Improvements in Horizontal Gravel Packing

Companies have been slow to adopt openhole gravel packs for inclined and horizontal well completions. This reluctance centered on operator concerns about the detrimental effects of gravity on gravel placement around sand-exclusion screens. Today, however, these attitudes are changing. Improved techniques, specialized screens, numerous successful installations and a proven record have increased confidence in the long-term performance of this technique for controlling sand influx in high-angle wellbores.

The number of directional and extended-reach wells increased dramatically during the past fifteen years, especially offshore. Operators complete many of these wells as open holes because of the high cost and difficulty of cementing casing and of achieving clean, effective perforations. Long openhole sections with large inflow areas have higher productivities than cased-and-perforated completions and are not as sensitive to drilling or completion damage. However, these types of completions still require reliable sand-control measures.

Gravel packing, an effective and widely used technique, places a granular filter media, or gravel, around metal sand-exclusion screens inside perforated casing or open hole. The gravel is round, well-sorted, clean natural sand or synthetic materials sized to exclude individual formation grains and smaller rock particles, or fines—commonly referred to as produced sand—while being held in place by the screens.

Completion operations involve pumping slurries of gravel and a carrier fluid into the formation or circulates back to surface through a wash pipe inside the screens and a tubing workstring. Gravel packs, used extensively in vertical wells for decades, were less common for high-angle and horizontal open holes in some areas, until recently.

Sand control for open holes traditionally consisted of stand-alone screens without gravel packs or, more recently, expandable screens. Stand-alone screens, however, often fail prematurely. Operators attribute these failures to incomplete borehole cleanout and partially plugged screens, which result in “hot spots,” or converging flow.

Concentrated inflow at discrete points leads to increased pressure drops, screen erosion, increased sand production and, ultimately, to a decline in well productivity. Newer expandable screens are run with an initial diameter that is smaller than the open hole, and then they are extruded against the borehole wall. These systems show promise for some sand-control applications if the expanded screens are strong enough to resist rock failure and sand influx.

However, if expandable screens are not compliant enough to seal tightly against washed-out and enlarged or irregular boreholes, their effectiveness may be only marginally better than stand-alone screens. Removing trapped filtercake after screen expansion also is a concern. Frequent screen-only failures led many operators to attempt more openhole gravel-pack (OHGP) completions.

Incomplete gravel packs and ineffective control of sand caused by early job termination, or screenout, resulting from annular blockage, or bridges, represent significant economic and operational risks for operators. A single sand-control completion offshore costs several million US dollars. Remedial interventions to clean out sand and repair wellbore damage often cost up to a million US dollars and involve significant production downtime.
Sand-control methods. In-situ chemical consolidation and selective or oriented perforating in cemented casing with positive zonal isolation avoids weaker zones or minimizes sand influx (top left). Cased-hole gravel packs control sand in laminated formations, lower quality sands and marginally economic vertical wells (middle left). Frac packs and screenless completions combine stimulation and sand control in reservoirs with layered pay zones, poorly sorted grains or low fluid transmissibility (bottom left). In open hole, stand-alone screens control sand in formations with large well-sorted grains and in wells with short producing lives (top right). Expandable sand screen (ESS) systems provide viable well completions, but long-term reliability has not been established (middle right). At high inclination angles, an openhole gravel pack (OHGP) often maintains well productivity or injectivity longer than other methods (bottom right).
This article reviews openhole gravel-packing techniques, including water packing and shunt-tube technology, which achieve higher sustained production and more consistent sand control in high-angle and horizontal wells than other types of completions. A case history from Nigeria describes the water-packing technique and postinstallation evaluation of OHGP results in a mature, heterogeneous reservoir with depleted pressure.

A second case history presents the evolution of sand-control completions in the Caspian Sea offshore Azerbaijan. This example reviews the relative performance of different sand-control completions, including measures taken to improve OHGP performance while reducing reservoir damage.

