UNLOCKING TIGHT HPHT RESERVOIRS ECONOMICALLY

Mohammed Munawar, NOV, USA, explains how new frac technology is opening the door to high-pressure, high-temperature (HPHT) reservoirs previously out of reach.

High-pressure, high-temperature (HPHT) reservoirs present special challenges. Extracting hydrocarbons from them at economical rates is not possible without durable tools for hydraulic fracturing. A major Middle East operator had a situation that existing tools could not handle – and asked for help. NOV responded by designing and producing the Voyager™ 15XT OH packer.

Typical, non-typical

At a formation's breakdown pressure, the net applied force exceeds both stress and formation strength. This breaks its rock, allowing hydraulic fracturing fluid to flow inside. Proppant is then placed to hold open the formation while hydrocarbons are extracted. Breakdown pressure differs from one formation to another, and mainly depends on the compressive stress along with formation strength itself. This has been a typical fracturing scenario for some time.

Tight HPHT reservoirs are anything but typical. Overcoming formation breakdown pressure in these cases requires a downhole completion that can deliver true 15 000 psi (1034 bar) differential pressure, withstand stimulation pressures and is able to convey the fracturing fluid.

Figure 1. *Voyager 15XT OH packer.*

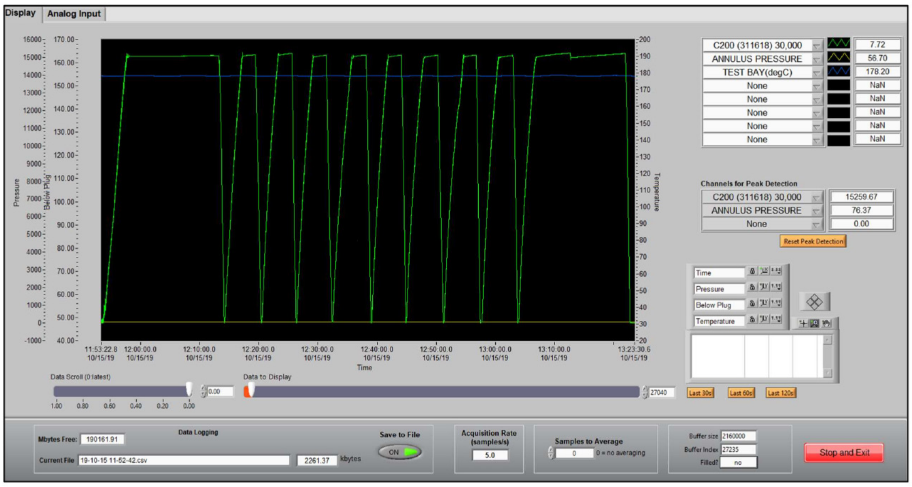

Figure 2. *Frac simulation test: cycle test, 10 times at 350 ˚F (177 ˚C).*

Figure 3. *GripR OH anchor.*

The challenge

A major Middle East operator had used a typical system in some areas of their reservoir. But other areas ran deeper, and their stimulation technique would not work there. They were surprised that they were unable to stimulate the stages even with a 10 000 psi (689 bar) differential pressure system. This scenario was beyond typical.

There was very high potential value in the extremely tight reservoir's HPHT hydrocarbons. But it had been unreachable because of the high pressures. Existing technology simply could not handle the formation breakdown pressures, and they could not economically bring hydrocarbons to the surface. New technology was required.

Requirements of Middle East operator

NOV was approached to develop a true 15 000 psi (1034 bar) openhole ball-drop system for the tight HPHT conventional oil and gas operations. The operator specified a series of rigorous technical tests. After technical acceptance, a field trial was commissioned with the following criteria:

- Installation without mechanical failure.
- Confirmation that the Flow Lock Sub™ was activated and closed during the installation.
- Proper activation of the frac sleeves during the fracturing operation while applying up to 15 000 psi (1034 bar) differential pressure.
- Indication that there was zonal isolation and that openhole packers were holding during the fracturing operations.
- Successful milling of frac sleeves' ball seats.

