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Changing the MPD Game on Land – a Unique Solution to Further Advance Unconventional Drilling Performance Improvement

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Abstract

Managed Pressure Drilling (MPD) is an adaptive process used to more precisely control the annular pressure profile throughout the wellbore while drilling. Converting conventional atmospheric drilling to a closed-loop circulating system enables the driller to optimize mud weight (MW) and ROP, more quickly detect influx and fluid loss, and discriminate wellbore ballooning and breathing, resulting in lower mud product cost, less stuck pipe, and potentially fewer casing strings. The process is executed by controlling flow conditions to maintain bottom-hole pressure according to a modeled pore pressure and fracture gradient drilling window. While the benefits of conventional MPD techniques are well known offshore, the economics of engineering, mobilization and rig up, and additional specialized personnel requirements are not supported in cost sensitive drilling programs such as unconventional land drilling.

Drilling contractor ownership of fit-for-purpose MPD equipment and services enable new concepts to leverage today's advanced land rig infrastructure including drives, manifolds, tanks, pumps, and gas-handling equipment. Engineering and integrating MPD capabilities into the rig with unique new workflows unlocks advantages in capital requirements, elimination of pre-job surveys and engineering, high mobilization and rig-up cost, and automation of tasks. The result is lower onboard personnel exposure and cost, reduced pad footprint, more efficient rig moves, and more transparent performance analytics. Scalability across a common rig platform, managed by the rig contractor, is now possible—thereby increasing cost-effective access to this technology for land operations.

This paper discusses the MPD-READY rig concept, technique, and performance examples achieved recently in US land resource plays.

Introduction

From start to finish, the oil and gas industry is primarily governed by the utilization and control of pressures, both manmade and naturally occurring. Managing pressure via direct and indirect application is an inescapable necessity at the forefront of drilling processes and contributes to the performance of operations, whether beneficially or adversely. Unexpected pressure-related events are among the costliest and most detrimental elements of drilling wells, but it is becoming more common in today's industry to utilize unique methods and technology in order to combat the likelihood of such occurrences. One of these methods is Managed Pressure Drilling (MPD).

Conventional drilling can be defined as Overbalanced Drilling (OBD), which relies on preventing formation fluids (whether liquid or gas) from entering the wellbore by maintaining hydrostatic pressure in the annulus greater than that of the pressure of the fluids encapsulated by underground formations, known as the pore pressure. While drilling fluid is circulated down the drillstring and up the annulus, the pressure inside the wellbore is greater than while static. This dynamic pressure increase, referred to as equivalent circulating density (ECD), is ideally less than the fracture pressure necessary to break underground rock and allow wellbore fluids to flow into formations. The margin in between these two limits is commonly called the Drilling Window.

Overbalanced drilling has been the traditional method with which to drill for over a hundred years, but has many disadvantages and limitations. Increasing the drilling fluid density may be necessary for hydrostatic pressure to be greater than pore pressure, but once ECD has met the limit of fracture pressure then the range of the drilling window has been exhausted and new approaches must be taken in order to drill deeper, the most common being running a casing string. Casing strings not only increase the cost of the drilling project but also limit the drilling window in deeper sections because reducing the diameter of the wellbore increases the frictional pressure loss of dynamic flow up the annulus—increasing ECD and repeating the dilemma. Multiple casing strings limiting the diameter of the wellbore similarly restricts the ability of the reservoir to produce hydrocarbons after production has begun, reducing the economic value of the well.

An elevated fracture pressure does not resolve all drawbacks of overbalanced drilling, however, as overbalanced drilling fluids invade and damage formations by depositing solids in pore spaces. Furthermore, the pressure fluctuations between dynamic and static conditions loosen the cementing material of formation rock, creating unconsolidated particulates that impair permeability. Both contribute to lowering the ultimate recovery from the well but are relatively unavoidable with this drilling technique.