Sand-Control Methods

Produced sand, or sanding, causes problems ranging from environmental concerns related to facility cleanouts, processing interruptions and proper disposal on the surface, to erosion of subsurface or surface equipment and potential loss of well control. Excessive sand influx can cause tubular or completion equipment failures downhole that delay production or result in lost reserves if the cost to sidetrack or redrill a well is prohibitive.¹

In the past, operators often had to restrict, or choke back, well production to levels below the critical inflow rate that initiated sanding. Operators successfully used this strategy in some areas to delay installation of sand-control measures, thus reducing upfront costs and avoiding initial completion damage, or high skin. However, restricting production adversely impacts profitability and may be impractical, especially for high-cost, high-rate deepwater and subsea wells.

Companies also used in-situ chemical consolidation to lock formation grains in place by injecting resins and catalysts into formations, generally through perforations in casing. However, placing chemicals across large zones and all perforations is difficult.³

Various techniques are available to exclude sand from produced fluids, including chemical consolidation, cased-hole gravel packs, selective or oriented perforating, hydraulic fracturing, frac packs that combine fracture stimulation and gravel packing, stand-alone or expandable screens, screenless completions and openhole gravel packs.

Depending on specific conditions and factors, these techniques have been applied with varying degrees of success. In high-angle and horizontal openhole wells, operators use stand-alone or expandable screens, openhole gravel packs and, in a few cases, frac packs or gravel packing above fracture-initiation pressure to control sand.⁶

In the past, cased-hole gravel packing was a reliable and widely used sand-control method in conventional vertical wells, but this technique often results in extremely high completion skins.⁷ Today, most cased-hole gravel packs are performed as a high-rate water pack (HRWP) or a frac pack, depending on local experience or available materials and equipment. In wells with cemented casing, selective and oriented perforating attempt to prevent sand production by avoiding weakly consolidated intervals or aligning perforations with maximum in-situ stresses to increase perforation stability.⁹

Hydraulic fracturing for sand control involves conventional and tip-screenout (TSO) treatments formed in perforations where a reduction in pressure drop, or drawdown, can minimize sand influx or, in some cases, prevent the onset of sanding.¹ Frac packing combines TSO fracture stimulations that create short, wide hydraulic fractures with gravel packing to control sand production from weakly consolidated formations.¹¹

Screenless completions combine selective or oriented perforating, in-situ consolidation and frac packing to control sand.¹² In some areas and under certain formation conditions, stand-alone or expandable screens may be an alternative to gravel packing or frac packing.¹³

The initial productivity of wells with stand-alone screens is usually good, but many of these screen-only completions fail to adequately exclude sand over time. Some wells completed with unpacked screens do not fail completely, but must be produced at significantly reduced rates because of partially plugged or eroded screens. Openhole gravel packs, which provide better borehole stability, tend to maintain productivity and control sand longer than stand-alone or expandable screens.¹⁴

Economic considerations often require operators to choose sand-control methods that maximize completion reliability over the productive life of a well or a field without limiting well productivity. The cost of future interventions to perform well workovers or recompletions is another important consideration when selecting and designing sand-control completions. In high-cost, high-rate wells, expensive remedial operations affect overall project profitability and economics.

Gas contracts, for example, often include penalty clauses for defaulting on production and delivery quotas. For cost- and risk-sensitive completions, especially in deepwater and subsea developments, high failure rates and the uncertainty associated with stand-alone and expandable screens may justify the choice of gravel packing. However, if additional data become available to support expandable sand screen (ESS) reliability, operators might choose to use ESS systems more frequently.

Today, more companies view OHGP completions as a viable sand-control completion for inclined wellbores, especially in high-rate wells and wells with long horizontal sections. Because of a proven record of installation reliability, many operators consider openhole gravel packing as the base case for sand control in subsea, deepwater, or large-diameter wellbores and ultrahigh-rate gas wells.

Water Packing in Nigeria

In 2002, Shell Petroleum Development Company (SPDC) evaluated openhole gravel packing as a sand-control option in the Niger Delta, Nigeria (next page).¹⁴ Previously, SPDC had drilled 30 wells with horizontal multilateral and sidetrack sections in shallow unconsolidated reservoirs. SPDC completed most of these wells with stand-alone slotted or prepacked screen liners in open hole.

