

Reservoir Screening Criteria For Underbalanced Drilling

Properly designed and executed underbalanced drilling operations can eliminate or significantly reduce formation damage, mud or drill solids invasion, lost circulation, fluid entrainment and trapping effects, and potential adverse reactions of drilling fluids with the reservoir matrix or in-situ reservoir fluids. The key to selecting appropriate reservoir candidates is achieving a balance of technical, safety and economic factors.

Underbalanced drilling is increasingly used worldwide to reduce near wellbore formation damage problems in oil and gas producing formations. It is not necessarily a panacea for all formation damage problems. In fact, if an underbalanced drilling operation is poorly designed and executed, there may be potential for greater damage than if a properly implemented overbalanced operation had been used.

If implemented properly, underbalanced drilling can increase oil and gas well profitability by reducing invasive formation damage to maximize production rates and by increasing ROP to reduce drilling time and costs. It can also eliminate various technical problems associated with overbalanced drilling operations such as differential sticking and lost circulation.

There have been many cases in which underbalanced drilling has been particularly successful in providing added value to operators, and the resulting publicity has contributed to the technology's rapidly increasing popularity. Unfortunately, there have also been many instances where underbalanced drilling operations have been less successful, not due to a

deficiency in the basic technology, but to the faulty execution or inappropriate application of the underbalanced drilling technology.

Not every reservoir is an ideal candidate for an underbalanced drilling operation and in some cases distinct disadvantages may exist in trying to execute an underbalanced drilling operation in comparison to a simpler more conventional overbalanced application. Extensive field experience has played an important role in determining the following key criteria and design considerations that should be examined when evaluating a well. Screening criteria are also provided to help operators ascertain if a given formation is, in fact, a viable underbalanced drilling candidate.

What Is Underbalanced Drilling?

Underbalanced drilling happens any time the effective circulating downhole pressure of a drilling fluid—which is equal to the hydrostatic pressure of the fluid column, plus pump pressure, plus the associated frictional pressure drop due to circulation—is greater than the effective pore pressure in the formation adjacent to the well bore. Most normally pressured formations

are in an overbalanced state when conventional water-based fluids are used in typical oilfield operations. If lower density oil-based drilling fluids are used or high natural formation pressures are present, an underbalanced condition may be generated. This condition, sometimes called "flow drilling," has been used successfully in Texas for years in the Austin Chalk. This article focuses on the condition where the formation pressure is low enough that an effective underbalance pressure cannot be achieved downhole without using a non-condensable gas to lower the effective fluid density of the circulating drilling fluid. This type of generation of underbalanced conditions is often referred to as "artificial" underbalanced drilling.

Caveats To Underbalanced Drilling

The major advantages of underbalanced drilling, such as increased ROP and decreased formation damage, are well known.^{1*} Avoiding lost circulation and sticking problems by using a less costly mud system can be a powerful incentive to try underbalanced drilling. Enabling oil production and flow testing during drilling operations—and avoiding the need for expensive com-

