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Application of Flow Modelling to Optimize Operational Cleaning of a Crude Oil Pipeline

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Abstract
One of the biggest challenges facing pipeline operators around the world is controlling pipeline corrosion since corrosion is a dominant causal factor associated with pipeline failures. It is now widely accepted within the oil & gas industry that operational pigging is a crucial measure for controlling internal corrosion in pipelines and hence maintaining pipeline integrity. This paper evaluates the use of flow modelling in optimizing pipeline operational pigging for internal corrosion prevention.

As an outcome of a Corrosion Management Plan developed by ROSEN for a crude oil pipeline operator, a flow modelling study was carried out to establish optimum flow conditions to prevent or minimize water separation and accumulation. Additionally, an assessment of effectiveness of cleaning activities, including cleaning tools (pigs) types and cleaning frequency required to maintain the integrity of the pipeline were evaluated. This involved performing sensitivity studies on cleaning frequency and pig design using the industry standard multiphase flow software OLGA with an aim of optimizing the cleaning strategy.

Based on results obtained through flow modelling, recommendations were made to the operator regarding the optimal cleaning frequency and pig configuration required to maintain sufficient cleanliness of the pipeline, control internal corrosion, whilst maintaining the highest production efficiency.

Keywords
modelling; pigging; optimization; corrosion

Introduction
Internal corrosion is one of the primary threats in upstream production and export pipelines. This is partly because the hydrocarbon fluids transported are usually unprocessed thus, contain some produced water. The presence of carbon dioxide (CO_2) in oilfield produced water is extremely corrosive to pipelines. Pipeline failure statistics identify internal corrosion as one of the main failure mechanisms. It is known to be a more difficult integrity threat to manage.
However, operational cleaning/pigging is an important tool to manage the threat of internal corrosion in pipelines. It is defined as pigging carried out at regular intervals on an in-service pipeline as part of an established maintenance routine, often prescribed for corrosion management and the need to maintain efficient pipeline throughput. This is achieved because the main objective of pigging is either the removal of any free water in the pipeline and/or to prevent the buildup of deposits under which certain corrosion mechanisms like under-deposit can develop. Pigging is also used to effectively apply corrosion inhibitors to the pipeline system.

Flow modelling can be used to identify locations of water drop-out and accumulation in pipelines. Pigging operations can also be simulated to evaluate the effectiveness of water removal in the pipeline based on the pig design properties.
Two-phase flow is generally complex due to the constant interaction of multiple variables involved. Complex flow regimes of oil and water phases can occur due to the constant interaction of forces between phases, such as buoyancy, turbulence, inertia and interfacial tension. These factors are further affected by pipeline design, topology, phase properties, phase quantities, process conditions and flow rates [1].
In upward inclined sections of hydrocarbon pipelines, oil phases are expected to travel faster than the water phase at low-flow velocities, due to their lower relative density. This results in the accumulation of water at the low points of the pipeline promoting internal corrosion, as shown in Fig. (1).

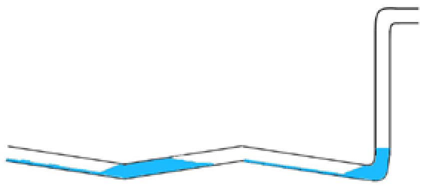

Figure 1. Water holdup in a two-phase pipeline.

Field Case Study

The following case study outlines an approach taken in a project to optimize the operational cleaning campaign for a client in the South America region as part of their corrosion management strategy (CMS) for the control of internal corrosion. The 32-inch 585 km pipeline was built in 1973, consisting of seven sections and transports crude oil from an onshore facility to a processing terminal. Although the operator followed an active cleaning program, active corrosion features of up to 35% wt. were detected at a few locations in the pipeline based on inline inspection results. Pumping stations along the pipeline also provided different crude blends to the pipeline system creating an additional challenge.

A flow modelling study was performed to support the ongoing development and implementation of a CMS [2], with the following objectives to:

- Establish the effect of the flow rate on the pipeline flow regime.
- Identify a flow rate-operating window that may be used to minimize and control pipeline internal corrosion.
- Understand the amount of water hold-up and identify its locations in the pipeline.
- Establish an optimized pig configuration and frequency to manage the water in the pipeline.

