Pigging as a Flow Assurance Solution – Estimating Pigging Frequency for Dewaxing

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Pigging is used widely for removal of wax build-up on the internal wall of a pipeline. Much information is available on the prediction of wax deposition levels in such lines and pigs play an important role in the removal of this expected wax accumulation. Although these tools are generally much cheaper than chemicals for wax inhibition or suppression, there is very little guidance available for the selection of the correct pig, the sizing of bypass ports and the pigging frequency. Incorrect selection can be dangerous since a significant build-up of wax ahead of the pig can plug the pipeline. This can lead to extended downtime and an expensive pipeline repair. For subsea launching, extending the time between pigging is advantageous since this means that fewer interventions are required to load the subsea launcher. Correct selection of the pigging frequency is therefore very important. This paper aims to provide direction on this subject, using the output from wax prediction models and expected daily wax build-up in the pipeline. The method outline can be used to determine a pigging strategy for pipeline start-ups; pigging at low flow; cleaning normally unpigged lines; progressive cleaning of problem lines and regular pigging of lines with full information on wax deposition or merely an indication of wax percentage in the flow.

Introduction

The presence of paraffins in crude oil or condensate can lead to wax deposition on the walls of sub-sea pipelines as they cool, restricting the flow through the pipe. It is possible to simulate the wax build up using thermodynamic and kinetic/deposition models to make an estimate of the wax deposition, see Figure 1. Although this is useful in anticipating wax build-up levels, comparatively little work is available on how to combat wax build up using pipeline pigs. Some rules do exist; for example, launching pigs after 2mm (0.078") of wax builds up in the line or after 50 barrels of wax gathers. These rules-of-thumb are useful but their basis is in question and therefore may introduce a degree of uncertainty.

Incorrect pigging and pig programs are dangerous. Such programs can lead to the plugging of pipelines resulting in an expensive cutout and costly downtime. Longer well step outs and greater export distances have also added to the problem since the pigs need to push wax further and further.

In a pipeline where oil cools as it flows, wax transport by molecular diffusion starts when the pipe wall temperature reaches the wax appearance point. The precipitation of wax results in a concentration gradient between the dissolved wax in the turbulent core and the wax remaining in solution at the pipe wall. This causes dissolved wax to diffuse towards the pipe wall where it subsequently precipitates.

Small particles, such as wax crystals, suspended in a flowing fluid, tend to move with the mean speed and direction of the surrounding fluid. The shearing of the fluid close to the pipe wall also causes a movement of the particles towards the pipe wall. This is shear dispersion. Wax can build up and reduce the effective diameter of the pipeline. However, the flow of fluid through the line keeps the bore open, albeit at a reduced diameter and increased pumping costs. The resulting diameter for a given flow rate is known as the "Equilibrium Diameter", see Figure 2.

Direct mechanical cleaning or scraping using pigs is the most popular method of wax removal from the pipe wall and subsequent transportation of this wax down the pipeline. In general, it must be the aim of a regular pigging program to remove all the wax from the pipeline (wax management) rather than merely keeping the line open (bore management). Bore management is more suited to pigging of problem lines or lines that have been out of service for a period (using progressive cleaning), but even then the ultimate aim would be to completely remove the wax build-up.

The pigging operation can involve a significant quantity of wax. A 1mm (0.039") of wax deposited over 20km (12.5 miles) of a 20" pipeline equates to a volume of 31m^3 (1094 ft^3) of wax (a solid plug of 157m or 515 ft!). For reasons given below, the operator must avoid such a solid plug at all costs, and so judicious selection of pigging frequency and bypass size is required for all such operations. The correct level of bypass flow through the pig can avoid such a wax build up.

