Proceedings of the 2014 10th International Pipeline Conference
IPC2014
September 29-October 3, 2014, Calgary, Alberta, Canada

IPC2014-33387

SYNERGY IN LEAK DETECTION: COMBINING LEAK DETECTION TECHNOLOGIES THAT USE DIFFERENT PHYSICAL PRINCIPLES

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ABSTRACT

Different leak detection technologies offer different benefits and limitations. Popular options include real-time transient models, statistical volume balance analysis and negative pressure wave systems. Atmos offers a combination of different systems to improve the leak detection performance on a pipeline. This paper outlines the very successful integration of a Statistical Volume Balance System and a Negative Pressure Wave System on a crude oil pipeline. The live product withdrawal tests demonstrated that the combined system maximized the reliability, detection speed, location accuracy and sensitivity of the overall leak detection system. This paper will examine the benefits and technical challenges of combining these two leak detection technologies. The integrated solution delivers the reliability and robustness of the Statistical Volume Balance System together with the rapid response time and location accuracy of the Negative Pressure Wave System. The field application of the two systems integrated on a 170 kilometer crude oil pipeline will be explained in detail, along with the results of some actual 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 relieved by the combination of technologies – utilizing multiple redundant and independent leak detection systems of different physical principles.

Different pipeline types require different leak detection methods to assure detection. Key factors that influence the performance of 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 the telecommunication system
6. End conditions such as tanks at the outlet or positive displacement pumps at the inlet
7. Pipeline operating scenarios such as batch operations, pigging, draining/filling and slack flow

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, Atmos offers several key leak detection technologies that can be combined as one integrated solution 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

Leak detection using statistical volume balance relies on the pressure and flow measurements taken from the pipeline. It is easily retrofitted onto pipelines by accessing current instrumentation and connecting via existing SCADA, PLC, and RTU systems. The Statistical Volume Balance System monitors the difference between 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 Corrected Flow Difference readings from the pipeline, and the Mean Corrected Flow Difference (MCFD), 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 most important. If the Corrected Flow Difference increases, 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 would be generated. The length of time taken from the start of a leak, 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 transients and operations on the pipeline, reducing the number of false alarms to a minimum. With direct measurements from the flow meters, the Statistical Volume Balance System can calculate a more accurate leak rate compared to most other Leak Detection Systems when a leak is detected on the pipeline.

The main strengths of the statistical volume balance method of leak detection include:

- Low false alarm rate
- Economical because it uses existing SCADA/PLC/RTU measurements of flow, pressure and temperature
- Can detect leaks under both steady-state and transient operations
- The SPRT method normally does not increase the minimum leak size detectable during transient operations
- Estimated leak size is directly calculated from the flow meters, leading to a more accurate leak rate result

NEGATIVE PRESSURE WAVE SYSTEM

The Negative Pressure Wave system, also (incorrectly) referred to as the acoustic 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 transients and operations on the pipeline, while being able to isolate and correctly identify the onset of leaks. Specialized equipment is required to acquire data at such high frequency as shown in **Figure 1**. This system is also referred to as the Rarefaction Wave System.

A minimum of one pressure transmitter is required at each end of the pipeline to be monitored, along with a high-speed data acquisition unit installed in the field to record the data locally. If only one pressure transmitter is installed at each end, a "blind zone" of approximately 3-5% of the pipeline length is placed at each end of the pipeline. Any leaks in the "blind zone" are rejected by the system as they can appear as transients or operations occurring outside of the pipeline. In order to eliminate any "blind zones", a secondary sensor can be used to identify the direction of the pressure wave near the ends of the pipeline. In order to compare the recorded data at the ends of the monitored pipeline, the data is GPS time-stamped with synchronization accuracy of one microsecond.

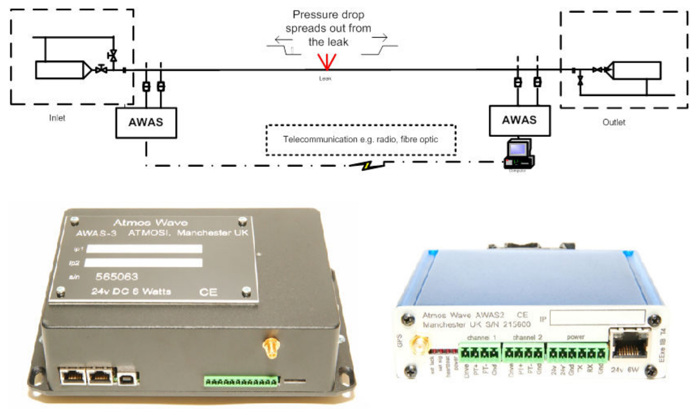

Figure 1 Overview of the Negative Pressure Wave System with different AWAS units

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, and 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 through the fluid, and the time it takes for the data to be processed and relayed to the operators.

