Advanced well completions

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As oil reservoirs age, the optimization of oil recovery becomes essential if oil production targets are to be met. This challenge is even greater in heavy oil fields due to lower reservoir energy and the requirement for high reservoir contact.

One of the most important aspects of heavy oil is its viscosity as this can directly impact the recovery and productivity of the reservoir. The viscosity difference between heavy oil and water creates an unfavourable mobility ratio, which generates quicker water breakthrough. This allows water to flow much faster through the reservoir and into the wellbore, displacing the oil production from producing zones. In tandem, reservoir heterogeneities can also exacerbate the issue resulting in a very high-water production rate which effectively means reduced oil production, whereby the primary recovery technique may leave as much as 70% of petroleum in the reservoir.

These challenges can be dealt proactively with the application of flow control devices to improve oil sweep in the reservoir and reduce the water cut in the production wells.

For many years, advanced well completions utilizing inflow control devices (ICDs) that restrict flow by creating additional pressure drops, have been used to mitigate the early breakthrough of unwanted water or gas in oil wells. ICDs are, however, fixed, simple and cost-effective configurations which are passive in nature and once water or gas breaks through, the choking effect cannot be adjusted without intervention.

Enhanced technology

As a new generation of the ICD, the Autonomous inflow control device (AICD) was introduced to function as a standard ICD prior to the breakthrough (proactive solution). After breakthrough, it can also restrict the production of unwanted effluents with lower viscosity, such as gas in light oil and both gas and water in heavy oil production (reactive solution).

The AICD is designed to automatically react to the properties of the fluid flowing through it by restricting the flow of less viscous fluids, such as water and gas, while allowing more viscous fluids, such as heavy oil, to pass through with minimum pressure drop. When used in horizontal wells that have been compartmentalized using swell packers, the AICDs restrict the flow of water in high water cut zones while allowing greater drawdown of the reservoir in high oil saturation zones, thus resulting in a reduced water cut and improved oil recovery for the overall well.

In new wells, the functionality of an AICD is similar to a passive ICD in that it can be used to create a more balanced inflow profile along the horizontal section prior to water breakthrough. The AICD can also be used in existing wells that may have already experienced premature water breakthrough by deploying as an inner, retrofit string. This leads to better oil recovery by reducing water production and improving sweep efficiency.

Tendeka’s FloSure AICD (a rate-controlled production device), comprises of three components; valve body, nozzle, and disk as seen in Figure 1 and is typically incorporated as part of a screen joint.

Tendeka has so far employed more than 34,000 AICD FloSure RCP valves in over 180 wells worldwide. In Figures 2a and 2b, the streamline or flow path through the device is marked by arrows.
The flow path across a range of applications and reservoir types is the same. Reservoir fluids enter the completion through the filter and flow along the annulus between the filter and base pipe into the inflow control housing where the AICD is mounted as shown in Figure 3. The fluids then travel through the AICD and into the interior of the production conduit where they combine with the flow from other zones.

A new set of flow loop tests has recently been completed to evaluate the performance for single and multiphase flow under typical heavy oil conditions. The characteristics are described by the differential pressure across the AICD versus flow rate through the device. Based on laboratory results, the oil-water volumetric flowrate ratio for oils with different viscosities can be calculated, for example, 5.1 for the oil viscosity of 27cP. In general, as the viscosity contrasts between oil and water increases, the effectiveness of the AICD rises making this technology particularly well suited to heavy oil applications.

Several commercially available reservoir simulators are now capable of modelling the performance of wells with advanced well completions and complex flow paths, such as annular flow. A recent study has shown that the AICD completion increases the total oil production of the well by 12% over the base case while reducing the water production by 10%. In comparison with ICD completions, there is just a 7% increase in total oil production over the base case, and 6% reduction in water production for ICDs over four years of production.

Robust regional results

Following successful installation in pilot wells, retrofitting existing completions with AICDs is now a common practice for some operators. For retrofit applications, an inner string consisting of AICD subs, swellable packers is installed within the existing wellbore. Compartmentalization is driven by the existing wellbore, whether that be standalone screens or gravel-packed completion along with packers for zonal isolation, or with cased and perforated wells. If extra compartmentalization is required, chemical annular isolations can be used.

To date, more than 180 wells have been completed with FloSure AICD technology. With more than 30 of the wells completed successfully with AICDs in heavy oil environments, the technology is a proven, robust solution to develop challenging reservoirs, for example, in Canada, the Middle East and China more efficiently.

