FLOODING AND DEWATERING OF A DEEP WATER 16 X 20-INCH PIPELINE

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A newly installed 16 x 20-inch pipeline requires a series of dual diameter pigs to flood the line for hydrotest and subsequently dewater all from shore to offshore using a compressor spread. This paper outlines the challenges and solutions adopted in terms of pig selection, design and testing, pig train design, flooding and pipeline dewatering to achieve the required dryness at the end of the pre-commissioning exercise.

Introduction

It is required to pre-commission a 140 km, deep water 16 x 20-inch pipeline from shore to subsea. The line, with the 20-inch section internally flow coated, will take processed gas from an FPSO to shore. The line consists of 83.6 km of 16-inch (constant bore 375 mm Internal Diameter, ID, complete with 5D bends at the Pipeline End Manifold, PLEM) in a deep-water trench followed by 56.4 km of shallow water 20-inch (with 455.6- and 466.4-mm IDs with 5D bends onshore) running to a gas plant. This is a 24.4% increase in diameter from 16-inch to 20-inch. For pre-commissioning (running from shore to subsea), a pig launcher is available onshore to allow pigs to be loaded and launched individually and a multiple pig receiver is available at the Pipeline End Manifold (PLEM) at a water depth of 518 m. A schematic of the pipeline, with the actual elevation profile is provided in Figure 1.

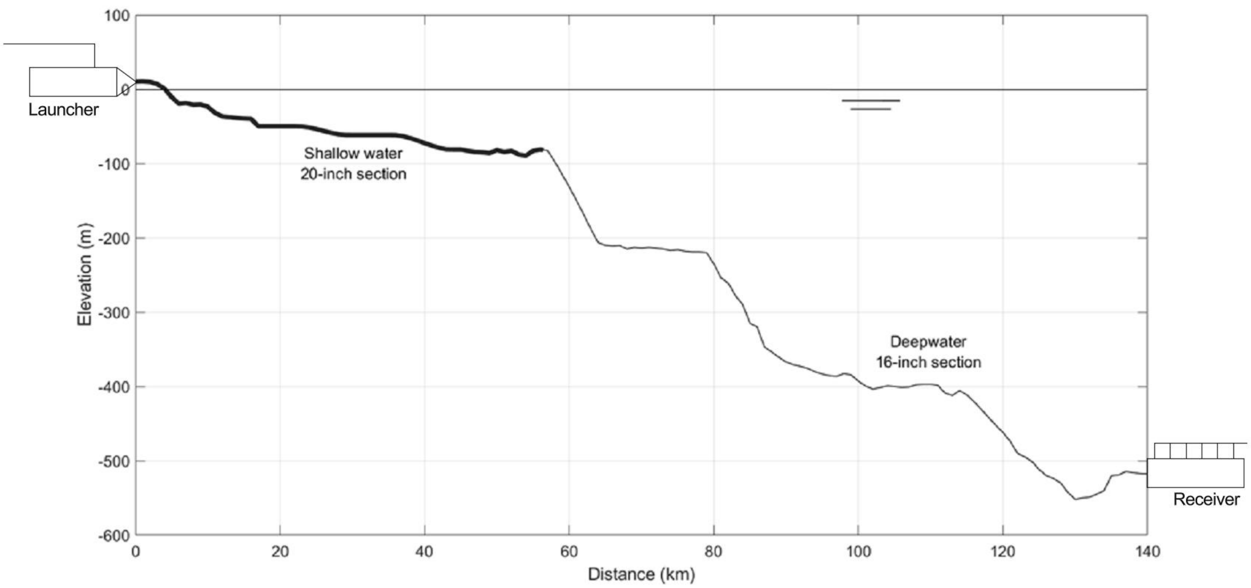

Figure 1, Schematic with elevation profile.

Prior to start up, it is required to Flood, Clean and Gauge (FCG) the line, followed by hydro test and then dewater the line to a specific target water content of less than 2% by volume in final Mono Ethylene Glycol, MEG, batch. In order to achieve these pre-commissioning tasks, the following is required: -

- Dual diameter pigs need to be designed and verified by testing;
- Conditions established for controlled flooding of the pipeline;

- A dewatering train specified;
- Detailed understanding of the dewatering operation provided in terms of pig train velocity and inlet pressure requirements.

Pig Design and Testing

Following on from detailed studies during Front End Engineering and Design (FEED), the line was maintained as piggable as possible with constant bore in the 16-inch section and only a 2.3% increase within the 20-inch section. Besides the dual diameter nature of the line, the pipeline is well designed for pigging as a result of this up-front work. The pigging study recommended that the midline reducer was concentric and also short at 320 mm. This is to allow the pig to span the feature (front and rear seals working in either 20-inch or 16-inch as the pig passes the reducer).

A 16 x 20-inch pipeline, with 24.4% increase in diameter is reasonably challenging but very achievable. Despite this, testing is still recommended through the main line components more by way of verification and to make small changes than any doubt over the outcome. The graph below shows a rough guide for dual diameter pig selection (based on non-foam type pigs) and shows that this specific case sits comfortably with a V-slot support type mandrel pig.

