Pipeline Flooding, Dewatering and Venting

Dr Aidan O'Donoghue, Pipeline Research Limited, Glasgow, Scotland

Abstract

Flooding, cleaning, gauging, dewatering and venting of offshore oil and gas pipelines during pre-commissioning involves pipeline pigging and expensive deployment vessel time. To aid in the planning of such operations, a number of analyses can be undertaken to determine the duration to perform each of these tasks. The mathematical models can also optimise the equipment required (hoses, pumps, compressors). Problems that could be encountered without a clear knowledge of how the operation will proceed can be avoided. The operation can be monitored by comparing recorded and predicted values, for example inlet pressure. This paper provides an overview of work performed to establish pig velocity, inlet pressure and pigging duration during various pre-commissioning tasks.

Introduction

Once a pipeline has been constructed, a number of tasks are generally undertaken for pre-commissioning and commissioning of the pipeline. These include: -

- Flooding with water in preparation for the hydrotest;
- Cleaning and gauging the line to remove construction debris and prove that the line is within diameter tolerance and that no damage or buckling occurred during construction;
- Hydrotest to establish the integrity of the pipeline;
- Dewatering the pipeline after the successful hydrotest. Given that water can potentially lead to corrosion or hydrates, this task is very critical and must be performed efficiently;
- Venting to a given pressure;
- Nitrogen filling or air purging;
- Gas or oil filling.

Failure to perform one of these pre-commissioning tasks correctly may lead to problems later. For example, gas ingress into the water during flooding may make hydro testing difficult; inefficient dewatering of the pipeline may lead to hydrate formation in gas lines or corrosion problems during production.

The tasks also take time to perform under difficult conditions. Vessel time is expensive and a delay in a given task may lead to costly overruns. It is necessary to have a model to make predictions for the operations to be optimised. The model output can be used to monitor the operation and to establish that it is proceeding as planned. Some aspects of this are discussed below and illustrated with an analysis case.

Analysis Case

To illustrate the aspects under discussion in this paper, an analysis case is taken. A 20” subsea pipeline is considered during pre-commissioning for use as a gas export line. The line is shown in outline in Figure 1 below.

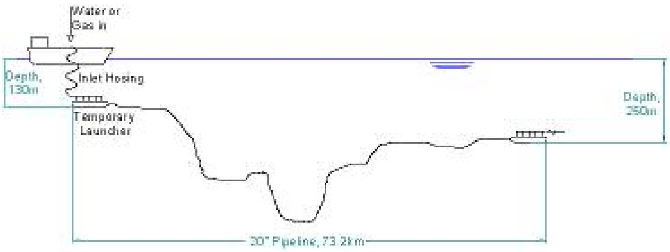

Fig. 1 – Schematic of field layout

The line consists of a temporary 20” multi-pig launcher. This has the capacity to hold 5 pigs for each pigging task (flooding and dewatering). The 20” pipeline begins at a water depth of 130m, falling to a maximum depth of 350m, with a temporary receiving head at 73.2 km. The water depth at the receiver is 250m complete with a non-return valve. The detailed pipeline topology is shown in Figure 2: -

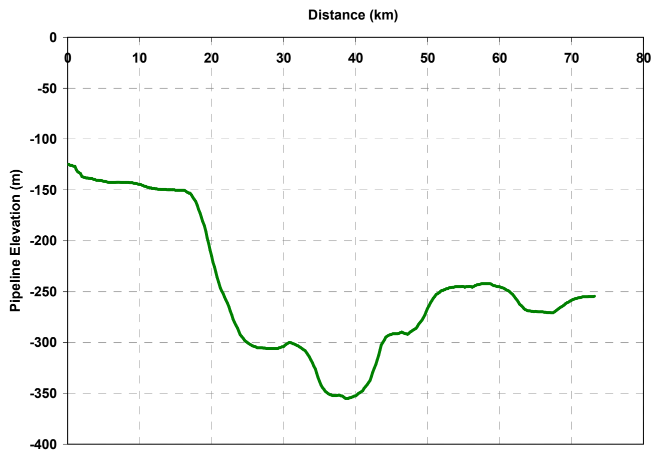

Fig. 2 – Detailed description of pipeline elevation

The pre-commissioning tasks for the pipeline are as follows: -

- Flood the line with water in readiness for the hydro-test;
- Perform the hydro test;
- Dewater the line using a glycol pig train;
- Vent the line to atmosphere.

