16” / 24” / 34” MULTI DIAMETER OPERATIONAL PIGGING

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1 Executive Summary

Pigging pipelines with internal diameter changes is nothing new and pigs regularly traverse pipeline systems across the globe with two or more internal diameter changes, however the extent of the diameter change generally does not exceed 60% of its original size. Once this diameter change is reached pigs will then require support to centralise the pig in the pipeline, such as wheels to support the additional weight.

This technical paper and associated presentation describe the details of the various challenges and solutions that enabled successful multi diameter pigging operations to continue with a pipeline internal diameter change that is 115% greater than the original size.

The aim of this technical paper is not to cover all pig types but will focus only on the pig designs recommended for use as a potential contender and ultimately delivering the successful outcome.

1.1 Introduction

For 27 years the Shell Gannet platform exported oil to the Repsol Sinopec Fulmar platform via a 16” x 107km pipeline. This pipeline was cleaned on a regular basis to manage wax / water hold up in the system and this was performed using standard 16” bi-directional pigs fitted with bypass ports. During this process all wax and pigs were disposed of and received at the Fulmar platform respectively. Oil from the Gannet export pipeline was then routed to Fulmar’s 24” export pipeline and onwards through the Norpipe system for processing at the Teesside oil terminal.

Following the decision made by Repsol Sinopec to decommission the Fulmar platform in 2017. Options for rerouting oil production from the Shell Gannet field needed to be evaluated to ensure it continued oil delivery to the Teesside terminal.

In 2018 the decision was made to extend and route the existing subsea 16” pipeline from the Gannet platform directly into a new subsea 24” wye piece which in turn connected directly in to the 24” / 34” Norpipe pipeline at the Judy platform location.

A new pig was therefore now required to clean the 16” pipeline and manage wax removal in this 128km section, followed by transitioning into the 24” & 34” system and traveling a total distance of 477km to the Teesside oil terminal.

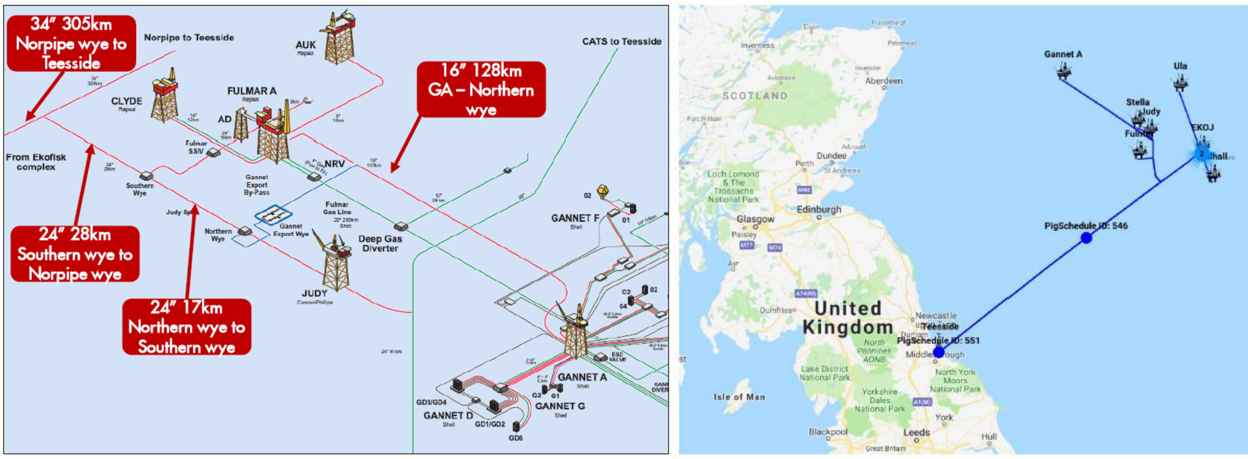


Figure 1 - Offshore pipeline system.

2 Pipeline Operating Overview

The pipeline system is fed by five (5) platform-based production systems with each producing varying degrees of crude oil at differing flow rates and pressures across the system. To add each of the platform-based production systems are at different phases of their operational life and with that will be decommissioned at varying stages during the production life span of the Norpipe pipeline system.