The Risk of Plugging

When wax builds up downstream of a pig it can lead to the blocking of the pipeline. The pig and wax plug can withstand very high differential pressures without moving. Production then stops. The mechanism by which this occurs is as follows: -

- The pigs scrape off wax from the pipe wall using guide discs or seals. The wax can be soft or harder wax;
- Wax gathers in front of the pig and the pig applies a force to the rear of the wax build-up;
- Due to a pressure gradient over the wax accumulation, the oil is squeezed out of the wax directly in front of the pig and it hardens;
- Due to the harder wax and the build up of a critical volume of wax ahead of the pig, the friction required to move the plug is too great for the pressure available and the pipeline blocks.

There are many examples of this occurring, especially in smaller diameter lines (for example 10", 12" and even 16"). In order to avoid such a solid plug, bypass is required through the pig along with a regular pigging regime. The frequency of pigging is important, as is the volume flow of bypass through the pig with respect to the expected volume of wax accumulation in the line. If the bypass is too low, then the wax build up can still overwhelm the pig, cutting off the bypass and again leading to a stuck pig. One other conclusion from this is that the use of pressure relief valves on pigs (Pressure Bypass Pigs) to "blow" the wax away when the pig is stuck, do not always work. This is since the differential pressure acts over the wax plug as a whole, not just over the pig. Hence, the relief valves do not pop. It is necessary to have fixed bypass through the pig.

The graph in Figure 3 shows the expected theoretical differential pressure required to push a volume of wax down different diameter pipelines. This shows that in the smaller diameter lines the risk of plugging is very high as the differential pressure required to push a solid plug of wax is very high. For example, it could take 100bars (1450 psi) to move a wax plug in a 12” line! In intermediate line sizes, the risk of plugging reduces. Without bypass however, large fluctuations in line pressure can result as the pig struggles to transport the wax along the line. In larger diameter lines, the risk of plugging is much less. This is due to the larger forces due to pressure. One unit of pressure in a 30” line results in a much larger force compared to a 10” line for instance.

The main problem for large diameter lines is receiving the wax plug and pig at the receiver. There are normally filters and strainers at the receiving facility. These may block if subjected to a large wax build up. The pressure then increases and the high pressure may trip out the line. For this reason, wax handling at the receiver station is the main perceived problem for larger diameter pipelines.

On receipt of such a pig and plug, the line may shut down and this causes additional disruption. Sometimes the line is down for several days or even weeks while technicians deal with the wax candle. The wax arrival results in an increase in line pressure, requiring shutdown of the inlet valve and line closure, see Figure 4. Again, a regular bypass pigging program can help avoid this scenario.

Bypass Pig Model

Based on the above information, the model used to estimate the pig frequency and bypass size utilises the “Continuity Principle”. This states simply that: -

> *“In order to avoid a solid build of wax ahead of the pig, then the rate of bypass through the pig should be greater than the rate of build-up of wax in front of the pig”*

Figure 5 shows this diagrammatically. The bypass rate should be such that it can carry away any wax build-up faster than the wax is arriving at the front of the pig. If this is not the case, then a wax plug can occur. Using this rule and the information known from the wax deposition model it is possible to design a pig (in terms of bypass) and estimate pigging frequency such that a wax plug will not build up and block the line. This simple model is presented in Appendix A.

The model assumes that the pig is fully efficient, i.e. that the pig can be designed to remove all the wax from the pipeline wall. This is not unreasonable in softer wax systems, but even with harder wax, a good heavy-duty bidirectional pig can be used to remove all wax from the pipeline wall.

Bypass is the mechanism by which a wax plug is avoided. However, sensible limits on the bypass should be used since too much bypass through the pig can result in the pig stalling in the line. Therefore, some guidance for bypass size and minimum product flow rate should be examined. Used correctly, this method can be used to determine a pigging strategy for pipeline start up; lines with low flow; normally unpigged lines; progressive cleaning of problem lines and regular pigging of lines with full information on wax deposition or just an indication of the wax percentage in the flow.

