Best Practices in Leak and Theft Detection

Abstract

In the oil and gas pipeline leak detection market today, there are several software based methodologies available — ranging from simplistic pressure wave methods, to real-time model-based volume balance techniques. All approaches have inherent advantages and disadvantages, definable in terms of simplicity of implementation/maintenance needs, reliability, cost, robustness, availability, and accuracy (minimum leak size and location). It is a fact that no one methodology can lay claim to be able to satisfy all the advantages over all operating regimes, and so the choice of a leak or theft detection system must be based on a clear user-defined set of objectives. This white paper aims to bring some clarity to the various leak and/or theft detection methodologies available today. It specifically highlights the fundamentals for achieving the best leak detection system and for each method; it considers the advantages, the disadvantages, and the applicability of that method for particular pipeline characteristics with particular hydraulic behavior.

Introduction

The ability to detect leaks — accidental or planned (theft) — on liquid and gas pipelines continues to be a subject for debate and the focus on leak detection has intensified. This is a result of high profile litigation, the increasing frequency of product theft, and the continuous drive for improved safety and environmental protection.

This paper focuses on software-based leak and theft detection as one of the detection technologies with the best cost-benefit ratio when based on instrumentation and data acquisition already required for operation of the pipeline.

EMERSON.

Emerson has been working in the area of leak and theft detection and location since the 1970s and has built an extensive level of experience through the implementation of over 300 live installations. It is firmly believed by the company that practical experience of the real-life implementation of leak and theft detection systems is the only true qualification for being able to provide an accurate assessment for what can be achieved with the technologies available today. There is a wealth of material available in today's market that claims an independent consideration of available technology, but all too often this material culminates in the form of biased hypothetical reports supported only with theoretical assessment or tests under ideal conditions.

The fundamental requirement for a leak or theft detection system is that it is able to detect leaks with limited false alarms. Too many false alarms and the system will be rendered practically useless. The system must also be able to cope with all operating conditions with minimal desensitization of the leak detection capability. Minimal desensitization is actually the difficult part. Unfortunately, many leak detection system vendors will claim that their particular solution can cope with all operating conditions without any loss of performance and this ultimately leads to disillusionment with the industry when this cannot be maintained.

Users frequently want a system installed with minimal interference and without the need to provide significant amounts of data. The expectation is high sensitivity, no false alarms, operation without attention, and no continuing maintenance costs. This should also be across all operating conditions. The industry has been too willing to promise all the good features and avoid mentioning the pitfalls, to the extent that there is skepticism about the existence of practical leak detection systems in the market. Emerson is acutely aware of this problem and will continue to actively take steps to correct it.

This paper describes the step-by-step process for ensuring that a leak detection system has its greatest chance of achieving satisfactory performance.

The Challenge of Leak and Theft Detection and Location

Let's start by outlining some typical relations between leak size and location — whether accidental or intentional (theft). 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, one hundred meters. But what does that actually mean?

In approximate terms, a leak of 1% of the current flow rate changes the pressure drop in the pipeline between 0 and 2%, depending on the location of the leak, and creates a flow imbalance of approximately 1% of the flow rate. Compared to typically specified measurement accuracy's of 0.1%, it seems to be a fairly simple task to detect the changes due to the leak effect.

However, the stated changes shall now be compared to the following typical operational variations and uncertainties:
- A flow change of 0.5% results in a pressure drop change of 1%
- A density uncertainty of 1% also creates a pressure drop uncertainty of 1%
- A pump easily generates pressure oscillations in the order of 3-5% of the pressure drop
- A tank change easily creates a pressure change of the same magnitude.

In terms of leak location, it should be remembered that moving the 1% leak 10% of the distance between pressure measurements, only 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 as 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 meters, as 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.

These numbers should illustrate why leak detection and location is not just a question of looking for pressure changes and flow imbalances in a time series of pressures and flow rates.

The impact of a leak is generally proportional to the leak size, so it should be equally obvious that the difficult part of leak detection and location is related to the detection of very small leaks. This also means that the total cost of detecting leaks increases with the need to detect smaller leaks with better location accuracy.

The methodologies discussed in this paper are in general limited to leak sizes of the order of two times the accuracy of the flow meters, and the location capability is in general limited to 5 to 10 % of the distance between accurately calibrated pressure instruments when considering leaks below 1%.

