UBD Technology Offers Pathway To Solving Complex Reservoir Problems

By D. Brant Bennion

CALGARY, ALBERTA, CANADA–Underbalanced drilling (UBD) is increasingly being used worldwide as an alternative technique to conventional overbalanced drilling to reduce invasive near-well bore formation damage problems in oil- and gas-producing formations. UBD operations can significantly reduce or eliminate formation damage concerns with respect to phenomena such as mud or drill solids invasion, lost circulation, fluid entrainment and trapping effects, and potential adverse reaction of invaded drilling or completion fluids with the reservoir matrix or in-situ reservoir fluids.

When applied correctly, underbalanced drilling and completion can provide a new approach to solving complex reservoir management problems. Even so, UBD is not necessarily a panacea for all formation damage problems. If a UBD operation is poorly designed and executed, there is the potential for greater damage than if a properly implemented overbalanced operation had been used in the same situation.

By rigid definition, an underbalanced condition is generated any time the effective circulating downhole pressure of a drilling, completion, stimulation or workover fluid (the pressure exerted by the hydrostatic weight of the fluid column plus whatever pump pressure is applied to the fluid system to circulate or inject it, and the associated frictional pressure drop) is greater than the effective pore pressure in the formation.

Unless abnormally pressured, most formations are naturally placed in an overbalanced state when water-based fluids of normal density are used in typical oil field operations. In some abnormally high-pressured formations (and in some normally pressured formations), a naturally underbalanced condition can be generated using conventional oil- or water-based drilling fluids. This condition is termed "flow drilling" if it occurs during a drilling operation, and it has been used successfully for many years in formations such as the Austin Chalk in Texas.

Much of today's discussions related to UBD concern a condition where formation pressure is sufficiently low that an effective underbalance pressure cannot be achieved downhole without entraining some type of non-condensable gas with the circulating drilling fluid to lower fluid density to the point where an underbalanced condition is obtained. This is often referred to as the "artificial" generation of an underbalance condition.

Advantages, Disadvantages

The advantages of UBD include:

- Reduced invasive formation damage;
- Minimal lost circulation and differential sticking;
- Eliminating the need for costly mud systems and the disposal of exotic muds;
- Improved rates of penetration, reducing drilling costs and increased bit life;
- Mitigating extensive and expensive completion and stimulation operations;
- Rapid indication of productive reservoir zones during drilling;
- The potential economic benefit from flush production during drilling; and
- The potential to flow test while drilling.

Many studies have investigated some of the potential disadvantages of the UBD process, particularly if poorly designed and executed. They include:

- Well bore stability and consolidation concerns;
- Safety and well control concerns in high-pressure or sour environments;
- Increased drilling costs (and complex completions, if required, because of the essential nature of completing the wells in a "live" condition);
- The inability to use conventional measurement while drilling technology for through-string injection techniques;
- Spontaneous counter-current imbibition effects;
- Gravity drainage effects in high-permeability zones, even under constant underbalanced flow conditions;
- Condensate drop out and gas liberation effects;
- Glazing or mashing (near-well bore mechanical damage);
- An increased propensity for corrosion problems if air- or oxygen-content reduced air is used as the non-condensable gas medium for generating an underbalanced condition; and
- Failure to maintain a continuous underbalanced condition, resulting in significant invasive damage because of periodic overbalanced pressure pulses due to pipe connections, bit trips, conventional MWD signal transmissions, localized depletion effects, frictional flow effects, hydrostatic column effects, multiple different pressured zones, variable pressure in a common zone, poor knowledge of original reservoir pressure, or operational or supply problems.

Figure 1 illustrates the effect of a periodic loss of an underbalanced pressure condition. By failing to establish a protective filter cake on the formation face, uncontrolled and severe fluid losses (that may occur during overbalanced "incidents" in a UBD operation) may result in severe invasion and damage. This severe invasion and damage often exceeds the damage that would have been generated if a conventional, well-designed, low-fluid loss overbalanced system had been used.

Solves Drilling Problems

Underbalanced drilling is not a solution to poor reservoir quality; the process does not inherently "manufacture" permeability. It can, however, yield significant production increases if the problem with conventional overbalanced completions is a high degree of formation damage or other drilling-related issue (severe lost circulation, extreme permeability zones, significant pressure depletion, major rock-fluid sensitivity issues with reactive clays, emulsions, or differential sticking) that cannot be overcome by conventional fluid or operational practices.

