOSPIPE™ and the instrumentation system

ATMOSPIPE™,, is a pipeline leak detection software developed by Shell to reduce false alarms while maintaining sensitivity and accuracy. ATMOSPIPE™, S is successfully used by SHELL, BP-AMOCO, ESSO, and the UK Ministry of Defense among others. ATMOS pipe is statistical based leak detection software that has been applied to oil, gas, chemical and product pipelines successfully. It is also one of the most tested leak detection systems in the world, and has detected more than 200 leaks during leak trials.

AtmosPipe™ is unique as it applies three leak detection methods simultaneously.

- Modified volume balance
- Pressure and flow monitoring
- Statistical analysis.

The use of the above methods, combined with a comprehensive data validation procedure and a rigorous decision making mechanism, makes AtmosPipe™ the most reliable yet sensitive leak detection system in the world.

Since the modified volume balance is used for statistical calculations, the system performance does not depend on the actual flow-rate in the pipeline. The repeatability of the flow meters will determine the minimum leak detectable without false alarms during both low and normal flowing conditions.

ATMOS PIPE applies the statistical techniques to detect changes in the overall behavior of flow and pressure at the ingress and egress points. 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 introduce a discrepancy between the ingress and egress flow-rate. The leak detection system is designed to detect such changes i.e. pattern recognition.

Leak determination is based on probability calculations at regular sample intervals. The basic principle used for the probability calculations is mass conservation and hypothesis testing: leak against no-leak. Although the flow and pressure in a pipeline fluctuate due to operational changes, statistically the total mass entering and leaving a network must be balanced by the inventory variation inside the network. Such a balance cannot be maintained if a leak occurs in a network. The deviation from the established balance is detected by an optimal statistical test method - Sequential Probability Ratio Test (SPRT).

The combination of the probability calculations and pattern recognition provides ATMOS with a very high level of system reliability i.e. minimum spurious alarm.

In December 1999, the desktop computer was installed on site to collect the operational data from the Dutch pipeline. This data was then used to tune the statistical leak detection system parameters so that no false alarms were generated under normal operational conditions. Once this tuning was completed, REL Instrumentation installed the new live leak detection system in March 2000 and fine-tuned it while live on site. The new leak detection performed well for all of the typical operating conditions on the Dutch line. ATMOSPIPE™ verified its ability to minimize false alarms and still detect real leaks during the on-site leak trial in April 2000. Following the successful performance of ATMOSPIPE™ on the Dutch line, RRP commissioned the installation of ATMOSPIPE™ on the remaining North and South pipelines.

The main functionality of the three leak detection systems is:

- Collection of flow, pressure, temperature and valve data at 10-second intervals.
- Validation of the above data so that faulty instruments are diagnosed and "bad" data is 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 optimize the system performance, the following key features were included (1):

Reliability

The SCADA system transfers approximately 100 measured variables for each of the three pipelines to the ATMOSPIPE™ computer every 10 seconds . It is highly probable that one of these measurements is incorrect at any specific time. ATMOSPIPE™ uses a comprehensive data validation module to eliminate errors introduced by such data faults. This module removes any misleading data before the leak detection algorithm processes the data. All data, however, is saved to the database for historical incident review should it be required.
The Data validation checks include:

- Range check: ATMOSPIPE™ verifies that the data values are within the instrument range or within the pipeline operating limits. Out of range data indicate either an instrument or wiring fault. ATMOSPIPE™ records this as an 'Out of Range' fault.
- Outlier check: Outliers are isolated values outside a reasonable fluctuation band for a variable. ATMOSPIPE™ tests whether an instrument reading is significantly different from its previous and subsequent value. If so, ATMOSPIPE™ registers this reading as an outlier.
- Stuck check: Stuck data are data that keep the same value for an unusually long period of time. Normally this indicates a faulty instrument or a breakdown in the telemetry system. ATMOSPIPE™ records this as a 'Stuck' data fault.
- Inconsistent data check: ATMOSPIPE™ tests whether an instrument reading is consistent with the current operating conditions (as indicated by the other instrument readings). For an instrument reading to be inconsistent, the other readings must be close to their expected values, and the faulty instrument reading significantly different from its expected value. It should be noted that this check is only possible where alternative instrument readings are available as a measurements crosscheck.
- Noisy data check: ATMOSPIPE™ tests whether the variance of an instrument reading within a moving time window has exceeded the allowed threshold. If yes, the new value of the moving window will be registered as noisy.

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 data. ATMOSPIPE™ 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 data from the block valves and pressure and temperature from the inlet and outlet have failed.

Each pipeline has its own ATMOSPIPE™ leak detection program running on the dedicated Leak Detection System desktop computer. This guarantees that even if the SCADA routines are unable to send data for one of the lines, the other two lines continue to perform leak detection. If such a data transmission error occurs, a watchdog signal alerts the operator of the communications issue so that it may be rectified as soon as possible.

Sensitivity

ATMOSPIPE™ is designed to maintain high reliability whilst minimizing the leak detection time 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 ATMOSPIPE™ employs different sets of statistical parameters for each of the modes.