Additional Constraints

The continuity principle allows estimation of the pig bypass design and pigging frequency. However, this section indicates a number of additional practical aspects: -

- Some operators only allow one pig to be present in the pipeline at a time. Given that bypass slows the pig down and wax continues to deposit after the pig has passed, then this will have a bearing on the pig, bypass design and pigging frequency;

- The model provides an initial starting point or initial pigging strategy for a new pipeline. As the operator gains more and more experience in pigging the line, then this strategy may change and the pig may alter. For this reason, it is advantageous to have spares and alternative pig configurations available for initial pigging of a pipeline;

- Dual diameter lines are, as ever, a special. In a dual diameter waxy line, the pig may not scrape as efficiently in the larger diameter and so the pig will not remove 100% of the wax. This situation is currently being addressed and ideas are being evaluated but at present, this is the case. There are guidelines available on efficiency but the wax remaining in the line from each pig run must then be added back into the continuity model;

- If the velocity of the pipeline changes for any reason, then the effect of this must be taken into account. For example if the pipeline flow increases, then the percentage flow bypass will decrease for a given pig design. If there is a flow reduction, a seasonal turndown for instance, then the pig could stall in the line as all the flow bypasses the pig. If the line is shut in for any reason, then there may be problems on restart. These aspects must be taken into account in any pigging strategy;

- Finally, the pig bypass can change because of pig frictional changes. For instance, pig wear can reduce differential pressure and so reduce bypass. This can be taken into account in the model in the same way as increased friction in thicker walled pipe sections can be taken into account.

The following case study demonstrates a typical example for estimating pig bypass design and pigging frequency.

Case Study, 10” Line with 3mm wax per day build-up

This case study is based on a 10” deep-water pipeline, 155km (96.8 miles) long in the Gulf of Mexico. The line transports waxy crude from platform to shore and has launching and receiving facilities at either end. The oil flows at a rate of 146m^3/hr (22,000bbls/day). The line is not yet in operation, but a detailed initial pigging strategy is required.

Due to rapid heat loss down the riser, the oil temperature rapidly cools below the wax appearance temperature and wax is soon deposited on the wall. It is estimated from analysis of the oil and thermodynamic/kinetic modelling that the maximum wax build up will be 3mm (0.118”) per day. The output curves are shown in Figure 6.

The operators of the line request that only one dewaxing pig is present in the line at a time. Additionally, to avoid excessive pressure drop in the line, it is requested that the increase in line head loss be limited to 1.5bars additional (21.75psi). This is based on calculations only as the line is not yet in operation.

Figure 7 shows the predicted pressure loss against number of days since pigging. This assumes that the pig is fully efficient and returns the line to the initial clean state after pigging. The graph shows that the pressure drop over the line could increase by 1.5 bar (21.75 psi) after only 4.8 days. Figure 8 shows the continuity condition calculation in graphical form. This indicates that with 1% bypass by area through the pig, the pig will take approximately 2.5 days to negotiate the line. If the bypass is lower than about 0.8% by area, then the interval between pigging required (continuity condition) is less than the time required to pig the line and so more than one pig would be needed in the line at once. Based on Figure 8, a pigging interval between 3.1 days using 1% bypass by area and 4 days using 1.25% bypass by area could be selected (i.e. launching a pig soon after the receipt of the last pig).

The calculation is conservative since 3 mm (0.118”) of wax are only deposited over a small percentage of the 155km (96.8miles). This is justified however, as the plug could build up over this short length and cut off the bypass if the bypass was insufficient. Once some knowledge of the system is gained in operation, then this condition could be relaxed slightly to speed up pigging.

The pig used will be a standard bi-directional pig with bypass ports to allow the 1% to be achieved. It is useful to provide pluggable bypass in steps of say 0.25% by area up to say 2% by area. This allows different bypass sizes to be selected in the same pigs by opening and closing bypass ports. Another aspect that is general believed to be useful is to provide additional drive discs and spacers to allow the pig configuration to be altered for the initial pigging of the line.

