MANAGED PRESSURE DRILLING

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Abstract

Managed Pressure Drilling (MPD) is an advanced form of primary well control usually employing a closed and pressurizable drilling fluids system that allows more precise control of the wellbore pressure profiles than mud weight and mud pump rate adjustments alone. Unlike conventional open-to-atmosphere mud returns systems at the rig floor such as drilling or bell nipples, the circulating fluids system employed by MPD technology is more akin to that of a pressure vessel.

Although the term, Managed Pressure Drilling or MPD is relatively new to the industry, having been first introduced in this context at the 2004 IADC/SPE Amsterdam Drilling Conference, the practice itself is not and it have been evolving on land programs over the past two decades. This is particularly true in the United States where 3 out of 4 land drilling programs drill at least one section with a closed and pressurizable mud returns system, up from 1 in 10 in 1995.

At the essence of MPD is the ability to apply surface backpressure while drilling ahead or shut in to make jointed pipe connections. Drill string non-return valves, a rotating control device, and a dedicated choke manifold are the basic tools required. Some applications of MPD may require other tools and technology developed and proven for the safe practice of UBD.

As if *necessity is the mother of invention*, these techniques enabled by drilling with a closed and pressurizable mud returns system have been driven by desires to reduce drilling non-productive time associated with drilling-related issues such as:

~ Narrow fracture to pore pressure “windows” and the associated kick-loss and well control scenarios,

~Loss circulation & associated excessive mud costs,

~Excessive casing programs,

~Slow Rate of Penetration (ROP),

~Well control issues, and

~Failure to reach TD with large enough hole.

Introduction

There are two **Categories of MPD: Reactive and Proactive.** Tooling up with a closed and pressurizable mud returns system at the rig floor and drilling with conventional fluids and casing program, MPD techniques facilitate more efficient *reaction* to downhole surprises. When Proactive MPD is practiced, the fluids and casing program are designed from the beginning, *proactively*, to benefit from drilling with a closed and pressurizable system, making jointed pipe connections with surface backpressure, etc.

There are four key **Variations of MPD: Constant Bottomhole Pressure, Pressurized Mud Cap, Dual Gradient, and HSE.**

This work hopes to further define the Variations of MPD, teach the drilling-related issues each variation addresses, and illustrate how each variation may be practiced from all types of rigs – land, jackup, barge mounted, platform mounted, moored semi submersible, and dynamically positioned drillships.

Although the principal teachings are applicable to drilling with coil tubing, this paper speaks exclusively to drilling with jointed pipe.

MPD mirrors evolution of Rotating Control Devices

The litany of techniques now defined by the industry as a technology within itself, MPD, has been slowly evolving over the past couple of decades. The evolution of MPD technology tracks the development of Rotating Control Devices and industry acceptance of their numerous applications.

It is interesting to note that although the tool in some evolution of its design has been available for at least 3 decades, the first API Specifications for RCD's, API 16RCD, was issued only this year, 2005. This, in itself, is actually a credit to the fit-for-purposes characteristics of RCD's in general. Most API manufacturing/refurbishing/testing specifications have come forth as a result of some sort of disastrous event where the equipment involved was determined to be the root cause. The API Specifications for RCD's, on the other hand, was initiated by the proactive efforts of the Standards and Specifications Sub-Committee of the IADC UBO and MPD Committee.

Drilling with jointed pipe, RCD's are required for Air, Gas, Mist, and Foam Drilling for more or less obvious reasons, and where a positive diversion of returns away from the rig floor is more of a key role than the application of surface backpressure.

They are also a required component of an Underbalanced Drilling system where the primary role is that of positive containment of produced hydrocarbons and where the application of surface backpressure is a crucial function.

It therefore comes as no surprise that the industry as a whole most often relates RCD's to Air Drilling and Underbalanced Drilling. However, when one considers that there are many more of these tools being used on drilling programs than the total sum of Air Drilling and Underbalanced Drilling programs, it's apparent the industry has found a number of other beneficial applications. It is these non-compressible fluids drilling and non-underbalanced drilling applications that fit now under the umbrella definition of Managed Pressure Drilling.

History of Rotating Control Devices

Air, Gas, Mist Drilling - Decades ago, the general acceptance of compressible fluids drilling to increase ROP and lower cost of drilling in hard rock environments spawned the development of Rotating Control Devices (RCD's).

