Leak detection for BTC

Joanna Mabe, Keefe Murphy, ATMOS International Limited, and Andrew Welsh and Gareth Williams, BTC Company, examine the commissioning of a real-time leak detection system on the BTC crude oil pipeline during start up.

Due to stringent environmental commitments, it was critical for the leak detection system (LDS) to work from the moment that crude oil was introduced into the 1768 km BTC crude oil pipeline. Without any prior operational data and with the pipeline partially filled, it was challenging for the ATMOS$^{(TM)}$ leak detection to monitor the integrity of the pipeline throughout the whole filling process.

The BTC crude oil pipeline runs from the Sangachal Terminal near Baku in Azerbaijan, via Tbilisi in Georgia, through Turkey to an export terminal located near Ceyhan on the Turkish Mediterranean coast (Figure 1).

BTC pledged to host governments, partners, lenders, NGOs and others that the highest possible performance of computerised leak detection would be provided from the point when hydrocarbons were introduced into the pipeline. Following successful completion of all hydrotests and commissioning activities, 700 000 m^3 of nitrogen were injected into the pipeline up to IPA1, the first intermediate pigging station along the line. This nitrogen remained in the pipeline all the way to Ceyhan. It was contained by closing block valves downstream of the injection point. When

Figure 1. Route of the BTC pipeline.

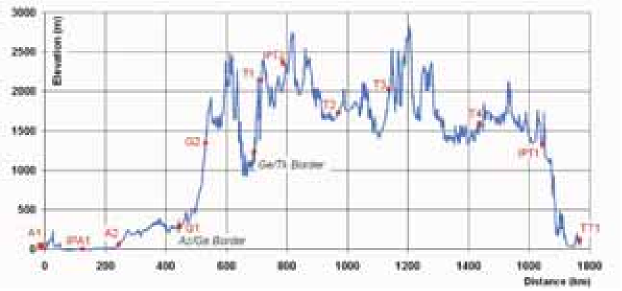

Figure 2. BTC pipeline elevation profile.

crude was pumped into the pipeline, two 'line fill' pigs were used to separate the crude from the nitrogen. Providing reliable leak detection for the partly filled pipeline section without any historical data was particularly unusual and difficult for the online leak detection system.

Despite these challenges, leak detection was provided. Close analysis of the system data in line with the pipeline operations and close co-operation with the engineering and operations teams was required.

Pipeline description

The pipeline is 1768 km long and is routed through some extremely mountainous terrain, rising to greater than 2500 m in Georgia and 2800 m in Turkey, remaining above 1500 m until near KP 1650 in Turkey, where it falls steeply towards the Mediterranean Sea. Figure 2 shows the elevation profile of the whole pipeline. Slack flow is inevitable at several high points along the pipeline in Georgia and Turkey. The leak detection system had to continue to work under such slack flow conditions.

The pipeline is 42 in. diameter for most of its length. There is a 46 in. section throughout Georgia and a 34 in. section in Turkey for the last 125 km into the Ceyhan terminal.

There are eight pump stations along the pipeline and 87 block valve stations. Pumping stations are at Sangachal terminal in Azerbaijan, a further station in Azerbaijan, two in Georgia and a further four pumping stations in Turkey. Each of these stations has a pig launcher and receiver and there are three further intermediate pigging stations (one in Azerbaijan and two in Turkey).

The pipeline is well instrumented. At each of the pumping stations in Azerbaijan and Georgia there are upstream and downstream flow, pressure and temperature meters available. At the pumping stations in Turkey there are upstream and downstream pressure meters, and downstream flow and temperature meters.

At all block valve stations there are upstream and downstream pressure meters, and downstream temperature meters. Upstream flow meters are available at six of the block valves in Turkey where slack flow is expected particularly when running at reduced flowrates. Additionally, fiscal flow and density meters are available at PSA1, PSG1 and PST1, the first pumping station in Azerbaijan, Georgia and Turkey respectively. Figure 3 shows the overview of the Azerbaijan Section, as presented on the ATMOS LDS.

System description

In order to achieve the best possible leak detection performance as committed by BTC, redundancy is provided within the ATMOS$^{(TM)}$ leak detection system architecture.

The pipeline is considered in discrete sections as shown in Figure 4:

- Seventeen sub-sections where flow readings are available.
- Three main 'country' sections - Azerbaijan, Georgia and Turkey.
- One further section - monitoring the entire pipeline.

This configuration allows the LDS to achieve the best possible leak detection sensitivity and response time, and provides a high level of redundancy.

In the event of losing a sub-section, for instance due to a critical instrument fault, there will still be leak detection provided by the 'country' section. It also allows slack flow areas to be isolated so that the sensitivity and performance of other sections do not have to be compromised.