With its high speed data sampling and accurate data synchronization, the Rarefaction Wave LDS (Leak Detection System) can provide an accurate leak location and fast response in leak detection. The system uses the difference in time from when the pressure sensors at the inlet and outlet respond to a leak, along with the wave speed of the pipeline product, to calculate the leak location accurately. 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 can be fairly cost efficient compared with the installation of flow meters to support other imbalance detection systems.

The Negative Pressure LDS has the following main advantages:

- Accurate leak location
- Short detection time for all leak sizes
- Does not require flow meters
- Cost effective to install

As the Rarefaction Wave System makes decisions based on pressure data only and does not use flow meters, the leak size estimations are derived solely from the pressure differential caused by the leak, and may not be as accurate as the Statistical Volume Balance System.

INTEGRATED SYSTEM

The Integrated System uses the Statistical Volume Balance System as the primary LDS, aided by the Negative Pressure Wave System with additional information. The two systems are running independently of each other on separate servers and communicate via OPC. The architecture of the field instrumentation and the servers are shown in **Figure 2**.

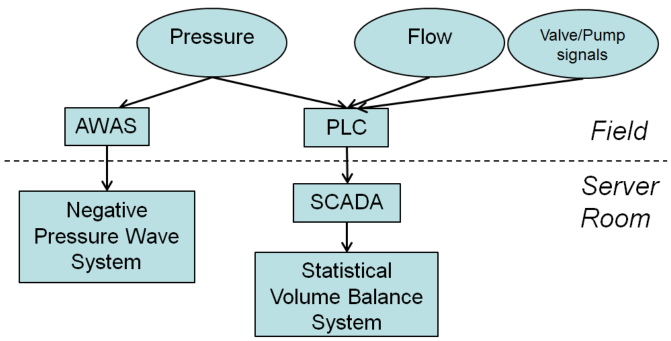

Figure 2 Architecture of the field instrumentation and the LDS servers

In combined mode, 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 and does not provide information directly to SCADA. In this mode, any alarms that the Negative Pressure Wave System produces do not go directly to the SCADA, but instead, the Statistical Volume Balance System is able to filter any false alarms and validate and confirm the alarms as being true leak events before sending them to the Operators panel or SCADA. This allows the Negative Pressure Wave System to be tuned to a higher sensitivity than what it would be typically configured to, and still achieve minimum false alarms for the Operators. Additionally, “blind zones” are eliminated without the need of a secondary sensor, since the Integrated System is able to filter out transients and operations initiated outside of the pipeline boundary from true leak events that may occur near the inlet and outlet of the pipeline.

Integration Logic of the Two Systems

There are two ways the Integrated System can alarm: 1) the Statistical Volume Balance System produces a leak alarm independently 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 Integrated System will raise the alarm. It functions as if the Statistical Volume Balance System behaves alone. Once the conditions of a leak are met, the Statistical Volume Balance System will provide all details and outputs to the Operators. In Case 2, when the Negative Pressure Wave System alarms, it sends the alarm to the Statistical Volume Balance System. The Statistical Volume Balance System then analyzes the current conditions of the pipeline during the Negative Pressure Wave alarm. If the probability of a leak condition is beyond the adjusted threshold, it will confirm the leak and then pass the leak alarm to the Operators. In Case 2, the probability threshold of the leak condition is set at a lower value than the threshold of Case 1 in order to decrease the leak detection time. The Integrated System uses the leak location provided by the Negative Pressure Wave System and the leak size provided by the Statistical Volume Balance System.

With the above integrated approach, the Negative Pressure Wave System provides the Integrated System a faster leak detection time and more accurate leak location while the Statistical Volume Balance System offers the high reliability of the SPRT method, more accurate leak size estimate, and its online learning ability.

The flow of information in the Integrated System is described in the flow chart as shown in **Figure 4** in the Appendix section.

