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Variations of Managed-Pressure Drilling Currently Practiced: Offshore Case Studies

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Abstract

Managed Pressure Drilling in marine environments is well on the path of widespread understanding and industry appreciation of potential for the technology. From years of evolutionary development on land programs, particularly in the United States and Canada, a number of offshore drilling decision-makers have now become "first adopters" of this technology with significant success and with good control of the well at all times during the drilling process. Perhaps the best way to quantify this statement is to mention that, to date, all first adopters of MPD from offshore rigs plan future MPD projects.

Unlike conventional circulating drilling fluids systems that are open to atmosphere on the rig floor, MPD tools and technology enable the circulating fluids system to be likened to the hydraulic characteristics of a pressure vessel. Several variations of MPD enable the effective wellbore pressure profile (e.g., equivalent mud weight) to be adjusted significantly with mud in the hole at the time, particularly beneficial when drilling in narrow formation pore pressure to fracture pressure margins and when the pressure environment limits may be relatively unknown. One variation of MPD addresses severe loss of circulation and excessive mud costs. Another addresses employee health, safety and environmental aspects that may be associated with drilling with conventional open-to-atmosphere mud returns systems at the rig floor.

A closed and pressurizable mud returns system is the enabling technology for most, but not all, applications of MPD. Drilling with a closed mud returns system reflects a relatively modest step change from conventional methods; most offshore rigs can accommodate the specialized equipment space requirements, benefits vs. cost are attractive, and the "MPD way of looking at drilling hydraulics" is relatively easy for drilling decision-makers and regulatory agencies to comprehend. Therefore, this paper will speak only to the "lower hanging fruit" MPD techniques that are enabled by drilling with a closed and pressurizable mud returns system or annulus.

More precise pressure management throughout the wellbore is an objective of all variations of MPD. Unexpected downhole pressure environments may be dealt with more efficiently with enhanced control of the well and usually with less interruption to the drilling program when such surprises are encountered.

An influx of formation fluids is not invited in MPD. Although some MPD tools and techniques are rooted in Underbalanced Drilling technology, this is a major distinction between MPD and UBD. A properly planned and implemented MPD program is likely to see fewer

hydrocarbons produced to the surface that if the prospect had been drilled conventionally.

This work will define MPD, introduce the audience to its unique terminology and explain its Variations with pressure-depth maps. As each variation addresses specific well construction and drilling challenges, examples of each that have been practiced to date will be described. In consideration of operator confidentiality, several that are in the advanced stages of planning will be addressed only in very general terms.

Background

A review of a typical depth-pressure map that reflects a conventional drilling program applied to a relatively unchallenging prospect is perhaps a good initiation to this discussion on Managed Pressure Drilling technology. See Figure 1., below.

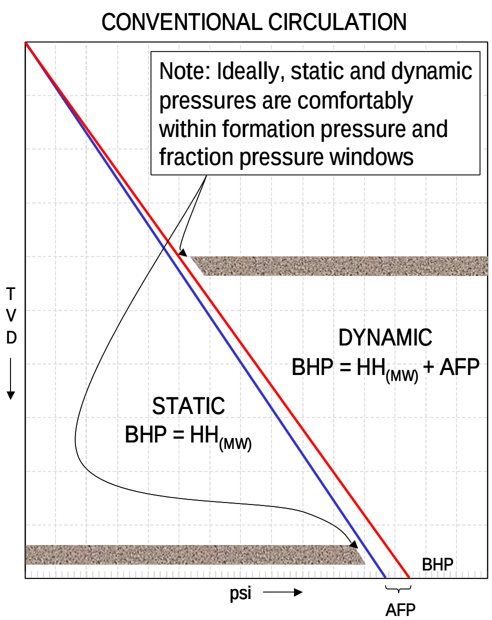

Figure 1

Unfortunately, a growing number of prospects, particularly offshore where depletion and water depths pose additional and unique hydraulic challenges to the drilling program, such an ideal case as presented above are becoming increasingly rare.

The luxury of drilling prospects that are "easy" appears to be on the wane. Increasingly more common is the requirement to drill through or into depleted formations and those that have narrow margins between formation pore pressure and fracture gradient. These drilling programs typically experience non-productive drilling time dealing with kick-loss scenarios. See Figure 2, below.

