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Flow Assurance for Optimization of Pigging Strategy for a Challenging Multiphase Deep-water Pipeline

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Abstract

There is an ever growing need amongst oil and gas operators to minimize costs, and maintain highest throughput and safety by minimizing unforeseen operational risks, production deferment or abrupt stoppages. Pipeline pigging is one of the integrity management options, often undertaken either to improve throughput efficiency or to ensure integrity of the pipeline. However, pigging is becoming ever more challenging with the development of deep-water assets, requiring use of exotic materials and increasingly demanding operating conditions. Interestingly enough, for many operators, pigging is often a non-routine operation, making it an unfamiliar task.

To address these challenges, ROSEN employs flow assurance combined with pigging feasibility studies in order to optimize pigging strategies. This integrated approach has shown significant benefit in quantifying risks, evaluating mitigation strategies to confirm piggability and optimizing the pigging campaigns.

In the current work we present a case study that illustrates how multiphase flow modelling was effectively employed to optimize a complex offshore “in-service” pigging operations. The industry standard OLGA multiphase flow simulator was used to model the pipeline and pigging operations which was successfully benchmarked against a historic bypass pig run. The validated flow models were used to revise the pigging operating envelope for the latest field conditions, to ensure successful cleaning whilst maximizing production throughput. The results of the latest successful field runs conducted based on the study recommendations made, will also be discussed.

Keywords
OLGA; Bypass pigging; Multiphase

Introduction

Pipeline pigging is an integral part of a pipeline asset integrity management program. This can include maintenance pigging as part of a corrosion management strategy, helping to minimize excessive liquids or debris hold up to improve operational capacity or to perform an in-line inspection (ILI) operation.

For any pigging operation, it is important to be clear about the ultimate objective before the right pigging equipment is selected (and configured) ahead of operational execution. Pipeline operators often address the complexities and challenges posed by ‘difficult-to-pig’ pipelines via performing a pigging feasibility study. This upfront review should consider the overall pigging project objectives, investigate the range of options available to demonstrate and predict the viability and cost of a chosen option. In addition to the obvious risks and practical challenges, such studies can be structured to address other potentially significant external factors as contributors to the full lifecycle costs of a pipeline.

Figure 1 (APPENDIX) shows the Piggability assessment process adopted by ROSEN. Depending on the outcome of such a study, a standard pig may prove to be adequate, but it is often necessary to implement a strategy and custom-build a tool that addresses any and all complexities of the pipeline system.

Flow assurance is an essential step in such assessments to ensure pipelines operational feasibility. Flow modelling can be used to estimate the amount of solid deposits (such as sand, wax) and liquid accumulation in the pipeline. Transient pigging analysis can be performed to assess the sufficiency of motive pressure, suitability of pig design and velocity tracking. Furthermore, sensitivity studies can be conducted to optimize pigging frequency and operating conditions.

The main objective of the paper is to discuss how ROSEN employs an integrated approach to optimizing the pigging strategy and campaigns by combining flow assurance with pigging feasibility studies. This will be demonstrated using a field case study where multiphase flow modelling was effectively employed to optimize a complex offshore “in-service” pigging operations. OLGA flow model representative of the subsea pipeline system was successfully benchmarked against a historic bypass pig run. The validated flow models were used to revise the pigging operating envelope for the latest field conditions, to ensure successful cleaning whilst maximizing production throughput. The results of the latest field runs conducted based on the study recommendations made, will also be discussed.

Case Study

The topic presented in this case study deals with our approach to optimization of pigging strategy for liquid management in a deep-water multiphase pipeline.

An operator in the Asia Pacific region owns a 80 km, 22-inch multiphase flowline system, located in up to 1,500m water depth. The subsea production wells are tied in to a Pipeline End Manifold (PLEM) and produces into the flowlines connected to a Topsides platform, as shown in Fig. (2). Flowline 1 is mainly used for the transport of production fluids to the topsides whilst Flowline 2 is used to supply recycled dehydrated gas from Topsides to Flowline 1, via a crossover at the PLEM, effectively creating a loop to maintain a minimum turndown flowrate (for the purpose of maintaining a low liquid inventory).

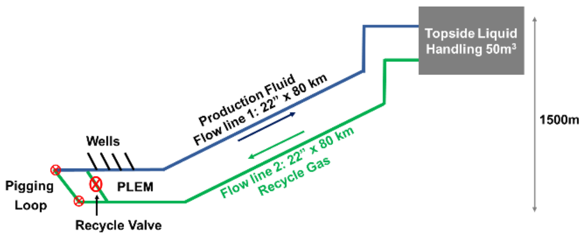

Figure 2: Schematic of the production system.