Mounted atop the annular BOP of a typical API BOP stack configuration, the most common design RCD consists of three components:

1.) Body with a Flowline Outlet Flange,
2.) Bearing Assembly with a Stripper Rubber capable of stripping drill pipe and tool joints,
3.) Clamp or Latch for securing the Bearing Assembly and Stripper Rubber Assembly to the Bowl.

The Inner Race of the Bearing Assembly, upon which the Stripper Rubber is fitted, rotates with the drill string. The Stripper Rubber sees only up-down movement of the drill string. The Outer Race of the Bearing Assembly is secured to the Bowl and does not rotate. For compressible fluids drilling, the tool serves as a rotating diverter to positively direct annulus returns away from the rig floor via the Blooey Line of a land drilling rig.

Stripper Rubber's are an "expendable item", wear with usage, and their performance is key to the RCD being "fit for purpose". Drill strings are typically an unfriendly surface for a rubber component to seal against and whose greatest enemy is frictional heat from irregular surfaces. Stripper Rubber design, manufacturing techniques and materials technology has improved immensely over time and the vast majority of drilling programs find their performance quiet acceptable. Additionally, a number of drilling practices have evolved that assure longer life before the stripper rubber begins to leak annulus returns and require replacement. A new stripper rubber should be sized to have a relaxed inside diameter approximately 7/8" less than the smallest outside diameter of the drill string, usually the drill pipe itself. Differential pressure induced vector forces on the cone shape of the outer profile of the stripper rubber assures the higher the pressure, the greater the seal-ability. Low-pressure seal-ability is via stretch-tightness of the "nose" of the stripper rubber.

Low-pressure capable RCD's are the most common design for compressible fluids drilling.

Underbalanced Drilling - The ability to apply surface backpressure within a closed circulating mud system is a key to practicing underbalanced drilling safely and effectively. A key incentive to practice UBD is to prevent invasive mud and cuttings damage to wells potential to produce. UBD therefore has a reservoir focus. An influx of hydrocarbons is invited during the drilling process and specialized downhole and surface equipment, including the RCD, is required to practice this technology safely and with positive environmental consequences.

Designs of "surface models" of RCD's to practice UBD from all types of rigs with surface BOP stacks, including surface BOP's on floating rigs have evolved over the past decade. Subsea models have been introduced that are applicable to riserless drilling in deep water and, in conjunction with subsea mud returns pumps, for practicing true dual gradient deep water drilling.

High-pressure capable RCD's are the most common designs for underbalanced drilling and most applications of MPD.

Managed Pressure Drilling – As discussed previously, if you are not using a RCD, perhaps with drill string floats and a dedicated choke manifold for Underbalanced Drilling…and you're not using the tool as a rotating flow diverter for Air, Gas, Mist Drilling…you are probably practicing one of the variations of MPD.

Spoken differently, if you are not using a RCD to drill with air or UBD, you have probably found by experience that a closed and pressurizable mud returns system enables more precise wellbore pressure management and enhanced control of the well.

You also have found that such capability allows you to:

~ Drill deeper open hole sections where the frac-pore windows are tight.

~ Mediate kick-loss and well control scenarios typically associated with narrow downhole pressure environment limits.

~ Deeper casing set points, perhaps eliminate a casing size en route to the total depth objective.

~ Avoid mud losses caused by circulating annulus friction pressure (ECD) by drilling with a lighter than conventional-wisdom fluid.

~ Avoid underground blowouts, e.g., mud losses associated with severely depleted zones.

~ Reduce mud costs associated with drilling into large cavities that have caused near or total losses and resulting well control issues in offset wells.

~ Practice one of the several types of dual gradient drilling.

~ Improve your chances of achieving the total depth objective with large enough hole.

~ Enjoy enhanced health, safety, and environmental consequences of drilling with a closed mud system at the rig floor.
~ Reduced non-productive time associated with circulating out kicks.
~ Increased ROP
~ Reduced mud cost.
~ Shorter drilling program.

Definition of Managed Pressure Drilling

The definition of MPD as defined by the IADC, as written in the draft chapter on MPD in the new SPE textbook-in-progress *Advanced Drilling Technology and Well Construction*, and further endorsed by several SPE MPD Applied Technology Workshops is as follows:

"MPD is an adaptive drilling process used to more 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.

