A Revolution in Reservoir Surveillance for Subsea Production Environments

Today's offshore production environment would have been hard to imagine a decade ago. Typically today, we see long horizontal wells and in many cases long horizontal multilaterals produce jointly to complex subsea well heads, and then the combined production pass through kilometre-long tie-backs to platforms or FPSOs. This advanced and still evolving production scenario provides operators the only cost-effective way to move progressively into deeper waters to recover hydrocarbons.

BY HENRY EDMUNDSON

With these advances, however, comes a headache. The complexity of the subsea environment makes it virtually impossible to monitor the behaviour of any given well or multilateral, let alone the behaviour of the field being developed. This makes it extremely challenging to plan future field exploitation. Key decisions such as where to infill drill, how to complete each well, how best to balance injection and production, all require down-hole production data for reservoir management purposes to tune well and reservoir models to match reality and reduce uncertainty in implementing field development strategies. Without downhole measurements, operators significantly compromise long-term production.

Monitoring modern wells is beset with challenges. Production is often co-mingled abolishing any evidence there might be from any individual well, and typically almost all wells are challenging and costly to access once they're put on line. Any type of workover hardware for monitoring production, whether it is conveyed by drill-pipe, coiled tubing or wireline, requires an expensive rig for deployment and of course must contend with a specific subsea completion. The sheer mechanical complexity of these completions also makes permanent downhole sensors such as fibre-optics increasingly difficult to deploy and ultimately fragile.

Advancing Surveillance

During the last 5 years, however, a new technology developed by RESMAN (RESservoir MANagement) has emerged to solve the above mentioned challenges in subsea developments. The technology leverages proprietary inert chemical tracers that are packaged in engineered solid polymer strips that can be inserted permanently into any type of completion across multiple completion compartments. An example is the inflow control device (ICD) completion typically used to provide an even distribution of production along the length of a horizontal producer, as shown in Figure 1.

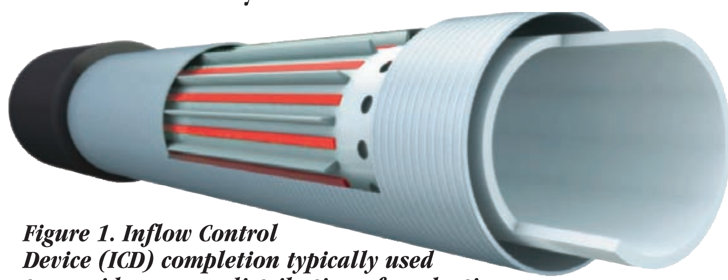


Figure 1. Inflow Control Device (ICD) completion typically used to provide an even distribution of production along the length of a horizontal producer (illustrations: RESMAN)

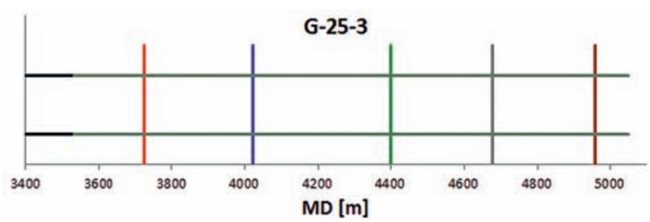


Figure 2. Placement of the intelligent tracers along the length of one of the wells

