TENDEKA

Drawing a line in the sand

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The deployment of advanced well completion technologies has become the norm to mitigate early water breakthrough toward the wellbore and improve oil recovery, and thereby, optimising the performance and sustainability of heavy oil wells. In addition, several studies have acknowledged that such devices act as a type of insurance policy against geological and dynamic reservoir uncertainties[1] to reduce the risk and variation in the expected oil production profiles.

One such example is an infill development campaign in a thin, heavy oil reservoir, in the South China Sea. Global production optimisation and advanced completion specialist Tendeka, was contracted by CNOOC China Ltd Shenzhen to mitigate the problems of uneven sweep and water production in a heavy oil, gravel-packed production well. This had not only created an irregular reservoir influx toward the wellbore, water mobility in the reservoir was at least 150 times bigger than oil mobility.

Combining AICD with sand control solutions

The well was drilled in a thin formation in unconsolidated sandstone with an oil column of 4.5m on average. The large contact area of the 440m long, horizontal well makes the successful exploitation of these reservoirs feasible.

As the wells are traditionally completed with screens, gravel pack or slotted liners to control sand production, performing conventional intervention techniques for dealing with excessive water production is a huge challenge. This is due to requirements to perform production logging testing (PLT) followed by squeezing cement or gel, setting plugs and isolating sections with blank straddles/packers. Firstly, this does not guarantee to deliver the optimum solution and secondly, is associated with high cost, risk and limits, especially for offshore operations.

Deploying Autonomous Inflow Control Devices (AICDs), a new generation of the inflow control device (ICD) to manage the reservoir fluid influx toward the wellbore can mitigate such challenges. The active flow control device delivers a variable flow restriction in response to the properties of the fluid and the rate of flow passing through. As demonstrated by many case histories, the introduction of AICDs has been proven successful in effectively controlling unwanted fluids. Tendeka has so far deployed more than 150 successful AICD applications in heavy oil formations worldwide.[2]

In some applications, ICDs/AICDs are deployed into weak sandstone reservoirs that are prone to failure and consequently, produce sand, so are frequently combined with a sand control solution, such as gravel packing techniques. This involves pumping a slurry of water and large sand particles/gravel into the annulus between the wellbore and the sand screen completion and allowing the carrier fluid to return via the sand screens, leaving the gravel in place.

The current methodology for gravel packing with ICD/AICDs in the well utilises a multiple alpha wave technique whereby, at least one conventional standalone screen joint is deployed at the toe of the well to provide a return path during the build-up of the alpha wave. Here, the flow rate is progressively reduced to maximise the dune weight until screen out is observed. Once the gravel packing operation is complete, the standalone screen section at the toe is isolated before the well is placed on production. Conversely, this technique does not allow a complete pack to be achieved and will allow more gravel to build up around the zonal isolation packers.

One other possible technique to provide sufficient flow path through the screen assembly is to integrate sliding sleeves into each screen joint but in long lateral wellbores. This may be prohibitively expensive and requires multiple, manual manipulations as the wash pipe is retrieved.

As shown in Figure 1, the use of a temporary bypass valve is recommended to enable standard gravel packing operations to be performed with (A)ICDs in the completion without significant additional cost, complexity or compromise. The dissolvable material is utilised with a valve located within the ICD/AICD housing to provide a high flow area path from the annulus to the tubing during completion operations.

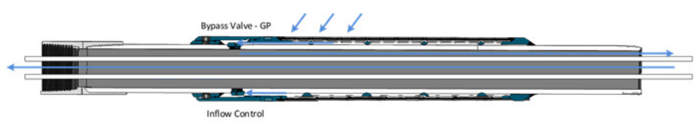

Figure 1: Gravel packing fluid path with a temporary bypass valve

The FloSure AICD device

The FloSure AICD was introduced to function as a standard ICD prior to the breakthrough (proactive solution) and restrict the production of unwanted effluents with lower viscosity after breakthrough such as water in heavy oil production (reactive solution). Figure 2 illustrates the principal components of the device.

