The use of single, multi-phase MPD and UBD techniques on numerous wells and hole sections has enabled the drilling of the un-drillable in various locations around the world, including Colombia

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- Artículo Técnico [X]
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Abstract

Colombia's first commercial oil well was drilled in the La Cira-Infantas field in 1918. (Barrancabermeja). The field is still active after more than a century, and some drilling operations, for example, have resorted to managed pressure drilling (MPD) with nitrogen injection to breathe new life into this onshore brownfield.

Conventional overbalanced drilling techniques have been used in oil and gas wells around the world to control reservoir pressures and the mechanical stability of rocks where different formations intersected. It wasn't until the 1990s that BP Exploration began using near-underbalanced drilling techniques in Colombia with the primary goal of drilling low-head wells. Later, many operator companies implemented managed pressure drilling (MPD) as a solution in several Colombian oil and gas pay zones to overcome operational issues such as fluid losses, differential sticking, hole stability, and influx events caused not only by the narrow margin operating window but also by high frictional pressure losses caused by increasingly complex wellbore geometries.

Years ago, these hole sections were drilled conventionally, but due to ongoing operational problems, influxes, and subsequent partial and/or total circulation losses, alternative techniques were required to reach section TD, mitigating these risks and events.

Unlike a few years ago, when the technology was considered cutting-edge, single and multi-phase MPD, as well as underbalanced drilling (UBD), are now widely used across almost all Colombian fields and have become industry standards. These techniques are successfully used around the world to overcome operational problems in high pressure, high temperature (HPHT), high pressure, low temperature (HPLT), and low pressure, high temperature (LPHT) wells in shallow and deep formation sections, delivering success by avoiding NPT and reaching planned TD.

Colombia, like other countries and regions, is currently in an MPD deployment stage that includes the use of state-of-the-art single and multi-phase MPD techniques, as well as UBD. This approach, when combined with dedicated engineering support, has increased safety and performance and, in some cases, enabled real-time formation evaluation through bottom hole pressure management with surface backpressure and nitrogen gas injection systems, among other suitable pressure control alternatives.

This paper summarizes the single and multi-phase MPD, as well as some UBD techniques, used on more than 200 complex and diverse hole sections in Colombian oil and gas basins for exploration and development. Gasified mud and concentric casing nitrogen injection drilling are two highly complex and specialized applications that will be also discussed.

Introduction

By the end of the 1990s, the number of "mature" or "depleted" land oilfields in Colombia began to rise dramatically across the Magdalena valley (upper, middle, and lower) basin, the Llanos basin, and southern Colombia. Well construction projects concentrated on many mature fields from northern Colombia to southern Colombia during the 2000s, with some exploration campaigns hampered by extremely complex reservoir situations. Low pressures, highly depleted intervals, narrow windows, and geomechanical challenges necessitated a significant change in drilling strategy.

Clearly, so-called conventional drilling was insufficient to reach the pay sections of these wells efficiently. As a result, major oil and gas operators used unconventional techniques such as UBD, and later MPD, to reach pay zones while minimizing formation damage in a wide range of depleted and mature fields.

The immediate success of a wide range of MPD and UBD applications was evident, and several fields were resurrected. This increased activity significantly, and UBD and MPD became required in a variety of fields.

MPD had been used on nearly every depleted and mature well drilled by Colombia's major operators by the mid-2000s. The discovery of new fields involving HPHT wells and complex geomechanical windows, on the other hand, brought with it a new set of challenges. The total number of NPT hours spent on well control, stuck pipe, and circulation losses had reached an all-time high. Such challenges for depleted and mature fields necessitated more than MPD and UBD. A very different approach was required for these newly discovered fields with high pressures, high temperatures, geomechanical instability, and complex geometries.

One obvious solution was MPD's continued success in depleted reservoirs. The majority of the area's service companies were asked to create feasibility analyses for several HP fields. All MPD service providers responded with a straightforward but powerful solution: proactive MPD.

MPD jobs designed to "navigate" narrow windows by managing annular pressure with specially designed mud weights and surface backpressure were able to respond quickly and safely to drilling events such as kicks and losses while minimizing the impact on drilling times.

Several trials were carried out in high-profile wells, and the technique proved to be effective and met client expectations. The technique reduced formation damage and generated significant savings in the aftermath of these wells' completion and cleanout processes.

In the second half of the 2000s, MPD for high-pressure wells and non-depleted reservoirs became common. It was widely used throughout Colombia, including oil and gas fields in the lower and middle Magdalena basins. The technique's systematic success was dependent on the use of more complex MPD systems such as automated chokes, early kick detection, and automated well control systems. Nitrogen injection was also becoming more common in low-pressure, high-angle wells. This paper describes the achievements made possible by MPD over a fantastic two decades.

Background

Colombian oil and gas wells face significant challenges due to changes in pressure profiles and downhole conditions. To meet established drilling and production goals, advanced techniques are required.

MPD and UBD are tried-and-true techniques for resolving various operational problems and reducing NPT in depleted and high-pressure wells. Conventional drilling techniques for these wells would demand extensive preliminary planning, consume excessive drilling time, increased costs, and, in some cases, result in a loss of final production.

Extensive research and comprehensive upfront planning have proven to be the key to successful drilling. Implementation of state-of-the-art technology and techniques can be a solution if the right people are involved. Through each phase of the project, effective management and the provision of a skilled team are required. It is essential to rely on proper engineering support and appropriate training for both the crew and office personnel involved in the project, (including the operator and drilling contractor personnel), Good communication is also required to ensure that that everyone on the rig site and in the office understands their roles and responsibilities.

MPD and UBD operations can be carried out safely if hazard and effects management process (HEMP) techniques such as hazard identification (HAZIP) and hazard operability (HAZOP) studies are included in the planning phase. Implementation must also include rig-site specific procedures, dedicated training, and emergency awareness preparation. The review and closeout phase must include a mechanism for capturing and sharing the project team's lessons learned for future and ongoing MPD or UBD operations.

The use of proper drilling fluid with the latest generation of downhole tools in combination with MPD and UBD techniques, the best operational drilling practices, and a multidisciplinary task team working closely with geosciences support all contribute to optimal performance in Colombia's highly complex geological environments. This has allowed for the drilling of over 200 wells while also resolving various problems across multiple basins and fields. Initially, the difficulties stemmed primarily from highly depleted reservoirs with hydrodynamically unstable formations. However, in more recent applications, the emphasis has been on preventing formation damage. As an example, several fields in the Magdalena valley basins (lower, middle, and upper) have produced positive results.

The 23 sedimentary basins are depicted in **Figure 1**, with the Guajira, Llanos, Magdalena Valley, and Putumayo basins producing the majority of the country's hydrocarbons.