Pigging is required for the line flooding (using a 5-pig train) and for the line dewatering. The line is initially air filled and there is a concern that during flooding the pig train will accelerate on the downward slope due to the head of filtered seawater behind the pig and the air downstream. One calculation that is performed is to investigate the speed of the pig train in this section. If the pig velocity is allowed to increase to an unacceptable level, this can reduce the efficiency of the flooding operation and possibly cause damage to the pig in the flooding train.

Once the line is flooded, it is hydro tested and leak tested if required. When this is complete, it is necessary to get the line ready for gas filling. The dewatering train is similar to the flooding train, except it consists of 5 pigs separated by MEG (Mono Ethylene Gylcol) slugs. The pig train is then propelled using dry compressed air. The following aspects require to be investigated: -

- The required length of the MEG slugs in order to provide a minimum water content in the pipeline after the pig train has been run;
- The required inlet air pressure to the riser hosing. The inlet hose size is not fixed and can be optimised. A large diameter hose will not choke but is costly. A smaller diameter hose could cause the flow to choke but is cheaper;
- The pig train velocity and time taken to dewater the system. This affects the time that the vessel must wait at the launching location and therefore the cost of vessel deployment for this operation;
- The possibility of shutting down the compressors early. The line elevation rises up again from the deepest section at 350m. It may be possible to switch off the compressors and still allow the pig train to be received. This is due to excess pressure in the system at the end of the line. Again, vessel deployment can be optimised.

This paper presents an analysis of this system and provides output that can be used to optimise the pre-commissioning operation.

Line Flooding with Pigs

The line is flooded using a four pig train separated by filtered seawater. The pig train and slugs purge the air from the system and avoid air ingressing to the hydrotest water upstream. Leakage occurring can affect the time required to perform the hydrotest or in extreme cases could require re-flooding.

The flooding train has water upstream and air downstream. This can lead to very high accelerations in steep downward slopes (such as risers) as illustrated in the following figure: -

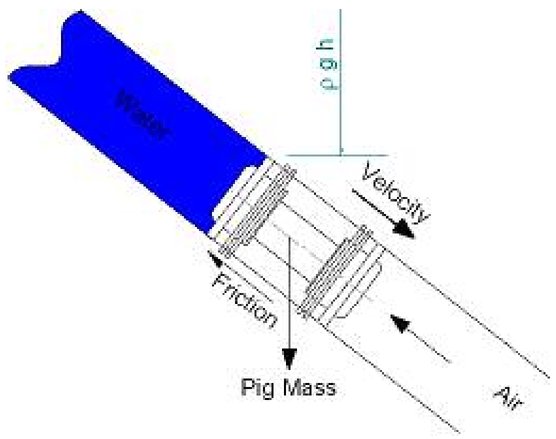

Fig. 3 – Force imbalance leads to high velocities

The pressure immediately behind the pig increases due to the head of water. The pig friction cannot hold this pressure back (especially at larger diameters) and therefore the pig accelerates to high velocities. It is necessary for the air pressure to increase in front of the pig and this can only occur if the pig accelerates. Additionally, the pig train pulls a vacuum behind the pig and at the pump.

High accelerations can lead to reverse leakage of gas back into the water. This is undesirable as it can adversely affect hydrotest. It is necessary to slow the train down as much as possible. If it is not possible to pack the line with air pressure, an alternative is to pump a volume of water ahead of the pig. This slows the train as the air pressure downstream can react quicker to changes in velocity and it becomes necessary to accelerate this mass of water. The pig motion can be dampened and controlled using this method.

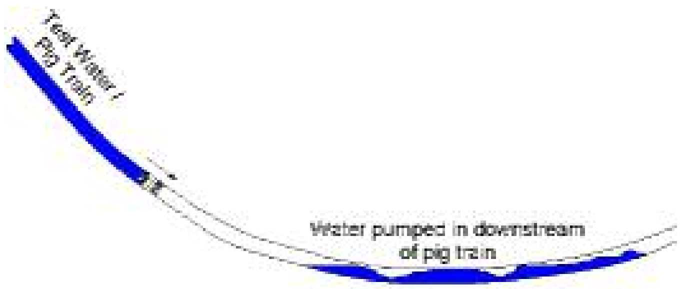

Fig. 4 – Water pumped in ahead of the pig train to dampen motion

The quantity of water required depends on the terrain and the pipeline diameter amongst other things. A model of the two-phase flow ahead of the pig has been established to help determine this quantity. This is the first 2-phase model attempted at Pipeline Research Limited and has provided encouraging results. Figure 5 shows the output for no injected water; 400m^3 and 800m^3: -

