Vinicius Carvalho, Scott LaVoie and Brock Williams, RESMAN, USA, examine a low-cost, low-risk alternative to production logging.
The oilfield reservoirs of today are more complex than ever, typically consisting of stacked, heterogeneous layers. Wells drilled in these reservoirs are also becoming increasingly complex, using state-of-the-art completions techniques.

Due to the high risks and costs of conventional surveillance technologies, such as production logging tools or permanently installed sensors, the great majority of wells in deepwater (a total of 400 subsea wells globally per year\(^1\)) and unconventional developments (more than 15,000 horizontal oil producers per year\(^2\) in the US) are produced without any assessment of the various sections of the reservoir interval or the completion method utilised.

Consequently, operators are forced to make reservoir management decisions without the key knowledge of the performance of the individual reservoir sections and it may never be known if the recovery from the reservoir was maximised.

**Bridging the reservoir surveillance gap**

RESMAN Intelligent Tracer technology helps provide knowledge of the inflow distribution across the reservoir interval by integrating intelligent tracers within the completion hardware. The tracer technology provides a production profile assessment for years of the well’s life.

This technology also detects the location of water inflow. Knowing which section in the reservoir interval is the cause of a well’s increase in water production is vital in effectively understanding the drainage pattern and identifying potential for bypassed reserves and the opportunity for sidetracks or new wells to access these reserves.

The installation of systems requires no cables, no connections, no intervention and no major changes to completion design or procedures. Thus, the risk inherited from intervention operations or wired sensors is eliminated. This is a robust solution for providing reservoir inflow information that has not existed before. It is risk-free, cost-effective, long-term and reliable, with hundreds of wells deployed successfully to date.

**Summary of applications:**
- Quantification of oil inflow contribution (Figure 1).
- Water breakthrough monitoring.
- Inflow assurance monitoring (flow control valves and packers functionality, multilateral and zonal inflow conformance).
- Detection of condensate banking and gas breakthrough.
How intelligent tracers work

The intelligent tracer technology can be formed into a variety of shapes to allow it to be integrated into a wide range of completion designs (Figure 2).

The systems are either oil sensitive or water sensitive and are designed to remain dormant until contacted by the target fluid. That is, the oil-sensitive systems remain dormant when in contact with water and the water-sensitive systems remain dormant when in contact with oil. Both systems are dormant in air.

When contacted by the target fluid, tracer molecules are released in very small quantities (Figure 3). This release is independent of flow conditions and happens at a lab-designed rate.

The company’s chemists have developed more than 70 uniquely identifiable chemical signatures for oil (RES•OIL) and another 70 for water (RES•H2O). It is important to note that these chemical signatures are unique in nature and cannot be found in any commercially available chemical library. This eliminates the possibility of mistaking these chemical signatures for various other chemicals found in production operations.

The intelligent tracers are strategically integrated with the completion equipment to monitor segments of the reservoir interval. Depending on the surveillance objectives, sections of the well or individual reservoir compartments are assigned with a separate and identifiable chemical signature for oil and/or water.

After well installation, the oil flows from the reservoir, contacts the RES•OIL systems, and the chemical signature is released into the oil, thereby marking it with a unique identification. Production from each reservoir compartment transports the tracer signatures to the surface (Figure 4), where production fluid samples are collected. The same process applies to the company’s water systems.

The samples are analysed and a dedicated team of experts models the results using software and inflow models that have been empirically verified in full-scale, flow-loop testing.

Extracting value from the data: inflow quantification with the flush out model

The Flush Out model is a proprietary mathematical technique developed to quantify inflow contribution from multiple reservoir intervals.

In this technique, intelligent tracers are deployed in each reservoir compartment that is connected to the main flow stream.

The intelligent tracers are designed to release their molecules in controlled rates that are independent of flow conditions. This feature allows a small volume of oil with a high concentration of tracer molecules to form during...
shut-in periods (Figure 3). When the well is started, initial production from the zone flushes out the fluids containing the high concentration of tracer molecules from the annular area to the main flow stream (Figure 4).

The zones with high inflow rates flush out the annular area faster than zones with low inflow rates, thereby preserving the high concentration of tracer molecules and generating a profile with steep rates of decline.