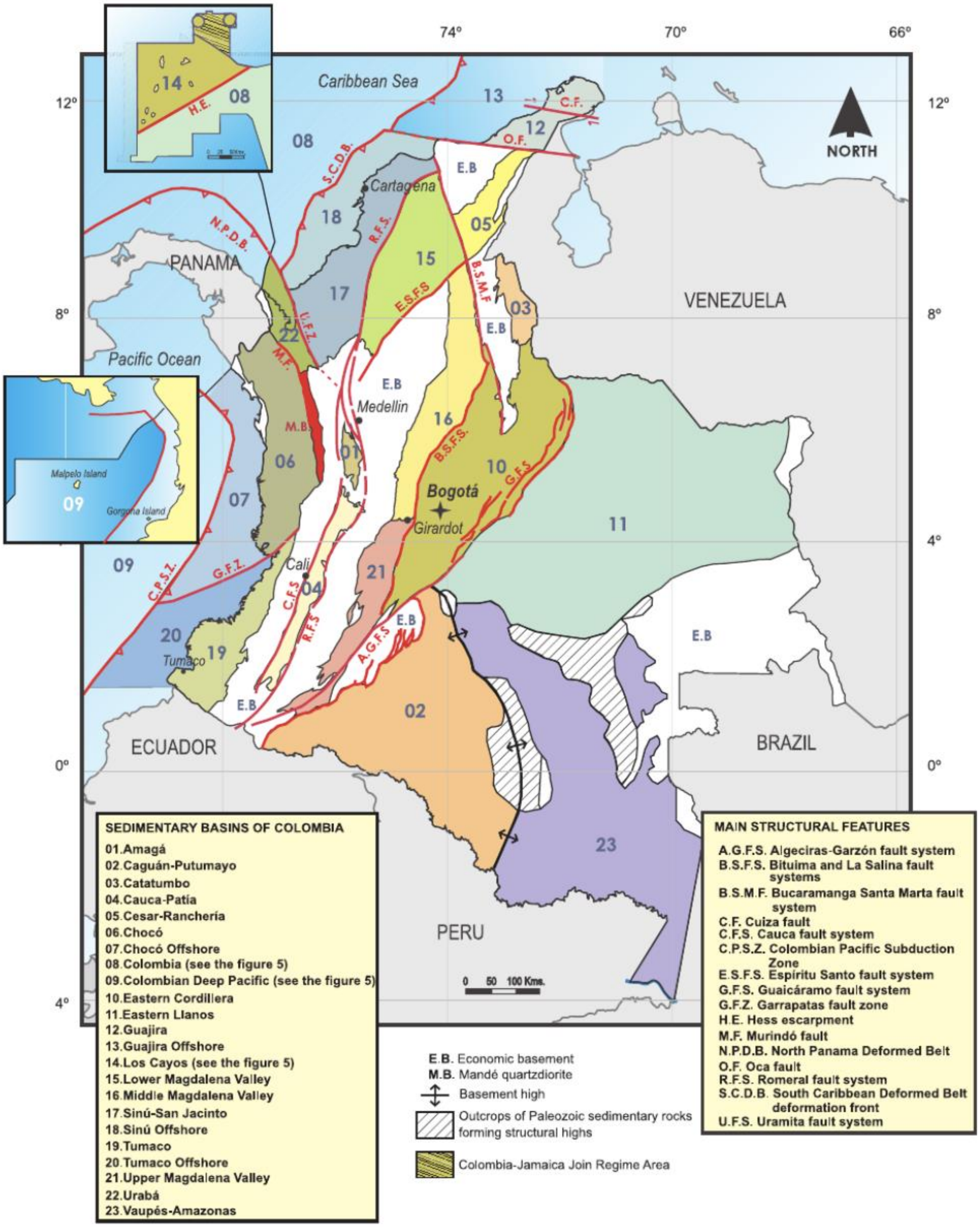

Figure 1. Colombia's Sedimentary Basins. Source: ANH.

MPD and UBD have been used pro-actively to solve complex scenarios caused by geological uncertainty and the use of high mud weight densities. Furthermore, these techniques have been used to drill sections with lower mud density, avoiding the risks associated with fracture pressure proximity. They have also enabled the crossing of several formations while keeping BHP below the weakest fracture gradient (FG) value to meet casing setting depth and pay zone targets while avoiding NPT, influxes, mud losses, and high potential risks.

Multi-phase MPD for Depleted Reservoirs

Colombian oil and gas wells face significant challenges due to changes in pressure profiles and downhole conditions. To meet established drilling and production goals, advanced techniques are required.

After many years of high production, reservoir pressure in Colombia's mature fields has decreased. Most of these fields' formation pressures have decreased from the original 8.4 -11 ppg to the current values of 2.5 - 4.5 ppg. Drilling conventionally across low reservoir pressure could only result in total loss conditions.

Multi-phase MPD and nitrogen injection through the drill string are currently being used to reduce pressure overbalance, which helps to reduce losses, differential sticking, and reservoir damage. The downhole tool performance at high nitrogen levels is a limitation of this technique. When more nitrogen is needed, less data transmission is obtained from the downhole tools.

As the use of directional wells became more common, downhole communication problems became a significant issue for trajectory control. Highly deviated and horizontal wells are required to maintain production levels above the predicted depletion. Signal boosters/intensifiers were installed in the BHA to address this issue, and directional drilling with RSS was used to control drilling tendencies. However, these were not viable options for high angle or horizontal wellbore placement.

Because of the need to develop these fields by drilling high angle/horizontal wells, various technologies, and techniques, such as electromagnetic pulse (EM), wired drill pipe, and concentric injection strings, were considered. These options were also limited. In some cases, the use of EM tools is restricted due to deep reservoirs or formation resistivity. Because gasified systems are hotter than fluid systems, wired drill pipe is temperature limited.

Globally, the concentric strings gas injection technique has been used after evaluating the fields' constraints and conditions (reservoir pressure, well profile and temperature). Various types of wells have been drilled using this technique, for example, in Mexico and the Middle East, and some are currently being planned for some wells in Colombia.

Despite the difficulties encountered with trajectory control and wellbore placement while drilling those types of wells with multi-phase MPD using drill-pipe nitrogen injection, the concentric string gas injection technique was analyzed as a solution for making the use of conventional mud pulse MWD/LWD tools feasible while keeping bottomhole circulating pressures within the operational window required to avoid circulation losses, ensure good hole cleaning, and control the risk of hole instability.

Concentric string nitrogen injection was designed to overcome the following problems:

1. **Directional tool premature failure due to pressure differentials and rubber swelling**
   Compressibility is one of the primary distinctions between liquid and gas (or dual phase gas/liquid) fluids. A small pressure changes in a compressible fluid, such as gas, can result in a large volume change. Most drill string components are unaffected by this, either because the pressure drop across the components is minimal or because the elements themselves are strong enough to withstand volume variations. Compressibility, on the other hand, has a significant effect on weaker elements, such as rubber mud motor stators with pressure differentials ranging from 200 to 2000 psi.

   The effective flow in (gas + liquid) can be calculated using the pressure drop in a mud motor, the volumes injected, the target pressures, and the temperatures. The flow-out value will be different. As the mud motor operates and the pressure differentials across it change, the effective flow difference changes constantly. The constant varying stresses on the rotor/stator accelerate wear and failure.