Ensure that the instrumentation gives the leak detection system its greatest chance of success

Most software-based leak detection systems utilize existing flow and pressure instrumentation that has been installed for controlling the pipelines operation. Unfortunately, this instrumentation has most likely not been installed with a leak detection application in mind. The leak detection system installed is then all too frequently expected to overcome instrument deficiencies without loss of performance, and that is the first step on the path of disillusionment with the leak detection system. Regardless of the methodology selected, it stands to reason that leak detection based on instrumentation will always be highly influenced by the performance of the instrumentation itself.

Of course, there will be different approaches for dealing with poor instrument performance and some approaches may recover from poor instrument performance faster than others may. But without exception, poor instrumentation is at the expense of capability. Accurate, repeatable, available, and correctly positioned instrumentation is required to maximize leak detection performance. It should then be accepted that any deficiencies in the instrumentation will ultimately lead to a reduced capability, whether in terms of minimum detectable leak size, accuracy of leak location, time to detect, number of false alarms, or leak detection availability (a component of performance frequently overlooked).

Review and ensure the necessary data acquisition performance

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. For example, a pressure measurement accurate to 0.1% of a 100 bar range means that it is accurate to 0.1 bar. If a deadband restriction is placed on the telemetry such that it only updates a value on exception greater than 0.5, or if the pressure readings are sampled from a location with 0.5 bar equipment induced noise, then the pressure measurement value is instantly deteriorated to an accuracy of 0.5%.

There should be little to no loss of resolution when converting an analog measurement. If a measurement attains 0.1% accuracy, it is clearly detrimental if the level of accuracy deteriorates as a result of conversion to a digital value before being transmitted. Ideally, the resolution of conversion should be at least 12 bit + sign.

In all probability, the measurements transmitted via the data acquisition system to the leak detection system (whether or not via SCADA) have not been measured at the same instance in time; there will be a skew in time between one measurement value being read and the next. To maximize the sensitivity of a leak detection system, it is important to try and re-align/interpolate the values such that they appear to have all been read at the same instance in time. This can only be achieved if the timestamp associated with the measurement is taken at the RTU immediately after the reading is logged.

If any of the above cannot be fully satisfied, if deadbands have to be placed on measurements, if the accuracy of conversion is poor, or if there is a significant skew in the measurements being taken without timestamping, this does not mean that leak detection cannot be performed. What it does mean is that there needs to be a mechanism in place that can help minimize the effect of missing, inaccurate, or skewed data. It inevitably means that the owner and operator of the system has to accept that there will — regardless of methodology chosen — be a reduction in leak detection, especially leak location capability.

The above effects can sometimes be minimized with the implementation of intelligent processing at the RTU level that can filter, average, and retain time series of data before transmission. Alternatively, before individual incoming data items are made available to the leak detection system, a first level of filtering should be applied to the data to identify data errors and to minimize the effects of inaccurate data measurement or poor data acquisition performance. This function is essential if false alarms due to data acquisition and/or instrumentation malfunction are to be minimized to the greatest extent. It reads and checks the values being received by the system and seeks to replace (emulate) suspect values. Checking routines could include checking that a value is within an expected range, that it has received an updated timestamp, that its value has changed, that it has an associated good status marked by the RTU, or that the individual measurements react in a physically correct manner relative to each other. Suspect values could, for example, be replaced with an interpolated value, the last known good value, an average of several previous values, a weighted average of previous values, the value of an equivalent instrument, etc.

The data emulations available depend heavily on the nature of the measured variable and its impact on the leak detection and location. Emulation of data is never a substitute for accurate real-time data.

It is therefore of paramount importance for satisfactory system performance that fully-functional data acquisition is maintained at all times allied with accurate and well-maintained (calibrated) instrumentation. The data pre-processing and emulation helps minimize loss of leak detection capability and instability, minimizing recovery time and ensuring that the leak detection has the best opportunity to continue operating without total suspension. A good leak detection system will actually help the user to identify even very small measurement problems and thereby — if proper action is taken in due time — also help in making the maintenance focused and effective.