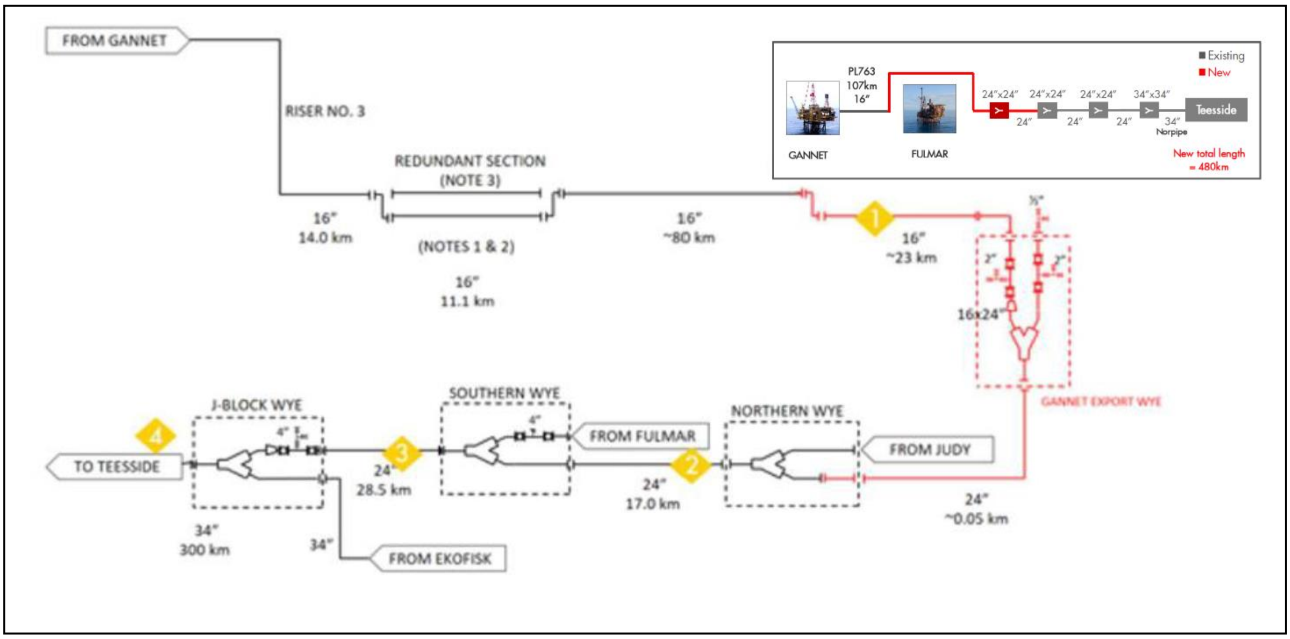


Figure 2 - Gannet to Teesside pipeline system.

2.1 Production from Gannet

Oil production from the Shell Gannet field is exported entirely through the 16” export pipeline. Gannet oil export temperature at the pipeline topsides >60°C with the product cooling to approx. 6°C as it travels subsea through the pipeline and is naturally cooled by the external sea temperature.

Pigs in the 16” export pipeline are launched via an oversized horizontal pig launcher and is isolated when not in use.

Figure 3 - Shell Gannet platform.

Oil production from the Shell Gannet field is exported entirely through the 16” export pipeline. Gannet oil export temperate at the pipeline topsides ranges 55°C to 70°C with the product cooling to approx. 6°C as the product travels subsea through the pipeline as it is naturally cooled by the external sea temperature. Pigs in the 16” export pipeline are launched via an oversized horizontal pig launcher and is isolated when not in use.

2.2 Production from J-Block

Figure 4 - Harbour Energy Judy platform.

Oil production from the Conoco Phillips J-Block fields enter the Norpipe system upstream of the 24” Northern wye.

The 24” pipeline is independently pigged from Judy to Teesside by Harbour Energy.

2.3 Production from Fulmar & Stella fields

Production from the Fulmar & Stella fields enter the Norpipe system upstream of the 24” Southern wye. The 24” pipeline from Fulmar platform and 10” pipeline from the FPF-1 platform are independently pigged to Teesside by Repsol Sinopec and Ithaca Energy respectively.

Figure 5 – Repsol Sinopec Fulmar & Ithaca FPF-1 platforms.

2.4 Production from Ekofisk

Figure 6 - Ekofisk offshore complex.

