FLOWSTATE

LDS VERIFICATION TESTS

Pictured above - instrumented leak skid used for commodity withdrawal tests

Flowstate has conducted over 260 commodity withdrawal tests on various pipeline segments.

This has allowed for verification and validation of the Flowstate LDS solution as well as provided valuable data for research and development. Test have included:

Line Types

Transmission lines
Gathering lines
Crude & Diesel lines
Multi-Grade lines

Leak Detection Methods

Statistical Volume Balance (SPRT)
Leak Signature Recognition
Rupture Recognition
*all enhanced with Deep Learning

Hydraulic Conditions

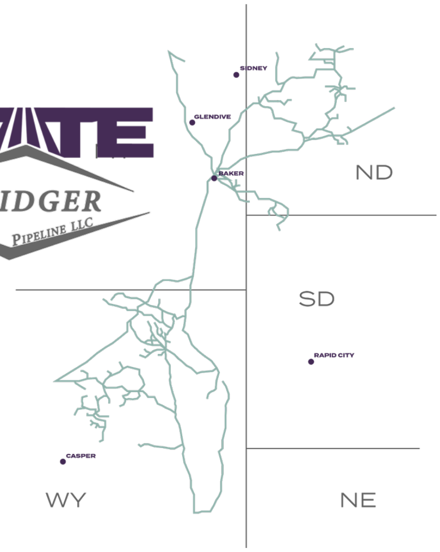
Packing/unpacking
Flow rate changes
Pump/Set-Point Changes
Batch Changes … and more

EXAMPLES INSIDE:

- **1.5% Leak on Transmission Line**
- **5% Leak During Batch Change**
- **8% Leak on Gathering - Start During No Flow**
- **5% Leak on Gathering Line**
- **Rupture on Gathering Line**
- **Rupture on Transmission Line**

30
Segments

260
Withdrawal Tests



How can we have so many withdrawal tests??

This is a question we get asked often.

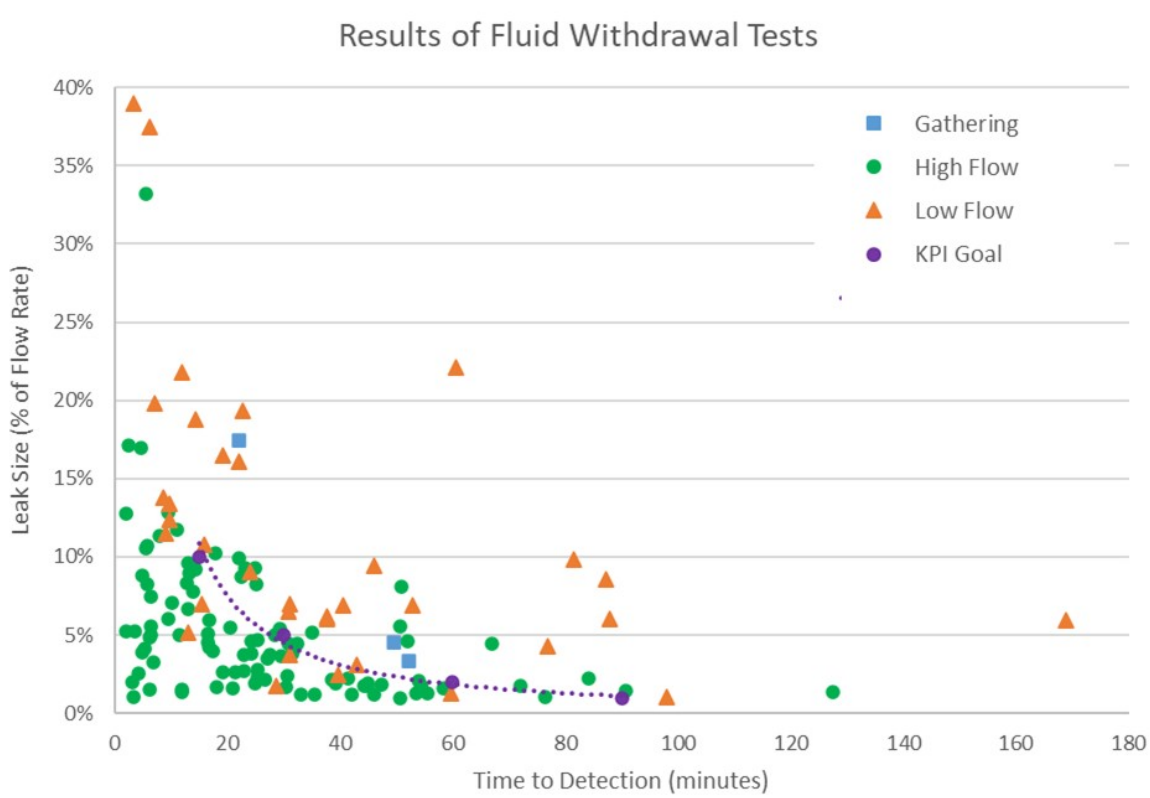
The answer is our ongoing partnership with Bridger Pipeline.

Through working with their engineering, control room, and field personnel, we have not only been able to install the Flowstate LDS on over 30 segments, but have been able to operate two leak skid trailers in a number operational scenarios.

Test Equipment

The commodity withdrawal tests described herein were conducted with a portable, trailer-mounted measurement skid that includes a 3" Micro Motion Coriolis meter, a Pressure Transmitter and an EDGE device with 4G Communication. It is rated up to ANSI 600 service and fabricated using different diameter piping to allow for a range of leak sizes. The EDGE device allows withdrawal flow and pressure data to be transmitted to the Flowstate monitoring environment so the "leaks" can be observed in real time. The skid is typically connected to a mainline vent near the trap or block valve and releases into a small tank after flowing through the meter. This test method was used to 'simulate' leaks on a number of pipeline segments.