Canada

For many years, wells in this area have a very high water cut, often above 99%. The reservoir is supported by a strong water aquifer, so the pressure is high, but the unfavourable oil/water mobility ratio with viscosity ranged from 150-1500 cP results in low oil production and excessive water production.

The operator requested a fit-for-purpose completion to be developed that would be economical in this challenging heavy oil environment with temperatures as low as 30°C. The goal was to reduce water production, increase oil rates, and improve oil recovery with an AICD completion system for new wells as well as retrofits.

The horizontal sections were segmented into compartments, 10 to 30 per well, using low temperature, hybrid swellable packers, where each stage is controlled by AICD devices. Regardless of where the water is entering the wellbore (high-permeability streaks, swept zones, proximity to the oil-water-contact, heel area, etc) each stage autonomously controls and limits the volume of water that can enter through...
the AICDs. This allows for higher pressure drawdown to be applied to the zones that have more oil, allowing increased oil production with lower water volumes.

An integrated AICD completion solution, including optimum AICD completion and PCP pump, allowed the wells to produce with a more aggressive production strategy using higher drawdowns and therefore:

- accelerated the oil production
- delayed the water breakthrough
- lowered the total fluid volumes
- reduced the water production per well
- allowed more wells to be connected into specific surface facilities simultaneously (i.e. cost reduction in surface facilities).

The design resulted in an overall increase in oil production by 150-250% with water production reduced by 40-50%. This resulted in an improved return on investment of more than 250% per well, with a far lower risk of water problems compared to the previous solutions applied.

To date, 10 wells, including three retrofitted wells, have been completed in Canada with AICDs and several others are planned in the near future.

**Middle East**

Several wells have recently been completed with AICDs for a major operator in the Middle East. The wells were completed in a heavy oil reservoir with the oil viscosity of over 300 cP. From analogue wells with conventional completions, the operator identified that a network of fractures would cross the wells. However, very limited data was provided about the fractures.

A comprehensive study was performed to capture the existing uncertainties and to optimize the completion design prior to the installation. The wells were successfully installed in 2018 and, although the well production has been limited to specific intake pressures of the ESPs, the production data over 18 months showed improved production with the AICD completions, resulting in further installation across various fields.

The AICD completion has managed the water cut of the wells, limiting the water production from the fractures. The water cuts were reduced to below 50% for AICD wells compared to 90% in the analogue wells, while oil increments of 20-30% were also delivered. Several other new AICD wells are being planned in the Middle East.

**China**

As another example of retrofitting AICD to current non-effective completions, AICDs were implemented in heavy oil brownfields in China as a retrofit solution when water cuts of wells have typically reached up to 96%.

One of the first AICD retrofit installations to control water cut in a heavy oil environment with viscosity around 30 cP had shown a significant improvement in oil production (Figure 5).

The results have shown a significant reduction in water cut from an average of 96% before AICD installation (2014) to around 93.6% after AICD installation. This was a significant reduction in water cut of the well producing liquid rate of 1000 m³/day. This subsequently increased oil production from 43 m³/d to 55 m³/d i.e. an increment in oil production of 27% resulted from AICD installation.

Following the positive results from the well, several other wells in the field have been retrofitted or been primarily completed with AICD completions.

**Low cost, long-term benefits**

Like ICDs, flowrate is an important parameter to AICD functionality. However, unlike ICDs, the AICD is capable of properly reacting to production fluid properties. This eliminates imposing unnecessary pressure drops and choking the stream of unwanted fluids, therefore improving well performance and productivity.

As a proactive-reactive device, AICD completion was found to be the most efficient completion at controlling the water production from high productive zones or the fractures, compared to the wells equipped with ICDs and other conventional completions.

Financially, inflow control technology is often considered an expensive solution for low-rate heavy oil wells with no thermal injection. However, with more than a dozen AICD-completed wells now online in Canada, along with a number of retrofits in the Middle East and China, there is considerable evidence that these multi-stage AICD completions consistently control water production and improve oil production.

Such projects prove that AICD completions, with low-cost sand screens and packers, is an economical solution that is essentially cost-neutral compared to conventional completions (cemented and perforated wellbore). Its application provides operators with significant long-term benefits as well as a type of insurance policy against geological and dynamic reservoir uncertainties to reduce the risk and variation in the expected oil production profiles.

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