Good Specifications Can Result In Useful Software-Based Leak Detection

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Software-based pipeline leak detection is one of the technologies with the best cost/benefit ratio when it is carefully specified and based on instrumentation and data acquisition already required for pipeline operations.

Fundamentally, a leak detection system must be able to detect a specified minimum leak with limited false alarms and cope with all operating conditions with minimal desensitization of the capability. A typical expectation of a leak detection system is to detect a leak of 1% of the normal flow rate and locate it within, say, 100 m. What does that really mean?

A leak of 1% of the current flow changes the pressure drop in the pipeline by anywhere between zero and 2%, depending on the leak location, and creates a flow imbalance of about 1% of total flow.

Compared to typically specified measurement accuracies of 0.1%, it seems a fairly simple task to detect the changes caused by the leak, but now look at the following approximate, but typical, operational variations and uncertainties:

- A 0.5% flow change creates a change in pressure drop of 1%,
- A density uncertainty of 1% creates a pressure drop uncertainty of 1%, and
- A pump or tank change easily generates pressure oscillations in the order of 3-5% of the pressure drop.

In leak location terms, moving the 1% leak 10% of the distance between pressure measurements creates a change in pressure drop of less than 0.1%. In other words, even if the impact of the leak is significant compared to the meter accuracy, it is often very small compared to even small operational changes and uncertainties. For leak location it is especially critical because even very small measurement errors or other uncertainties can destroy the leak location capability, if not managed properly. Even under ideal conditions, it can be extremely difficult to locate small leaks within 100 m, because this will require a maximum distance between pressure instruments of 5-10 km and a sampling rate and a maximum time skew of 0.1 second.

The previous information should illustrate why leak detection and location is not solely a question of looking for pressure changes and flow imbalances in a time series of pressures and flow rates.

Instrumentation

Most software-based leak detection systems utilize flow and pressure measurements that have rarely been installed with a leak detection application in mind. It stands to reason that leak detection based on instrumentation will always be highly influenced by the performance of the instrumentation itself. Accurate, repeatable, available and correctly positioned instrumentation is required to maximize leak detection performance. It is accepted that any deficiencies in the instrumentation will ultimately lead to a reduced leak detection capability.

There is little benefit in maximizing the instrumentation performance if the data acquisition system cannot maintain and transfer the information to the same level of resolution. If a measurement is specified to a given accuracy, then the data acquisition must be able to transfer data to at least the same level of accuracy as provided by the instrumentation.

What Performance?

The specification for system performance is often based on:

- How much product loss can be accepted from an environmental perspective.
- Characteristics arising from theft such as a minimum leak rate, reaction time and accuracy of location.
- A battle between vendors to out-do each other in a bid to win work.

In accordance with API 1155, leak detection performance should be specified through the following criteria:

Sensitivity: Specified as a minimum flow rate detectable rather than % of total flow-rate (often misleading). The time to detect the leak should be the confirmation time for a leak of a given size at the worst possible location on the pipeline. This time may well be minimal when compared with the time to react and find the leak.

Robustness: Specified as a percent availability assuming instrumentation and telemetry performance operates in accordance with its specified criteria. The purchaser should ask for the percent of the time that the minimum detectable leak size will be detectable, the percent of the time that the system will be desensitized and to what level it will be desensitized and the percent of the time that the leak detection will be totally suspended. It is unreasonable to ask a vendor to quote the desensitization level resulting from poor data acquisition.

Reliability: Specified as the number of false alarms generated in a given time period if instrumentation and telemetry performance is in continual accordance with its specified criteria.

Accuracy: Specified as the maximum distance between the estimated leak location and the actual leak location and its variation with leak size.

Sometimes it has to be accepted that the wanted performance cannot be achieved and that if significant improvement is needed in capability, the best way of achieving this is through improved or additional instrumentation.

Software-Based

Software-based leak detection principles include regular measurements.

Leak detection and location in pipelines based on regular measurement of pressure and/or flow is one of the basic leak detection methodologies developed in different forms over the past 30+ years.

All methods are based on analysis of time series of pressure and/or flow imbalance because these present some well-known reaction to leaks, including:

- The pressures will drop in all/most locations along the pipeline for some time after the leak develops.
- The pressure drop will initially be greatest at the leak location.
- The flow measurements will show an imbalance between flow in and out of the pipeline.

Large leaks are easy to detect by analyzing the trend of pressure or flow imbalance from a visual perspective, but an accurate location of the leak always requires good synchronization of data and some level of numerical analysis of the trends (Figure 1).

The picture changes quite dramatically if operation at the time of leakage shows significant variation with time. In this case, one needs to look for a small indication of a leak in what appears to be a very noisy signal. The common process used to extract the interesting fraction of a noisy signal is to apply numerical or statistical filtering. A properly designed filter can remove so much noise that the leak effect becomes visible and it is its effectiveness that defines the leak detection and location capability.

Filters entirely based on the history of the signal itself (for example, moving average and first order linear filter) can easily be demonstrated to remove too much of the leak effect to be applicable on their own. This is the sort of filtering one often sees in simple so-called "Leak Detection" functions implemented in supervisory systems.

