

## **Leak Detection and the Human Factor**

Topic: What can leak detection systems really achieve?  
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### **Abstract**

*'Leak detection systems do not work and only generate false alarms'* is still heard quite frequently. This is unfortunate since just the opposite is true. Modern state-of-the-art systems are highly reliable while permitting sensitive leak detection and accurate leak localisation.

This paper starts with the basics, why install a leak detection system and how to choose a system that suits your application. The focus is made on the Human Factor. What is important for the people working with this system? For example; No false alarms might be preferred above looking for the ultimate sensitivity and thereby increasing the opportunity for false alarms.

Typical leak detection specifications, such as sensitivity and accuracy, are also taken into consideration. Are these specifications relevant to real life situations or do they only refer to fully stationary pipeline conditions that are only encountered in theory. In practice pipelines always exhibit (small) transients. In addition, the accuracy of the installed instrumentation, data refresh rates, time allowed to detect a leak, position and number of field instrumentation and many other factors influence the performance of a leak detection system. When selecting a system, field test results from similar applications may form the best reference.

The paper describes the E-RTTM technique that KROHNE uses for PipePatrol, their Leak Detection and Localisation System. The paper explains, without going into mathematical details, how the model works and why KROHNE has chosen this model as the basis for their system. Today E-RTTM based systems like PipePatrol can boast of many proven applications on gas, lpg, crude oil and refined product pipelines. Field test results from an ethylene sub-critical gas pipeline are described to demonstrate that modern leak detection systems are more than a theoretical exercise; they do work and do this without false alarms.

## 1 Introduction

Speaking about leak detection system immediately leads to the first fundamental question; *'Why a leak detection system'*? A well known reason is of course legislation. In Germany all new pipelines that transport polluting, toxic or combustible gasses or liquids may only be operated if two independently continuously working leak detection systems are in place. The requirements for leak detection systems are laid down in the TRFL (Technical rules for Pipelines).

Legislation is however not the only reason for implementing a leak detection system. Items like safety and protection of the environment are obvious. Loss of image is also an important issue. A company's image can be seriously damaged if this company comes in the news as 'not having done everything to prevent a leak'. Less known is that modern leak detection systems can provide relevant pipeline information, such as pressure and flow profiles along the pipeline, that can improve pipeline operation drastically. Finally, the quicker and more reliably a leak can be detected, the quicker it can be repaired and monetary losses can be minimised.

### 1.1 Finding the correct system

Once a decision is made to implement a leak detection system, the optimum system has to be selected. Because the available systems from different suppliers are based on different techniques this process can be time-consuming. In this paper a number of decision criteria are discussed. The paper does not focus on the technical details of each system, rather it focuses on the human aspect; 'what is important for the operator'?

Reliability is of major importance for all operators. After two false alarms there is a danger the operator will ignore further leak alarms or will even switch the system off. Bottom line is that leak detection system should not give false alarms under any circumstances.

A second decision criteria is sensitivity; the system should be able to detect the smallest possible leak. The time required to detect this leak and the operational mode of the pipeline are also important: A leak detection system that can detect small leaks (e.g. 1% of nominal flow) sounds promising, but if it takes 24 hours before it detects the leak the system is of little interest. Since pipeline operations frequently show transient behaviour, due to operational changes such as changing pumping capacity or opening or closing valves, sensitivity figures should be interpreted carefully. Does a figure refer to stationary or transient conditions and how much time is required to detect a leak.

Performance figures are only meaningful if they refer to the pipeline conditions (transient or stationary) and the time required to detect a leak.
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In case of for example a sensor failure, the system needs to be robust and should definitively not give a false alarm. Ideally it remains in operation. Redundant sensors might be installed to overcome a reduction in sensitivity due to a sensor failure. A final decision criteria is accuracy of the leak localisation. When a leak is detected, the localisation should be accurate enough to access the location with limited effort and within a reasonable time span.

## 1.2 A theoretical or practical approach

A comparison of different types of systems shows that most systems promise impressive sensitivity and accuracy figures. As explained an analysis of the figures should incorporate whether they include stationary or transient pipeline operation and the times required to detect a leak. Secondly do the figures come from a purely technical calculation or can they be backed-up with field test data.

Field test results from similar applications are the best recommendation.
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A simple example can be given for leak localisation. Leak localisation is typically done by analyzing pressure waves. Since pressure waves travel with the velocity of sound, their typical velocity in a liquid hydrocarbon is 1300 m/s. When a leak localisation of  $\pm 10$  meters is specified, this means the refresh rate of the pressure reading should be  $10/1300 = 7$  ms (milliseconds). In a purely mathematical approach, ignoring all transients in the line, this localisation is possible. In an industrial application however, this scenario is unrealistic since refresh rates are typically between 0.5 and 30 seconds. Even a refresh rate of 0.5 seconds physically restricts the minimum achievable accuracy to  $1300 \cdot 0.5 = \pm 650$  meter.