In addition to the difficulty of cleaning out horizontal sections before and after installing completion equipment, stand-alone screens without gravel packs are prone to partial plugging, screen erosion, sand influx and loss of productivity, which led SPDC and other operators to try expandable screens. These problems often are related to incorrect fluid quality and practices during installation. Fluid cleanliness and conditioning, if managed properly, can reduce the number of stand-alone screen failures.

An ESS provides larger inflow area with less wellbore friction than conventional screen liners, but current designs do not always adequately seal against borehole irregularities. Like conventional stand-alone screens, ESS systems also are affected by factors related to fluid quality, possibly even more so because of potential plugging of small screen openings.

During 2001 and 2002, noncompliant fixed-cone tools were used to expand most of the ESS systems. Today, more compliant expansion tools are available, but they have hole-size limitations. Expandable screens also tend to cost more, require longer delivery times and have unproven long-term productivity and sand-control effectiveness. However, there have been reports of ESS completions that have produced sand-free for more than five years.
The Obigbo-North field is located in the OML-11 and OML-17 blocks about 18 km [11.2 miles] northeast of Port Harcourt, Nigeria. This field was discovered in October 1963. The reservoir consists of unconsolidated sands with permeabilities ranging from 900 to 7,000 mD and porosities of 21 to 33%. The Obigbo-North field comprises 66 reservoir blocks: 55 oil-bearing and 11 gas-bearing. More than 50 wells have been drilled in the field.
These disadvantages restrict ESS utilization in remote areas and mature fields with limited incremental production or reserve potential. Gravel packing, on the other hand, has proved reliable in cased and openhole vertical wells; recent horizontal OHGP installations have been less susceptible to partial screen plugging and sand erosion. An OHGP generally has lower completion damage, or skin, sustains productivity longer than conventional standalone screens, and may sometimes be more cost-effective than current ESS systems.15

In the Obigbo-North field, SPDC selected Well QWSB-53 for an OHGP. This was the first OHGP by SPDC and the first in the Niger Delta. SPDC and Schlumberger performed a waterpacking treatment in mid-2002 with the objective of achieving 3,000 B/D [477 m³/d] of sand-free oil production. Water packing involves low concentrations—0.5 to 2 pounds of proppant per gallon [0.06 to 0.24 g/cm³]—of gravel transported by a low-viscosity carrier fluid, usually brine (above).16

The low side of a borehole packs first until gravel reaches the far end of a section, also called the toe, or until gravel forms a bridge because of formation collapse or high fluid leakoff. Excessive fluid loss is caused by a combination of inefficient fluids, high formation permeability and poor or damaged filtercake, and low reservoir pressure, resulting in treatments that exceed formation breakdown, or fracture gradient, pressure. Gravitational forces dominate during this “alpha” wave, so gravel settles out in an advancing dune front until the particle bed reaches an equilibrium height. When fluid flowing above the bed reaches the critical velocity for particle transport, gravel again moves toward the far end, or toe, of a horizontal section. This alpha wave stops after reaching the end of a workstring internal wash pipe, the toe of a horizontal section, a gravel bridge or collapsed formation.

A second deposition process, or “beta” wave, begins packing the annulus topside back toward the beginning, or heel, of a horizontal section in a “beta” wave (6 to 10). Surface treating pressures provide an indication of how water-packing treatments are progressing (bottom left).
SPDC then drilled a 1,000-ft [305-m] horizontal section to total depth using a 0.49-psi/ft [11 kPa/m] water-base drilling fluid. After reaching total depth, drillers circulated the borehole clean with no significant fluid loss, which indicated that filtercake on the sandface provided a good seal. To minimize screen plugging, SPDC displaced the open hole with a solids-free fluid of the same composition as the reservoir drilling fluid without calcium carbonate, but with additional salt to maintain a 0.49-psi/ft pressure gradient. The casing was displaced with filtered brine before running the sandface completion assembly, which consisted of available screens from warehouse stock (right).