At the other end of the spectrum, there are hydraulic-model-based filters. It should be fairly obvious that if one can design a filter that accurately models the noise, then the only response left will be that of the leak. However, it is clear that the less accurate the model is in comparison to the real system performance, the less efficient this level of filter will be.

Optimal leak detection and location for a specific pipeline is a question of balance between investment in design, implementation and maintenance of instrumentation, telemetry and software on one side and the requirements for availability, capability and robustness on the other. Using too few, incorrect or poorly designed filters may give an impression of high capability under ideal operating conditions, but overall may result in low availability and robustness.

Selecting A System

There are two principal methodologies available in the market today, that which interrogates measurement deviations at different locations on the pipeline and that which monitors balance of flow in and out of a pipeline section (Figure 2).

Measurement Deviations

The Pressure Measurement Deviation Method monitors pressure measurements along a pipeline. If a leak occurs in the pipeline, the pressure at the instruments drops at a rate dependant on the size, rate of leak development and the distance from the leak. By recording the time each pressure instrument detects the change in pressure, under certain conditions it is possible to determine the location and size of the leak.

However, the pressure change must be detectable and this method cannot analyze the signal persistently. That means that if the system fails to detect the change in pressure as it occurs, then the leak will never be detected. High-resolution pressure measurements, therefore, need to be available but absolute measurement accuracy is of less importance. It is also a requirement that the detection system receives very rapid updates of every pressure signal (several times a second).

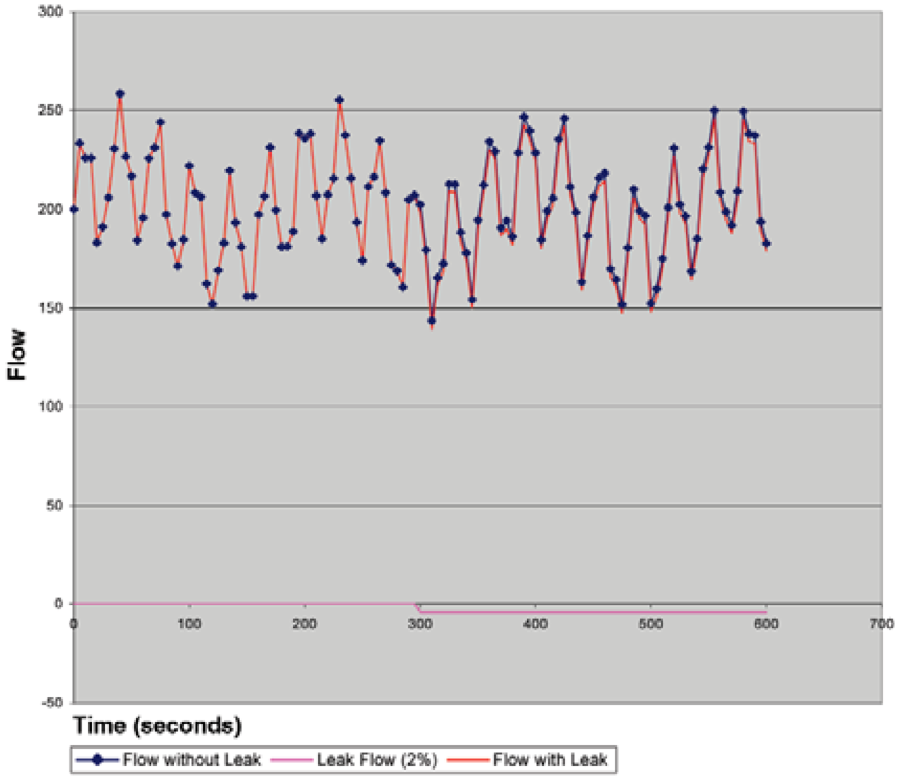

Figure 1: The minimal effect of the leak on the measured flow signal. Leak occurs at 300s.

The dissipation in the pressure change within the pipe is a function of distance and compressibility of the fluid so the capability of this method deteriorates with increasing distance between measurements and increasingly compressible fluids.

Under transient conditions, or with pipelines in which the product properties vary, it is necessary to decrease the sensitivity of the leak detection and under some circumstances, suspend it all together.

The measurement deviations method is best suited to steady state, single product liquid pipelines. It is simple to install, it does not require detailed information on the pipeline or the product and — under ideal operating conditions — it can locate leaks accurately. However, it does require rapid measurement updates, its capability is limited with compressible fluids and - if the leak is not detected on its occurrence — it will never be detected.