Many operators attempt to apply UBD technology in extremely poor-quality formations, expecting high production rates when even if a well were drilled and completed in a completely undamaged fashion, productivity would be uneconomic because of permeability limitations.

There are four main questions operators must answer to decide whether to implement UBD technology in a given reservoir situation. First, considering past experience, can this particular well be drilled and completed using overbalanced technology (not necessarily the same overbalanced technology that was used in the past and yielded marginal or disappointing results)? Second, based on an engineering evaluation of reservoir parameters, will UBD provide a significant technical or economic advantage to the project? Third, what is the risk of failure/problems associated with the UBD operation? Finally, does the expected increase in value justify the increased risk compared to conventional overbalanced drilling and completion practices?

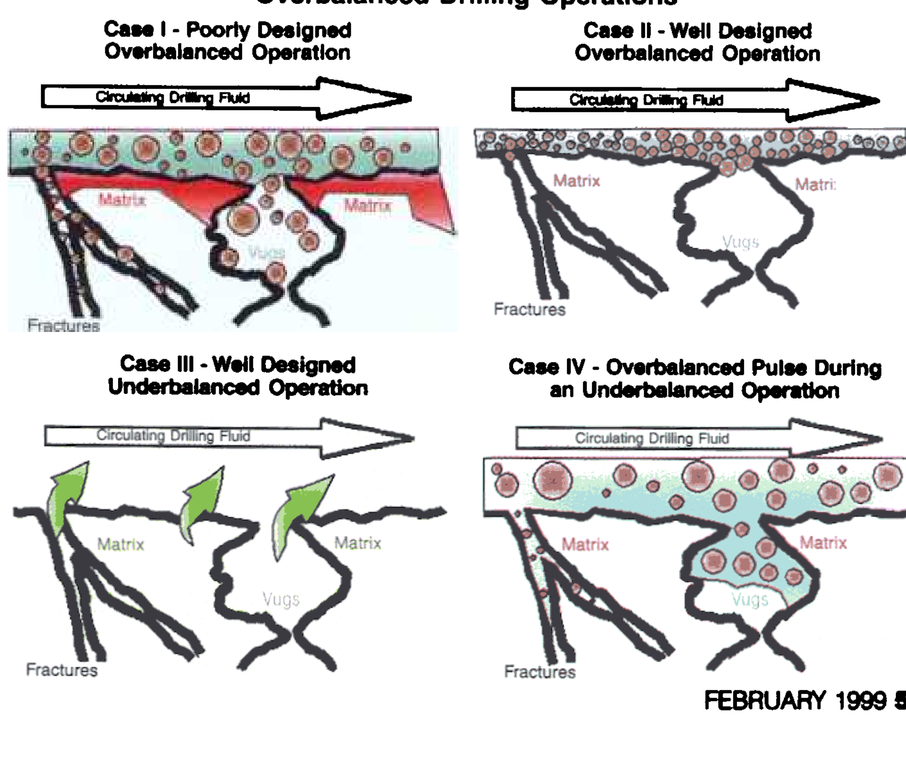
Figure 2 is a schematic of a typical UBD process using a closed surface control system. The vast majority of the UBD operations performed to date have utilized jointed drill pipe and injecting the base drilling fluid and some type of non-condensible gas directly down the drill string. This is not necessarily because this is the best technology, but because it is the least expensive and easiest to execute with the number of conventional jointed pipe rotary rigs available.

Most of these through-string injection UBD projects have used water-based fluids (often produced water) and nitrogen. The average gas injection rates have been in the range of 1.5 million-2.0 million cubic feet a day, although this is highly dependent on reservoir pressure and the amount of reservoir gas that can be produced to assist in the UBD operation once the producing zone has been penetrated.

Liquid circulation rates vary widely depending on the bottom-hole pressure

FIGURE 1

Well- versus Poorly-Designed Under- and Overbalanced Drilling Operations



required and the amount of fluid produced from the formation. The liquid circulation rate is a dominant factor in controlling effective bottom-hole pressure. Typical liquid flow rates in many UBD operations have ranged between 2,400 and 6,500 barrels a day. Detailed calculations and monitoring are required to ensure that significant annular slug flow (which can cause large bottom-hole pressure swings) does not occur, but that sufficient turbulence is maintained for adequate hole cleaning and cuttings transport to minimize pipe sticking problems.

Real-Time Data Acquisition

Real-time data recording and gathering systems–both down hole and at the surface–are essential to ensuring success with any UBD operation, allowing the performance of the entire operation to be monitored in order to maintain an optimum underbalanced condition.