Determine the performance wanted from your leak detection system

The specification for performance of a leak detection system is often based upon one of the following:

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

In accordance with API 1155, leak detection performance is usually specified through the following criteria:

1. **Sensitivity** — This should be specified as an absolute minimum flow rate detectable, because a percent of the total flow rate is often very misleading. The greater the maximum possible flow rate within the pipeline, the greater the minimum detectable leak size will be (but the better the leak location as well). The time to detect the leak should be asked for as the maximum time to detect a leak of a given size. A leak that occurs furthest from instrumentation will take the longest time to detect, and it is this time that should be specified. This may well be minimal when compared with the time to react and find the leak.

2. **Robustness** — This should be asked for in terms of a percent of the instrumentation availability and telemetry performance is in continuous accordance with its specified performance criteria. Depending on the methodology, desensitizing the leak detection capability may be necessary (e.g., due to transient conditions, significant product variation or due to receipt of inaccurate data from the pipeline). 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, the level it will be desensitized to, and

the percent of the time that the leak detection will be totally suspended. Information on the operating characteristics of the pipeline and the product will need to be provided by the purchaser to be able to specify this information. The vendor should also specify what reaction the system will take when faced with poor data acquisition or instrument performance but it is unreasonable to ask a vendor to quote the resulting level of desensitization. This is because the level of error attributable can rarely be predetermined and prolonged inaccuracy will inevitably lead to total suspension of the leak detection process anyway.

3. **Reliability** — This should be asked for as the number of false alarms that would be generated if instrumentation and telemetry performance is in continuous accordance with its specified performance criteria.
4. **Accuracy** — This should be asked for as the maximum distance between the estimated location and the actual leak location and its variation with leak size. Locations down to less than 1% of a pipeline section (between line pressure measurements) are rarely available with methods other than pressure measurement interrogation and then only under very specific conditions (refer to page 9).

Sometimes, it has to be accepted that the wanted performance cannot be achieved with a particular method or due to deficiencies in data acquisition and/or instrumentation. Purchasers should be wary of suppliers who are happy to guarantee unobtainable performance just because a specification asks for it or place impossible requisites on telemetry and instrumentation performance in terms of update rate, etc. in order to achieve it. In some cases, the physical hydraulic behavior means that stringent leak detection performance is simply impossible. It is quite often the case that if significant improvement is needed in leak detection capability, the best way of achieving this is through improved or additional instrumentation.

Software-based leak detection principals

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 as these present some well-known reactions to leaks:

- The pressures will drop in all/most locations along the pipeline for some time after the leak starts to develop
- The pressure drop caused by the leak will initially be greatest at the location of the leak
- The flow measurements will show an imbalance between flow into and flow out of the pipeline (imbalance caused by the leak).

For very large leaks (line ruptures), it is often easy to detect it has occurred by analyzing the trend of pressure or flow imbalance from a visual perspective. However, an accurate location of the leak always requires good synchronization of data and some level of numerical analysis of the trends. The smaller the leak is the smaller the trace of the leak in the pressure and flow imbalance trend. If the normal operation is very steady (time independent) when the leak develops, it may still be possible to detect the leak visually or at least with some fairly simple numerical analysis of the trends.

The picture changes quite dramatically if the normal operation at the time of leakage shows significant variation with time (as a result of transients, interference from equipment operation, variable product properties, etc.). In this case, you need to look for a small indication of a leak in what to the human eye and a numerical analysis appears to be a very noisy signal.