Accuracy

When ATMOSPIPE™ generates a leak alarm it also provides leak rate and location estimates. 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.

ATMOSPIPE™ 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.

SITE ACCEPTANCE TEST

Following the initial installation in March 2000, ATMOSPIPE™ operated continuously with a minimal number of false alarms (any false alarms were reviewed and tuned away during this initial commissioning period). RRP conducted a Site Acceptance Test in April 2000 to test its performance when a leak occurs.

On the April 11 2000, a first leak of about 89 m3/hr (approx 4%) was generated on the Dutch line by opening a small valve off the mainline and diverting product into a vacuum tanker. This leak was introduced at block valve 912, approximately 122 kilometers from the Rozenburg pumping station. ATMOSPIPE™ generated a confirmed leak alarm just 3 minutes and 30 seconds after the leak had begun. ATMOSPIPE™ simultaneously reported that the location was at block valve 912 by station section 5 and a distance of 32,191m, which is located at the end of section 5. The leak size was estimated correctly.

A second smaller leak, approximately 1 % of normal flow (33 m3/hr), was introduced next. This was confirmed as a leak in 8 minutes and 30 seconds, again with good leak location and leak size estimation.

Finally a transient condition was created by operations, moving ATMOSPIPE™ into a transient detection mode. Once ATMOSPIPE™ had recognized this transient, a leak was generated. ATMOSPIPE™ gave confirmation of a leak in 16 minutes, again reporting the leak size and location correctly.

An overview of the results obtained during the leak trial can be seen in table A1.1 below.

Table A1.1 Site Acceptance Test Results

Leak Size	Operating Conditions	Actual Detection Time	Actual Leak Size Estimate
4%	Steady State	3 mins 30 secs	89.56 m^3/hr
1%	Steady State	8 mins 30 secs	33.96 m^3/hr
Variable	Transient	16 mins	86.44 m^3/hr

SYSTEM PERFORMANCE DURING NORMAL OPERATIONS

ATMOSPIPE™ has been monitoring the RRP Pipelines since May 2000. Significant operational changes have occurred during this period, for example:

- The normal flow rate has increased from 2500 to 3000 m3/hr on the Dutch line. This has not caused any false alarms by the ATMOSPIPE™ system.
- RRP has performed pigging on all the pipeline lengths.
- The pipelines have all been shut-in for periods of time when no flow is pumped into or out of the shut-in pipeline section.

None of these changes have impaired the functionality or the reliability ATMOS PIPE™.

Examples of the typical operational changes experienced by AtmosPipe on these pipelines can be seen in Figures 6 (Flows) and 7 (Pressures). Remarkably, these operational changes did not cause the system to give any false alarms. The operational changes shown occurred on the same day as the leak trials, and the measurement responses during the actual leak trials can also be seen in the figures.

Start time 9:00:07 AM **End Time 12:59:55 PM**

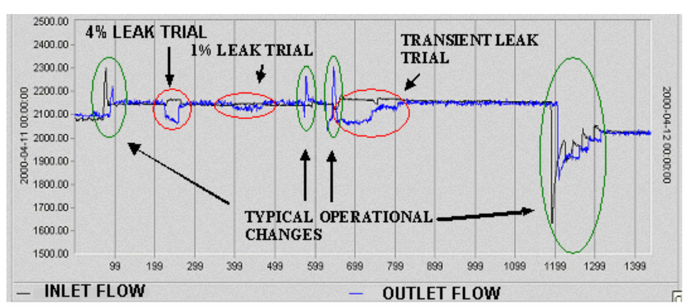

Figure 6: Flow trends from the Dutchline (sample Numbers 10 Seconds)

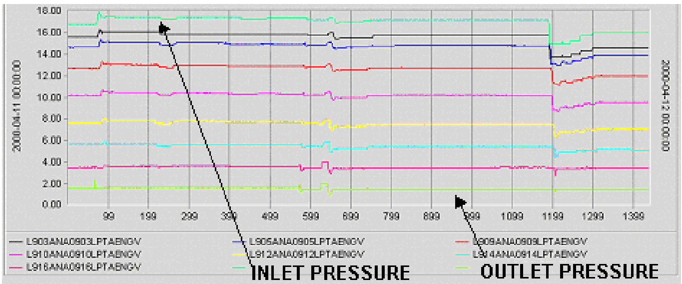

Figure 7: Pressure trends from the Dutchline

CONCLUSIONS

The performance of ATMOSPIPE™ on the three RRP pipelines proves that this leak detection maintains high sensitivity with virtually no false alarms during all normal pipeline-operating conditions. The Site Acceptance Test clearly demonstrates the high sensitivity of the system under all operating conditions.

Following the successful application to the Dutch Pipeline, RRP has installed ATMOSPIPE™ on both the North and South crude oil pipelines. During normal pipeline operations, ATMOSPIPE™ does not generate nuisance alarms, and over the last year of operation, it has proven to be highly reliable.

In the near future the German Authorities will require a leak detection system, which is capable of detecting and locating leaks in steady state and transient conditions. RRP has asked the Authorities to test and approve the system.

ACKNOWLEDGMENTS

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