Technical Notes

~MPD processes employ a collection of tools and techniques which may mitigate the risks and costs associated with drilling wells that have narrow downhole environment limits, by proactively managing the annular hydraulic pressure profile.

~MPD may include control of backpressure, fluid density, fluid rheology, annular fluid level, circulating friction, and hole geometry, or combinations thereof.

~MPD may allow faster corrective action to deal with observed pressure variations. The ability to dynamically control annular pressures 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."

Innovative Thinking – Moving MPD Offshore

It has now been explained why many U.S. land programs are practicing MPD. It has been illustrated that most of the reasons are to deal more efficiently with drilling related issues, hazards, or challenges that can be addressed or eliminated entirely by drilling with more precise wellbore pressure management, containment, control, and diversion.

The stage is set to ask the question "Now that the techniques of MPD have been well proven to be beneficial to land drilling programs, one would suspect that MPD would more beneficial to offshore drilling where the spreadsheet cost and hydraulics are much more challenging?"

The answer is yes…and a number of "first adopters" of MPD in marine environments have proven the technology to be fit for purpose. All plan future wells. It has been said that this is a very impressive track record for a "new" technology.

However, we now know that it is only the label, MPD that is new. The techniques have evolved over several decades on land programs to a point it's obvious they are a technology within themselves. The specialized equipment required for MPD in marine environments has been well proven for the more demanding practice of UBD and applicable to all types of offshore rigs.

When one gives the facts some thought, it is easy to convince oneself that MPD will probably become status quo thinking in the next half-decade or decade.

At some point in the future, depletion and/or water depths will manifest hydraulic challenges that can only be addressed by true state underbalanced drilling. In this context, MPD is uniquely positioned to fill the drilling technology evolution gap between conventional drilling and underbalanced drilling.

Categories of MPD

There are two Categories of MPD:

Reactive MPD – When planning to drill with conventional-wisdom casing set points and fluids program, the rig is equipped with at least a RCD, choke, and drill string floats as a means to more safely and efficiently deal with, for example, unexpected downhole pressure environment limits, e.g., lower or higher pore or fracture pressure than the fluids program was designed for at that depth. Of the rigs practicing MPD on land drilling programs, most are practicing the Reactive category of MPD. As a means of preparing for unexpected developments downhole, the drilling program is equipped from the beginning to deal with surprises. This, in part, explains why a growing number of insurance underwriters require drilling programs they insure be drilled with a closed and pressurizable mud returns system.

Proactive MPD – The drilling plan, including HazId/HazOp studies, is designed from the beginning with a casing, fluids and open-hole program that takes full advantage of the ability to more precisely manage the pressue profile throughout the wellbore. A "walk the line" variation of MPD technology usually incorporates making jointed pipe connections with surface backpressure applied via choke operation in harmony with the rig mud pump rate. Proactive MPD offers the greatest benefits to offshore drilling of conventional oil, gas, and ultimately, commercial quantities of methane gas hydrates. Total depth objectives may be reached with fewer casing strings on many prospects, less drilling non-productive time, fewer mud density changes to T.D., and enhanced control of the well.

Variations of MPD – Tools Required

This section speaks to the four key variations of MPD. All require at least a RCD suitable for the type of rig, its physical location in respect to the BOP, and with a pressure containment capability for containing the maximum pressures that may seen at the surface, plus safety factor. All also require the use of at least two drill string non-return valves (e.g., floats, preferably wireline retrievable to eliminate the possibility of an unexpected trip just to replace a stuck or plugged valve), and a dedicated choke manifold.

Some MPD applications invite the use of other tools and technology associated with underbalanced drilling. **Hydraulic Flow Modeling** is applicable and very worthwhile in many applications of MPD by estimating pressures, developing the fluids program, determining casing set points, and may prove invaluable in defining equipment requirements to handle expected surface pressures. **Reservoir characterization** is helpful in identifying MPD candidates. **Downhole Deployment Valves** enable much faster tripping than without.
A **Nitrogen Production Unit** may be applicable to lighten the mud sufficiently to drill within narrow margins or to practice one of the several types of dual gradient drilling. An **"Automatic Choke"** may be particularly beneficial when practicing the Constant Bottomhole Pressure variation.