Many early UBD operations did not have the ability to conduct real-time downhole pressure measurements. The result was many supposed underbalanced wells actually drilled in a complete or periodic overbalanced state. Later improvements used memory pressure gauges to acquire downhole pressure profiles, but only after it was ascertained that a continuously underbalanced condition had not been maintained and damage had already been done. Finding out after the fact that an operation was not underbalanced is little consolation for a failed job.

The development of electromagnetic telemetry (EMT) and extended-range EMT downhole tools capable of transmitting downhole pressure and survey data directly to the surface using an electromagnetic pulse, or coiled tubing applications with an internal wireline for direct downhole data transmission, have greatly enhanced the technology for UBD by allowing real-time acquisition of pressure and location data while drilling. Wet-connect systems have also been used with varying degrees of success.

Coiled Tubing

In many aspects, coiled tubing is custom designed for an effective UBD process. The advantages of coiled tubing are obvious in that the single unjointed pipe facilitates the operation of the UBD process in a more continuously underbalanced mode. Using an internal wireline allows accurate and real-time MWD measurements, which can be less problematic than EMT tools. Surface pressure operating constraints with coiled tubing are much greater (10,000 psi) in comparison to the limited pressure range of 1,500–2,500 psi offered by the majority of rotating control heads used in jointed pipe UBD operations.

Coiled tubing technology has proven viable and practical for effectively drilling horizontal and vertical wells–particularly in re-entry work out of smaller casing sizes, deepenings, and sidetracks where the objective is to barely enter the zone to get flow back to surface, and re-entering existing horizontal wells to drill extensions and additional lateral legs underbalanced.

The disadvantages of coiled tubing are the time and commitment involved in using a newer technology, the availability of equipment, concerns over accurate depth control and safety concerns in high-pressure wells with large volumes of pressurized gases at surface in the exposed, non-injected CT string. Also of concern are depth control and reach limitations for horizontal drilling applications. A major challenge today for any CT operation is obtaining the experienced personnel and mobilizing the equipment on site to make CT technology a cost-effective contender with more readily available jointed pipe systems.

The operational system that is best for a particular application is determined by the technical, safety and economic points of view. Technically, the preferred system will yield the best bottom-hole pressure control with a continuously underbalanced condition and allow accurate and continuous real-time bottom-hole location and pressure measurements. This heavily favors coiled tubing–particularly for small-diameter holes and re-entries–but cost, availability and required horizontal reach may eliminate CT. Alternate parasite string or annular injection techniques may also be considered, although these techniques are often costly, and from an abandonment perspective, may be more problematic for the parasite string approach.

Jointed pipe operations will likely continue to be used in the majority of systems for the next few years until CT costs and availability, plus improvements in technology, allow it to assume a more dominant position in the UBD marketplace.

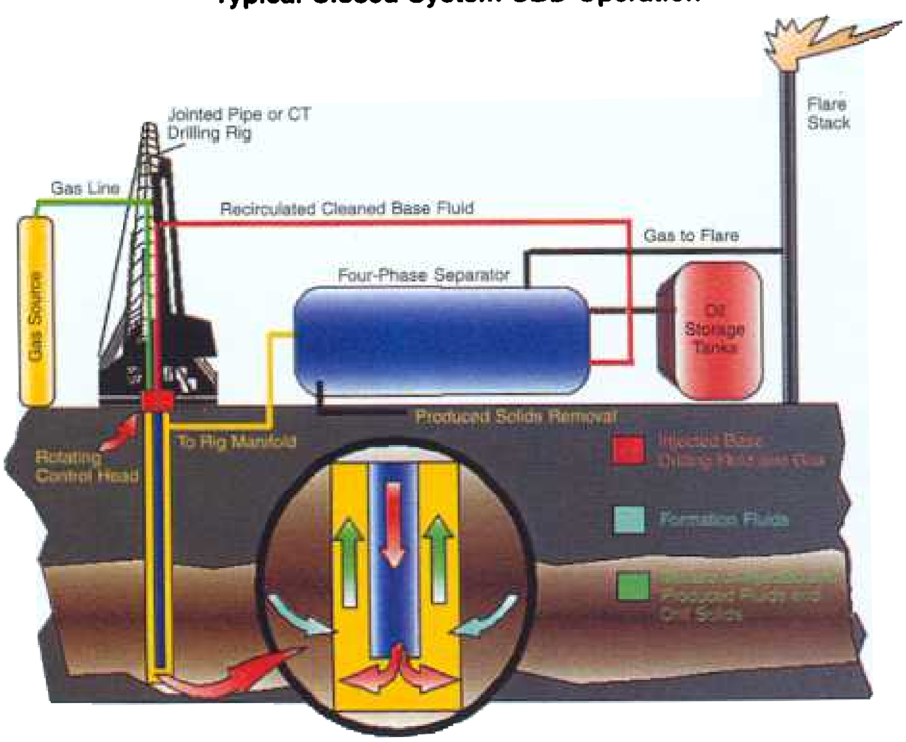
Prime Applications

Potential prime applications for UBD include:

