Does underbalanced drilling really add reserves?

UNDERBALANCED DRILLING IN its various forms has been used in the oil and gas industry for more than 20 years. There are many mentions in the literature of resultant well productivity improvements. In contrast, there is little written in the literature about what contribution UBD makes to reserves and ultimate recovery.

UBD-RELATED RESERVES

To calculate the reserves attributable to UBD rigorously, one should look at all reasonable development schemes, the associated well and field recoveries, the costs and associated reserves, and the resulting economics.

In the cases presented here, we have insufficient information to attribute reserves rigorously, but we do have enough information to make reasonable inferences about incremental economic reserves attributable to UBD techniques.

The procedure used in this article for estimating reserves attributable to UBD operations is simple. If a conventional development scheme will recover economic reserves of X bbls, and a UBD scheme will recover economic reserves of 1.5X, then the portion of the reserves attributable to UBD is 0.5X reserves.

This practical method of considering reserve contribution does not address recovery factor. However, we discuss recovery factor where information is available.

In most of the case histories discussed, UBD is used in partially depleted fields to revive production. UBD also is often a crucial element of a larger system, in which UBD is used in conjunction with horizontal drilling.

Neither horizontal nor UBD by itself could produce the reserves that both can when combined.

A more complex example of the use of UBD is seen in enhanced oil recovery (EOR) projects, which are most often undertaken in mature fields with semi-depleted reservoirs. The total system to achieve incremental recovery comprises infill wells and surface facilities to inject a fluid or gas. If wells cannot be drilled successfully in a depleted field without UBD, then UBD becomes an enabling technology crucial to the success of the entire EOR project. As such, it is reasonable to assign UBD a value equal to a portion of the entire project value or project reserves.

TYPES OF RESERVES ADDITIONS

Incremental reserves are rooted in three fundamental benefits of UBD:

• Reduced formation damage. Although skin is typically considered to affect the acceleration of reserves, it may also be argued that reserves can be added by allowing more zones to contribute to the wellbore, or by lowering abandonment pressure.

• Improved access. UBD techniques make it possible to drill wells in circumstances where conventional drilling techniques do not work. This was found to be the single biggest contribution to reserves in the case histories considered here. In many cases, UBD was used in underpressured or partially depleted reservoirs only after conventional wells proved expensive and unsuccessful.

• Reservoir evaluation while drilling. Many wellsite geologists can cite cases where productive zones have been missed completely because they were drilled overbalanced. They looked "good" on a log, but were not tested because of lack of shows, or were tested and produced little or nothing. Drilling through the same zone underbalanced may reveal a completely different story, as shown in a well in Lithuania in which an entirely new producing zone was discovered while drilling underbalanced. In this case, the reserves of the new zone were attributable to UBD.

Most commonly, the reserve improvement derives from a combination of the three benefits listed above. There are fewer cases where the reserve increment comes from a single aspect.

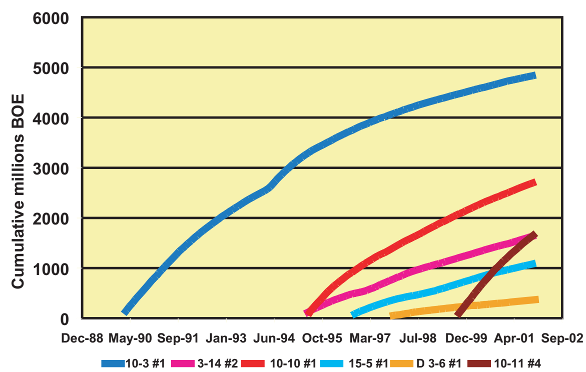
The following case histories have several common features:

• UBD was used in an existing producing field.

• Conventional well practices resulted in well construction problems (e.g. lost circulation), or skin damage and productivity loss, or both.

• Operators often used UBD only after trying a myriad of conventional and often costly drilling techniques such as light weight fluid, lost circulation material, etc.

• Every operator clearly recognized a learning curve for UBD cost and time; multiple wells are needed to rise to the level of efficient and optimized operation.



Cumulative production from selected wells in the Hatter's Pond field.

HATTER'S POND

Hatter's Pond in Alabama is a gas condensate field at a depth of 18,000 ft, producing from the Norphlet dolomite and Smackover sandstone. This field was discovered in 1974 and has produced 210 Bcf and 50 million barrels condensate up to 1999.