Several operators have found that a hybred program incorporating MPD and **Drilling With Casing** to be the best technical and commercial solution to prospect wells that manifest wellbore instability in the upper hole sections that otherwise would require an extensive and casing program and multiple trips. This approach is a giant step in the direction of the industry's vision of "One Trip Well" technology.

Constant Bottom Hole Pressure (CBHP) Variation

This variation of MPD is attractive to consider when offset wells have shown kick-loss scenarios and well control issues associated with drilling into relatively unknown or narrow downhole pressure environment limits. Typically, such tight drilling windows manifest themselves first by loss of returns immediately upon resuming circulation after a jointed pipe connection. If the well was not kicking in static condition during the connection time, this indicates the circulating Annulus Friction Pressure (AFP) or Equivalent Circulatng Dennsity (ECD) additive to bottomhole pressure or Equivalent Mud Weight (EMW) as a result of starting the rigs mud pumps has exceeded the formation fracture pressure somewhere in the open hole section. This is the “loss” in a kick-loss scenario.

If one then reduces the mud density with an eye upon avoiding exceeding the fracture gradient upon resuming circulation, you are perhaps at risk of the well allowing influx of reservoir fluids when static, e.g., shut in to make jointed pipe connections. This is the “kick” in a kick-loss scenario. When encountered, dealing with such issues adds significantly to the time to drill the well, increases mud cost, and obviously manifests well control situations one would otherwise like to avoid.

The conventional-wisdom method of determining the effective bottom hole pressure (EBHP) or Equivalent Mud Weight (EMW) is the sum of the mud weight hydrostatic plus the circulating annulus friction pressure. When the rigs mud pumps are off, there is no circulating annulus friction pressure additive to the hydrostatic head of the mud in the hole at the time.

EBHP or EMW = MWHH + □AFPCirculating.

Note the period after AFP. The only way to change the downhole pressure profile with the mud in the hole at the time is by changing the rigs mud pumps rate. Period.

The CBHP variation of MPD method of determining the wellbore pressure profile adds an important dimension to the conventional formula by enabling hydraulic backpressure to be applied upon the annulus returns:

EBHP or EMW = MWHH + □AFP + □Backpressure

Now one has the ability to eliminate the significant pressure spikes that would otherwise occur during the process of making jointed pipe connections. A more constant pressure profile can be maintained, drilling ahead vs. mud pumps off when making drill string connections. This enables a lighter than conventional fluids program to be used without risk of influx when making connections and when the wellbore is not subjected to circulating annulus friction pressure. The hydrostatic head pressure when not circulating may be less than the formation pore pressure. However the application of surface backpressure in harmony with mud pump rates maintains a state of overbalance and this, of course, prevents the well from kicking during connections. With such a CBHP fluids program, more of the frac-pore window is available for drilling progress and this is a key to avoiding loss circulation upon regaining circulation after connections.

Pressurized Mud Cap Drilling (PMCD)

This variation of MPD has evolved on land drilling programs over the past decade. It is particularly beneficial to tool up to practice this method in cases where offset wells have encountered grossly depleted zones and where extreme mud loss has resulted from drilling horizontally into inclined fractures or into formations containing large cavernous voids.

PMCD operations involve drilling with a sacrificial fluid, seawater with appropriate inhibitors being common when drilling in marine environments, and no returns to the surface. A “mud cap” of heavy fluid, perhaps the rigs kill fluid, is pumped down the annulus with a dedicated mud cap pump via the RCD. The column height and density of the mud cap is predetermined with an eye upon keeping surface backpressure requirements to a minimum. The sacrificial fluid is less dense than the conventional heavy mud used on offset wells and where massive losses and well control issues prevailed. When drilling and “circulating”, the sacrificial fluid, much less expensive than conventional mud, is prevented from surfacing via the hydrostatic head of the mud cap and augmented by additional surface backpressure as needed via the RCD and dedicated choke manifold. Instead, the mud and cuttings are forced into the very zone that would otherwise be a drilling hazard.

With this method, it has been said that upon learning that offset wells have experienced excessive mud cost due to severe loss circulation, it may be more good than bad news…this because the presence of such a trouble zone enables drilling with a lighter fluid with increased rate of penetration, less overall mud cost, increased control of the well and in some prospects may make the difference in achieving the total depth objective.