Component research and results

The company pursued a flexible design for HPHT reservoirs – with the ability to include multiple limited entry. A multi-stage fracturing technique was selected as the ideal method of stimulation. Using openhole packers for zonal isolation and frac sleeves for stimulation to maximise efficiency allowed for continuous pumping operations, and removed the risk of perforation-explosives and multiple wireline runs.

In the process, 2 years in design and function testing were invested in order to meet or exceed the operator's qualifications requirements. The use of company testing facilities in Norway, Canada and the US proved the robustness, flexibility and reliability of the components and integrated system to produce hydrocarbons at a reasonable cost – on demand.

Frac system

NOV started with a solid base: the Voyager frac system had already been deployed and proven in 10 000 fracturing stages in 250 wells around the world. This range of experience in deploying ball-drop systems for various reservoir environments and customers proved crucial in designing and developing the system.

The system meets the challenges and needs of both conventional and unconventional HPHT wells. Proper selection of pressure settings and the ball and seat sizing are critical to the success of a deployment. Each component was sized and approved by the customer for this test, with support from the company's extensive testing and qualification work. The system and its components performed as promised.

Openhole packer

The Voyager 15XT OH packer (Figure 1) is a dual-element hydraulically activated packer for 5.875 to 6.125 in. openhole wells. Applying differential pressure against a temporary or permanent plugging device in the casing below sets the packer. Setting pressure can be adjusted through field-accessible shear pins.

To ensure robustness, the packer was subjected to the highest standards and testing. It is fully qualified to API 19OH V1 for 15 000 psi (1034 bar) at 350˚F (177˚C). Additional pressure cycling testing was also conducted to simulate worst-case stimulation pressures. Here, the packer element was subjected to 10 cycles of 15 000 psi (1034 bar) at 350˚F (177˚C) and 10 additional cycles at 150˚F (66˚C), in addition to 30 cycles at 260˚F (127˚C) on the body of the packer to simulate multi-stage fracturing operations (Figure 2). All cycles successfully met criteria requiring less than 1% leak off.

Openhole anchor

The GripR™ OH anchor (Figure 3) is run as an integral part of the casing/liner to anchor downhole equipment, creating multi-stage zonal isolation in high-pressure, openhole applications. It has nearly full-circumference, bidirectional slips that keep the liner in place, despite expansion and contraction forces caused by high-rate stage fracturing and production. It is also self-centralising. Furthermore, its full-bore design allows passage of frac balls or plugs for stimulation.

The anchor is set hydraulically. First, the Flow Lock Sub plugs the casing below the anchor, then differential pressure is applied at the anchor. Multiple anchors may be run between openhole packers to stabilise the casing during fracturing and production.

An anti-preset feature prevents the anchor from setting during the running of the casing/liner. Cyclical tests at 15 000 psi (1034 bar) and 350˚F (177˚C) were performed on the anchor, like those required for the Voyager 15XT OH packer. Beyond these, the GripR was set in a 6.125 in. ID fixture and subjected to tensile and compressive loads confirming that it mechanically holds 350 000 lbf (1 556 878 N).

Fracturing sleeve

Stimulation requires reliable frac sleeves. The i-Frac™ flex sleeve (Figure 4) is a ball-drop-activated multi-stage fracturing sleeve for openhole or cemented completions. Multiple stages can be installed in a wellbore, with each stage containing between 1 to 20 sliding sleeves for optimised fracture design. This allows operational and stimulation flexibility for single- or multiple-point limited-entry openhole assemblies. For each stage, one ball is pumped from the surface to open all sleeves in

