Introduction
As pipeline operators try to mitigate the effects of leaks, leak detection systems are becoming increasingly important. By detecting and locating leaks as soon as possible, operators can minimize the amount of product released, maximize public and employee safety, reduce environmental impact, minimize clean-up costs, and limit legal liability. An effective leak detection system will also assist operators in meeting regulatory requirements. However, a leak detection system that is prone to false alarms results in unnecessary expenditure.

Pipeline operators have experimented with several types of leak detection systems. This white paper identifies the major types, positions material balance systems within Computational Pipeline Monitoring (CPM) systems, and discusses the advantages of material balance systems based on mass rather than volume. Finally, this white paper discusses the role that Micro Motion meters can play in mass balance systems, and provides several examples of existing systems.

Background
Pipeline leak detection systems fall into three general categories:
• Pipe integrity monitoring (e.g., pipeline pigging)
• External monitoring (e.g., human inspection, vapor sensors, acoustic emissions monitoring)
• Internal fluid state monitoring

A variety of issues are associated with the first two categories, e.g.:
• Low reliability
• Inability to detect remote leaks
• Inability to detect leaks quickly
• Inability to detect leaks on a continuous basis
• High labor requirements
• Vulnerability to tampering

The third category, where the hydraulic state of the fluid in the pipeline is monitored, is the most common. This type of leak detection is normally software-based, and is called Computational Pipeline Monitoring or CPM, a term coined by the American Petroleum Institute (API) in 1994.

CPM methods
There are two principal CPM methods:
• The first method uses pressure or acoustic analysis, which analyzes the pressure wave in the fluid that is caused by a leak. This method allows very fast detection of a leak (a function of the speed of sound in the fluid), but the leak must be fairly large for the system to pick it up.
• The second method uses the material balance of the pipeline (or segments of the pipeline). This method compares the quantity of material entering the pipeline with the quantity of material flowing out. Any differences that cannot be accounted for by changes in temperature, pressure, or linepack suggest the existence of a leak.

The most effective leak detection systems combine these two methods.

Material balance systems
Material balance systems can be based on either volume or (direct) mass.
• For material balance systems based on volume, the volume measurements at each end of the pipeline (or segment) must be comparable. Temperature differences and/or pressure differences between the input measurement and the output measurement will introduce error that must be compensated for. This

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1. Material balance systems based on inferred mass (mass derived from volume) are essentially volume-based, and have all the limitations associated with volume measurement. In this discussion, the term "material balance systems based on mass" refers only to systems that utilize direct mass measurement.
requires measuring temperature and pressure at both ends of the line, in addition to volume, and then converting the volume measurement either to “standard” conditions or to mass (the preferred solution). However, if either temperature or pressure varies significantly inside the pipeline, the end measurements are not truly representative and the applied compensation factors are not accurate. Temperature compensation, in particular, can be challenging if the pipeline is exposed to different environments (e.g., if some segments are below ground, under a body of water, etc.).

* For material balance systems based on mass, because mass measurements are not affected by temperature or pressure, no temperature or pressure compensation is required.

Accordingly, material balance systems based on mass require less instrumentation, and because only one measurement device is used, they are typically more accurate.

However, a rigorous leak detection system, whether volume-based and mass-based systems, will require linepack compensation. Linepack compensation adjusts measurements for the amount of material in the pipe. Linepack compensation is implemented by the software component of CPM systems, and is one of the primary reasons that the software is required.

**Requirements for an effective mass balance system**

Although a mass balance system is theoretically accurate, its real-world accuracy depends on the accuracy of the mass measurement devices and the linepack calculation. Meter accuracy directly determines the system’s sensitivity, or ability to detect small leaks. Furthermore, the overall accuracy of the system is a function of the least accurate meter.

Accordingly, all meters must be of custody transfer quality, e.g.:
- The meters must provide high-accuracy measurement.
- All measurements must be repeatable through changing process conditions (changing flow rates, density, viscosity, etc.).
- All measurements must be reliable and sustainable over time.

Micro Motion offers an array of Coriolis meters that meet these requirements. Various models are available with an accuracy specification of 0.1%, and for the most rigorous applications, the enhanced ELITE meter with an accuracy specification of 0.05% can be used. Combining direct mass measurement with high accuracy, these meters are the ideal choice for leak detection applications.

In addition, Micro Motion Coriolis meters provide other features that are useful in a leak detection system:
- Because Coriolis meters measure density as well as mass, the system can be used for secondary functions. For example, the density measurement can be used to monitor changes in process fluid composition, e.g., to track batches of product as they pass multiple metering stations, or to monitor product quality.
- Because the Coriolis meter measures the density of the entire flowing stream, independent of fluid composition, it is more accurate for process fluids with complex or variable composition than other technologies that infer the density (e.g., using lookup tables).
- The meter verification feature, available with newer Micro Motion meters, enables a quick online check of meter performance. When variation between meters is out of tolerance, operators can quickly rule out false alarms or meter damage.
**Case studies**

This section presents four real-world situations in which Micro Motion meters are used for leak detection.

*Leak detection using flow reconciliation*

A refiner in the eastern United States needed a leak detection system to meet the pipeline monitoring requirements established by the Department of Transportation. The pipeline in question is 74 miles long and 12 inches in diameter. It carries various Canadian crude oils including sweet, sour, and heavy crudes.