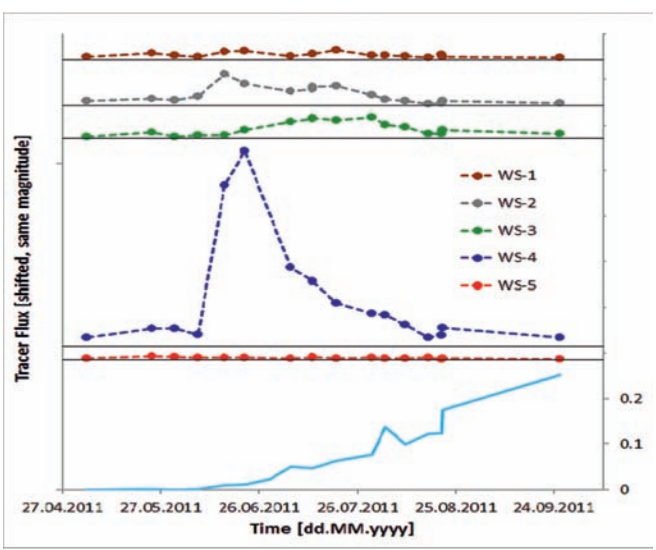


Figure 3. Plot of water flux over a five-month period

These inflow tracers systems are non-radioactive and are "intelligently" released from the polymer strips only when in contact with produced fluid. When the RESMAN intelligent tracers systems are not in contact with the target fluid, they turn-off thereby preserving their life-time. Some intelligent systems are released to oil (RES·OIL), others to water (RES·H2O). In addition, there are currently over 80 different signatures (over 40 available for each fluid type).

Placing intelligent inflow tracers at different points in the well and then collecting samples at the production platform or FPSO and analysing them for tracer type and concentration, typically in the parts per trillion (PPT) range, allows an interpretation of the production profile in the well. So far the technology has been successfully deployed in over 160 wells spanning 50 fields worldwide, and acceptance is increasing.

Co-Mingled Production

The most basic interpretation is a qualitative approach where the mere detection of an oil or water

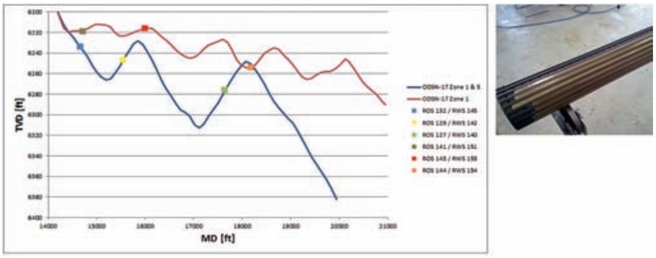


Figure 4. Two multilaterals were equipped with RES·OIL and RES·H2O tracers

tracer at surface offers a clear diagnosis. For example, this can be used to monitor well clean-up, where the presence or absence of inflow oil tracers from different zones immediately indicates the state of initial production. Later in the life of the well, inflow water tracers distributed along the length of a completion can provide an immediate indication and location of water breakthrough.

In an offshore subsea field in North America, two horizontal wells drilled from the same platform were instrumented with both intelligent oil and water tracers. Figure 2 shows the placement of the intelligent tracers along the length of one of the wells.

After the well had cleaned up and production had stabilised, samples were taken at regular intervals, roughly every two weeks, resulting in the following plot of water flux over a five-month period, as shown in Figure 3.

This shows clearly that the blue-colour RES·H2O system at 4,250 metres is seeing the first water breakthrough, and that this agrees time-wise with the water-cut record for the well. Combining the RES·H2O water tracer data with the RES·OIL oil tracers that were placed at identical depths in the well, it was confirmed that the grey and green zones, further along the well, were also contributing some water.

Quantified Zonal Inflow

It is a peculiarity of this new technology that tracer is released at a constant rate, independent of the rate of production. Nevertheless, each of the polymer systems is engineered for the operator's specific subsurface needs, taking into account several dozen parameters. Generally, the intelligent oil tracer system can be designed to last 3 to 5 years, and the water tracers will last typically for 1 to 2 years from the moment water breakthrough first occurs. This fact that these proprietary systems release tracer at a constant rate regardless of flow rate allows for a different technique to be employed to obtain a quantitative interpretation. This in turn allows the operators to determine percentage inflow contributions from each zone. Quantitative interpretation requires the well to be shut in for a short period (several hours). This can be combined with an operational stoppage for any other reason or with the shut-in period required for a conventional well test. While the well is shut in, intelligent tracer molecules are continuously released (at a constant rate) in the vicinity of each polymer-tracer system, building up "clouds" of locally concentrated tracer. Then, when the well is put back on stream, these clouds are immediately produced to surface where fairly rapid sample-taking can reveal their various arrivals.