   Another effect commonly observed on drill string components is that nitrogen molecules, due to their small size, tend to move inside the pores of the rubber elements. As pressure is removed from the elements and the gas expands, this causes rubber to swell. At certain temperatures and pressures, nitrogen gas penetrates the motor stator elastomer. The nitrogen expands as the conditions change (short trips, reaming, etc.), causing the elastomer to chunk. **Figure 2** depicts the findings of an investigation into mud motor failures in drill string nitrogen injection operations in southern Mexico. **Figures 3** and **Figure 4** show a failed mud motor stator used in a nitrogen injection MPD application in wells in southern Mexico.

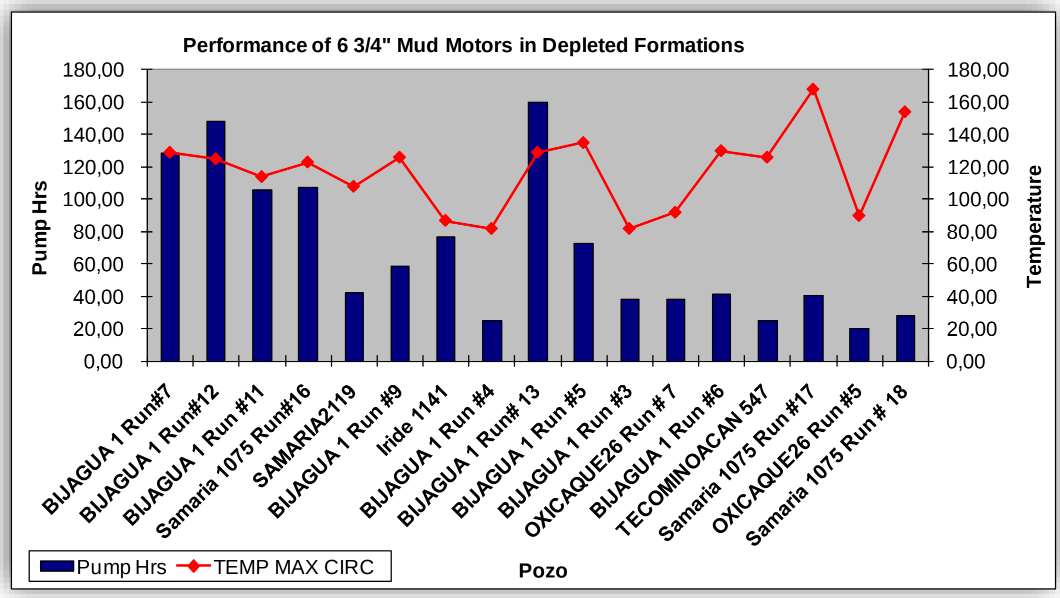

Figure 2. Mud motor failures in drill string nitrogen injection operations in south Mexico

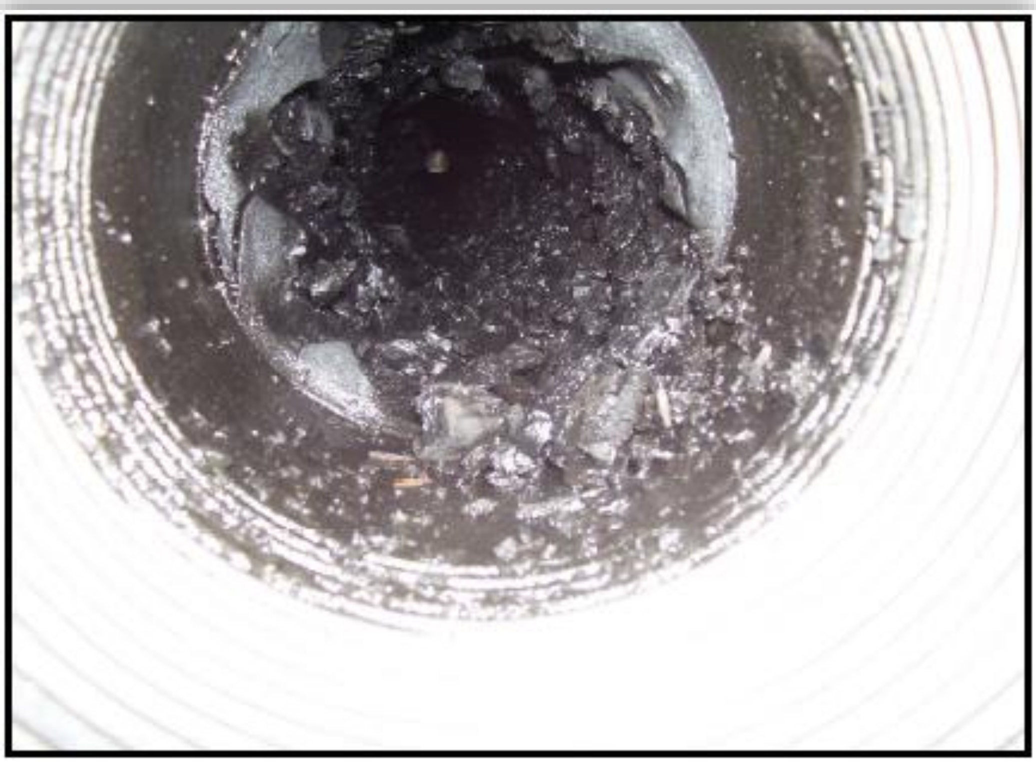

Figure 3. Failed mud motor stator which was used in a nitrogen injection MPD application in south Mexico

