The technique of using gas lift to lighten a fluid column so it will continue to flow naturally goes back to the mid-19th century. One of the oldest known artificial lift techniques, gas lift is elegant in its simplicity, a fact that has contributed to its longevity. But even a winning technique can benefit from a little 21st-century technology. Although gas lift has been economical and generally reliable over the years, it has suffered from a few shortcomings. Principal among these are gas injection rate limitations, inadequate maximum operating pressure ratings and leaks back to the annulus.

Despite its simplicity and economic benefits, gas lift has had limited application for stimulating production from subsea installations. Typically, subsea wells are allowed to produce naturally, or are augmented by water injection schemes or seabed booster systems that reduce backpressure on the wellhead. After these techniques have reached their economic limits, the wells typically have been abandoned. It has been postulated that if a gas lift system could be developed that overcame the shortcomings of previous systems, it would represent a game-changing improvement in the technique’s capabilities.

A TEST CASE

Statoil was able to supply the perfect scenario in the case of its Norne Satellites development. Lying about 125 mi (200 km) from the northern Norwegian coast at 66°N latitude, the Norne FPSO produces from the Norne field and its two satellite fields, Staer and Svale. Staer is about 2.8 mi (4.5 km) northeast of Norne, and Svale is an equal distance northeast of Staer. The satellites produce from three subsea installations comprising five producing oil wells and three water injection wells, Fig. 1. Maximum reservoir depth is 8,150 ft (2,484 m), and water depth is about 1,245 ft (380 m). The producing reservoir is composed of sands of the Åre formation. This layered, heterogeneous reservoir is characterized by vertical anisotropy. Additional development challenges include unfavorable oil-water mobility on Svale due to high oil viscosity, highly permeable streaks that may encourage early water breakthrough, propensity to produce sand and difficulty in predicting the degree of communication across several faults.

All these, plus significant uncertainties in identifying the properties and volumes of untested segments, led Statoil to believe that the best way to produce the Norne Satellites was through the combination of openhole sand-control completions with intelligent well systems, augmented by high-performance gas lift and downhole injection of scale inhibitors.

Complex challenges call for complex solutions. Statoil’s analysis caused it to conclude that a single production strategy would not meet all the requirements. The company needed water injection for pressure support and displacement, but too aggressive an injection scheme could lead to premature water breakthrough, bypassed oil volumes and unacceptable sanding. Reservoir drainage was complex, with multiple drainage points in each of the Åre sands. Statoil planned to use inflow control valves to control production from individual reservoir zones, which were to be completed using openhole gravel packs around sand screens. Gas lift valves were to be installed in each well to reduce the backpressure on the wellheads and to lift the oil from the reservoir.

At this point a problem was encountered. Normal gas lift valves lacked the pressure range and pressure integrity needed to operate in the Norne Satellite wells. They typically operated at a maximum pressure of 2,500 psi with a gas throughput of 1.5–2.5 MMcfd. At Norne, pressures were slightly lower than 3,500 psi and throughput was estimated at 8.0 MMcfd. In addition, standard gas lift valves often suf-
fer from an unstable flow condition called “heading,” which causes pressure fluctuations between the tubing and annulus.

SEARCH FOR A SOLUTION

Some of the problems facing Statoil had been addressed, but no existing gas lift system satisfied all the requirements posed by the Norne Satellites development. The ideal system would allow continuous and stable gas injection at the deepest possible point in the well.

Schlumberger offered its proprietary XLift system, a recently released high-pressure, high-performance gas lift. After completion of the first two wells, and during initial gas lift operations, it was discovered that the original check valve system was not capable of sustaining the required barrier seal. Working in collaboration with Statoil, who contributed testing facilities at the company's Karsto Metering and Technology Laboratory and at the International Research Institute of Stavanger, Schlumberger engineers tested and qualified the new gas lift system for the Norne applications. The new system incorporated the requisite upgrades and innovations, Fig. 2. Gas flow tests and modeling were performed at the Karsto facility, and liquid flow tests were done in Stavanger. The objectives of the testing were to qualify the system’s operation under dynamic pressures and throughputs, to verify the pressure integrity as a key component of the tubing pressure barrier envelope, to meet the rigorous requirements of the Norne Satellites well completion schedule and, ultimately, to meet the pressure barrier requirements of the Norwegian Petroleum Safety Authority.

Schlumberger addressed the specific problem areas posed by the Norne case with the new design, while taking the opportunity to demonstrate the wide applicability of the new-generation gas lift system for deepwater subsea developments.

Pressure. The new system has been enhanced to operate between 2,000 and 5,000 psi. This pressure range provides several advantages over traditional gas lift systems. The higher operating limit allows gas lift valves to be installed below the mudline with confidence. The upper valve can be used to unload the entire riser, thus reducing wellhead backpressure. The 5,000-psi upper operating limit doubles that of traditional gas lift valves, allowing emplacement of gas lift mandrels in some of the deepest subsea completions. It also reduces the number of gas lift valves required.