The Ekofisk offshore complex is the main exporter of oil through the Norpipe system with production entering the system 50km upstream of the 34” J-Block wye.

The 34” pipeline is independently pigged from Ekofisk offshore complex to Teesside by Conoco Phillips.

2.5 Teesside Oil Terminal

Production from all the above offshore fields is ultimately received into the Conoco Phillips oil terminal at Teesside. The pipeline is equipped with an oversized horizontal 34” pig receiver.

Due to the number of shippers exporting oil to the Teesside oil terminal and the respective independent pigging operations from each of the platforms. All pigging operations are co-ordinated and authorised by Conoco Phillips to ensure that the pipeline system is duly cleaned, and water hold up managed.

Figure 7 - Teesside terminal.

3 Pigging Challenge

As a result of the 16” pipeline subsea reconfiguration, several challenges presented themselves which needed to be overcome before the pipeline could be used as a reliable export route once again. Any future pigs launched from the Gannet platform need to be able to travel unaided and perform all the following tasks in the sequence below:

A. Capable of launching from the 16” Gannet “A” export pig launcher.

B. Routinely in a single pass clean and remove hard / soft wax deposits within the 16” x 128km pipeline section, whilst providing variable degrees of bypass ahead of the pig.

C. Transition from 16” to 24” diameter and routinely sweep water from the 24” Gannet wye to Northern wye.

D. Independent travel through 24” x 45km pipeline which incorporates 3 x 24” equal wye structures.

E. Transition from 24” to 34” diameter and pass through a 34” equal wye structure.

F. Independent travel through 34” x 305km pipeline from the Norpipe wye to the Teesside terminal.

G. Capable of unhindered travel through the 34” subsea hydro coupler at KP100.

H. Capable of passing a 34” 3D bends and receipt into the 34” Teesside terminal pig receiver.

I. Capable of travel unassisted as production flowrates diminish from 2019 to 2032.

3.1 Production Pig Speeds

Flowrates across the field are planned to reduce significantly over the period 2019 to 2030. See the table below for expected pig speeds in the 16”, 24” & 34” pipeline sections.

Pig speed meter per second based on oil production rates	**16” Gannet**	**16” Gannet & 24” Judy**	**16” Gannet, 24” Judy & Fulmar***	**16” Gannet, 24” Judy, Fulmar & 34” Ekofisk**
2019	0.23	0.25	0.33	0.97
2023 (* Fulmar offline)	0.16	0.17	0.17	0.95
2030	0.09	0.08	0.08	0.38

Table 1 - Future production pig speeds.

As production continues beyond 2023 and as Fulmar is taken out of production, pig speeds in the 16” & 24” are expected to be very low.

4 Pig Basis of Design

Fundamentally the pig design for this pipeline system is required to be a minimum of dual module to give it the ability to seal and pass through the 3 x 24” wye pieces as well as having the ability to pass through 16” 5D bends. Single module pigs should not be considered, as the length required to seal in a 24” wye piece would put the pig body at risk of coming into contact with the internal radius of the 16” 5D bend.

There is no requirement for the pig to travel in reverse, therefore all pig designs shall be mono directional.

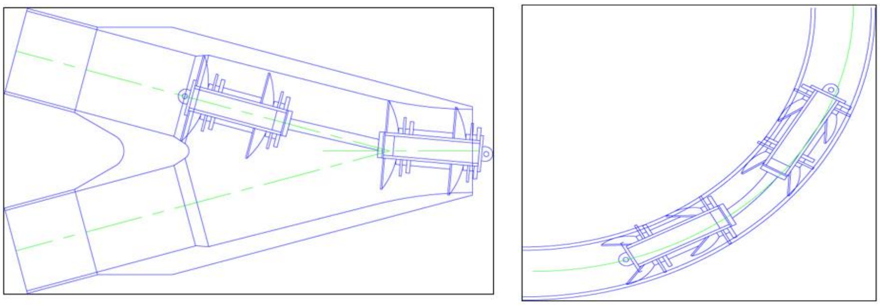


Figure 8 - Examples of dual module pigs passing through a 24" wye piece and 16" 5D bend.

As the pig will be fitted with (16” & 24”) dual diameter components as a minimum, the pig would need to be launched from a cassette to ensure that the larger diameter elements are suitably compressed to the 16” diameter prior to entering the 16” pipeline system.

