The separation process is a fundamental part of all hydrocarbon production. The ideal for operators is to produce oil free from gas and water, remove all liquids from gas, and discharge produced water that is within environmental limits.

The application of a TRACERCO Diagnostics™ Separator Study allows the detection of process issues in separator and water treatment systems in real time. Using data collected, solutions can be found to better control separation and prevent harmful discharge. This article describes how this technology can be used to identify problems that occur within separation systems including:

- Scaling
- Oil in water
- Damage to vessel internals
- Blockages in perforated plates
- Flow distribution
- Residence times
- Slugging
- Emulsions
- Foam
- Deposit build-up

Scale Problems
Produced water can be very rich in salts, in fact the dissolved solids content in produced water is usually much greater than that of normal sea water. Salts are initially dissolved in the water present in a reservoir but as conditions change when the water is produced, the salts may form solids and deposit as scale. This can reduce pipe diameters, plug vessels and equipment that in turn can lead to diminished separation efficiency.

Regular density measurements across pipe work where scaling may be an issue allows a quantification of the amount of scale that is building up, allowing timely interventions to be performed by a specialist cleaning company prior to a complete blockage. As scale is more dense than production fluids, its presence within a pipe can be readily detected using a TRACERCO Diagnostics™ Pipe Scan.

Figure 1 illustrates results from a scan used to detect a blockage within a 15.2 cm produced water pipe. Measurements were taken every 25.4 cm along the blocked line.

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and a density versus distance plot was created. Knowing the approximate density of the scale and knowing the density of material that should have been present within the pipe, any reduction in signal was due to scale build-up. Using this data the thickness of scale could be determined at each position and the blockage accurately located.

Fluid Distribution, Residence Times and Equipment Blockage Measurement

Specialist radiotracer studies on separators can be used to detect problems such as oil in water, water in oil, gas undercutting, or liquid carryover. It can also detect the effect of blockages in perforated plates, flow distribution and accurately measure individual phase residence times.

The basic principle of a tracer investigation is to label a substance or phase and then follow it through a system. Looking at tracer studies from a problem solving point of view, if problems of fluid transport can be described in terms of ‘When?’, ‘Where to?’, and ‘How Much?’, then they can be solved by means of tracer techniques.

The basic requirements of a tracer include:
- Identical behaviour to the material under investigation
- Unambiguous detection at low concentrations
- No affect on the process under investigation
- Minimal residual concentration in the product.

The criteria can be met by the use of short-lived radioisotope tracers and by careful selection of the most appropriate tracer for a particular application. The technology requires a number of sensitive radiation detectors to be located on the walls as well as the inlet and outlet of the vessel under investigation. A radiotracer is injected into the process and if the material flows past a detector position it will register as a response versus time. Analysis of each detector response provides information on flow distribution and timing allowing flow dynamics within the vessel to be determined.

Figure 2 shows the position of detectors during a tracer study on a gravity separator. A gas, oil or water radiotracer is injected upstream of the vessel to allow adequate mixing with all phases. The first detector (D1) is positioned just after the injection point and provides information on the shape of the injected radiotracer pulse. The next four detectors (D2) are positioned as a ring around the inlet pipe. By comparing the radiation intensity against time for each of the detectors, flow distribution at the inlet can be studied and maldistribution detected. These also act as a zero point for residence time within the vessel. The next ring of detectors (D3) is typically focused around the lower parts of the vessel outside of any inlet devices. Assuming a separator with inlet cyclones these detectors will show any maldistribution or gas undercutting from within the inlet equipment.

More detector rings (D4) may be positioned close to separator internals such as perforated plates. Comparing data from each of these will give information about partial or full blockage of the plates indicated by maldistribution. In addition, comparing results from detectors in one ring along the vessel length with results from other detector rings, information is provided showing how a specific phase moves laterally through the vessel. The detectors at the gas outlet (D5) give flow distribution and vapour residence time in the separator. They also provide information on liquid carry over following liquid tracer injection. Detectors around the oil and water outlets (D6 & D7) detect residence time of the specific phase, oil in water underflow, water in oil overflow as well as gas undercutting.