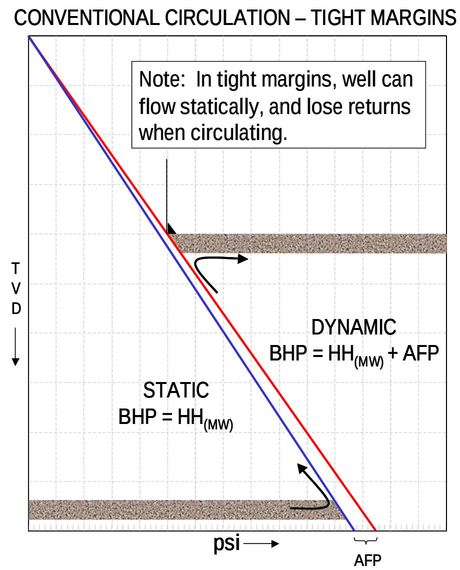

Figure 2

Introduction

Demand is increasing for a technology that offers more precise wellbore pressure management, containment and control. Specifically, a technology that offers a wider range of options to efficiently change the pressure profile with mud in the hole at the time via means that are in addition to the conventional method; which is - mud pumps on, off, or vary the pump rates.

Many centuries ago, Plato wrote *"Necessity, who is the mother of invention"*. Such is the case of Managed Pressure Drilling tools and techniques.

MPD techniques and the required equipment have evolved since at least the mid-sixties on U.S. land drilling programs to a point they are considered status quo, e.g., "been doing that for years". They evolved as a direct result of finding solutions to a litany of drilling-related issues that would otherwise contribute to non-productive time, excessive cost, control-of-the-well issues, or failure to reach the total depth objective with

large enough hole for the well to be economically viable.

By drilling with a closed and pressurizable mud returns system and consequently viewing the circulating fluids system as a pressure vessel, drilling may continue with more precise pressure management and fewer interruptions.

In the most basic configuration, a closed and pressurizable circulating mud system is accomplished with modest additional equipment to most rigs; drill string floats (non-return valves), a Rotating Control Device (aka rotating control head), and preferably, a dedicated choke manifold.

How does viewing the circulating fluids system as a pressure vessel contribute to more precise pressure management?

1.) **The rigs mud pump rates may be adjusted on the "front side" of the circulating fluids system with a resulting change in circulating annulus friction pressure.**
2.) **With a Rotating Control Device stripping the drill string and diverting mud and cuttings returns to a dedicated choke manifold on the "back side", adjustments can be quickly made to both the static and circulating pressure profiles by the application of casing backpressure.**
3.) **Jointed pipe connections may be safely made with casing pressure.**

The concept of closed and pressurizable systems and operations has been practiced for decades in the Process Industries. For example, employee health, safety, and environmental considerations, product quality, and energy efficiencies have rendered "open pit" mentality undesirable and unwelcome on a broad scale in the chemical, pharmaceutical, petroleum and petrochemical facilities today.

Applying this thought process to the drilling industry, particularly the offshore industry, has been described as "new and innovative". Perhaps this is because in part it differs from teachings that came into favor decades ago with the broad acceptance of rotary rigs, drilling with weighted mud.

Nevertheless, the results of MPD have included faster ROP in some cases, less loss of circulation in others. The ability to drill in narrow pressure margins while avoiding kick-loss scenarios has developed to be an important benefit. In several applications, the greatest benefit has been that of reaching the total depth objective and accessing an otherwise economically un-drillable prospect.

The author finds it interesting that many of the techniques that fit under the current definition of MPD were "discovered" by drillers and tool pushers in the middle of the night who had a desire to achieve a certain depth objective - "The drilling and mud engineers are home asleep…I need to get to where they expect me to be by the time I have to fill out my morning report…and I have to get there with the mud I have in the hole".

For years, many of the techniques were considered "tight-hole" secrets by operators and "competitive advantages" by drilling contractors and consultants. This explains in part why such an extended time expired before the assortment of techniques was recognized by the industry as a technology within itself. It has been only in the past several years that these techniques have been described in technically acceptable venues and presented to offshore drilling decision-makers for consideration. And, it has been only within the past few years that offshore variations of RCD's has been developed, pre-qualified and successfully field trialed to operate on all types of offshore rigs.