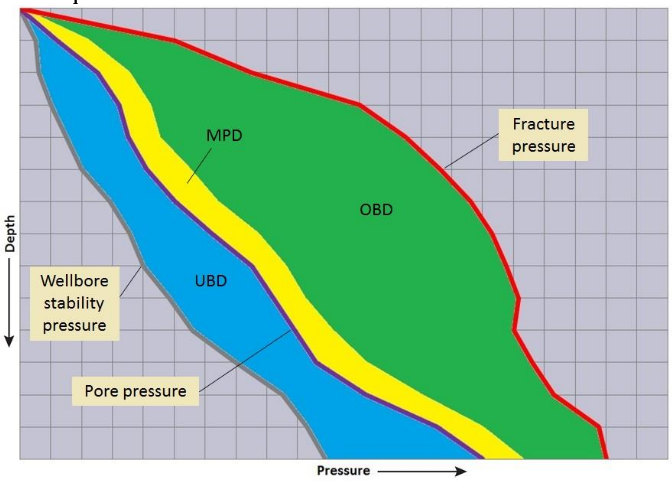

Figure 1 - *An illustration of the Drilling Window concept and various methods of drilling.*

The ability to manage downhole pressure with only mud rheology, circulating rates, and drillstring mechanics increases the risk of stuck pipe events, whether differential or otherwise, and efforts to recover from these scenarios may prove costly or even impossible. Horizontal drilling also proves troublesome for pressure management as the drilling window at the beginning of the horizontal section is the same at the total depth (TD) of the well yet the annular pressure is always greater at TD, which can limit the ability to drill further into the reservoir.

If the difficulties of OBD are met with reducing bottomhole pressure (BHP) then controlling influxes can become a new challenge. Well control is arguably the most critical operation of any drilling project and can easily become the costliest. Treading at or below the lower side of the drilling window can prove dangerous with well control and wellbore instability problems. Considering all of the aforementioned and today's industry ambitions, the need for directly controlling downhole pressures is more prominent.

By definition, Managed Pressure Drilling is 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. This is traditionally achieved by replacing the uppermost section of the conventional annular pressure/returns managing system (e.g. a BOP and a bell nipple, respectively), which is open to atmosphere, with a Rotating Control Device (RCD) that seals the annulus of the well against the drillstring and allows pressure to be applied from surface to bottomhole. The fluids returning from the well are then diverted to a MPD manifold equipped with some fashion of a choke system, allowing fluid flow to be deliberately constrained and forcing a controllable pressure differential back into the well.

The MPD service provider is traditionally hired by the Operating Company and separate from the Drilling Contractor. The MPD equipment requires time, labor, and space to install to the rig and well-trained personnel to manage the system. Complex hydraulics models are utilized to engineer the proper pressures to hold during drilling operations and constant coordination between the MPD service provider and drilling personnel is required at all time in order to be successful.

While solving many conventional challenges with OBD, contracting a third party MPD provider may incur new challenges to the project including coordination of efforts for operations, time and labor associated with rigging down/up equipment for rig moves, complexity of communication between all stakeholders of the project, and overall cost which may not be supported in cost-sensitive drilling programs such as unconventional land drilling.

Drilling contractor ownership of fit-for-purpose MPD equipment and services enable new concepts to leverage today's advanced land rig infrastructure including drives, manifolds, tanks, pumps, and gas-handling equipment. Engineering and integrating MPD capabilities into the rig with unique new workflows unlocks advantages in capital requirements, elimination of pre-job surveys and engineering, high mobilization and rig-up cost, and automation of tasks. The result is lower onboard personnel exposure and cost, reduced pad footprint, more efficient rig moves, and more transparent performance analytics. Scalability across a common rig platform, managed by the rig contractor, is now possible—thereby increasing cost-effective access to this technology for land operations.