The following illustrates some of our withdrawal test results to date. The purple "KPI Goal" curve shows the performance goals we have for "Class A" segments (larger, packed transmission lines.) The collection of tests represents a variety of line types as well as operational conditions, including transient events, etc.



Target KPI

Large Transmission Lines

10%	<= 15 min
5%	<= 30 min
2%	<= 60 min
1%	<= 90 min

Find a few examples in the following pages. →

VERIFICATION TEST

1.5% Leak on 20" Transmission Line with Meter Noise

Test Objectives

The objective of the test was to verify KPI of 2% leak in 45 min or 1% in 90 min.

This test was executed on a portion of a 193-mile, 20" transmission line. The input (A) of the segment is a pass-through station midway on the line. The output (B) is the receipt hub of the line. Both stations have a Coriolis meters, though it can be seen that the output meter is quite noisy. The output station has a back pressure control valve. Additionally, the line undergoes some significant elevation changes as shown below.

Segment Profile

Diameter: 20"
Length: 96 miles
Flow Rate: 3740 bph

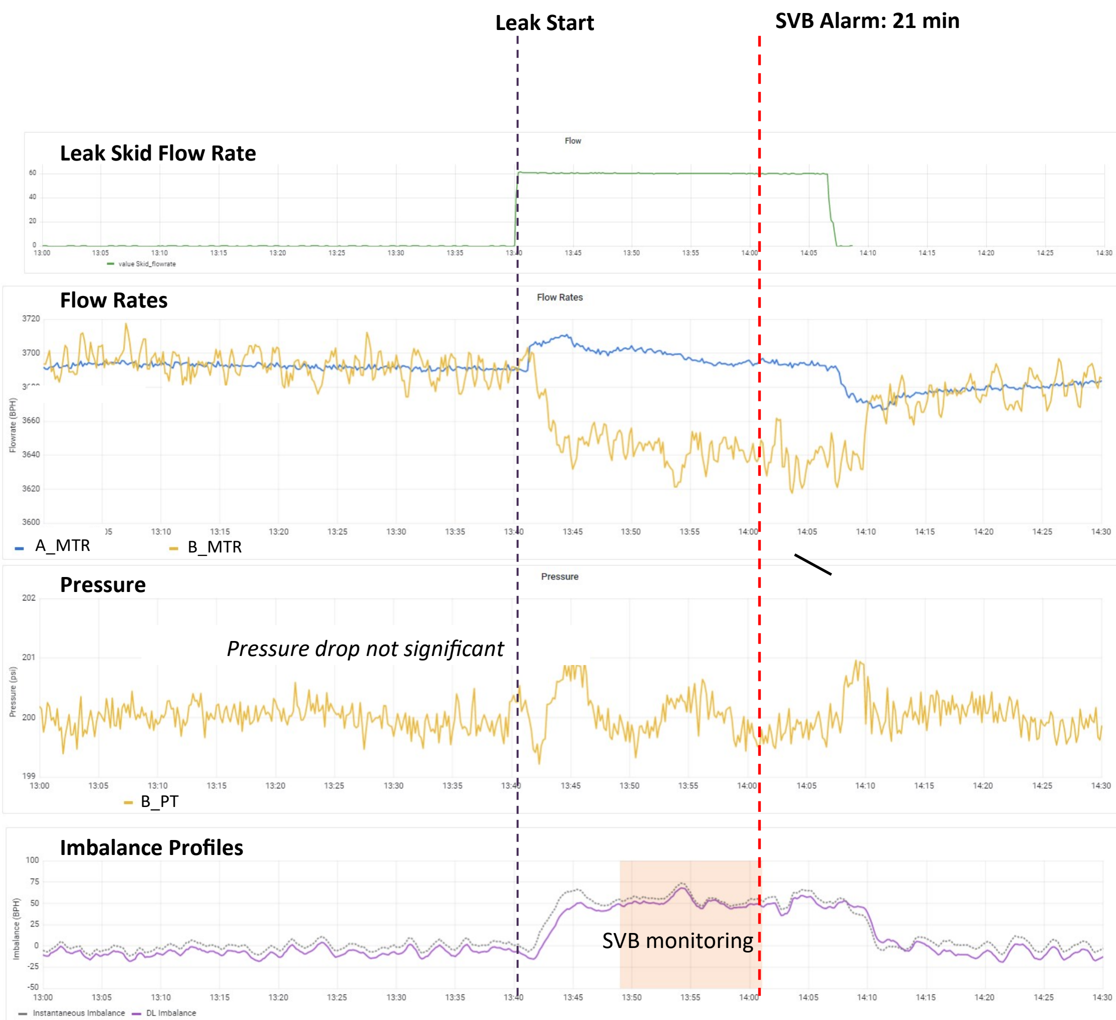
Data used:
- FR—Flow rate
- P — Pressure
- SP—Control Valve Set Point

Test Results

'Truth Data' From Leak Skid:
Start-Stop: 13:40:10 - 14:07:10
Total Duration (min): 45
Total Volume (bbls): 27.05
Average leak rate (bph): 59.75

From Flowstate LDS:
Alarmed at: 13:46:10
Time to detection (min): 21
Estimated duration (min): 44
Estimated volume (bbls): 23.49
Estimated leak rate (bph): 53.5

Test Results

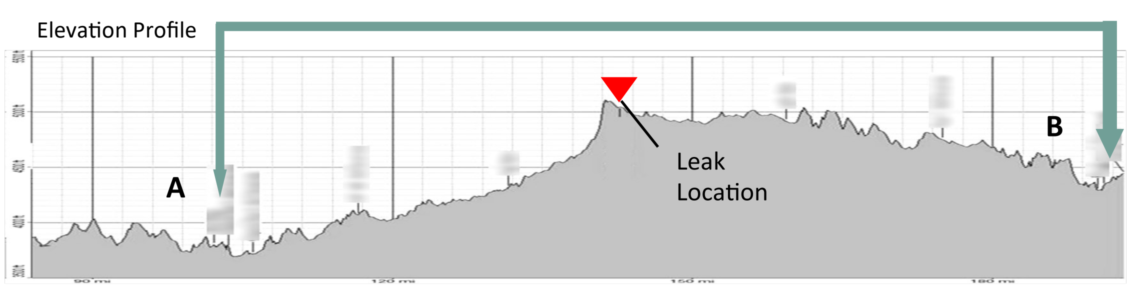


Summary

Although the leak in this example is apparent to the eye in the Flow Rates graph at right, the 60 bph leak is jut 1.5% of the segment flow rate.