Each of the redundant leak detection systems rely on flow, pressure and temperature measurements along the pipeline to determine if a pipeline leak has occurred. Therefore to have the leak detection capability available, it is essential that the following conditions are satisfied for the pipeline section to be filled prior to start-up:

- The pipeline instrumentation commissioned and in good working order.
- Communications from the field and Integrated Control and Safety System (ICSS) verified.
- The interface between the ICSS and LDS tested and commissioned.

Typically, commissioning of a leak detection system starts when the pipeline is already full, the above conditions have already been satisfied and the following conditions have been met, such as steady state operations, system tuning, leak trials.

In the case of the statistical leak detection system for the BTC pipeline, given that it is sectionalised, commissioning was possible as soon as sections were filled and therefore, leak detection was provided from the moment crude oil filled the first section. As more pipeline sections were filled, more leak detection systems were activated.

In addition, some parameters of the standard algorithm were temporarily modified during the line fill phase to be able to provide leak detection in the partially filled pipe section. This means that leak detection is possible as soon as oil first enters the pipeline.

There was also an ATMOS$^{(TM)}$ application to track pigs in the pipeline; both cleaning and 'line fill' pigs. The location of the 'line fill' pigs defined the location of the oil front as the pipeline was being filled.

This application proved particularly valuable during line-fill as knowledge of the location of the oil front with respect to the elevation profile was essential to diagnose events being reported by the LDS. The online pig tracking application was able to track pigs where traditional on-the-ground pig tracking techniques suffered as a consequence of vapour pockets, steep downhill land profiles and bad weather.

Filling operation

The line was filled with crude oil at a fixed rate of approximately 150 mbd. The oil/N_2 interface was maintained using two high seal, bi-directional pigs known as the 'line fill' pigs, which were spaced approximately 400 m apart. Ahead of the 'line fill' pigs was a large pressurised nitrogen blanket approximately 120 km long. The nitrogen was used to inert the pipeline and maintain a backpressure to help control the speed of the pigs in downhill sections.

Selected block valves in the section to be filled were used to control the nitrogen pressure ahead of the 'line fill' pigs. These specific valves were left closed and the nitrogen throttled around them using their bypass valves as the oil front approached. Once the pressure had equalised at either side of a closed block valve, the bypass valve was closed and the block valve was fully opened. Nitrogen pressure then built up against the next closed block valve and the procedure was repeated. This ensured the pressure in front of the pigs was maintained as much as possible throughout the Oil/N$_2$ displacement.

Because a partially filled section behaves so differently from a full section, leak detection under these conditions is normally considered impossible. However, with the high level of instrumentation on the BTC pipeline, ATMOS$^{\text{(TM)}}$ Pipe Statistical Pipeline Leak Detection (SPLD) System was applied to each partially filled section as soon as crude entered the section.

Due to the uncertainties in the pig behaviour and potential faults in the newly installed instrumentation system, all leak alarms were diagnosed in conjunction with the pig tracking system.

Leak detection on filled sections

Once a section was filled, the actual pipeline data for this section was used to tune and optimise the leak detection system. As more sections were filled, more sub-systems were activated to monitor more kilometres of the pipeline. The performance of each sub-system improved as more actual pipeline data became available.

Each section was tuned to full sensitivity during steady-state operations. However, transients (such as unexpected pump trips) during this time were not expected to be representative of normal operations so the system was tuned to a reduced sensitivity during line fill transients.

The ATMOS$^{\text{(TM)}}$ Statistical LDS was close to being fully tuned and commissioned by the time the entire pipeline was full. However, the final fine tuning of the system is inevitably slightly different from the initial tuning carried out during incremental line fill as it requires the whole pipeline to be in operation.

Once a section of the pipeline was full, the standard leak detection algorithm could be applied as the minimum instrumentation requirements were fulfilled: flow and pressure measurements at both the inlet and the outlet of the pipeline section.

Flow and pressure measurements along the line are the significant variables feeding the algorithm after data validation checks are carried out. Then statistical analysis is performed on the flow imbalance calculation to determine whether a leak condition is present. If a leak is detected then an alarm is generated and an estimate of the leak size and location is reported.

The system also adapts itself to changes that occur in the pipeline. The system accommodates inventory changes by monitoring pressure variations in the pipeline and normal metering errors by continuously estimating the flow difference between the inlet and the outlet.

The minimum the system requires to be tuned is a sample of 'normal operation' including transients caused by pumping operations and throughput changes.