The commonly accepted process used to extract the interesting fraction of a noisy signal (the leak influence on a pressure or flow imbalance) is to apply some sort of numerical or statistical filtering. A properly designed filter can remove so much noise that the leak effect becomes visible. It is the effectiveness of the process implemented to remove the noise from the signal that defines the leak detection and location capability.
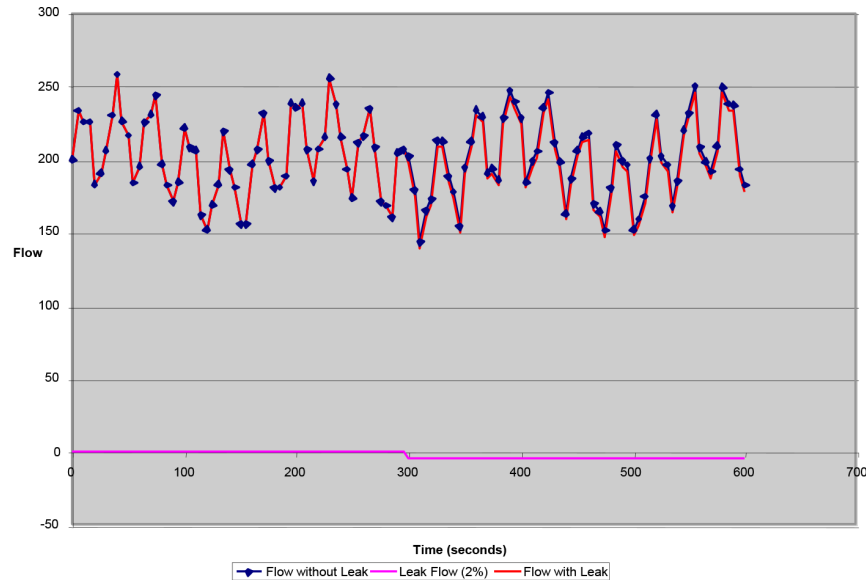
Figure 1. The Effect of the Leak on the Measured Flow Signal – Leak Occurs at 300s

Numerical filters are characterized by providing a filtered value, Xf(t), for every signal value, X(t), and the difference X(t) - Xf(t) ideally contains the effect of the leak. In other words, X(t) - Xf(t) is equal to zero (or very small) when there is no leak, and (typically) positive when there is a leak.

Statistical filters are generally characterized by looking for statistically significant changes in the average signal taking into account the actual noise level described by say the standard deviation.

Every filter has specific characteristics, i.e., a given filter may remove mainly noise with specific frequency, e.g., a regular sinusoidal oscillation created by a pump but all filters also remove some fraction of the signal you are interested in — here the leak effect.

Filters entirely based on the history of the signal itself (e.g., 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 often seen 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 you can design a filter that accurately models the noise, then the only response left will be that of the leak. The fact the majority of the noise seen on measurement signals from a pipeline originate from external and internal process variations (equipment operation and product changes) indicates a 'filter' that can calculate pressure and flow variations in real time, based on the knowledge of such changes, is the most efficient filter you can get. It is also clear however, 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 may overall result in low availability and robustness (high number of false alarms). Implementation of complex filters such as a hydraulic model may provide both high availability and accuracy, but may be more expensive and reduce the robustness if not properly maintained.

Selecting the Most Appropriate Level of Leak Detection System

Selection of the appropriate system is a choice that is more of an engineering assessment, considering performance criteria, cost, instrument availability, and time to implement, rather than a proving exercise for a particular leak detection technology. There are two principal methodologies that exist in the market today, that which interrogate measurement deviations at different locations on the pipeline and that which monitor the balance of flow in and out of a pipeline section.

Measurement deviations

The 'Pressure Measurement Deviation' method monitors pressure measurements along a pipeline length. If a leak occurs in the pipeline, the measured pressure at the instruments installed on the pipeline drops at a rate dependent on the size and rate of development of the leak as well as the distance from the leak. By recording the time each pressure instrument detects the change in pressure and knowing the speed of travel of the pressure wave within the fluid, under certain conditions, it is possible to determine the location and even the size of the leak. The performance of the measurement deviations approach is determined by the following:

- The magnitude of the pressure change must be detectable at the pressure instruments. High-resolution pressure measurements therefore need to be available although absolute measurement accuracy is less important.
- The dissipation in the pressure change is a function of distance and compressibility of the fluid. It therefore follows that the capability of this method deteriorates with increasing distance between pressure measurements and increasingly compressible fluids to a point where capability on a gas system is very poor.
- Transient waves travel at around 1000 m/s in liquids and 300 m/s in gases. Therefore, in order to ensure detection of the leak via the change in pressure, it is a requirement that the detection system receives very rapid updates of every pressure signal (several times a second and often only possible by analyzing the pressure signals locally). Such a methodology cannot analyze the signal persistently and that means that if the system fails to pick up the change in pressure as it occurs, then the leak will never be detected.

Numerical and statistical filters that analyze the pressure measurements for the leak signal can remove the effect of random noise on the signal. Extensive site experience shows that it is difficult for this approach to effectively filter the effects of non-randomized variations such as product variation and transients imposed by manual or automatic manipulation of equipment on the pipeline. Therefore, 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.