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Appendix A, Bypass Model

The bypass model is used to determine the required pigging frequency. It is assumed that without bypass, the line will become plugged at worst or a large solid volume of wax will arrive at the receiving facilities at least. Other constraints on the operation of the line are used in conjunction with this model to allow the final pigging frequency to be determined: -

The bypass flow through the pig is determined by: -

$$Q_{bypass} = C_d \sqrt{\frac{2\,\Delta P}{\rho}}\, A_{bypass} \qquad \text{...Equation 1}$$

The rate at which wax approaches the pig at the area of maximum wax deposit is given by: -

$$Q_{wax} = N\, v_p\, \pi\, d\, t_{wax,daily} \qquad \text{...Equation 2}$$

In order that a wax plug does not build up in front of the pig, the rate of bypass (Equation 1) must be greater than the rate at which wax approaches the pig (Equation 2). This is known as the Continuity Criteria and is demonstrated in Figure 5: -

$$Q_{bypass} > Q_{wax} \qquad \text{...Equation 3}$$

Rearranging Equation 3 yields a pigging frequency in days, *N*, (or number of days between pig launches) based on this continuity criteria: -

$$N < \frac{C_d \sqrt{\frac{2\,\Delta P}{\rho}}\, A_{bypass}}{v_p\, \pi\, d\, t_{wax,daily}} \qquad \text{...Equation 4}$$

Where: -

N	Number of days between pig runs;
C_d	Discharge Coefficient (Typically 0.7);
ΔP	Pig Differential Pressure;
ρ	Oil density;
A_{bypass}	Bypass area;
v_p	Pig Velocity;
d	Pipeline Internal Diameter;
$t_{wax,daily}$	Maximum daily wax deposit