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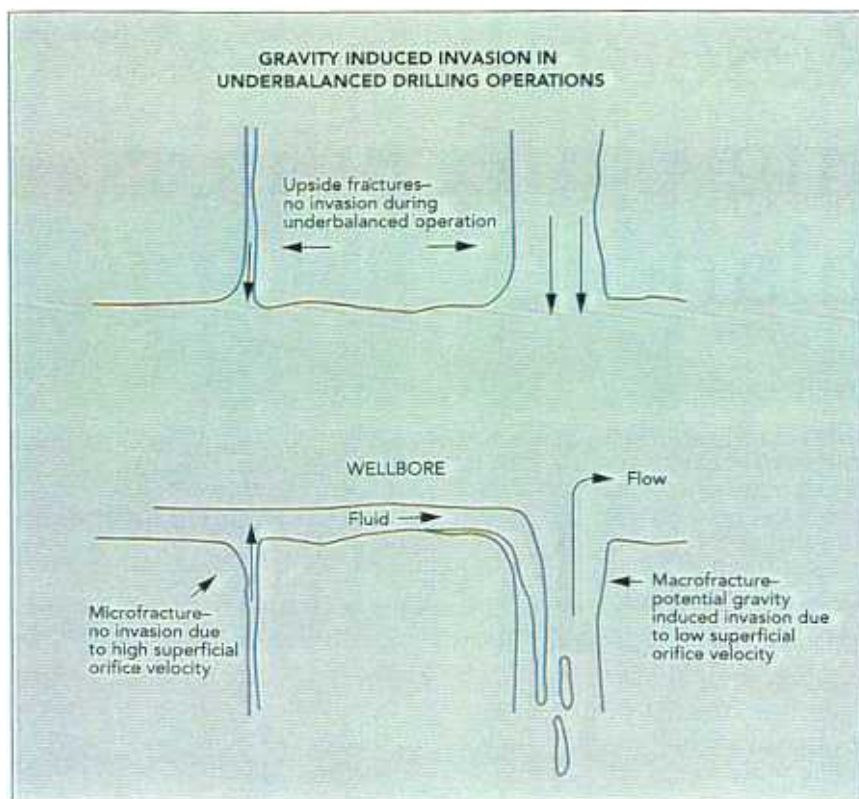


Fig. 1. Fluid invasion of macrofractures can happen even in underbalanced drilling due to the force of gravity.

pletion and stimulation operations—are excellent financial reasons for underbalanced drilling.

However, there are potential disadvantages to the underbalanced drilling process, particularly if it is poorly designed and executed.^{4,10} These include:

- Wellbore stability and consolidation concerns.
- Safety and well control concerns in high pressure or sour environments.
- Increased costs for drilling.
- Inability to use conventional MWD technology for through-string injection techniques.
- Spontaneous countercurrent imbibition effects.
- Gravity drainage effects in high permeability zones, even under constant underbalanced flow conditions.
- Condensate dropout or gas liberation effects.
- Near wellbore mechanical damage such as glazing or mashing.
- Increased propensity for corrosion problems if air or oxygen-containing gas is used to generate the

underbalanced condition.

- Discontinuous underbalanced conditioning.

Continuity Is Crucial

Failure to maintain a continuously underbalanced condition can result in periodic overbalanced pressure pulses, or spikes, that can cause significant invasive damage. These spikes can be due to:

- Pipe connections.
- Bit trips.
- Conventional MWD signal transmissions.
- Localized depletion effects.
- Frictional flow effects.
- Hydrostatic column effects.
- Multiple zones of different pressures.
- Variable pressure in a common zone.
- Poor knowledge of original reservoir pressure.
- Operational or supply problems.

Eliminating or minimizing these conditions can keep pressure spikes from ruining an otherwise viable underbalanced drilling project.

Underbalanced drilling can yield significant increases in production if conventional overbalanced approaches have experienced formation damage or if problems such as differential sticking have occurred. However, it will not improve production from marginal reservoirs that simply have low permeability. The two main criteria in deciding whether or not to implement underbalanced drilling technology in a given reservoir situation are:

- Determining if underbalanced drilling offers a significant technical or economic advantage compared to traditional overbalanced drilling methods, and
- Determining if there is an expected increase in value that justifies any associated risk.

Appropriate Candidates For Underbalanced Drilling

Reservoirs With Lost Circulation or Fluid Invasion Potential. These would include zones with intercrystalline permeability of more than 1,000 md; large, macroscopic open fractures; heterogeneous carbonates with massive interconnected vugular porosity; or pressure depleted zones that would result in overbalance pressures greater than 1,000 psi. The worst case scenario for overbalanced drilling would be a combination of one of these high permeability features with significant pressure depletion.