Redundancy

The Integrated System can also be set up so that if the Statistical Volume Balance System has a failure, such as a flow meter malfunction, the alarm outputs of the Negative Pressure Wave System will be passed directly to the Operators panel or SCADA. The two systems run on separate servers, so in the case that the Statistical Volume Balance System server fails, the Negative Pressure Wave System is able to correctly identify the server failure and adjust its configurations. Because the sensitivity of the Negative Pressure Wave System is set higher than normal in the Integrated System, in the case of the Statistical Volume Balance System failure, it will automatically adjust its sensitivity back to the normal level and implement “blind zones” if needed. This allows the Negative Pressure Wave System to act as a primary standalone system and to detect leaks independently. In the case that the Negative Pressure Wave System server fails, the Statistical Volume Balance System will adjust its threshold on the time it takes for the system to alarm, and it will calculate its own leak location using the data at SCADA scan rates.

RESULTS

The Integrated System was installed on a 4", 170 km thermoplastic pipeline transporting crude oil at a nominal flow rate of 15.8 m^3/hr. The pressure transmitters for the Negative Pressure Wave System were installed at the inlet, outlet, and every valve station along the pipeline, separating the pipeline into four different segments. The maximum pressure meter spacing was 76.3 km. It was determined by the client based on their standard practice of installing pressure transmitters at every block valve. Note that the pressure transmitters for the Negative Pressure Wave System can be spaced further apart, as demonstrated successfully on a 48" crude oil pipeline, the pressure wave traveled over a distance of 234.5 kilometers.

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 using various leak sizes. The minimum leak size tested by the client was 1.5% of the nominal flow rate; however, the Integrated System is able to detect smaller leaks. The test results were collected from the Integrated System and compared to the actual details of the leaks provided by the client after completion of the testing. The location and leak rate of the actual withdrawal tests alongside the results of the Integrated System are shown in **Table 1** in the Appendix section.

During the leak withdrawal testing, since the Statistical Volume Balance System was tuned as normal, the system was able to produce results as a standalone system. These results are plotted in **Figure 5** with the results of the Integrated System to show how the Integrated System provides a faster detection time than the standalone Statistical Volume Balance System. Over the period of ten months, the client has not reported any false alarms.

CHALLENGES AND FUTURE DEVELOPMENT

The signature of a pressure drop used by the Negative Pressure Wave System to determine the leak location accurately is dependent on the aspect ratio of the pipeline cross sectional area to pipeline length. A pipeline is able to maintain a clear pressure wave front as long as the aspect ratio is high enough. For example, the Negative Pressure Wave System has been successfully tested on a 234.5 km long, 48" diameter pipeline; the pipeline where the Integrated System runs on is a 4" diameter thermoplastic pipeline with the longest segment being 76.3 km. The significantly lower aspect ratio and the use of thermoplastic pipeline material meant that the pressure wave would dissipate much faster in this pipeline. During the period of testing, pressure oscillations of about 6 kPa were observed at the inlet as shown in **Figure 6** in the Appendix section. The combination of the pressure oscillation and the low aspect ratio made it difficult for the leak location errors to be minimized in some of the leak tests.

The results of the Integrated System show that, for the larger leaks the Statistical Volume Balance System alarmed quicker than the Negative Pressure Wave System. In these cases, 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. Following the leak tests, more comprehensive logic is being developed to use the leak location of the Negative Pressure Wave System even when the Statistical Volume Balance System alarms first.

One challenge of applying the Integrated System was determining the leak probability threshold after receiving an alarm from the Negative Pressure Wave System. Using months of pipeline operational data, an optimal balance between the reliability of the statistical system and the rapid response of the Negative Pressure Wave System was achieved.

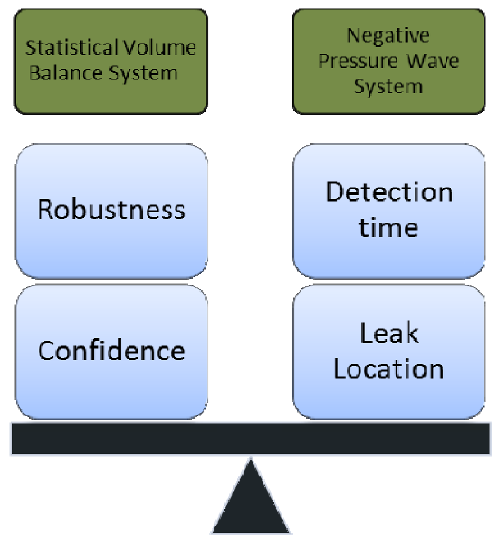

Figure 3 The Integrated System proves to be a challenge in balancing the Statistical Volume Balance System and the Negative Pressure Wave System

CONCLUSIONS

Recent leak detection studies and the previous leak trials confirm that different pipeline types, different fluids and different operating conditions require varying solutions to optimize the detection of any type of pipeline leaks. Pipeline leak detection system 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 advantages and can be best suitable for specific conditions. One method may optimize leak detection sensitivity on a specific pipeline, another method may 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.