Figure 9 - Example of 16" launch cassette.

4.1 Wax Management

The pig's ability to clear wax in the 16” system is also key and therefore bypass across the pig had to be available to control the pig’s speed and to enable wax ahead of the pig to be flushed from the pipeline. Generally, this comes in the form of bypass ports in the body of the pig allowing flow through the pig from back to front as the pig travels.

4.2 Centralisation

Centralising the pig is key along with supporting the pig's weight in the larger diameter, as more steel and urethane is needed in the larger diameter to create a seal in the pipe. Large heavy pigs tend to sit in the base of the pipe and therefore bypass in low flow situations quite easily.

4.3 Neutral Buoyancy

The pig’s weight is key to the success of the pigging operation in all 3 diameters. To achieve neutral buoyancy in crude the pig is required to weigh 89 kg. All pig trials are to be performed in water therefore the pig would be fitted with weights to increase it to 93kg making it neutrally buoyant in water.

4.4 Compression Set

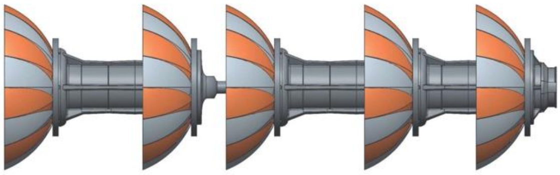
Counter the effects of compression set in the compressed urethane components of the pig, to later enable the pig to reform into the larger diameter is also a contributor to the pig's success. This is particularly important when the propelling medium is heated.

5 Phase 1 – 2017 Pig Designs

The first phase of pig design and testing took place in 2017, where by two concept designs were evaluated as potential contenders. Both of the proposed pig designs are modular in construction, this allows for greater flexibility when testing as components can be changed to modify and improve the pig's travel through the system, should it be required.

For the purpose of pig selection at this time, neither pig was fitted with bypass as the pig is ultimately being selected for its piggability of the system at this time and bypass could be incorporated into the design at a later date.

5.1 16/24A "Sun Pig"



The 16/24A pig is dual module and made up of all polyurethane components. The two modules are joined using a PU coupling. All components are slid over the 178mm OD pig body and held in place by a stopper plug which is fitted inside the hollow pig body and fixed by using a clamping ring and retaining bolt.

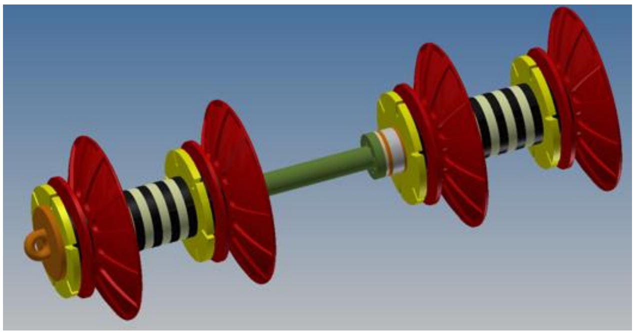
The body of the pig remained hollow to allow for buoyancy aids to be fitted and tracking devices to be fitted. The pig is equipped with formed 16" guide and sealing discs. The 24" elements of the pig are of a collapsing cup design.

A typical Dual Diameter Pig Cup in open position

A typical Dual Diameter Pig Cup in compressed position

It was proposed to make the pig bodies of different lengths available for the trials. This will allow different pig configurations to be tested e.g. a three and two cup combination as per image above or a two and two cup combination also. With the Sun pig's ability to be built in several configurations due to its modular design.

5.2 16/24B Pig



Carbon steel dual module pig complete with a flexible PU coupling between the modules. Fitted with standard PU 16" guide and sealing discs on both modules.

The pig bodies were fitted with retaining flanges onto which were bolted the 16" guide and seal discs together with spacers and the 16" x 24" Dual Diameter cups. The 16" components will be relatively standard, except the guide discs which would incorporate "V" slots to allow greater flexibility when the pig negotiates the smaller bore sections of pipe. The body of the pig remained hollow to allow for buoyancy aids to be fitted and tracking devices to be fitted.

The 24" diameter cups are moulded in pipeline grade PU and incorporate support ribs backed with a sealing membrane.

The flexible coupling for the above pigs comprised of two steel flanges. The two flanges have a length of carbon steel chain connected between them and the chain is then encased with hard polyurethane.