Due to the elevation changes on the line, the release at the test location (red triangle in the bottom chart) did not result in a pressure drop sufficient to trigger a Leak Signature Recognition alarm. Although it requires a little more time to conduct the statistical test, the Statistical Volume Balance (SVB) model identified the imbalance and a leak alarm was triggered 21 minutes into the 'leak' as shown in the Imbalance chart at right.

An intermediate pressure reading could potentially improve time to detection. However, the measured time to detection of 21 min was well within the Target KPI of 2% in 45 min or 1% in 90 min.



FLOWSTATE VERIFICATION TEST

5% Leak on Multi-Grade Line During Batch Change

Test Objectives

This test had two objectives:

- Validate the Deep Learning imbalance model on a multi-grade line
- Demonstrate the ability to detect a leak during (or near) a batch change

The test segment is a simple 1-in, 1-out segment that experiences multiple batch changes each day. The top two graphs below show a typical day exhibiting batch changes and associated flow rate changes. (Test period shown in dotted box.)

Segment Profile

Diameter: 16”
Length: 137 miles
Flow rate: 2500—3000 bph

Topology:
1 input
1 output

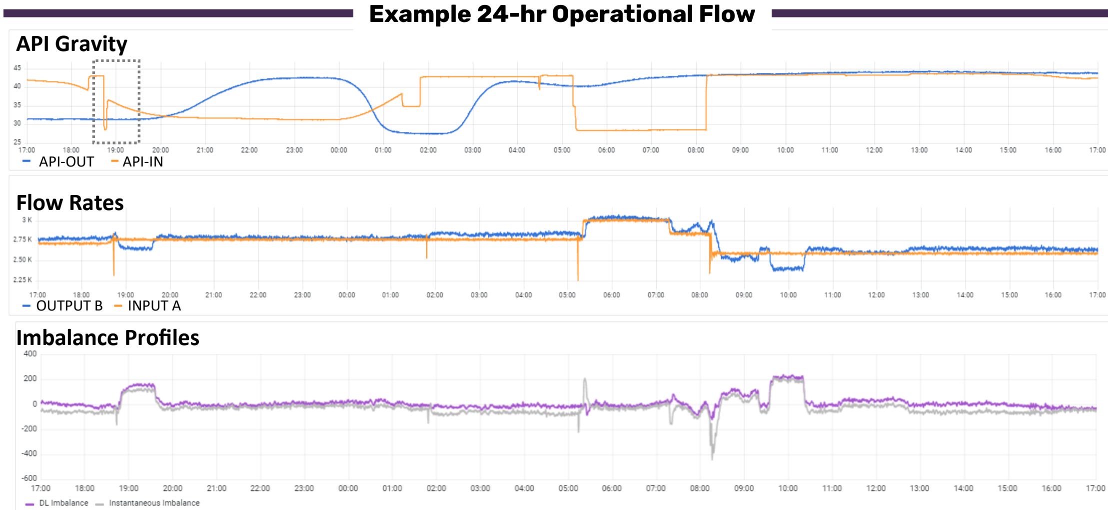
Data used:
FR—Flow rate
P— Pressure
PS—Pump Status

Test Results

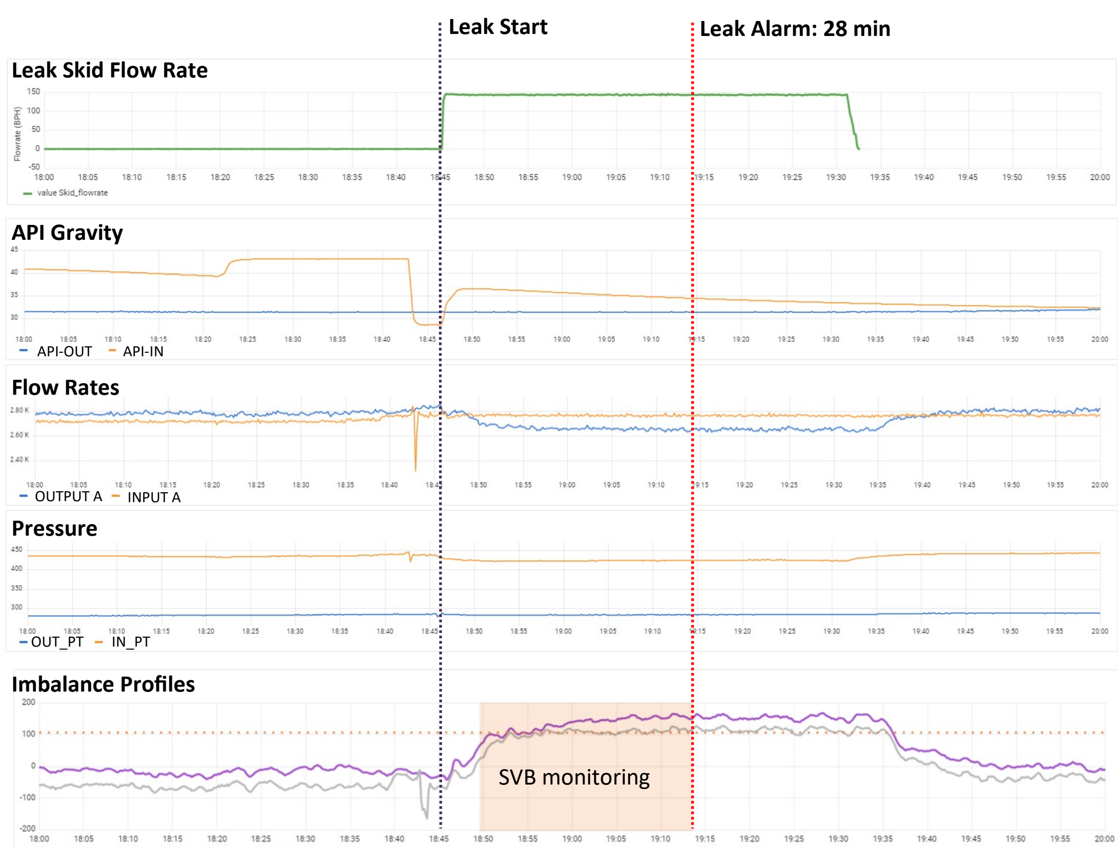
‘Truth Data’ From Leak Skid:
Start-Stop: 18:45 - 19:32
Total Duration (min): 47.17
Total Volume (bbls): 110.62
Average leak rate (bph): 141.7