Figure 3 shows examples of detector responses from a liquid tracer study on a vertical two-phase separation vessel. The

Figure 2 – Typical detector positions in a gravity separator.

Figure 3 – Measurement results from a vertical two-phase separator.

Figure 4 – Measurement of liquid distribution in a vertical separator.

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time between liquid tracer injection and detector response at the outlets provides residence time in the process vessel. Additionally, the shape and duration of the signal at the outlets gives information about mixing in the vessel. Finally, the presence of tracer response at the gas outlet detector allows measurement of liquid carry over from the vessel. Figure 4 shows the response from an inlet detector and four detectors positioned at equal distances around the vessel at the same elevation. Results reveal uneven flow distribution within the vessel with increased tracer and hence liquid flow in the western quadrant. In addition, the southern quadrant reveals less liquid flow at a lower velocity indicating poor distribution or a potential blockage in this section of the vessel.

Damage to vessel internals
Damage to vessel internals, especially an inlet device, can have a serious impact on the ability of a vessel to separate oil, water and gas. A TRACERCO Diagnostics™ Scan can be used to check the mechanical integrity of vessel internals. If the process is on-stream, measurements are limited to the vapour space above liquids. However, if the vessel is drained, virtually anything can be measured.

Figure 5 shows examples of scan lines and detector positions used to check that all inlet cyclones in a separator are in place. Solid structures between source and detector attenuate the signal and the amount detected gives an estimate of how much steel there is across the measurement path. In recording the data, the transmitted intensity, expressed in detector count rate is plotted on a logarithmic scale so that the transmission characteristic faithfully reflects the density profile of the scan line. The detected intensities provide information about the integrity of the internals. This information can be used to explain separation inefficiencies and help plan necessary shutdown repairs.

Rag Layer (emulsion) and Deposit Build-Up
TRACERCO Diagnostics™ Scanning technology can also be used to detect deposits and vapour profiles in pipelines, the presence and extent of a rag layer between oil and water and solid deposits in separators.

Figure 6 shows typical interface profiles at different lateral positions along a separator vessel. The extent of rag layer can be measured by the gradient of the response change between oil and water. Typical results show oil-water interface quality improvement as measurements are made away from the inlet device moving towards the weir or outlet bucket. The technology can be used very effectively in emulsion breaker chemical trials to determine the best type and concentration to use in a particular vessel. In turn, this can lead to significant cost savings as well as reduce the environmental impact of excess chemical use.

Solid build-up in a vessel is of importance as any significant reduction in the free volume of a vessel will lead to a reduction in residence time leading to reduced separation efficiency. Neutron scanning technology holds many advantages over infrared with measurement being made without the removal of insulation and is not affected by external heat sources on the vessel surface.

Detection of Vapour and Liquid Slugging
Slugging can cause major upsets and process instabilities resulting in production losses as well as an increase in harmful discharges. In some situations the presence of slugging can damage process equipment. If slugging is found to be present within a process system it is important to understand its characteristics. This may allow changes to be made that will reduce or eliminate its presence and the detrimental affects on process hardware.

Figure 5 – Cross sections of inlet cyclones in a separator vessel. Examples of source, detector positions and scan lines are shown.

Figure 6 – Shows interface profiles at various positions in an MP separator vessel.

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Companies are fast realising the importance of fully understanding what makes a successful pigging campaign. Tracerco is experiencing an ever-growing number of enquiries about its flow assurance study and pig tracking service, as clients realise the benefits of optimising their cleaning regimes, and the peace of mind gained while tracking critical pipeline pigs. Tracerco has completed projects worldwide, including challenging environments such as the Arctic Circle and in the deep waters of the Gulf of Mexico.

Why pig a pipeline?

Introducing a foreign object into any pipeline carries a risk of blockage and it is important to understand why pipelines are pigged to determine the most suitable detection methods.