These reservoir candidates are prime applications for underbalanced drilling due to the difficulty of designing effective overbalanced fluid systems. Particularly in the case of fractured or heterogenous carbonate reservoirs, it is difficult to generate uniform, stable filter cakes to prevent invasion by mud filtrate and solids, and still allow unrestricted flow from the formation after cleanup. When filter cakes do form in such situations, they often cause problems with differential sticking, which can lead to the catastrophic situation of stuck pipe.

Keep in mind that some fluid losses may occur in horizontal wells with macroscopic permeability features due to gravity-induced drainage (Fig. 1).⁶ **Formations With Rock-Fluid Sensitivity.** Considerable formation damage

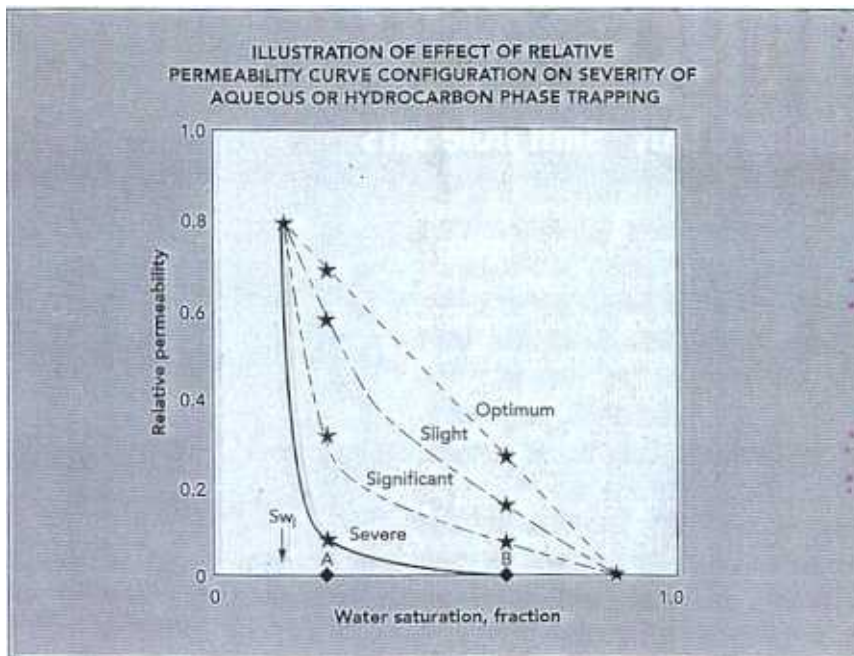


Fig. 2. Phase trapping can range from slight to severe depending on the relative permeability curves.

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. These clays will expand on contact with non-inhibited water-based fluids and can significantly affect productivity and, in some cases, near-wellbore consolidation. Some formations may also contain deflocculatable clays and fines, or migratable materials, such as kaolinite clay, detrital rocks fragments, pyrobitumen and anhydrite. Many of these problems can be addressed through either underbalanced drilling or the appropriate use of overbalanced technology with oil-based or inhibited water-based fluids.

Formations With Fluid-Fluid Sensitivity. Underbalanced drilling can prevent the invasion of incompatible drilling fluid filtrate into the formation, which can mitigate adverse reactions of these invading fluids with the formation brine or oil. One such reaction is the formation of highly viscous oil-in-water emulsions which may become trapped in the near wellbore region. Other reactions include reduction in permeability due to deasphalting of reservoir crude by invading oil-

based fluids, scale formation and solids precipitation by mixing incompatible water-based mud filtrate with in-situ formation brine.

Appropriate geochemical testing and compatibility testing can eliminate this problem for most conventional overbalanced operations. However, in extreme situations, underbalanced drilling may be used to avoid introducing potentially reactive material into the formation in the first place.