Figure 3., below is an example depth-pressure map illustrating how PMCD differs from a conventional circulating mud drilling program.

Figure 4., below is a sketch of a typical fluids system used for the practice of Pressurized Mud Cap system on land and fixed offshore rigs that have surface BOP stacks and where there is no need to compensate for vessel heave while drilling with a pressurized mud returns system.

Figure 5., below, is a photo of a PMCD installation on a jackup rig with surface BOP stack offshore Angola. In this photo, the RCD Bearing & Stripper Rubber Assembly is not clamped to the Bowl of the RCD. At this point in the drilling program severe loss circulation has not yet occurred and a Drilling Nipple is clamped instead to the Bowl of the RCD. Returns are being taken conventionally. At first indication of severe losses, the Drilling or Bell Nipple is removed, the RCD Bearing and Stripper Rubber Assembly installed, and the flexible flowline shown is the conduit for spotting the mud cap in the annulus. PMCD is initiated by drilling with the sacrificial fluid and required surface backpressure augmenting the hydrostatic head of the mud cap, forcing mud and cuttings into the theft zone.

Figure 6., below is a schematic of the RCD installation and associated flexible returns lines connections to existing moonpool equipment on a deepwater (floating) rig for the practice of PMCD. In this example, the moored sems-submersible has a subsea BOP with marine riser and telescoping slip-joint. The slip-joint is typically the weakest link in the riser system relative to pressure containment. With the Inner Barrell of the slip-joint collapsed into the Outer Barrel, locked, and its seals pressurized, most marine riser systems are safely capable of 500 psi. In such a MPD application in deep water, the RCD effect a closed and pressurizable mud returns system and its flexible flowlines compensate for vessel heave, this in lieu of the slip-joint that has been rendered non-functional.

Figure 7., below is a photo of PMCD from a floating rig offshore Sarawak East Malaysia, in this case to overcome the drilling hazards associated with the potential for near-total losses upon drilling into large underground voids.

Dual Gradient Variation (DG)

This variation of MPD has been well proven on many land programs. Many may argue that it has seen only very limited practice in marine environments.

However, every offshore rig that has a marine riser booster pump and booster pump line ran down outside the riser to a riser injection point has likely used that system (most often for hole cleaning purposes) by injecting drilling fluid (with no cuttings) into the marine riser. The result is one pressure-depth gradient (less dense mud in the annulus) above the injection point and another (more dense mud) below that point – thus, dual gradient.

The DG variation of MPD simply carries that method further. The wellbore is drilled with two different annulus fluid gradients in place. How this is accomplished depends on the operating environment. Techniques to practice this MPD variation include injecting a lower-density, perhaps nitrified fluid, through a parasite casing string on land programs or into a deepwater rigs booster pump line to further reduce the effective bottomhole pressure without having to change the density of the mud in the hole at the time. A well designed application of this variation may change the bottom hole equivalent mud weight significantly without having to change mud density or pump rates.

Dual gradient riserless drilling involves a subsea RCD, subsea pump, and flexible returns flowline back to the rig. The result of such a "top-hole drilling package" is more precise wellbore pressure management when establishing subsea locations via riserless drilling. Objectives; better deal with shallow-to-the-mudline geohazards, avoiding the practice of Pumping & Dumping" heavy muds onto the mudline, recover expensive drilling fluids, and/or retrieve cuttings for perhaps more appropriate onshore disposal.

Figure 8 is an illustration of a riserless dual gradient top-hole drilling package.

HSE Variation

Sometimes referred to as Returns Flow Control variation of MPD, the primary objective is to gain the benefits of a mud returns system on the rig floor that is closed to atmosphere for health, safety, and/or environmental reasons.

Another example of this variation is drilling on a production platform where simultaneous production is ongoing. Here, the intent is to prevent drilled cuttings gas from escaping to atmosphere at the drilling nipple, bell nipple, or upper marine riser and triggering atmospheric explosive vapor monitors and in some installations, automatically shutting down production elsewhere on the platform. In some jurisdictions, operators are required to alert regulatory authorities to such production shutdowns, thus another desire to limit cuttings gas releases on the rig floor.

Conclusion

There are several strong indicators that the practice of Managed Pressure Drilling in marine environments is poised to see significant uptick in the next decade. Althogh a relatively new concept to many offshore drilling decision-makers, drilling with a closed and pressurizable mud returns system at the rig floor makes uniquely good sense for a number of reasons.