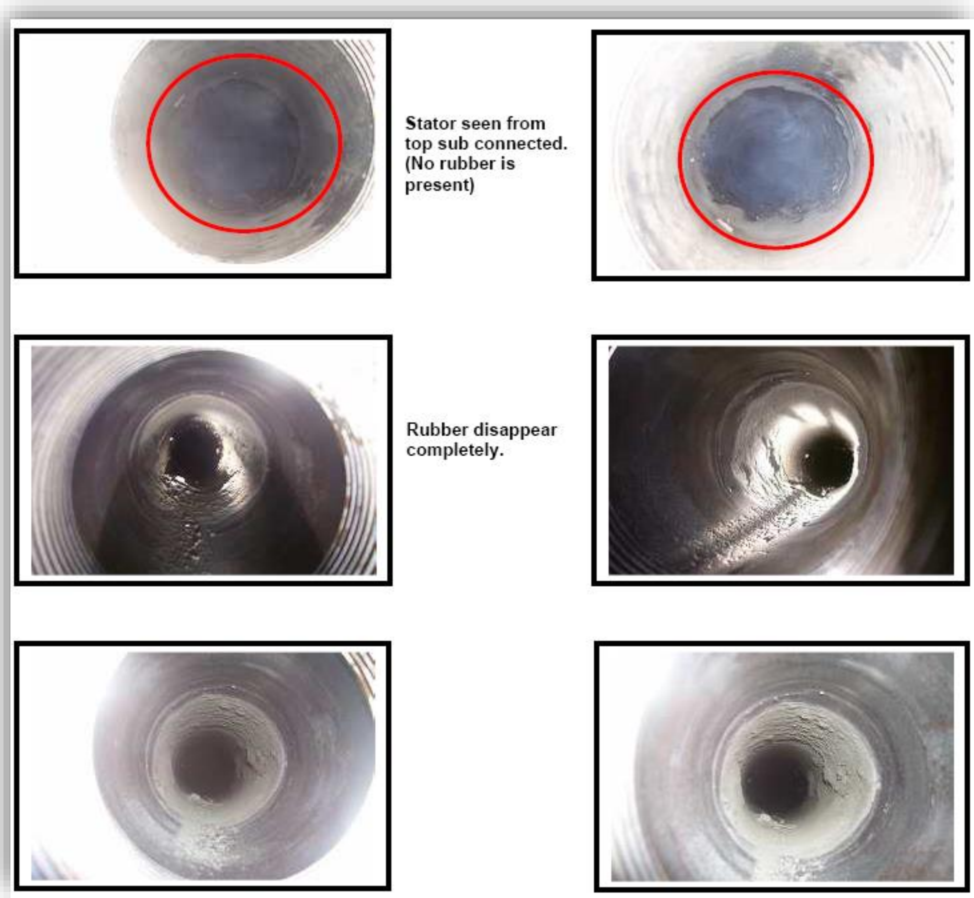

Figure 4. Chunked elastomer stator due to nitrogen injection

2. Directional tool signal losses due to nitrogen injection

The injected gas volume fraction in the drill string has a direct effect on the mud pulse telemetry of MWD/LWD tools, as is well known in the MPD industry. This effect becomes so strong that mud-pulse telemetry ceases to function at sufficiently high gas volume fractions.

When compared to single-phase liquid drilling fluids, the compressibility of the gas has the greatest impact on this issue. Because the gas bubbles inside the dual-phase fluids are compressible, they act as small dampeners, attenuating the signal pressure pulses.

According to some industry best practices, gas volume fractions of approximately 20% should be the maximum allowed for transmitting M/LWD tool information via mud pulses. However, there have been no formal studies on the subject to date, and some local studies show that with signal boosters, such values can be increased to more than 30%.

The phenomenon of MWD pressure pulse transmissibility in a two-phase flow is illustrated in **Figure 5**. Part A shows two-phase circulation down the drill string with MWD pressure pulses traveling through the fluid's continuous liquid phase. The MWD pressure pulse can transmit to the surface if the liquid phase is continuous (external phase surrounding the gaseous N2 phase). Part B shows how the MWD pressure pulse is blocked when the continuous liquid phase is removed and a distinct gas and liquid interface forms across the ID of the drill pipe from the two dissimilar fluids. The transmission of MWD signals is hampered by a distinct fluid interface. This scenario, depicted in Part B, occurs when the dual phase fluid's gas volume fraction is increased. This condition can be achieved by either lowering the system pressure (as when circulation is stopped during a connection or survey) or increasing the nitrogen injection rate so that nitrogen becomes the dominant fluid phase (nitrogen becomes the external phase surrounding the liquid phase).

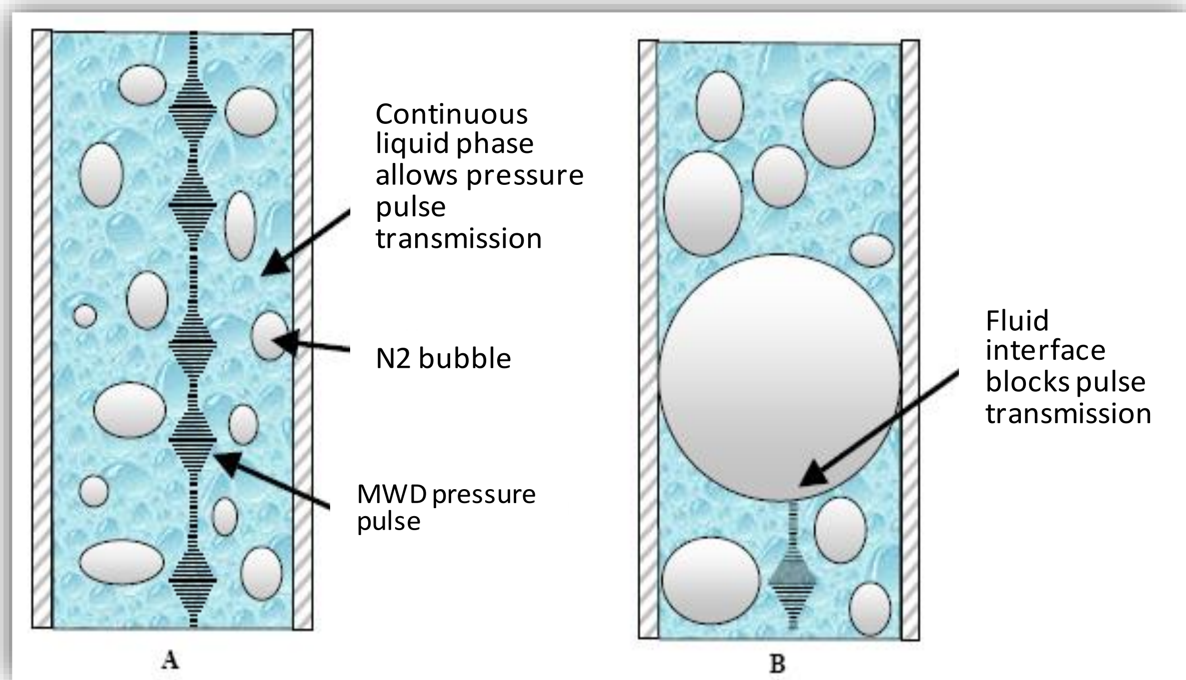

Figure 5. Effects of the nitrogen injection flow rates in the mud pulse data transmission quality

The effect of the gas/liquid ratio on signal quality is depicted in **Figure 6**. In this study, the highest gas/liquid percentages were discovered precisely where signal was lost (around 32%), and signal was restored after significantly lowering this percentage (to about 23%).

