ON-LINE, NON-INTRUSIVE DIAGNOSTIC TECHNIQUES FOR PIPELINE INSPECTION AND FLOW ASSURANCE

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CONTENTS

1. INTRODUCTION

Tracerco have, over the past forty years, offered the **Tracerco Diagnostics™** technology to look at the performance of oil and gas process systems. The measurement services offered involve the use of radioactive sealed sources and unsealed radioisotope tracers to provide a rapid and detailed picture of systems performance whilst remaining on-line. These techniques are carried out on-line, external to the pipeline, with no interference to normal pipeline operations, and effectively allow us to ‘look’ through vessel and pipe walls to measure contents and process parameters.

This paper focuses on selected areas of the **TRACERCO Diagnostics ™** technology as applied to Pipeline Inspection and Flow Assurance. It describes the radioisotope measurement technologies that are used for:

- Pipeline pig tracking and locating.
- Isolation tool positioning and monitoring during pipeline repair operations.
- Leak Detection in umbilicals and pipelines.
- Monitoring critical liquid interfaces during deep-water pipeline installation.
- Liquid slugging measurement - size and frequency of slugs in gas lines.
- Pipeline deposit location and amount.
- Pipeline deposit profile and inventory of long distance pipelines.
- Flow measurement and flowmeter calibration.
- Moisture under insulation detection for corrosion prevention.

This paper will show how the techniques are employed, the type of results that are achievable, and describe selected case studies.

2. BASICS OF RADISOTOPE TECHNOLOGY

There are four main types of radioactivity. These include alpha particles, beta particles, neutrons, and gamma electromagnetic radiation. Alpha and Beta emissions have limited use in industrial applications, as they are very weakly penetrating, and thus cannot be detected through a steel wall. Neutrons have a very specific use for diagnostic purposes and can be used to determine the presence and location of hydrogenous liquid within a process system. Electromagnetic gamma radiation is most commonly used for on-stream non-intrusive investigations, as the radiation emitted is able to penetrate and pass through matter, such as steel, allowing its detection at the outside walls of a process system.

Gamma radioisotopes are used in two fundamental physical forms:

a) Sealed source scanning techniques

b) Unsealed Radioisotope Tracing Techniques

A sealed source consists of a small pellet of a radioisotope that is sealed within a steel case. The source is mobilised to a place of work, used and then transported from the site after completion of a work schedule. Sealed sources can be used to scan through a pipe to identify such things as lining integrity, density of liquid present, presence of fluid or gas slugging, solids build-up and other process anomalies.

Unsealed radioisotopes are a radioactive solid, liquid or gas that follow a particular material through a system. Sensitive radiation detectors are placed on the outside surface of a pipe and detect the unsealed tracer presence upon its flow past specific positions. Careful consideration must be given to the type and amount of tracer used to ensure, if adding to a product stream, the material does not remain radioactive after completion of the project.

Due to the penetration ability of gamma emitting sealed and unsealed radioisotopes used, very little preparation is needed on site to carry out a measurement, for example there is no need to remove lagging from a pipeline, or if subsea no requirement to remove concrete coating if present. Due to the ability to rapidly gather data, studies can involve repeat testing at a variety of process rates and conditions, and results are available immediately.

In all of the above applications it is important to note that, due to the use of sensitive radiation detectors, the amount of radioactive material used is very low. Comparing the technologies with Non Destructive Testing, amounts used are some 1,000 times smaller. The on-line non-intrusive testing methods, and use of small levels of material, mean that there is no disruption to normal operations.

3. RADIOISOTOPE TECHNIQUES USED

3.1 Tracerco Diagnostics™ Scan

The application of radioactive gamma transmission scanning requires the use of a sealed source and a sensitive radiation detector set on adjacent sides of a pipe. The source and detector are at a fixed distance apart within a yoke. The yoke is positioned across the pipe. The transmitted radiation signal passing from the source through the vessel is recorded at the detector. An output of radiation intensity is produced. The radiation intensity is directly related to density by the following equation:

$$\mathbf{I = I_o e^{-\mu\delta x}}$$

Where I = radiation measured at the detector,

I_o = radiation intensity at source position

μ = constant for specific isotope

δ = density, x = distance between source and detector

The radiation intensity I_o of the source is constant, μ is a constant and if the distance is fixed by using a solid yoke, measuring the intensity I at the detector will allow bulk density between the two points to be measured.