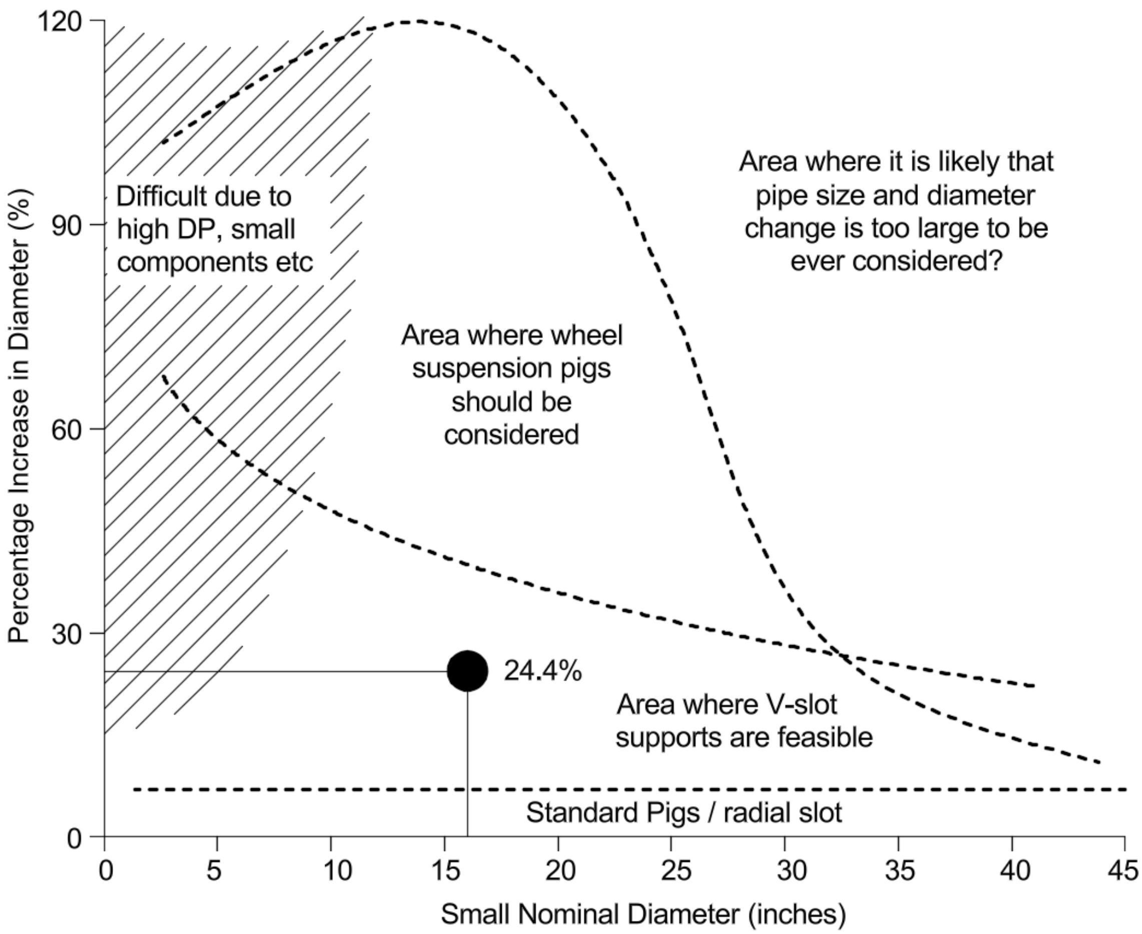

Figure 2, Dual diameter pig selection guide based on over 100 previous projects. Note that an efficient disc type seal is required in both diameters for pre-commissioning. Operational pigging can be more lenient in terms of seal efficiency. Note that a <u>polyurethane</u> disc seal is considered to be required in all diameters for pre-commissioning to provide an effective seal.

The functional requirements for the pigs (both FCG and dewatering) are set out below. It was decided upfront that the same design will be used for both tasks but with some small modifications and differences. The pig may also be used as the basis of a future operational pig (this time from 16-inch to 20-inch).

FCG	DEWATERING
• Good cleaning ability and reasonable sealing. Consider directional bypass in first pig to help remove loose debris; • Bi-directional / reversible; • Include magnets for ferrous debris; • Negotiate / span all pipe features; • No trapped cavities in pigs or in pigs in contact; • Correct length for receiver; • Signalling and tracking included; • Locking of all fasteners (to agreed standard)	• Normally uni-directional pigs / excellent sealing required (test required – "No visible leakage"); • Ability to seal when static and at longitudinal welds; • Negotiate / span all pipe features without leakage; • Locking of all fasteners; • No trapped cavities in pigs or between pigs in contact; • Bumper noses to avoid contact; • Signalling and tracking included – isotope is ideal; • Silicone sealant to avoid through body / bolt leakage.

Table 1, Functional requirements for the two operations. Note that despite the dual diameter nature of the pipeline, no compromise on pig sealing ability is accepted. The pig must seal as well as a single diameter pig.

Pipeline Research Limited provided an initial pig design (see below) with sufficient detail on the configuration to allow a detailed drawing to be provided by the manufacturer.

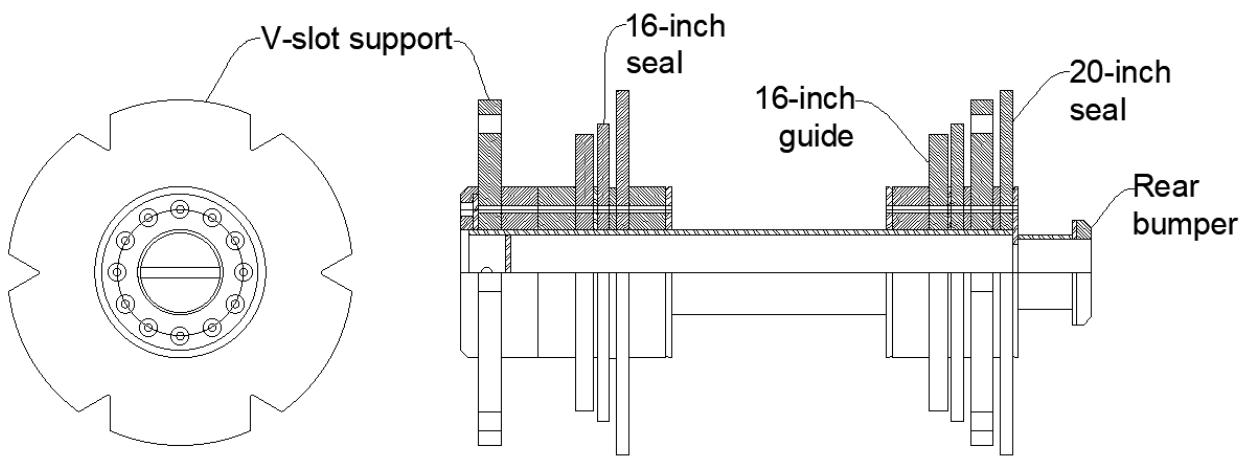

Figure 3, Outline pig design for testing. A set of spares – alternative seals, larger 16-inch seals, spacers etc were also specified for test purposes.