Alternatively, the concentration of tracer molecules in the fluid that is flushed out from a low-performing zone becomes more diluted as it enters the main flow stream and travels to the surface. Consequently, the tracer concentration profile presents a noticeably less steep rate of decline when compared to a high-performing zone (Figure 5). The flush out model analyses and compares the rate of decline in tracer concentration between each monitored zone and quantitatively determines the respective relative inflow rates.

The validity of the flush out model was verified in a full-scale, flow-loop test with joint industry project (JIP) partners Eni and Statoil at the Institute for Energy Technology (IFE) facilities near Oslo, Norway (Figure 6). The results of this test demonstrated that this analytical model can predict flow within 5% accuracy.

The flush out model can be used in deepwater developments with several miles of tie back and commingled production from multiple subsea wells.

Because of the multi-year life of the systems, operators can understand reservoir inflow contribution not only during the startup of each well, but also over time by performing new measurements with no intervention or risk.

As an example, the flush out model has been selected as the solution to quantify inflow contribution and detect water influx in the next frontier of deepwater exploration – the Lower Tertiary in the Gulf of Mexico – by several operators in the region.

**Tangible benefits of intelligent tracer technology**

**Cost optimisation**

This technology can be significantly more cost-effective than other reservoir surveillance methods. There is no additional rig time, no expensive completion hardware is needed, and no extra personnel are required at the well site for installation.

As an example, a super major IOC estimated costs for running a single subsea production log to be in the range of US$25 000 000 - US$40 000 000.

Alternatively, intelligent tracers can be used periodically over several years to detect water breakthrough and to reassess zonal inflow contribution with the flush out model without intervention well and at a fraction of the price of a single log from a PLT.

Additionally, multi-stage fracturing wells carry significant uncertainty regarding zonal performance over time. For example, many wells in the Bakken (Williston Basin) may experience strong initial oil production followed by a rapid decline in rates.

Nevertheless, feedback from a reservoir engineer working for an operator in North Dakota indicated that their reservoir models considered a uniform inflow distribution across all stages and along the entire 10 000 ft horizontal. By using the flush out model in a single representative well from a given pad to understand inflow contribution changes over time along the lateral, the operator could optimise well design and achieve a significant cost reduction for several other wells in the same pad.

**Improvement of oil recovery**

By using this intelligent tracer technology to understand inflow distribution and the location of water influx, operators can obtain proper...
inputs for reservoir simulations and field depletion planning decisions regarding wellbore placement, number of wells, completion design, equipment functionality and integrity.

Considering an empirical 3% improvement in oil recovery from a single subsea well producing 10 000 bpd based on such findings from the flush out model, the incremental revenue from production would be US$6 570 000 per year for a single subsea well or US$32 850 000 incremental revenue per year for a five-well subsea development.

**Health, safety and environmental advantages**
The tracer technology uses chemicals in extremely low concentrations (parts per trillion) that are compatible for water discharge. No radiation is used.

In addition, unlike production logging operations, no well intervention is required. Consequently, the risk to people, environment and equipment is minimised.

**Case studies**

**Monitoring zonal inflow assurance and performance in subsea wells**

An operator had three surveillance challenges in a subsea well: (1) confirm flow control valve functionality; (2) ensure packer sealing integrity; and (3) determine the relative inflow performance of the two monitored intervals. The well was approximately 18 000 ft deep and had a two-mile tie back to the production facility.

Intelligent tracers with uniquely identifiable signatures were installed in two reservoir compartments of the three-zone subsea well (Figure 7).

The well was initially produced from a lower zone (Zone 3) that was not controlled by a smart valve. Zones 1 and 2 were controlled by smart valves that were closed for several hours. As Figure 8 shows, no intelligent tracer molecules were present in the flow, thereby providing assurance the flow control valves and packers were performing as intended.

The smart valve in Zone 2 was opened while the smart valve in Zone 1 remained closed. Analysis of intelligent tracer concentration revealed that: (a) the smart valve in Zone 2 successfully opened; (b) the mechanical packer between Zones 1 and 2 continued to provide isolation; and (c) the smart valve in Zone 1 functioned properly and provided a seal.

