At a water depth of over 1000 m, an offshore field was experiencing all the challenges of a deep-water oilfield. Despite a large aquifer below the oil reservoir, the expectation was that only a small amount of water would be produced. At the onset of the planning phase, it was determined that the use of some form of flow equalising technology would be beneficial to delay water breakthrough. However, this concept was discarded for the first two wells due to a low frac gradient associated with the long horizontal sections that could have caused issues during gravel pack pumping.

Following the completion and flow of the first two wells in the field, analysis of water tracer data from solid polymer tracers integrated into sand screens and placed along the length of each of the two wells showed a dominant water flow towards the heel of each well (Figure 1).

During completion of the first two wells, a better evaluation of the minimum horizontal stress was obtained. Therefore, the operational window was enlarged, and it was determined that it would be possible to apply flow equalising technology together with gravel packing in future wells to try to mitigate water breakthrough.

The well design was completed after a comprehensive reservoir simulation to identify key reservoir characteristics in order to apply autonomous inflow control device (AICD) technology effectively. It demonstrated that water production would again be predominant from the heel to middle section of the well and the AICD configuration was selected based on the reservoir permeability and the oil/water saturation profile.

Computer simulated results using common solutions, such as reduced carrier fluid density, progressive pump rate reduction and use of friction reducer, to extend the operational window, showed that 94% of the open hole would be packed at the end of pumping operations.
To increase coverage targeting 100% pack, the following enhanced design strategy was simulated and adopted after showing promising results:

- Use of a toe end sacrificial screen, to allow the gravel pack alpha wave to be pumped with normal pump rates and conventional density proppants.
- A change to low density proppants after covering the sacrificial screen to allow transportation into position at lower pump rates.
- Low proppant concentration at the beginning of the job.
- Decreasing the pump rate to the minimum limit.
- Use of a 4 in. wash pipe inside the 6 5/8 in. screens.
- Use of three AICD screens up into the casing in a non-producing zone, instead of blank pipe. These contained eight inserts to give an additional 24 holes in the screens, allowing some degree of continued fluid return while packing the open hole until screen out.

As part of well surveillance activities, the operator wanted to carry out a well evaluation to determine the benefits of the design strategy in balancing and ultimately reducing aquifer water production.

The solution

The most cost-effective method to carry out well evaluation to establish oil and water positional inflow was through use of solid polymer tracers integrated into sand screens prior to running in hole. The technology is environmentally safe, and a low-cost way to quantitatively measure water production profile over time.

The solid polymer tracers are chemical compounds tailored to mark only the oil or water phase under investigation. Non-radioactive, non-adsorbing, non-degrading, and compatible with common oilfield chemicals, tracer measurement technology provides advantages over traditional inflow measurement methods. Unlike a production logging tool (PLT), tracers do not require intervention of any kind, or for the well to be shut-in. They can be used in wells with electrical submersible pump access restrictions, provide insight over time rather than a mere snapshot of production, and can be used at a fraction of the cost of a PLT, without constraints on wellbore length.

Solid polymer tracers were integrated into the AICD sand screens (Figure 2) during manufacture and placed at specific areas of interest downhole during run in hole (RIH) of the lower completion.

Flow of fluids from a well using AICD systems enters the main production tubing at discrete points. It is possible to use tracer concentration decay curve analysis from this type of well to gain information on the amount of fluid flowing into the wellbore at each of the positions traced. Tracer decay curve analysis is completed by sampling the well at a high frequency, following well clean-up or a brief shut in. During the shut in, concentrated clouds of tracer accumulate in the fluids at their respective locations. During well flow, each cloud disperses and flows to the surface, and their timing and shape are measured using captured samples and tracer analysis. The shape of the individual decay curve analysis used to determine the amount of oil flowing into the well at specific locations.
tracer concentration over time is compared and used to calculate the zonal flow rates using mathematical models. The faster the flow, the faster the decay of the tracer from the well. An example of decay curve analysis can be seen in Figure 3 where the dark blue position shows the highest flow, followed by red, pink, green and light blue, with yellow showing zero flow into the well.

In addition, proprietary software enables data interpretation relating to water cut within the wellbore and uses water tracer concentrations linked to surface area contacted by producing water, where the tracers are located to provide a relative water cut assessment to be made. An example of water cut interpretation can be seen in Figure 4 where 90% of the water is in contact with a large surface area of the yellow tracer when compared to the red. This results in more tracer being released than in the red position. A comparison of tracer concentration in a surface water sample allows the relative water cut to be measured.

The results

The oil tracer responses from the well during a transient test are shown in Figure 5. The analysis of each tracer decay curve allowed for a comparison of speed of flush out to be measured. An assessment could also be made regarding where the dominant oil flow was occurring from within the well.

Figure 6 shows how the well started with dominant water flow of primarily water-based completion fluids from the mid-section of the well. Over the next two years, the water distribution balanced a little better, and importantly was not showing dominance from the heel of the well, with an average of 40:60 flowing from the upper half versus the lower half.

In addition, following the initial clean out flow from the well, the distribution of oil flowing from the well was balanced with an average of 50:50 flowing from the upper and lower halves (Figure 7). The lack of oil tracer presence during the last testing round matches where the dominant water flow was originating. This was indicative of a lack of oil contact with the tracer during the shut-in period, as tracer clouds build and confirms the water tracer data.

A comparison of the cumulative oil produced from the three wells (with two containing no AICDs and one using AICDs) clearly showed benefits of AICD use with significantly more oil production in a shorter period of time as presented in Figure 8.

When reviewing water production from each of the three wells, the data also showed a significant benefit in AICD use with water cut increasing much more slowly in the well with the AICDs, than in the two wells that did not have any water control capabilities (Figure 9).

Conclusions

Tracers allowed a low-cost evaluation method of quantitative oil inflow and water cut measurement in subsea wells without any intervention. They were shown to be compatible with open hole horizontal gravel packing (OHHGP) and AICD use, and in this case, established that some equalisation was achieved, restricting water inflow from the heel and balancing oil inflow.

This resulted in lower cumulative water production and enhanced oil production from the well using AICDs when compared to the other two wells that did not use AICD technology.