Methodology

Flow models representative of the 32-inch pipeline system were developed using the industry standard multiphase flow software, OLGA 2020. The thermodynamics software, Multiflash, was used to model the required thermodynamic properties of the different crude oil blends transported in the pipeline. Steady-state model benchmarking was carried out prior to carrying out the pigging operations. The steady-state analysis resulted in an acceptable pressure and temperature match against the client's current field operating conditions.

The findings from the flow study were broken down into the following sections (i) water accumulation analysis, (ii) pigging analysis and (iii) optimization of operational cleaning (pigging) strategy.

Flow Modelling

The complex dynamic interactions of a multiphase fluid flow are governed by conservation of mass, momentum, and energy, coupled with fundamental thermodynamics and heat transfer. A rigorous multiphase flow code can perform such calculations to provide key internal flow related parameters such as pressure and temperature profiles, flow regime, water hold-up, water condensation rates, water wetting, slugging propensity and frequency, wall shear stress etc.

In "difficult-to-pig" pipelines, the operator can use NACE Internal Corrosion Direct Assessment (ICDA) [3] to assure the integrity of the system. Flow modelling is a critical step in the identification of corrosion hot-spots, causal and contributing factors, and mitigation methods.

OLGA multiphase simulator is used to determine the relationship between flow parameters and how they affect corrosion mechanisms. It also comes equipped with the NORSOK, IFE Top of the Line Corrosion and de Waard 95 corrosion models [2], which are integrated within the flow codes. This is quite advantageous and time-saving, as corrosion rates get estimated for given in-situ flow conditions and parameters.

Flow analysis together with corrosion modelling represent a key pillar within a holistic approach to corrosion management [4], as shown in Fig. (2).

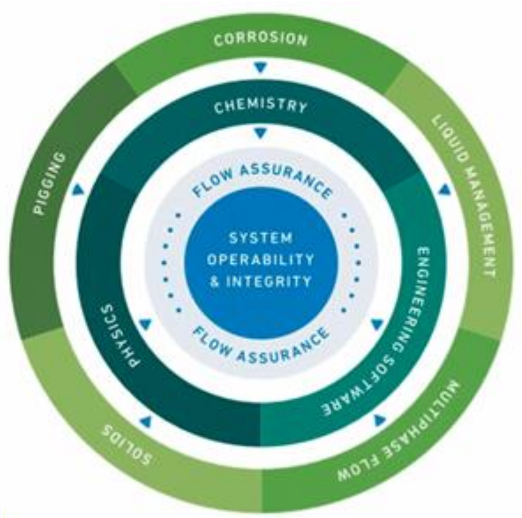

Figure 2. Relationship between Pipeline System Integrity, Flow Assurance and External Factors.

In this paper, the impact of flowrate on minimizing the water content was one of the main ideas explored therefore none of the corrosion modules within OLGA were activated. However, the Pigging module within OLGA was configured using pig properties based on ROSEN's intellectual property knowledge (tool friction factors). Different tool design configurations were also assessed to evaluate their pipeline cleaning effectiveness.

Results and Discussion

I. Water Accumulation Analysis

In crude oil pipelines, water starts to accumulate excessively when the operating flowrates drop below a critical flowrate. Sensitivity analyses were performed to understand the change in total water volume in the pipeline, as a function of the flowrates, as well as predicting the associated flow regime by the flow model, shown in Fig. (3) of the Appendix.

The steady-state analysis results presented in Fig. (3) showed that a substantial water drop-out occurs, when the flowrate falls below a threshold flowrate range of 1250-1500 m^3/h (0.6-0.8 m/s). As the pipeline's historical and future operating flowrates were well above the threshold flowrate range, it was concluded that the effect of flowrate increase on the reduction of pipeline water content was negligible.

A comparison of water holdup and inline inspection (ILI) corrosion features results for sections of the pipeline was performed, with the result for one section presented in Fig. (4) of the Appendix. The water holdup here is defined as the water volume per total liquid volume of the pipeline across its cross-section. The flow modelling results indicated that the pipeline was subject to a constant presence of a thin film of water along its entire length, i.e., culminating just below 0.73% water holdup, whilst the rest represented the fraction of the transported crude oil.

There were a few occurrences where the water fraction dropped to about 0.61% or increased to about 0.75-0.76%, but was deemed insignificant, when considering relatively uniform distribution of the internal corrosion damage along the pipeline bottom and the water holdup minima and maxima. Although, some correlation between the water fraction and the corrosion (distribution and severity) was evident. Fig. (4) showed that the peak fluctuations in water holdup coincided with the locations of the deepest corrosion features recorded during the inline inspection.