A second example can be given for sensitivity. In fully stationary pipeline conditions the sensitivity of a leak detection system can go down to the accuracy, or in some systems even the repeatability, of the installed flowmeters. Unfortunately fully stationary pipeline conditions are a purely theoretical exercise, and even if they do occur, the system needs a virtually unlimited long detection time to reach such a state of sensitivity.

## 2 PipePatrol, KROHNE's Leak Detection and Localisation System

During the development of PipePatrol, reliability was one of the key design elements. To overcome the limited performance of traditional systems in transient conditions, KROHNE decided to base PipePatrol on RTTM technology (Real Time Transient Model). To avoid false leak alarms a leak recognition algorithm was incorporated and as a result the model behind PipePatrol is called an E-RTTM (Extended Real Time Transient Model). The following paragraph explains what E-RTTM is and how it works. We have focussed on basics, and minimised the explanation of the underlying algorithms. More technical information, including the underlying algorithms, is available on request but is not required to understand the basics of the RTTM technique.

### 2.1 RTTM, the Real Time Transient Model

RTTM uses measurements of flow, temperature and pressure at the inlet and outlet of a pipeline. The flow is measured by flowmeters and simultaneously calculated from the pressure and temperature readings. The RTTM algorithms that are used to calculate flow from pressure and temperature readings are not further described in the paper. A simple (and limited) analogy can be made to a differential pressure or orifice flowmeter, where the flow is calculated from two pressures.

Comparing the calculated flow (from P and T readings) with the measured flow (from the flowmeters) results in the flow residuals at inlet and outlet. This is best explained with the graphs below. Figure 1 represents a simple line balance situation where only flow at the inlet (blue, ingress) and outlet (red, egress) is measured. Subtracting the outlet flow from the inlet flow gives the flow imbalance as shown in the right graph.

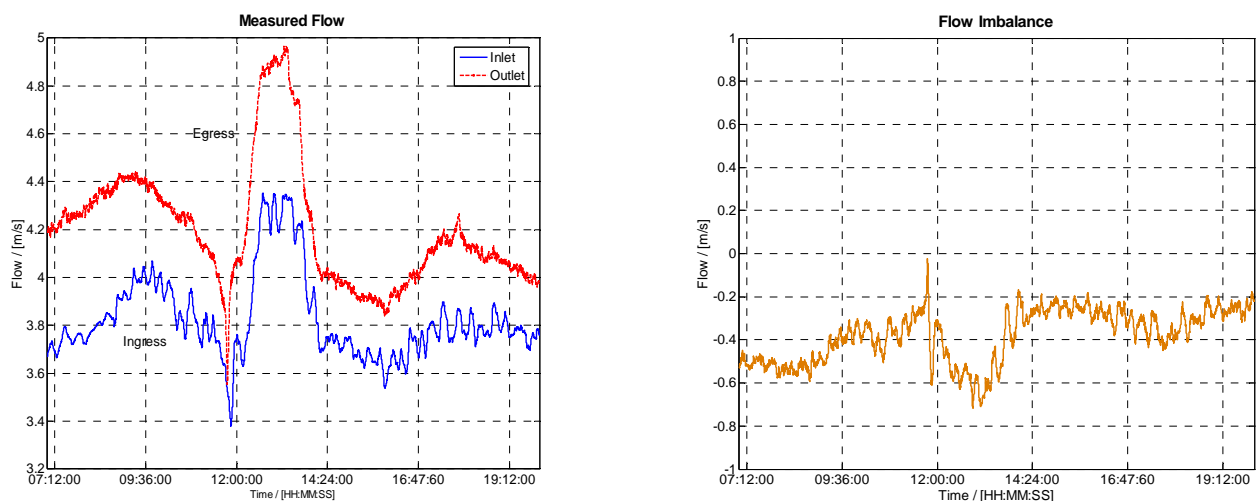


Figure 1: A simple line balance. The left graph shows inlet and outlet measured by a flowmeter. The right graph shows inlet minus outlet flow.

Figure 2 shows what happens with the RTTM approach. The left-hand graph now shows 4 lines, the blue line shows the measured (also called estimated) flow at the inlet, the green line shows the corresponding calculated flow at inlet. On the outlet side the measured outlet flow is given by the red line, the calculated flow by the brown line. When the measured flow at the inlet is subtracted from the calculated flow at the inlet the result is the blue line in the top graph on the right. Similarly the result for the outlet side is the red line in the graph below.

