Originally appeared in:
World Oil
March 2007 issue, pgs 27-34.
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Managed pressure drilling—What is it anyway?

There are many ways to determine the downhole pressure environment limits and manage the annular hydraulic pressure profile.

Kenneth P. Malloy, Stress Engineering Services

In the conventional drilling circulation flow path, drilling fluid exits the top of the wellbore open to the atmosphere via a bell nipple, then through a flowline to mud-gas separation and solids control equipment, an open vessel approach. Drilling in an open vessel presents difficulties during operations that frustrate every drilling engineer. Annular pressure management is primarily controlled by mud density and mud pump flowrates. In the static condition, bottomhole pressure (P_{BH}) is a function of the hydrostatic column's pressure (P_{Hyd}). In the dynamic condition, when the mud pumps are circulating the hole, P_{BH} is a function of P_{Hyd} and annular friction pressure (P_{AF}), Fig. 1.

In an open-vessel environment, drilling operations are often subjected to kick-stuck-kick-stuck scenarios that significantly contribute to Non-Productive Time (NPT), an add-on expense for many drilling AFEs. In an open vessel, pressures cannot be adequately monitored unless the well is shut-in. So, well-control incidents are predicated on increased flow, where precious time is wasted by pulling the inner bushings to check for flow. In that short time, the influx volume becomes larger and can be more difficult to manage. The recently developed Managed Pressure Drilling (MPD) method offers better ways to control P_{BH}.

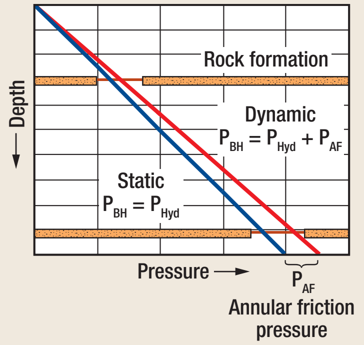

Fig. 1. Ideally, static and dynamic pressures are within formation-pressure and fracture-pressure windows.

UNDERBALANCED DRILLING

MPD originates from a few specific technologies developed by its forbearer—underbalanced drilling. In addition to improved rate of penetration, the chief objectives of underbalanced drilling are to protect, characterize and preserve the reservoir, while not compromising the well's potential. To accomplish this, influxes are encouraged. Influxes traverse up the hole and are controlled by three major surface containment devices:

- Rotating Control Device (RCD)
- Drilling Choke Manifold (DCM)
- Multiphase separator.

If the well is producing while drilling, gas is flared, recirculated or sent to a gathering station for sale. If the drilling is land based, produced oil is stored in stock tanks.

RCDs include surface BOP rigs and subsea BOPs with marine riser and top-hole batch drilling. DCMs are used for backpressure management and are either manual and automatic. These two tools are used for both underbalanced operations and MPD. Other tools used either individually or in concert with others for MPD include:

- Continuous circulating system
- Non-return valves
- Downhole deployment valves
- Surface phase separation
- ECD reduction tools
- Nitrogen generation
- Pressure monitoring
- Hydraulic flow modeling.

Some of these MPD-enabling tools are required; others are optional or not applicable.

MANAGED PRESSURE DRILLING

On land and in some shallow water environments, a comfortable drilling window often exists between the pore-pressure and fracture-pressure gradient profiles, through which the hole can be drilled safely and efficiently, Fig. 2. From an offshore prospective, MPD was and still is driven by the very narrow margins between formation pore pressure and formation fracture pressure downhole. Narrow margins are most pronounced in deepwater drilling, where much of the overburden is seawater, Fig. 3. In such cases, it is standard practice to set numerous casing strings at shallow depths to avoid extensive lost circulation.

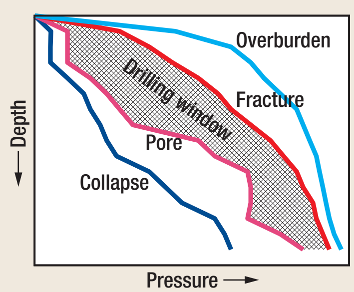

Fig. 2. Land-based and shallow-water drilling using single-density drilling fluid have a wide drilling window.

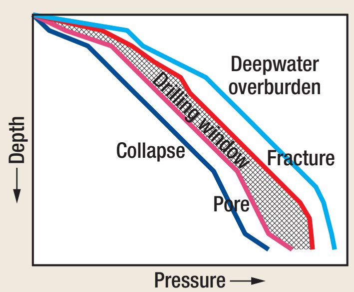

Fig. 3. Deepwater drilling using single-density drilling fluid has a narrow drilling window.