This technique therefore can be used to determine changes in density due to gas slugging, oil in water or water in oil, solids build-up on the pipe wall or loss of lining from a pipe inner wall. The technique can be used for surface applications as well as sub-sea. Some typical project examples include:

- scale or sludge thickness in well flow lines and associated manifolds
- deposit in sub-sea lines
- deposit in flare and relief valve lines
- hydrate blockage in sub-sea gas lines
- air/liquid interface measurement in pipe lines
- slugging frequency within a sub-sea multiphase pipeline

3.2 Tracerco Diagnostics™ Flow Study

In industrial processes the need to measure flow of all types of material arises frequently. Radiotracer techniques have been found useful among the available methods, often offering advantage over the more conventional ones. Applications for which this technique is regularly used include checking or calibration of installed flowmeter's, measurement of flow in systems where no flowmeter's are installed and flow distribution studies in multiflow systems.

A pulse velocity method is the predominant method used. This involves the injection of a sharp pulse of suitable radiotracer into the process stream and its passage downstream observed by a pair(s) of radiation detectors positioned externally on the pipe with the first detector sufficiently far from the injection point to ensure lateral mixing of tracer. By measuring the time interval between detector responses and knowing the distance between the detector the mean linear velocity can be calculated. If full bore turbulent flow can be assumed then the velocity can be converted to volumetric flow knowing the pipe internal diameter. Accuracy will depend on the precise circumstances but the mean velocity can usually be measured to better than ± 1%. The total accuracy on the volumetric flow depends on how accurately the internal diameter is known, and is typically 3-4% working from piping

specifications, although this can be improved by measurement of outside diameter together with ultrasonic wall thickness measurements.

Whilst this method is usually employed in basic flow measurement it has been successfully used in the area of **Flow Assurance**, where it is used to measure the location and extent of solids within a pipeline. In this application the flow rate through the system must be known and kept constant. Detectors are positioned at known distances apart along the pipeline. A pulse of tracer is added to the pipeline and its velocity past detector positions measured. Using the velocity and flow rate the average bore size can be calculated between detector locations. This measurement can give critical information prior to any proposed pigging operations are actually performed.

3.3 Tracerco Diagnostics™ Pig Tracker

The Tracerco Diagnostics™ Pig Tracker system is the most reliable method of tracking pipeline pigs or plugs available on the market today. It can be used to track pigs or monitor isolation plugs for movement in pipelines that are difficult to monitor by conventional tracking devices. The Pig Tracker system relies on a small radioactive source being attached to the pig or plug just prior to launching. One or more GammaTrac™ units placed on the outside of the pipe can then monitor its progress down the pipeline.

The Pig Tracker System for labelling and tracking of pipeline pigs and plugs offers the following significant advantages:

- Outstanding reliability and proven track record
- Very cost effective
- Simplicity of operation
- Operates on any diameter pipeline
- Applicable to gas/liquid operations
- Operate on "dual walled" pipelines

The radioisotope sources are produced under the guidance and supervision of Tracerco and are tailored for each individual project. This enables the level of radiation at the outside of the pipe to be kept very low so that all personnel **DO NOT** need to be classified radiation workers. Sources are loaded into and unloaded from the pig at launch and recovery time by a Tracerco Engineer. If the pipeline is subsea, the GammaTrac™ units can be attached to the pipeline by divers or ROV, and can be either battery operated or powered through the ROV umbilical or independent cables from a platform or DSV. They can work to a water depth of 3,000 metres, and can flag the passing of a pig, locate lost pigs, count and time numerous pigs past a set point, and function as an alarm unit for monitoring isolation plug movement.

3.4 **Tracerco Diagnostics™ MUI – Moisture Under Insulation**

A probe consisting of a source of high energy, or `fast' neutrons and a detector that is sensitive to low energy, `thermal' or `slow' neutrons is held against the side of the vessel or pipeline under inspection and moved along the surface. Fast neutrons from the source penetrate the wall of the vessel and interact with the medium inside. If the medium is hydrogenous, neutrons are moderated to thermal energies by collision with hydrogen nuclei. Slow neutrons diffusing back out from the vessel are detected. The detector response is thus a function of the hydrogen concentration of the material adjacent to the probe.

A large change in signal is observed when the probe moves across a liquid \vapour interface. Lesser changes in signal occur at interfaces between liquids of different hydrogen concentrations. In general, the greater the magnitude of the slow neutron signal the greater

the concentration of hydrogen nuclei and this is to an extent correlated with bulk density; but geometrical effects at the macroscopic and microscopic level mean that the technique is not strictly quantitative for measuring the density of liquids in vessels.