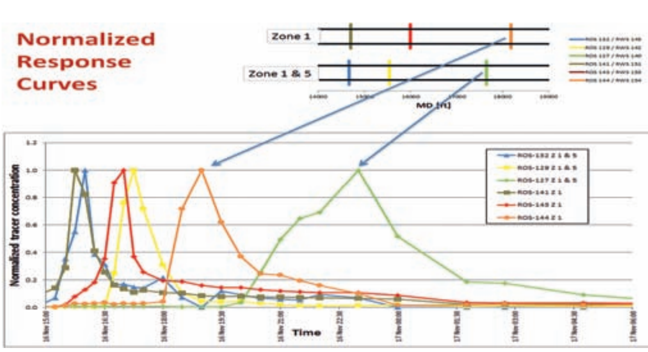


Figure 5. After a shut-in period the well was produced and tracer concentrations were measured from samples taken at the surface at five-minute intervals

quantitative interpretation then becomes possible giving a percentage contribution of each zone instrumented, as in Figure 6. Expert interpretation is critical to this process taking into account dozens of parameters such as well bore hydraulics, reservoir properties, etc.

This example benefited from the fact that samples could be taken right at the well head on the platform. If production is co-mingled with other wells and mixed even more as it travels several kilometres along tie-backs to a collecting station, a more sophisticated technique must be brought into play.

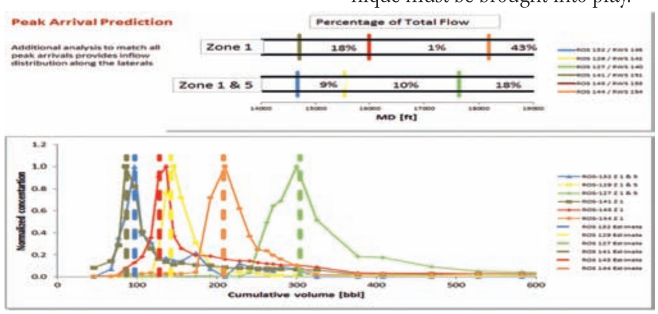


Figure 6. A quantitative interpretation then becomes possible giving a percentage contribution of each zone instrumented

Advanced Interpretation

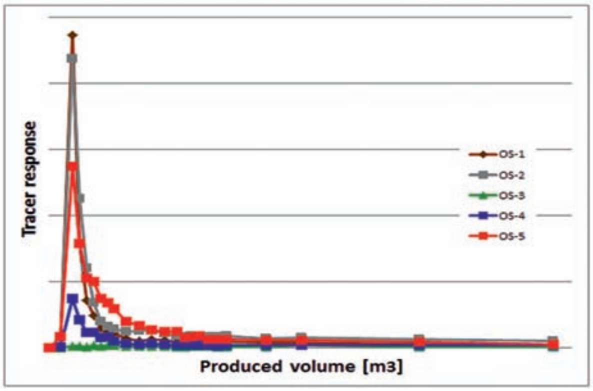
In this example from the USA, two multilaterals were equipped with RES·OIL and RES·H2O tracers at the locations shown in Figure 4. Note that completion design of the inflow tracers is generally positioned away from sumps or crests to avoid possible zones of fluid stagnation.

After a shut-in period the well was produced and tracer concentrations were measured from samples taken at the surface at five-minute intervals, as shown in Figure 5. It is clear that tracer clouds from zones closest to the heel are seen first, followed by tracer clouds from more distant zones.
The interpretation is more complex than it might first seem, because flow from one zone will impact the speed of ascent of tracer clouds from other zones. However, a flow model has been developed to take this into account, and a

Simple Integration

In passing, it should be noted that a unique feature of this technology is the ability to monitor several wells by sampling their combined production at a collecting stage or FPSO. This is the reason for having over 80 intelligent tracer signatures for oil and water, allowing, for example, four distinct signatures in each of up to 10 wells or any other combination – even more intelligent tracer systems are in development due to operator requests. It is also the reason for progressively increasing detection levels beyond one in a trillion. The more one well's inflow tracers are mixed with other wells, the more dilute the intelligent tracer signature becomes.