- Reservoirs with significant circulation loss or fluid invasion potential (fractures, vugs, extreme permeability consolidated/unconsolidated intercrystalline formations, and zones of extreme pressure depletion);
- Formations that exhibit extreme rock-fluid sensitivity;
- Formations that exhibit significant fluid-fluid sensitivity;
- Formations with subirreducible oil or

FIGURE 2

Typical Closed System UBD Operation



water saturations;

- Formations of highly-variable quality; and
- Formations where low rates of penetration are problematic.

Reservoirs with significant lost circulation or fluid invasion potential would include zones of extreme intercrystalline permeability (1,000 milliDarcies and greater); large macroscopic open fractures; heterogeneous carbonates with massive, interconnected and high-permeability vugular porosity; zones of extreme pressure depletion (resulting in extreme overbalance pressures of 1,000 psi or greater); or the worst-case scenario–a combination of one of these high-permeability features in a significantly pressure-depleted situation.

These reservoir candidates are prime applications for UBD because of the difficulty (particularly in fractured and heterogeneous carbonates) of designing effective overbalanced fluid systems that will generate uniform and stable filter cakes to prevent significant invasion in the near-well bore region by potentially damaging mud filtrate and solids, yet still be readily removable to allow unrestricted formation flow. When filter cakes do form, they often tend to result in problems with differential sticking, which can lead to expensive and sometimes terminal stuck pipe problems.

Rock-fluid sensitivity is a concern because considerable formation damage can be caused by the adverse reaction of incompatible water-based filtrates with in-situ clays or other reactive materials. Many formations contain hydratable clays such as smectite or mixed-layer reactive clays that expand on contact with non-inhibited water-based systems and can significantly affect productivity, and in some cases, near-well bore consolidation. Some formations may also contain deflocculatible clays and fines or velocity migratable materials (kaolinite clay, detrital rocks fragments, pyrobitumen, anhydrite, etc). Many of these problems can be addressed by appropriately using overbalanced technology with hydrocarbon- or inhibitive water-based fluids.

The invasion of incompatible drilling fluid filtrates into a formation can result in potential incompatibility between the invading fluids and the in-situ formation brine or oil. Reactions could include the formation of extremely viscous oil-in-water emulsions that can become entrapped in the near-well bore region and cause reduced permeability, the "de-asphalting" of in-situ reservoir crude (caused by contact with incompatible invading foreign hydrocarbon-based fluids), or the formation of scales and precipitations (caused by the reaction with water-based filtrates and in-situ formation brines).

Appropriate geochemical and compatibility testing can generally eliminate this problem for most conventional overbalanced operations. Conversely, in some situations where the potential for damage is extreme, UBD may be contemplated to avoid introducing the potentially reactive material into the formation in the first place.

Permanent entrapment of an increased saturation of water or hydrocarbons in the near-well bore region can significantly reduce the productivity of the formation as a result of adverse relative permeability effects. If the wrong base fluid is used, UBD may aggravate this problem because of spontaneous counter-current imbibition effects. But if appropriately designed, UBD technology can be an efficient means of mitigating potential problems with adverse fluid retention and trapping effects. Using a non-wetting fluid as the base fluid for a UBD operation generally negates the potential for spontaneous imbibition and reduces the potential for phase trapping as long as a continuously underbalanced condition is maintained.

Formations of highly-variable quality–including highly-laminated formations or more massive sandstone, or carbonate formations that exhibit a wide variation in reservoir permeability and porosity (a large variation in pore throat size distribution)–represent major challenges to designing effective overbalanced fluid systems that effectively bridge and protect the wide range of pore features. In general, overbalanced systems are designed in these situations to protect the better-quality portions of the matrix, since this is the zone from which the majority of production will occur. In some cases, this approach can significantly damage portions of potentially productive formations. Using UBD can result in more uniform production from the target interval.