Phase I

During Early Life production in 2017, ROSEN was requested by the operator to assess the feasibility of conducting operational cleaning and ILI pigging whilst ensuring continuous production [1]. This complex production asset presented several challenges.

Pigging large quantities of liquid holdup (> 1,500 m^3) with a limited liquid handling capacity and drainage rate could overwhelm the Topsides. Production in deep-waters could pose a high hydrostatic head, insufficient motive pressure for pigging and a likelihood of wells backing out. The dual flowlines operated with different service fluids meant the pig had to be designed to handle different line velocities and flow regimes. Maintaining pig velocities within the production flowline is challenging as additional flow (production fluid) is introduced at PLEM after pig traverses from Flowline 2 into Flowline 1. This meant that the operator would have to monitor the pig and then switch off the recycle gas compressor at Topsides after pig traverses into Flowline 1 to avoid excessive flow and therefore pig velocity excursion. Developing an “on-line” pigging program presented significant risks considering the single source of production and importance of maintaining supply bearing in mind that this asset produces most of the client’s revenue.

ROSEN combined flow analysis along with pigging feasibility studies in order to successfully optimize pigging operations whilst maximizing throughput [1]. An optimized solution, which minimizes the generated liquid slug during pigging, was found by introducing a cleaning pig with a fixed 4% bypass port after sweeping the line with gas at high flowrates. The OLGA simulations were used to quantify the benefits of bypass pigging in minimizing liquid surge events [2]. Flow simulations showed that the bypass pig traversed slower than a standard pig, and with an extended liquid slug due to fluidization thus making the slug handling manageable at the Topsides facility, as shown in Fig. (3). Bypass pigging, in this case, was advantageous to maximize production flowrates during pigging operations.

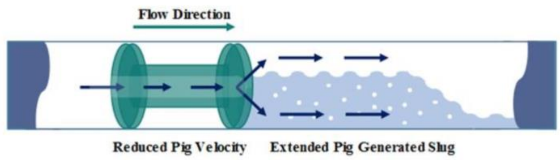

Figure 3: Working principle of Bypass Pig.

Phase II

In a follow up to Phase I, in 2021, ROSEN performed the flow analysis for the pigging operations planned during Mid Life production. This time, the operating pressure at the Topsides was reduced from 75 barg in Early Life to 33 barg during Mid Life operations. The study also included validation of the Phase-I OLGA model against the 4% bypass foam pig field run, which was successfully conducted in 2019; as based on the recommendations made in Phase I.

Model Validation

In 2019, the operator had performed a cleaning campaign using a 530 mm OD, 4% bypass foam pig. OLGA 2019.1 simulator with “OLGA HD” solver was used to perform the pigging analysis. The cleaning pigging cycle followed the following key operational steps per the Phase I study recommendations:

1. The production maximized to maximize liquid sweep by diverting flows from all wells to maintain 400 MMSCD in flowline 1. No recycle gas was used.
2. The production was gradually reduced from 400 MMscfd to 285 MMscfd with gradually introduction of the dry Recycle gas in flowline 2.
3. The gas sweep was then maintained for 2 days with 285 MMscfd production and around 225 MMscfd recycle gas.
4. The flowrates are reduced to 200 MMscfd in both flowlines. The 4% bypass foam pig is inserted in flowline 2 and propelled by the Recycle gas.
5. The recycle gas is then turned down to zero after the foam pig traversed the PLEM to control pig velocity. Pig is propelled back to the Topsides with the production fluid alone.

Figure 4 (APPENDIX) shows the pressure and flowrate trend data during pigging runs. Overall, both the foam pigs traversed the entire pipeline loop in around 24 hours, at an average pig velocity of 1.5 m/s. An average of 340 m^3 of pig generated liquid slug was removed, with no reported liquid surge at the Topsides.

The PLEM pressure was recorded as 141 bara while the recycle gas pressure was recorded as 125.6 bara during the two days of recycle gas sweeping. During the pigging operation, the PLEM and recycle gas pressures were recorded as 125 and 111.5 bara, respectively.