The rear bumper nose is a necessary feature to allow the rear 20-inch seal to fold efficiently and to allow each pig to be pushed into the pig receiver subsea without causing un-necessary interference between pigs and seals.

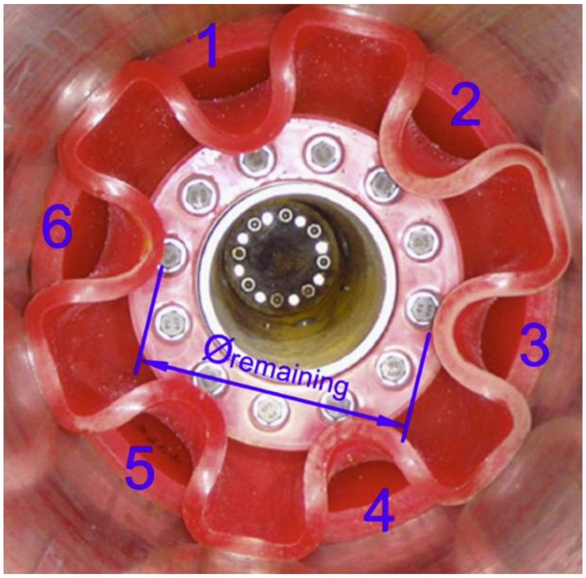

Figure 4, Rear buckled seal in 16-inch. A rear bumper nose is important to avoid a second pig contacting the buckles and potentially causing a plug as it pushes forward. This could occur in the receiver.

Open ended testing with water drive, through the main pipeline features, was conducted to confirm piggability and make any necessary adjustments to the design. It was also confirmed that the same overall design concept would suffice for FCG and for dewatering. Testing included flip trials (pressure required to make the seals fail), reversal in the 16-inch and 20-inch, a 16-inch smart gauge run and a final air dewatering to show that the seals were sufficient and pigging with low pressure gas was possible.

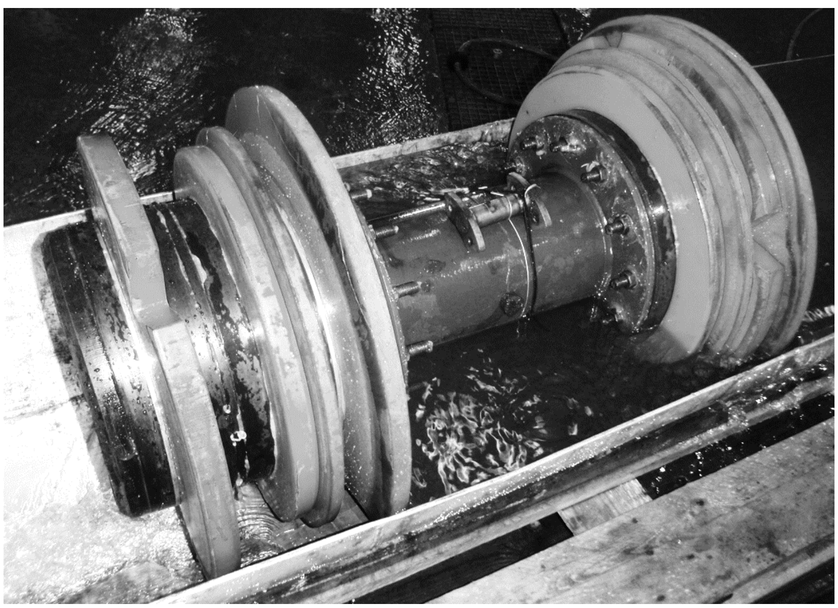

Figure 5, Pig during testing. Small changes were made to the design – notably additional spacers and deeper V-slots but the overall configuration remained the same.

Once the design was finalised, a set of FCG and dewatering pigs could be procured in readiness for the offshore operation.

Note that the tests also provided pig differential pressures for use in the offshore pig train design: -

- DP in 20-inch 0.25 bar;
- 1.5 bar in 16-inch straight.

Pipeline Flooding

It was planned to flood the pipeline with filtered and chemically treated seawater in readiness for hydrotest. A pig train consisting of three pigs is pumped from shore to the subsea pig receiver at KP 140. Prior to flooding the pipeline, the line is air filled at atmospheric pressure. During the flooding operation, there is a risk that the pig train could “runaway” due to high liquid head upstream and low air pressure downstream. The result can be high train velocity and a risk of sucking air into the line due to vacuum conditions back at the pump. Pig train “runaway” is not desirable as it demonstrates a lack of control.

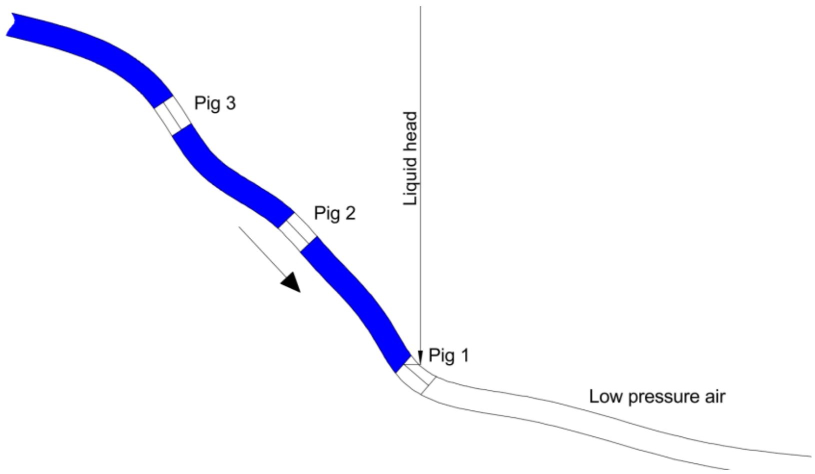

Figure 6, The pig train can accelerate due to the high liquid head, insufficient friction from pigs and low-pressure air downstream.