This technique can also be used to measure the hydrogenous content of pipeline lagging, and can accurately determine the location and extent of water under lagging. This is a useful method to use as part of a regular preventative maintenance inspection program to identify and replace sections of wet lagging that could otherwise eventually lead to external pipeline corrosion.

4. PIG TRACKING CASE STUDIES – Tracerco Diagnostics™ Pig Tracker

4.1 Case Study 1 – isotope tracking during corrosion inhibitor pigging operations

A UK offshore operator had experienced severe internal corrosion problems in a sub-sea oil export line, which had resulted in failure of the pipeline and a subsequent release of oil to the sea. The subsequent pipeline management program included regular corrosion inhibitor runs, which involved running two pigs through the line with a slug of corrosion inhibitor in between. The trailing pig was designed so that it did not make a seal with the line, allowing the corrosion inhibitor to be gradually coated onto the line. As the corrosion inhibitor is used, the trailing pig is pushed closer to the lead pig. To check that the process has worked correctly, both pigs are tagged with radioisotopes so that GammaTrac™ units can accurately measure the distance between them at launch and receipt. Radioisotopes were chosen as the measurement method due to their accuracy and 100% reliability, and have been used for over 20 of these pigging runs in the last two years with 100% success and zero failures.

4.2 **Case Study 2 - isolation tool positioning during pipeline repair operations**

A 24-inch pipeline between two platforms offshore Malaysia was leaking product to the sea. In order to repair the leak it was proposed to position isolation plugs either side of the leak point to allow repairs without emptying or depressurising the pipeline. During these operations it was important to position the isolation plugs as close as possible to the leak point, so the isotope tracking technique was used due to its high reliability and ability to accurately position the isolation plugs to within 5cm of their desired position. Radioactive sources were loaded onto both isolation plugs, as well as the other sealing bi-directional pigs in the train. The launch of each pig and plug was confirmed on the launch platform by external GammaTrac radiation detection units, and subsea GammaTrac detectors connected to an ROV from a diver support vessel were used to track the pig train as it approached the leak point. At this time the pumping speed was reduced and each plug accurately positioned in the desired location. The isolation plugs were then activated and the necessary pipeline repairs made. During this time two subsea GammaTrac detectors were clamped to the pipeline at the position of each radioactive source, and connected through an ROV to an alarm unit on the vessel. This was to act as a safety device so that if there was a failure of an isolation plug any minor movement of only a few centimetres would trigger the alarm and warn divers to immediately vacate the area. Once the repairs had been successfully completed the plugs were deactivated and pumped to the receiving platform. Confirmation of the arrival of each plug and pig was made by a GammaTrac detector on the platform, after which the sources

were removed and transported back to shore. The sketches below show the pig train position and arrangement. [SEE APPENDIX A]

5. LEAK DETECTION CASE STUDY – Tracerco Diagnostics™ Pig Tracker

The technique involves the insertion of a miniature pigging tool containing a small emitter. The tool is inserted into one end of the hose, which is then reconnected to the pumping system. Whilst the opposite end of the hose is closed pumping is started. The driving force behind the pig moves it towards the leak. Once the pig reaches the leak the driving force diminishes and the pig stops. In order that we can track the pig during pumping and then accurately locate it when it reaches the leak position we provide our sub-sea or surface detector units. These can be diver operated with a visual sub-sea display or mounted on an ROV. This service has been fully proven in a number of projects for oil and gas operators as well as hose manufacturers.

Tracerco were recently requested by a major umbilical cable company to help them identify the position of leaks occurring within an umbilical bundle. To identify the position of the leaks, Tracerco used the **TRACERCO** Diagnostics™ Pipeline Assurance techniques, using a miniature pig tracking tool. Each of the umbilicals, of which there were four suspected of leaking, had a diameter of 6mm, therefore only one pigging tool was required. All four umbilicals were inspected by inserting the miniature pigging tool into one end of the umbilical and then tracking fluid was used to push it along. The progress of the pigging tool was monitored and when it stopped, the umbilical was inspected, split (to remove tool) and then repaired. Due to the speed of the technique all four umbilicals were inspected and repaired within a full working day.