A volumetric calculation determined that 9,237 lbm [4,190 kg] of gravel would be required to pack the 6-in. openhole annulus. Schlumberger pumped gravel using a filtered 12% potassium chloride [KCl] brine carrier fluid. Injection pressure and rate, and sand concentration were monitored at surface to track the alpha and beta waves (below right).

Gravel was placed in four stages at different concentrations while reducing the injection rate to adjust for injection pressure increases. In formations with low fracture gradients, Shell completion engineers often reduce the slurry injection rate once a beta wave initiates to avoid prematurely breaking down formations prior to developing enough dune height to completely cover the screens. This technique lays down additional alpha waves on top of previous dune beds.

This resulted in multiple alpha waves and complete screen coverage. The operator pumped a total of 13,500 lbm [6,123 kg] of gravel, but reversed out 2,670 lbm [1,211 kg] of excess gravel, leaving about 10,830 lbm [4,912 kg] of gravel around the screens, which corresponds to an actual borehole size of 6.25 in.

After gravel packing, the running tool and wash pipe were retrieved. A 3⅜-in. tubing string with a tubing-retrievable subsurface safety valve and gas-lift mandrels for future artificial lift was installed. A 10% hydrogen chloride [HCl] acid treatment energized with nitrogen [N₂] was displaced in the horizontal section using ½-in. coiled tubing and a downhole tool with 360° rotating jet nozzles to generate hydraulic turbulence and make closer contact with filtercake on the borehole wall.

15. Skin is a dimensionless measure of completion damage. Positive values represent damage. Zero is equivalent to the productivity of an undamaged formation. Negative values represent stimulated producing conditions.


Obigbo-North field wellbore and completion schematic. Shell Petroleum Development Company completed Well QWSB-53 with 965 ft [294 m], or 32 joints, of screen deployed in open hole without centralizers.
Post-treatment cleanup improved well performance by diverting acid across the horizontal section and by ensuring deeper penetration. The well initially produced oil at 3,250 B/D [517 m³/d]. A spinner inflow profile, pressure drawdown and total production rate from a memory production log indicated 100% pack efficiency, with the entire horizontal section producing into the screen assembly.

This completion demonstrated better initial inflow capability and longer sustained productivity at a higher drawdown pressures than other wells with stand-alone screens. It also saved the SPDC Eastern Asset Team US$ 300,000 compared with previous ESS installations.

Low-rate water packing was a technical, operational and commercial success in the Niger Delta. SPDC continued to improve fluid quality and fluid handling, reduce nonproductive rig time and monitor OHGP performance to determine whether this technique was suitable for other wells.

Horizontal openhole gravel packing was later discontinued because of premature screenouts and incomplete gravel packs on some other wells. The water-packing technique was deemed too complex to execute without proper onsite technical expertise and supervision.

Subsequently, SPDC installed several openhole gravel packs using Alternate Path shunt-tube screens and Schlumberger MudSOLV filtercake removal service, which were extremely successful. These high-rate gas-well completions were not horizontal, but had high-angle wellbore inclinations over relatively short intervals of about 100 ft [30 m]. SPDC continues to evaluate Alternate Path screen technology for longer pay intervals.

Alternate Path Technology

If gravel packing is required, operators must choose between water packing with conventional screens or using screens with Alternate Path shunt tubes, two field-proven techniques for completing long openhole sections. Mobil Oil Corporation, now ExxonMobil, developed Alternate Path technology in the late 1980s and early 1990s to address problems associated with gravel bridging (below).

Alternate Path gravel packing. This technology ensures complete packing of gravel around sand-exclusion screen assemblies and across an entire horizontal section. Shunt tubes attached to the screens provide conduits for slurry to bypass gravel bridges and fill annular voids (top and bottom right). Shunt packing does not depend on filtercake to prevent fluid loss. If the annulus between screens and openhole packs off prematurely (1 to 3), slurry diverts into the shunts, and gravel packing proceeds toward the toe even with no fluid returns, or circulation, to surface (4 and 5). Usually, pump rates are reduced after shunt flow begins, and treating pressure increases because of the small shunt-tube diameters (bottom left).