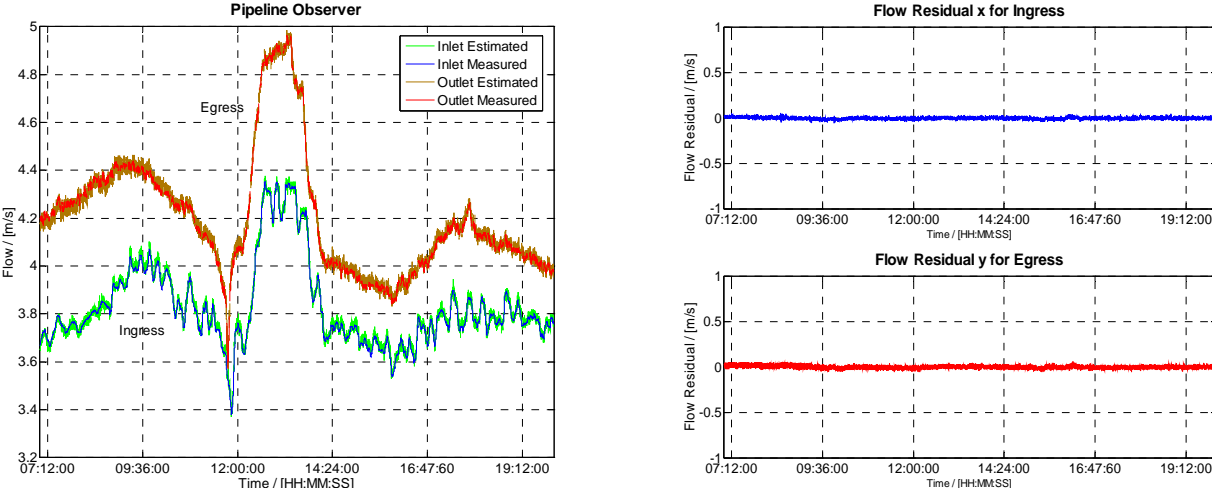


Figure 2: The RTTM approach: The graph on the left shows measured and calculated flow at the inlet (ingress) and outlet (egress). The graphs on the right show the difference between measured and calculated flow at the inlet (blue line) and outlet (red line).

The two graphs on the right show the ‘true’ leak flow at the inlet and outlet. Both lines are around zero since there is no leak in this line. A leak near the inlet will create a significant shift from zero in the blue line. A leak near the outlet will have a similar effect on the red line; leaks in between will show in both graphs. For example, if the pipeline is 10 km long and there is a leak at 8 km, the leak effect will show for 80% in the outlet graph and 20% at the inlet graph. Using RTTM therefore not only allows leak detection, but also leak localization.

Figure 3 summarizes the RTTM technique. The orange line represents inlet minus outlet flow, based on a simple line balance where only flowmeters are used. The blue line represents compensated inlet flow (i.e. calculated minus measured inlet flow, the blue line in the right top graph from figure 2) minus compensated outlet flow (the red line in the right bottom graph from figure 2). The blue line thus represents the actual leak flow where a compensation is made for the transient pipeline behaviour.

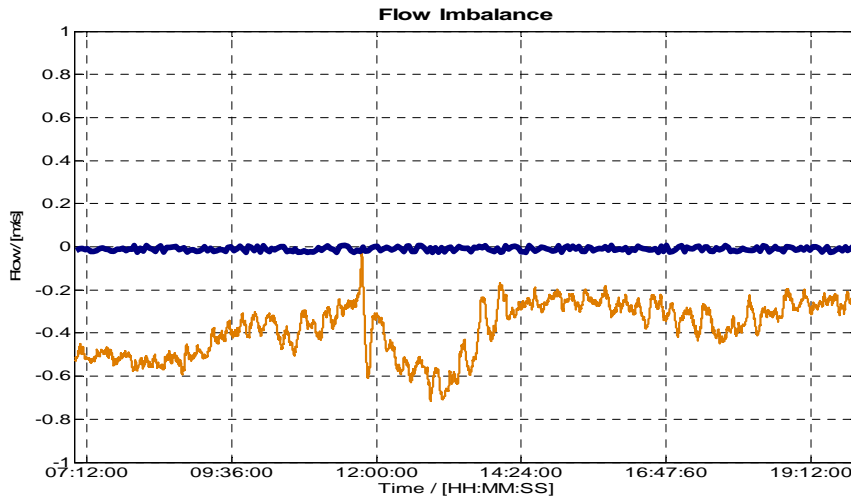


Figure 3: The difference between inlet and outlet flow using a simple line balance method (orange line) and using an RTTM model (blue line). The RTTM technique compensates for all transients.

## 2.2 Introducing a leak recognition algorithm – differentiating between a sensor failure warning, and a true leak alarm

KROHNE decided to extend the RTTM model with a leak recognition algorithm. If a predefined threshold is exceeded, PipePatrol first analyzes the leak pattern. A spontaneous leak will always show a specific leak pattern (see figure 4). A sensor drift will not show this specific pattern and will manifest with a slowly increasing leak rate. After the leak pattern has been analyzed, the E-RTTM model will either set off a leak alarm or a sensor warning. The system makes a clear and unmistakable difference between a warning that a sensor needs attention and an alarm for a true leak.