Once a filled section of the pipeline had been tuned, then the settings for this tuned section were used as a starting point for subsequent newly filled and un-tuned sections. This allowed newly activated sub-sections to start off at a more realistic sensitivity minimising the number of false alarms being generated.

Incremental line fill took several months to complete as new pipeline sections and stations became available for filling. Between line-fill stages there were numerous periods of no flow and in these times the LDS performed shut-in leak detection on the filled sections.

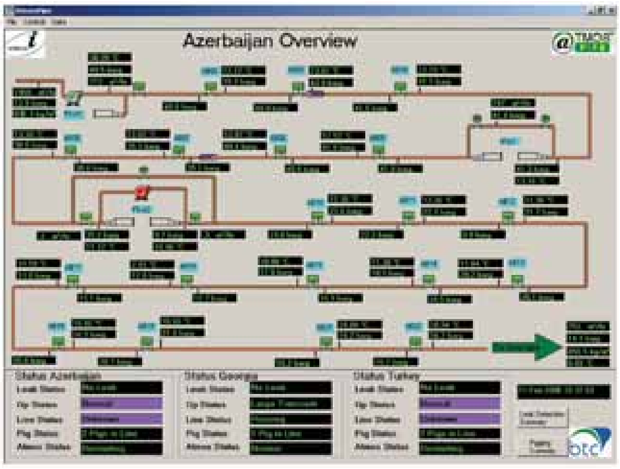

Figure 3. Overview of the leak detection system in the Azerbaijan section.

Leak detection on the 'line fill' section

When the crude oil first entered a pipeline section, the reliability and performance of the overall instrumentation system were uncertain, particularly for the part where no crude was present.

During the line fill operation, the hydraulics in the pipeline were significantly different from those in a filled section. The pressure downstream of the 'line fill' pigs was governed by nitrogen being moved along the pipeline. This gas filled section provided a compressible cushion for the 'line fill' pigs to push against and as such did not behave as a liquid would.

In addition, the minimum instrument requirements were not met: the outlet flow measurement needed to be disregarded, as that section of pipe was effectively empty. Also the number of pressure measurements increased as the section was gradually filled.

Due to the above challenges, standard leak detection technologies cannot perform leak detection effectively.

For the 'line fill' section, some parameters in the standard algorithm needed to be adapted. There was no outlet flow measurement so a raw flow difference was not available. The whole inventory was continually changing so the inventory correction was not as it would be for a filled section. The algorithm was modified to use the available data, i.e., the inlet flow reading and all available pressure measurements.

As the pipeline section was filled, data was analysed so that the rate of change of pressure in the line could be monitored for leaks alongside the inlet flow measurement. The inlet flow of the section was also monitored to establish whether the pipeline was under shut-in or running conditions. The performance of the 'line fill' section gradually improved as the oil front passed more block valves and more valid pressure measurements were incorporated into the calculations.

This system relied on maintaining the pressure along the line and having a functional inlet flow measurement at all times as these were the inputs into the statistical algorithm.

This adaptation was only required for partially filled sections. Once full this method was disregarded and the standard algorithm was applied.

Leak detection on the full pipeline

After the crude filled the whole pipeline, the leak detection system had to be fine-tuned and all the sub-systems and whole country systems activated. The system performance had to be optimised to its highest possible sensitivity.

EXAMPLE: LINE FILL IN LATER SECTIONS AND FULLY OPERATIONAL LDS IN EARLIER SECTIONS

Sections of pipeline that had been filled and that had seen enough representative pipeline data were optimised to remove false alarms and provide the highest possible leak detection sensitivity. These sections were then left to run as 'normal' and the only changes expected to these were further fine-tuning changes once the pipeline became fully operational.

There were no true leaks during line-fill but normal pipeline and station activity presented the opportunity to prove that leak detection was active.

Figure 5 illustrates the LDS sensitivity of the section between IPA1 and PSG1 under shut-in conditions. This section had been tuned to 'Filled Line' sensitivity. Unfortunately, it was missing some instrumentation at an intermediate pump station due to a communications fault, so its performance is degraded. The trend shows the system reacting to what was indicative of a very small shut-in leak. The 'leak' was in fact generated by extracting oil from the upstream side of PSG1 to fill the pipe work and Crude Topping Unit (CTU) Feed Tank located at PSG1 for the first time. This was extraction of oil from the shut-in section of pipeline into an un-metered empty section of pipeline and process equipment.

The 'leak' started at an extremely small volume, rising after 30 minutes to approximately 10 m^3/h as confirmed by the engineer responsible for the site works. The LDS detected this simulated leak in 45 minutes. This corresponds to a leaked volume of approximately 6 m^3 before alarm. The leak location was reported as at PSG1. This was the correct location.