From Flowstate LDS:
Alarmed at: 19:13:30
Time to detection (min): 28:10
Estimated duration (min): 47.33
Estimated volume (bbls): 116.77
Estimated leak rate (bph): 148.0

Example 24-hr Operational Flow



Test Results



Summary

First, it can be seen in the Flow Rates plots at right (both the 24-hr above and test results below) that there is an offset between the input and output meters that changes depending on which crude type is being transported. Despite this, the deep learning model has learned the operation well and does an excellent job of predicting the output flowrate. In contrast, the Instantaneous imbalance is a little more impacted by the offsets and shows more disturbance during batch changes.

For the test, the withdrawal started at 18:45, during the process of a batch change. Within a couple minutes, the volume imbalance is detected and the SVB model begins tracking it until it ultimately alarms at 19:32—approximately 28 minutes after the start of the leak.

Despite the operational activity, the system still met a target KPI of 5% leak within 30 minutes.

FLOWSTATE VERIFICATION TEST

8% Leak on Gathering Line with Operational Activity
Leak Start During No Flow

Test Objectives

Test ability of system to catch a leak that starts while system is not running (No Flow).

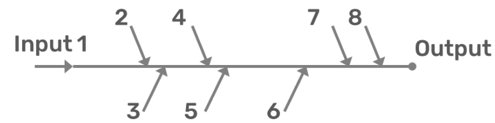
The test segment is a very active gathering line with 8 inputs that are on and off several times through the course of a day (as shown in the top chart below). Though the line is flowing most of the day, there are times where it is not running. A worst case scenario might be if a leak were to start during this shut down period. This test was designed to see how quickly the LDS could detect a leak that started during shutdown.

Segment Profile

Diameter: 6 5/8"
Length: 16.64 miles
Flow rate: 300—1000 bph

Topology:
- 8 inputs (origin, 7 injections)
- 1 output

Data used at each station:
- Flow rate
- Pressure
- Pump Status



Test Results

Leak Start: 8:30:10
Leak Size 26-29 bph

Time of Alarm: 9:35:50
Time to Detection: ~66 min

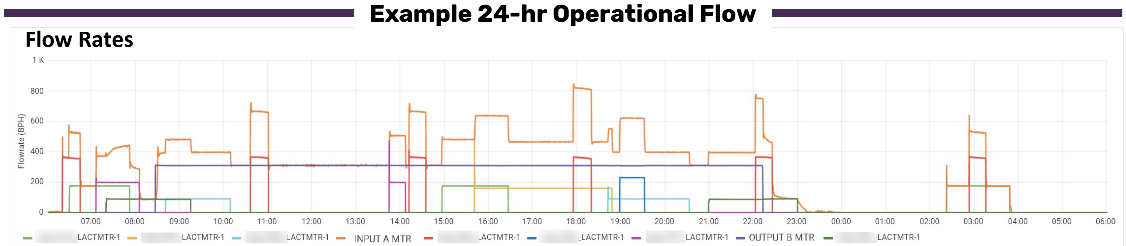
Summary

The withdrawal test starts at 8:30 at a t rate of 26 bph. The segment kicks on 20 minutes later from at 8:50 flowing at about 316 bph. The segment takes about 9 minutes to pack up from Input to Output. At this point, the "leak" is flowing at about 8% of the segment flow rate.