In conclusion, the 'measurement deviations method' is usually best suited to steady state, single product liquid pipelines. It is simple to install and does not require detailed information on the pipeline or the transported product. This method under ideal operating conditions can locate leaks very accurately. However, while this method does require rapid updates of the pressure measurement signal (several times a second), it does not work well with compressible fluids and if the leak is not detected on its occurrence, it will never be detected. As the product becomes more variable or as the operation becomes more transient, the installation/tuning period will increase. This is because the degree of desensitization of the system has to be carefully determined if false alarms from these effects are to be avoided.

The volume balance method

The principal behind the volume balance approach is the conservation of volume at 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 (pipeline inventory).

Volume in (t0 –t1) – Volume out (t0 –t1) – Change in Volume (t0 –t1) = Volume Balance (1)

Under a no leak condition, the volume balance will be zero. It follows that under leak conditions, the amount of fluid entering the pipeline will exceed the amount exiting the pipeline and the volume balance will increase to the size of the leak (calculated using the equation above). In exactly the same way as the measurement deviations method analyzes the pressure, the volume balance method analyzes the magnitude of the volume balance through numerical filters and/or statistical analysis.

The volume into the pipeline and the volume out of the pipeline can be obtained from the volumetric 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 with product properties that do not vary, the change in standard volume within the pipeline will be maintained close to zero. Under these circumstances, the inaccuracy will be predominantly dictated by the accuracy of the flow measurements with the effects of random noise being removed through numerical filtering and/or statistical analysis.

Under transient conditions or where product temperature and/or properties vary, it is necessary to accommodate their influence on the change in inventory. Ignoring the calculation of the change in inventory and averaging the response over very extended time periods can still lead to the detection of very small leaks. However, to fully average out the effect of transient variations takes several hours and the effects due to product temperature and property variations can take days. Leak detection times measured in terms of several hours or days (depending on detectable leak size) are rarely acceptable and therefore, accurate determination of the change in inventory (an additional level of filtering) is required on a regularly updated basis if detection times are to be kept at an acceptable level.

The change in pipeline inventory due to transients can be determined from a profile of pressure and temperature values along the pipeline length. These values can be obtained from measurements often installed at intermediate block valve stations. If the compressibility and thermal expansion of the product, and the stiffness and thermal expansion of the pipe itself is known to the system, the product inventory at the process condition can be calculated through empirical formula. For liquids, volumetric variation with pressure and temperature is minimal and the equation of state is relatively simplistic and accurate but this is not the case with gases. Gas volume varies significantly with pressure and temperature and is more difficult to determine. It requires that the super-compressibility is accurately calculated and the choice of the gas equation of state required depends on the compositional breakdown of the gas and the pipeline's operating pressure and temperature envelope.

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. The advancement of the product through the pipeline is updated on a cyclical basis and is determined from the measured volume of product entering the pipeline from one update to the next. When the change in inventory is calculated at each of the pressure and temperature measurements, the properties used within the equation are the properties of the product calculated to be at the location of these measurements. Again, the location of the product properties is a relatively simplistic module for liquids, but in gases it is a very complex calculation.

Liquids travel along a pipeline's length at a relatively uniform velocity but in gases, the velocity is variable and highly dependent on the pressure and temperature of the fluid.

The process inventory is then an integration of the process volumes calculated along the pipeline length from which the total inventory at standard conditions can be derived. The change in the inventory term is then simply the difference in the determined standard inventory value from one update to the next (t0 to t1).

Leak location is not determinable directly through the volume balance method and therefore some additional processes are required if the leak is to be located. One method of leak location is to analyze the change in the measured pressure profile. Since the volume balance determines the leak size, it is then possible to determine where a leak of such size would be located in order to result in the change seen in the measured pressure profile. Alternatively, the same form of approach used for the measurement deviations method (analyzing the time the change in pressure occurs at different pressure instruments) can be used for locating the leak in conjunction with the volume balance method for actually detecting the leak.