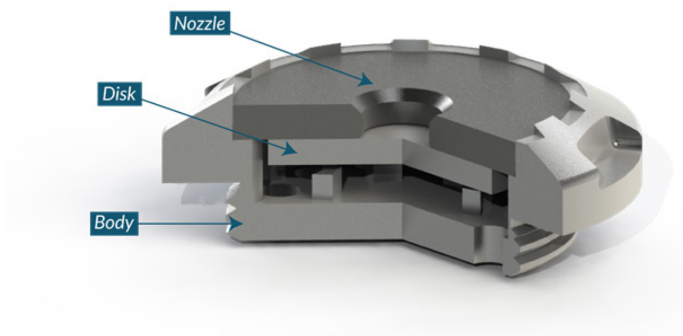

Figure 2: Construction of FloSure AICD

The AICD is typically incorporated as part of a screen joint where the produced fluids enter the completion through the screen and flow in the annular space between the screen and the unperforated base pipe into the AICD housing where the device is mounted. Fluids then flow through the AICD into the interior of the production conduit where they combine with the flow from other zones.

As an active device that regulates the flow of fluids, usually by the conversion of potential energy (pressure), it is capable of modifying its control characteristics automatically in response to fluid properties flowing through it. It generates a variable pressure drop based on the size of the inlet nozzle and on the gap created between a levitating disk and the top plate of the housing in which it is contained. Fluid flow enters the device through the nozzle at the top plate, impacts the disk, and spreads radially through the gap between the disk and the top plate, then discharged through several outlet ports in the body.

Due to its dimensions, the devices can be threaded directly into the base pipe. It is possible to have up to four threaded ports compatible with AICD, passive ICDs, chemical treatment valves or blanking plugs on each screen joint. This provides a high degree of flexibility for reacting to reservoir uncertainty after drilling and inventory flexibility as the valve can be mounted or replaced anytime, even at the rig.

Dynamic reservoir simulators are required to estimate the production benefits of the AICD over well lifetime. As actual well trajectory and reservoir properties are rarely the same as planned, the actual well is simulated just after drilling with a static near-wellbore simulator to optimise placement of screens, blanks and swellable packers prior to completion.

Well completions and reservoir properties

As part of CNOOC's infill development campaign, wells C1H (completed with gravel pack with stand-alone screens but no AICDs) and C2H are located in the same reservoir formation in the field. C1H is near the oil boundary of the main reservoir and is 400m apart from C2H, shown in Figure 3.

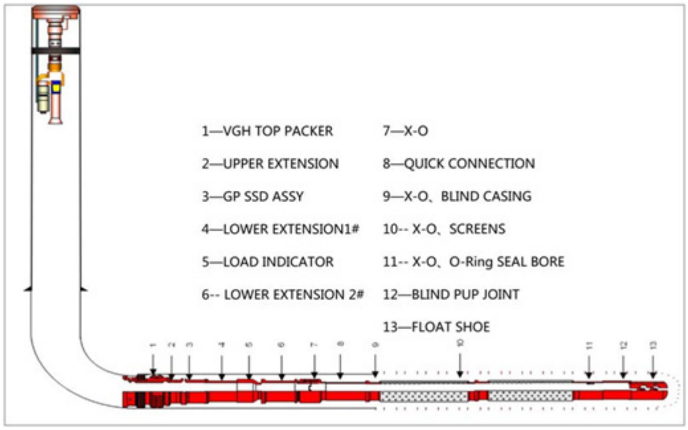

Figure 3: Well C2H completion schematic

While the well C2H is quite similar to C1H, both in terms of reservoir properties and completions, it was chosen as the analogue well to observe the AICD performance. At the initial stage of production, the water cut of well C2H was about 6% and then increased rapidly to 80% in just three months and then stabilised at 90%. This is in line with the performance of other wells which were not completed with AICD completions in the field.

Well C1H was selected as a pilot well for further AICD applications in upcoming wells in the field. The reservoir pressure nearby well C1H is about 13.5Mpa and border water aquifer supports the reservoir pressure for both C1H and C2H wells. The formation temperature is about 74°C, the formation thickness is 7.5m with an average effective thickness of 4m, the average porosity of 26.6% (from logging interpretation). The average permeability is 514 mD, the average shale content is 13.6%, and the degree of heterogeneity is high. Also, the reservoir sand is unconsolidated and very loose with a high shale content.

As the conventional completion method cannot restrain the influence of mud and sand migration on productivity, it was necessary to gravel pack the completion of well C1H to prevent mud and sand plugging. A dual trip completion was chosen to run for this well. This first allowed gravel packing the annular area between the screens and open hole and then retrofitting an inner string of AICD subs and zonal isolations inside the screens.