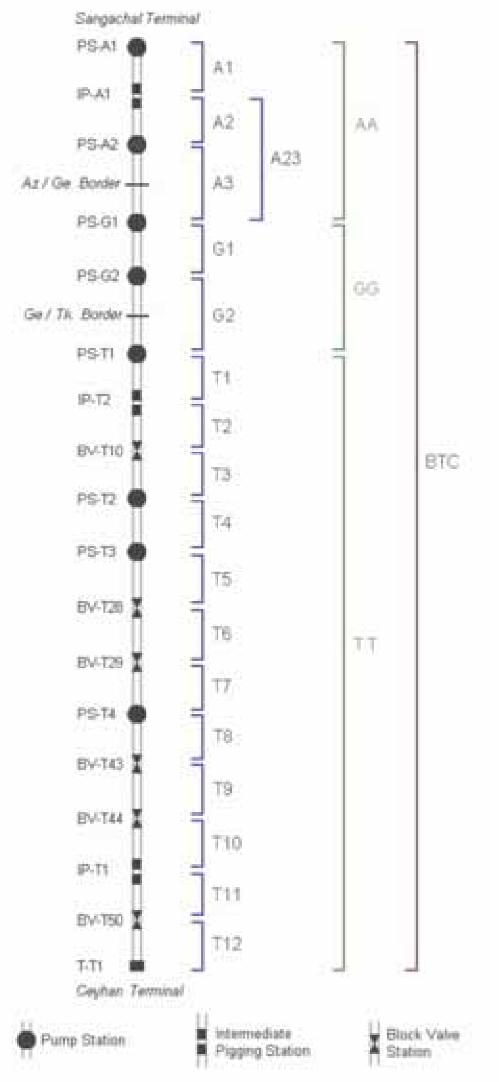

Figure 4. Leak detection sections.

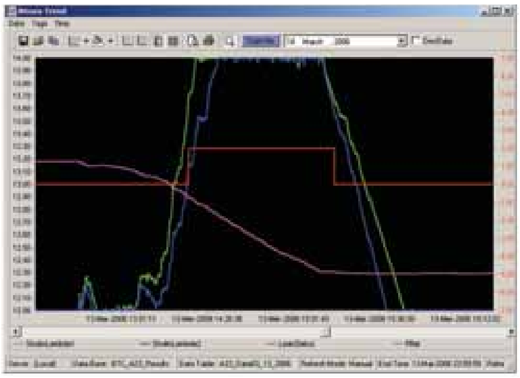

Figure 5. Trend displaying full section LDS response to a 'simulated leak' under shut-in conditions. Primary axis: average line pressure (purple). Secondary axis: lambda variables (blue and green) and leak status (red).

Conclusion

Traditionally, leak detection is one of the last systems to be commissioned and come online in a pipeline project. This is sometimes due to a lack of commitment or a lack of belief in leak detection technology, leading to a lack of urgency. Inevitably, this often results in the production taking priority over LDS commissioning until some time after the pipeline is in full flow. However, it is also widely accepted that leak detection system commissioning cannot commence before the pipeline is fully operational.

BTC and ATMOS have co-operatively striven to break this paradigm and develop a leak detection system that delivers real benefit at the first point of hydrocarbon introduction and is therefore close to optimal tuning on day one of full production.

BTC and ATMOS have demonstrated that leak detection is possible in a partially filled pipeline, and during line-fill - i.e., at all times from the moment fluid first enters the pipeline. The results from the LDS during line-fill must be used with a high degree of understanding and could not be used in isolation from other systems, e.g. knowledge of where the oil front is with respect to the elevation profile, knowledge of the current state of commissioning of all the associated systems - pumps, stations, status and accuracy of instrumentation, block-valves, and in-depth knowledge of how the LDS and pipeline operations interact with each other.

The benefits of commissioning the real-time ATMOS$^{(TM)}$ leak detection system on the BTC pipeline during line fill are clear:

- The LDS had already been tested over 12 months by the time oil reached the terminal at Ceyhan.
- The LDS was successfully detecting illegal taps and thefts soon after the pipeline became operational. Typically, at this time in a pipeline project, leak detection system commissioning would only be commencing.
- The LDS had been tested many times by commissioning processes during line fill, while commissioning pump stations, filling pump loops, commissioning surge relief tanks, etc., leading to a high degree of acceptance and operator confidence.

Conversely there was also a cost:

- A high degree of commitment and cooperation from the BTC engineering and operations team and ATMOS International throughout the entire process was required to achieve these benefits. This cost is minor in comparison with the benefit of active leak detection during line fill and with accelerated final system tuning and commissioning.