The original reservoir pressure was 9,200 psi, but by 1999 it had reached an average pressure of 2,700 psi, a "blowdown" phase. Gas injection had been used in previous years to maximize condensate recovery by maintaining reservoir pressure.

The 18 producing wells averaged 100-400 barrels condensate per day and 3-6 MMcf/d in 1999. Using UBD technology, the operator hoped to exceed those rates in a new well.

With this low reservoir pressure (equivalent to 1.5 ppg), recent wells drilled with conventional mud systems had experienced losses to the formation. In addition, the fluid invasion damaged the formation and reduced production rates.

The operator considered several drilling fluid alternatives, including foam, and decided to drill the well with natural gas misted with diesel. Given the reservoir temperature of 350 F, and the presence of 100 to 700 ppm H2S, all well operations had to be planned with great care.

After setting 7 5/8-in. casing above the Norphlet, the 10-11 #4 well pay section was drilled out with a 6 ½-in. bit using 2,600 standard cubic feet per minute gas and 25 gallons per minute diesel.

The well achieved 25 MMcf/d while drilling, and was producing 16 MMcf/d and 800 barrels condensate per day after completion. As of Feb 2002, it had produced over 11 Bcf of gas and 550,000 barrels oil (MBO).

All the wells are crestal wells in the same or adjacent sections, and all wells except the 10-11 #4 were drilled conventionally. The decline curves indicate that the 10-11 #4 well achieved several times the initial rate of the other wells drilled in the 1990s.

This is all the more impressive when one considers that the reservoir pressure when 10-11 #4 was drilled was lower than for wells drilled in previous years.

Cumulative production plots clearly show the outstanding performance of the 10-11 #4 UBD well. The 10-11 #4 UBD well performed as well as the 10-3 #1 well drilled 10 years before.

By February 2002, the 10-11 #4 well had produced roughly 1,000 MBOE more than the more typical wells 3-14 #2 and 15-5 #1. For purposes of crediting reserves to UBD, we assume that the incremental reserves recovered by the 10-11 #4 well was half of the difference between its cumulative recovery to date and that of more typical wells 3-14 #2 and 15-5 #1. That difference is equivalent to 500 MBOE. It could be argued given the low reservoir pressure at which this well was drilled that 75% or more of the incremental reserves could be attributable to UBD.

If one assumes 3, 5, or 10 more years of field life with wells maintaining their current trend, the incremental benefit will be several times greater.

RHOURDE EI BAGUEL

Rhourde El Baguel, one of the largest fields in Algeria, was discovered in 1962 and produced 430 million barrels of oil (15% of oil in place) up to 1995. Peak production occurred in 1968 with 94,000 barrels of oil per day (BOPD) being produced from 17 wells. Production in 1995 was 25,000 BOPD from 21 wells.

This highly undersaturated reservoir had an original pressure of 5,750 psi, with a bubble point of 2,390 psi. Reservoir pressure had declined to approximately 2,000 psi by the mid 1990's.

The operator, SONARCO, planned to implement an EOR project using lean gas injection. Additional wells on approximately 160-acre spacing were required to create the 11 nine-spot injection patterns to implement the project.

The operator estimated that EOR could recover an additional 500 MMBO, equating to about 35% of the oil in place.

The operator commenced the infill program with conventional wells, using a lightweight oil based mud. Even with this low-density fluid, an overbalance of roughly 1,900 psi resulted. Problems ensued, including lost circulation, stuck pipe, abandoned coring attempts, inability to achieve the planned total depth of the well, and significant skin damage.

Lost circulation material and sized calcium carbonate were tried without success. Costs for the overbalanced (OB) wells ranged from roughly $1,865-$6,000 per meter drilled, averaging $3,520 per meter over the nine-well program.

At this point, the operator sought a more cost-effective method of drilling and, after considering several options, decided upon underbalanced drilling using foam. The logistics involved in mobilizing UBD equipment to a remote location in the Sahara was a significant challenge.

More than 27 wells were drilled with foam, including two of the wells that had been suspended during the overbalanced drilling program. The UBD wells were much more successful in meeting the objectives of the project, including reaching the desired total depth, coring, logging, and low skin factor.

It is clear that there is a learning curve in applying UBD techniques. Cost for the underbalanced wells averaged $3,974/meter, but the last nine UBD wells cost less than the lowest cost overbalanced well, which had cost $1,865/m. Costs for the last several UBD wells averaged $1,253/m.