The collapse, pore-pressure, fracture-pressure and overburden profiles often change in more mature fields because of production and depletion. The drilling window that was once generous becomes narrower, making it more challenging to "drill within the lines" without losing circulation or inviting influx.

Unlike underbalanced drilling, MPD does not actively encourage influx into the wellbore. The primary objectives of MPD are to mitigate drilling hazards and increase operational drilling efficiencies by diminishing NPT. The operational drilling problems most associated with NPT include:

- Lost circulation
- Stuck pipe
- Wellbore instability
- Well-control incidents.

These four categories accounted for 25–33% of all Gulf of Mexico NPT, prior to Hurricanes Ivan, Katrina and Rita.

The Underbalanced Operations and Managed Pressure Drilling Committee of the International Association of Drilling Contractors has defined MPD as "an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly."

- The MPD process employs a collection of tools and techniques to mitigate the risks and costs associated with drilling wells that have narrow downhole environmental limits, by proactively managing the annular hydraulic pressure profile.
- MPD may include control of backpressure, fluid density, fluid rheology, annular fluid level, circulating friction, hole geometry or combinations thereof.
- MPD may allow faster corrective action to deal with observed pressure variations. The ability to control annular pressures dynamically facilitates drilling of what might otherwise be economically unattainable prospects.
- MPD techniques may be used to avoid formation influx. Any flow incidental to the operation will be safely contained using an appropriate process.

The centerpiece of the definition is "precise control." The technology allows drillers to control bottomhole pressure from the surface within a range of 30–50 psi. One MPD method does not address all problems and MPD is application specific. The drilling engineer will have his choice of many options to best address the drilling problems encountered.

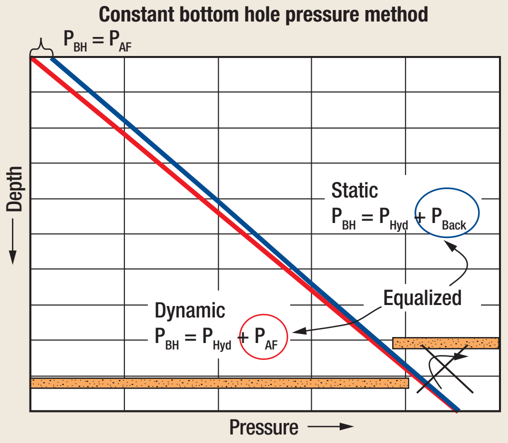

Fig. 4. The constant bottomhole-pressure variation of MPD uses lower-density drilling fluid and imposes backpressure when static to equalize annular friction pressure.

While there are some similarities in equipment selection, as well as similar training needs for personnel, MPD is not a "poor boy" version of underbalanced drilling. On the contrary, done properly, contingencies need to be explored requiring engineering forethought and planning, even though the equipment footprint is typically not as extensive.

The vast majority of MPD is practiced while drilling in a closed vessel, using an RCD with at least one drillstring non-return valve, and a DCM. Various manufacturers produce API monogrammed RCDs that conform to API Specifications 16RCD. API recently published API Spec 7NRV, *Specifications for Non-Return Valves.* Manual-controlled and microprocessor-controlled chokes are available depending on the application.

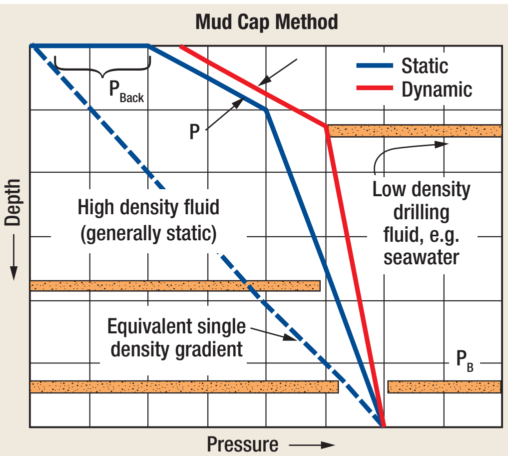

Fig. 5. The pressurized mud-cap method uses a lightweight scavenger drilling fluid in the drillpipe. After circulating around the bit, the light-density fluid and cuttings are injected into a weak zone uphole. A higher-density fluid remains in the annulus above the weak zone along with optional backpressure to maintain annular pressure control.