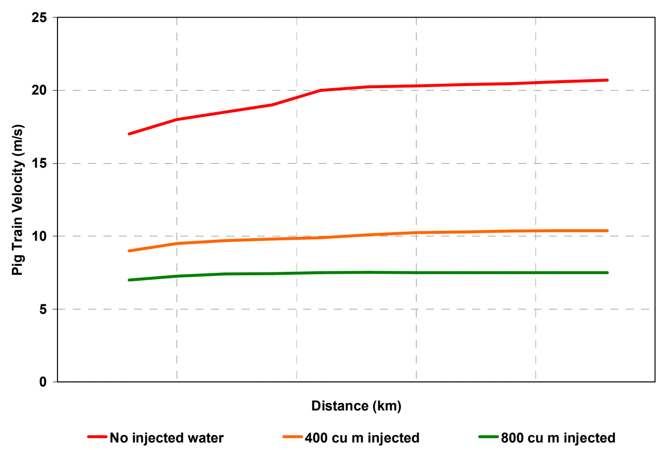

Fig. 5 – Effect of injected water volume on pig train velocity

A decision could then be taken on the volume of liquid to be pumped in ahead of the pig train. In this example, the 400m^3 case would be a good compromise between velocity and volume pumped.

One aspect that needs to be taken into account if this approach is to be adopted, is the possibility of additive heads (air lock), especially in hilly terrain. This may cause problems with pumping later in the process.

Pipeline Dewatering using Pigs

Once the line has been flooded and successfully hydro tested, the dewatering pig train is run. The pipeline and pre-commissioning specification states that the line must contain no more than 4% water at the end of the dewatering operation. This enables the export of sales quality gas via a local tie-in at the end of the section shown above.

Sizing the Glycol Slugs

The proposed pig train is shown in Figure 6. This consists of 5 pigs. The first three slugs in the train are MEG slugs. The length of these slugs needs to be determined. The final slug is compressed air or nitrogen and provides a final mop-up of glycol in the line, removing glycol spillage from offtakes and tees.

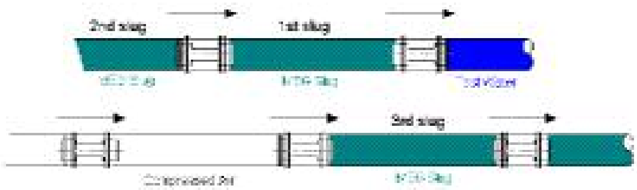

Fig. 6 – Overview of Pig Train

A common method for estimating the total volume of glycol required in the pig slug is to use the following formula:

$$Vol_{Glycol} = 0.7\,d\,L \qquad \text{Eqn. 1}$$

This provides a total volume of glycol in m^3 given the pipeline diameter, *d* in metres and the length, *L* in km. Further investigation into this formula reveals that this provides a single slug length (between two pigs) sufficient to achieve a 60:40 Glycol to water mixture at the end of the pipeline. This ratio is the minimum glycol content to avoid hydrate formation.

In the case discussed above a more exacting dewatering exercise is required. It is clear from analysis of the mixing of the water and the glycol in the slugs, that increasing the number of pigs increases the efficiency of the dewatering process. Using a mixing analysis, the table below provides an indication of water percentages in each slug at the end of the pipeline: -

Slug Length (m)	%Water, 1st Slug	%Water, 2nd Slug	%Water, 3rd Slug
100	49%	24%	12%
150	39%	15%	6%
185	34%	12%	4%
200	33%	11%	3%
250	28%	8%	2%

Table 1 – Dewatering efficiency against slug length

The result is that a choice of 185m slug lengths between each of the pigs will result in a final water content of 4%. This assumes that the pigs are efficient and fit for purpose. The benefit of this analysis is that the optimum volume of glycol is chosen. Too little would lead to ineffective dewatering and too much which would take up valuable room on-board the vessel.

Sizing the Inlet hoses

The inlet hose from the vessel to the temporary trap is required to be 175m in length. In order that this does not choke during the dewatering operation, it is necessary that the hose be large enough in diameter. If the diameter is too large, then the hosing becomes expensive. Therefore, the hose size can be optimised.