Figure 5 (APPENDIX) shows a trend plot of the pig velocity in the pipelines during these operations. The green line represents the pig velocity through the system, the black line represents the total distance travelled by the pig throughout the system and the blue line represents the liquid surge at the Topsides. The trend plot shows that after two days of the recycle gas sweeping operation the pig velocity in the recycle gas line was observed to be close to velocities of about 1.4-1.5 m/s. After the pig passed through the PLEM the velocity was observed to have started rising to velocities of about 3-4 m/s in flowline 1. The pig velocity increases due to the gas expansion at lower pressure towards the outlet of the flowline 1. No liquid surge was predicted.

The model validation exercise showed that predicted values were in accord (<1% difference) with the 2019 field pressure and pig velocity data.
The total pigging time predicted showed a difference of 8%, which was attributed to the fact that the Topsides choking was not modelled. This would then mean that the foam pig would arrive slightly faster in the simulations than expected during field operations; operator used Topsides choking to safely receive the pig.

The pig generated liquid slug obtained from OLGA was over predicted by 18% compared to the field data that was provided. The condensate (liquid) loading during 2019 was suspected to be lower than the value used in the 2017 analysis. The model was deemed satisfactory by the client to perform the pigging analysis.

Optimization of Pigging Strategy

During Mid-life operations, both flowlines are used simultaneously for production flow. The Topsides pressure will be maintained at 33 barg (when compared to 75 barg during Early Life) to maximize production flowrates and fluid velocities in the flowline. In order to reduce high liquid accumulation in the pipelines during low production flow in middle life operations, the mimimum gas flow in the pipeline needs to be maintained above 150 MMscfd.

The lower pressure at the Topsides during mid-life operations meant that the gas velocities could reach up to 17 m/s at the maximum allowable gas flowrate of 400 MMscfd. This is expected as significant gas expansion can occur when the gas transits from the high pressure PLEM (>150 barg) towards the outlet of the pipeline. Pig velocity control (amongst other complexities discussed in Phase I) and managing pig generated liquid slug posed the biggest challenges during Mid-life operations.

Pigging analysis was performed using OLGA multiphase flow simulator evaluating cleaning pigging with a fixed bypass port opening, after the flowlines are swept with recycle gas to minimize the liquid holdup. All scenarios considered three types of cleaning pigs: foam pig, brush pig and a brush pig with magnets, with up to 6% bypass port opening. Bypass pig calculations within OLGA was configured to take into account detailed pig-pipe wall pig 'static' and 'dynamic' frictional factors, based on the respective pig designs. For example, the lighter foam pig would experience a lower friction or pressure differential across the pig when compared to an aggressive and heavier brush pig with magnets. The overall evaluation also considered a pig frictional range which is generally the highest during the tool launch but reduces significantly during transit, especially towards the outlet of the pipeline.

After the pig passes the PLEM into the return leg (production line), in order to limit the pig velocity excursion, the simulations considered an additional scenario of isolating the Recycle line at the PLEM. During Phase I study, it was sufficient to isolate it only at the Topsides. This would limit the residual recycle gas flowing into the production line.

To ensure the safety of pigging operations, a 10% safety margin was applied on the allowable bypass pigging velocity range. Therefore, the optimised flowrates and corresponding bypass opening was required to meet an acceptable cleaning pig velocity range of 1.1-4.5 m/s.

Results and Discussion

Flow analysis of fixed bypass cleaning pigging was conducted to determine the ideal recycle gas sweep and production flowrates to determine the operational envelope. Figure 6 (APPENDIX) shows flow modelling results of the optimization exercise for the Mid-Life Operations.

OLGA simulations showed that the sweeping the line at 150 MMscfd for at least 6 hours was ideal to minimize the liquid content in the line from 1500 m^3 to 400 m^3. Due to stoppage of residual recycle gas from SSTB2 after the pig passes the PLEM, the production gas flowrate can to be maximized during cleaning without exceeding the pig velocity limits. Table 1 shows the optimised flowrates and corresponding bypass setting required to meet the new acceptable pig velocity range. As observed from the results, flow simulations showed that 160-250 MMscfd of production flow could be maintained throughout the sweeping and pigging operations.

Table 1. Optimized Production Flow and Bypass Opening

Pig type	Production Flowrate Range (MMscfd)	% Bypass Opening
Foam	160 - 250	4
Brush Magnet	175 - 250	2

In line with the latest recommendations made, the client successfully performed the Mid-life cleaning pigging operations in 2021.