Presuming that the wellbore is capable of pressure containment, drillers can better monitor the wellbore's pressure distribution on a real-time basis using MPD. In a closed system, drillers see pressure changes immediately. By more precisely controlling the annular wellbore pressure profiles, influx and loss detection are virtually instantaneous. Rig personnel and equipment safety during everyday drilling operations is enhanced. Drilling economics tend to improve through the reduction of mud costs and drilling-related NPT.

The constant bottomhole pressure method, the mud-cap method, casing while drilling, equivalent circulating density reduction and the dual-gradient method are a few of many proactive MPD variations used to manipulate the wellbore pressure profile to diminish or eliminate chronic drilling problems. Hydraulics contributes directly to many drilling problems.

DRILLING HYDRAULICS

In conventional drilling practices, the hydrostatic pressure (P_{Hyd}), created by the mud column density together with the circulating annular friction pressure (P_{AF}), controls the bottomhole pressure (P_{BH}):

$$P_{BH} = P_{Hyd} + P_{AF}$$

When the mud pumps are shut down to make a connection, P_{AF} is zero, leaving P_{BH} controlled by the mud's hydrostatic column. Should P_{BH} be greater than the hydrostatic pressure, an influx of hydrocarbons can occur. The driller must then circulate the kick out of the hole with kill mud, typically at a slow pump rate. The slow pump rate minimizes the influence of P_{AF} during the kill procedure, while the higher-density mud increases P_{Hyd}, so that after circulating out the kick, P_{Hyd} balances P_{BH} without the influence of the P_{AF}.

In MPD applications, the wellbore is closed and able to tolerate pressure. With this arrangement, the driller can better control P_{BH} with imposed backpressure (P_{Back}) from an incompressible fluid, in addition to the hydrostatic pressure of the mud column and annular friction pressure, Fig. 4:

$$P_{BH} = P_{Hyd} + P_{AF} + P_{Back}$$

REACTIVE VS. PROACTIVE

There are two basic approaches to using MPD—reactive and proactive. Reactive MPD uses MPD methods and/or equipment as a contingency to mitigate drilling problems, as they arise. Typically, engineers plan the well conventionally, and MPD equipment and procedures are activated during unexpected developments. Proactive MPD uses MPD methods and/or equipment to control the pressure profile actively throughout the exposed wellbore. This approach uses the wide range of tools available to (a) better control placement of casing seats with fewer casing strings, (b) better control mud density requirements and mud costs, and (c) provide finer pressure control for advanced warning of potential well-control incidents. All of these lead to more drilling time and less NPT time. In short, proactive MPD:

- Drills operationally challenged wells
- Drills economically challenged wells
- Drills "undrillable" wells.

Using an RCD alone does not necessarily constitute MPD operations. An RCD is an excellent supplemental safety device and adjunct to the BOP stack above the annular preventer. Used alone, it is at best a highly effective reactionary tool, which can be used to safely mitigate hydrocarbons escaping from the wellbore to the rig floor. This method is sometimes described as the Health Safety Environmental Method.

As additional equipment and know-how are added, the operation becomes more and more proactive. The full-time use of the Rig Choke Manifold (RCM) to control the annular pressure profile, while drilling ahead, is not recommended. The function of the RCM has always been for well-control incidents. A well-designed and dedicated DCM offers functionality and sufficient redundancy for safe MPD operations.

With rare exceptions, Non-Return Valves (NRV) are placed in the drillstring to block retrograde flow up to the surface. Options of microprocessor control and backpressure pumps can often enhance the technique commonly referred to as the constant bottomhole pressure method. Using the appropriate tools, drilling within the drilling window enables one to "walk the line" between pore pressure and fracture pressure without inviting influx or lose of returns.

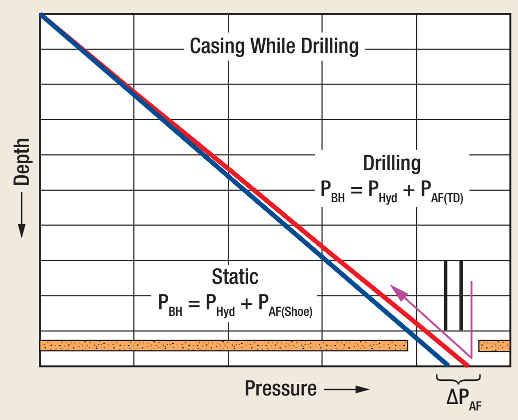

Fig. 6. In casing while drilling, pumping manages friction pressure through the casing drillstring.

