ABSTRACT

Different leak detection technologies offer different benefits and limitations. Popular options include real-time transient models, statistical analysis, and negative pressure wave systems. This paper outlines the successful integration of a statistical volume balance system and a negative pressure wave system on a crude oil pipeline. The results of the Site Acceptance Test validate the combined system’s increased reliability, detection speed, location accuracy and sensitivity.

This paper will also examine the benefits and technical challenges of combining these two technologies. The field application of the two systems on a 170 km (105.63 mi) crude oil pipeline will be explained in detail, along with the results of controlled product withdrawal tests on the pipeline.

INTRODUCTION

The US Department of Transportation Pipeline and Hazardous Materials Safety Administration Final Report of Leak Detection Study [1] correctly suggests that the recurring theme of false leak alarms in pipeline leak detection can be solved by the combination of technologies – utilizing multiple redundant and independent leak detection systems.

Different pipeline types require different leak detection methods to assure detection. Key factors that influence the performance of different leak detection technologies include:

1. Number of sensors on the pipeline
2. Topology of the pipeline
3. Accuracy, repeatability and response time of sensors on the pipeline
4. Sensor digitization
5. Availability and quality of a telecommunication system
6. End conditions such as tanks at the outlet or positive displacement pumps at the inlet

The impact of the above factors will vary depending on the location of the leak and the operating condition of the pipeline at the time of the leak. For this reason, the leak detection technologies that Atmos offers can be combined to make a specific multi-method leak detection system that is optimized to detect all types of leaks on a pipeline.

STATISTICAL VOLUME BALANCE SYSTEM

Atmos Pipe is a leak detection system that uses statistical volume analysis, which relies on the pressure and flow measurements taken from the pipeline. It is easily retrofitted onto pipelines by accessing existing instruments and connecting via existing SCADA, PLC, and RTU systems. The statistical volume balance system monitors the difference from the inlet and outlet flow corrected by the inventory change, also referred to as the Corrected Flow Difference, to determine whether the pipeline is in a leak condition.

The Corrected Flow Difference is used in a statistical hypothesis testing method known as the Sequential Probability Ratio Test (SPRT). The SPRT calculates the ratio of the probability of a leak being present to the probability of no leak being present by using the current Corrected Flow Difference readings from the pipeline, and the Mean Corrected Flow Difference, or what is normal to the pipeline during leak-free conditions. Since the system uses existing flow and pressure readings to compare the normal conditions of the pipeline, the repeatability of the instrumentation is highly important. If the Corrected Flow Difference increases statistically, the probability of a leak increases. If this increase persists for a long enough time and the leak probability becomes significantly greater than the no-leak probability, then a leak alarm will be generated. The length of time taken from a leak...
starting, to the alarm sounding, is configured within the settings of the system and varies depending on the leak size and operating conditions.

The statistical volume balance system can also use other pipeline signals such as pump status, tank level, density and temperature readings, to identify different transients and operations on the pipeline, minimizing the number of false alarms. With direct measurements from the flow meters, the statistical volume balance system is able to calculate a more accurate leak rate compared to most other leak detection systems.

The main strengths of the statistical analysis method of leak detection include:

- Low false alarm rate
- Economical because it uses existing SCADA/PLC/RTU measurements of flow, pressure and temperature
- The SPRT type can detect leaks under both steady-state and transient operations
- Unlike model based systems, the SPRT system normally does not increase the minimum leak size detectable during transient operations
- Estimated leak size is directly calculated

**NEGATIVE PRESSURE WAVE SYSTEM**

The negative pressure wave system, also (incorrectly) referred to as the acoustical system, relies solely on high speed pressure readings to identify whether a leak has occurred on the pipeline. The system acquires and analyzes the pressure data at a frequency much higher than the typical 5 seconds SCADA rate, capturing data at 60 samples per second. The system uses a combination of low and high pass filters along with image pattern techniques to identify different transients and operations on the pipeline. Specialized equipment is required in order to acquire data at such high frequency.

A minimum of one pressure transmitter is required at the ends of the pipeline to be monitored, along with a high-speed data acquisition unit installed in the field to record the data locally. In order to compare the recorded data from either ends of the monitored pipeline, the information is GPS time-stamped with synchronization accuracy in parts per million.