5.3 Phase 1 Pig Trials

Pig trials performed to see how the pigs would travel in 2 pipe diameters (16” & 24”) and their ability to remove wax in the 16” diameter.

16/24A “Sun Pig”

This prototype pig performed well in the 16” diameter, however, did not remove the wax from the 16” as efficiently as a standard bi-di pig. 16/24A traversed the system however it was noted that the discs did not recover in the 24” section as well as expected.

16/24B

This pig was very difficult to load in the 16” pig launcher due to the friction from the larger discs. This prototype pig performed well in the 16” diameter and removed the wax from the 16” as per the standard bi-di pigs. 16/24B traversed the whole system and the larger discs recovered in the 24” section as expected.

Conclusion: 16/24A failed to remove wax as expected and 24” discs recovery, therefore the decision was taken to move forward with 16/24B design.

6 Phase 2 – 2018 Pig Design

In Phase 1 it was shown that the 16” & 24” pipeline features can be traversed with this pig design, focus was now to ensure the pig can pass through 34” diameter unaided and without intervention from another pig in the system.

The update from 16/24 B to 16/24D was all about weight saving and to increase the pig's buoyancy. By increasing the pig’s buoyancy, allows the pig to better centralise in the 24” diameter with an aim to seal effectively and also to travel through the 34” x 305km section by using the flow of oil to push the neutrally buoyant pig all the way to Teesside unaided.

6.1 16/24D Pig

The pig was changed to a dual module titanium body c/w internal cavities and external collars fitted with syntactic foam elements to save weight and increase buoyancy. The 24” discs were replaced with 24” spider arms to give support and reduced thickness 24” sealing discs.

Calculations showed that to enable the pig to be neutrally buoyant in crude the pig would need to weigh approx. 89 kg in air and with all the changes made to the pig and the exchange of components the complete dual diameter pig achieved a weight of 8kg in water. Buoyancy was further verified by submersing the pigging in a water tank to check the pig’s buoyancy and trim.

6.2 Phase 2 Pig Trials

Pig trials were performed with the 16/24D pig to review its ability in the 34” section and its interaction with the other pigs in the system if they were to meet at key locations across the system.

The trials were performed at very low flow rates to give an understanding of how the pig behaves when also trying to transition a diameter change (16” to 24” and 24” to 34”)

A target flow rate of 60m3/hr (pig speed 0.15 m/sec) was set as a benchmark for the pig to be able to travel through the 16” & 24” section. This was achieved in part during this trial, but the pig did tend to stall at points in the 24” section and required the flowrates to be increased to approx. 150m3/hr to complete the journey.

Figure 10 - 16/24D during interaction trials.

The pig’s ability to travel through the 34” system was adversely impacted by its 8kg weight in water where the pig tended to travel at the bottom of the pipe, requiring flowrates up to 550m3/hr to make the passage to the 34” pig receiver.

Interaction with other pigs in the system, revealed no issues.

Conclusion: The pig design is certainly the correct vehicle to progress to the next stage, however the 8kg weight in water is certainly impacting its ability to travel in the larger diameters.

Weight losses at a component level need to be investigated further to make the pig neutrally buoyant in water and subsequently crude oil.

7 Incorporating New Technology

With approx. 8kg of weight to lose and the requirement to make the 16”/24” pig neutrally buoyant in water / crude, new exotic materials generally not considered for standard pig manufacture were incorporated.

- Microsphere glass bead encapsulation into PU components
- Improved syntactic foam for increased buoyancy internal and external mounted on the pig.
- Reduced thickness of 24” sealing discs
- Titanium body “pepper potted” to reduce mass of titanium from the body, whilst ensuring the pig body integrity and strength.

Microspheres are small spherical particles, with diameters in the micrometre range (typically 1 μm to 1000 μm (1 mm). Glass microspheres are primarily used as a filler and volumizer for weight reduction.

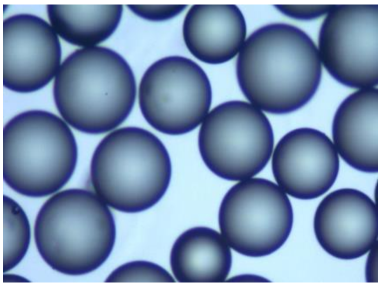


Figure 11 - Glass microspheres.