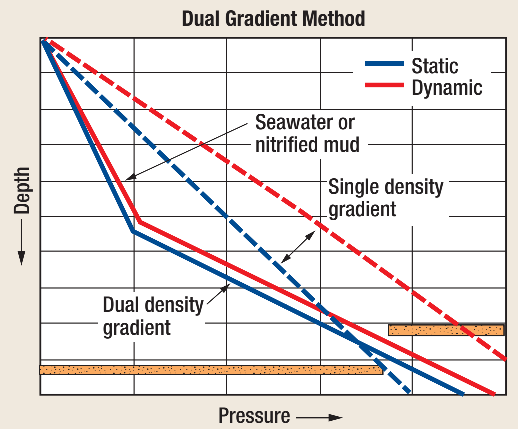

Fig. 7. The dual-gradient variation uses two density gradients, a lower density on top and higher density on the bottom.

CONSTANT BOTTOMHOLE PRESSURE METHOD

While the name Constant Bottomhole Pressure Method (CBPM) implies control of the bottomhole pressure at the bottom of the hole, its actual objective is to control the most troublesome pressure anomalies within the exposed wellbore. Typically, the drilling fluid is lighter than "normal," so the hydrostatic column is statically underbalanced.

During drilling, influx is avoided with the increase in annular friction pressure from pumping. During connections, drillers control influx by imposing backpressure or by trapping pressure in the wellbore. At the least, an NRV, placed inside the drillstring, stops mud from flowing up the drillpipe to the surface.

MUD-CAP METHOD

This method also addresses lost circulation issues, but by using two drilling fluids. A heavy, viscous mud is pumped down the backside in the annular space to some height. This "mud cap" serves as an annular barrier, while the driller uses a lighter, less damaging and less expensive fluid to drill into the weak zone, Fig. 5.

The driller pumps the lightweight scavenger fluid down the drillpipe. After circulating around the bit, the fluid and cuttings are injected into a weak zone uphole below the last casing shoe. The heavy, viscous mud remains in the annulus as a mud cap above the weak zone. The driller can apply optional backpressure if needed to maintain annular pressure control. The lighter drilling fluid improves ROP because of increased hydraulic horsepower and less chip hold-down.

CASING WHILE DRILLING

Casing while drilling uses casing as the drillstring, so that the well is drilled and cased simultaneously. Because of the narrow clearance between the formation wall and casing OD, annular friction pressure can be a significant variable in ECD control. Flow within the small annular space contributes to increased annular friction pressure from the shoe to surface, Fig. 6.

DUAL-GRADIENT METHOD

Drillers have used dual-gradient drilling successfully, primarily in offshore applications, where water is a significant portion of the overburden. Since this liquid overburden is less dense than the typical formation overburden, the drilling window is small, because the margin between pore pressure and fracture pressure is narrow, Fig. 3. Because of weak formation strength, deepwater conventional drilling applications usually require multiple casing strings to avoid severe lost circulation at shallow depths, using single-density drilling fluids.

The intent of the dual-gradient variation is to mimic the saltwater overburden with a lighter-density fluid. Drillers can accomplish bottomhole pressure adjustment by injecting less-dense media, such as inert gas, plastic pellets or glass beads, into the drilling fluid within the marine riser. Another method is to fill the marine riser with saltwater, while diverting and pumping the mud and cuttings from the seabed floor to the surface.

Both of these methods alter the fluid density near the mud line. Two different fluids produce the overall hydrostatic pressure in the wellbore, which avoids exceeding the fracture gradient and breaking down the formation. This saves drilling operations from spending NPT addressing lost circulation issues and associated costs, Fig. 7.

EQUIVALENT CIRCULATING DENSITY REDUCTION

Equivalent Circulating Density (ECD) can be reduced by modifying the annular pressure profile directly. Using a single-density drilling fluid, a downhole motor can add energy to create an abrupt change in the annular pressure profile, Fig. 8.

CONNECTIONS

While making a connection, loss of annular friction pressure can be directly compensated by judicious use of imposed backpressure to control the bottomhole pressure. In severe kick–stick–lost circulation scenarios, supplemental backpressure with an incompressible fluid can complement the low-density drilling fluid. Options to control annular friction pressures with downhole pumps are readily available, as well.