Figure 7 show the before and after pictures of the 4% foam pig and the 2% brush pig runs supplied by ROSEN. Both the pigs were received in a relatively good condition with minor wear and tears on body. No deformation observed on the gauge plate.

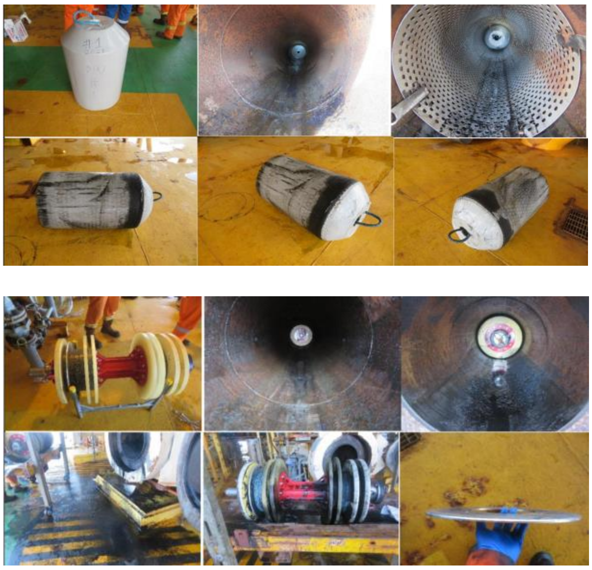

Figure 7. 2021 Mid-life pigging: Before and after pictures of the 4% Bypass Foam Pig (Top) and 2% Bypass Brush Pig (Bottom)

Conclusions

The success of the 2021 Mid-field cleaning pig runs demonstrated the reliability of OLGA simulator for multiphase flow and pigging analysis.
Pigging calculations needs to take into account detailed pig-pipe wall frictional factors, based on the respective pig designs.

Although full production could not be maintained due to the velocity in the production pipeline, following an extensive flow assurance and pigging feasibility analysis, an optimized “online” cleaning pigging program was recommended for liquid holdup removal and to ensure first pass success.

The benefit of performing the flow assurance study was a reliable and cost effective confirmation that an acceptable level of production could be maintained during execution of the proposed campaign. Flow assurance techniques combined with pigging knowledge allowed the client to pig the pipeline whilst still maintaining a level of production thus avoiding a costly shutdown.

References

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[2] Pinto, A; Voss, W; Lindner, H; Ladwa, R; *Multiphase Pipeline Operational Pigging, Flow Assurance Study Comparison To Real Operation And Model Validation - A Field Case Study*, Rio Pipeline, Brazil, 2017