Figure 12 - Neutrally buoyant PU discs.

PU disc mixed with microsphere content, showing the disc has neutral buoyance in water versus a standard disc which is not able to float.

2 x Titanium pig bodies “pepper potted” to remove weight and internal cavity fitted with syntactic foam inserts to provide additional buoyancy.

Figure 13 – Pig bodies.

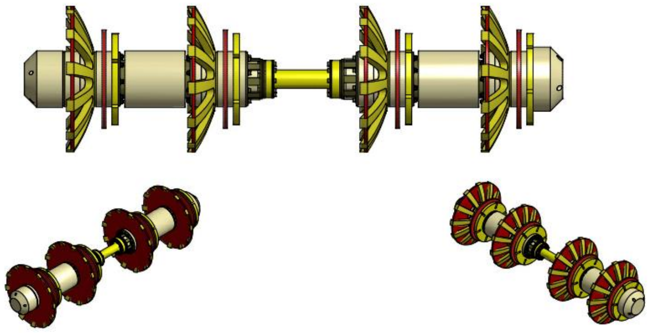
Figure 14 - 16/24E Neutral buoyancy check.

Following the changes above, the pig was able to achieve neutral buoyancy in water (89kg in air). This was confirmed following a buoyancy check in a test tank.

8 Phase 3 - 2019

In 2019 the 16/24 pig was upgraded to the “E” edition of the pig which was built and trialled for use.

8.1 16/24E pig



This dual diameter and dual module pig features several new elements in its construction.
The pig’s weight being the key contributor to its intended success in navigating the 3 x pipeline diameters, with a weight in air of 89kg and weighted to 93kg to be neutrally buoyant in water for its intended onshore pig trial.

To reduce the pig’s weight this was performed in a number of ways.

- The number of sealing and guide discs in both 16” and 24” were reduced were possible and additional syntactic spacers fitted.
- All steel parts were replaced with titanium, excluding the chain link in the tow arm.
- PU sealing and support components were moulded using microsphere components.
- Syntactic foam buoyancy modules were fitted internally and externally to the pig.

8.2 Phase 3 Pig Trials

Following the weight loss and increased buoyancy modifications made to the pig, 16/24E was then made ready for pig trials once again in 2019.

Trials	Results
16” wax removal trial	Passed, with wax removal better than standard 16” pig
16” 5-day compression trial	Mixed results signs of deformation, but pig still recovered to 24” diameter
16” to 24” transition at low speed	Pig able to travel at 30m3/hr in 16” (0.07 m/sec) and 100m3/hr in 24” (0.1 m/sec)
24” to 34” transition at low speed	Pig able to travel at 100m3/hr in 24” (0.1m/sec) and 150m3/hr in 34” (0.08 m/sec)

Figure 15 - 1624E wax removal / compression test / passing through 24" & 34" acrylic spools.

Conclusion: Pig put forward for operational service in the pipeline system.

9 Operational Pigging

Prior to any operational pigging run, the pig needs to be equipped with bypass across the pig to allow wax to be displaced ahead of the pig. Generally, bypass on a standard pig is via predrilled holes in the pig body to allow flow to pass from rear to front of the pig. As 16/24E internals are packed with syntactic foam inserts, this means there is no throughput for bypass through the body.

Predrilled holes were then included in the 16” discs to allow through put of flow from rear to front.

Additionally, a further weight reduction and increase in buoyancy was needed to make the pig neutrally buoyant in crude oil.

9.1 Gannet to Fulmar

The pig was first run in an operational environment from the Gannet platform to Fulmar platform (16” x 108km) prior to the Fulmar platform being bypassed. On receipt of the pig at Fulmar, it was evident that the heat effect from oil at >60° at launch had an impact as compression set of the discs was partially present on the 24” sealing discs as this point. However, the pig was received at Fulmar without issue.

9.2 Gannet to Teesside

Figure 16 - 16/24E received at Teesside 34" pig receiver.

In mid-2020 the 2nd operational pigging run from Gannet platform to Teesside took place in the new pipeline configuration. Based on flowrates it should take approx. 11 days to travel from Gannet to Teesside, however 5 days into the run it became evident that the pig was suffering from compression set of the 24” discs once again as it failed to trigger pig detection equipment at the newly installed subsea 24” Gannet wye location and beyond.