External shunt tubes on Alternate Path screens allow slurry to bypass any blockage that forms in the annulus between screens and casing or an open hole during gravel packing. This technology helps ensure a complete gravel pack below annular bridges. However, shunt tubes restrict the size of screen that can be deployed, which is a limitation.

Unlike water packing, this technique does not rely on filtercake integrity. If the annulus becomes restricted, pumping pressure increases and slurry diverts into the shunts. These tubes provide a conduit for slurry to bypass collapsed hole, external inflatable packers or annular gravel bridges at the top of intervals or adjacent to zones with high fluid leakoff.

Gravel packing with Alternate Path screens uses gravel pumped at higher concentrations—4 to 8 lbm/gal [0.48 to 0.96 g/cm³]—in viscous carrier fluids. Engineers adapted Alternate Path screens for use in longer openhole horizontal sections. Transport shunts without ports are attached along the entire length of screen assemblies to reduce friction pressures while gravel packing long intervals; shunts with exit ports, or nozzles, serve as packing tubes.
This configuration reduces carrier-fluid leakoff into the annulus, limits slurry dehydration, and delivers slurry to packing tubes at 4 to 6 bbl/min [0.6 to 0.9 m³/min]. Slurry flows from transport to packing tubes through a manifold at each screen joint and exits through wear-resistant, carbide nozzles to pack voids behind screens at 0.5 to 2 bbl/min [0.08 to 0.3 m³/min]. Shunts and nozzles are designed to reduce gravel buildup inside shunts.

Gravel does not easily make turns through small exit ports, so large angled nozzles that extend into the flowstream increase the tendency for slurry to exit the shunts. Treatments are performed using nondamaging fluids with good gravel-carrying capacity and low friction characteristics.

Blank pipe above screen assemblies also can be fitted with transport tubes to provide a path for slurry in the event of borehole collapse or formation of a gravel bridge at the top of an interval. In addition, a pipe shroud with predrilled holes surrounds the entire Alternate Path screen assembly to centralize the screens within the shroud and to protect the shunt tubes during installation.

Shunt Packing in Azerbaijan
BP operates the Azeri, Chirag and Guneshli (ACG) fields in the Caspian Sea (above right). Since 1997, BP has installed several different types of sandface completions in 29 primary and sidetrack wells, including both producers and injectors. During this period, sand-control methods evolved from water packing with conventional screens and cased-and-perforated completions to stand-alone screens, expandable sand screen (ESS) systems and openhole gravel packing with Alternate Path screens.

Water Packing with Conventional Screens—BP completed two early Chirag producing wells, A-02 and A-03, as openhole gravel packs using the water-packing technique. Well A-02 produced oil from December 1997 until March 1999 with associated sand rates of less than 10 lbm/1,000 bbl [28.5 g/m³] and no water. Since then, BP periodically shuts this well in because of high gas production. Buildup tests in December 1998 and November 2004 indicated positive skins of 3.2 and 2.1, respectively.

Well A-03, a similar completion in January 1998, produced oil with sand rates of 2 to 3 lbm/1,000 bbl [5.7 to 8.6 g/m³]. Buildup tests in December 1998 and July 2003 both indicated positive skins of 4.4. Despite relatively low gravel-pack efficiencies of about 25% and higher skin factors in each well, water packing with conventional screens achieved acceptable sand control. To date, neither the A-02 nor the A-03 well has produced water, and no sand has accumulated in either wellbore. However, as BP began drilling more extended-reach wells with high-angle and horizontal sections through pay intervals, completion engineers shifted to Alternate Path screens.

Cased-and-Perforated Wells—Well A-06 and Sidetrack A-06z represent two of nine oil producers and two water injectors in the Chirag field with cased-and-perforated completions. In 1998, the A-06 completion initially produced sand at high rates that eventually stabilized at 1 to 3 lbm/1,000 bbl [2.9 to 8.6 g/m³], but with occasional bursts that exceeded 100 lbm/1,000 bbl [285 g/m³]. A pressure buildup test indicated a low skin of negative 0.9.