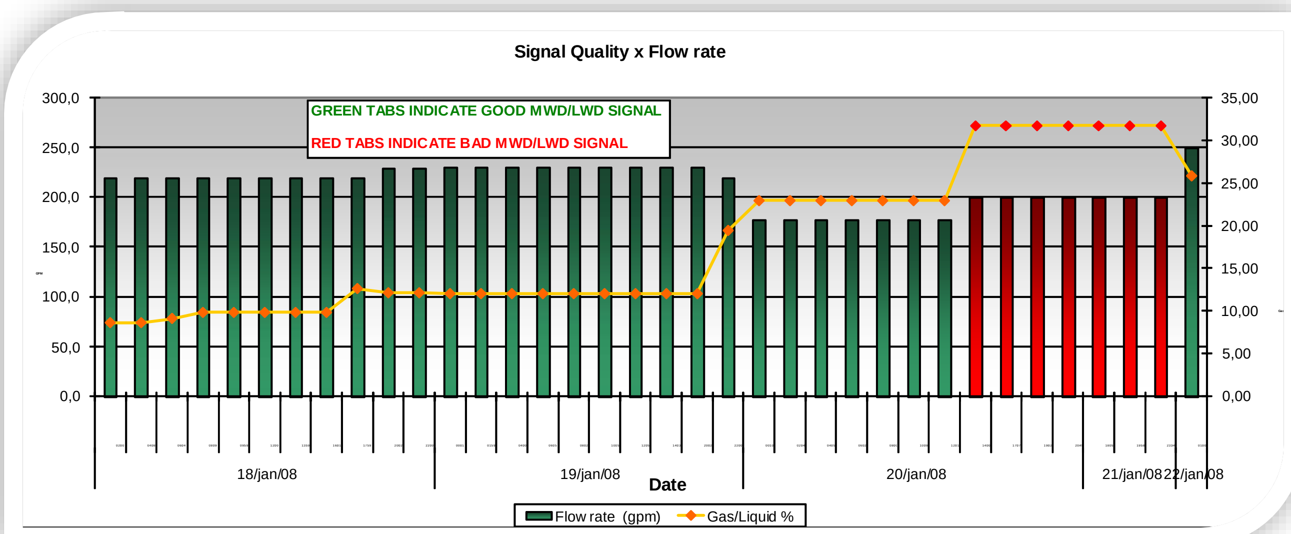

Figure 6. Effect of gas/liquid ratio on signal quality

Because of the nitrogen injection through the drill pipe, the telemetry is greatly attenuated. As a result, neither the directional nor formation evaluation data required for reservoir steering can be obtained while drilling.

3. The effects of temperature on downhole tools due to gas friction

Temperature affected the directional and M/LWD tools on several occasions when using drill pipe nitrogen injection MPD. This effect demonstrates a direct nonlinear relationship between the gas injection volumes and the tool's recorded temperature. This is due in part to the low heat conductivity values of the gas when compared to that of the fluid, resulting in a lower dissipation of the heat generated by the friction of the high velocity fluid molecules across the tools. The temperature effect is exacerbated as the nitrogen fraction increases, which has frequently resulted in tool failures.

In one case in southern Mexico, the large amount of nitrogen injection required to reduce BHP and avoid mud losses caused the annular temperature to quickly rise above 150 °C, increasing friction with drill pipe rotation. As a result, the tool's lithium battery exploded, severely damaging it. (See **Figure 7**).

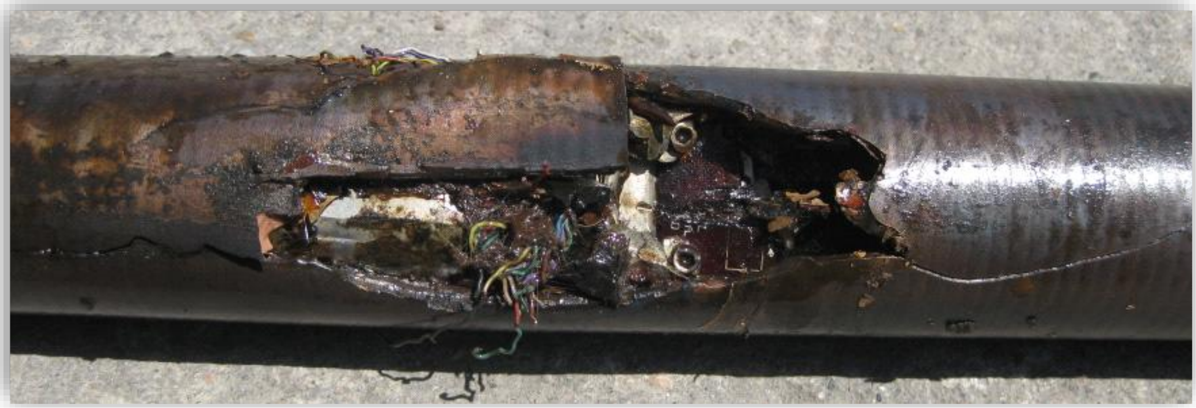

Figure 7. M/LWD lithium battery explosion due to the high temperature during nitrogen drill string injection

4. Hole cleaning

The amount of liquid injected down the drill string in any conventional dual-phase MPD application is less than that of a typical single-fluid drilling operation. The decrease in this liquid injection rate is primarily due to compensating for the additional gas volume injected as well as the additional pressure losses generated in the drill string due to gas friction as the gas expands and accelerates upwards in the well.

Two scenarios emerge because of gas expansion:

- Because gas is at its highest pressures near the bit hole, cleaning efficiency and solids transport are primarily controlled by liquid phase velocities and solids concentration.
- Gas expands and generates turbulence higher in the annulus, which help in the transport of cuttings and improves cleaning efficiency.

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The first condition (near the bit) causes hole cleaning issues that must be closely monitored, particularly since MPD aids help in obtaining higher ROPs. This condition is improved when using concentric string application because the well is circulated with higher liquid flow rates. When analyzing the second condition (higher in the annulus) in both conventional and concentric nitrogen injection applications, gas expansion helps with hole cleaning. However, with greater efficiency in the concentric string application, more liquid is available.

Furthermore, two empirical criteria are typically studied for hole cleaning analysis: annular liquid velocity and cuttings transport ratio (CTR). Despite the use of a biphasic fluid, hole cleaning relies solely on the liquid phase, so a minimum velocity of 55 m/min for vertical sections and 70 m/min for hole angles greater than 45° is required. If this condition cannot be met due to hole size (larger annular reduce annular velocity), the CTR criterion is used. CTR considers slip velocity to generate a unitless value ranging from 0 to 1. The recommended values for vertical and high angle/horizontal hole sections are 0.70 and 0.90, respectively.

The Solution for High-Angle/Horizontal, Deep and Depleted Reservoirs

In the concentric nitrogen injection technique, a temporary liner tieback is placed on top of the intermediate liner. Gas is pumped through the injection ports from the liner tieback micro annulus to the tieback-drill pipe annulus, and the well section is drilled through the reservoir. Figure 8 shows a typical well configuration for concentric casing nitrogen injection in deeper and mature fields in southern Mexico. When the concentric annulus is used to inject nitrogen, the well is virtually drilled like a conventional well, with only liquid going inside the drill pipe, eliminating the limitations of conventional pulse telemetry.