This observation, on one hand was a result of general complexity of fluid flow modelling, and on the other hand, a consequence of a multitude of random environmental factors, which influence initiation, dormancy, activation and propagation of active corrosion sites. For example, the smearing and/or accumulation of wax and sediment during ineffective operational cleaning may promote as well as disturb under-deposit corrosion and bacterial activity, displacement of loose corrosion scales or accumulation of debris in areas of localized corrosion in any given location.

II. Pigging Analysis

The operational cleaning had been carried out by the client twice per week subject to the crude oil being transported.

The client used two types of cleaning tools, as shown in Fig. (5). There were no other cleaning elements configured on the tool to provide a more aggressive level of cleaning. The separator tools were configured with four sealing discs and two guide discs, whilst the cleaner tool had two thin guide discs and two conical cups.

Figure 5. Separators (left) and Cleaners (right).

The client's tools were non-aggressive, which could reduce the effectiveness of removing water and deposits within the pipeline, adding to the potential of under-deposit corrosion. Cup designed tools like the ones currently used by the client tend to smear debris on the pipe wall by riding over it. They should only be used for light cleaning duties, an example is shown in Fig. (6), where debris can be seen to be left behind by the pig.

Figure 6. Example of a cleaning tool cups.

For the effective removal of debris, brushes are typically used to scrape the pipe wall free of debris. If the metallic debris is a concern, brush tools can typically be configured to include magnets to assist in the removal of magnetic particles, which often include corrosion products.

The operational limitations of the used cleaning tools were evident in the pigging flow simulations, see Fig. (7). The analysis showed that it only took about 1.2 days for the water content to build back to normal steady-state levels after a cleaning run using a tool design not fit for purpose.

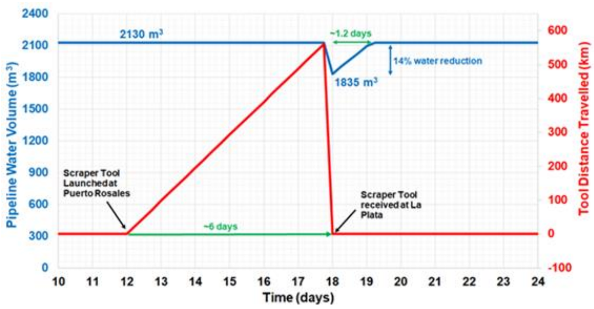

Figure 7. Simulation results of a single cleaning tool (current design).

III. Optimization of Pigging Strategy

Cleaning frequency optimization is typically performed based on a combination of historical debris returns, tool design, wax and water accumulation rate, downstream water handling capacity and operational constraints. The following criteria were considered to optimize the operational cleaning strategy for this asset:

Water Holdup:

- Increased operating flowrates lead to reduced water holdup in the pipelines and an improved flow regime (water dispersion). However, the use of flowrate to control the water volumes in the pipeline was limited.

Internal Corrosion:

- A lower total water content in the pipeline leads to reduced water wetting and thus, reduced potential for internal corrosion.
- Effective cleaning of the pipeline inner wall to remove debris, scales, wax and water film decreases the potential for internal corrosion.
- An increased cleaning frequency can minimize the water volume build-up, effectively clean the pipeline, and control and reduce the risk of internal corrosion.

Pigging Tool Design:

- A good tool design effectively means less cleaning runs are required to achieve the objective of minimizing internal corrosion.

Consequently, pigging flow simulations were performed using OLGA for the purposes of optimizing cleaning strategy by performing sensitivities on cleaning frequency and an improved pig tool design.

Fig. (8) shows a summary of results where it can be seen that at least six cleaning runs per week would be required to improve the total water content management, based on the current tool configuration. A 12-hour cleaning interval (14 cleaning runs per week) would result in a maximum improvement in total water content reduction of only 11%. However, it must be noted that there are other benefits of increased pigging frequency, apart from the removal of solids, i.e., reduced risk of under-deposit corrosion and microbiologically influenced corrosion.