Figure 4. *i-Frac flex sleeve.*

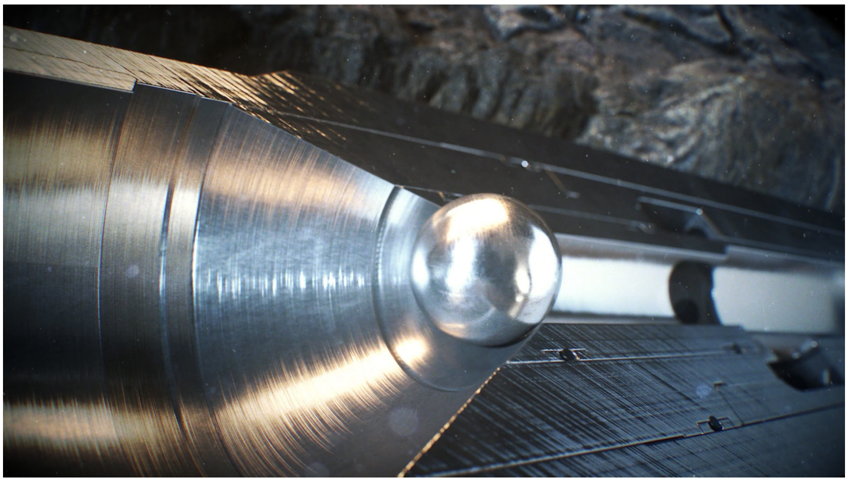

Figure 5. *Flow Lock Sub.*

Figure 6. *BPS Maxx.*

the given stage. The frac job is then continuously pumped with no preparation time between stages.

The flex sleeve was qualified at 15 000 psi (1034 bar) for 10 pressure cycles at 350˚F (177˚C), followed by 15 000 psi (1034 bar) collapse testing from outside to inside. Functionality testing was then performed, including opening the frac sleeve to confirm sleeve opening/activation.

Circulation/lock sub

The Flow Lock Sub (Figure 5) is used in multi-zone, openhole completions to allow circulation through the float shoe until it is time to test the casing/liner integrity. First, a ball is dropped or pumped into its seat in the sub. Then, predetermined pressure applied to ball/seat closes and locks the Flow Lock Sub. Pressure integrity is maintained above and below the sub, even if the ball rolls off the seat. Once closed, the casing/liner is tested, and a hydraulically set packer or liner hanger may be set without additional intervention.

Pressure-activated toe port

BPS™ Maxx toe port units (Figure 6) are used in horizontal completions, enabling fluid injection at the toe of the well without intervention. This reduces the costs and risks of traditional tubing-conveyed perforating guns or wireline tractors to otherwise gain access to the formation at the toe. They use the same field-proven technology as the standard BPS toe initiation subs used in 20 000 installations. But once activated, the high flow area of a BPS Maxx toe initiation sub supports frac sleeve operations with three times greater injection rates than their standard BPS ports.

The BPS Maxx is fully qualified for applications up to 400˚F (204˚C), with absolute activation pressures ranging from 8000 to 21 000 psi (556 to 1448 bar).

System results

In August 2020, NOV deployed the Voyager 15XT frac system as an integrated seven-stage proppant frac trial well. The system's packer compartmentalised the open hole as designed. The activation ball landed and closed the Flow Lock Sub, helping set the packers and the GripR OH anchor. A pressure test was performed, and the system met the first trial HPHT well criterion.

Fracturing stimulation was then performed in October 2020. The BPS toe initiation port was opened, followed by dropping balls for corresponding frac sleeves. Each stage was stimulated, and instantaneous shut-in pressures for pre- and post-fracturing indicated that the packers held during the stimulation, providing zonal isolation. This allowed stimulation at a 40 bbl/min. (6.36 m^3/min.) maximum flow rate in a 20 000 psi (1379 bar) bottomhole pressure environment. Thus, NOV met or exceeded the remaining trial HPHT well criteria and successfully completed the multi-stage stimulation.

Conclusion

For challenging HPHT completions, industry operators no longer need to compromise on performance. The company's new frac system opens the door to target and stimulate reservoirs that were previously out of reach because of higher formation breakdown pressures. Operators can extract hydrocarbons from tight HPHT reservoirs at reasonable costs and desirable flow rates.