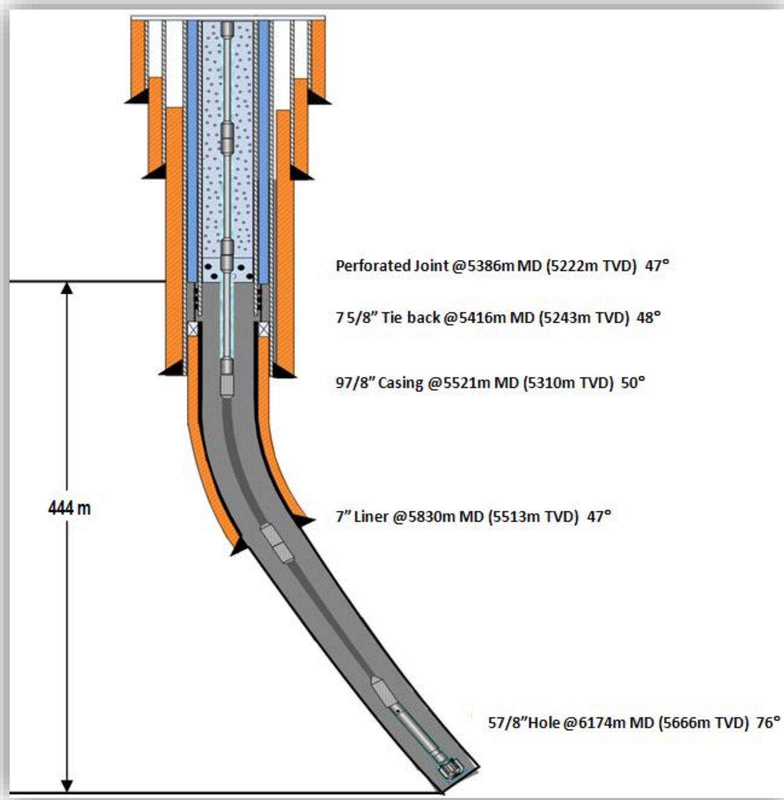


Figure 8. Well Configuration for Concentric String Nitrogen Injection in Mexico

The system is simple mechanically, but several factors must be considered when designing it: the depth (TVD) and deviation of the injection ports, the micro-annular for nitrogen pumping, the total flow area at the perforated joint, and the nitrogen volume required for the designed ECD. Additionally, the gas/liquid relationship into the primary annulus, the density of the liquid phase in the annulus, the critical nitrogen volume, and the choke manifold manipulation at the surface for required ECD must be outlined. These criteria are critical for achieving a stable system while pumping nitrogen through the concentric string and avoiding flow batching effects.

In a concentric string application, greater vertical distance between injection ports and total depth results in a smaller system pressure reduction. This concept is more easily understood when compared to a gas lift system, where the smaller the lightened fluid column, the smaller the bottomhole pressure reduction. This restricts the technique to wells with nitrogen injection ports near the total vertical depth of the well, i.e. high-angle or horizontal wells.

Due to the multi-phase characteristics of the injected fluids, which are rarely in steady-state condition, the ability to create and maintain near underbalanced/underbalanced conditions is complicated. This results in transient flow behavior and constant changes in bottomhole pressures. Attaining near underbalanced/underbalanced conditions in both conventional and concentric string MPD applications is dependent on several parameters, including fluid densities, flow in, well and drillstring geometries, and target bottomhole pressures. As shown in **Figure 9**, all of these parameters can be simulated together to generate an operating window.

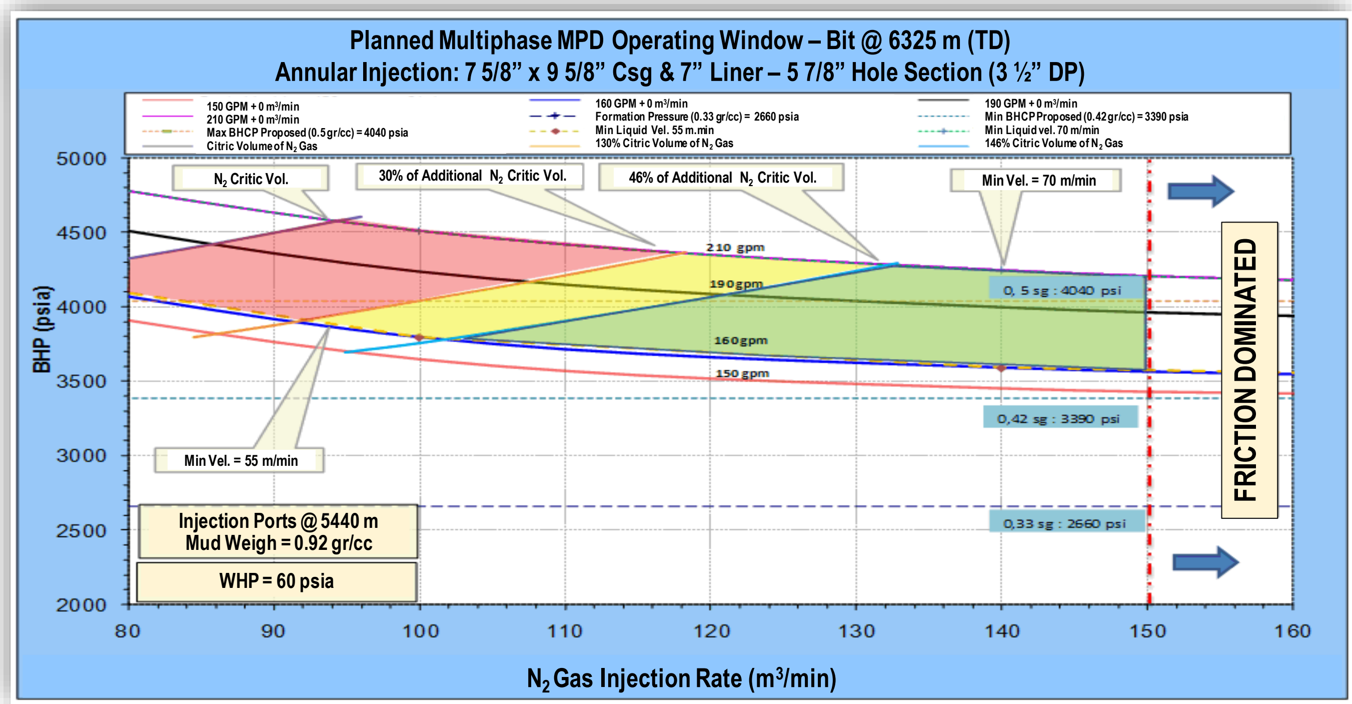
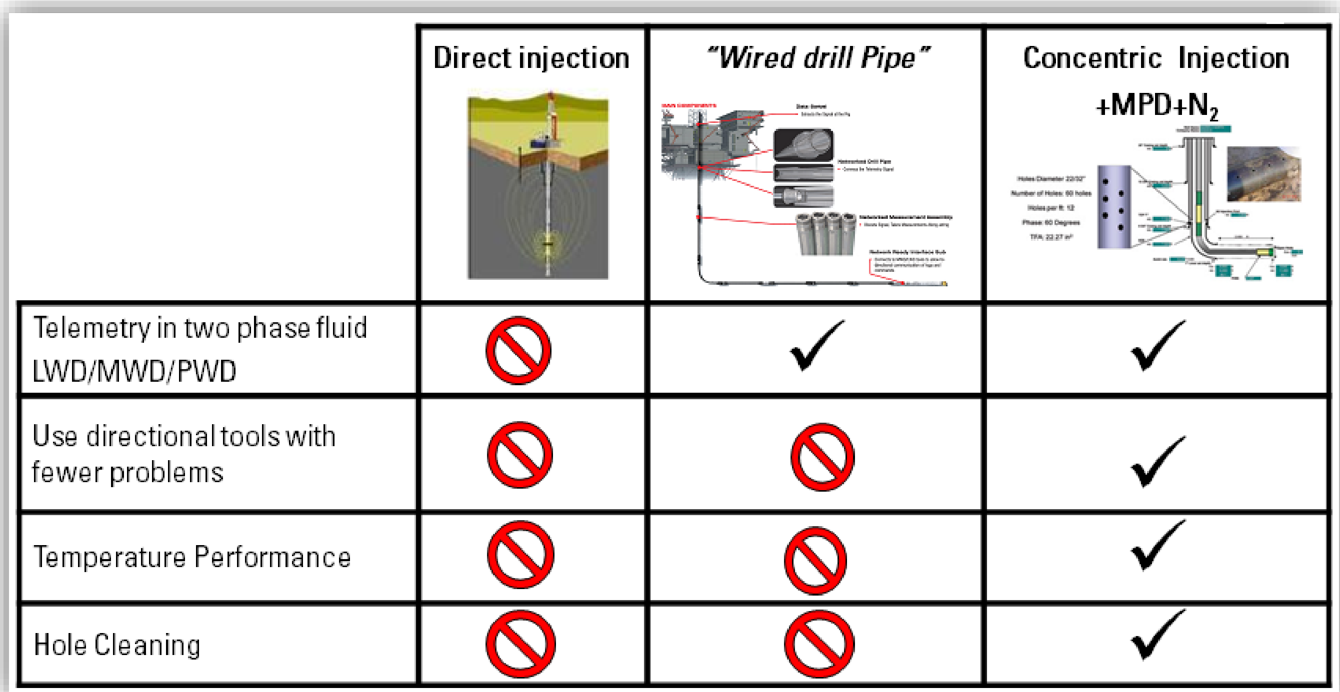