Figure 1, Typical Wax Deposition Curves

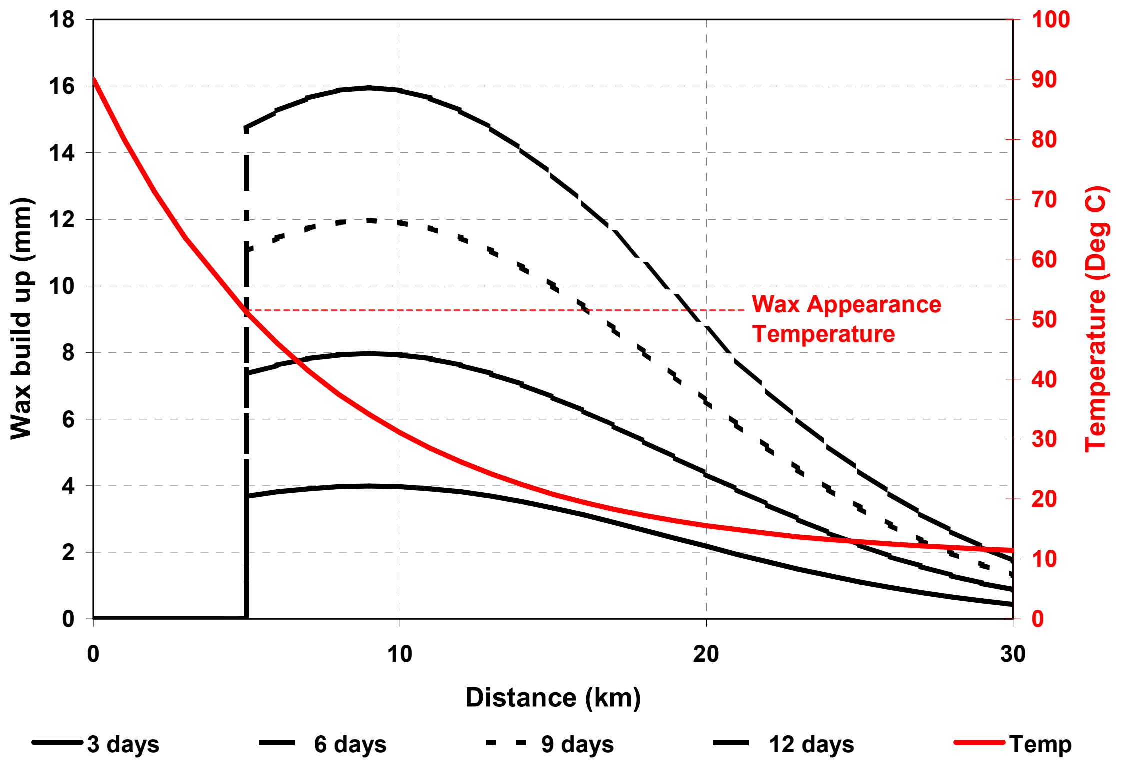


Figure 2, Wax Equilibrium Diameter

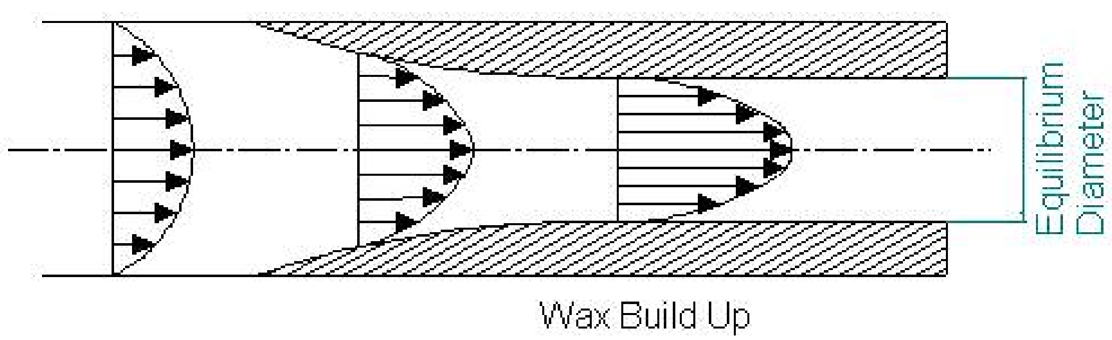


Figure 3, Effect of Line Diameter

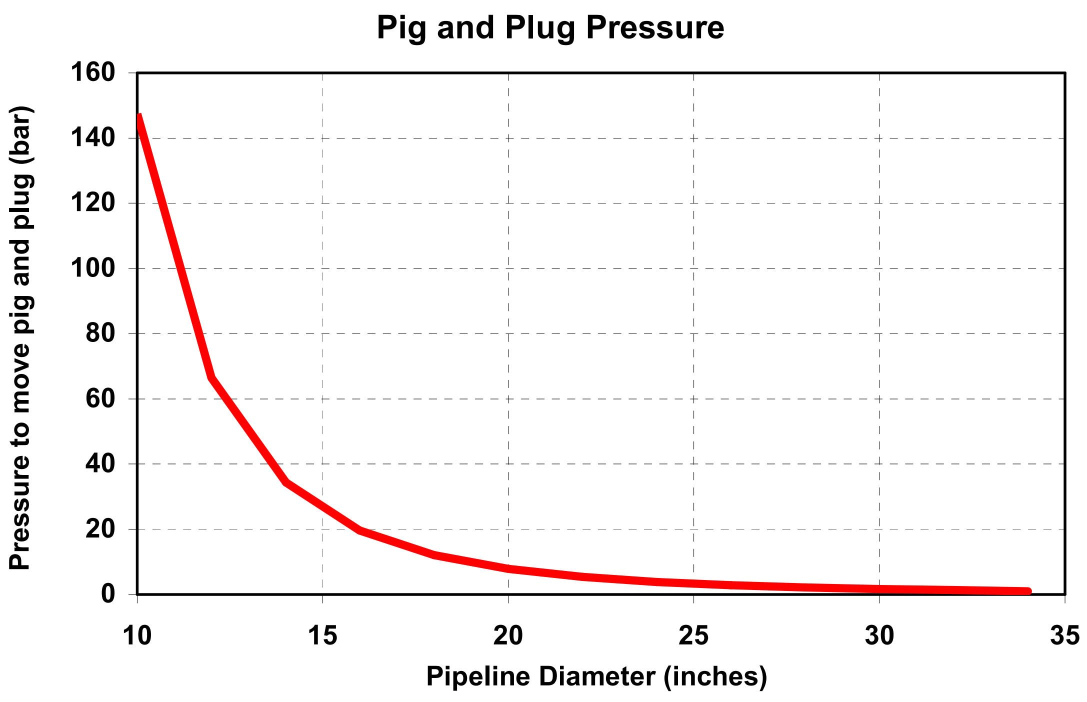
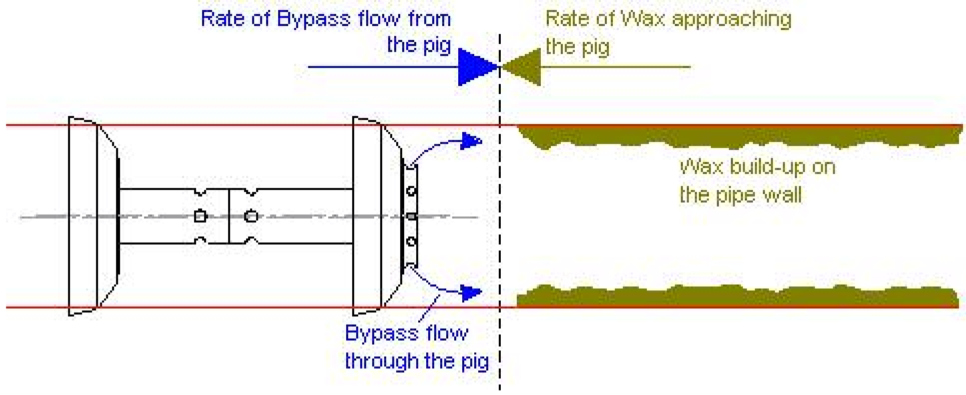


Figure 4, Receipt of Wax Accumulation (Courtesy of Statoil)

Figure 5, Continuity Principle



To avoid a wax accumulation ahead of the pig, then the rate of bypass flow from the pig must be greater than the rate of wax approaching the pig.