However, after water breakthrough in early 2000, sand production increased dramatically, and BP had to restrict outflow from this well. In November 2000, a coiled tubing workover cleaned out sand fill and set a cement plug in the wellbore to isolate lower sands and reestablish...
water-free production from the upper sands. Water breakthrough in these zones during November 2001 again caused sand production to increase.

Early in 2002, BP abandoned the A-06 wellbore and sidetracked it to quickly restore production. Pressure buildup tests in the new casing-and-perforated A-06z wellbore indicated a low skin of negative 1.6, but high sand rates required BP to choke back production after this well also began producing water in March 2003. In December 2003, Well A-06z was abandoned and sidetracked again as an OHGP completion, which has since produced oil with low sand rates of 1 to 3 lbm/1,000 bbl.

**Stand-Alone Screens**—Three Chirag field wells, including A-09 and A-18, were completed with stand-alone screens. In April 2002, a pressure buildup test on Well A-09 indicated a low skin of negative 2.8. This well produced oil and minimal sand until water breakthrough in September 2003 when sand rates became excessive even at low water cuts of 3 to 6.

Well A-18, completed with stand-alone screens, initially had to be choked back because of excessive sand. After BP gradually increased the production rate over three months with corresponding increases in sand, produced sand began to decrease despite increasing oil rates. Pressure buildup tests indicated an initial skin of negative 1.8, which gradually decreased to an extremely low negative 5. Sand influx continued to decrease, except for intermittent bursts, but this well never achieved maximum productivity because of persistent sanding.

**Expandable Sand Screens**—BP completed two Chirag field wells with ESS systems. One, the A-08z sidetrack, was drilled as a water injector. But during the cleanup flow period in December 2002, this well produced oil with no water. Pressure buildup tests indicated a positive skin of 3.3. The well produced at low sand rates of 1 to 5 lbm/1,000 bbl [2.9 to 14.3 g/m³] until March 2004 when it was converted to injection.

BP installed the second ESS completion in a sidetrack of Well A-09. The original wellbore, A-09, had been completed with stand-alone screens. It produced high oil rates until water production increased in September 2003 from less than 0.1% to 10% with significant volumes of sand. BP sidetracked this well as A-09z and recompleted the new wellbore with expandable screens in April 2004. Well A-09z produced oil with no water and had sand rates similar to Well A-08. However, skin gradually increased from negative 1.5 to positive 0.3, possibly because of increasing gas production.

BP completed both A-08z and A-09z sidetracks with relatively low-strength ESS screens. Well logs and absence of initial or subsequent bursts of sand common in both cased-and-perforated and stand-alone screen completions helped confirm a high degree of ESS integrity. After a period of production, however, caliber logs revealed screen deformation, particularly across shale sections. Sand control and well productivity have not been affected, but long-term ESS performance is still uncertain.

**Alternate Path Screens**—Since November 2000, BP has installed 13 Alternate Path completions in five producers and three water injectors in the Chirag field and in five producers of the Azeri field. BP originally planned to convert Well A-15-T1, the first Chirag field well to be completed with Alternate Path AllPAC screens, to water injection after a brief production period. The sandface completion included 380 m [1,247 ft] of AllPAC screens with two transport shunts, two packing shunts and a protective shroud.

BP kept Well A-15-T1 as a producer, and in December 2000, this OHGP well produced oil at 15,400 B/D [2,448 m³/d] with no water. The well began producing water in January 2003. Water cut increased to about 7% at the end of 2003, and then to 14% by mid-2004. Sand rates, however, remained at 0.3 to 5 lbm/1,000 bbl [0.86 to 14.3 g/m³] in contrast to significantly greater sand production from wells having stand-alone screens and cased-and-perforated completions with water cuts as low as 3 to 5%.