There are a number of possible solutions: -

- Pre-pack the line with air to a higher pressure to hold back the train. This means getting compressors available well in advance of the dewatering and this might be difficult to arrange;
- Pre-flooding the line, prior to pigging, with chemically treated seawater. Additional water winning and chemicals are required for this;
- Partial flooding to introduce some water into the line to act as a buffer and increase the pressure downstream at the same time. The success of this depends on the line elevation profile.

Due to the nature of the landfall, provision of water for a pre-flood was not easy to arrange and it was also planned to have the dewatering compressor spread set up for early dewatering following hydrotest. For this reason, the first option, pre packing with air, would be adopted, if necessary.

Calculations can be performed to establish the inlet pressure at the pig launcher during the flooding operation. Note that although the initial line pressure was atmospheric, this would increase as the pig train progressed until the pressure reaches seabed ambient pressure when air is evacuated via the Non-Return Valve (NRV) on the receiver (circa 52.1 bar gauge). This means that eventually the risk of “runaway” is removed and the line self-packs.

For this particular flooding operation, the inlet pressure is governed by: -

$$p_{in} \quad = \quad p_{air} + \Delta p_{air/loss} + \Delta p_{pigs} + \Delta p_{water/losses} - p_{water\ head}$$

Where: -

- p_{in}, is the inlet pressure at the pump;
- p_{air} is the air pressure in the pipeline, compressing to a maximum of 53.1 bara;
- $Dp_{air/losses}$ is the frictional losses of air flow in the pipeline and out of the receiver once the air pressure and seabed pressures equalise;
- Dp_{pigs} is the pig differential pressure as measured in tests (0.25 bar in 20-inch straight pipe and 1.5 bar in 16-inch straight pipe);
- $Dp_{water/losses}$ is the frictional losses of water flow in the pipeline at planned 470 m^3/hour and through hoses and inlet pipework;
- $P_{water\ head}$, the hydrostatic head of flooding water upstream of the leading pig.

A simulation and with various sensitivities can be performed to establish the inlet pressure against water / air interface location (see below).

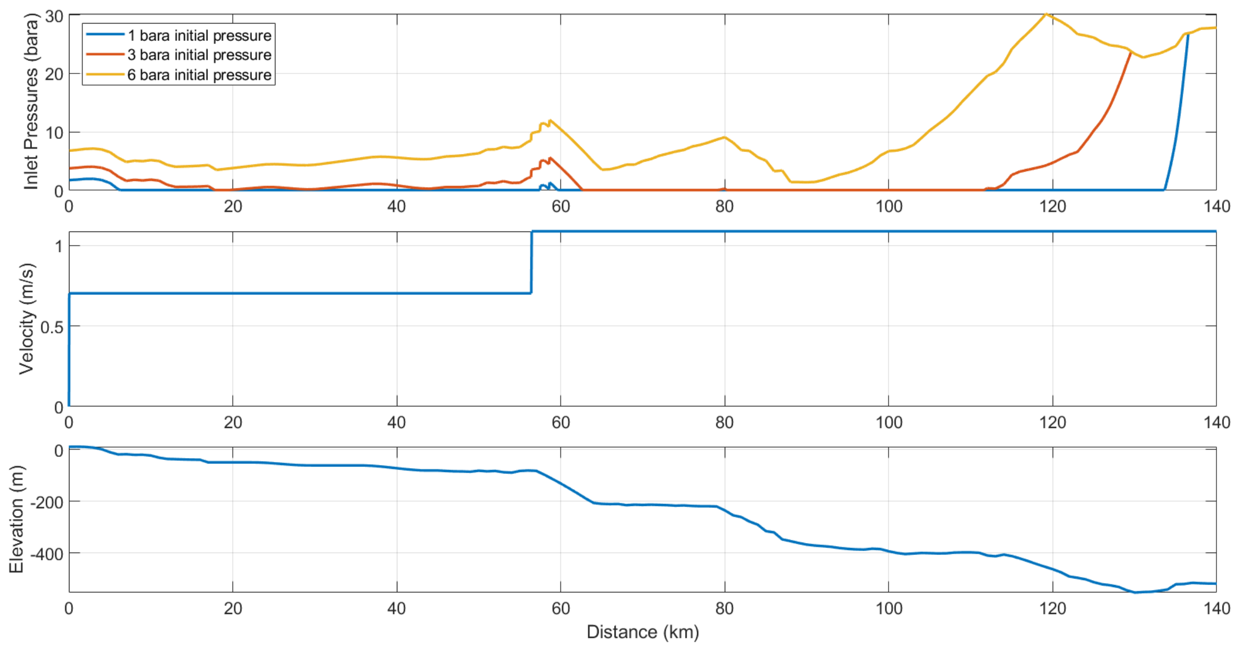

Figure 7, predicted inlet pressure (top plot) against water / air interface for different pre-pack air pressures.

With 6 bara (5 barg), then the line inlet pressure remains above atmospheric for the duration of the pig run. Further sensitivities were performed to examine the effect of reduced pig train differential pressure, wear in the 16-inch section and loss of pumping volume. Given just 6 hours to pressurise with the 6000 scfm spread available, this was then adopted as the solution prior to FCG.

The actual flooding operation was then logged at 15 minutes intervals with inlet pressure, flow and time / date recorded. The following output shows the actual readings (in red circles) against predicted (solid blue line). Allowing for and correcting for fluctuations in the pumping flows, there is general agreement in magnitude and trend.

