FORMATION DAMAGE AND UNDERBALANCED DRILLING

BOTTOM LINE

Proper understanding of the formation, formation fluids, drilling fluids and drilling approach can allow the evaluation of many potential drilling-induced formation damage issues. This allows one to choose solutions appropriate for a given formation/well. For several types of reservoirs, including fractured, vugular formations and subirreducibly-saturated formations (i.e., many tight gas reservoirs), underbalanced drilling (UBD) can be an economically attractive solution. However, those using UBD must pay attention, since there is the potential for severe formation damage if UBD is not properly executed.

PROBLEM ADDRESSED

Drilling has the potential to be one of the most damaging portions of a well's life cycles. To reduce drilling-induced formation damage, one must understand the myriad potential causes and how to address those causes.

KEY WORDS:

Candidate Selection
Formation Damage
Horizontal Wells
Modeling
Operational Practices
Underbalanced Drilling (UBD)

TECHNOLOGY OVERVIEW

Introduction

Drilling has the potential to be one of the most damaging portions of a well's life cycle. There are three major classes of potential formation damage that can occur during drilling operations, which are:

- *Mechanical formation damage*. This includes fines migration, mud solids invasion, phase trapping issues, bit/drillstring interactions (glazing/mashing) and geotechnical-induced skin. Fines migration is generally localized to the near wellbore area due to rapid falloff in radial invasion velocity. It is often not a significant problem. Mud solids invasion is more of a concern in openhole completions, high perm formations, fractured/vuggy porosity or conditions of extreme overbalance pressure. Reservoirs exhibiting phase trap problems are subirreducibly-saturated lower permeability gas reservoirs (i.e., tight gas sands, the Powder River and Green River basins being good examples), conventional gas reservoirs and strongly oil-wet sands and carbonates.
- *Chemical formation damage*. This can result from filtrate-rock interactions, filtrate-mud-reservoir fluid interactions, wettability alterations and cuttings dispersion and transport.
- *Biological formation damage*. This can lead to plugging issues, corrosion issues, and toxicity issues (sulfate-reducing bacteria).

Formation damage may be more severe in horizontal wells because of:

- Increased exposure times
- Openhole completions
- Localized depletion/drawdown effects
- Difficulty of stimulation
- Anisotropic flow effects that increase damage effects in low vertical permeability reservoir situations.

General concepts to reduce formation damage include (1) using good rheology, low fluid loss drilling, completion and stimulation fluids, (2) rapid recovery of any water-based fluids exposed to the formation, (3) minimizing overbalance pressure and (4) underbalanced drilling.

Underbalanced Drilling (UBD)

UBD is a condition where the total pressure exerted by a circulating drilling fluid is less than the pore pressure in the adjacent formation. Prime motivations for UBD are to reduce invasive formation damage and improve productivity, evaluate formations while drilling, reduce drilling problems (lost circulation, stuck pipe), and achieve performance drilling in low rate-of-penetration formations. Note that much of the UBD benefit of reducing formation damage will be lost if overbalanced completion, kill or workover operations are required at some time in the future.

In selecting the base fluid for UBD, one must consider the potential for damage in an overbalanced incident, rheology and fluid loss control ability, friction issues affecting UB pressure, cost and environmental concerns. Foams provide low water content, are regenerable, exhibit good fluid loss control in OB incidents, limit imbibition potential and have good rheology and hole cleaning ability. An oil-based foam

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could be considered the Holy Grail because it reduces imbibition potential, reduces phase trap potential and improves clay/shale stability.

Common base gases include nitrogen (cryogenic, pressure swing absorption-generated, membrane-generated), natural gas, processed flue gas or air. Issues that must be considered are expense, availability, toxicity, corrosion potential, explosion potential, solubility issues, foaming issues, and phase behavior (compressibility) issues. The best base gas to use is a function of the project (location, type, # of wells), composition of produced fluids, pressure and temperature conditions, and the degree of aversion to risk. Fluids-solids issues that might be encountered include cuttings dispersion and transport (often an issue with some oil-based systems), cuttings-stabilized emulsions, and solubility and pH effects.

Identifying a UBD Candidate

There is an envelope where UBD is economically attractive. Configuration of the envelope will depend on pressure, permeability, well geometry/spacing/location in drainage area, well costs and incremental costs for UBD, and reservoir fluid type and viscosity and phase behavior character. Ultimate benefit will depend on:

- Does near-wellbore skin dominate productivity?
- What is the incremental cost?
- What is the risk factor of improperly conducting the UBD operation?

