ENSURING HAZARDS DON'T CAUSE HAVOC

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Ecopetrol S.A. (Ecopetrol) operates a complex pipeline network across Colombia. The company aims to protect people and the environment from potential hazards. Based on the results of oil spill quantity calculations, Ecopetrol had defined high consequence areas (HCAs) and effective measures to mitigate potential emergencies for its Caño Limón-Coveñas pipeline. ILF Consulting Engineers (ILF) was requested to reassess a 93 km pipeline section between Toledo and Oripaya in order to develop controlled operational emergency shutdown (COESD) procedures and numerically verify these utilising a hydraulic pipeline model.

As this article outlines, Ecopetrol worked alongside ILF on a joint project, performing a 'segmentation study' for the section under evaluation.

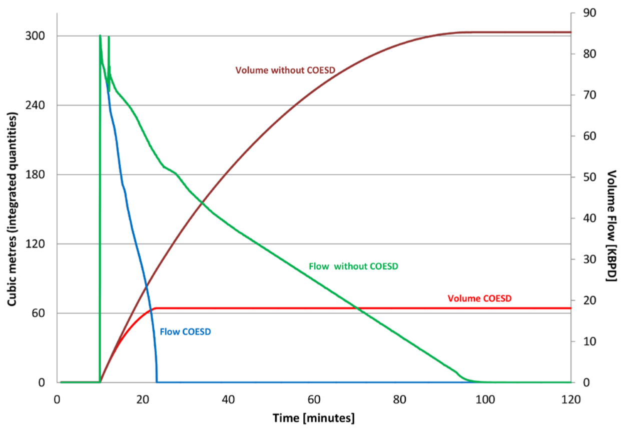

Figure 1. An example of the spill volumes on a downhill section of pipeline with a 2 in. leak hole.

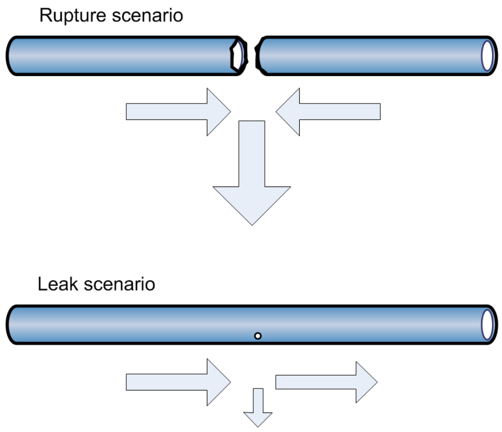

Figure 2. A comparison of rupture vs leak scenario immediately after an incident.

Background

Starting near the city of Arauca, the Columbian Caño Limón-Coveñas pipeline runs close to the country's border with Venezuela, through Norte de Santander Department, before it turns off to the west near the city of Tibú. It then continues to the Coveñas terminal station on the Caribbean coast. The pipeline transports crude oil across a total length of approximately 771 km.

Ecopetrol's pipelines and facilities (such as valves and pumps) are remotely controlled from regional control centres by certified personnel. All of the control centres along the Caño Limón-Coveñas pipeline are connected to assigned pipeline stations through a reliable telecommunication system.

In previous years, Ecopetrol has suffered ruptures and oil theft (due to illegal tapping) on its pipelines. Quite often, these attacks have caused large leaks or ruptures and, in the worst case, full bore ruptures have been caused. Full bore ruptures lead to substantial oil spills, with some of them contaminating the water supply of nearby towns and cities and causing the pipeline to shutdown. Fast detection of such leaks or ruptures and immediate execution of optimised emergency response measures are indispensable preconditions for keeping the total oil spill quantities to a minimum. After such an incident, pipeline operation can only be resumed after having the pipeline repaired, which is often a several day challenge.

The segmentation study undertaken by Ecopetrol and ILF was between the pipeline's Toledo pumping station to its Oripaya pipeline station. This section of the pipeline runs as an 18 in. underground line through mainly mountainous areas. It crosses two major mountain peaks; one being around 2800 m high and the other approximately 1700 m high. Segmentation valves are installed along the pipeline in such a way that the potential oil spill quantities can be substantially limited by co-ordinated shutdown of pumping stations and isolation of the leak.