The initial check is to establish if the riser will choke. This is undesirable as the inlet pressure required would be excessive. The check is performed using compressible calculations. The following table summarises the output: -

Hose Size	Number of hoses	Choked?
2"	1	Yes
	2	Yes
	4	No
3"	1	No
	2	No
4"	1	No
	2	No

Table 2 – Inlet hose checks

From the table, and using the inlet flow and pressures expected, it appears that the 2" hose will cause the flow to choke. This means that four 2" inlet hoses would be required. Alternatively, a single 3" or 4" hose would be capable of taking the required capacity.

Pig Train Velocity, Inlet Pressure and Pigging Duration

When the pig train is loaded, it is necessary to push the dewatering train to the end of the pipeline using compressed air. Insufficient compressors or problems with inlet hosing will mean that the pig velocity is too low or the inlet pressure is too great. An analysis is performed to establish the air inlet requirements for the pig train to provide a pig velocity in the region of 0.5 m/s. This has been established in the dewatering specification as the target velocity. Additionally, the duration of the dewatering operation requires to be established.

The pressure output is shown in Figure 7. This displays very little difference in inlet pressure for the range of hoses considered: -

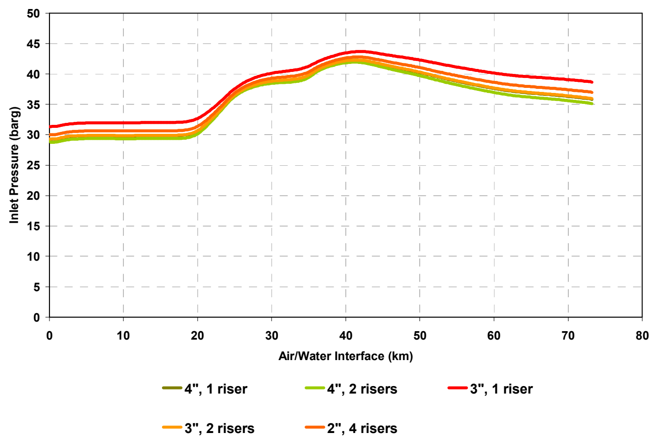

Fig. 7 – Inlet Pressure for different hose diameters and number of risers

By recording the inlet pressure as the pig train is moving down the pipeline, it is possible to establish the pig train progress. This can be compared with the predicted values against time or volume pumped. Any problems with the pig train can be observed and this is an effective technique for pig train monitoring. The pig train velocity is shown in Figure 8 below.

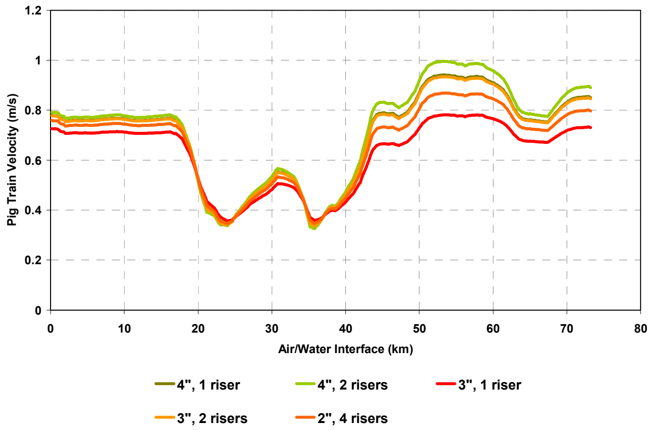

Fig.8 – Pig Train Velocity for different diameter and number of hoses

There is little difference between the pig train velocities. If anything, the larger diameter riser could allow the train to move too fast at the given inlet flowrate. This could of course be corrected by reducing inlet flow, but it appears that a single 3" hose would provide ample capacity for this job.

The pigging duration is given in Table 3: -

Riser ID (mm)	1 Riser (hours)	2 Risers (hours)	4 risers (hours)
4"	32.04	31.40	-
3"	34.57	32.13	-
2"			33.05

Table 3 – Pigging Duration for different hoses

The pigging durations are fairly similar and a single 3" hose may be the best choice. The final choice depends on other factors such as the cost of the hoses and other hoses being bought for the project as a whole.

One aspect that can also be taken into account in this analysis is the effect of line specification changes. This could be changes in pipeline wall thickness or even a change in pipeline diameter in dual diameter pipelines. When pumping a dewatering train from a large diameter line to a small diameter line a short pause while the pressure builds up behind the pig can be expected. This depends on the required pressure in the small diameter line. As the pig slows down, the pressure downstream of the pig reduces and so the delay is expected to be short.