The negative pressure wave system is an onset system that identifies the instantaneous pressure drop that occurs at the start of a leak event. The time to identify the leak does not rely on the leak size, although larger leaks may give a clearer signature, therefore the response time of the system is the same for all leak sizes. The response time of the system is determined by the length of the pipeline, the time it takes for the pressure wave to travel to the sensors, and the time it takes for the information to be processed and relayed to the Operators.

With its high speed data sampling and accurate data synchronization, the negative pressure Leak Detection System (LDS) can provide an accurate leak location and fast response in leak detection. The system uses the difference in time when the pressures at the inlet and outlet responds to the leak along with the wave speed of the pipeline product to calculate the leak location. Compared to systems that analyze data at SCADA scan rates, the negative pressure LDS can locate a leak within meters of the actual location.

Because the system is solely pressure dependent, the system is fairly cost efficient compared to other systems that require installation of flow meters.

The negative pressure LDS has the following main advantages:

- Accurate leak location
- Short detection time for all leak sizes
- Cost effective to install

**INTEGRATED LDS SYSTEM**

The integrated system uses the statistical volume balance system as the primary LDS, aided by the negative pressure wave system. The two systems are both running independently of each other on separate servers and communicate via OPC. The statistical volume balance system continuously provides outputs of the current pipeline conditions to SCADA while the negative pressure wave system only provides information to the statistical volume balance system. In case one system fails, the other system can continue to run, providing leak detection redundancy. The alarms that the negative pressure wave system produces do not go directly to the SCADA. By design, the negative pressure wave system is tuned to be more sensitive than it would be as a standalone system. The statistical system is able to filter any false alarms from the negative pressure wave system or validate and confirm the alarms before sending them to the Operators. This allows the sensitivity of the negative pressure system to be increased without generating false alarms.

There are two ways the integrated system can alarm: 1) the statistical volume balance system produces a leak alarm or 2) the negative pressure wave system alarms and the statistical volume balance system confirms the alarm. In Case 1, the probability of the leak condition must reach a threshold before the system will raise the alarm. It functions as if the statistical volume balance system behaved alone. In Case 2, the negative pressure wave system sends the alarm to the statistical system. The statistical system then analyzes the current conditions of the pipeline during the negative pressure Wave alarm. If the probability of a leak condition is beyond an adjusted confidence level threshold, a confirmed leak alarm will be sent to the SCADA. In Case 2, the statistical system’s probability threshold of the leak condition is set at a lower value to speed up the leak detection time. The integrated system uses the leak location of the negative pressure system
and the leak size of the statistical system.

With the above integrated approach, the negative pressure wave system enables faster leak detection and more accurate leak location estimates while the statistical volume balance system offers the high reliability of the SPRT method and its online learning ability. The process of information can be seen in the flow chart of Figure 1.

RESULTS

The integrated system was installed onto a 170 km (105.63 mi) reinforced thermoplastic pipeline, transporting crude oil at a nominal flow rate of 15.8 m3/hr (99.38 bph). Actual leak tests by controlled oil withdrawals produced very impressive results. A total of nine leak withdrawal tests were carried out at different leak locations with various leak sizes. The integrated system did not alarm during normal pipeline operations and various transient operations. The Integrated System provided the estimated leak locations and leak sizes.

The results of the integrated system can be seen on Table 1 alongside the actual leak details. The integrated system alarmed during all the leak withdrawal tests. For all the leak tests, the estimated leak locations came within 2.3 km (1.43 mi) of the actual leak locations, about 1.35% of the total length of the pipeline. The estimated leak sizes were all within 0.7 m3/hr (4.4 bph) of the actual leak sizes.

In larger leak scenarios, the statistical volume balance system alarmed more quickly than the negative pressure wave system, as seen in Leak 9. In this case, the integrated system was not able to use the leak location results of the negative pressure wave system since the leak results were already sent to SCADA. Still, the leak location provided by the statistical system proved to be very accurate.

Figure 2 displays a graph presenting the leak rates of the tests versus the system’s leak detection time.

CHALLENGES AND FUTURE DEVELOPMENT

One challenge of applying the integrated system was determining the leak probability threshold after receiving an alarm from the negative pressure system. Using pipeline operational data, an optimal balance between the reliability of the statistical system and the rapid response of the negative pressure system was achieved.