Flow from the well recently ceased because of liquid loading, but the OHGP maintained adequate sand control during two years of water production. This performance established openhole gravel packing with Alternate Path screens as the design basis for subsequent well completions.
Well A-19, the longest extended-reach well to date in the Chirag field, was drilled and completed in December 2004 to tap an undeveloped area of the field, 6 km [3.7 miles] northwest of the Chirag-1 platform. The sandface completion included 504 m [1,653 ft] of AllPAC screens with two packing shunts, two transport shunts and a protective shroud (previous page). BP calculated a gravel-pack efficiency of 91% in the A-19 well. Pressure data indicated that slurry diverted into the shunts during gravel packing (right).

Pressure buildup tests in January and February 2005 indicated near-zero positive skins of 0.5 and 0.1, respectively. The well produced oil rates that exceeded the 20,000-B/D [3,180-m³/d] test-separator capacity. Sand influx averaged less than 1 lbm/1,000 bbl [3 g/m³] with no produced water. BP expects the output of Well A-19 to reach 29,500 B/D [4,690 m³/d], the highest rate in this field. This is a significant achievement after eight years of production, with reservoir pressure depleted 1,000 psi [6.89 MPa] below initial conditions.

Four other wells were completed using similar procedures, two in the Chirag field and two in the Azeri field. Both Chirag wells had positive skins of 2. Well A-12x produced oil at 9,000 to 12,000 B/D [1,431 to 1,908 m³/d] and had a sand rate of 0.4 to 1 lbm/1,000 bbl [1.2 to 3 g/m³]. Well A-06y produced oil at 14,000 to 15,000 B/D [6,900 m³/d] and had a sand rate of 1 to 2 lbm/1,000 bbl [3 to 6 g/m³].

One of the two Azeri field completions, Well B-05, produced oil at 42,000 B/D [6,677 m³/d] with extremely low sand rates of 0.2 to 0.3 lbm/1,000 bbl [0.6 to 0.9 g/m³]. The second Azeri well, B-09, produced oil at 35,000 B/D [5,565 m³/d] and had similar low sand rates, but is still choked back. This level of productivity is notable because a borehole problem prevented screens from reaching total depth, so only one zone contributes to production.

These completions resulted in high-productivity wells. Installation of sandface equipment was successful in all the wells except one, Azeri B-09, where the screens got stuck midway down the openhole section. This problem has occurred in other areas, when screens were run after displacing oil-base mud with water-base fluids. Difficulties running screens to total depth in water-base fluids motivated BP to modify completion procedures in the next two Azeri wells.

The Azeri Well C-04, completed in December 2004, was the first completion in the ACG development to have sandface equipment run with oil-base fluids in the wellbore. The completion equipment included 600 m [1,969 ft] of AllPAC screens with two transport shunts, two packing shunts and a protective shroud. Estimated gravel-pack efficiency was 66%. A buildup test indicated zero total skin.

Well C-01Az, a similar completion, had a positive skin of 2.5. A higher estimated gravel-pack efficiency of 93% resulted from increased drilling-fluid density and corresponding reduction in inward movement of the hole before gravel packing. A large-scale surface test identified no significant problems with displacing oil-base fluids from screens, so BP plans to use these modified techniques on future openhole gravel packs.

Fluids and displacement procedures used in this development program have evolved since the first Alternate Path completion in November 2000. Initially, BP drilled cased-and-perforated wells and completions with stand-alone screens using oil-base fluids. Early wells with openhole gravel packs were drilled using water-base fluids that were essentially reduced viscosity, or thinned, mud from previously drilled hole sections. The wells also were gravel packed with water-base fluids.

BP anticipated that wells would become more challenging and that high-angle and longer extended-reach wellbores would be difficult to drill and complete using water-base fluids. BP, ChevronTexaco, Petrobras and Total initiated a joint venture to develop oil-base fluids for drilling and completing OHGP wells.

Reservoir sections of the first two wells completed with Alternate Path screens in the Chirag field and one well in the Azeri field were drilled with water-base fluids. A synthetic oil-base mud was used for reservoir drilling in the next three Chirag field producers and the next four Azeri field producers.