Due to the pronounced topography of the Caño Limón-Coveñas route in the Norte de Santander region, optimal emergency response measures vary from location to location. The investigated section between Toledo and Oripaya are divided into 15 subsections for individual emergency response, each with their own COESD procedures. These subsections are determined by the location of existing segmentation valves and by pronounced topographical features. As soon as the pipeline operator has detected and confirmed a leak or rupture and its location, the optimal emergency response for that situation and pipeline section is initiated and executed.

The segmentation study

Ecopetrol and ILF's segmentation study was executed between December 2015 and March 2016. The task included an initial 'as-built' review and evaluation report. Hydraulic calculations were performed to confirm the potential oil spill volume profile in the addressed section. The 'as-built' report was completed by site visits to different types of pipeline stations. The next major task was to develop and calibrate a hydraulic model (DNV GL SPS; formerly known as STONER® pipeline simulator) for the entire Caño Limón-Coveñas pipeline. The ultimate aim of the segmentation study was to elaborate, optimise, define and verify emergency response measures for the specific local conditions along the pipeline section.

The initial review of 'as-built' documentation included the pipeline itself and its stations, the redundant telecommunication network, as well as the local and remote control facilities (based on a supervisory control and data acquisition system). A key focus of this was the current placement and maintenance status of segmentation valves as their reliability is essential for when responding to emergency situations, such as leak isolation.

HCAs are pipeline sections where a potential oil spill would either release large volumes or where a leak of any size would have a severe impact on the population and environment.

As stated previously, using DNV GL SPS, a hydraulic model was developed for the Caño Limón-Coveñas pipeline for further internal use by Ecopetrol. The model was calibrated against real process snapshots. A calibrated hydraulic model can be used for various engineering tasks, 'what-if' analyses, forecast calculations, operator training and, as it has been used in the segmentation study, to verify the effectiveness of

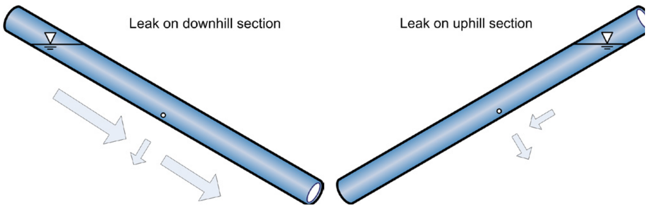

Figure 3. Typical leak scenarios on downhill and uphill sections when applying COESD procedures.

Table 1. An example of COESD procedures for one of the pipeline sections	
Step number	**Response action**
1	Initiate shutdown of all upstream pumping stations (Caño Limón, Banadia and Samoré) immediately.
2	Shut down the Toledo pumping station immediately.
3	Close SVS2 (Iscalá Norte) immediately.
3R*	Close SVS2 and SVS3 (Puerto Colombia) immediately.
4	Inform the Orú pumping station about the shutdown.
4R*	Initiate the shutdown and blocking of the Orú pumping station immediately - skip steps 5 and 6.
5	Open the trend display for pressure reading at Puerto Colombia and open the hydraulic display. Monitor both displays. The Orú pumping station should be kept in operation until either the pipe at the leak location is empty (when pressure reading at Puerto Colombia shows constant average value) or when column separation occurs at Alto de Morretones.
6	If one of the conditions in step 5 is met, close SVS4 (El Caney) and SVS3 (Puerto Colombia) before initiating shutdown and blocking of pumping station Orú (to be executed at Orú).
7	Close the Oripaya main line block valve.
* Steps 3R and 4R are to be used instead of steps 3 and 4 if a rupture occurs.	

emergency response actions by transient hydraulic simulation. Figure 1 is an example in which the total spill volume was reduced by approximately 80%, from around 300 m^3 (brown curve) down to approximately 60 m^3 (red curve) when following the defined COESD procedures. The blue and green curves show the leak volume flowrates in kilo barrels per day (1 kilo barrel per day = 6.625 m^3/hr) with and without applied COESD procedures.

As part of the segmentation study, individual COESD procedures were specified for all 15 subsections between Toledo and Oripaya. These were identified specifically with respect to emergency response to leaks and ruptures. Based on the findings of the 'as-built' review, recommendations for potential improvements and additional requirements for the implementation of the COESD procedures were highlighted.