Although much of the technology developed for the safe practice of underbalanced drilling operations are applicable to MPD, an influx of formation fluids is not invited. However, one is better prepared than conventionally to deal with any that may be incidental to the operation and do so with less drilling non-productive time.

Only selected components of a UBD "kit" are required to practice the variations of MPD. This serves the technology well in the sense most offshore rigs have space limitations.

Conventional Well Control practices are applicable to MPD.

Regulatory agency acceptance of MPD technology has been positive. However, because MPD is different than conventional practices in some respects, most agencies strongly encourage involving them early in the MPD planning process.

At this juncture, there have been approximately 50 applications of MPD in marine environments. Most have occurred within the past 18 months. Whether in shallow or deep water, all "First adopters" of MPD in marine environments plan future MPD projects.

The author wishes to be so bold as to make the observation that in the evolution of horizontal drilling to todays status as a status quo technology, and the now general acceptance of top drives…did not experience such a commendable track record in early years.

MPD is off to a good start in marine environments.

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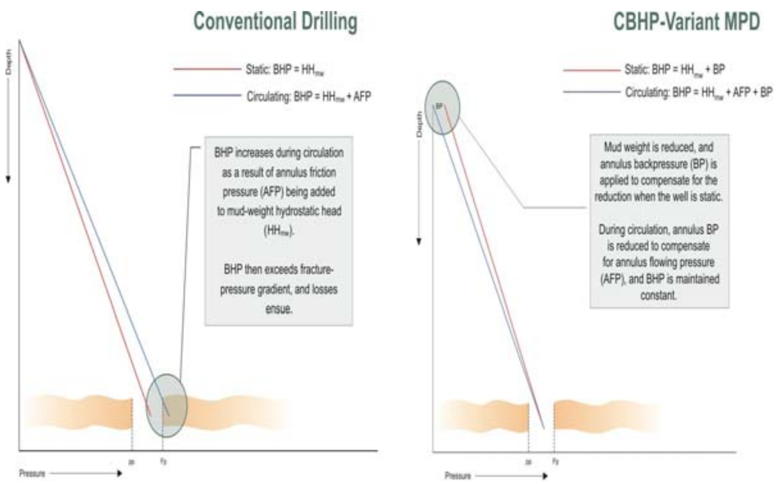
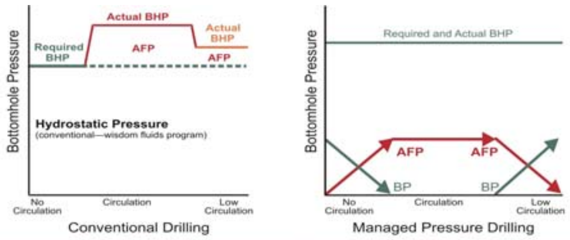
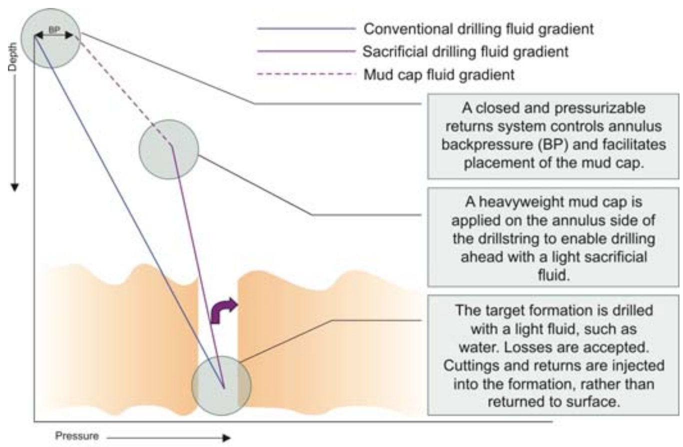