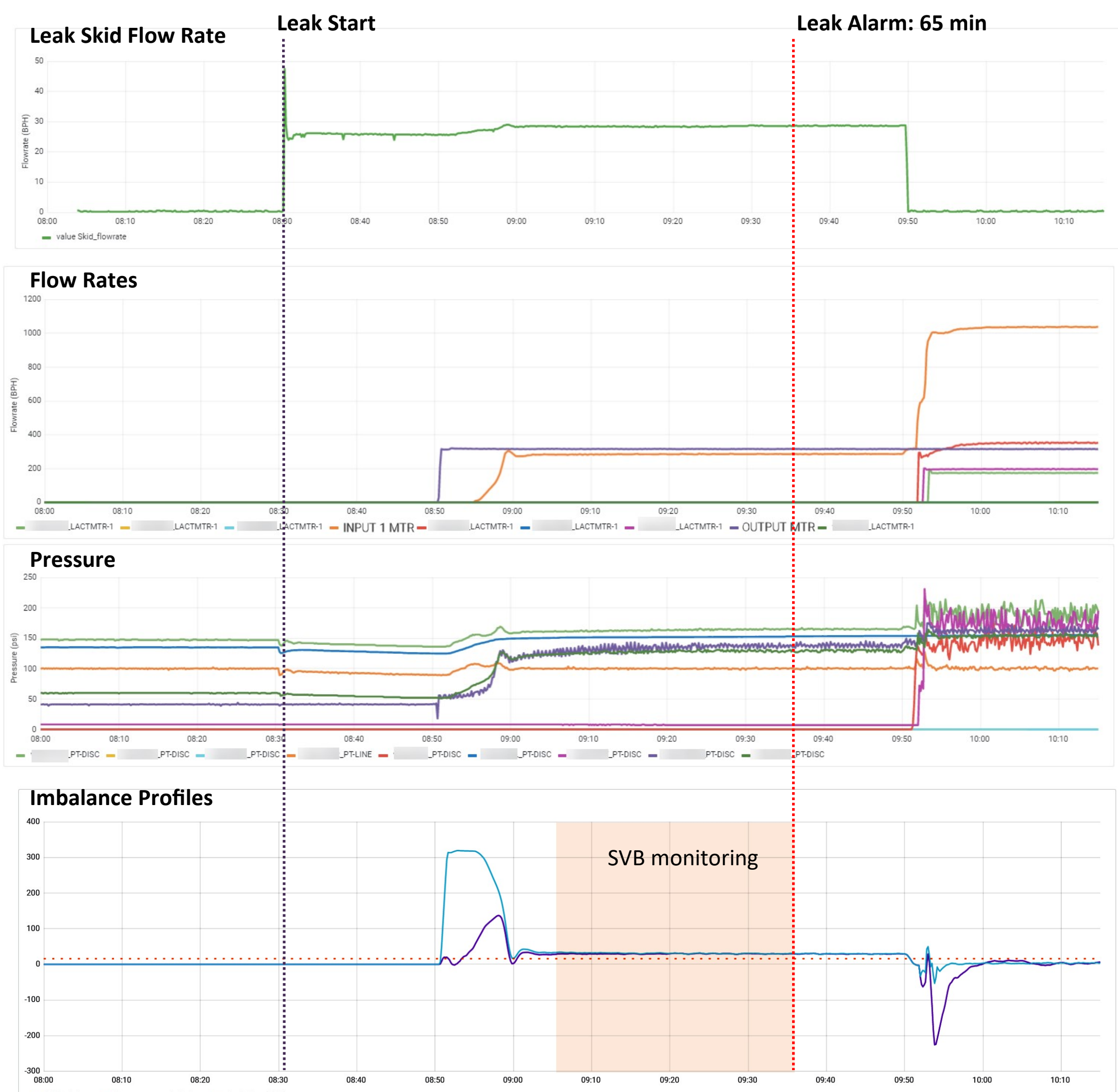
The bottom graph shows both the Instantaneous Imbalance (simply the difference between flow coming out and flow going in at any time) and the Deep Learning Imbalance (difference between what is coming out and what is expected to be coming out). There is a large disturbance as the line kicks on and is packing up, but both imbalances detect missing commodity after the line is packed. The LDS statistical volume balance method begins monitoring the imbalance at 9:05 and issues an alarm at 9:35—about 1 hour after the leak had started and about 40 minutes after the line had started flowing. **At this point, the leak could be limited to approximately 30 bbls.**

It is noted that although both imbalances detect the leak, the smaller transient with Deep Learning allows for tighter alarm thresholds.

Example 24-hr Operational Flow



Test Results



FLOWSTATE VERIFICATION TEST

5% Leak on Gathering Line with Operational Activity
Leak Start During Line Packing

Test Objectives

Test moderate sized leak (~5%) during packing/unpacking with meter offset.

Detection Method: Statistical Volume Balance (SVB)

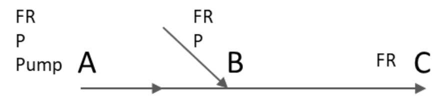
Leak was initiated after the primary input station had been active for nearly 20 minutes and the line was about 75% packed. During the course of the leak, the primary input shuts down, but an injection is started. It is noted that the normal offset between the input and output meters is about 20 bph or 4% of input flow rate.