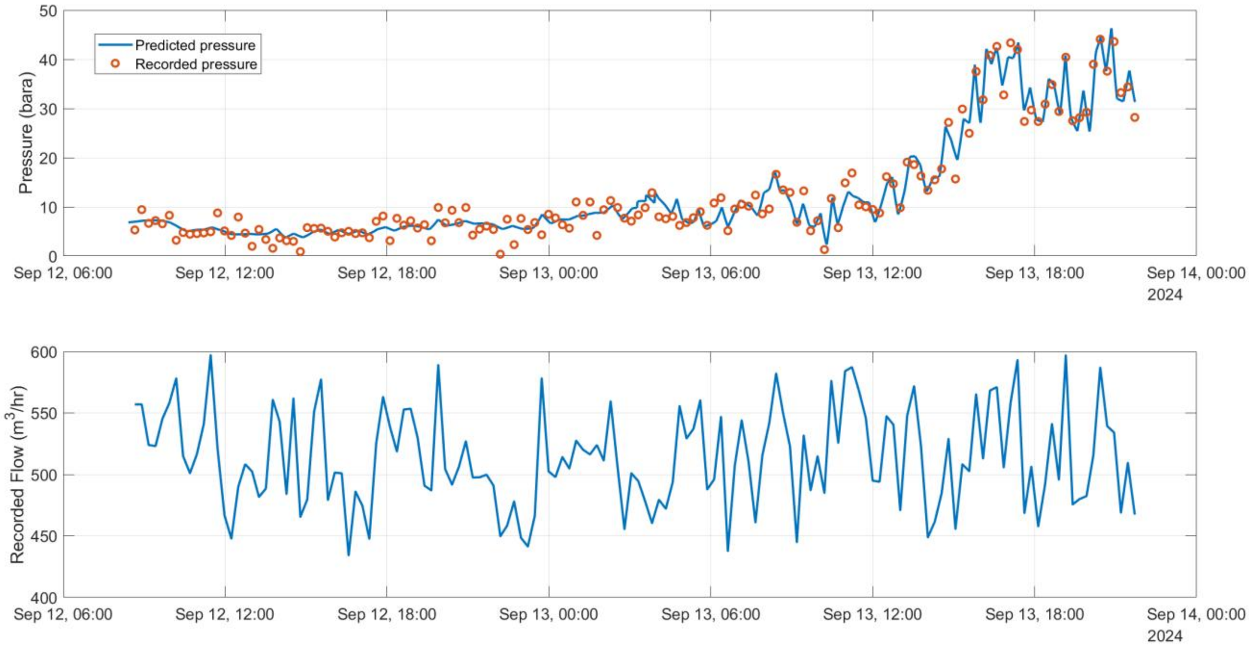

Figure 8, Predicted and actual inlet pressures during FCG showing broad agreement.

The model was adjusted in real time using the flow rate from the field and used to track the progress of the pig train against time using the inlet pressure prediction. If a problem arose, then the variation between actual and predicted pressure would provide an indication and trigger a response. The exercise also provides valuable information for the dewatering run as the same subsea receiver and outlet arrangement (but including an orifice for speed control) would be utilised.

Dewatering Pig Train Design

A pig train with Mono Ethylene Glycol (MEG) batches was determined as the pipeline conditioning method. As stated, the target remaining water content for the line was 2% water in MEG maximum. The following base case pig train was proposed for dewatering the pipeline: -

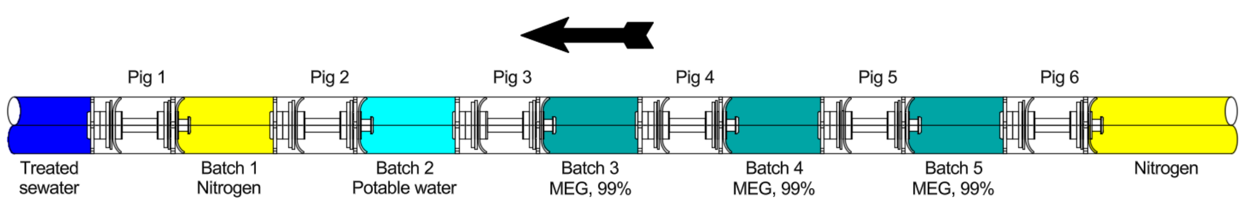

Figure 9, Outline dewatering pig train design.

The nitrogen batch is required to remove bulk water from tees and offtakes in the line. The potable water batch allows the chloride content (essentially a measure of the salinity of the water) to be reduced. The MEG batches then reduce the water content to the acceptable or required level. An analysis is performed to determine the length of the batches and to put detail onto this initial design. The following graph shows MEG percentage for batches 3 to 5 and how this reduces the water content to circa 1.5% using three batches of MEG, 35 m^3 each: -

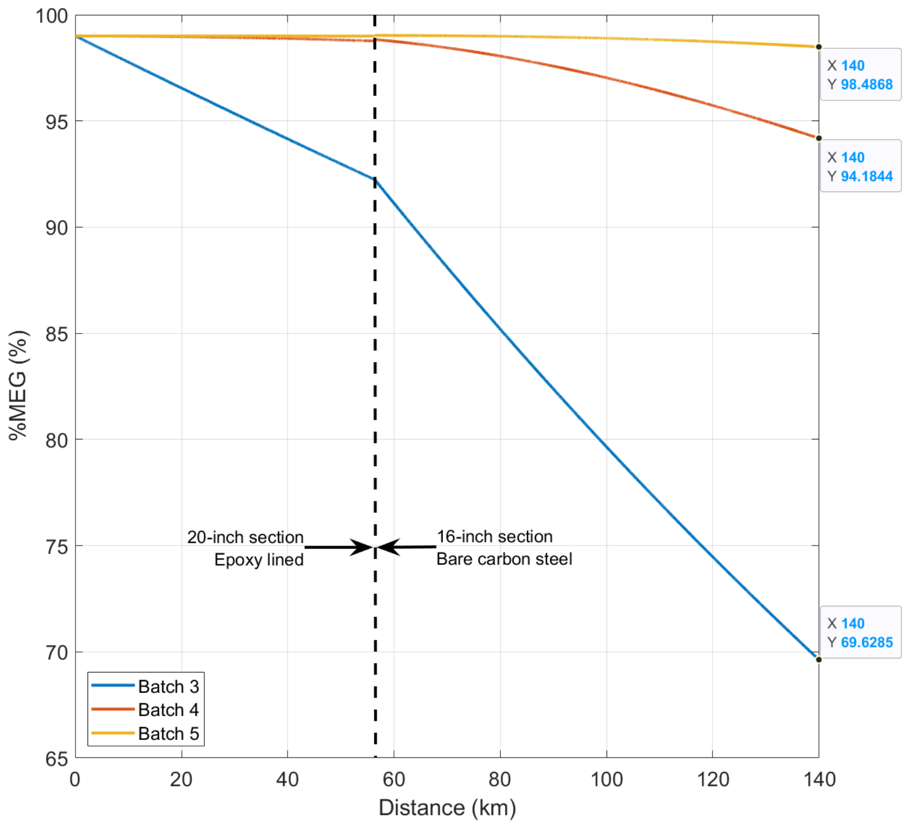

Figure 10, MEG conditioning with three batches of 34 m^3 99% pure MEG each.