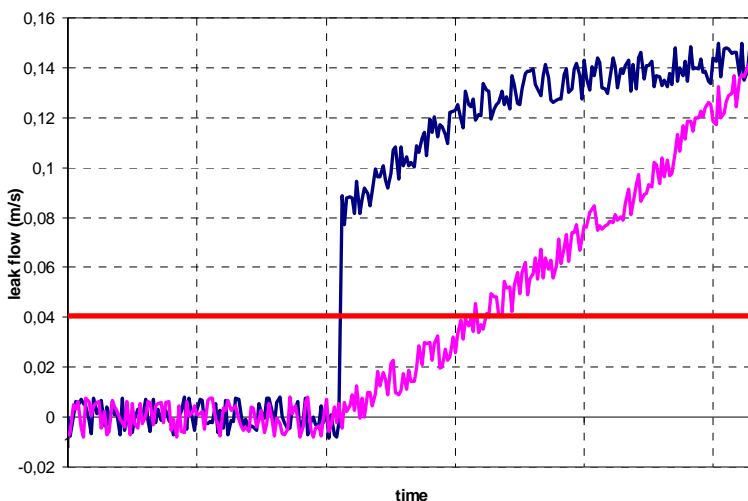


Figure 4: The red line indicates a predefined threshold. Both the magenta and the blue flow imbalance lines exceed this threshold; however, only the blue line shows a typical leak pattern and will set off a leak alarm. The magenta line is typical for a sensor drift and will raise a sensor failure warning – not a leak alarm.

### 2.3 PipePatrol, a dedicated LDS system

To maximise reliability PipePatrol is installed on a dedicated industrial PC. On requirement redundant components are included. This PC is called the PipePatrol Monitoring Station and runs completely autonomously. The HMI (Human Machine Interface) runs on a separate Operator Station or can be included in the existing SCADA system.

PipePatrol can be divided into two kernels; the Pipeline Observer and the Pipeline Classifier (see figure 5). The Pipeline Observer runs the RTTM algorithms that calculate flow from pressure and temperature readings. The Pipeline Classifier analyzes the difference between the measured flow (coming from the flow meter) and the calculated flow (coming from the Pipeline Observer). In case a predefined threshold is exceeded, the Pipeline Classifier will first analyse whether this is caused by a sensor drift or by a spontaneous leak and a sensor warning or a leak alarm will be given. The Pipeline Classifier subsequently calculates the leak location and the leak rate.

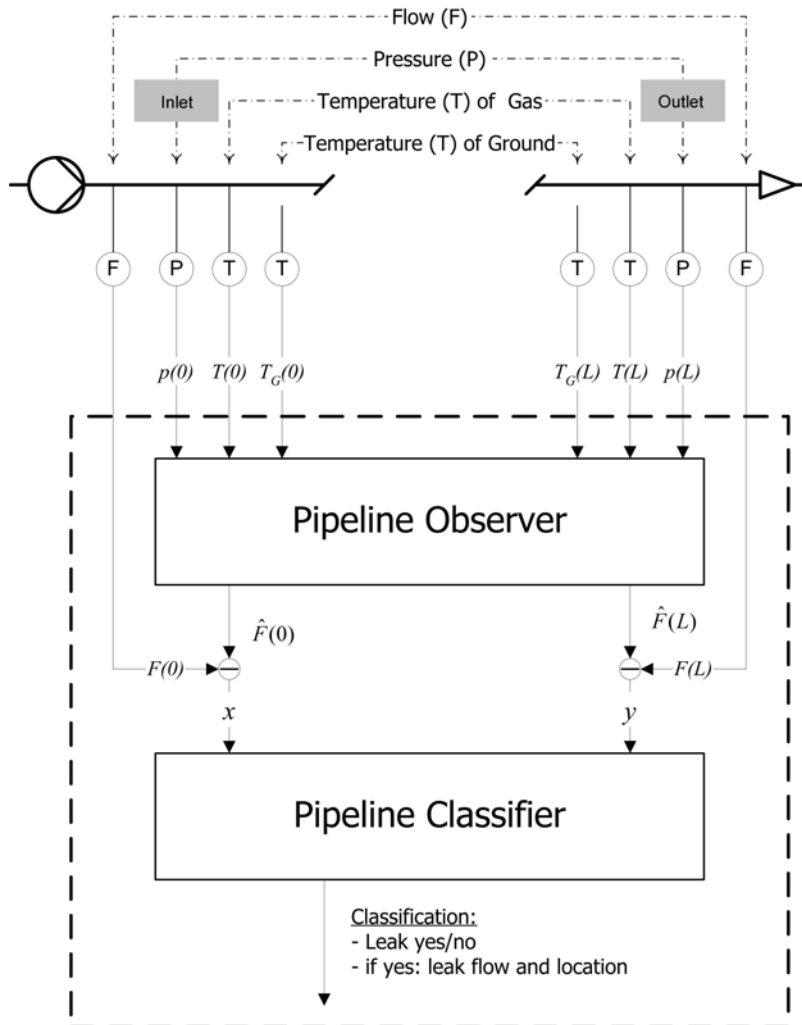


Figure 5: PipePatrol runs two kernels. The Pipeline Observer supports the RTTM algorithms. The Pipeline Classifier supports the leak pattern recognition, therewith improving PipePatrol to an E-RTTTM based system.