The Norne Satellites development’s higher pressures necessitated a redesign of the bellows unit. Gas lift valves use a metal bellows or pressure dome that is pre-charged with gas. The bellows expands and contracts to operate the valving mechanism. Previous designs using formed Monel bellows lacked the required pressure rating and durability, so Schlumberger chose an innovative edge-welded bellows technology that uses a series of individual discs whose inner and outer circumferences are alternately laser-welded to one another to form an ultra-high-pressure bellows of tremendous strength. The new bellows has double the pressure rating of the formed Monel types. In addition, the new edge-welded bellows assembly is designed with a hydraulic piston that gives it a mechanical advantage. This means that it takes a higher gas injection pressure to overcome a lower dome charge, and actually move the valve to its open position. The concept is similar to that used in subsurface safety valves.

Throughput. Producing a valve capable of injecting gas volumes in excess of 10 MMcfd required a slightly larger system. Accordingly, the new valve has an OD of 1¾ in. The entire valve and side-pocket mandrel pocket bore have been enlarged to achieve the higher performance. The valves have also been made longer to achieve the desired pressure ratings and flow dynamics. A new side-pocket receptacle called the XLG had to be built as well. Unfortunately, this means the new system is not backwards-compatible. The only way it could be retrofitted to a well would be to pull the completion and install new mandrels.

Operation. A key factor in gas lift performance is achieving a critical flow regime. When the valve opens and gas first begins to enter the tubing, it is flowing at subsonic velocity. A choke is placed in the valve to boost gas velocity above the speed of sound, which usually occurs when the differential pressure across the choke is 40–60% of the injection pressure. The reason for the choke is that subsonic gas rates can potentially create extremely unstable oil flow conditions in the tubing. This manifests itself in a condition called “heading,” in which flow variations inside the tubing cause instabilities in the gas flowing in the annulus, and vice versa. Not only can these instabilities cause slug flow in the tubing, but they also have a disruptive effect on the operation of intelligent well monitoring and control systems. Earlier-generation gas lift valves used a square-edged choke like a flow bean to achieve supersonic velocity, but these typically require excessive differential pressure. Schlumberger solved the heading problem with a proprietary orifice venturi valve design called NOVA. Using a venturi design, critical gas velocities could be obtained with as little as 8–10% differential pressure. The significance of this improvement can be understood when one considers that at extreme well depths it is often difficult to get more than 10% differential pressure. Having been field tested around the world, the NOVA design was incorporated into the new valve to ensure continuous stable operation. Sophisticated dynamic flow testing and computer modeling were used to generate the dynamic flow profile of the...
valve. With this model, ultimate valve performance can be predicted for a given set of well conditions and the appropriate venturi orifice can be specified.

A final problem area was the possibility, inherent in every gas lift system, of fluid and production well pressure leaking into the annulus through the check valve. Previous systems’ velocity valves were normally open, closing only when they sensed backflow. They were susceptible to leaking, a problem that Statoil wanted the new design to eliminate. The new gas lift system uses a positive-sealing check valve that acts as a barrier (when gas injection is not occurring) to eliminate leaks.

RESULTS
Since the installation of new gas lift valves, the measured productivity of the Norne Satellite fields has been close to the original predictions, Fig. 3. It should be pointed out that the J2 well’s observed production was influenced by a reservoir pressure that was higher than predicted, caused by communication with the main field. As previously mentioned, premature water breakthrough was an anticipated risk. Unfortunately, water breakthrough from highly permeably strata occurred almost immediately after the field was placed on production. This loaded up the well and triggered the gas lift valves to sustain production. The positive-sealing check valve has proved valuable during continued system integrity testing.

At Norne, the final surface pressure for injected gas was 3,335 psi at the FPSO. Actual injection rates ranged from 7.06 MMcfd (200,000 cmd) to 10.6 MMcfd (300,000 cmd) against a projected rate of 8.82 MMcfd (250,000 cmd) per well. Increasing gas lift injection rates has resulted in a lighter fluid column in the producing string for each well, enabling the required production rates under gas lift. But this also increased the total friction loss in the wells and in the production pipeline. Using the well performance models calibrated to actual field production tests, production was optimized by fine-tuning each well’s gas injection rate.

The complex solution implemented at the Norne Satellites was intended to optimize long- and short-term production. It is believed that, working together, intelligent well systems, gas lift and scale inhibition will increase the field’s ultimate recovery. The new gas lift system benefited production almost immediately. Later in the production cycle, it is anticipated that the other elements will prove to be of equal importance.

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