Note that it is not planned to measure the water content in the MEG by taking samples due to the difficulty subsea. The calculations above, good control over the dewatering train in terms of quality of MEG, volume of MEG batches and control of the pig train during the operation are considered to be adequate.

The same analysis is performed for chloride content. Although the chloride content of MEG is expected to be low, a conservative level of 5 ppm is used. The aim is to get the seawater content (estimated at 20,000 ppm) down to less than 20 ppm. The graph below shows the output using 35 m^3 of potable water along with the MEG train proposed above.

Finally, a nominal nitrogen batch size to capture water from the tees and offtakes of 1500 sm^3 is used for batch 1 taken into account the expected pressures in the line and the fact that pigs 1 and 2 will get closer and closer as the local pressure increases.

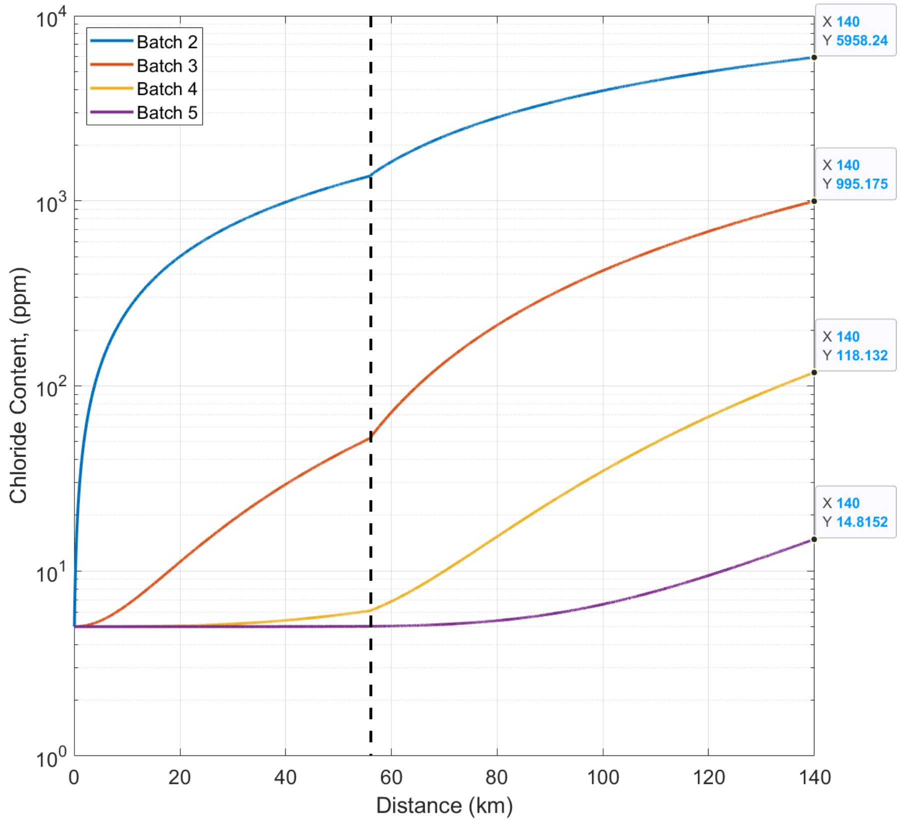

Figure 11, Expected chloride content at the end of the operation.

The final pig train is as follows: -

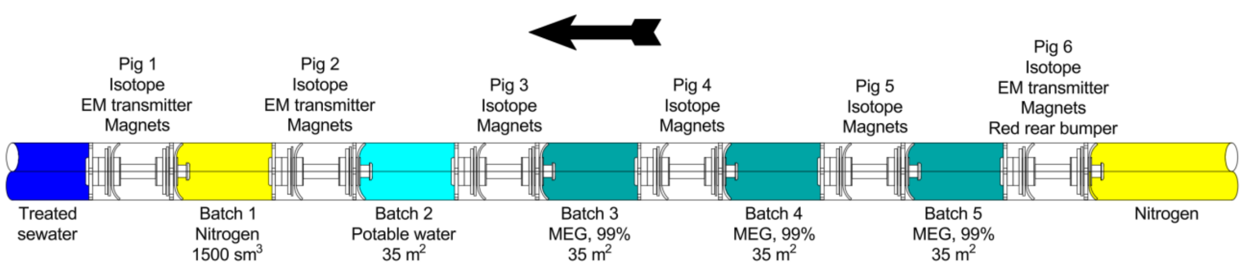

Figure 12, Final pig train design. Note that the final pig has a different colour rear bumper to allow the project team to determine immediately on retrieval of the receiver that the final pig has been recovered.

Dewatering

An initial analysis was performed to determine compressor requirements and the need for orifice control at the end of the line in the receiver outlet pipework. The analysis also allows the pig train velocity and inlet pressures to be determined against time and pig train location.

The inlet pressure to the pipeline is determined from the following components in a similar analysis to the flooding: -

$$p_{in} = p_{pig\ train} + \Delta p_{water\ head} + \Delta p_{orifice} + \Delta p_{water/losses} + \Delta p_{nitrogen/losses} + \Delta p_{hotstab} + \Delta p_{contract}$$

Where: -

- p_{in}, is the inlet pressure after the compressor / or at the launcher;
- $Dp_{pig\ train}$ is the pig train differential pressure made up from 6 pigs;
- $Dp_{water\ head}$, the hydrostatic head ahead of the trailing pig;
- $Dp_{orifice}$ is the pressure drop across the orifice at the end of the line, initially chosen as 80 mm;
- $Dp_{water/losses}$ is the frictional losses of water flow in the pipeline ahead of the pig train;
- $Dp_{nitrogen/losses}$ is the frictional losses of nitrogen (or air) flow in the pipeline behind the pig train;
- $Dp_{hotstab}$ is the pig differential pressure across the hotstabs used on the receiver and calculated using Cv values provided by the manufacturer;
- $Dp_{contract}$ is the additional losses due to sudden contraction from large pipe to small (especially at the receiver).