Formations With Potential For Spontaneous Imbibition. The mechanism of aqueous and hydrocarbon phase trapping has been discussed in detail in the literature.^{11,12} Permanent entrapment of water or hydrocarbons in the near wellbore region can result in reduced formation productivity due to adverse relative permeability effects (Fig. 2). If the wrong base fluid is used, underbalanced drilling may aggravate this problem due to spontaneous countercurrent imbibition effects.⁸ However, appropriately designed underbalanced drilling technology can be an efficient means of mitigating potential problems with fluid retention and trapping effects. Using a non-wetting fluid as the base fluid for an underbalanced drilling operation can

prevent spontaneous imbibition and reduce phase trapping potential as long as underbalanced conditions are maintained. This would prevent direct displacement and entrapment of the base drilling fluid into the formation.

Formations of Highly Variable Quality. Highly laminated formations or massive sandstone or carbonate formations that exhibit wide variations in reservoir permeability, porosity or pore throat size distribution represent major challenges to designing effective overbalanced systems. In these scenarios, overbalanced systems are usually designed to protect the better quality portions of the matrix, from which the majority of production is expected to occur. This can result in significant damage to other portions of potentially productive formation. The use of underbalanced drilling technology in some of these situations can result in more uniform production from the target interval.

Formations With Low ROP. For some hard rock formations, rates of penetration (ROP) up to 10 times higher can be obtained with underbalanced drilling compared to overbalanced drilling, thereby reducing drilling times and associated costs. In a limited number of cases the primary motivation for underbalanced drilling has been for ROP purposes rather than formation damage avoidance.

Contraindications For Underbalanced Drilling

Combination Of High Pressure And High Permeability. Although deep, high-pressure, high-permeability zones represent one of the best potential applications for underbalanced drilling from a formation damage perspective, safety and well control issues at the surface may arise. Downhole pressures above 4,300 psi, particularly in gas reservoirs, are more suited to conventional rotary drilling equipment and rotating diverter heads. The use of coiled tubing drilling in such situations may be preferable, as surface pressure ratings are much higher. Conversely, if high surface injection pressures are required, a large volume of pressurized fluid at the surface in the uninjected CT string may also present a safety hazard.