In conclusion, the method of volume balance 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 additional intermediate pressure and temperature measurements. The closer the measurements, the better the leak detection and location performance. Experience shows that as the operation becomes more transient or as the product properties become more variable, there is a need to desensitize the capability of the leak detection system with total suspension under highly transient conditions (pump or compressor start/stop). Greater desensitization is required for gas pipelines to a point where this method will not work on gas pipelines without intermediate measurements (such as offshore pipelines). As the product becomes more variable or as the operation becomes more transient, the installation/tuning period will increase. This is because the degree of desensitization of the system has to be carefully determined if false alarms from these effects are to be avoided.

The volume balance method only needs instrumentation data to be updated once every few seconds (as opposed to several times a second for the measurement deviation method). Leak location through analysis of the change in the measure pressure profile is of limited accuracy and becomes more inaccurate with less frequent updates of the measurement values. If leak location is chosen to be determined through the pressure measurement deviation method, then the pressure measurement values need to be updated several times a second.

A problem frequently seen on pipelines is that the pressure and temperature measurements along the pipeline are not maintained to the same accuracy as measurements at supply, pump, regulator, and delivery stations – simply because these measurements are not required in the daily operation. The consequence is often that leak detection systems dependent on these measurements are severely desensitized.

The real-time model component

A real-time model attempts to replicate the physical hydraulic behavior of the pipeline in real time, driven by flow, pressure, temperature, and product property measurements obtained from the pipeline. 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. In fact, the real-time model does not need intermediate line measurements if they are not available. The accuracy of the model is dependent on the accuracy of pipeline and product characteristics being made available to the model and the complexity of the real-time operation itself (ranging from steady state liquid pipelines to multiphase pipelines).

The real-time model can be regarded as an additional filter. With good 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 if a model is available, it could be used to increase the sensitivity of the two principal methods by filtering the effect due to transients, product property, and temperature variation.

To enhance the measurement deviations method, a comparison is made between the measurement value and the value calculated by the model for the same location that has already filtered the effects due to transients, product property, and temperature variation. 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 real-time model can calculate a far more accurate inventory term by integrating the volumetric profiles. Maximum accuracy can be achieved by implementing separate models between each of the pressure measurements along the pipeline (assuming intermediate pressure measurements are accurate).

Leak location capability will also be improved with the introduction of the real-time model. This is because the effect of transient, temperature, and product property variation on the leak location results can be filtered leaving the leak location calculations to be undertaken on the effects resulting only from the leak.
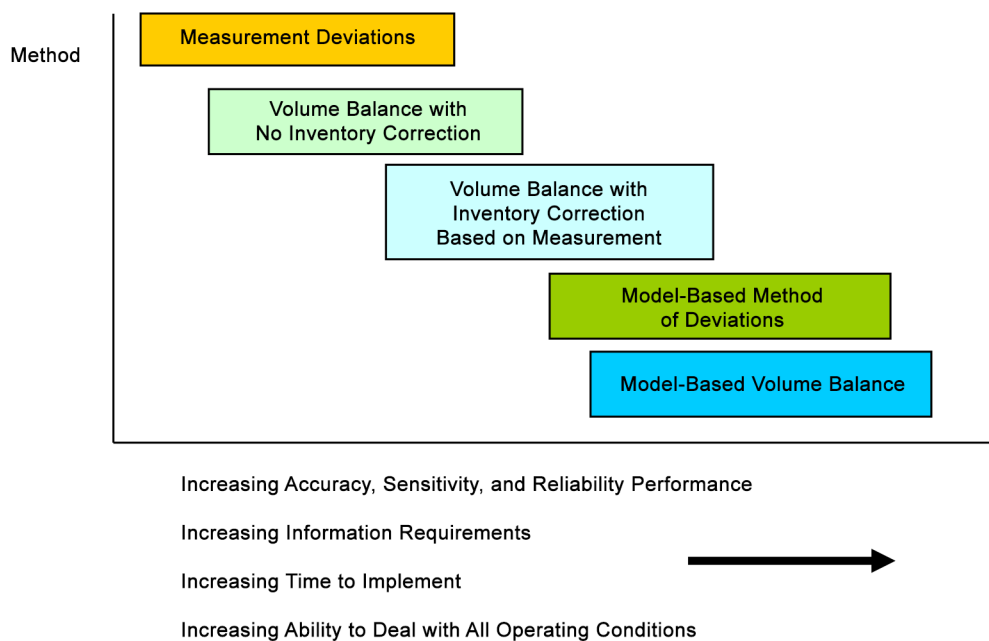
Method