As with all methods, as the product becomes more variable or as the operation

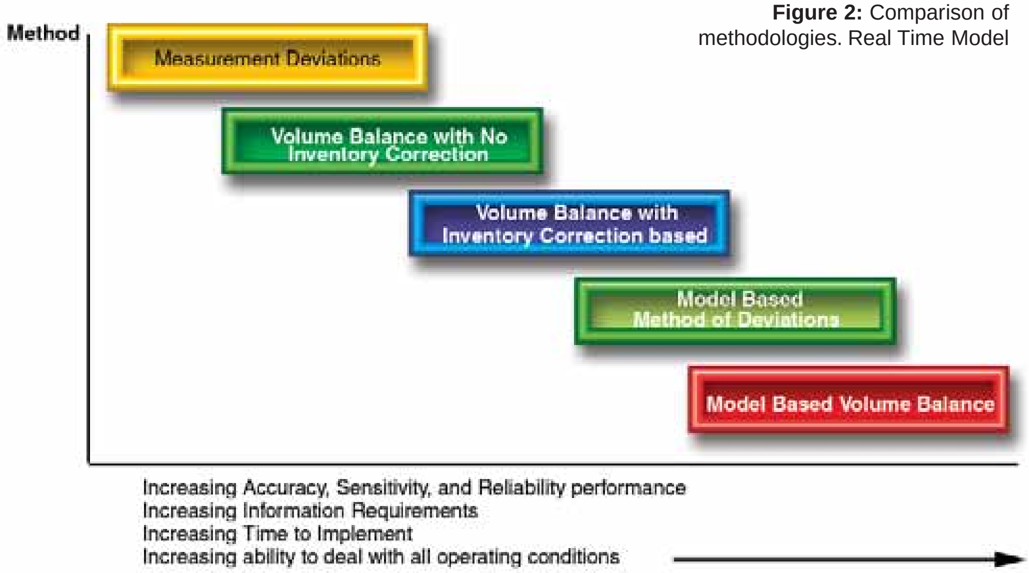

Figure 2: Comparison of methodologies. Real Time Model

becomes more transient, the tuning period will increase. This is because the degree of desensitization of the system has to be carefully determined if false alarms are to be avoided.

Volume Balance Method

The principle behind the volume balance approach is the conservation of volume at a standard condition. The volume of fluid that enters the pipeline over any time interval minus the volume of fluid that exits the pipeline over the same time interval must be equal to the change in fluid volume inside the pipeline over the same time interval (inventory).

In the same way as the measurement deviations method analyzes the pressure change, so this method analyzes the magnitude of the volume balance through numerical filters and/or statistical analysis.

The volumes in and out of the pipeline can be obtained from flow rate or accumulator measurements, but it is the ability to accurately determine the change in product inventory that influences the accuracy of this methodology.

Under steady state conditions, the inaccuracy will be predominantly dictated by the accuracy of the flow measurements, but under variable conditions, it is necessary to determine the effects on the pipeline inventory. This can be calculated using pressure and temperature measurements along the pipeline. It is a reasonably accurate calculation with liquids because the variation in volume with pressure and temperature is minimal, but this is not the case for gases for which it can become a complex calculation.

The change in inventory due to variation in the product properties within the pipeline can be determined through the implementation of a tracking module that tracks the base product properties (compressibility and thermal expansion coefficient) along the pipeline. Again, the location of the product properties is a relatively simplistic module for liquids, but in gases it is a very complex calculation.

The volume-balance method works well on steady state pipelines where product properties do not vary and the installation is relatively quick. For more transient pipelines, it is necessary to have intermediate pressure and temperature measurements available. The closer the measurements, the better the leak detection performance. Experience shows that as the operation becomes more variable, there is a need to desensitize the capability. Greater desensitization is required for gas pipelines to a point where this method will not work without intermediate measurements (such as offshore pipelines).

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The volume-balance method only needs instrumentation data updated once every few seconds. Leak location is not determinable directly through the volume-balance method. Therefore, some additional processes are required if the leak is to be located. One method is to analyze the change in the measured pressure profile, but this is of limited accuracy. Alternatively, the same form of approach used for the measurement deviation method can be utilized, but then the pressure measurement values need to be updated several times a second.

A real-time model replicates the physical hydraulic behavior of the pipeline driven by flow, pressure, temperature and product property measurements. It works by calculating detailed flow, pressure and temperature profiles at intermediate steps along the pipeline that are far smaller than the typical distances between line instruments.

The real time model can be regarded as an additional filter. With good and accurate configuration data and accurate, frequently updated instrumentation data, very detailed real-time models can be created that closely replicate transient conditions and accurately determine the position of product property variations (gas or liquid). It should be clear that this can increase the sensitivity of the two principal methods by filtering the effect due to transients, product property and temperature variation.

To enhance the measurement deviation method, comparison is made between the measurement value and the same value calculated by the model. This is often called the Method of Deviations Analysis or Method of Point comparison and can be applied to flow as well as pressure measurements

For the volumetric balance method, the model can calculate a far more accurate inventory term by integrating its internal profile calculations. Maximum accuracy can be achieved by implementing separate models between each of the pressure measurements along the pipeline (assuming intermediate pressure measurements are accurate).

Since the effect of transients, temperature and product property variation on the pressure profiles can be removed, leaving the effects resulting only from the leak, it follows that the leak-location performance can also be improved with availability of the real-time model. ***P&GJ***