COESD procedures

The primary idea behind the concept of COESD is to expedite the pressure reduction at the leak opening down to atmospheric pressure by co-ordinated measures both upstream and downstream of the leak. This, therefore, implies that it is not necessarily recommendable to shut down the entire pipeline and close all segmentation valves immediately after a leak has occurred.

Common to all leak and rupture incidents is the need to immediately shut down the pipeline upstream of the leak. This is done by shutting down pump stations and closing main line block valves (segmentation valves) to reduce and, finally, stop further flow towards the leak. All of the following response measures depend on the local conditions at the leak's location, such as topography and pressure, as well as whether it is a leak or a rupture.

While the most effective local response actions need to be investigated in detail, in general, it can be stated that:

- If a rupture occurs, the pipeline splits up into hydraulically independent parts upstream and downstream of the rupture. Since the pipeline cannot be operated any longer, the best emergency response in this case is to immediately shut down the pipeline upstream, which includes closure of the next available block valve upstream of the leak, and close the next available downstream block valve to prevent potential backflow from downstream. The leaking pipeline section is isolated.
- If a leak occurs on an uphill section, the pipeline should be shut down upstream. This involves closure of the next available block valve upstream of the leak, and closure of the next available downstream block valve to prevent backflow.
- If a leak occurs on a downhill or flat section, the next available block valve upstream of the leak should be shut down. Additionally, if possible, the pipeline should be kept running downstream to expedite pressure reduction at the leak location. This may be accomplished by keeping downstream pumping stations in operation until the leak runs dry or by draining the pipe into downstream tanks.

COESD procedures include these general response measures. However, the remaining specific response actions and mitigation measures have to be defined individually in relation to the pipeline system being addressed, as well as individually for each pipeline section. COESD procedures will also differ for leaks and ruptures. An example of this is given in Table 1.

The differentiation between a leak and a rupture is, on the one hand, related to the ratio of leak rate and normal operational flowrate in the pipeline. Typical definitions of ruptures mention 20% or more of normal throughput. On the other hand, in the case of a rupture, it is no longer possible to maintain substantial flow downstream of the rupture. More likely is backflow from downstream due to the initially pressurised pipeline. Figure 2 illustrates the two distinct situations. It is clearly visible from Figure 2 that, in a case of a rupture occurring, there is no longer any hydraulic coupling between the upstream and the downstream part of the pipeline. The emergency response measures on the upstream and downstream sides are, therefore, independent of each other. When a rupture occurs, it is best to reduce and eventually stop further flow towards the leak from either side as fast as possible.

The situation is different for leaks. When a leak occurs, there is substantial flow downstream of the leak and the pipeline is still operable. Shutdown upstream of the leak and closure of upstream valves reduces and finally stops further flow towards the location of the leak. Depending on the average slope around the location of the leak, the COESD procedures differ. On a flat or mainly downhill section, draining of the pipeline can be expedited by maintaining the downstream flow until the leak runs dry. Figure 1 shows such a situation. On uphill sections, it depends on the specific details of the pipeline system (such as elevation profile and the available facilities) as to whether there is further potential to expedite draining of the line after shutdown upstream. ILF has developed individual COESD procedures with quite different solutions for various important pipeline systems.

Summary

Fast leak or rupture detection, along with a co-ordinated emergency response, will most effectively reduce total spill quantity. This requires sensitive and reliable leak and rupture detection systems. Moreover, it is essential to reliably detect and locate a leak as fast as possible, particularly for ruptures.

COESD procedures provide valuable support for the operating personnel. They specify the sequence and chronology of the mitigation measures that should be executed. It is important to have defined leak and rupture response procedures in place to be followed by operators in control centres and by maintenance personnel. Emergencies are uneasy situations so having effective COESD procedures means that operators and maintenance teams should be relieved from difficult decisions.

If a huge sudden leak or full bore rupture occurs, there is no potential for optimising the leak response procedures. The COESD procedure for such situations is to shut down the pipeline and close the next available upstream and downstream valves as fast as possible to isolate the leaking pipeline section.

The COESD concept is most effective for reduce the total spill volume on flat and downhill sections, on which pressure reduction can be expedited by maintaining the downstream flow until the leak runs dry. On uphill slope sections, how to best respond to leaks depends on several factors and on the upstream and downstream facilities that are available.

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