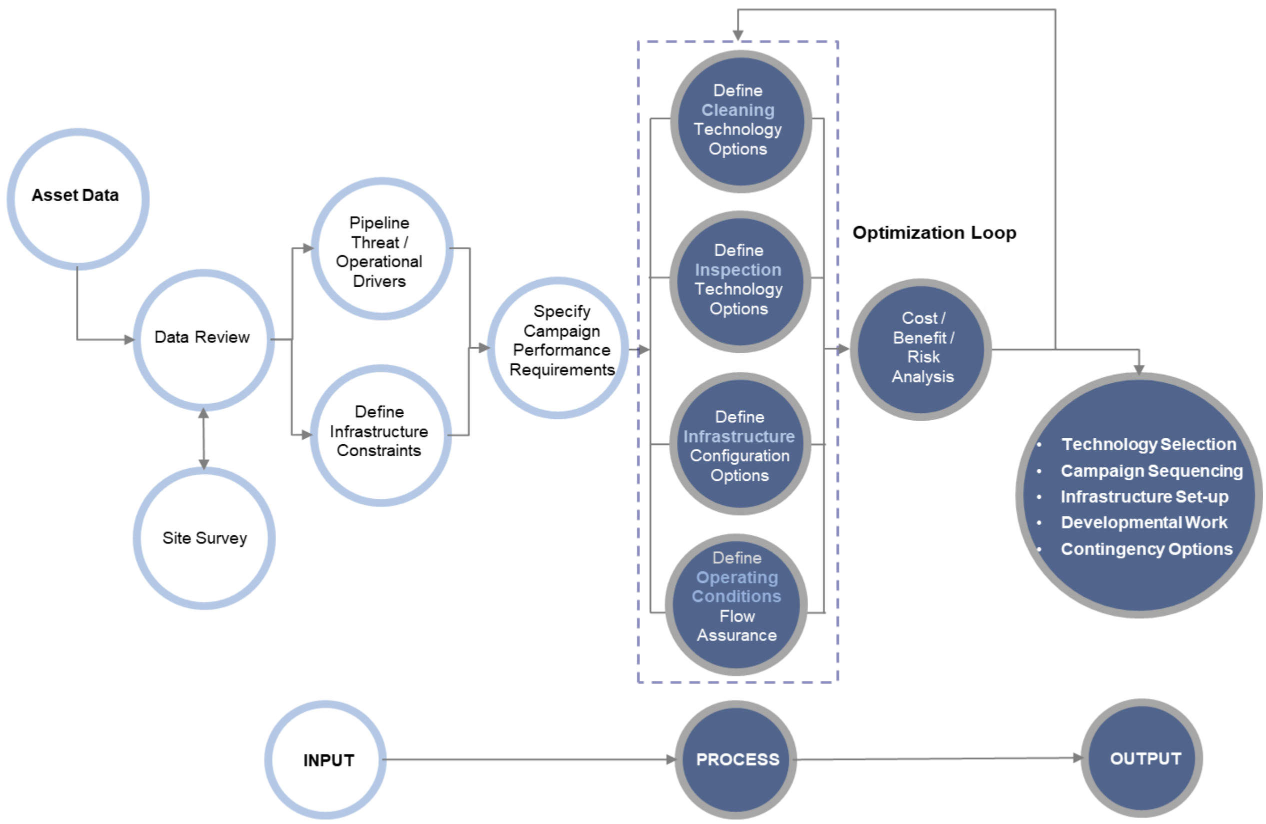

Figure 1. Piggability Assessment Process

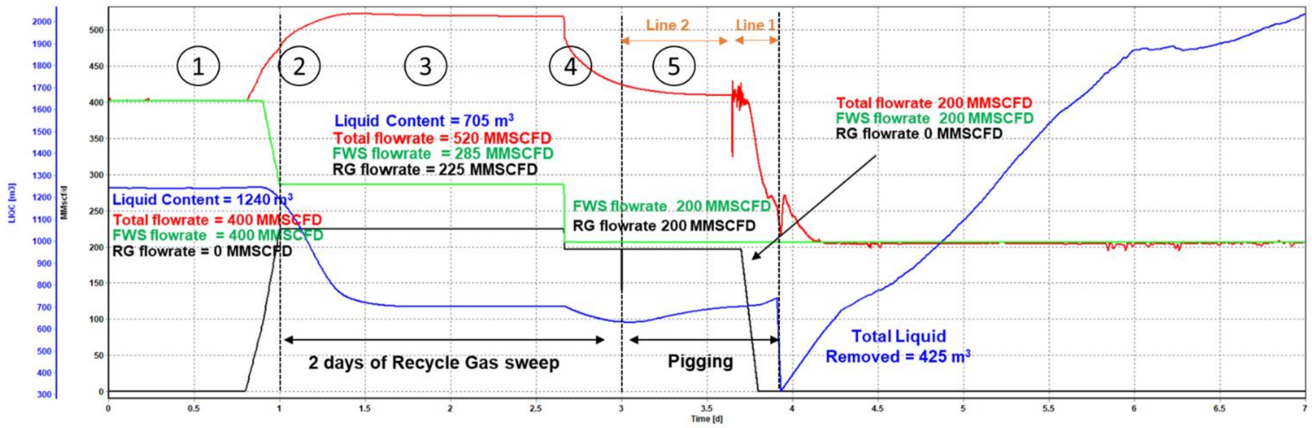

Figure 4. Early-Life 4% Bypass Foam Pig Run – OLGA Total Pipeline Liquid and Gas Flowrate Trending