NOMENCLATURE

AWAS – Atmos Wave Acquisition System

DCS – Distributed Control System
MCFD – Mean Corrected Flow Difference
OPC – OLE for Process Control
PLC – Programmable Logic Controller
RTU – Remote Terminal Unit
SCADA – Supervisory Control And Data Acquisition
SPRT – Sequential Probability Ratio Test

ACKNOWLEDGEMENTS

The authors would like to thank their client for the opportunity to implement the integrated leak detection system and for their support in our efforts to create the best leak detection technology we can.

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1. Shaw, David and Martin Phillips, Ron Baker, Eduardo Munoz, Hamood Rehman, Carol Gibson, Christine Mayernik. "U.S. DEPARTMENT OF TRANSPORTATION PIPELINE AND HAZARDOUS MATERIALS SAFETY ADMINISTRATION FINAL REPORT, LEAK DETECTION STUDY" – DTPH65-11-D-000001, December 10, 2012.
2. Zhang, Jun and Andy Hoffman, Keefe Murphy, John Lewis, Michael Twomey. "REVIEW OF PIPELINE LEAK DETECTION TECHNOLOGIES". PSIG 1303, PSIG Annual Meeting, 16 April – 19 April 2013, Prague, Czech Republic.

APPENDIX – TABLES AND FIGURES

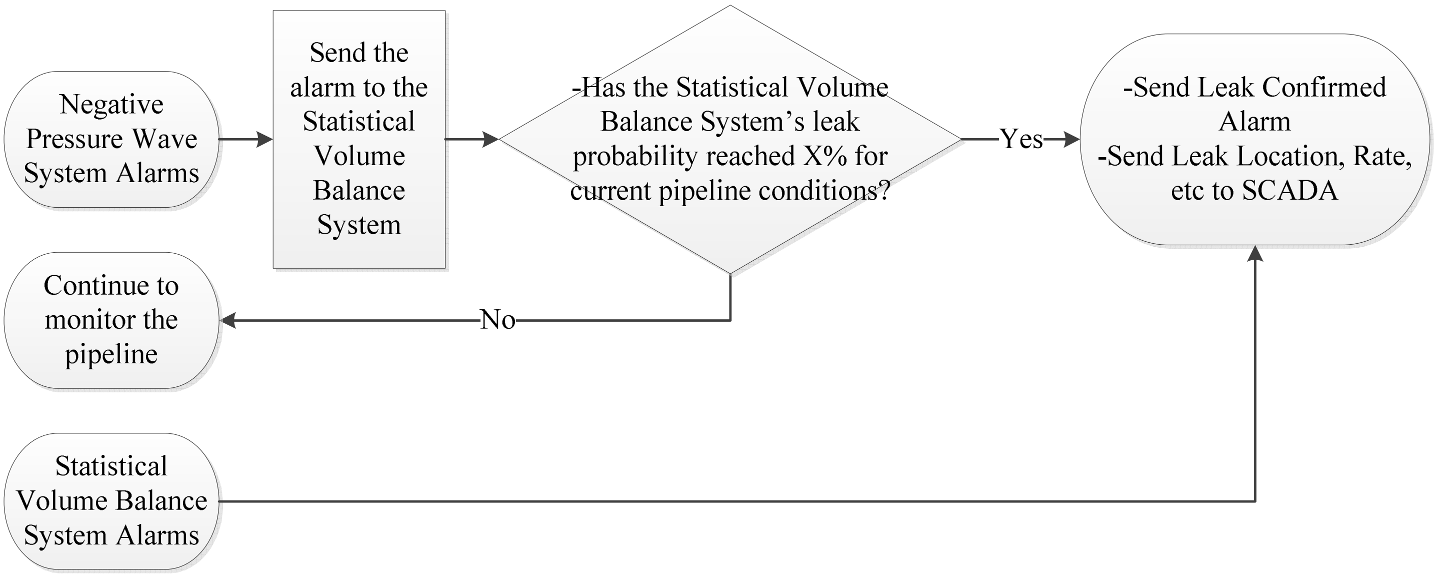

Figure 4 Flow chart of the Integrated System logic

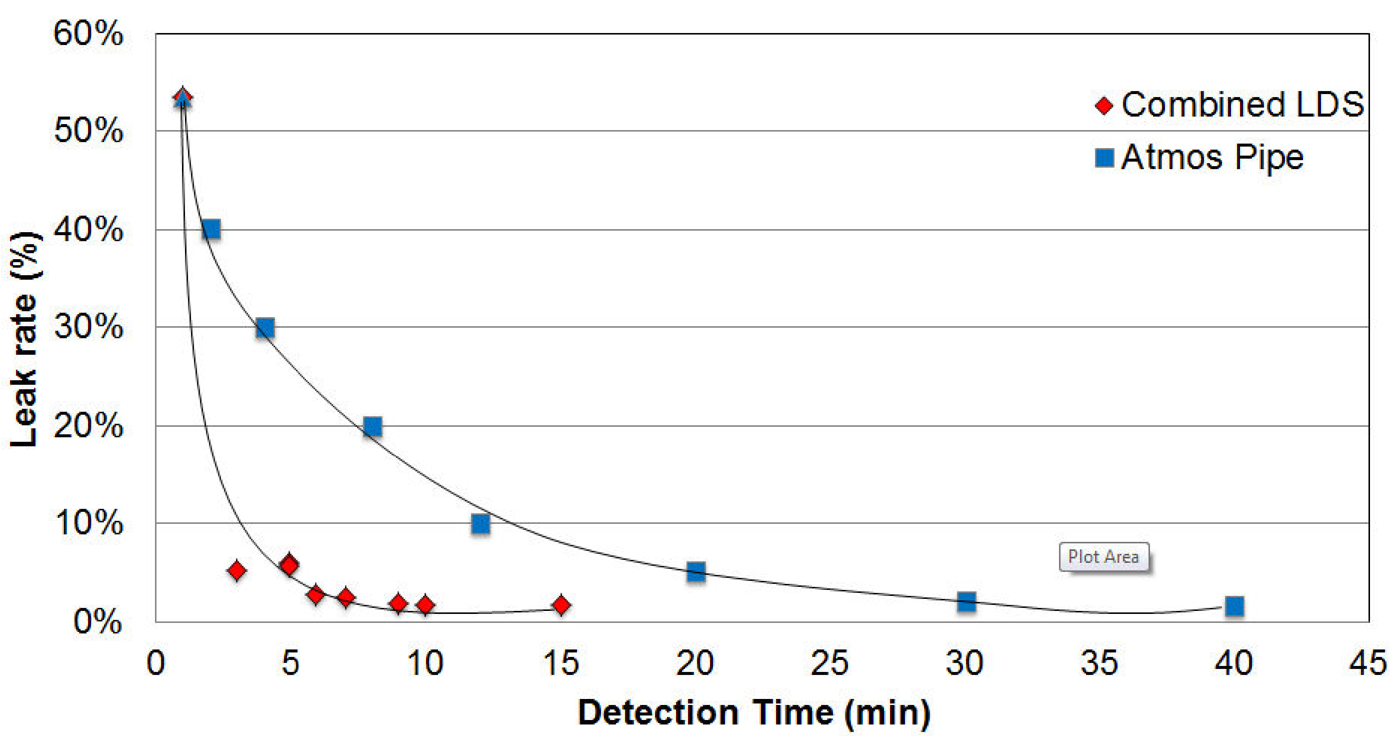

Figure 5 Leak rate vs detection time of the Integrated System and the standalone Statistical Volume Balance System

Figure 6 Pressure oscillations of approximately 6 kPa at the inlet observed during the leak tests (black - inlet, pink – outlet)

	Actual Leak Details			Integrated System Results		
Leak	Leak Rate [m^3/hr]	Leak Rate %*	Leak Location [km]	Detection Time [mins]	Leak Rate [m^3/hr]	Leak Location [km]
1	0.23	1.5%	170.235	15	0.124	169.679
2	0.23	1.5%	0	10	0.187	2.202
3	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 the details of the actual leak tests