Subsequently, the smart valve in Zone 1 was opened. Analysis of intelligent tracer concentration showed that the valve opened successfully.

RESMAN also used its flush out model to determine the relative inflow performance between the two zones installed with intelligent tracers. Zone 1 presented a response that indicated its inflow rate was 70% more than Zone 2.

The operator was able to confirm the successful operation of the flow control valves and sealing integrity of the packers. In addition, quantitative analysis revealed that Zone 1 was a significantly better producer than Zone 2.
Fracture valves from each stage via pup-joint carriers. (Figure 9). The systems were placed in the annular space, adjacent to the signatures were installed in eight stages of a multi-stage fracturing well to improve fracture design, well placement and well length.

Many operators are fracturing long horizontal wells in multiple locations without any feedback on the effectiveness of these stimulation treatments. Knowledge of the flow from each zone would allow improvement of fracture design, well placement and well length.

In this example, intelligent tracers (RES•OIL) with uniquely identifiable signatures were installed in eight stages of a multi-stage fracturing well (Figure 9). The systems were placed in the annular space, adjacent to the fracture valves from each stage via pup-joint carriers.

Production was shut in for 24 hours and the well was re-started. Production fluid samples were taken at the surface to be analysed and the results modelled. The flush out model was used to quantitatively measure the amount of inflow from each zone.

Each purple square in Figure 10 shows the concentration of the RES•OIL system installed in stage 1 (heel of the well). The dashed line represents the flush out model results for this data set. In contrast, Figure 11 shows the flush out response from stage 8 (the interval toward the toe of the well).

The rate of decline of the profile from stage 1 (Figure 10) was noticeably less steep than the rate of decline of the profile from stage 8 (Figure 11), indicating inferior flow performance from the heel of the well (stage 1) when compared to the toe (stage 8).

The inflow distribution calculated for each producing interval (Figure 12) revealed that more than half of the production of this well originated from stages 7 and 8, while the middle of the well (stages 4 and 5) displayed very poor performance.

With this information, the operator re-evaluated its reservoir models and improved its drilling and completion strategy for future wells in the field.

Identifying the location of water breakthrough in subsea projects with commingled production

An operator wanted to determine the location of water breakthrough in a complex subsea field development without intervention or major modifications to the existing completion design.

RES•H2O systems were integrated into the existing completion screens of the producing intervals from the three wells. Each well had four zones and commingled their production to a facility located two miles from the wells.

The completion was run in hole without deviations from normal procedures, with no additional rig time or extra personnel at site.

The intelligent tracers remained dormant until two years after well completion, when a rapid increase in water cut was noticed at the production facility. The water breakthrough events activated the release of only the specific signatures that were installed in the affected zones.

Analysis of production fluid samples revealed two independent water breakthrough events in one of the subsea wells (Figure 13). The first event corresponded to an increased concentration of the RES•H2O signature installed in Zone 1 of the affected well. Approximately 20 days later, the analysis identified a second water breakthrough event in Zone 3 of the same well.

Based on the water breakthrough findings, the reservoir team adjusted the reservoir models and improved the management of the field-wide water flood programme. This included adjustments to injector well rates and placement of future wells.

The solution was a good fit for this application because the RES•H2O systems were adaptable to the existing sand screens and are long-term, very low risk and cost-effective. Following the successful results of this campaign, the operator installed the systems in every new producer well of this subsea development.

Conclusion

Reservoir production information that has been typically inaccessible for a very high number of wells in key market themes is now technically feasible by using intelligent tracers, which have been extensively used in hundreds of wells worldwide.

The technology provides a chemical production log that can be used periodically to detect the location of water breakthrough and to estimate zonal inflow contribution over the course of several years without well intervention and with minimum risk for implementation.

This information, combined with other state-of-the-industry seismic and drilling advances, provides insights into the reservoir conditions to improve reservoir modelling accuracy and provide additional intelligence to reservoir management decision-making, including future well placements, production management, water flood management and completion concept selection.

Finally, understanding the performance of the various layers in the reservoir and the effectiveness of the completion techniques are key factors to optimise the capital efficiency of the investments in today’s E&P projects, especially with the recent decline in oil prices.

References

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