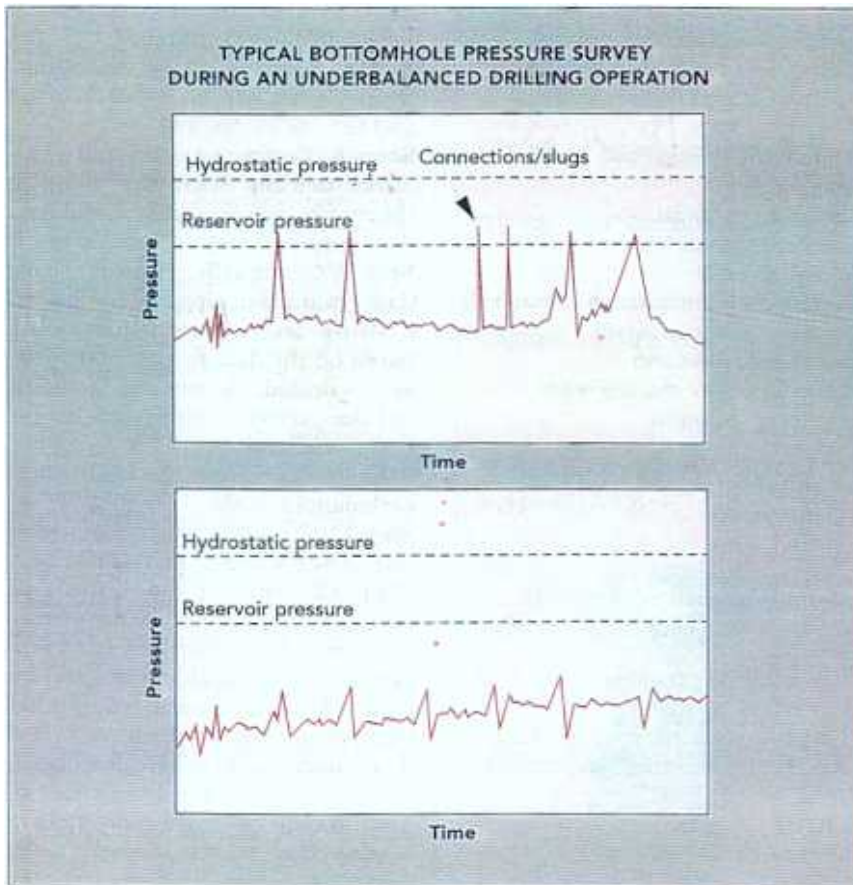


Fig. 3. Bottomhole pressure spikes that occur when breaking for connections can be reduced by circulating nitrogen prior to connections. This will help maintain a continuous underbalance condition.

Non-continuous Underbalance Conditions. This is the greatest indication that an underbalanced drilling operation may not be suitable. Many of the formation damage mitigation aspects of underbalanced drilling would be lost and the operator may actually cause greater damage if underbalanced conditions are not maintained continuously during both drilling and completion operations. There is little advantage to drilling in an underbalanced mode and then completing the well in an overbalanced mode, unless increased ROP is the only motivation for underbalanced drilling. It should be emphasized that real-time downhole pressure measurements are essential to ensure the success of any underbalanced drilling operation. The use of EMT technology for conventional jointed pipe drilling has improved the ability to monitor downhole pres-

ures in these operations. This approach is preferable to conventional MWD operations that periodically pulse the formation with an overbalanced pressure condition, or costly parasite or concentric string approaches. The reliability of EMT technology still limits its use in formations greater than 8,200 ft (2,500 m), but current improvements like mid-string repeater stations promise to extend the technology to deeper applications.

Coiled tubing drilling represents what many feel is the future in underbalanced drilling due to its ability to maintain more continuously underbalanced conditions. Additionally, using an internal wireline approach for MWD will be less problematic. However, current coiled tubing technology is limited with respect to depth and extended reach applications.

If conventional jointed pipe is

used, pressure pulses during connections can be minimized by using double pipe stands, rapid connections and appropriate circulation practices prior to breaking for connections to maintain more uniform underbalanced conditions (Fig. 3). Top drive rigs offer the advantage of drilling with triple pipe stands, which further reduces the number of connections required.

Underbalanced drilling should be avoided in reservoirs where any type of hydrostatic kill on the formation would be required for specialized completions, bit trips, etc.

Reservoir Pressure Constraints. As a general rule, reservoirs having multiple zones of different pressures—or significant areal pressure variations in a given target zone—are undesirable candidates for underbalanced drilling.

Normal Formations. Most formations would benefit from a perfectly designed and executed underbalanced drilling operation, but underbalanced drilling operations can be more expensive than conventional overbalanced drilling, and by their nature may have certain risks and problems. For normal formations, such as homogeneous intercrystalline formations with permeability less than 500 md, and formations with low rock-fluid and fluid-fluid sensitivity, a properly designed overbalanced operation may yield comparable or superior results to a more expensive and risky underbalanced operation.

Screening Process

Proper reservoir screening is essential for vertical or horizontal underbalanced drilling. Using the following systems approach, operators can gather enough information to initiate the design work for a viable underbalanced drilling process. The recommended "12 Steps" for the evaluation process include:

Step 1. Gather complete information (see sidebar) from pre-existing data sources or acquire data directly, if necessary.

Step 2. Have drilling, reservoir engineering, geology and underbalanced drilling experts prescreen the preliminary data to determine whether the well meets the base criteria for opti-

DATA NEEDED PRIOR TO SCREENING PROCESS

Reservoir Properties

- Current downhole pressure.
- Pressure variations within a common reservoir zone.
- Presence of multiple producing zones and pressures in each zone.
- Location of oil, water and gas contacts.
- Presence and location of sealing/non-sealing faults.