### 3 Leak detection on an ethylene gas pipeline

This chapter describes the leak testing on a 112 km long sub-critical ethylene gas pipeline. The pipeline has two branches at inlet and outlet (see figure 6) and therefore can be seen as a small pipeline network. Due to the high compressibility and non-ideal behaviour of ethylene gas the pipeline is in constant transient operation. Despite that its application is very demanding for a leak detection system, E-RTTM technique makes reliable leak detection possible.

Because continuous pipeline operation is mandatory, the application is characterised by strong redundancy requirements. While this application describes a gas pipeline, similar application notes for liquid pipelines are available on request.

#### 3.1 Application details

Ethylene ( $C_2H_4$ ) is produced in the petrochemical industry by steam cracking and is used primarily as an intermediate in the manufacture of other chemicals. It forms a raw material for polyethylene, polystyrene and PVC. Ethylene is highly flammable, mixtures with air are explosive and inhalation can lead to unconsciousness.

Figure 6 shows the pipeline configuration. Most of the field instrumentation was already present so the leak detection system could use measurement data from existing instruments. Flow is measured at inlet and outlet with a mixture of Coriolis mass flowmeters and orifice plates. Additional pressure measurements are available from 12 of the 14 intermediate valve stations. Density measurements are not required, since density is calculated from P and T readings at inlet and outlet. The pipeline has a length of 112 km (70 mile) and a diameter of DN 250 (10"). Inlet pressure is 34 bar (493 psi), outlet pressure is 24 bar (348 psi).

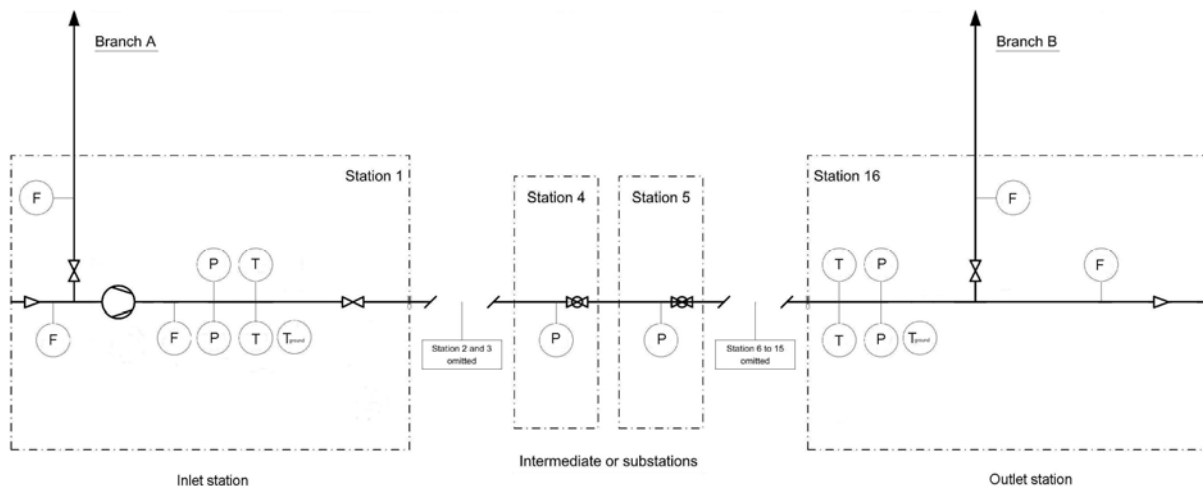


Figure 6: Overview of the 112 km long Ethylene pipeline. Flow is measured at inlet and outlet, additional pressure measurements are made on twelve of the fourteen valve stations.

Data communication in this application is based on PLCs. To avoid any breakdown of the communication three different communication lines were installed, of which two lines for redundancy reasons (see figure 7 for details). The refresh rate for the reading from inlet and outlet instrumentation is about 1 second. The refresh rate for the intermediate pressure readings is about 30 seconds.