For some hard rock formations, significantly greater rates of penetration can be obtained with UBD, significantly reducing drilling time and associated costs. In fact, the primary motivation for UBD in some operations has been improved ROP.

Non-Applicable Reservoirs

Major criteria that make UBD unadvisable for a reservoir include combinations of extreme pressure and permeability, situations where a continuous underbalance condition is likely to be compromised, reservoir pressure constraints, and normally pressured intercrystalline formations of less than 500 mD permeability and limited rock-fluid and fluid-fluid sensitivity.

Although deep, high-pressure and high-permeability zones represent perhaps one of the best potential applications for UBD, from a formation damage perspective, safety and control issues with respect to well control at the surface may become problematic with high downhole pressures (particularly in gas reservoir applications) using conventional rotary drilling equipment and rotating diverter heads. Using coiled tubing drilling in such situations is preferable since surface pressure ratings are much higher. Conversely, if high surface injection pressures are required, then a large volume of pressured fluid is present at the surface in the uninjected CT string, which also presents potential safety hazards.

A situation where a continuous underbalance condition is likely to be compromised is one of the single greatest flags to a UBD operation. Much of UBD's benefit is lost and the operator may actually be in a greater damage scenario if underbalanced conditions are not maintained at all times during both drilling and completion. There is little advantage to drilling in an underbalanced mode (unless increased ROP is the only motivation), and then using normal overbalanced practices to complete a well.

Coiled tubing drilling represents what many feel is the future in UBD because of the ability to maintain a relatively con-

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UBD . . . .

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tinuous underbalanced condition and deploy MWD using internal wireline. Pressure pulses during connections with a conventional jointed pipe can be minimized by using double or triple pipe stands, rapid connections and appropriate circulation practices prior to breaking for connections to minimize the degradation of underbalance pressure that occurs during or after a connection is made. Large-drive rigs offer the advantage of drilling with triple pipe stands, further reducing the number of connections required. Other factors include reservoirs where any type of hydrostatic kill would be required for specialized completions, bit trips, etc.

Reservoirs that may exhibit zones of multiple different pressures or a significant areal variation of pressure in a given target zone may be difficult candidates for UBD.

The case can be made that most formations can benefit from a perfectly designed and executed UBD operations. While this is probably true, the unfortunate fact is that UBD operations tend to be considerably more expensive than conventional overbalanced drilling, and by their nature, may be fraught with risks and problems. So, for normal formations, it is likely that a well-designed conventional overbalanced operation can yield comparable or superior results to a more expensive UBD operation.

Underbalanced drilling is a very complex process that should not be designed and implemented on a "gut feel" basis or because it appears to be the trendy approach to a difficult problem. When properly designed and executed, however, UBD provides a whole new approach to complex reservoir management problems and may facilitate the economic exploitation of reserves unobtainable using any other technology.

The detailed study and design of the UBD process by a multifaceted reservoir team is required, along with acquiring the necessary data to ensure that the operation is viable for the reservoir under consideration. If UBD is considered, the process must be designed, implemented and monitored correctly. Failing to carefully plan and design an operation can result in improperly applying UBD technology in a potentially viable situation, resulting in significant losses of capital and production potential. ❒

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FERC . . . .

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collected a 4-cent surcharge from the customers that were not obligated to take gas at Carleton in order to compensate the other customers for the higher gas prices there. Northern wanted to be able to discount this surcharge before it discounted its main transportation rate, but FERC wanted the opposite result. Some small customers wanted exemptions, but FERC did not grant any.

On appeal, the D.C. Circuit affirmed FERC. The court writes, "If the global settlement (of the Order 636 restructuring case) covered any and all receipt point capacity allocations related to or arising out of Order 636 restructuring, it would bind in perpetuity all parties with respect to problems and situations unknown and unforeseen when the agreement was created."

The bottom line is that the decisions made in the Order 636 restructurings in the early 1990s don't necessarily apply forever. ❒

Williams Discovers Gas In Leon County, Texas

TULSA–Williams says it has discovered natural gas at its Nash No. 2 well located in the Kenwood Field of Leon County in East Texas. The discovery is the third for Williams' exploration and production unit since July, the company indicates.

The Nash No. 2 well has tested at a rate of 25.8 million cubic feet of gas a day at a flowing tubing pressure of 5,360 psi on a 24/64-inch choke while continuing to unload treatment fluids.

Williams says it owns 170,000 gross leasehold acres and 52,000 net leasehold acres throughout the East Texas pinnacle reef trend. ❒