Managed Pressure Drilling
MPD Call Out vs MPD-READY Land Experience Highlights

Features	MPD-READY Rig	Traditional MPD Call Out
Equipment Transportation	✓ Equipment permanently installed **Cost Optimization**	✗ Frequent Installation **Freight Charges + mark up**
Rig Survey and Readiness	✓ Engineered Plan Ready **Cost Optimization**	✗ Rig visit / P&ID / X-overs / Reports **Additional Effort and Costs**
Single Source Provider	✓ Existing Organizational Structure **Daily Basis at Rig Site**	~ Different Organizational Structure **Sporadic Rig Visit**
Safety Management System	✓ Unified Well Control Policy **Risk Mitigation**	~ Separate Well Control Policy **Additional Coordination Required**
MPD equipment Installation	✓ Rig Floor Level **Fast Rig Skids**	✗ Ground Level **Additional Timeline for Installation**
MPD Software and Controls	✓ Driller Chair HMI **Rig-Integrated**	✗ Independent HMI **Limited Information to Driller**
Visible MPD Data	✓ Sensors and Calculations Output **Via Rig DAQ System**	~ No Transparency on MPD Data **Limited Info Shared to Rig DAQ**
KPI's	✓ Visible Equipment Performance **Equipment Condition Monitoring**	✗ Not visible **Not Offered**
R&M	✓ At Rig Site **Cost Optimization**	~ Non Rig Site **Additional Charge**
Unmanned MPD Crew	✓ Proper Tools Development **Rig Integration/Automation**	~ Independent System **Non-Rig Integrated**

Figure 2 - *High-level differentiators between MPD-READY rigs and traditional MPD call out services.*

MPD-READY Rig Improvements

Equipment Integration

There are several components necessary to have a capable MPD system including a choke manifold and control system, RCD, and mud-gas separator (MGS). How these components are installed into the rig need to account for ingress and egress of areas, rig walking and skidding schedules and paths, hazardous area classifications, lineup capabilities, rig crew interactions, feasibility of effective operating, and many more other items to consider. Even the different components, such as the RCD and MPD manifold and control system, may come from different service providers and although both directly affect the performance of the other, not to mention the drilling project as a whole, lack of ownership and cooperation between the service providers may prove detrimental to operations. For the Operator's project management, doing business with multiple companies in order to provide the same service may prove cumbersome with time, cost, and communication as well. Even for just these reasons alone, there are many tangible benefits to integrating the entire MPD system to the drilling contractor's rig as opposed to simple installation to existing components.

For traditional MPD installation, returning fluids need to be directed to the MPD manifold rather than the conventional flow line. In order to achieve this, either existing unused conduits must be occupied by the MPD service provider or existing lines must be reconfigured to flow to the MPD manifold while also considering higher pressure requirements of surface piping. With rig contractor ownership and integration, however, the contractor's engineering department can specifically plan ahead and design the optimal way to incorporate the MPD functionality with the existing flow paths. Teeing off the RCD with two hydraulically actuated gate valves not only allows for utilization of conventional drilling flow lines and MPD use remotely with the toggling of a lever, but also minimizes the risk of injury by negating the need to locally manipulate valves on top of the BOP stack. The 5,000 psi rated gate valves fortify the integrity of well control abilities by providing an additional, reliable high pressure seal and with proper engineering from the contractor can remain installed for the remainder of the rig's contract as the BOP handling system can effectively move from well to well without rig down and rig up, saving many hours of non-productive time (NPT).

By efficiently utilizing the RCD with the MPD system, this leaves additional annular conduits at the disposal of operations. Teeing off the kill line with double barrier well integrity and high pressure pipe into the 2" inlet of the RCD provides additional lineup capabilities as well that can be utilized for surface MPD operations without the need of an auxiliary pump. Utilizing the rig's existing mud pumps and the MPD's 2" equalization line, MPD-READY rigs now have the ease and capability to flow across the wellhead with the rig mud pumps for stripping operations with surface backpressure (SBP), annular sealing component equalization in the event of a shut in well, changing out the RCD bearing assembly while maintaining surface pressure on the well, and manipulating SBP even with the top drive disconnected from the drillstring. Providers of the MPD service, RCD components, and rig mud pumps all residing under the same entity foster operational coordination and communication amidst several simultaneous processes.