Figure 9. Typical planned Operational Multiphase MPD Window

Techniques that can be used in low pressure, high temperature (LPHT) wells:



	Direct injection	"Wired drill Pipe"	Concentric Injection +MPD+N_2
Telemetry in two phase fluid LWD/MWD/PWD	⊘	✓	✓
Use directional tools with fewer problems	⊘	⊘	✓
Temperature Performance	⊘	⊘	✓
Hole Cleaning	⊘	⊘	✓

Figure 10. Concentric injection comparison chart

Figure 10 shows three of the possible techniques that can be applied in low pressure, high temperature (LPHT) wells. The following are their respective advantages and disadvantages:

- The direct injection method has been used in wells with low nitrogen injection rates, particularly in tangent hole sections. However, risks have been taken in the hole cleaning process. Problems have arisen during pipe trips, necessitating the implementation of additional contingencies, such as drill pipe conveyed logging after drilling.
- Wire drill pipe has been used as a viable solution to preserve data transmission and enable downhole conditions to be measured, evaluated, and acted upon in real time. However, the use of WDP in most of the cases is limited by the temperature rating of the interface (150 °C), the drill pipe diameter, the open hole to be drilled, and the cost.
- • A concentric injection string is a casing design arrangement that uses a secondary annulus to inject gas into the primary annulus to reduce bottomhole pressure while pumping drilling fluid through the drill string. As illustrated in **Figure 10**, this method has more advantages because hole cleaning is improved. A single-phase fluid is pumped down the drill string, allowing for normal mud pulse telemetry and avoiding the harsh conditions of biphasic operations.

Single-phase MPD (manual and automated systems)

Drilling conventionally in formations with differential sticking, simultaneous gas influxes, and drilling fluid losses (narrow mud weight window) has historically been extremely difficult. So, using conventional drilling techniques here typically results in NPT due to the constant variation of mud density required to respond to influxes and losses.

MPD has been used to drill through the pay zone. The goal is to optimize the drilling process by reducing operational issues associated with the narrow mud weight window (loss of circulation, well control, and differential sticking) and increasing rig safety.

The single-phase MPD technique in these cases relied on maintaining constant bottom pressure throughout operation. This proactive MPD methodology is used to compensate for annular friction losses during connections or when the mud pump speed is reduced.

Drill string movement can be controlled in MPD dynamic well control scenarios for faster reaction time and a wider range of course of action options. When considering current well conditions, avoiding the need to stop, shut-in, and circulate the well can save a significant amount of rig time.

These well challenges in production hole sections necessitated the use of an automated choke system rather than a manual choke system. The use of such a technique added value to the client in terms of reduced formation damage, increased penetration rates, and early reservoir characterization. The use of an automated system also allows for a reduction in personnel and better control of surface and downhole parameters.

All automated MPD benefits (dynamic FITs, dynamic flow checks, and CBHP control) have been used in very narrow mud weight window applications to detect and control kicks, identify, and control ballooning effects, and maintain bottomhole pressure within the high-pressure narrow window. Proper hydraulics simulation selection, configuration, and continuous calibration during drilling operations have been critical to drilling the production sections and successfully reaching target depths (See **Figure 11**).

Single-phase MPD (operational challenges)

Some key observations were made after gathering information and studying data from several wells in Colombia:

- Very narrow mud weight window
- Fluid losses and influxes causing continuous well control events
- Formation pressure uncertainties (inaccurate estimations)
- Poor decisions in a crossflow scenario (procedures either incorrect or not descriptive enough)
- Influxes
- Continuous well control events
- Ballooning effect