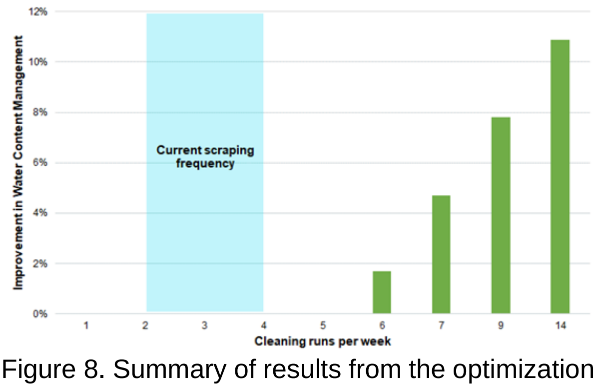

Figure 8. Summary of results from the optimization of operational cleaning strategy analysis.

Tool design is a key criterion for frequency optimization since an effective design means fewer cleaning runs. This is because if the pig tool's diameter is smaller than the pipeline's inner diameter, back leakage occurs between the tool and the pipeline wall (seal bypass). Essentially, the cleaning tool is highly likely to leave behind water and debris due to this seal bypass. Results from the conducted analysis are presented in Fig. (9), showing the effect of a cleaning tool with 0% seal against a tool with a 0.5% and 1% seal bypass. The results show that even a small seal leakage can lead to ineffective removal of the water film.

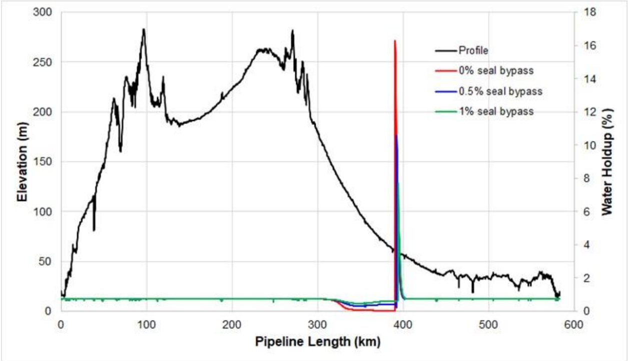

Figure 9. Effect of seal bypass on water film removal.

The tool with a 0.5% seal bypass can be seen to be more effective at reducing water film than the 1% seal bypass however, the 0% seal bypass tool is still the most effective in water film removal. Another key observation to note is that the pig tool reduces the water film to almost zero for approximately a 25-50 km section; however, the water build-up behind the tool replaces the water relatively quickly.

Conclusions

Operational pigging is an effective solution available to operators for managing internal corrosion in pipelines. In this paper, the use of flow modelling has been demonstrated to aid the process of optimizing the operational cleaning of a crude oil pipeline.

Based on the outcomes of the flow modelling study, it was recommended to the client to adopt a new cleaning tool design more effective in both water and debris removal and continue to maintain the original implemented cleaning strategy. As shown in Fig. (10), combining highly efficient sealing elements to brush tools, combined with magnets, will enable a single pass to be performed for effective cleaning and water removal.

Figure 10. ROSEN 32" Ultimate Brush/Magnet Tool recommended for the cleaning operation.

The client was advised to implement a systematic analysis of debris recovered, conduct several runs with the newly developed cleaning tool and evaluate the results to develop an initial schedule for the new operational cleaning strategy. Further optimization of cleaning frequency could be considered based on the results from debris analysis.

Flow modelling combined with corrosion analysis and pigging expertise provided a cost-effective method of determining the optimal cleaning frequency and pig configuration required to maintain sufficient cleanliness of a crude oil pipeline. An optimal operational cleaning program aids operators to control internal corrosion, whilst maintaining the highest production efficiency.