Definition of MPD

The IADC MPD & UBO Committee first defined Managed Pressure Drilling. A SPE Applied Technology Workshop and several other venues

dedicated to discussing the technology have further validated the following definition:

"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 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, 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 may facilitate drilling of what otherwise would 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.***

Categories of MPD

There are two "categories" of MPD, Reactive and Proactive.

Reactive MPD – When attempting to drill with conventional well construction and fluids programs, one is "tooled up" with at least drill string Floats, RCD, and Choke as an enabling configuration to more safely and efficiently deal with an unplanned pressure environment or rock mechanics at that depth with the mud in the hole at the time. Given the predominance of U.S. land drilling programs drilling with closed and pressurizable systems, most are practicing this category of MPD today. Consequently, many drilling programs may not be realizing the full potential of the technology when one keeps in mind that most of the "easy prospects" have already been drilled and a growing number would benefit from more of a "take control" approach (see Proactive, below).

Proactive MPD – The well's casing, fluids, and open-hole programs are designed from the beginning with the objective of taking full advantage of the ability to more precisely manage the pressure profile throughout the drilling process. This "walk the line" category of MPD technology is expected to offer the greatest benefits to both onshore and offshore drilling.

Variations of MPD

Where the intent is not to invite an influx of formation fluids during drilling, but to manage pressure more precisely, four key Variations of MPD have evolved:

HSE,
Constant Bottomhole Pressure Drilling,
Pressurized Mud Cap Drilling, and
Dual Gradient Drilling.

<u>HSE</u> Variation – The objective is to drill with a closed annulus returns system on the rig floor vs. an open-to-atmosphere drilling nipple, upper marine riser, or bell nipple for the express purpose of enhancing employee health, safety and environmental considerations.

<u>Constant Bottomhole Pressure</u> (CBHP) Variation – Also known as "ECD Management", the objective of this variation is to address drilling-related issues typically associated with drilling into narrow or relatively unknown pressure environment windows. Most often the CBHP fluids program is slightly lighter than conventional. When not circulating and the circulating annulus friction pressure additive is not present, the bottomhole pressure may be at balance or slightly less than the pore pressure of the formation being drilled. Influx of formation fluids is prevented by the application of backpressure on the annulus. E.g., choke open

when the rigs mud pumps are on and choke closed when the pumps are off. A constant annulus pressure profile is maintained whether circulating or shut in to make connections by one of several ways of orchestration of varying mud pump rates vs. varying amounts of backpressure applied to the annulus.

Where EMW is the equivalent mud weight, MW is mud weight hydrostatic pressure, AFP is circulating annulus friction pressure and BP is backpressure applied to the annulus at the surface via the RCD and Choke, this variation of MPD may be explained:

$$\mathbf{EMW = MW_{HH} + \Delta AFP_{CIR} + \Delta BP_{CASING}}$$

Below is another method of illustrating the CBHP variation of MPD. Circulating annulus friction effects on the annulus pressure profile that are associated with whether or not one is circulating at the time are negated via manipulation of surface backpressure in harmony with the circulating rate, e.g., no backpressure when circulating and drilling ahead; backpressure applied when shut in to make jointed pipe connections. A rule of thumb - the amount of surface backpressure one may expect to require when not circulating is roughly equivalent to the value of the circulating friction pressure experienced at that depth drilling in the previous stand of pipe. See Figure 3.

