Joe Kelly, Principal Engineer, Atmos International, discusses how to optimally balance sensitivity, response time, and reliability with real-time leak detection for offshore pipelines.

As the offshore oil and gas industry evolves, the complexity and criticality of its infrastructure demand increasingly sophisticated integrity monitoring systems. Pipeline leak detection systems are at the forefront of this challenge, particularly for long-distance subsea pipelines transporting hydrocarbons under high pressure.

While individual technologies like statistical volume balance (SVB) and negative pressure wave (NPW) have been used for decades, recent advances in data acquisition, system integration, and algorithmic processing have enabled operators to adopt multimethod leak detection configurations that significantly enhance performance and reliability.

# In the balance

Discussing pipeline applications on a crude oil pipeline and wet gas pipeline, this article explores how combining SVB and NPW methods has helped achieve exceptional leak detection performance in offshore operations, including detection thresholds below 1% of reference flow, high location accuracy and minimised false alarm rates. By analysing field results from oil and wet gas pipelines, the engineering trade-offs and integration strategies that define an effective multimethod leak detection system will be examined.

## Understanding the two core technologies

### Statistical volume balance (SVB)

The SVB method is based on the principle of conservation of mass. It continuously monitors the volumetric flow rates at the inlet and outlet of a pipeline and applies statistical hypothesis testing to determine whether deviations from expected flow balances indicate a leak.

The sequential probability ratio test (SPRT) is used to distinguish between leak and no-leak probability. This approach allows the system to detect subtle deviations while minimising false positives. SVB's effectiveness depends on high quality flow data, precise inventory correction to account for pressure and temperature-driven changes and adaptive learning mechanisms to account for instrumentation drift and operational changes.

### Negative pressure wave (NPW)

NPW technology detects leaks by capturing the characteristic pressure drop generated at the onset of a release. This pressure wave propagates bidirectionally from the leak location and is sensed by high-frequency pressure sensors placed at pipeline endpoints or along its length. The time delay between wave detection at each sensor allows for calculation of the leak's location.

Figure 1 shows two charts, each showing the response to a leak as captured by the same pressure sensor at two locations (inlet and outlet). The chart on the left has a lower resolution (12-bit ADC) and lower scan rate, making it more challenging to distinguish the leak's signature from the background noise or to determine the timing of pressure changes with accuracy. The chart on the right distinctly highlights the pressure drop caused by the leak at both sensors. The magnitude of the pressure drop relative to the background noise and the sharpness of the pressure changes are clearly visible, enabling accurate determination of the timing of the pressure drops. These factors are crucial for maximising the precision of leak location estimation.

For an offshore pipeline, high performance data acquisition units sampling pressure at 60 Hz with 20 bit resolution can capture the sharp pressure wavefront even in the presence of transient noise. However, attenuation becomes a limiting factor for long pipelines and the NPW system is most effective when complemented by a volume balance method.

## Case study 1: wet gas pipeline

A wet gas pipeline system operating with a high gas-oil ratio was monitored using SVB. Although significantly shorter than the crude oil pipeline, this system illustrates the adaptability of SVB under different operating conditions.

The pipeline was instrumented with Venturi flow meters at each subsea well and at the topside facility. The SVB system utilised mass flow measurements in tons per hour, benefiting from the high repeatability of the instrumentation. Flow rates at the inlet and outlet were closely matched under stable conditions, with deviations within 0.5%, allowing a minimum detectable leak size of less than 1%.

Transients were occurring during normal pipeline operations, often triggered by changes in field conditions or well cycling. Inventory correction proved highly effective in these situations. During events where flow imbalances arose, the system compensated using pressure data, maintaining the corrected flow difference close to zero. This not only helped preserve sensitivity but also filtered out disturbances caused by operational transients.

One particular advantage of this setup was its ability to identify persistent instrument bias. In one example, the raw flow difference exhibited a consistent offset of around 6 t/hr. The SVB adjusted for this, centring the flow difference around zero and maintaining high leak detection sensitivity. This automatic bias correction was critical in extending operational confidence without requiring immediate instrumentation recalibration.

System validation was supported by recurring well clean-up operations. Every six months, one of the wells was isolated and recirculated, effectively removing its contribution from


**Figure 1.** SCADA sampling (left) versus Atmos' data acquisition unit (right).

the overall inlet flow. This created conditions equivalent to a controlled leak test (Figure 2). The SVB system responded by generating a leak alarm with a sensitivity of approximately 2.3% and a detection time of under 20 minutes. These operations provided an ideal mechanism for verifying the system's ability to detect real-world leak conditions.