In the three Chirag field wells and the first two Azeri field wells, the entire wellbore was displaced with water-base fluid before running sandface completion equipment. On the two most recent Azeri wells, screens were run in oil-base mud.

To date, BP has gained significant experience that can be applied in other wells in the Chirag and Azeri fields and the deepwater Guneshli field. Fluid systems currently available provide BP with the option of implementing oil-base gravel packing if necessary.


Looking Ahead

Many recently discovered fields require sand management. For example, BP estimates that within five years 50% of its oil and gas production will be from weak and unconsolidated sandstone reservoirs. In the Niger Delta region of Nigeria where Shell Production Development Company operates, 70% of hydrocarbon reserves lie in shallow reservoirs prone to producing sand.

Selection of suitable sand-prevention techniques is a challenge that requires a substantial amount of data, acquired at significant cost. Even then, sand-control measures that appear viable based on initial data often fail. This makes experience in a particular area an important factor in planning and design of future well completions.

Based on experience, cased-and-perforated completions yield low skins, but produce large volumes of sand, even before water breakthrough. These completions require restricted production rates and longer flow periods to achieve postcompletion cleanup. They also involve repeated cleanout of surface separators, and the transport and proper disposal of sand at surface with associated health, safety and environmental risks. Sand fill in wells requires frequent remedial well interventions, and flow from these wells eventually must be choked back significantly.

Completions with stand-alone screens exhibit low skins, but often produce large volumes of sand initially. Subsequently, sand influx rates decrease, but there still can be occasional bursts of higher sand production. However, both cased-and-perforated and screen-only completions produce large amounts of sand as water production increases, even at low water cuts, necessitating expensive premature sidetracks in some fields.

ESS completions have low skins and currently appear to provide sand control equivalent to an OHGP, but the long-term impact of screen deformation, and ESS performance and reliability after water breakthrough remain unknown. Many initial ESS completions have been converted to injection after short periods of production; others were installed too recently for conclusive evaluation.

An OHGP with high pack efficiencies controls sand, even when intentionally designed with larger gravel to allow limited volumes of smaller fines to be produced. In addition, openhole gravel packs tend to control sand more effectively than other methods after water breakthrough.

Unless formations have extremely clean, well-sorted grains, subsea production and injection wells that may produce sand and most completions in deep water—greater than 1,000 to 2,000 ft [305 to 610 m]—should be gravel packed to avoid costly remedial interventions, especially when large reserve volumes are involved. Many operators now prefer openhole gravel packing in wells with long horizontal sections to reduce sand-related failures and minimize associated productivity decline.

Ongoing improvements in fluid designs and displacement procedures are helping operators increase the productivity of openhole gravel-pack completions, while reducing overall field development and operational costs. These improvements include reservoir drilling using oil-base fluids, running completion equipment and screens in oil-base fluids, displacing the entire wellbore with water-base fluids and gravel packing with water-base viscoelastic surfactant fluids.

For example, improved BP completions practices in the Chirag field have resulted in a continuous reduction in completion skins to near zero, with incremental oil productivity benefits of 600 to 800 B/D [95.4 to 127 m3/d] per well (above). Switching to oil-base drilling fluids increased drilling efficiency, improved hole conditions, and reduced drag when running screen assemblies in high-angle and horizontal wells. In addition to environmental benefits due to eliminating discharge of water-base fluids, BP also realized savings exceeding US$ 130,000 per well by recycling synthetic oil-base fluids and reducing gravel-packing fluid costs through elimination of enzymes in the carrier fluid.

Openhole gravel packing has evolved as operators and service companies have gained experience and a better understanding of formation damage and gravel placement in horizontal wells. It remains the sand-control method of choice to protect screens and provide improved sandface completions.

Successes like those achieved by Shell in Nigeria and BP in Baku have established operator confidence in the effective application and long-term performance of openhole gravel packs. The reliability of OHGP completions is contributing to a shift in the well-construction and sand-control philosophies of many drilling and completions teams.