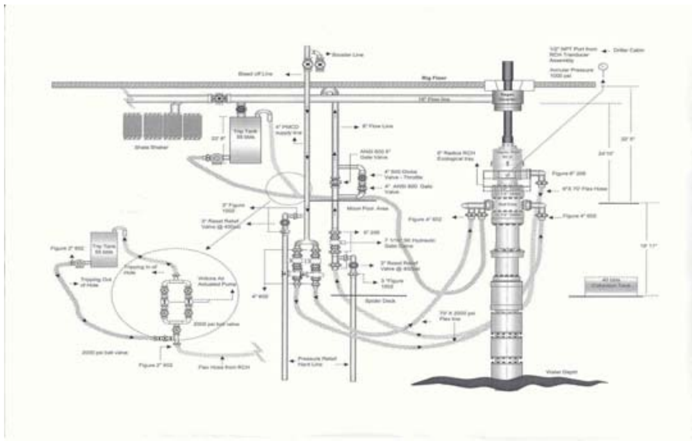
Pressure-versus-depth illustration of conventional drilling compared to CBHP MPD. Applied annulus backpressure is controlled by an RCD that allows maintaining BHP at a constant value that does not exceed formation fracture gradient, even when circulating.

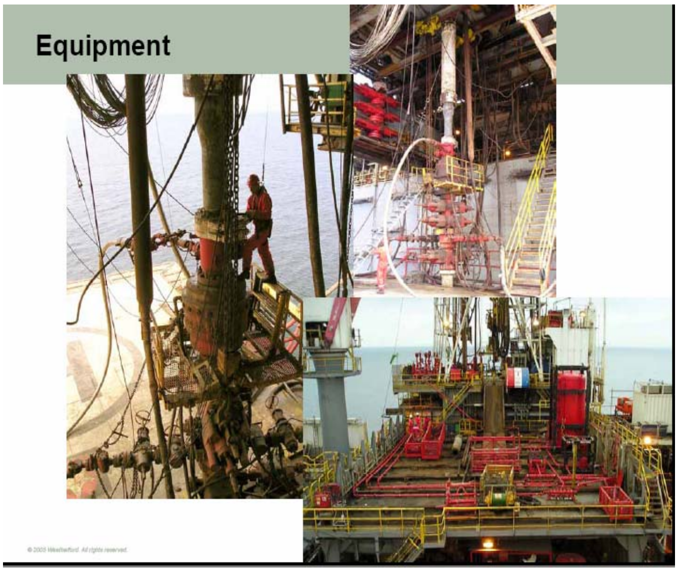


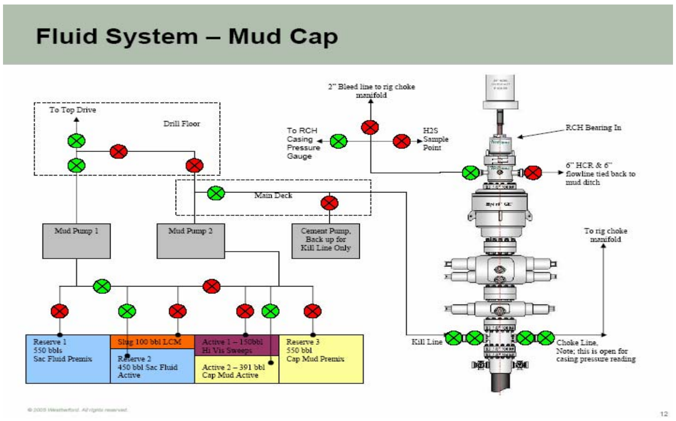
During conventional circulation, annulus friction pressure is added to hydrostatic pressure and increases total BHP. In CBHP-variant MPD, reduced surface annulus pressure compensates for increases in annulus flowing pressure during circulation.

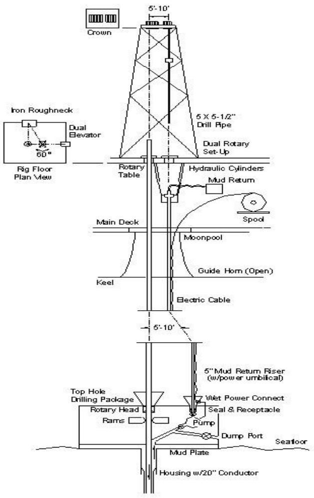


Pressure-versus-depth illustration of PMCD. A high-density fluid "mud cap" is placed on the backside of the drillstring. An RCD and choke enable control of surface backpressure while drilling ahead with a lighter, less costly fluid. Losses into the hazard zone are accepted.









TOP HOLE DRILLING PACKAGE
SINGLE LINE CONCEPT