Rock Properties

- Location and classification of different lithological flow units.
- Vertical and horizontal in-situ permeability.
- Porosity.
- Pore size and pore throat distribution of major rock types.
- Presence of macroscopic permeability features like fractures, vugs, etc.
- Continuity of reservoir strata and macroscopic permeability features.
- Matrix composition, including grains, clays, etc.
- Geomechanical strength and properties of target formation.
- Initial saturation characteristics of the target zone (S_{wi} , S_{gr} , S_{or}).
- Capillary pressure characteristics.
- Wettability characteristics.
- Relative permeability characteristics (water, oil and gas).
- Glazing potential.

Reservoir Fluid Properties

- Composition of oil, gas and water.
- Asphaltene and paraffin content of oil.
- Cloud and pour point of oil.
- Aniline point of oil.
- Viscosity and density at downhole and surface conditions.
- Bubble point pressure and PVT properties of oil.

- Dewpoint pressure and CVD properties of rich gases.

In-Situ Fluid/Drilling Fluid Compatibility

- Emulsion potential.
- Hydrate potential.
- Scale potential.
- Potential for precipitation formation or asphaltene deposition.
- Gas entrainment and disengagement characteristics.
- Explosion potential.
- Corrosion potential.
- Degradation of base fluid resulting from dilution by produced formation fluids.

Rock/Drilling Fluid Compatibility

- Potential adverse reaction with clays.
- Reaction with overlying or interbedded hydratable shales.
- Formation dissolution.
- Countercurrent imbibition potential.
- Reactivity with cuttings and cuttings transport potential.

Choice of Base Fluid

- Produced water.
- Fresh water.
- Inhibited brine.
- Inhibited brine with solids control.
- Produced crude.
- Refined crudes.
- Foams.

Choice of Density Reducing Agents

- Nitrogen.
- Natural Gas.
- Oxygen content reduced air.
- Air.
- Flue Gas.
- Low density suspended solids, such as glass spheroids.
- Low density liquids.

mal underbalanced drilling implementation described above.

Step 3. Review all gathered information. This is best done by a cross-functional team consisting of drilling engineers, reservoir engineers, geologists, geophysicists, petrophysicists, production engineers, underbalanced drilling experts, consultants, laboratory and analytical staff, regulatory and

safety experts and representatives from the drilling and service companies that will be involved in the operation. Begin the initial planning to drill the well.

Step 4. Assimilate and review the best possible services and techniques to drill and complete the reservoir in a proper underbalanced fashion.

Step 5. Select key personnel and

equipment to execute the underbalanced drilling operation.

Step 6. Conduct a prespud meeting.

Step 7. Procure, transport, set up and test the equipment.

Step 8. Commence the underbalanced drilling operation. Acquire the maximum amount of useful data during operations.

Step 9. Continually review real-time data obtained during underbalanced drilling and make adjustments based on the data to ensure that the well is drilled according to the original design, with contingencies for unexpected events.

Step 10. Complete the well in underbalanced mode.

Step 11. Carry out a post-completion review by the cross functional team.

Step 12. Begin production and repeat the Step 11 review process.

Underbalanced drilling is a complex process which should not be designed or implemented on a gut feel basis, or because it appears to be the trendy approach to a difficult problem. When properly designed and executed, underbalanced drilling provides a whole new approach to complex reservoir management problems and may facilitate the economic completion and exploitation of reserves unobtainable by any other type of currently available technology. Detailed study and design of the underbalanced drilling process by a multifaceted reservoir team is required, along with acquisition of the necessary data to ensure that the operation is viable for the reservoir under consideration. Failure to carefully plan and design may result in significant losses of capital and production potential. ●

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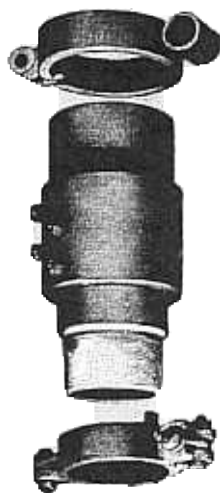
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