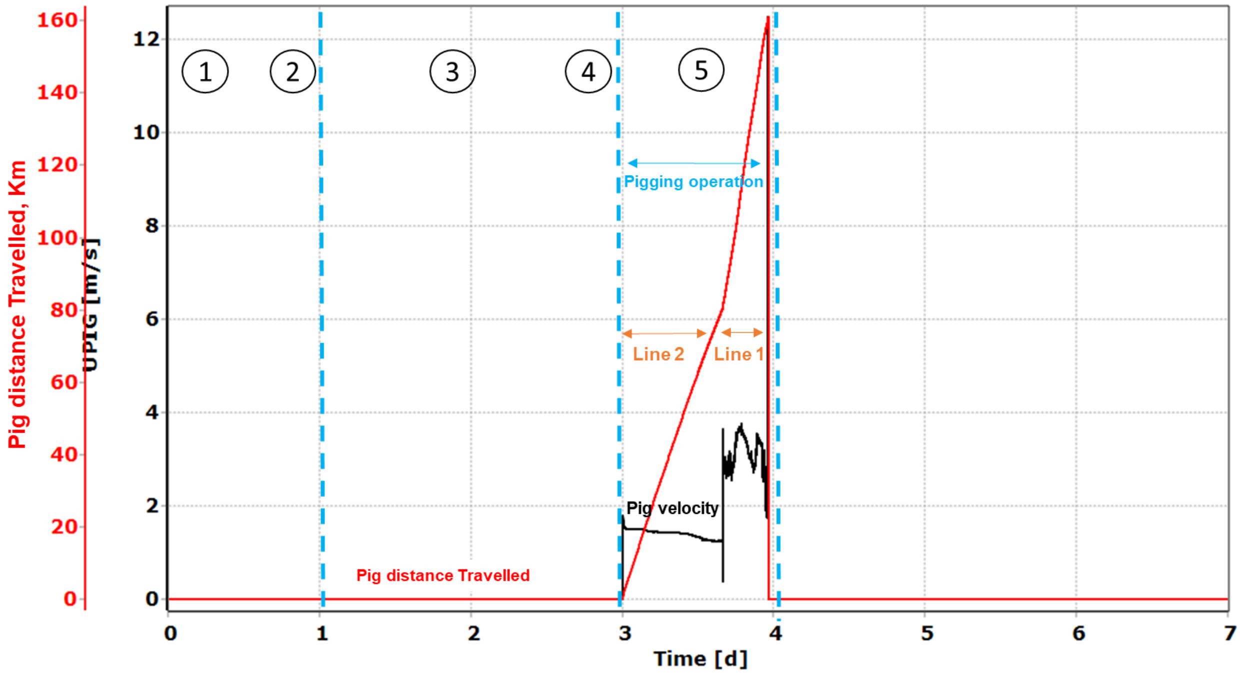

Figure 5. Early-Life 4% Bypass Foam Pig – OLGA Pig Velocity Results.

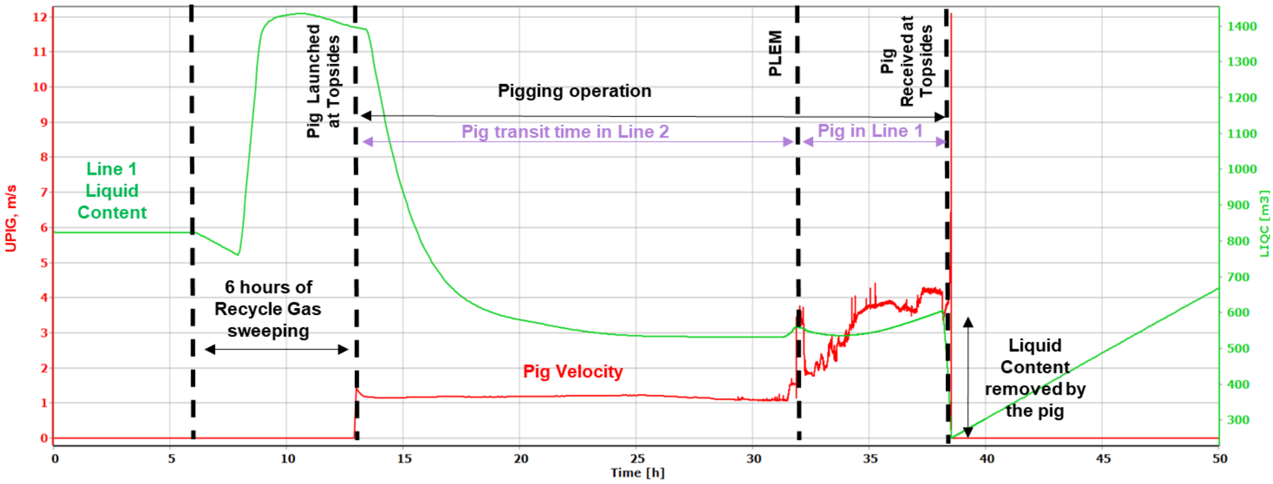

Figure 6. Mid-Life Optimized Pigging Scenario – 2% Bypass Brush Pig.