More comprehensive logic and additional tuning parameters are being developed to optimize the integrated system performances to match the unique behavior of the different pipeline sections.

CONCLUSIONS

Recent leak detection studies and the previous leak trials confirm that different pipeline types, different products and different operating conditions require different solutions to optimize the detection of any type of pipeline leaks. Pipeline vendors should offer a range of leak detection technologies that can be combined to achieve the most reliable, sensitive and accurate leak detection system.

Each leak detection method has its strengths and suitable applications. One method will optimize leak detection sensitivity on a specific pipeline, another method will provide the best location accuracy, and another the best reliability. Thus a weighted combination of these methods will often provide the best overall leak detection solution for each type of pipeline and leak detection problem.

The statistical volume balance system combined with the negative pressure wave system has proven to be a very effective leak detection system. The results of the leak withdrawal tests confirm the integrated system’s excellent reliability, fast detection speed, accurate leak location, and high sensitivity.

NOMENCLATURE

- DCS – distributed control system
- LDS – leak detection system
- PLC – programmable logic controller
- RTU – remote terminal unit
- SCADA – supervisory control and data acquisition
- SPRT – sequential probability ratio test

REFERENCES


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| Leak | Actual Leak Details | | Integrated System Results | |
|---|---|---|---|---|---|
| | Leak Rate [m³/hr] | Leak Rate %* | Leak Location [km] | Detection Time [mins] | Leak Rate [m³/hr] | Leak Location [km] |
| 1 | 0.23 | 1.5% | 0 | 10 | 0.187 | 2.202 |
| 2 | 0.28 | 1.8% | 76.4 | 9 | 0.271 | 74.554 |
| 4 | 0.37 | 2.3% | 170.235 | 7 | 0.292 | 169.522 |
| 5 | 0.39 | 2.5% | 0 | 6 | 0.353 | 0.01 |
| 6 | 0.80 | 5.1% | 170.235 | 3 | 0.621 | 169.595 |
| 7 | 0.90 | 5.7% | 76.4 | 5 | 1.046 | 78.726 |
| 8 | 0.91 | 5.8% | 0 | 5 | 0.753 | 2.329 |
| 9 | 8.43 | 53.4% | 0 | 1 | 7.73 | 0 |

Table 1 – Results of the integrated system vs. Actual Leak Details (SI Units)

*based on a nominal flow rate of 15.8 m³/hr

| Leak | Actual Leak Details | | Integrated System Results | |
|---|---|---|---|---|---|
| | Leak Rate [bph] | Leak Rate %* | Leak Location [mi] | Detection Time [mins] | Leak Rate [bph] | Leak Location [mi] |
| 1 | 1.447 | 1.5% | 0 | 10 | 1.176 | 1.369 |
| 2 | 1.447 | 1.5% | 105.802 | 15 | 0.780 | 105.456 |
| 3 | 1.761 | 1.8% | 47.483 | 9 | 1.705 | 46.336 |
| 4 | 2.327 | 2.3% | 105.802 | 7 | 1.837 | 105.359 |
| 5 | 2.453 | 2.5% | 0 | 6 | 2.390 | 0.006 |
| 6 | 5.032 | 5.1% | 105.802 | 3 | 3.906 | 105.404 |
| 7 | 5.661 | 5.7% | 47.483 | 5 | 6.579 | 48.929 |
| 8 | 5.724 | 5.8% | 0 | 5 | 4.736 | 1.447 |
| 9 | 53.03 | 53.4% | 0 | 1 | 48.62 | 0 |

Table 2 – Results of the Integrated System vs. Actual Leak Details (British Units)

*based on a nominal flow rate of 99.38 bph
FIGURES

Figure 1: Integrated System Logic Process

Figure 2: Integrated System Results – Leak Rate vs. Detection Time
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Mark Kim attended UCLA for his undergraduate studies. He earned his Bachelors of Science in Civil Engineering with a minor in Environmental Engineering. Since graduation, Mark has worked as a Project Engineer at Atmos International and has been fortunate to be a part of many different projects, developing and maintaining leak detection systems, while building relationships with clients.