6. PIPELINE INSTALLATION MONITORING CASE STUDY - Tracerco Diagnostics™ Scan

Tracerco have recently been involved with a large pipe-laying project for a major operator in the Gulf of Mexico, providing Pipeline Installation Monitoring services. During the laying of the pipeline, which was taking place in deepwater (approximately 2000 metres depth), the pipeline had exceeded its critical weight and had been dropped from the barge. The reason for this was that the pipeline was being laid partially flooded with water in order to counteract the high pressures present, but control of the air/water interface in the pipeline was lost and the pipeline was filled with water. This excess weight caused the pipeline to snap and consequently the pipeline fell to the seabed. Apart from this being a dangerous occurrence, it was a very expensive process to recover the pipeline and replace the damaged sections.

Tracerco were therefore requested to utilise the Tracerco Diagnostics™ Scan technology to provide a monitoring system that would be permanently deployed off the back of the barge around the pipe string as it was laid. The water level in the pipeline was continuously monitored and controlled to ensure that it didn't rise too far, which would have caused the critical weight to be exceeded again, and has prevented any similar dangerous and expensive occurrences. Depending on the required height of the water level, the detection system is either deployed on chains off the back of the pipe stinger and hard wired to the monitoring station on deck, or if the critical height is close to the seabed the detection system is deployed through an ROV.

7. LIQUID SLUGGING CASE STUDY - Tracerco Diagnostics™ Scan

A major oil and gas company was recently experiencing problems with intermittent liquid slugging in a gas pipeline on one of its facilities. The slugging was causing operational problems and damage to downstream equipment. Tracerco were requested to investigate the

problem by use of temporary scanning systems placed on the outside of the pipeline, linked to continuous data loggers. The size and timing of each slug could clearly be seen, and the
monitoring was carried out continuously as the operator adjusted throughputs to get an indication of optimum operating conditions.

Tracerco are now currently working with one of the major oil companies to develop this service into an on-line system. Proprietary software will analyse the real-time signal output from the sensors, and produce online measurement data giving speed and size of slugs. The software can be run on most industrial computers, and delivers output data in a form suitable for controlling typical industrial PLC's (Programmable Logic Controllers). The flow control regime can then be regulated and optimised in direct response to advance knowledge of slug arrivals.

8. PIPELINE DEPOSIT MEASUREMENTS CASE STUDY - Tracerco Diagnostics™ Scan

A sub-sea 6-inch gas flow line was thought to be blocked by 'hydrate' with an approximate density of 0.98 g/cc. A gamma ray transmission survey was used at exposed sections of the pipeline, using an ROV with a fixed yoke scanning system attached. A radioactive sealed source was positioned on one side of the pipeline and the amount of radiation transmitted through it was measured with a radiation detector. The separation of the source and detector was kept constant ensuring that the intensity of transmitted radiation was a function of density of the medium it passed through. Thus it was possible, from measurements of radiation intensity at the detector and radiation intensity entering the pipe, to determine the density of material in the pipeline and make inferences about the distribution of flowing or deposited materials. Hundreds of measurements were taken at approximately one-metre intervals along the exposed pipeline, and this approach located and assessed the extent of the deposit within the pipeline.

The results can either be provided as a mean density of material across the pipeline, or if the approximate density is known the results can be shown as amounts of material in the line. An example of the results is shown in APPENDIX B:

9. PIPELINE DEPOSIT PROFILE AND INVENTORY CASE STUDY - Tracerco Diagnostics™ Flow Study

A 12” NGL pipeline connects an offshore platform to an industrial area onshore. The pipeline was designed to allow a NGL flow rate of 4000 metric tonnes per day. The pipeline is 117Km long with a diameter of 12” and a fill volume of some 8,537 m^3. The system is sub-sea for 89 of the 117Km length and partially buried. The lowest point in the system lies within a tanker channel. The span of this section is some 4 Km. The NGL flow rate is significantly lower than design limits, therefore some restriction was postulated.

The continuous increase in production of hydrocarbon offshore lead to a requirement by the operator to optimise production in the NGL pipeline. In order to ascertain the current condition of the pipeline, an assessment was required to ascertain the capability of inspecting the pipeline utilising a MFL inspection tool. Prior to performing any inspection work, it was necessary to quantify the amount of any debris within the pipeline.