AICD completion design workflow

An extensive pre-drilling study, including static and dynamic well/reservoir modelling, was performed to investigate the value of using AICDs and to determine the strategy for the completion. The objective was to efficiently produce a liquid production rate range of 500-3000 bbl/d over the well lifetime.

Figure 4 shows the predicted performance of AICDs for the fluid characteristics of the reservoir in a single-phase condition. It demonstrates the AICD significantly distinguishes oil and water due to its significant viscosity difference.

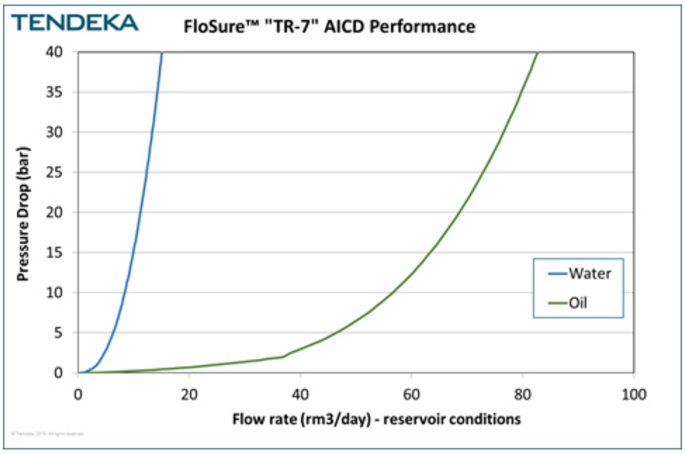

Figure 4: AICD performance curve

Within the short period in between reaching targeted drilling depth and running the completion tally in the well, the interpreted real-time log data i.e. saturation, permeability and calliper data plus the drilled well trajectory, were used in a static wellbore modelling software to finalise the lower completion of the well.

This modelling was involved in simulating several completion designs (various packer placements and AICD numbers) to optimise the well performance. Placement of packers was crucial to the optimum AICD performance and subsequently, the added value from the well[3] as only three packers were practically possible to install.

The final design was an inner string completion comprising 20 AICDs on 2 7/8" subs (one per sub) at four zones compartmentalised with three swellable packers to control water production. Figure 5 shows the design of installed lower completion, the distribution of AICDs and packer locations.

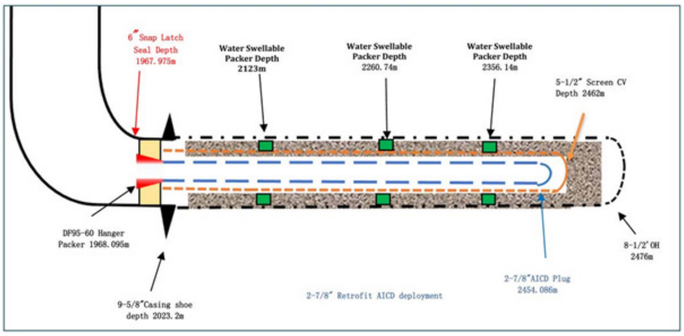

Figure 5: Well C1H completion schematic

The performance of well C1H with the AICDs, which has been producing since December 2018, has resulted in a significant volume of oil while water cut of the well is still below 20% after 12 months of production. This well not only has no problem in terms of sand production, it has also successfully delivered 200% increase in total oil production compared to the offset well. When comparing actual performance versus the predicted performance of well C1H, it has performed significantly better than estimated, producing an average oil production rate of 713 bbl/d – 43% higher than the optimistic oil production rate.

Over the same period, the offset well with no AICD devices encountered water production in the first two weeks and water cut has kept increasing to 88% as shown in Table 1.

Well Name	Total Oil Production (bbl)	Total Water Production (bbl)	WC (%)
Well C2H with no AICD	120,000	530,000	88
Well C1H with AICDs	250,000	20,000	20

Table 1: The performance of wells C1H and C2H after 365 days of production

In summary, the combination of AICD devices and gravel pack completions could effectively prevent sand production and control water in the field while improving oil well recovery rate compared to analogue wells. This would have guidance and reference significance for the development in similar unconsolidated and high argillaceous heavy oil reservoir and have extensive promotion value in the field.

The project clearly demonstrates the possibility of a successful combination of AICD and gravel packs. AICD completions ensure a balanced contribution from all reservoir sections while significantly limiting water production while the gravel pack kept the valves and the well safe from the impact of sand.

References

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