As an increasingly large number of conventionally “unpiggable” and difficult to inspect pipeline systems approach the end of their design life, and with these pipelines often being used in challenging environments and in harsh service operations, new techniques are needed to ensure that these pipelines are safely able to continue operating. This is particularly important considering the continued financial pressures being faced by the oil and gas industry.

Introduction

Discovery™ is the world’s first subsea Computed Tomography (CT) scanner. It is a non-intrusive external scanning technique which does not affect the operation of the pipe. It also does not require removal of any external coating applied to the pipe, being equally adept at scanning through 50mm of heavy concrete weight coats as it is at scanning through micron-thick fusion bonded epoxy coatings.

CT scanners are particularly suited for scanning pipelines that, for various reasons, may be difficult to inspect by conventional techniques, such as in-line inspection or local inspections such as UT or PEC. Reasons a pipeline may be considered difficult to inspect or unpiggable include:

- No pig traps installed or pig traps removed
- Multi-diameter pipes
- Tight bends in the line, particularly those associated with smaller diameter pipes
- Pipe cleanliness - deposit or build up inside the pipe bore which may not be controlled by any existing applied inhibition mechanisms
- Internal coatings or linings
- External coatings
- Additional metal items such as heating elements, centralizers or piggyback pipe supports
- Low or even no flow rate
- Dead legs
- Pipe-in-pipe or multi-pipe systems

In these situations, an operator may be forced to simply “manage” their pipeline with assessments and models which, while useful, are limited by the information they are built on. In turn, this can lead to over-conservative approaches which could prematurely “fail” a perfectly acceptable pipeline. This is a particular concern for pipelines approaching the end of their design lives and where information pertaining to their historic operation may be unreliable or unavailable.
Computed Tomography (CT) and Discovery™

Discovery™ operates along the same basic principles as CT scanners used in hospitals worldwide, with the main difference being the type of source used. For medical CT an x-ray source is used, whilst for Discovery™ a gamma ray source is used. The reason is that the gamma ray’s high energy photon beam can pass through denser materials such as steel, whilst an X-ray CT beam is lower energy and less ionizing (and therefore safer for the person being scanned) but the lower energy means it cannot even pass through bone.

The principle behind Discovery™ (and CT scanning) is relatively simple – the CT beam passes through a material and the density of this material can then be calculated by how much the beam is weakened (the attenuation coefficient). Reconstruction models then take this information and use it to generate an accurate image of the scanned item. CT reconstruction models are easiest understood by considering them as being like Killer Sudoku puzzles, so loved by commuters worldwide. In Killer Sudoku, you have a grid with values at the end and from this you have to work out what sum gives the correct answer (Figure 2). Now, whilst a 9 x 9 Killer Sudoku grid is a normal (if tough) challenge for a daily commute, for industrial CT scanners the grid is many times larger. Consequently, it is only possible to “solve” a CT scan by the use of computers and iterative algorithms.

![Figure 2: Two of the Many Possible Solutions to a Simple Killer Sudoku Puzzle](image)
Selected Projects

With Discovery™ now having performed over 500 scans on pipelines, flowlines and risers in the Gulf of Mexico, and a similar number across the various North Sea sectors, Discovery™ has proven itself across a wide variety of pipe systems, highlights of which include:

Piggyback Pipe Systems

Whilst piggyback pipe systems provide many benefits to an operator (a single pipeline route being just one example), inspecting piggyback pipe systems has previously provided a particular challenge as the narrow spacing between the pipes makes it difficult for traditional techniques to perform a full 360 degree scan.

Unlike traditional inspection methods which need full access to all areas of the piggyback pipe, using specially designed external spacers, Discovery™ clamps around the outside and in one single scan performs a full scan of both of the piggyback pipes (Figure 3).

![Figure 3: Piggyback Pipe Inspection](image)

In Figure 3, both the main production pipeline and smaller piggybacked support line are clearly visible at all positions and orientations. This means that wall thickness and flow measurements can be taken and assessments can be performed. The bolts and pins securing the two halves of the specially designed pipe clamp can also be seen around the outside of the scan field, as can the ties used to separate the upper and lower pipes.

Pipe-in-Pipe Systems and Pipe Bundles

Pipe-in-pipe systems and pipe bundles are particularly difficult to inspect by traditional methods for many reasons, including:

- Can’t visually inspect the inner pipes from outside
- Not possible to inspect the outer pipe from inside (due to annulus)
- Inner pipes may be lined or manufactured from a corrosion resistant alloy (CRA)
- Centralizers or spacers – extra (irregular) material inside the pipe
- Heating elements or insulation

Pipe-in-pipe systems are also ideal for use in challenging environments or for transporting products where a high temperature needs to be maintained, as they provide the highest level of insulation since the annulus allows for an area where a low conductivity material (such as air, nitrogen or aerogels) can be contained. Whilst it would be possible to produce a single pipe with sufficient external insulation coating to maintain temperature, the amount of insulation required makes it impractical.