The following planned output was determined from the dewatering model: -

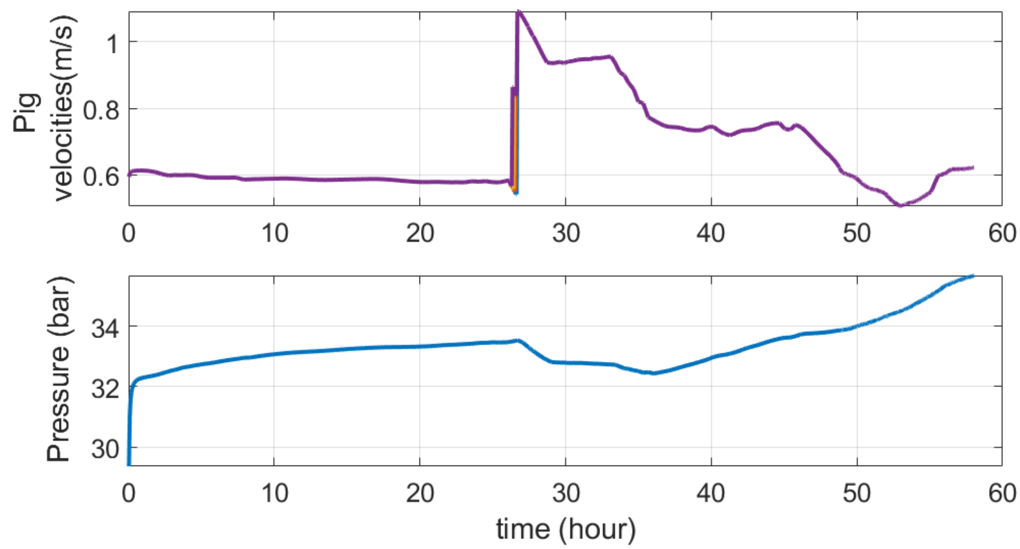

Figure 13, Pig train velocity (top) and inlet pressure at the launcher as determined using 3.3 sm^3/sec (7000 scfm) gas flow and an 80 mm outlet orifice plate.

The result caused some discussion within the project as it was expected that the pig train would stop at the reducer as pressure built up to push the pigs into the tighter 16-inch section. The plan was to have a tracking vessel on standby at the reducer to check that the pigs were slowly entering the smaller bore pipe. However, the analysis showed that the pigs would not stop or even slow at the reducer and there was no discernible increase in pressure at the inlet.

The reason for this is explained in the figure below: -

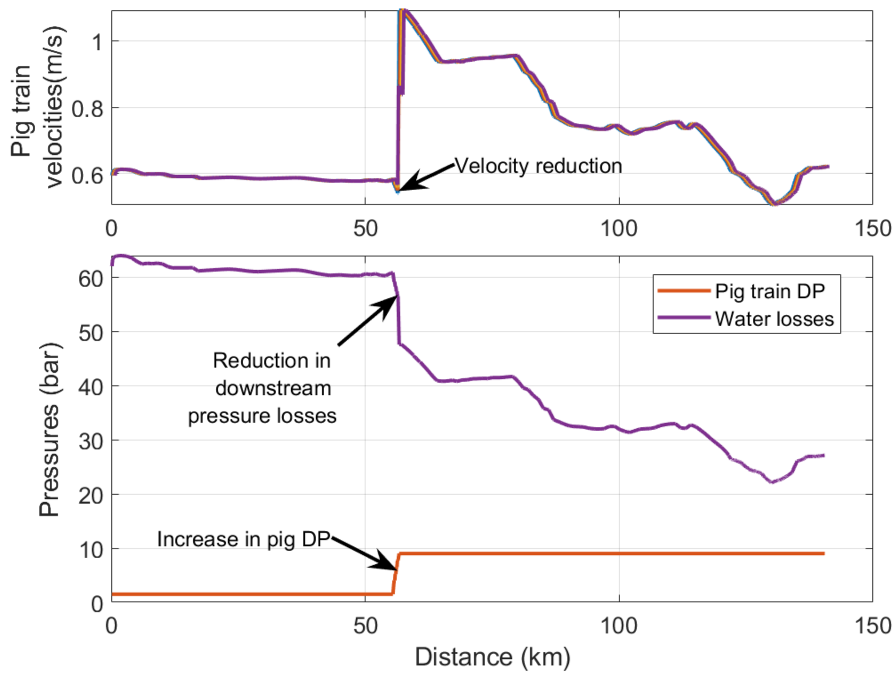

Figure 14, A small reduction in train velocity as the pigs enter the reducer is enough to reduce the hydraulic losses downstream of the pig thus offsetting the increase in pig differential pressure.

The gas pressure does not need to rise upstream of the pig train as the water losses reduce downstream. This acts to compensate for the increase in pig differential pressure and there is then no halting the pig progress through the line. Armed with this information, the timetable was adjusted and the vessel would sail direct to the receipt location once it was confirmed that the train was directly through the reducer.