While on the subject of logistics, it is also worth remarking that the deployment of this technology is simple in the extreme. Once the planning has been done, in other



Zone	Relative contribution per joint
OS-1 (toe)	38
OS-2	34
OS-3	1
OS-4	6
OS-5 (heel)	21

Figure 7. Decays were clearly present and the rate of decay has been translated to relative contribution to total flow

words working out where to place the polymer-tracer systems in the completion hardware, the actual deployment is done by a skilled technician in a third-party completions shop. No extra personnel or equipment go to the rig or offshore. Also, the sampling can be done by a company man and then simply dispatched to RESMAN for analysis.

Flow-Loop Verification

The more sophisticated interpretation technique uses the same shut-in as before mentioned, but looks more closely at the transients that each tracer "cloud" produces when the well is put back on production. It turns out that the decline of each transient is inversely correlated to zonal inflow. This was first hypothesised by RESMAN scientists and observed in the field, and then verified in landmark experiments at the world renowned IFE flow laboratory near Oslo. For the well shown in Figure 2, these declines were clearly present and the rate of decline has been translated to relative contribution to total flow, as shown in Figure 7.

An interpretation like this relies on a several key assumptions due to various challenges related with cross-flow and multiphase fluid dynamics. When designing a surveillance program, these conditions are attended to during pre-design, to ensure that a reliable interpretation condition is met. This pre-design has proved reliable for providing robust interpretations. Sustaining reliable interpretations in multi-phase flow and/or poor zonal isolation are challenges for the future which are being attended to through multi-year R&D efforts.

Zero Risk

Having tracer clouds develop in isolation means that the inflow control device (ICD) is one ideal vehicle for this inflow surveillance technology, although all types of completion hardware are adaptable. This new surveillance technology has many attributes to recommend it, besides the fact that in many cases it remains the only option for evaluating production from subsea horizontals and multi-laterals. It poses zero environmental impact – the tracers are tested for toxicity, biodegradability and bioaccumulation.

The technology poses zero mechanical risk, to the completion or well, since the engineered polymer strips are inserted beforehand in the completion hardware and are mechanically passive. Then there is no need for electrical or fibre communication to the surface, since the tracer itself provides the communication channel. Finally, the logistics are simple, as noted above, and the decision to install the tracers can be made comparatively late, if required, in the planning and preparation cycle of the completion.

Monitoring for Years

Most important, since these intelligent tracer-systems continue to release tracer over a period of years, the new technology provides in-situ production monitoring during most of the life of the well. The technology is also remarkably cost-effective. One operator calculated that the entire investment of equipping a well with RESMAN intelligent tracers was immediately recouped when poor zonal isolation was diagnosed and corrected saving thousands of barrels of production.

Another offshore operator estimated that the cost of installing chemical tracers and using them to monitor production over a five-year period would still be an order of magnitude less costly than mobilising a rig to make just one intervention run. The bets are therefore on that this new technology will cause a step change in offshore reservoir surveillance. ■

The Author:

Henry Edmundson is Founder and a Director of R9 Energy Consultants. Mr Edmundson retired from Schlumberger in 2013 where he was most recently Global PetroTechnical Director. He also serves as Chairman of the NExT Client Advisory Board which is a wholly owned Schlumberger business, is the largest training provider in the upstream industry. His career with Schlumberger spanned 45 years. He was the founding editor of the Oilfield Review, a key communication of technical innovation for the E&P industry. Since 1995, he created successively the knowledge management, technical career ladder, competency management, and training platforms for Schlumberger's several thousand technical staff. Mr Edmundson holds an MSc in Mathematics from University of Bristol and an MA, Engineering from Cambridge.