In terms of allocating a value to UBD techniques, it is clear that the EOR project would have been marginal at best using conventional drilling techniques. Only after adopting UBD techniques were wells created that could allow the project to move forward economically.

Considering that the remaining recoverable reserves were 500 MMBO, a considerable portion of this should be attributed to UBD techniques. For purposes of this discussion, we shall conservatively suggest 20% or 100 MMBO attributable to UBD. It's easy to argue that the portion attributable to UBD is larger or smaller, but it's clear that the UBD contribution is nevertheless significant.

LITHUANIA

UBD has found recent success in the Gargdzai region of Western Lithuania. During 1966 to 1994, 8-10 vertical wells were drilled conventionally in six fields.

The producing reservoir was the Middle Cambrian Sandstone at a depth of 6,300-6,600 ft, having a thickness of 200 to 250 ft. Although the wells were completed as producers, initial rates were low, typically less than 130 BOPD, and declines were rapid due to lack of aquifer pressure support.

Subsequent analysis suggested that conventional drilling caused water blocking, pore-throat plugging, and swelling clays, all of which contributed to the low productivity.

Minos Nafta became operator of the fields in 1996, and began trying different methods to improve productivity, including fracturing, diesel as a drilling fluid, horizontal wells, and UBD. Three fields are considered in this case history: Peitu Siupariai, Diegliai, and Pociai.

With eight conventionally drilled producers as a starting point, the operator drilled one vertical well and five horizontal wells underbalanced.

Field production had peaked at about 2,000 BOPD in 1997, prior to drilling UBD. By mid 2001, after UBD, field production exceeded 8,400 BOPD and was rising.

Several of the wells produced 2,000-4,000 BOPD while drilling, and one well, D-8, became the most prolific well in Lithuanian history. The well reportedly produced at rates of up to 5,601 bbl/day and a cumulative volume of 43,197 bbl during drilling.

One well, the PS-2, demonstrates the reservoir evaluation aspect to UBD. Prior to drilling, the uppermost zone in this well was not thought to be productive; in offset wells and fields this zone was drilled through without detecting any hydrocarbons because of the high mud weights used.

Drilling underbalanced through this zone, however, produced 4,000 BOPD during the drilling, a 30-fold increase compared to offset well G-7. Drilling was suspended and the well was completed after 5 meters of penetration due to the prolific oil influx.

The EUR estimates, derived from decline curve analysis, show an increase of reserves of 2.3 MMBO and 1.6 MMBO for Pietu Siupariai and Degliai, respectively, a five to tenfold improvement.

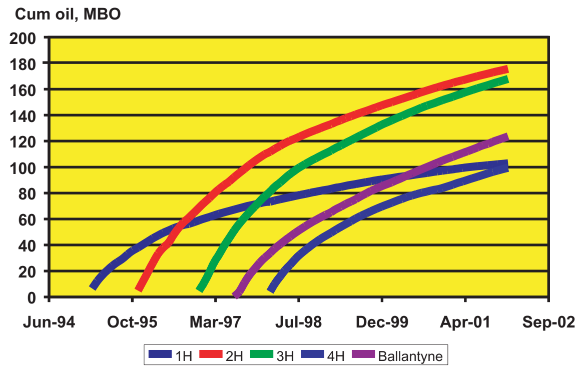
Similar improvements in EUR are estimated in Pociai field also. UBD technology in combination with horizontal wells truly unlocked the potential of these fields.

WAYNE FIELD, NORTH DAKOTA

The Wayne Field in Williston Basin produces 28° API oil from the Mission Canyon formation, a fractured carbonate reservoir at a depth of 4,000 feet. This 15-20 ft thick reservoir averages 24% porosity and 100 millidarcies permeability. The original reservoir pressure, 1,900 psi in 1957, had dropped to about 900 psi by 1994 when the operator's development effort commenced.

The reservoir's active bottom-water drive mechanism quickly became evident in the pattern of production.

The original vertical wells showed an initial production of 70 BOPD, but the oil cut declined rapidly over the first year and stabilized at 10 BOPD (90% water cut).



Cumulative production through February 2002 of five horizontal wells in the Wayne field in the Williston Basin of North Dakota.

By the end of 1985, 33 of these vertical wells were on production, and through 1994 the field produced 2.5 MMBO and 24 million barrels of water, equating to a recovery factor of only 10.4%. Decline curve analysis indicated that the EUR would be about 3.5 MMBO (106 MBO EUR per well), or only about 14.6% of the original oil in place.