Shutting down Compressors

One aspect that could be investigated is the effect of shutting down the compressors before the pig train gets to the end of the line. In view of the fact that the terrain slopes back up near the end of the line, there is pressure stored from the deepest part of the dewatering that can push the pig train to the receiver. This can result in savings being made on fuel and allow the next part of the job to be undertaken earlier.

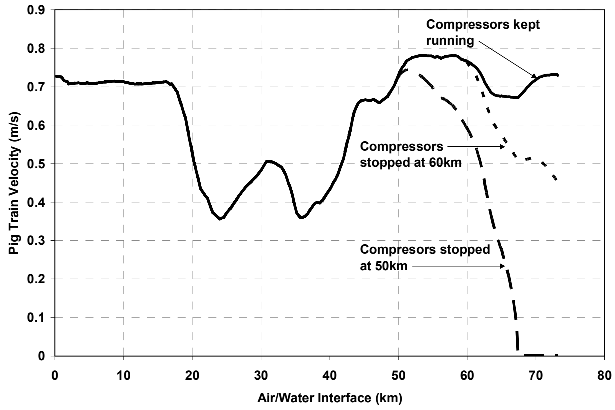

Fig. 9 – Effect of stopping pumping

The graph shows pig train velocity against pig train position in the pipeline. The solid line shows the velocity when the compressors are kept running until the pigs are received. The effect of stopping pumping too early is shown in the bottom dashed line. Here the pig train will stop before it gets to the receiver. Pumping will have to be restarted and a delay will have been caused.

If the compressors are shut down once the pig train reaches 60km, then the train slows down, but is still received. Effective pig tracking and locating is advisable if this is to be employed.

Venting Model

Once the pig train has been received, it is necessary to vent down to atmosphere through the inlet hosing, pipework and silencer. A further analysis is provided to compare the venting times for each hose diameter and size.

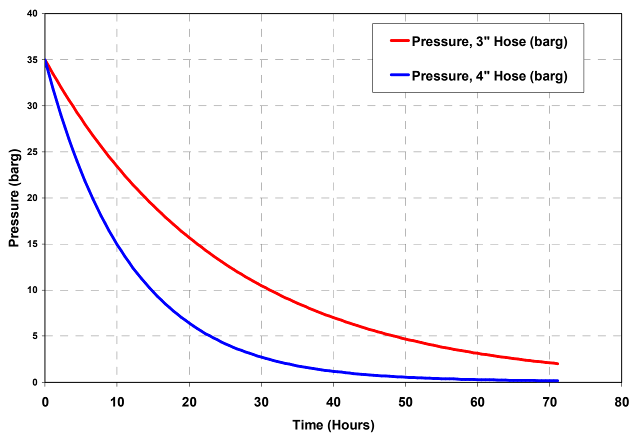

Fig. 10 – Venting times

The output shows the difference in venting time for the 3" and 4" hoses. The model output is not as accurate for lower pressures due to frictional effects in the pipeline. Nevertheless, this demonstrates that venting the line may take an additional two days with the 3" hose. In the final analysis, this may mean that the 4" hose is the final choice for the air inlet or venting hose.

Conclusion

The analyses performed in this paper allows several estimates to be made: -

- Pig train velocity in steep downward sections during flooding, cleaning and gauging. A two-phase model allows the pig train velocity dampening to be assessed;
- The Glycol slugs in the dewatering train are sized using a mixing calculation to estimate the volumes of MEG required. This can reduce the volume of MEG to be stored on the vessel but still provide effective dewatering;
- The inlet hoses to the pig trap are sized initially on compressible considerations to avoid any choking in the system. This must be checked at all stages in the development;
- The pig train velocity and required inlet pressure for dewatering can be estimated. This allows the dewatering duration to be established. The output is also useful for monitoring the dewatering operation;
- The model can be utilised to fine tune the dewatering in terms of shutting down the compressors before the pigs are received;
- Finally, a venting model is made to allow an estimate of the time required to vent the line to atmosphere.

These models and methods allow the pre-commissioning time to be optimised and the cost of vessel deployment reduced or minimised. A final conclusion is not drawn in this paper because there are other aspects to be established such as cost of other equipment, vessel deck space, interaction with other operations and so on. However, the analysis provides a very useful input into the overall planning exercise.