CONTINUOUS CIRCULATING SYSTEM

Another method to control the annular pressure profile, while making a connection, is to maintain the ECD while the connection is being made. Pipe rams and a blind ram can be configured to effectively maintain circulation, even while the drillstring is apart during the connection. The continuous circulating device breaks the drillstring connection and, through a sequence of operations, diverts the fluid flow across the open connection. The device then makes up the new connection to the appropriate torque and drilling continues, Fig. 9.

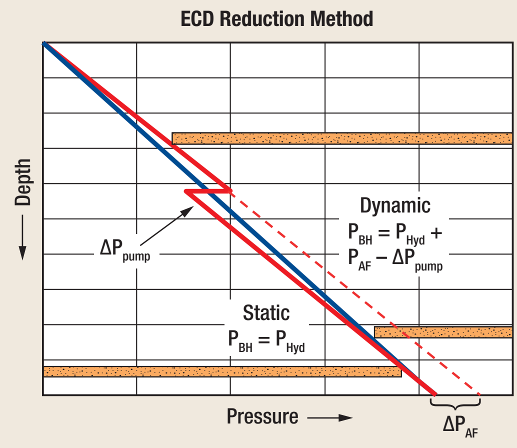

Fig. 8. To create a reduction in ECD, a downhole pump produces a pressure differential that modifies the annular pressure profile.

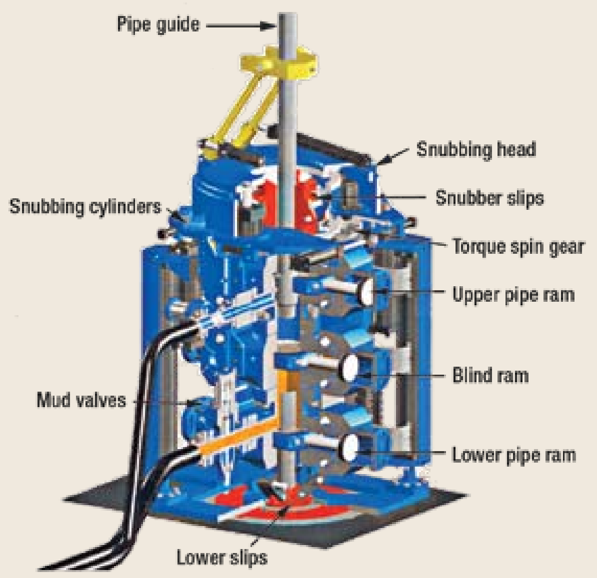

Fig. 9. A continuous circulating device maintains the equivalent circulating density, while the connection is being made.

TRIPPING

Since every MPD operation is application specific, no one tripping procedure fits all situations. Engineers should discuss the tripping procedure and agree upon it during HAZID/HAZOP conferences. Well control is paramount. The annulus may require some filling to compensate for the drillstring's effective volume that is removed during tripping. Backpressure can be applied to compensate for the lack of annular friction pressure until the margin encroaches on the limits defined in the drilling plan. Stripping in or out of the hole with high casing pressures can shorten seal element life. At some point, it may be advisable to spot a weighted, high-viscosity pill to control the well statically. On the trip in the hole, the pill can be circulated out.

HYDRODYNAMICS

Virtually every variation of MPD involves manipulation and management of the pressure profile, particularly in the exposed wellbore. Many factors affect downhole hydraulics, including:

- Wellbore geometry
- Drilling fluid density
- Drilling fluid rheology
- Annular backpressure
- Wellbore strengthening
- Annular friction pressure.

Used singularly or in combination, drillers can manipulate, manage and exploited these factors to accomplish MPD objectives, decrease NPT and reduce associated expenses.

In many cases, where the drilling plan includes a hole section that requires proactive MPD, a very detailed wellbore hydraulic analysis will foretell the success of various MPD methods. It will also guide the drilling engineer while he contends with the drilling operation's hydrodynamics in real time.

TRAINING

Many drilling operations are already practicing reactive MPD. Moving from conventional drilling to proactive MPD is a step change. The step-change magnitude is roughly equivalent to the change from cable tool to rotary drilling. Proactive MPD may require specialized well engineering design and planning. Rig crews may need additional guidance to supplement their well-control training. They will need to learn how to use today's tools safely.