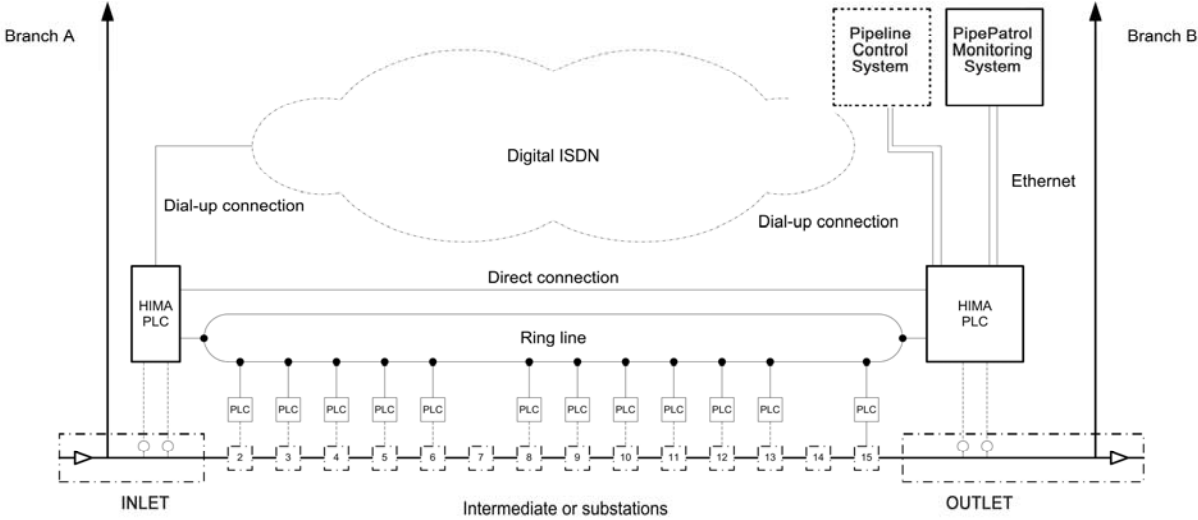


Figure 6: Data communication system with redundant communication lines.

All instrument data readings are fed into a dedicated, stand-alone industrial PC (and a redundant second PC). The PipePatrol E-RTTM algorithms are run on this PC and the critical information is fed into the existing pipeline control system. PipePatrol's diagnostic information is integrated in the HMI and forms an additional module for the operator to the existing pipeline control system.

### 3.2 Leak testing

Various leak tests were carried out. The first test was a heavy transient operation test. Since the pipeline is operated continuously, a start-up or shutdown could not be carried out. For this reason the transients were introduced by temporarily closing the valve at branch A (see figure 6). A special transient operation day was organized for this. The results of this test are represented in figure 8 below.