Discovery™ has proven itself to be particularly adept at scanning pipe-in-pipe systems (Figure 4), providing accurate wall thickness measurements for both inner and outer pipes as well as being able to provide a report on the condition of the spacing between the inner pipes. A test-tank example of extreme pipe movement of the inner pipe with respect to the outer pipe, as has been seen now in several Discovery™ scans, is provided in Figure 5.

![Figure 4: Pipe-in-Pipe Inspection with Selected Wall Thickness and Spacing Measurements](image1)

![Figure 5: Pipe-in-Pipe Inspection Showing Extreme Movement of Inner Pipe](image2)
With pipe bundles being, at least to Discovery™, the same as pipe-in-pipe systems, pipe bundles present only a similar level of complexity. Figure 6 shows a test-tank scan of a pipe bundle where the various pipelines, umbilicals and even seam weld and rust accumulation in the bottom of the pipeline can clearly be seen.
Concrete Weight Coated Pipes

Historically, to perform a conventional inspection campaign on an unpiggable concrete weight coated pipe, most inspection techniques would require the operator to remove the concrete weight coating on the pipe. There are several issues with this approach, including:

- Accidental damage during or after concrete weight coating removal
- Potential exposure of external pipe surface to corrosive environment
- Reduced production whilst concrete removal occurs
- Repair of concrete weight coating once scanning complete
- Increased inspection time and cost

Discovery™ scans through the concrete weight coating, reducing the time and cost of the inspection campaign without reducing the safety of the pipeline. As can be seen in Figure 7, Discovery™ was clearly able to identify (to the standard tolerance) the pipe wall thickness and areas of wall thickness reduction, the seam weld and pipeline ovality. In addition, Discovery™ could clearly identify the positions of the concrete rebar and supporting metalwork.

Figure 7: Concrete Weight Coated Pipe Inspection
Build-Up and Blockages

Wax and hydrate are two common flow assurance threats when transporting unprocessed hydrocarbons. Both can precipitate out of the transported product and deposit onto the line. Initially this decreases the pipeline’s cross-sectional area and reduces the volume of fluid able to be transported at a time whilst at the same time increasing production costs as more power is required to propel the fluid along the pipeline (Figure 8). Eventually this can cause complete pipe bore blockages and damage, either because of continued product precipitation or due to chunks of deposit being transported along the line. The end result is an increase in production costs and a restriction in the operational capacities of the line. On some lines, high product temperatures need to be maintained in order to inhibit wax and hydrate formation to minimize the risk of blockages and the need for more invasive remediation strategies.

[Figure 8: Hydrate Formation and Remediation Loop - Real Time Monitoring with Discovery™]

Maintaining the temperature also reduces the risk of under-deposit corrosion - a corrosion mechanism of concern to many Operators as maintaining sufficient product temperature can be difficult. Under-deposit corrosion is a localised corrosion mechanism that tends to be very aggressive and is difficult to control by inhibitors as they cannot reach the corroding metal due to the presence of the deposit layer. Discovery™ scans can be performed on operational lines, enabling an operator to see the actual fluid flow conditions during the pipes normal operation and quickly and easily identify any areas of water hold-up, deposits or any other flow-associated issue. To quote one Senior Pipeline Engineer “In just one ten-minute scan, Discovery™ has shown me more about the condition of this pipeline than I have obtained from all of my modelling over the last two years”.

As can be seen in Figure 8, Discovery™ was successfully able to identify all the hydrate formation and dissociation steps and accurately identify the actual product pressure to within 0.1g/cm³. This provided an Operator with the data necessary to implement the most suitable remediation strategy to resolve the issue, improving productivity and reducing costs - whilst at the same time reducing the environmental impact of the process.
Conclusions

By using Discovery™, Operators can now inspect traditionally “unpiggable” and difficult to inspect lines and “see” inside operational pipelines to a higher degree than has previously been available – all without interrupting production and therefore differing revenue.

In a single scan, Discovery™ generates data for wall thickness (integrity) assessments as well as providing accurate measurements of flow profile and product density. Since this can be done on a fully operational pipeline, Discovery™ allows an operator to confirm and monitor that flow assurance and remediation strategies are working, as well as ensuring that corrosion and inhibition strategies are effective and suitable.

Since Discovery™ entered the market in 2015, over 500 scans have been performed - allowing Operators to save on inspection programs, safely extend the operational life of their lines, as well as maximise productivity.