Pipeline pigging is carried out for the following reasons:

- To clean pipelines before use.
- To fill lines for hydrostatic testing, dewatering following hydrostatic testing, drying and purging operations.
- To periodically remove wax, dirt and water from the pipeline.
- To sweep liquids from gas pipelines.
- To separate products to reduce the amount of mixing between different types of crude oil or refined products.
- To control liquids in a pipeline, including two phase pipelines.
- To inspect pipelines for defects such as dents, buckles or corrosion.
- To isolate sections of a pipeline for tie-in or repair purposes.

In critical applications where accuracy, reliability and confidence are most important, isotopes have scored particularly well in market studies. The following applications are the most crucial and are more readily suitable for isotope tracking:

Any application after first installation, such as flooding, cleaning and gauging – In this instance, installation may have caused the pipeline to buckle, or an engineering defect may cause the pig to get stuck and any delays will result in higher project costs.

Any inspection campaign using intelligent pigs – These pigs can be very long, in order to accommodate all of the inspection tooling required. Thus, they have a higher potential to lodge in the pipeline while negotiating bends or overhang pig trap valves.

Isotope tracking has been found to be one of the most reliable, accurate and confidence giving solutions in critical applications.

The first pig run - After any pipeline modification work, as debris may remain or an engineering defect may have occurred.

Whenever a pipeline isolation tool is being used – and accurate positioning is critical and/or long signal life is required to reliably track the tool after de-isolation.

Other factors that are important when assessing the criticality of a pig run include:

- Whether a pipeline has ever been inspected before. This is due to an unknown volume of deposit that may be present in the pipeline.
- Pipelines that, due to the nature of the product flowing, have the potential for hydrates to form. This will cause flow blockages and restrict the motive force in the pipeline to drive the pig through.
- Concern over a valve and whether it is fully open to allow the passage of a pig.
- How accurately a pig needs to be located.

Figure 9 – This photograph shows the location of stuck pig due to engineering modification not relayed to pigging contractor.

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The time in which a pig must be able to be located. For instance, some pipeline modification work can take up to a year. Thus, knowing where the pipeline pig is after that time is highly advantageous.

The ultimate objective of every pig run is to complete the task required and return the pipeline to its original operating condition in the shortest time possible. A stuck pig can have extremely costly implications. Therefore, it is important to determine with confidence the likely success of any pigging campaign, have a contingency should the pipeline pig become stuck (including accurate location), and monitor the effectiveness of any campaign.

Choosing a radioisotope tracking service

Isotopes are mainly chosen for critical applications. A small, low powered radioactive source is attached to the pig body prior to being launched, which sends a constant gamma-ray signal that can be detected on the outside of the pipeline. This solution has a number of benefits:

Detection time

As an isotope constantly emits a naturally occurring signal, it means that there are no concerns regarding battery life. So, should an operator be using a plug to isolate a line and the downstream modification work does not go to plan, there will be no concern over having to

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locate the pig within a certain time period. Therefore, pigs can now be launched from subsea launchers, lying dormant for a number of months prior to use again, using isotopes. This will eliminate concern about detection after launch.

Accurate positioning
Due to the highly collimated radiation beam, a pig’s location can be accurately located. Thus, in terms of a long tool, it may only just fit in a pig receiver. Therefore, knowing the exact location of the back of the pig will allow an operator to close the trap valve with confidence that damage will not occur to the valve or the intelligent pig.

Reducing component parts
Whenever systems are considered, those with fewer component parts are more reliable, so reducing the need for batteries by using a naturally occurring signal increases reliability.

Other benefits of using isotopes for pig tracking include:

- The pipe diameter does not matter. Isotopes can be used to track pigs in small umbilical lines and the largest transport lines (i.e., from several millimeters to several meters in diameter).
- Thick wall pipelines or weight-coated lines do not present a problem for the transmission of the signal.
- The contents of the line are irrelevant to the passage of the signal; gas, liquid or multiphase.
- Can be used for pipe-in-pipe pig tracking. Other technologies are seriously affected by this type of application.
- Can be attached to any type of pig or pipeline tool on the market with no effect on the performance of the pig. Batteries used in other technologies can be extremely cumbersome.
- The signal can be detected at all times irrespective of whether the pipeline is subsea or on land. So, should a subsea pipeline come onshore at a terminal, the isotope is always detectable.
- Multiple pigs can be tracked and/or located. Using differences in the amount of radiation emitted or different isotopes with different "signatures", each pig can be given a unique identifier.