References

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Appendix

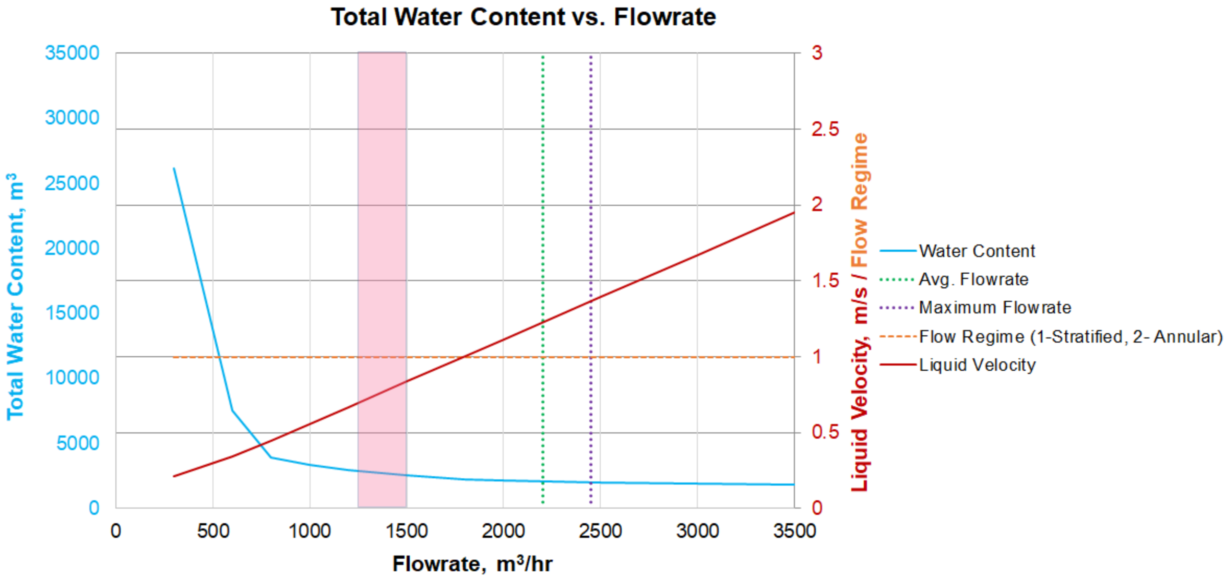

Figure 3. Total pipeline water content as a function of flowrate.

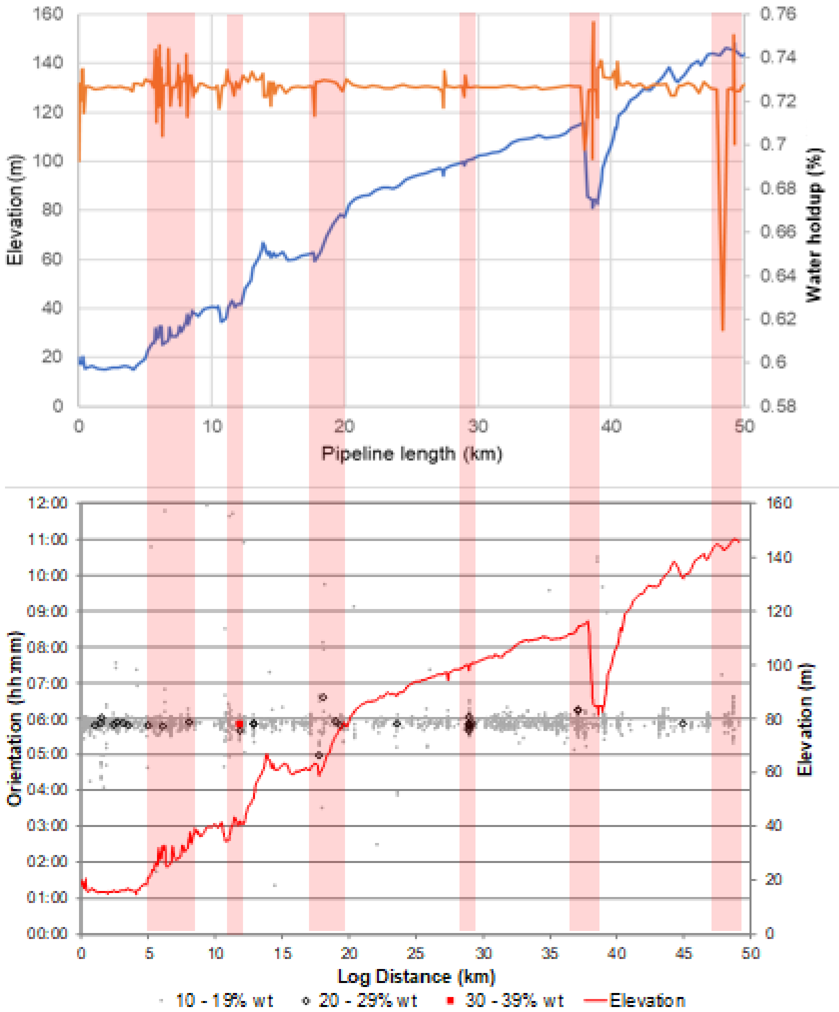

Figure 4. Comparison of ILI and Water Holdup Results.