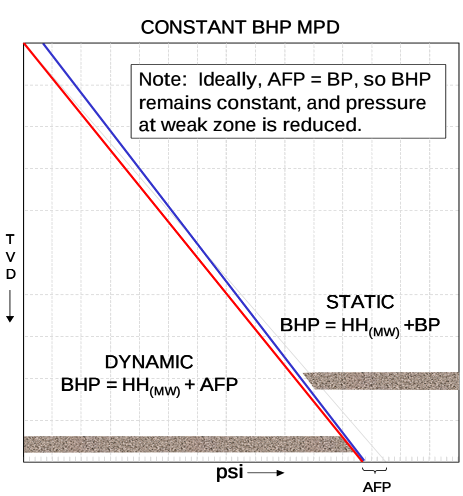

Figure 3

<u>Pressurized Mud Cap Drilling</u> (PMCD) Variation – The objective of PMCD is to address near or total loss of circulation issues that have occurred on applicable offset wells, perhaps from a requirement to drill through grossly depleted zones or cavernous voids. In addition to drilling non-productive time, such severe mud losses on offset wells may have resulted in exceeding the programs Authorization For Expenditure, well control challenges or perhaps failure to reach a total depth objective. AFE's for drilling prospects that indicate high risk of total or near-total loss of circulation commonly are exceeded due to mud cost and extensive casing programs. In deep water, more expensive floating rigs may be required to accommodate extra deck space and buoyancy for casing.

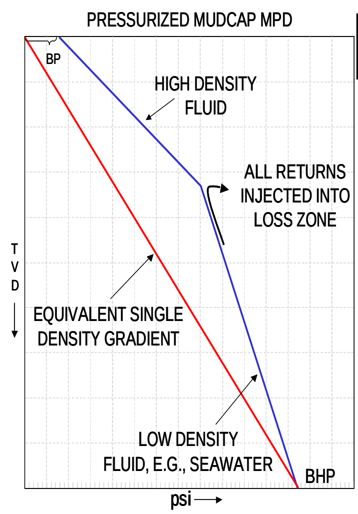

Figure 4

Figure 4. is an illustration of a comparison of conventional vs. PMCD. Visualize a situation where mud weight hydrostatic pressure alone or mud weight hydrostatic plus circulating annulus friction pressure finds little or no resistance to being lost into the formation or a karstified void.

Little can be done with conventional methods except costly efforts to fill the annulus with copious quantities mud, loss circulation materials, etc.

If one is prepared to practice PMCD at the first indication of gross loss of circulation, a predetermined fluid column height of heavy mud (mud cap) may be placed in the annulus via a dedicated mud pump and RCD. This mud cap serves as a barrier to annulus returns to the surface. Drilling continues, not with conventional mud density, but with a lighter and less expensive fluid, perhaps water. This fluid is

"single passed" or "sacrificial", that is, it and the cuttings it carries in the open hole are forced into the very uncased zone or zones that would otherwise be the root cause of loss circulation. The amount of backpressure applied is typically impacted by the rigs mud pump rates, e.g., little or no backpressure when not circulating, some backpressure may be required to augment the mud cap column hydrostatic when circulating.

A characteristic of PMCD is no returns to surface. However, the hydrostatic pressure of the sacrificial drilling fluid may be less than pore pressure at some depth in the open hole, but no formation fluids are produced to the surface, as in underbalanced drilling (UBD).

Prospects for sour oil or gas may be candidates for PMCD if the open-hole characteristics are fortunate enough to have a grossly depleted or fractured zone above the pay zone in a vertical well or at the heel of a horizontal well.

Although the drilling fluid is sacrificed, it is less expensive than a conventional mud. ROP increases significantly and there is less potential for differential sticking and resulting well control issues.

Dual Gradient MPD – As has been previously described, the CBHP variation of MPD facilitates a fairly significant ability to adjust wellbore pressure profiles with mud in the hole at the time via the use of backpressure applied to the annulus at the surface. However, this author predicts that a growing number of ultra deepwater, extended reach, and narrow sidetrack drilling programs that face high Equivalent Circulating Density values will benefit from Dual Gradient MPD within the next half-decade. See Figure 5.