Flow assurance studies
Considering an example, assuming a pig is run in a 24 in. pipeline 100 miles long and removes 0.016 in. of wax material from the wall of the pipeline. After 100 miles, a plug approximately 1450 ft. long would form. Therefore, it’s important to define how much deposit is located in a line. Tracero’s involvement with many pigging campaigns starts well before the launch of the first pig. Often, clients have applications where a pipeline pig has never been run through a line; or well conditions have changed with time, meaning conditions are occurring that can affect the flow properties of the pipeline, such as wax, hydrate, sand or scale. As part of its Precision Diagnostics portfolio, Tracero offers its flow assurance study technique that can be used to ensure the effective flow of oil and gas through an oil and gas processing facility or pipeline.

Many operators are extremely cautious when it comes to tackling pipelines that have never been pigged, as there is the potential for tools to become stuck due to unknown deposit amounts. Tracer techniques, similar to a barium meal used in medical technology, can be used to determine deposit location. The tracer injection technique requires the injection of a small amount (typically no more than 50 ml) of low activity radiotracer into the line in the form of a sharp liquid pulse, enabling the fluid velocity between externally mounted radiation detector loggers to be measured to better than 0.1% accuracy. For a known flowrate, a velocity between points can be derived. However, should deposits be encountered, this will cause the velocity of the tracer pulse to increase. Comparing this to the pipeline flowrate for the duration of the test enables the amount of deposit between successive detectors to be calculated. The tracer used is designed to flow with the particular material through the system. Sensitive radiation detectors are placed on the outside surface of the pipe (detectors are depth rated to 3000 m) and detect the unsealed tracer as it passes each specific detector position. These measurements can be used to directly measure fluid velocity, flowrate, phase distribution and deposit inventory.

Running a flow assurance study before and after a pig cleaning campaign will allow an operator to determine the effectiveness of the pigging run. This has significant benefits:

- Many intelligent pig runs fail due to the cleanliness of the pipeline after cleaning. A flow study will determine whether the line has reached an acceptable standard for the intelligent pig run to begin, reducing the likelihood of an expensive re-run of the intelligent pig.
- Pig cleaning campaigns can be optimised. Reducing runs to the minimum necessary will have the following benefits: minimise cost by reducing the number of times pigging specialists need to visit a platform; limiting the potential for environmental incidents by reducing the number of containment breaks that take place; and an increase in safety as pigging operations can be attributed to two explosions in the last decade.
- Pipeline dosing chemicals can be optimised, thus, having significant cost and environmental benefits.
Figure 7 shows the set-up of a TRACERCO Diagnostics™ Slug Monitoring system. It consists of two non-intrusive densitometers positioned at a known distance apart on pipe work. The measurement of density change in the pipe over time at each position and analysis of the shape of the density change allows a slug to be fully characterised with key information such as velocity, size, and frequency. In addition, the estimated arrival time at a separator can be calculated so remedial action can be taken to avoid damage or upset.

A typical slugging trend is shown in Figure 8, which shows flow differences between two deepwater risers. Ultimately in this instance, one of the wells feeding Riser E was considered to be an unstable producer and was converted into a water injection well due to its impact on overall production.

**Conclusion**

A TRACERCO Diagnostics™ Separator Study complements other diagnostic tools and techniques available to production engineers. The technology is non-intrusive with results generated on-site. This allows rapid understanding of fluid flow and mechanical integrity within a hydrocarbon separation train by essentially making the process transparent. This approach significantly eliminates guess work when trying to resolve process issues and allows accurate process data to be gathered providing information so that engineering decisions on process improvement or repair can be quickly made and implemented. If deemed necessary, immediate changes to a system can be made with further measurements to assess if improvements have resulted.

If you wish to find out more about this technology, please contact a representative in your area or visit our website at www.tracerco.com.
Please send me additional information on Tracerco’s offshore/reservoir applications:

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