COMPARING RISKS

The DEA155 joint industry project, *A Probabilistic Approach To Risk Assessment Of Managed Pressure Drilling In Offshore Drilling Applications*, is an attempt to better define the risks of using MPD, compared with conventional drilling techniques. Included in that comparison are:

- Expected trouble incident frequency
- Incident duration
- Consequences (incident cost, includ-

ing direct and indirect safety incidents)

- Incident detectability.

ECONOMICS

The size of the prize is virtually limitless. In one offshore case, after two unsuccessful sidetracks using conventional drilling techniques, where most of the time was spent fighting lost circulation, stuck pipe, fishing and well-control incidents, MPD was considered. After extensive hydraulic analysis, CBPM was chosen. The rig underwent slight modification to accept some required MPD equipment.

When the rig personnel were sufficiently trained, MPD operations kicked off where prior sidetracks had failed. MPD techniques drilled and proactively maintained ECD within the pore-pressure and fracture-pressure window, so that lost circulation was avoided. The operator eliminated time fighting lost circulation, kicks, wellbore instability and stuck pipe, and completed the well's objectives with cost savings. The chief contributors to overall savings were NPT reduction and mud-use reduction.

One of the challenges for DEA155 is to determine the extent of worldwide offshore MPD operations. The initial results are very encouraging. The incremental increase in day-rate expenditures ranges between 10 and 40%, but that same range can be applied to the decrease in drilling days. Besides getting the well drilled, operators can expect the return on investment in multiples, based on savings from diminished NPT and safety incidents.

How many undrillable wells would benefit from better economic drivers, like less drilling NPT, fewer casing strings, fewer mud property changes, smaller mud losses and better "real-time" well control? The benefits of Managed Pressure Drilling (**M**akes **P**roblems **D**isappear) are so numerous that it deserves serious consideration in your next well design. **WO**

ACKNOWLEDGEMENT

The author acknowledges the excellent work of the Underbalanced Operations and Managed Pressure Drilling Committee of the International Association of Drilling Contractors, since its inception in 1996. The author gratefully acknowledges the technical details and insight provided by companies whose equipment and experience is reflected in this article. Special thanks go to Dr. Joe Fowler, Jack Miller and Patrick McDonald of Stress Engineering Services; Don Hannegan of Weatherford; Rick Stone and the entire staff at Signa Engineering. Thanks also to Vincent Roes, Mark Chustz and Leo Maekiaho at Shell; Johan Eck-Olsen and Knut Taugboel of Statoil; John Lofton of Chevron, James May of Smith International, Don Reitsma of @Balance; Fred Hefren, George Conner and Michael Else of Minerals Management Service; and Oliver Coker and Kenneth Smith of ConocoPhillips for their many contributions.

BIBLIOGRAPHY

Dodson, J. K. and T. Dodson, personal communications, 2003–2006.

Elkins, H., Managed Pressure Drilling Conference proceedings, Galveston, Texas, March 2005.

Hannegan, D., "Managed pressure drilling," SPE Advanced Drilling Technology & Well Construction Textbook, Chapter 9, "Novel Drilling Methods, section 10—MPD" (to be published).

Medley, G. and P. Reynolds, "Distinct variations of managed pressure drilling exhibit application potential," *World Oil*, March 2006.

Pruner, A., "Key issues and technologies for the rapidly evolving casing while drilling technique," *World Oil*, March 2004.

Roes, V., Reitsma, D., Smith, L., McCaskill, J. and F. Hefren, "First deepwater application of dynamic annular pressure control succeeds," IADC/SPE 98077, presented at the IADC/SPE Drilling Conference, Miami, Feb. 2006.

Smith, K., Weddle, III, C. E. and C. P. Peterman, "Dual-gradient drilling nearly ready for field test," *World Oil*, Oct. 2000.

Smith, K., "MPD helps to make problems disappear," *Drilling Contractor*, Sept./Oct. 2006.

Tian, S., Medley, G. H. and C. R. Stone, "Optimizing circulation while drilling underbalanced," *World Oil*, June 2000.

THE AUTHOR

Ken Malloy is a University of Houston graduate and a Registered Professional Engineer. He has a long-standing interest in managed pressure drilling and underbalanced operations, safe operations and drilling efficiency, wellbore stability, HPHT issues and well control. He is a member of the IADC's Underbalanced Operations and Managed Pressure Drilling Committee. Malloy is co-investigator and project manager for joint industry project DEA155, a risk assessment study of managed pressure drilling. He is presently employed at Mohr Engineering, a Division of Stress Engineering Services in Houston.