There are a number of methods to achieve dual gradient, some much more complex than others. The most complex involves tricking, hydraulically speaking, the wellbore in a deepwater prospect into "thinking the rig is setting on the seafloor", this because the hydrostatic head of heavy mud and cuttings within a tall marine riser system is removed

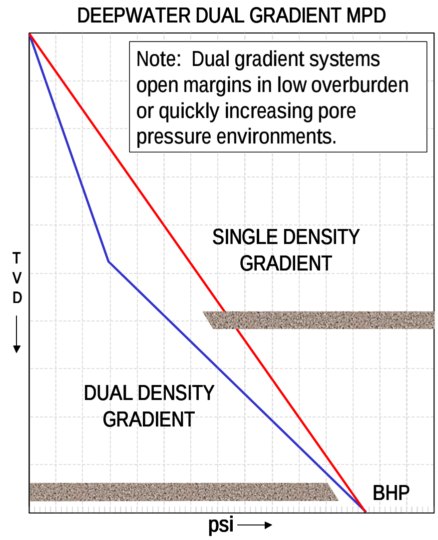

Figure 5.

completely from contributing to equivalent mud weight in wellbore annulus. A subsea RCD serves as an annulus barrier in the marine riser. The riser is filled with seawater to prevent collapse. Subsea pumps at or near the mudline pump annulus returns to the rig via a flowline.

Other variations of Dual Gradient involve:

1. Subsea pumps taking annulus returns from the marine riser nearer the surface than at the mudline.

2. Injecting light liquids, inert gas, or hollow spheres into the marine riser, perhaps via a floating rigs existing marine riser booster pump line, concentric casing, or parasite string.

3. When drilling riserless, a subsea mud recovery system returns (rather than Pumping and Dumping at the mudline) mud and cuttings to the floating rig.

Offshore MPD Activities To-Date

All Variations of MPD generally described in this work have been successfully practiced from both fixed rigs with surface BOP stacks and from floating rigs with subsea BOP stacks. (One major operator is in the advanced planning stages to enable MPD from a floating rig with a surface BOP in the moon pool.)

All found sufficient benefit to plan future offshore MPD wells when and where prospects indicate the technique to be applicable.

The PMCD variation has been applied by a major operator to a number of shallow and deepwater prospects in Malaysia, Indonesia and Angola as a solution to near-total loss of mud risks when drilling through cavernous voids.

The HSE variation has become an ongoing practice offshore Viet Nam, Denmark, and soon, in Ekofisk Field, Norwegian North Sea. In these examples, a key objective has been to prevent drilled cuttings gas from escaping to atmosphere from open annulus returns on simultaneous drilling-production platforms, thereby triggering atmospheric sensors and automatically shutting down production.

The CBHP variation has been practiced on several wells from jackup and platform rigs in the U.S. and Mexico Gulf of Mexico, primarily for ECD management purposes and reduction of non-productive rig time.

How valuable is MPD?

The employee health and safety aspects of practicing the HSE variation cannot be quantified. However, when the benefit also includes avoidance of an interruption to production elsewhere on a platform, the value is obviously very significant.

The value to operators to date who have practiced the CBHP and PMCD variations of MPD is averaging approximately $1 Million U.S. Dollars per well.

Conclusion

The benefits of drilling with more precise wellbore pressure management and with less drilling-related non-productive time are particularly attractive to offshore drilling where the hydraulic challenges are usually greater than even the most complex land program.

Today, a growing percentage of offshore prospects are economically un-drillable with conventional technology. MPD offers a means to increase economic drill ability and do so short of inviting an influx of formation fluids. The practice of MPD has been proven to increase recoverable assets. MPD has a commendable onshore well control incident track record that is now being repeated offshore.

Where UBD may be viewed by many today as a quantum leap in marine environments and to be practiced only when an absolute necessity to achieve a producing prospect, MPD is a relatively modest step-change from conventional well construction and fluids programs, equipment requirements and rig modifications. However, like UBD, MPD requires much more planning than conventional. A HazId/HazOp process should be conducted in advance of spudding a MPD prospect. Contingency plans must be clearly defined and rig crews carefully trained.

Applicable regulatory agencies should be invited to be involved early in the planning process. Regulatory agencies have indicated a willingness to assist in ways to make MPD work safely and with "less-than-conventional-operations" impact on the environment. Agencies involved in MPD programs to date have shown they do not wish to be viewed as a barrier to appropriately planned and implemented MPD applications within their jurisdictions.

At some point in the future, many offshore prospects will require that they be drilled underbalanced for reservoir productivity reasons. However, for the next decade, reducing the costs associated with offshore drilling-related challenges will be a focus.

MPD is a uniquely suitable, timely, and now-proven technology to practice in marine environments.

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