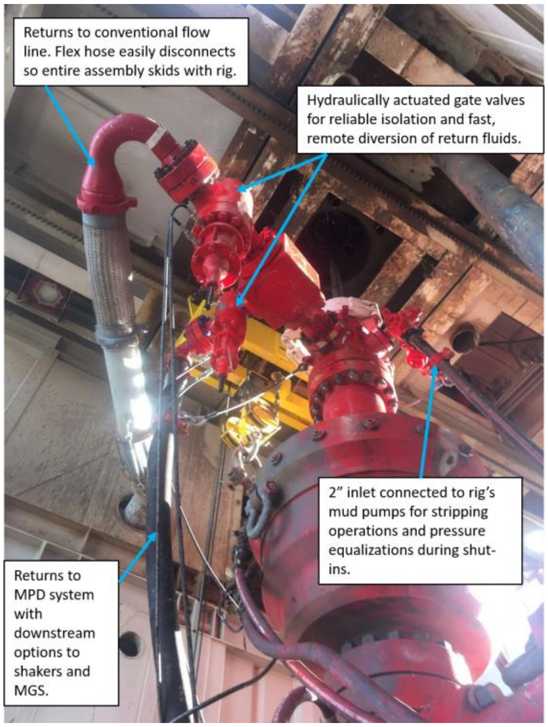

Figure 3 - *RCD integration to the BOP stack where hydraulically-actuated gate valves are used to divert fluid to either the conventional flow line or MPD system. The flex hose easily disconnects from the flow line and the entire system walks with the rig as it is without the need for additional rig down/up. Also installed is a 2 inch inlet to flow at surface with the rig's mud pumps for multiple operations such as stripping with SBP and pressure equalization for dynamic bearing assembly change-outs.*

Downstream capabilities are also significant factors to consider with operations. By integrating the MPD hardware to the rig, it is possible to utilize each flow path the rig has to offer with the actuation of a valve. These paths include directing return fluids from the flow line to the shakers, from the flow line to the MGS, from the MPD manifold to the shakers, or the MPD manifold to the MGS. All flare and panic line components remain functional per standard operations and each system component is able to be isolated.

Integration of all hardware components via the engineering department of the drilling contractor also yields additional benefits such as saving time by eliminating the need for rig down and rig up between rig moves, easy-access to all pieces of equipment while maintaining a clean installation and low footprint, and reducing hardware and piping needed to install the MPD system. MPD-READY rigs validate the concept of "plug and play" such that the system is designed to work perfectly with that specific rig upon installation without reconfiguration or user-intervention. Drilling Contractor engineering the assimilation of the MPD system into their own rigs yields planned, customized integrations.

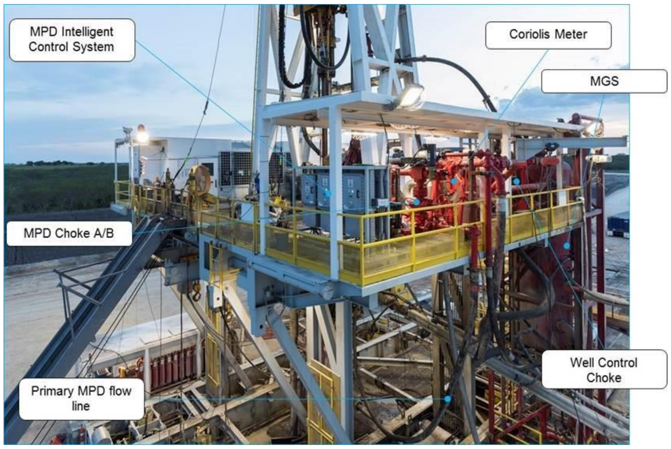

Figure 4 - *The MPD manifold, Coriolis meter, well control choke, and MGS integrated to the rig floor is easily accessible by the rig crew for lineups and maintenance. System acts as a "walking manifold" with no additional rig down/up needed while the rig is moving from well to well.*

Integration with Modern Rig Sensor Technology

A substantial drawback of non-integrated MPD service includes partial utilization of existing rig sensors or the need to redundantly measure system components in order to provide service. With the advancement of rig technology and data acquisition in the modern industry, real-time data sharing is possible both locally and remotely, benefiting on-location operations as well as remote engineering and transparency of service quality.