The refiner chose to use flow reconciliation to meet DOT requirements. Three metering stations were installed: one at each end of the pipeline and one in the center. PD meters were installed at each station. With constantly changing environmental conditions and fluid properties, the PD meters were not sufficiently accurate to meet requirements. The refiner was unable to demonstrate to authorities that there were no leaks currently in the pipeline or that an effective leak detection system was in place.

A project to improve the flow reconciliation was undertaken. The refiner installed two D600 meters from Micro Motion, one at each end of the pipeline, and mass totals from these two meters were compared every hour:

- If the totals matched within 0.7%, the pipeline was assumed to be intact.
- If the totals varied by more than 0.7%, an alarm was generated.

The conversion to Micro Motion meters was immediately successful, and the refiner was able to meet DOT requirements.

However, when mass flow rates from the two meters were compared on a continuous basis:

- If pipeline operation was steady, the meters agreed to within 0.1%.
- If pipeline operation changed (e.g., a tank was switched or a pump was shut down), the readings would diverge until flow again reached steady state.

Figure 1 shows two examples of changes in pipeline operation and the effects on measurement. In Figure 1, the data lines represent mass flow rate from Meter 1 at the tank farm (the pipeline entrance) and Meter 2 at the pipeline exit. The meter readings are in close agreement until Event 1 (a tank switch at the tank farm). The tank switch registers only on Meter 1. When the disruption is over, the meter readings again agree until Event 2 occurs (a pump shutdown at the pipeline exit). Both meters register this change, but at different times. Event 3 (pump restart) is also registered by both meters but at different times.

![Figure 1. Flow data – Steady state vs. pipeline events](image)

These results demonstrate the importance of linepack compensation in leak detection systems. If only the hourly reconciliation is used, it would be possible for a leak to go undetected for up to an hour, but comparison of flowrate data cannot distinguish between pipeline events and leaks without the assistance of linepack compensation.

*Leak detection using a four-meter voting system*

A refiner based in Europe sends products from the refinery to a tank farm located on the opposite bank of a large river. The pipelines run below the riverbed, and local authorities required a leak detection system to monitor for leaks into the river.

The original system used a volume-based materials balance system with both PD and turbine meters. This system generated a large number of false alarms, so a new system based on mass measurement was designed.
To increase statistical accuracy and reliability, four Micro Motion meters were installed on each pipeline, two at each end (see Figure 2). Mass flow data is reported to a central station. If the four meters agree to within 0.5%, the pipeline is assumed to be intact; if any one of the four meters is outside this limit, an alarm is generated. Because of the relatively short length of the pipeline, linepack compensation was not needed.

The system was so successful that it has been implemented on 18 pipelines in this site.

![Figure 2. Micro Motion meter in pipeline to tank farm across river](image)

**Leak detection with linepack compensation**

The state of Alaska has established some of the most stringent pipeline leak detection requirements in the United States, and possibly the world. All leak detection systems are inspected, tested, and monitored by the state.

At one site, PD meters were installed at various points along a large crude oil pipeline into a refinery. Although a statistical pipeline monitoring system was in place, the leaks were being masked by the noise of the PD meters. The site was unable to pass the state audit.

When replaced by Micro Motion meters (see Figure 3), and mass flow rather than volume flow was reported to the leak detection software, the leak detection system reached the required levels of effectiveness and received state approval.

![Figure 3. Micro Motion leak detection meters in Kenai, Alaska](image)

**Leak detection on pipeline transporting multiple fluids**

An 800 km pipeline in Canada transports C2+ (ethane and higher hydrocarbons), condensate, and crude oil. Only a mass-based Coriolis system can easily measure process fluids of such varied composition. Other methods either infer density from look-up tables or require a separate density device.

The pipeline operator has installed Micro Motion Coriolis meters (see Figure 4), and uses them for leak detection and for custody transfer – the same meters support both functions.

![Figure 4. Micro Motion meters used for both leak detection and custody transfer](image)
Summary
The most effective leak detection systems utilize a combination of a pressure or acoustic analysis system and a material balance system. The most accurate, reliable, and robust material balance systems are based on mass, rather than volume, and incorporate linepack compensation.

Coriolis meters from Micro Motion measure mass accurately and reliably across changing process and environmental conditions, with no requirement for external temperature, pressure, or density data. Using leak detection systems that include Micro Motion meters, pipeline operators can detect leaks effectively with a minimum of false alarms. Coriolis meters from Micro Motion also support a variety of secondary functions such as process fluid monitoring or custody transfer.

About the author
Julie Valentine is the Refining Industry Marketing Manager for Micro Motion, Inc., in Boulder, Colorado. Julie is a graduate of the Colorado School of Mines in Golden, Colorado with a B.S. degree in Chemical and Petroleum Refining Engineering. She spent eight years with UOP, primarily in the Technical Services Group, where she was involved in the commissioning, start-up, and troubleshooting of UOP process units around the world. Julie joined Micro Motion twelve years ago and now focuses on how and where to apply Micro Motion’s Coriolis technology in the refining industry.
Micro Motion supports PlantWeb® field-based architecture, a scalable way to use open and interoperable devices and systems to build process solutions of the future.

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