Segment Profile

Diameter: 6 5/8”
Length: 13.27 miles
Flow rate: 450 bph

Topology:
2 inputs (origin, 1 injection)
1 output

Data used:
FR—Flow rate
P— Pressure
Pump—Pump Status

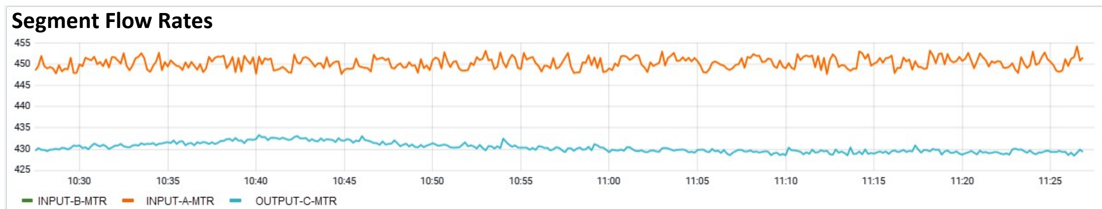


Test Results

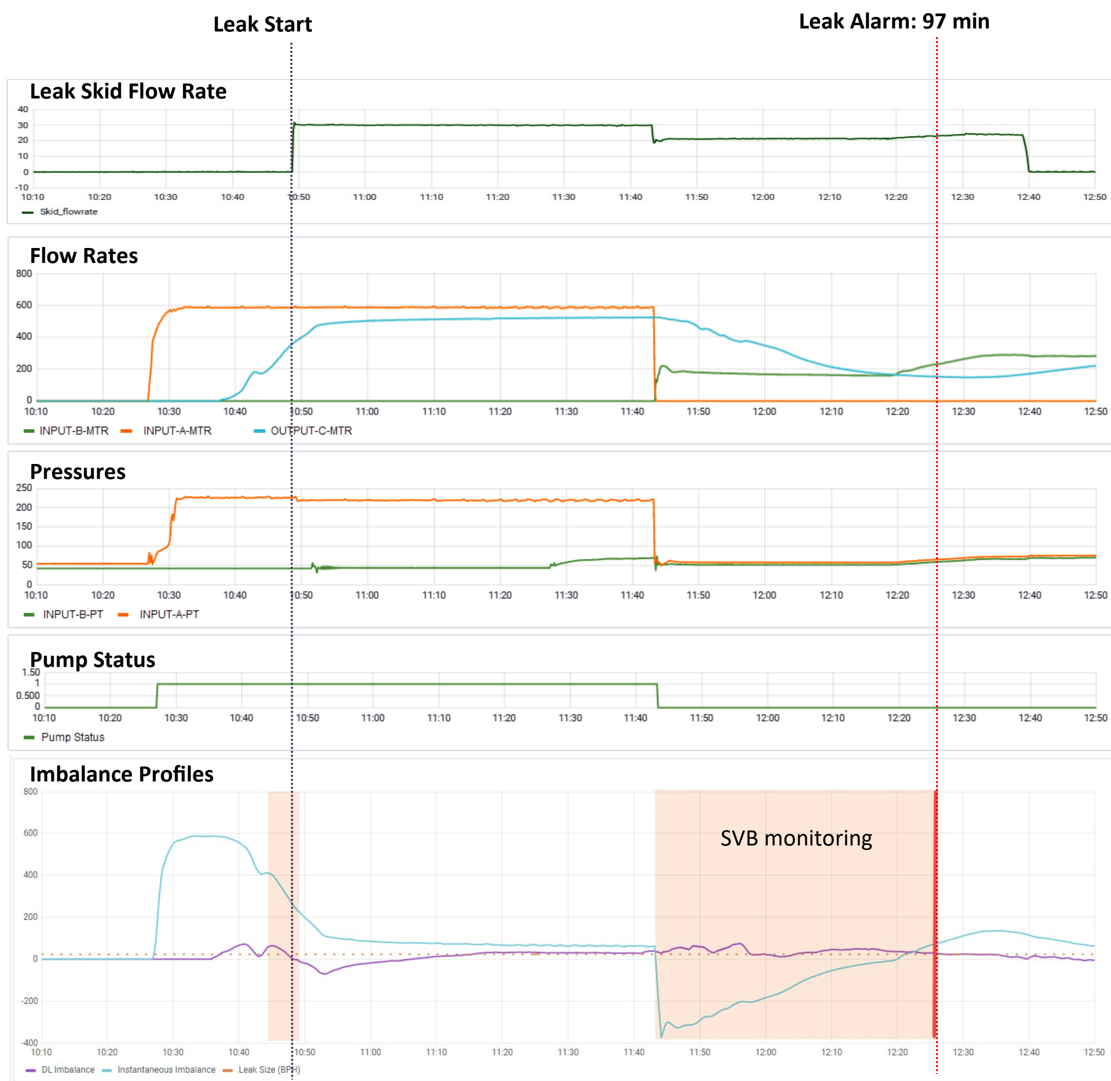
‘Truth Data’ From Leak Skid:
Start-Stop: 10:49:10 - 12:39:50
Total Duration (hrs): 1.85
Total Volume (bbls): 47.53
Average leak rate (bph): 25.73

From Flowstate LDS:
Alarmed at: 12:26:50
Time to detection (min): 97
Estimated duration (hrs): 1.34
Estimated volume (bbls): 45.11
Estimated leak rate (bph): 33.55

Standard Operational Flow Rates—20 bph (4%) Meter Offset



Test Results



Summary

The first plot to the right shows the existing 20 bph offset that is observed on this segment. This amounts to about 4.4% of the input flow rate. The leak rate in this test was 25 bph or 5% of flow rate—only slightly greater.

In the Imbalance Profiles plot, the blue line represents a simple line balance while the purple line represents the imbalance predicted by the Flowstate’s proprietary Deep Learning model. It can be seen that the DL model is more robust to the normal activity and meter offset on the line, yet in time it reveals the anomalous condition caused by the “leak”. With that, the SVB leak detection algorithm is able to pick up on the imbalance. After monitoring for a bit, it determines that conditions may be a leak and issues an alarm.

Traditional imbalance methods perform poorly in these conditions which adversely affects both the minimum detectable size and the time to detection.

Test Objectives

Test the timely detection (<10 minutes) of a significant leak event (>10%) on a gathering line.

Detection Method: Rupture Recognition

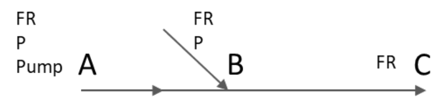
This withdrawal test was conducted when the primary input (A) and the injection (B) were both active and the line was completely packed. Commodity was withdrawn at 75 BPH which represented just over 11% of total input flow rate.