Drilling options include conventional overbalance (cheap, simple, followed by fracturing and stimulation), low damage overbalance with custom-designed drill-in fluid, or UBD. Key questions to consider are: Is the reservoir permeability to low to allow economic production rates even with a perfectly executed UBD operation? Could the reservoir be drilled successfully using more advanced conventional overbalanced techniques and fluids than may have been used in the past? Generally, prime candidates for UBD are:

- Highly pressure-depleted formations
- Fractured, vugular formations exhibiting drilling problems and lost circulation
- Very formation damage-sensitive formations
- Subirreducibly-saturated formations
- Formations exhibiting very low rate of penetration (ROP) with overbalanced drilling

Less favorable UBD candidates include:

- Formations dominated by matrix low permeability rock
- Combinations of very high pressure and high permeability
- High H2S content in reservoir fluids
- Variation in zonal pressures
- Poor mechanical stability of target zone
- Unknown reservoir pressure
- Near-dewpoint rich gas systems
- Normally-pressured, average-type reservoirs for which better designed conventional technology may be effective with less expense and risk

Operational Practices

UBD is not without its challenges. Potential problems with UBD include:

- Safety and control concerns
- Wellbore stability
- Increased cost/logistics
- Potential severe formation damage if not properly executed
- Hole cleaning concerns
- Completion and workover issues

Incremental expenses for UBD include increased cost for surface and well control equipment, more exotic Measurement-While-Drilling (MWD) procedures, gas costs and loss of produced gas, increased corrosion risks in some cases, special personnel and design generally required, and exotic completions are sometimes required. UBD adds reserves in some cases, but generally the net present value increase primarily results from higher early-time production.

Failing to maintain the UBD condition on a constant basis eliminates much of the benefit of UBD. Overbalanced pulses allow whole mud and solids into fractures, filtrate and localized solids to invade the matrix, and can push whole mud and solids into macro porosity. Sequential invasion and filter cake creation, and then removal during UB flow phase may result in cumulatively "deeper" damage occurring. Common causes for loss of UB pressure while drilling are pipe connections, conventional/MWD operations, kill jobs/bit trips, localized depletion, variable/multiple pressure zones, frictional flow effects and poor hole cleaning. Rapid pressure-transient increases, even if the peak value is still less than the bulk reservoir pressure, may still result in near-wellbore overbalanced invasion and damage effects. The lower the perm/pressure of the formation, the more sensitive to rapid pressure-transient increases the system will be. Methods of reducing overbalanced pulses include:

- Coiled tubing (avoid connections)
- Parasite or concentric string approaches
- High fraction circulation prior to connections (reduces near-wellbore pressure and may aggravate problems with localized depletion)
- Maintaining annular flow
- Rapid connections
- Drill with double/triple pipe stands

Friction effects during UBD are controlled by well length, well and drillstring geometry, fluid types/ratios/viscosities, hole cleaning effectiveness, circulation rates of fluids, amount of inflow from wellbore, stability of flow (dispersed vs. slug), and surface backpressure. For a given wellbore geometry, there is a maximum length of wellbore that can be drilled underbalanced. Regarding bottomhole pressure (BHP) versus gas flow rate, there are two regimes. In the hydrostatic-dominated region (lower gas flow rates), as gas rate is increased, the reduction in overall system density reduces the hydrostatic head significantly, which reduces the effective BHP. In the friction-dominated region (higher gas flow rates), the gas flow rate becomes so high that increases in gas rate do not reduce overall fluid density enough to counteract the increased friction due to the higher rate. Most operators prefer to operate slightly into the friction-dominated region as this tends to reduce BHP sensitivity to minor oscillations in gas and liquid rate.

Other potential damage issues include:

- *Countercurrent imbibition issues*. This occurs when imposed underbalanced pressure gradient is not large enough to overcome natural capillary pressure suction forces. This is common in subnormally-saturated tight gas reservoirs or when there is a large vertical standoff from free water contact. To avoid countercurrent imbibition, use a non-wetting base fluid, add an interfacial tension reducing additive in water-based fluid to reduce trapping potential, and maintain a suitable level of UB pressure to counteract imbibition effects if drilling at the top of a transition zone.
- *Macroporous invasion/drainage*. This can occur in macroporous features (large fractures) on the low side of a horizontal well during during fluid-based drilling when there is insufficient velocity to counteract gravity drainage.
- *Glazing and mashing*. Glazing is generally only an issue in homogeneous low perm sandstones or with air drilling/pure gas drilling. Glazing issues can be avoided with mist drilling or air hammer/percussion drilling. Mashing is caused by working action of rotating/sliding drill string and non flush joints on the wellbore surface. It is aggravated by poor hole cleaning and a poorly centralized drill string.
- Trapped fluid saturation evolution. The point can be made that condensate accumulation or critical gas saturation creation will unavoidably occur in any event once normal production operations commence. Excessive drawdowns during UBD may aggravate the problem.

Fluid-fluid compatibility concerns that must be addressed include incompatible water-water reactions (scales and precipitates), incompatible oil-oil reactions (sludges, asphaltenes), water-oil emulsions and paraffin deposition.

Modeling

Before embarking on UBD, numerous screening lab tests need to be performed. In this screening, reservoir damage under a variety of conditions (overbalanced, UBD, etc.) can be estimated using expert system software pulling from a historical database of formation damage information. Models can predict production rates and decline/cumulative performance under base case and UBD drilling. Then, combined with an economic model, one can evaluate the true economic potential of UBD. Models provide an indication of the approximate gas-liquid rates required to achieve UB conditions. They can be calibrated against real time data to optimize the drilling process "on the fly." Although extremely useful and recommended, one must remember that models are still just a tool.

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