As previously, the pig train was tracked with detailed flow and pressure data provided at 15 minutes intervals and a report made every 6 hours. This was then used to update the prediction and allow the indication of arrival time to be updated for the vessel. Some small adjustments were required to be made for example to the outlet losses and to the pig train DP which appears to be lower in the field than in test (probably due to the lubricating effect of MEG and wear of the seals). The following shows the final output with pressures and estimated train velocity during tracking: -

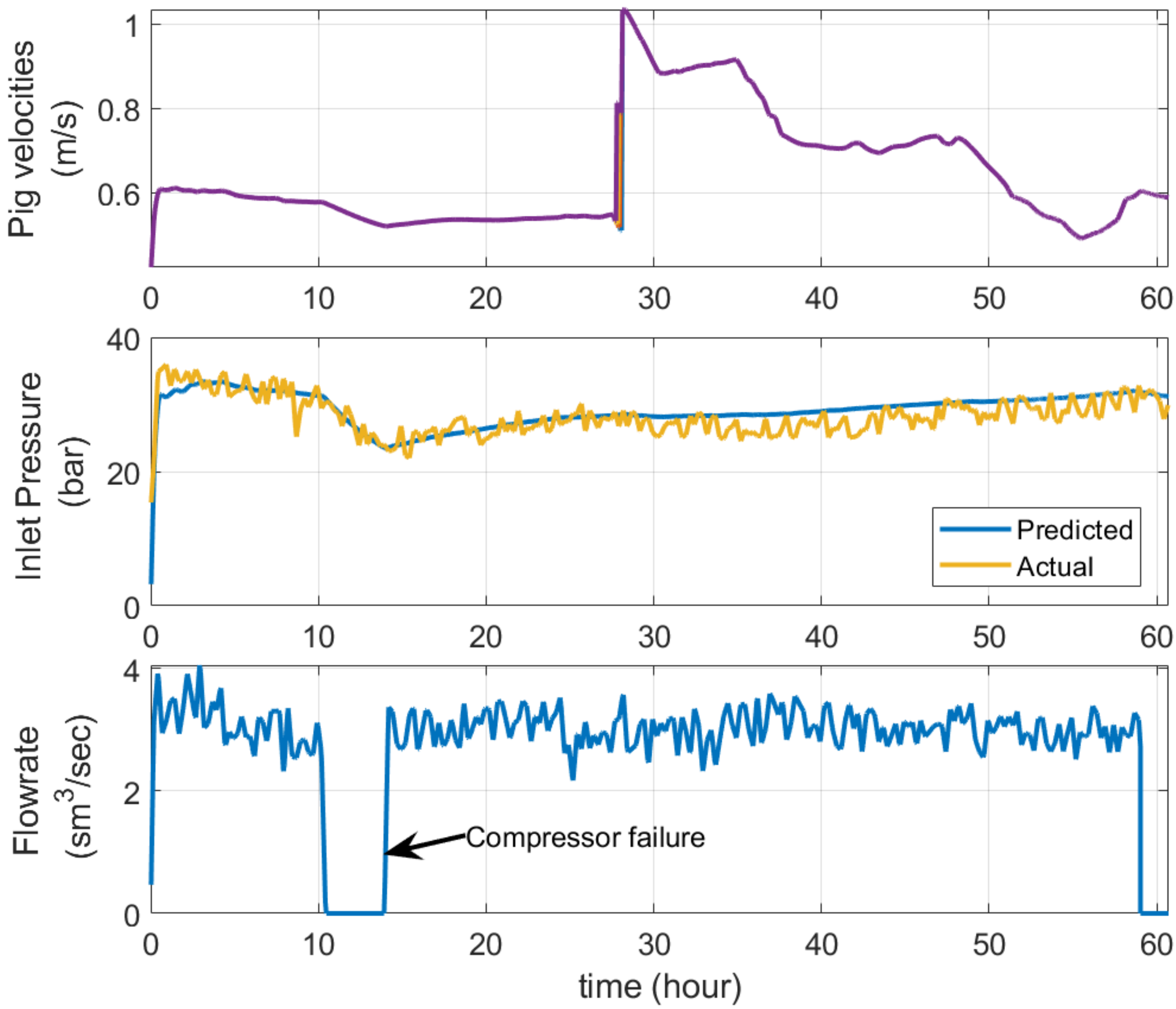

Figure 15, Estimated pig train velocity (top); actual and calculated inlet pressures (middle) and actual inlet flow (bottom).

The following points are noted: -

1. Some adjustment to the input parameters is required to establish a match between estimated and actual (for example to the receiver pipework losses, pig DP etc);
2. As predicted, the pig train did not stop at the reducer and the vessel was able to get to the receipt end on time;
3. Based on inlet flow, then there is very little evidence of the pig train entering the reducer and into the 16-inch pipe. If this was not appreciated, then there may have been some concern over pig train progress;
4. The compressor failure did not mean that the pig train stopped as there is still sufficient stored energy in the system to keep the train running.

Overall, the operation and project in general was a success and the pipeline was considered to be ready for operation. The pigs behaved very well and allowed the dewatering exercise to be completed without issue despite the dual diameter nature of the line. There was no compromise in sealing ability despite the changes in diameter and the tests performed demonstrated no visible leakage in either the 20-inch or 16-inch pipes (based on open ended tests with water and a closed test with air to dewater the test loop).

Conclusions

The following conclusions are made based on this work: -

- In a dual diameter pipeline, the midline reducer should be short and concentric to allow the pig to span the feature while remaining on centreline;
- The outline pre-commissioning pig design can be used in different guises for flooding, gauging and dewatering. It can also form the basis of a future operational pig;
- No compromise on sealing efficiency is acceptable for a dual diameter line, polyurethane disc seals should be used in all diameters and “no visible leakage” is the aim in tests;
- A rear bumper nose is very important in dual diameter pigging to avoid a possible plug as pigs contact and interfere with buckled seals. The colour of the rear bumper nose for the last pig can also allow the project to know immediately that the last pig has been received on retrieval of the receiver;
- Open ended testing (water drive, air downstream) to view the pig passage and low-pressure air dewatering tests (air drive, water downstream) are important to prove the pigs and show that they are fit for purpose;
- FCG pig train runaway can be avoided with air pre-packing to a calculated pressure or by pre-flooding the line;
- Dewatering pig train calculations allow the number of batches and batch sizes to be determined to result in the require dewatering efficiency and chloride content;
- Matching actual and calculated pressures allows the train to be tracked and a good estimate of the train arrival time to be provided and updated;
- It is not necessarily the case that a pig train will stop at a reducer during dewatering and it depends on the losses in the system but this can be determined by simulation.