The radioisotope pulse velocity technique was used to measure the velocity of the NGL at numerous points along the line. Given the NGL flowrate through the pipe, it was possible to calculate the mean cross sectional area between these points and thus estimate any restriction within. A sharp pulse of radiotracer was injected at the platform into the 12-inch NGL

pipeline. The NGL flowrate from the platform was monitored at hourly intervals throughout the course of the survey. The progress of this pulse was then monitored using a sensitive

radiation detector mounted on an ROV, deployed from a dive support vessel, positioned at strategic locations along the pipeline. A record of the tracer pulse centroid was made along with the relative position of the ROV as the pulse passed the detector. Accurate locations for the ROV, and hence, radiation detector, were obtained from the vessel’s dynamic positioning system. Once the pulse had passed the radiation detector, the ROV would be repositioned at a convenient location downstream of the tracer to await the arrival of the pulse once more. Again the time of the tracer pulse centroid and detector position were recorded. This procedure was repeated along the entire length of the pipeline to shore, whereupon fixed detectors monitored the progress of the pulse up to its arrival at the industrial area.

Provided accurate measurements of the actual flowrate of NGL through the pipeline were available, it was possible to compare these readings to the measurements taken by Synetix. Therefore, some time after the initial tracer injection, the NGL flowrate from the platform was measured using the radioisotope pulse velocity technique in an attempt to corroborate the flowrate readings supplied.

Velocity of the tracer pulse was successfully measured over 9 days. From the records of time versus distance, the velocity of the NGL was calculated. Areas of the pipeline that contained solids build-up or restrictions would exhibit a higher velocity (given a constant flowrate) than areas with no restrictions (full-bore flow). Provided full bore turbulent flow exists, it was possible to compare these measurements to given flowrate figures and hence calculate the effective internal diameter of the pipe. This was then used to calculate the degree of restriction in the pipe.

The first graph in APPENDIX C shows the responses from the detector over a 4.5km section.

The pulse peak heights generally tend to diminish in height as the pulse spreads, but are also dependent on the alignment of the ROV on the pipeline. However, since the measurements are taken as time differences between consecutive pulse centroids, the pulse peak height is irrelevant. Comparisons between measured and derived velocity along the full pipeline length are shown below, as well as the pipeline depth relative to sea level. Also shown is the depth of the pipeline over the inspected length. If two phase flow was present, then it is probable that the gas would have accumulated in the highest points of the pipeline, thus reducing the available cross sectional area for liquid flow and increasing the velocity of the liquid accordingly. The pipeline depth was included in order to ascertain if the areas of increased velocity coincided with the high points of the pipeline.

It can be seen that the areas of increased velocity in the first third of the pipeline coincide with rises in the line - but not the highest points. This suggests that the increased velocity in these areas is due to debris that has been deposited on the upward slopes of the pipeline due to the flow being unable to transport solids up these inclines. [see APPENDIX C, graph 2]

Finally the velocities measured were used to show the % restriction in the line and represented in figure 4. This showed that, over the first 35km the restriction was on average 20% of the bore but was up to 50-60 % at the 15km and 32km areas. [see APPENDIX C, graph 3]

10. MOISTURE UNDER INSULATION DETECTION CASE STUDY - Tracerco Diagnostics™ MUI

In the 1980's, a 12km Chlorine Line in Continental Europe fractured due to external corrosion resulting in a massive release of chlorine to the environment. The subsequent investigation concluded that this catastrophic failure was due to a build-up of water under the lagging, which had gone undetected for a long period of time, eventually corroding the pipeline and causing the environmental release. A requirement placed on the pipeline operator was therefore to either regularly replace the whole 12km of lagging or find an inspection technique to identify specific sections of wet lagging so that only these sections were replaced. After many trials, the Tracerco Diagnostic ™ MUI scan was identified as the ideal technique for this purpose.

An annual Tracerco Diagnostic ™ MUI scan inspection of the complete 12km line has therefore been carried out each year, which takes approximately four days, and any sections of wet lagging identified and subsequently removed. The wet sections are generally sporadic, over only a few metres, and only replacing these specific sections has provided huge cost savings.

11. CONCLUSION

There is a large range of non-intrusive on-line inspection techniques available that enable difficult, and sometimes previously thought impossible measurements to be made. Radioisotope technology offers a powerful and well-proven inspection technique when problems are encountered or pipeline conditions are uncertain. The technology has been adapted in recent years to assist pipeline inspection and flow assurance issues, and is increasingly being used by operators and contracting companies world-wide.

This paper has covered some applications, but there are undoubtedly other applications of this technology yet to be discovered. Historically the application of these techniques has expanded purely due to customer requirements that lead to continuous innovation, and I am sure will continue to do so.