Using a combination of ullage from each of the platforms the pig was eventually recovered to Teesside a number of weeks later, showing the 24” spider arms and discs had badly deformed to circa 18”.

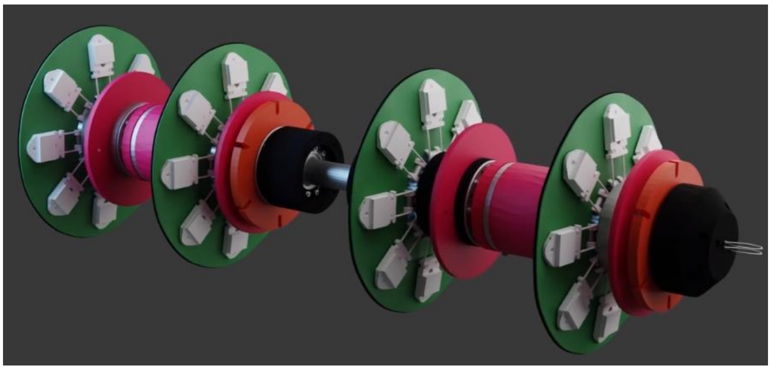
Conclusion: No further operational pig runs and back to the drawing board on the 24” elements.

10 Phase 4 - 2020

Given the failure of the 24" PU spider arms and the 24" sealing discs due to heat and resulting in compression set of these components.

10.1 16/24F pig

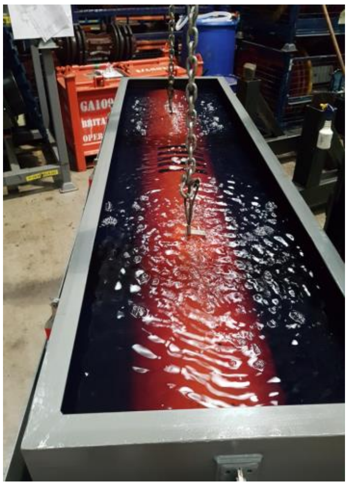
24" PU spider arms were moved to a steel torsion spring design to counter the effects of heat at the launch end of the pipeline. Giving the ability for the 24" sealing elements to spring into position once the 16" to 24" transition is reached.



The 24" sealing discs are now thinner and backed with a Kevlar sheet for further heat protection, both sealing disc and Kevlar sheet are both attached to each of the 8 x torsion springs.

10.2 Phase 4 Pig Trials

Figure 17 - 16/24F Heat trial.



To understand if the changes made to the pig could withstanding the >60° when held in a compressed state, the pig was subjected to heat trials where the pig was pulled into a 16" cassette and then submerged in diesel at 60° for 5 days. This would replicate the pig's condition whilst being held and launched from the Gannet platform.

Following successful completion of the heat trial, the pig showed very little effects of compression set and the torsion springs returned back to the 24" diameter with ease. At this point the same pig was then pumped through the test rig to confirm that the pig can indeed pass through the 16", 24" & 34" diameter changes and all associated pipeline features as per the flow set out in section 8.2.

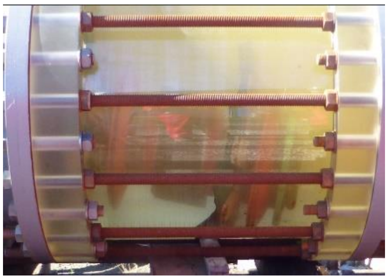


Figure 18 - 16/24F Passing through 24" & 34" acrylic spools.

Conclusion: Pig put forward once again for operational service in the pipeline system.

11 The Solution

The dual diameter 16/24F has routinely removed wax in the 16", swept water in the 24" & transited the 34" x 477km pipeline from the Gannet platform to the Teesside terminal for more than 2 years (2021 to 2023) and will continue to whilst the Gannet platform is exporting oil to Teesside.

The pig travels the complete system in approx. 11 days from launch to receipt at a frequency of every 30 to 60 days.

The 1624F pig is designed, built, tested, and refurbished for each operational pigging run by Pigtek Ltd.

Figure 19 - 16/24F Ready for deployment.

12 Acknowledgments

The following departments and companies are acknowledged for their part in the project:

- Shell E&P UK
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