Segment Profile

Diameter: 6 5/8”
Length: 13.27 miles
Flow rate: 586 bph

Topology:
2 inputs (origin, 1 injection)
1 output

Data used:
FR—Flow rate
P— Pressure
Pump—Pump Status

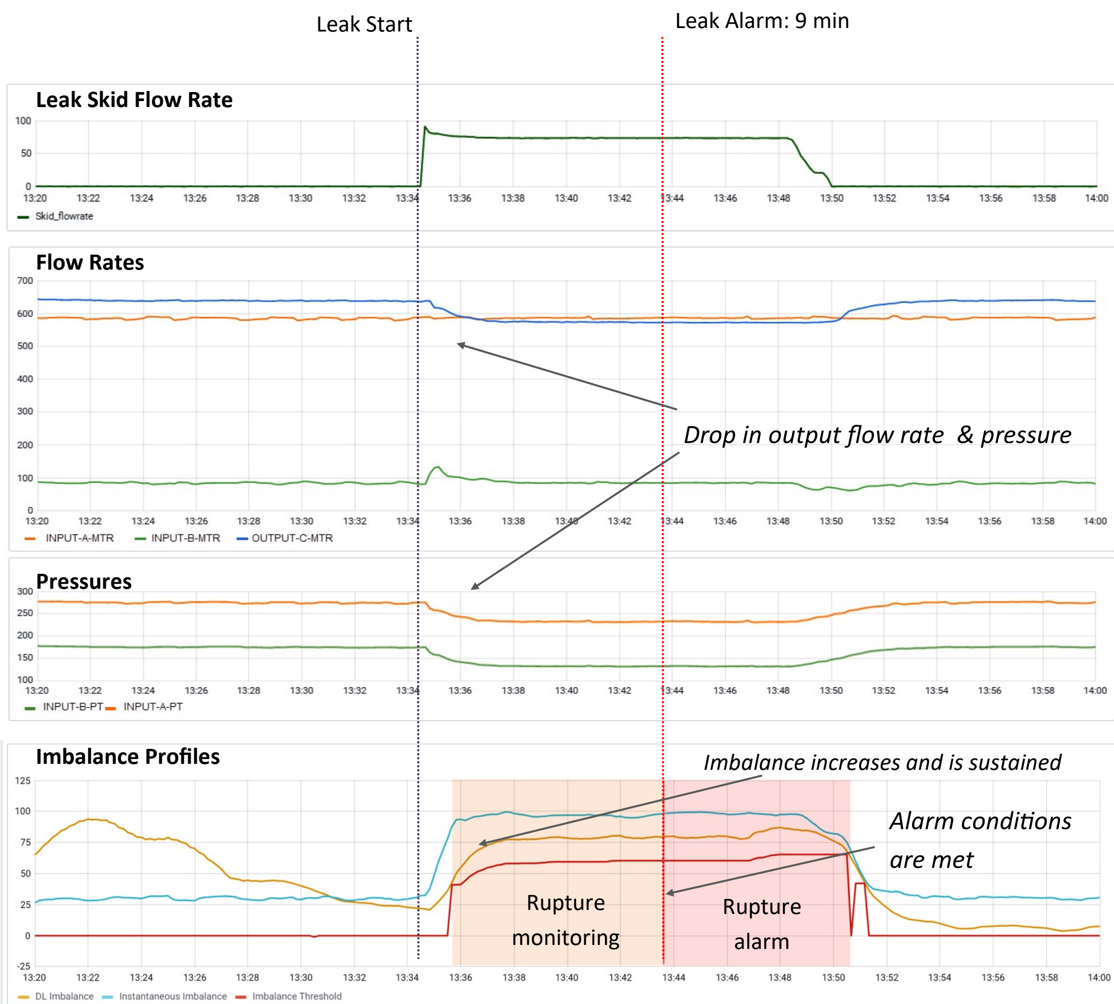


Test Results

‘Truth Data’ From Leak Skid:
Leak Time: 13:34:40 - 13:49:50
Total Duration (hrs): 0.26
Total Volume (bbls): 18.05
Average leak rate (BPH): 70.64

From Flowstate LDS:
Alarmed at: 13:43:40
Time to detection (min): 9
Estimated duration (hrs): 0.42
Estimated volume (bbls): 25.5
Estimated leak rate (bph): 59.6

Test Results



Summary

The Flowstate LDS Rupture Model is designed to look for a large, rapid drop in pressure or output flow rate (>10%) accompanied by a sustained imbalance—indicative of a significant commodity loss.

It can be seen in the top chart that the Leak Skid started withdrawing oil at 13:34:40 at a rate of 74 bph, or about 11-12% of the segment’s total flow rate at the start of the test.

This withdrawal resulted in a drop in output flow rate (blue curve in second chart) and a drop in pressure. The rate of change (ROC) of the drop was significant enough to trigger the first condition for the Rupture Alarm.

The segment was already in a state of imbalance due to activity on the line. However, once the ROC is detected, the imbalance threshold that must be met to indicate rupture is raised, as can be seen by the red threshold line in the Imbalance Profiles chart on the bottom . It is seen that the imbalance is indeed above this level and so the rupture model begins monitoring.

Once the rupture criteria persisted for the specified amount of time, an alarm was raised and was sustained through the end of the simulation (when imbalance returned to normal).

This simulated leak was detected within 9 minutes from the initiation of the leak simulation. It is noted that Rupture alarms take a little while longer to alarm due to the required certainty demanded of the alarm type. The alarm slightly overestimated the total leak volume and duration compared to the data obtained from the Leak Skid. The leak rate however was slightly underestimated.

Rupture Recognition on Transmission Line

Test Objectives

The LDS Rupture Recognition method looks for a significant (>10%) drop in output flow rate or any pressure on the line accompanied by a sustained volume imbalance.

The goal of this test was to verify a leak of size >10% would be detected quickly by this alarm method. The segment in this test is at the end of a 193-mile transmission line.