The wet gas pipeline's performance metrics include detection sensitivity down to 0.73% of nominal flow and response time of under 1 minute for a 13% leak. These results demonstrated not only the versatility of the SVB method in wet gas systems but also its reliability when supported by consistent instrumentation and good maintenance.

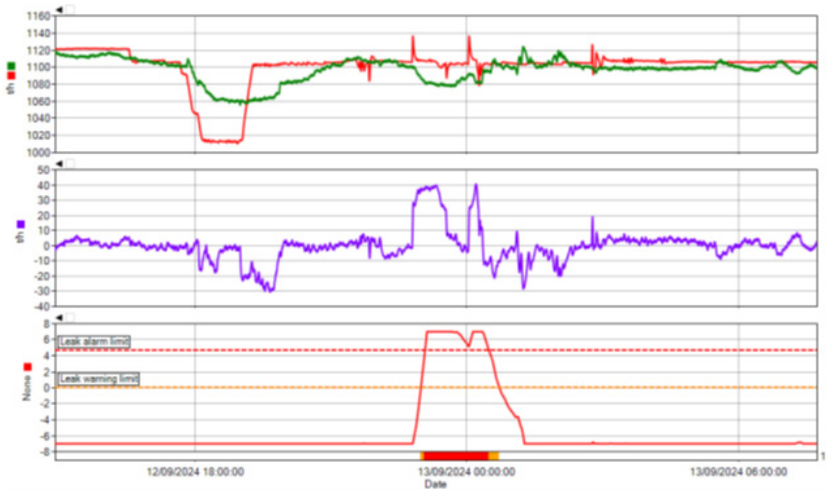


Figure 2. The wet gas pipeline leak detection system identifying a controlled leak caused by well clean-up.

## Case study 2: oil pipeline with integrated SVB and NPW

A dual method leak detection system was implemented on a crude oil pipeline transporting approximately 120 000 $m^3$/d.

The SVB delivered a high-performance leak detection system achieving sensitivities of 0.5% in 12 minutes and 2% in 3 minutes, with a location accuracy of 3 - 5 km in the pipeline. Only 6 false alarms were generated in 2024 (on average 0.5 false alarm per month).

The NPW system achieved a response time of 11 minutes and location accuracy of approximately 200 m in the 283 km pipeline. Only 4 false alarms were generated in 2024 (on average 0.3 false alarm per month).

This performance was supported by high resolution multipath ultrasonic flow meters with standardised calibration, enabling repeatable measurements and leak detection thresholds below 1%. Advanced inventory correction accounted for pressure transients such as packing and unpacking, maintaining flow difference stability and minimising false positives. Adaptive tuning based on operational data allowed the system to self correct for drift over time too.

Implementing NPW on the long offshore pipeline introduced specific challenges. Wave attenuation over long distances limited sensitivity near pipeline ends, with sensitivity ranging from 1 - 4% near the midpoint to approximately 7 - 8% near the inlet or outlet. In the absence of intermediate pressure sensors, leak localisation depended entirely on endpoint readings, making high frequency acquisition essential. Leak validation was accomplished using filtering algorithms and 3D mapping.

## The value of a multimethod leak detection system

The dual method configuration enhances operational decision making. For example, if a flow meter error triggers a leak alarm in the SVB system but the NPW system shows no corroborating evidence and high frequency pressure data reveals no anomalies, operators can confidently classify the event as a false positive and avoid an unnecessary shutdown.

In the context of a two hour shutdown which would have resulted in a loss of 10 000 $m^3$ of crude oil transport, at US$70/bbl this equates to a financial impact of approximately US$4.4 million. The multimethod leak detection system provides leak detection and risk mitigation through cross verification.

High resolution data acquisition also supports accurate leak localisation, pig tracking and stuck pig detection, pressure surge diagnostics, and real time monitoring of pipeline transients.

## Engineering considerations for system integration

To deploy effective multimethod leak detection system in offshore environments, several factors must be addressed. For example, high frequency and high resolution data acquisition is essential for NPW.

Instrumentation quality is also critical as precision sensors improve detection thresholds.

Reliability is improved through use of virtual servers, mirrored systems and backup instruments. Maintenance is supported through structured framework agreements, which include regular reviews and tuning cycles. Successful deployment also relies on skilled personnel and close collaboration with vendors to manage commissioning, tuning and long term support.

## Conclusion

It is possible to balance sensitivity, response time and reliability with multimethod leak detection. The implementation of multimethod leak detection systems represents a robust and forward thinking approach to pipeline integrity. By integrating SVB and NPW technologies, supported by high fidelity instrumentation and rigorous operational protocols, operators can achieve a rare balance of sensitivity, speed, and reliability. For those looking to optimise leak detection in complex offshore environments, this case study offers a valuable reference grounded in technical rigour and field tested results.