Measurement Deviations

Volume Balance with
No Inventory Correction

Volume Balance with
Inventory Correction
Based on Measurement

Model-Based Method
of Deviations

Model-Based Volume Balance

Increasing Accuracy, Sensitivity, and Reliability Performance

Increasing Information Requirements

Increasing Time to Implement

Increasing Ability to Deal with All Operating Conditions

Figure 2. Comparison of Methodologies

In conclusion, a real-time model can significantly improve the accuracy of the two principal leak detection methodologies especially on systems with increasingly complex operation and behavior. The disadvantage of the real-time model component is that more detailed information on the pipeline and equipment characteristics are required for its implementation. It can take longer to implement and it appears less robust and more complex to maintain. It is also of limited benefit if it is not well-tuned. Graphical configuration and advancements in technology have helped significantly limit these disadvantages and perhaps surprisingly, the tuning times onsite are not significantly increased in comparison to non-model-based implementations. Furthermore, it is worth remembering that a real-time model provides essential support for other pipeline management applications — from detection of measurement errors, to more detailed real-time information about the pipeline operation (e.g., flow and product details between measurements), to accurate input for forecast applications.

Testing the Leak Detection System

The most obvious way to test a leak detection system is to physically extract product from a particular location on the pipeline and check if the system sizes and locates the leak correctly. These tests are often conducted under ideal steady-state conditions and without variation in the product properties. Under these conditions, nearly all methods will work well, with the measurement interrogation method appearing to be the most accurate in terms of leak location (if the pressure meters are closely spaced and polled very frequently). However, it is when the system is exposed to the range of conditions over its operating life that the system is really tested. Only under extended operation can its ability to deal with transient conditions, temperature, and product variation be fully considered — in terms of the number of false alarms generated and the level to which it has been desensitized. In the test environment, conditions are usually perfect and the minimum leak size can usually be detected. A good additional test for the system is to extract product from the system for given leak sizes just after a transient condition is created in the pipeline (such as a significant change in pump or compressor speed or valve movement).

The Emerson Philosophy

Our Emerson team has more years of experience with various combinations of numerical filters, statistical filters (methods) and hydraulic models in various combinations for different pipelines than any other company in the world. In fact, in the North American market, the implementation of the most sensitive and accurate systems in the world have been installed and continue to operate well within today's operations. We understand that to obtain the best result, i.e., the highest probability of detecting the smallest leak — or theft — and the highest probability of not detecting a leak when there is no physical leak (false alarm) under different operating conditions, it is often necessary to combine different numerical and statistical filters — a technique now well developed by Emerson.

Over the past 38 years, our experts have developed the transient hydraulic real-time model almost to perfection and can, under most operating conditions with the right data input, remove up to 99.9% of the process noise from any signal, and thereby detect very small leaks. However, the conditions for using this model are seldom perfect, and therefore Emerson applies both averaging, first order, and statistical filters to maximize the leak detection and location capability under all typical operating conditions. This is not only when the operation is very steady or where a simple numerical or statistical filter would be sufficient.

Emerson promotes the implementation of non-model based solutions when best suited to a particular pipeline and its operation. We also promote a combination of methods if necessary in order for specified criteria to have the greatest chance of success. For example:

- It may be that a highly sensitive system is not required and that minimization of cost is a prime factor. For this scenario, a non-model based solution is sufficient.
- For a pipeline where information on product or pipeline characteristics is unavailable, it may be more appropriate to implement a non-model based system until a real-time model based system can be implemented to support it.
- It may be that a combination of methods (model-based leak detection via the method of volume balance with leak location based on the measurement deviations method) is the most appropriate for maximized sensitivity.
- It may be that a combination of the measurement deviations method and the volume balance method is required to ensure minimal false alarms with a voting algorithm implemented to weight the results from the two methods.

At Emerson, we have all of the tools (types of filters) collected in one package called PipelineManager™. Based on experience, we can and will design the best combination of filters to obtain the desired availability, accuracy, and robustness for the specific pipeline, instrumentation, and communication for the most practical operating conditions on the pipeline within the budget available. Furthermore, the access to all possible tools within the same flexible software package ensures the most cost-effective adjustment to unexpected or changing operating conditions, new performance requirements, or changes in instrumentation and data acquisition.

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