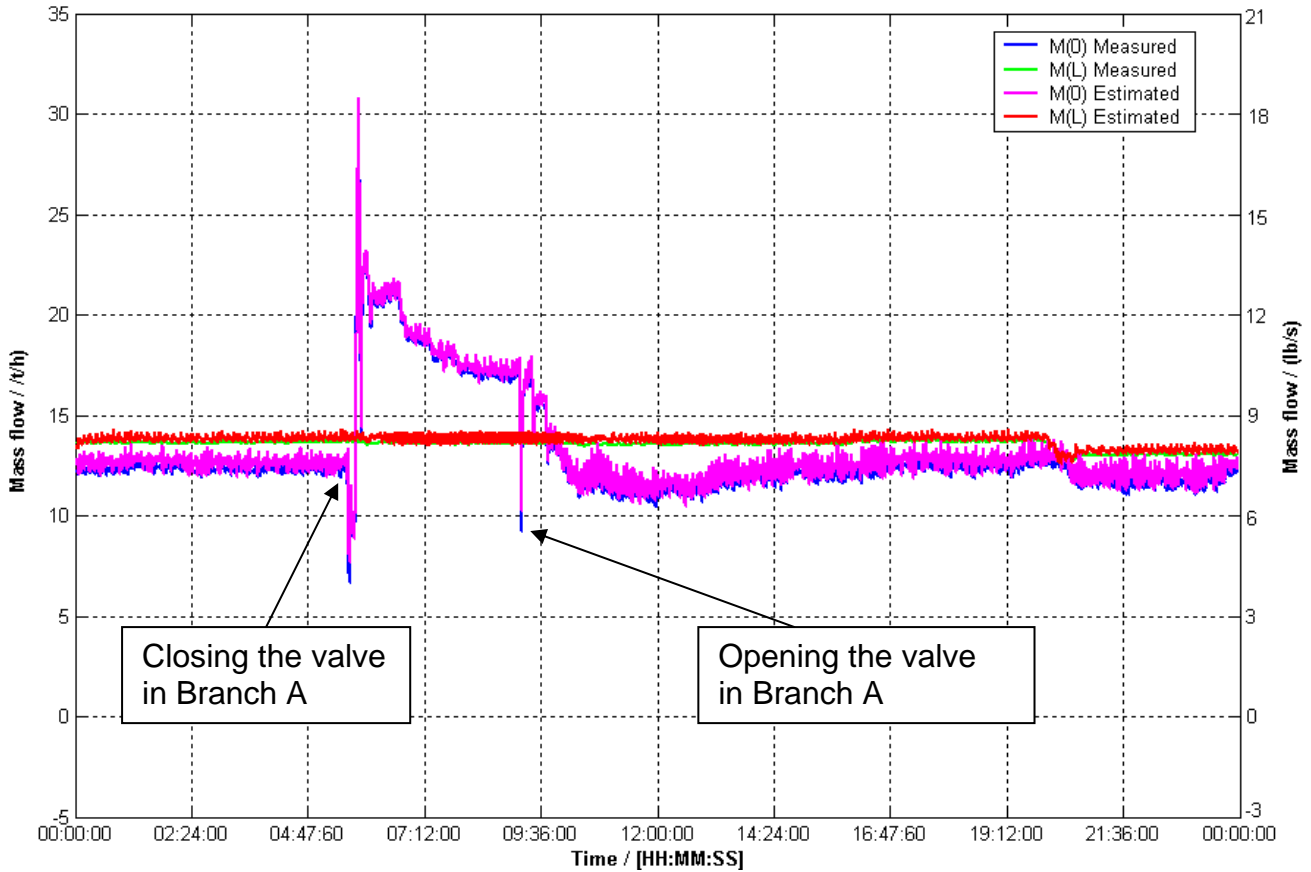


Figure 8: The blue line represents the measured flow at the inlet, the magenta line the calculated (also from P and T readings) flow at the inlet. The green line represents measured flow at the outlet, the red line the calculated flow at the outlet.

A second test was carried out by introducing a leak. A valve at station B (bypassing the flowmeter, see figure 6) was opened for about 10 minutes at a leak rate of approximately 2 tons/hour. Figure 9 shows an overview of the measured and calculated flows during this period. The leak can clearly be identified here.

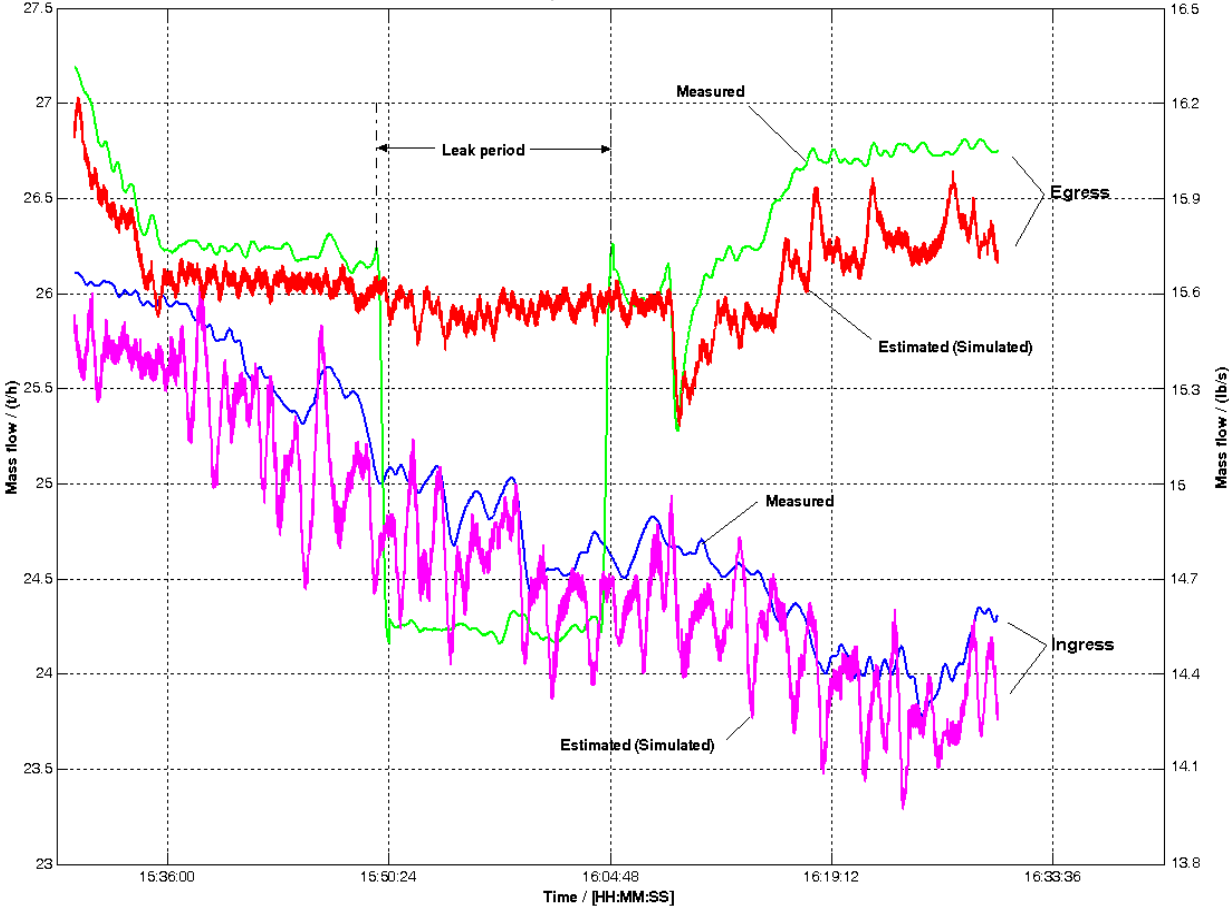


Figure 9: The blue line represents the measured flow at the inlet, the magenta line the calculated (from P and T readings) flow at the inlet. The green line represents measured flow at the outlet, the red line the calculated flow at the outlet. The deviation between calculated and measured flow at the outlet can be clearly seen during the leak trials.