Figure 6, Case Study – Wax Deposition Curves

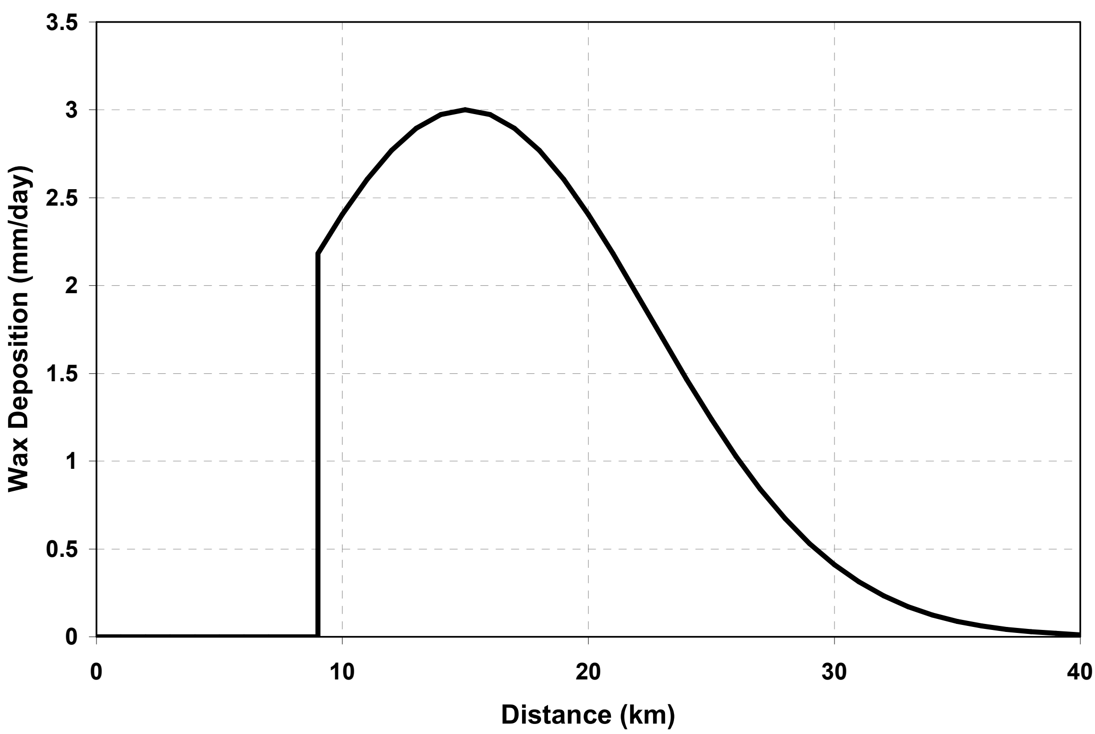


Figure 7, Case Study – Increase in Pipeline Pressure Drop against Time

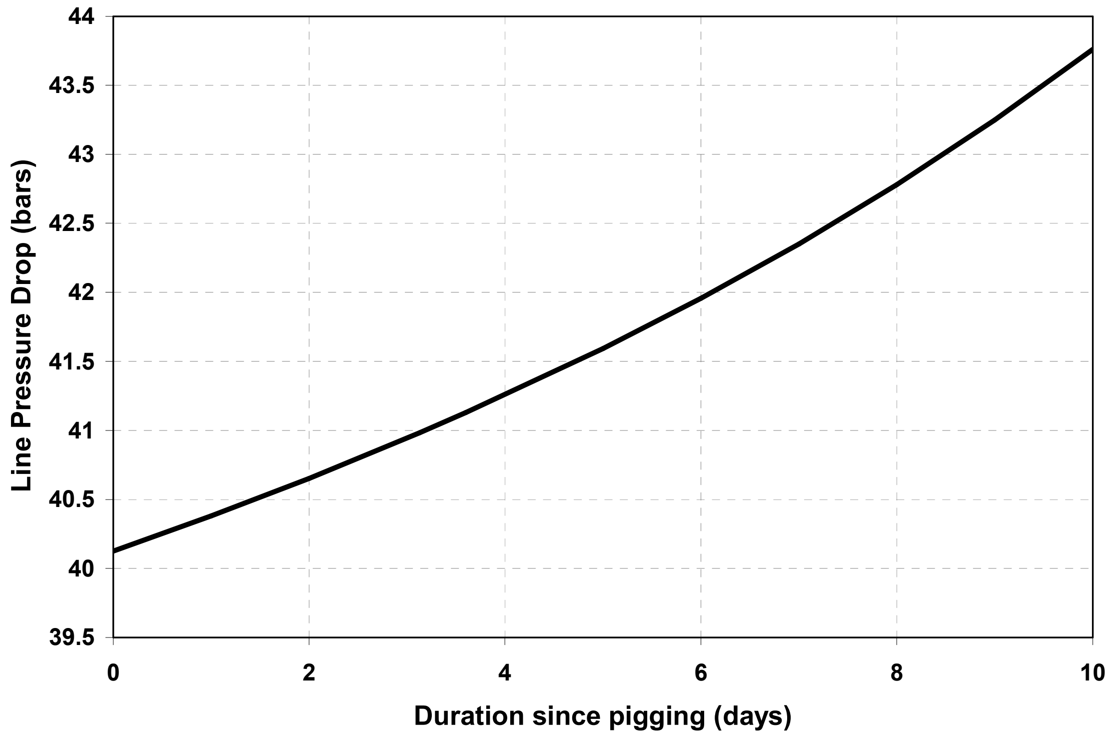


Figure 8, Case Study – Continuity Considerations