Segment Profile

Diameter: 20”
Length: 91 miles
Flow rate: 2840 (up to 6000 bph)

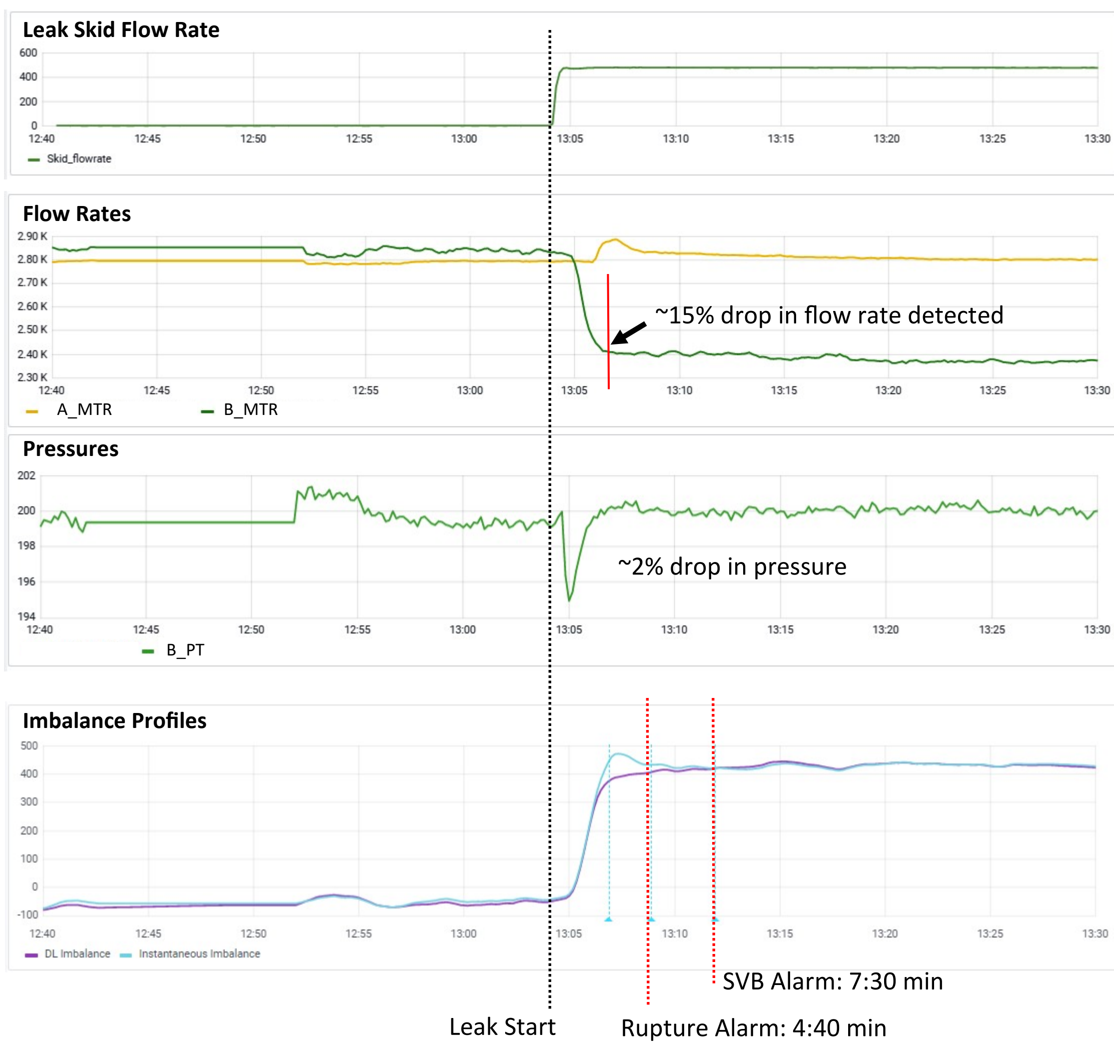
Topology:
1 input
1 output

Data used:
FR—Flow rate
P— Pressure
SP —Control Valve Set Point

Test Summary

‘Truth Data’ From Leak Skid:
Start-Stop: 13:04:10 - 13:35:00
Total Duration (min): 31.2
Leak Rate (bph): ~475.0

From Flowstate LDS:
Alarmed at: 13:08:50
Time to detection (min): 4:40
Estimated duration (min): 3.6
Estimated leak rate (bph): 319.4



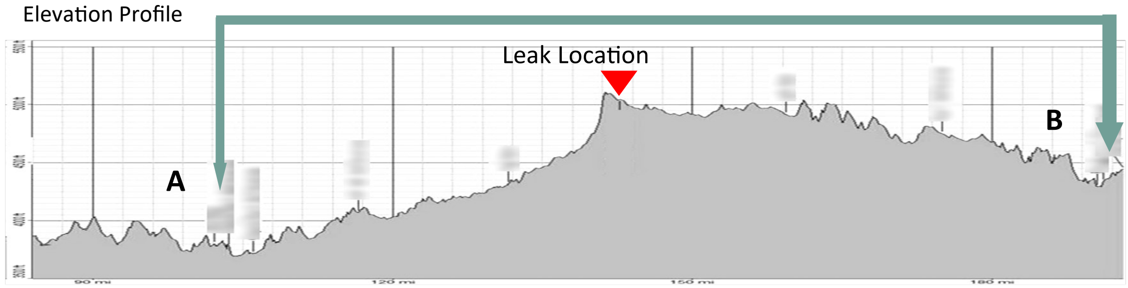
Results

The volume flow rate withdrawn by the skid was measured at 475 bph. This was about 16-17% of the output flow rate at the start of the test. The LDS detected the necessary drop in output flow rate to begin monitoring for rupture. The imbalance volume and duration exceeded thresholds set for the alarm at a time of 4 min 40 seconds into the ’leak’.

It is noted that the Signature Recognition method did NOT alarm in this case due to an insufficient drop in pressure (only a brief ~2% drop due to location).

The Statistical Volume Balance (SVB) method DID alarm ; the 5% model alarmed at 13:11:40 which was 7 min 30 seconds into the ‘leak’. Because it is designed to be able to catch leaks down to 5% of flow rate, the SVB model is designed to monitor the imbalance for a longer duration before triggering an alarm.

Elevation Profile



Flowstate
120 N. Center
Casper, WY 82601

www.flowstatesolutions.ai
info@flowstatesolutions.ai