Figure 10 shows the residual (i.e. the difference between calculated and measured flow at the inlet minus the difference between calculated and measured flow at the outlet). This figure shows that a leak is identified after only 100 seconds after it was created.

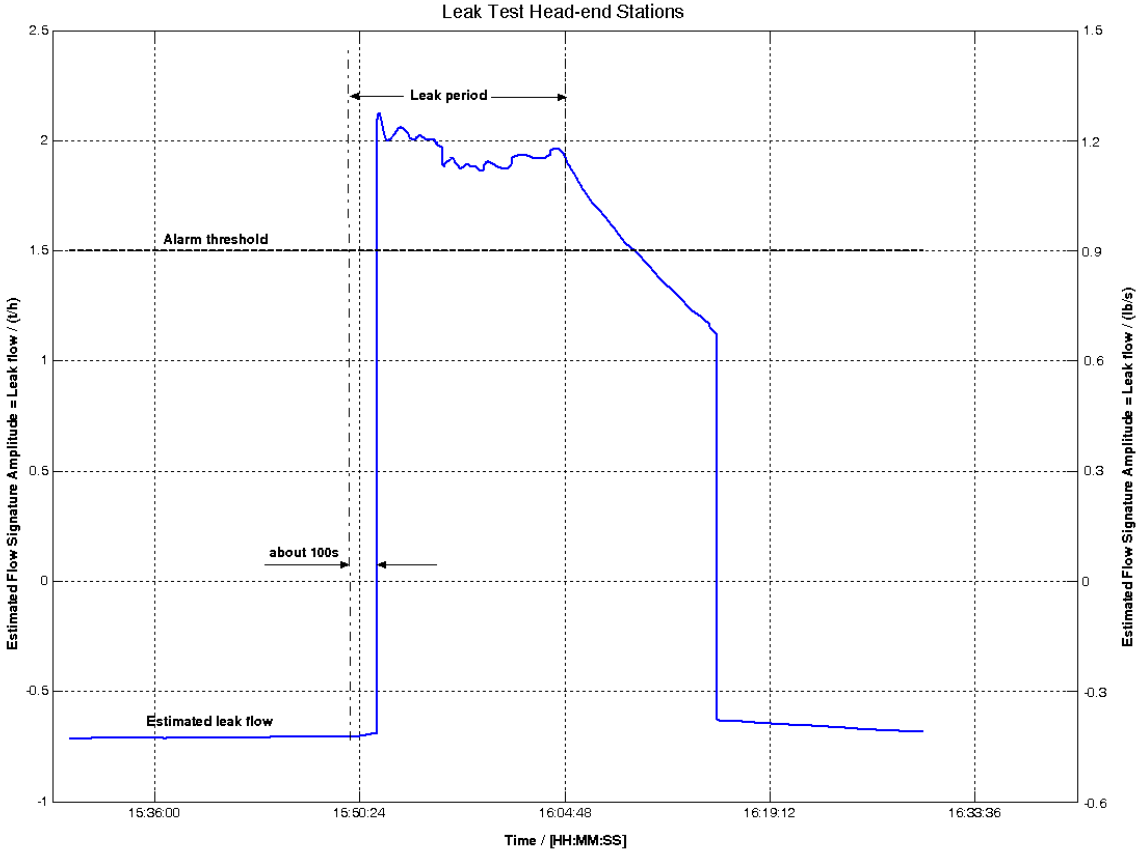


Figure 10: This line represents the difference between the inlet residuum (measured flow at the inlet – calculated flow at the inlet) and the outlet residuum (measured flow at the inlet – calculated flow at the inlet). During the leak trials the pre-defined threshold of 1.5 ton / hour was exceeded. After 100 seconds (less than two minutes) this resulted in a true leak alarm!

**3.3. Results from the leak tests**

Based on the above mentioned leak trials, the system has been configured such that it will detect any leaks which cause more than a 0.2 bar pressure loss (note that nominal pressure is 34 bar at the inlet and 24 bar at the outlet). By using a combination of different leak localization methods leak locating errors of less than 0.1% of the pipeline length are achievable. To date the system has not given any false alarms during normal operation.

#### **4 Conclusion**

Modern leak detection systems work and do this without false alarms. State-of-the-art E-RTTM systems have overcome the limitations that more traditional systems have under transient pipeline conditions.

This paper describes the field test results of PipePatrol, an E-RTTM based leak detection system, on an ethylene gas pipeline. Despite that ethylene is a non-ideal compressible gas and the pipeline operates constantly under transient conditions, PipePatrol allows an accurate and false alarm free operation.

To make sure a leak detection system work optimally, the correct system has to be selected. Care should be taken during this selection. Specified accuracy and sensitivity figures are often based on a theoretical approach, whereby items as data refresh rates and transient pipeline conditions are easily overlooked. Preferably field test results from similar applications are consulted.