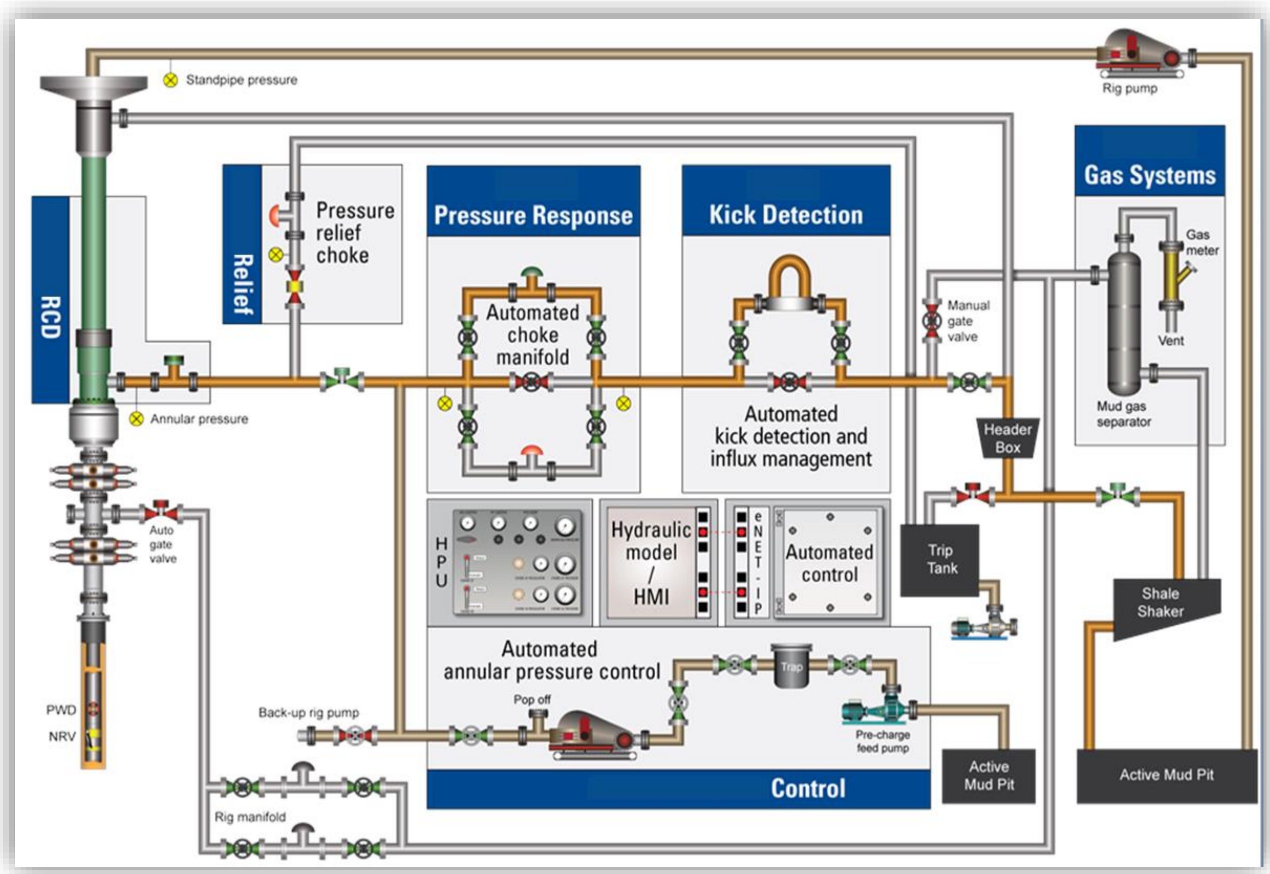


Figure 11. Typical automated MPD system configuration.   Source: ANH.

Single-phase MPD (operational risks)

Original risks identified included

- Mud contamination (fluid from formation)
- Differential sticking
- High potential risk in conventional well control
- Surface equipment pressure limitations
- Unavailable formation stability data

Single-phase MPD objectives

Combining advanced technology with wellsite engineering support, the objectives identified for employing the MPD techniques included:

- Increase the safety of personnel and equipment using a closed loop control system
- Perform a controlled formation pressure test using the MPD choke
- Reduce fluid losses and well control events
- Avoid unnecessary changes in mud density
- Minimize NPT and therefore reduce operating costs
- Facilitate the production of hydrocarbons by reducing formation damage

Single-phase MPD strategy

Each application has a decision flowchart that addresses operational issues as well as the risks associated with MPD operations. Using the appropriate process, any unexpected influx during the operation can be safely controlled. The ability of MPD to dynamically affect and control annular pressures makes it easier to detect and control potential influxes during drilling or circulation without having to stop operations, minimizing risks while also providing the opportunity to act quickly, reducing NPT associated with unpredicted pressure variations.

The MPD strategy proposed in several wells has been to drill with mud densities lower than those used in conventional drilling while maintaining surface backpressure (SBP). To maintain a constant bottomhole pressure, additional backpressure would be applied during connections. Applying backpressure while drilling would allow for an immediate response to even the smallest mud loss event, as surface backpressure could be immediately reduced to stop the losses. On the other hand, at the first sign of detected influx, the surface backpressure could be increased to increase the bottomhole pressure (BHP) and prevent formation fluids from entering the well. The MPD system's level of automation allows for a quick and timely response to any abnormal pressure that may be detectedw hile drilling the well.

It is critical to recognize and respond to ballooning properly in any well with a small margin between formation and fracture pressures. If the mud density increases due to a misinterpretation of ballooning, the situation will be exacerbated by increasing the ECD, which could lead to formation fracturing.

Single-phase MPD Well Control and Tripping Strategy

MPD must be used not only during the drilling phase, but also for tripping and other operations such as logging, cementing, liner trips, and casing running.

Because each MPD operation is application-specific, no single tripping procedure is suitable for all circumstances. During the planning process, engineers should discuss and agree on the tripping procedure. MPD saves NPT, casing strings, and drilling fluid, but if the drill string trip is not performed correctly, the entire job may be lost.

Well control is critical. To compensate for the drill string’s effective volume being removed during tripping, the annulus must be topped up. Backpressure is applied to compensate for the lack of annular friction pressure until the margin reaches the drilling plan's limits. High casing pressures can shorten the life of the RCD seal element when stripping in or out of the hole. At some point, it may be advisable to spot a weighted, high-viscosity pill to statically control the well. The pill can be circulated out during the trip in the hole.

Single-phase MPD Benefits and Lessons Learned

MPD must be used not only during the drilling phase, but also for tripping and other operations such as logging, cementing, liner trips, and casing running.

- Proper planning, risk assessment to identify potential high-risk problems, quality equipment, and experienced personnel are critical to success.
- One of the most remarkable benefits of the use of the MPD technique in Mexico has been the minimization of NPT while drilling related to formation influxes during connections and tripping. Also, no differential sticking, and mud loss mitigation have been experienced.
- MPD has increased safety for the rig site with its H2S bearing reservoirs and by having a closed circulation system at surface.
- Reduction in well control events
- Real knowledge of the formation pressure in most of the fields
- The performance of the automated MPD system has allowed effective control of the desired backpressure by reducing significant variations on bottomhole pressure
- Personnel exposure time at high pressures has been reduced with the system's remote control
- The MPD system allowed tripping to the bottomhole and pulling out to the surface while reducing the possibility of losses and influx events
- Conventional MPD techniques provide the best options to drill sections with very narrow mud weight window, but crossflow environments may be better managed by correctly using options like automated MPD systems.

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Nomenclature

BHA	=	Bottomhole Assembly
BHP	=	Bottomhole Pressure
CBHP	=	Constant Bottomhole Pressure
CTR	=	Cuttings Transport Ratio
DPM	=	Dynamic Pressure Management
ECD	=	Equivalent Circulating Density
ESD	=	Equivalent Static Density
FG	=	Fracture Gradient
FIT	=	Formation Integrity Test
HAZIP	=	Hazard Identification
HAZOP	=	Hazard and Operability
HEMP	=	Hazard and Effects Management Process
HPHT	=	High Pressure / High Temperature
HPLT	=	High Pressure / Low Temperature
LPHT	=	Low Pressure / High Temperature
LWD	=	Logging While Drilling
MPD	=	Managed Pressure Drilling
MWD	=	Measuring While Drilling
NPT	=	Non-Productive Time
N_2	=	Nitrogen
PI	=	Productivity Index
RCD	=	Rotating Control Device
ROP	=	Rate of Penetration
SBP	=	Surface Backpressure
TD	=	Total Depth
TVD	=	True Vertical Depth
UBD	=	Underbalanced Drilling
VNMWW	=	Very Narrow Mud Weight Window

English System Conversion Factors

1 g/cm^3	= 8.33 ppg
1 m	= 3.28 ft
1 m^3	= 35.315