The dramatic and quick increase in water cut in these wells was evidence of water coning, a common fact of life in such thin, bottom-water-drive reservoirs.

The coning led to high oil recovery from a small well-flushed zone around the wellbore, but limited the amount of drawdown pressure that could be applied to the reservoir.

As a result, the average drainage radius of the wells was only 240 feet. Since the wells were drilled on 40-acre spacing, this left more than 50% of the reservoir area unproduced. Horizontal wells appeared to be a logical solution.

Overbalanced Horizontal Drilling. GeoResources drilled the first well, the Oscar Fossum H-1, as a conventional lateral drilled with an overbalanced polymer mud system having a density of approximately 8.4 pounds per gallon. The H-1 well horizontal section was drilled with steerable assembly as a 6 1/8 inch hole out of 7-in. production casing.

Steering proceeded with no problems in the first half of the lateral, but after that point the overbalanced situation led to increasingly severe steering and differential sticking problems. Steering the tools in the last 300 ft of the hole became extremely difficult.

While rotation was still possible, sliding and steering were necessary to keep the hole in the target zone. Although the well was TD'd near the planned horizontal length of 1,808 ft. it was clear that future wells would require a different drilling technique if longer laterals were to be accomplished.

Initial production of the H-l well was satisfactory, but not as high as had been expected for its well length. Thereafter the well's production profile began a moderate decline, and both of these factors were considered to be indications of possible reservoir damage.

Underbalanced horizontal drilling. The next four horizontal wells were drilled either near-balanced or underbalanced. The H-2 well (drilled with native crude) was nearer to being balanced, but it is included because UBD techniques were used (a rotating head and fluids with a circulating density lower than that of conventional drilling fluids).

The most immediate benefit of UBD in Wayne Field was access. Underbalanced techniques were primarily responsible for doubling well lengths compared to the first overbalanced well (Fossum #1) where the operator reached the practical limit of OB drilling.

One can also argue that construction of multilaterals would have been difficult or impossible with conventional OB techniques.

Using 2,000 ft as the technical limit for OB drilling in this formation, and adding in the additional legs of the H-3, UBD techniques added an incremental 8,009 ft of lateral length in the remaining four wells.

The high initial oil and total fluid rates in the four UBD wells are attributable primarily to the longer horizontal well lengths, but may also be indicative of reduced formation damage.

The UBD wells averaged 156 BOPD and 422 barrels fluid per day during the first year, compared to 117 BOPD and 248 barrels fluid per day for the H-1 well.

Long-term benefits of UBD. Roughly six months after the completion of the drilling program, decline curve analysis suggested that the conventional horizontal well should recover about 175 MBO and the underbalanced wells should recover 275 MBO, compared to an EUR for vertical wells of 80 MB0.

The overbalanced Fossum H-1 well has continued to underperform compared to the other wells. This under-performance cannot be attributed to geology, since the H-1 is in a zone geologically as good as, or possibly better, than the H-2, H-3 and Ballantyne State wells. Artificial lift has also been similar for each well.

Although the four underbalanced wells cost more to drill, they paid out nearly twice as fast than the conventional horizontal well, and are expected to deliver approximately twice the reserves and NPV.

In today's oil price and well cost environment, a similar project could achieve even better economic results.

CONCLUSIONS

• Underbalanced technology can be a critical component in adding incremental reserves, especially when used in conjunction with other technologies such as horizontal wells, EOR processes, etc.

• The incremental reserves attributable to the use of underbalanced technology can be large.

• These case histories quantify incremental reserves from the three key reservoir-related benefit of underbalanced technology: improved reservoir access, reduced skin damage, and better ability to evaluate the reservoir while drilling.

• Underbalanced technology is commonly used in mature producing fields.

• When redeveloping mature fields, operators often attempt development with conventional well practices that result in well construction problems (e.g. lost circulation), or skin damage and productivity loss, or both. These difficulties can be mitigated by judicious use of underbalanced technology.

REFERENCE

This article was adapted from IADC/SPE 81626, *Does Underbalanced Drilling Really Add Reserves?* by **Randall Cade**, **Weatherford International**; **Ringys Kirvelis**, **Minjos Nafta**; and **Jeffrey Jennings**, **GeoResources Inc**.