Drilling contractor ownership of the MPD system facilitates new capabilities of both the rig and MPD system by tethering component sensor data sharing and communication. Although Wellsite Information Transfer Specification (WITS) is recognized by a number of companies internationally and is supported by many hardware devices and software applications as a method of simple data transfer, Transmission Control Protocol / Internet Protocol (TCP/IP) is a more robust and reliable solution with many more capabilities but is normally restricted to solely intracompany use for security reasons. With drilling contractor ownership of the MPD system, all rig data and auxiliary MPD sensor data can be shared reciprocally through the use of a single, commonly-familiar Ethernet cord. This allows for the MPD control system to not only measure flow out with its flow meter but also receive flow in from the rig – from which the rig can calibrate its pumps' efficiencies. Trend data from pit volume totalizer (PVT) systems can be displayed for the MPD operator while choke positions and SBP can be trended for the driller. Working side-by-side, both personnel can coordinate their actions together and proficiently plan actions simultaneously, resulting in more competent drilling operations.

Figure 5 - *With Drilling Contractor ownership of MPD, all enunciators are channeled through the same data-acquisition system, allowing for full visibility of all rig states and unified operational monitoring and analysis.*

Channeling the MPD information through the drilling contractor's data acquisition system also proves beneficial for the operator as a single system with which to monitor, analyze, and export data is thus consolidated. All personnel at the rig site and at remote operations centers have real-time access and visibility to all aspects of the drilling operation and can easily customize his/her configuration of data in order to personalize the preferred method of operational monitoring. Even differing types of mutually exclusive meters measuring redundant elements of the operation can be compared for sensibility of drilling conditions and early diagnosing of adverse scenarios. Historical data is pre-collated for convenient interpretation and multi-well analysis, aiding the operator in optimizing future well plans.

Enhanced Personnel Training and Improved Intercompany Relations

Cooperation between multiple entities can often be a struggle in the oil and gas industry for multiple reasons including physical proximity limitations, lack of intercompany solidarity, and many others. Drilling contractor ownership of fit-for-purpose MPD solutions curtails these issues by uniting ownership of both the rig components and the MPD system under the same colors. This is highly beneficial for not only coordination efforts, but also for training purposes.

As automation progresses and drilling processes are further adapted to cover multiple functions, so will the rig crew as time advances. The rig crew of the future is meticulously trained and technically savvy enough to perform complex operations successfully, however, modern-day operations are commonly fractioned between service providers and drilling contractor, limiting the exposure and knowledge-absorption of the rig crew to drilling methods and techniques outside of their everyday scope. Expanding the rig crew's understanding of the concepts, physics, and logistics of all aspects in drilling a well develops them to become better drillers and promotes safer, more efficient operations. Partnering together the MPD-trained staff and the rig crew inside a single organization with a competency assessment management schedule and training systems in place accelerates the cross-training of all personnel.

As technology continues to evolve and more functions of a drilling rig become automated, it stands to reason that the rig crew must also develop and adapt. An organization's ability to learn and translate that learning into action rapidly is the ultimate competitive advantage. Optimizing rig personnel management via both avenues lowers cost and mitigates risk to injury, improving the bottom lines of all companies involved.

Integration Advantages with Modern Day MPD

Technological innovations and advancements often take leaps in the oil industry, refining processes already implemented and unlocking the ability to perform new techniques.

Electrically actuated servomotor chokes enable superb speed and control capabilities of MPD systems while Coriolis meters provide top-tier flow measuring accuracy, allowing for more precise control of downhole pressure and the drilling of narrow pore-fracture gradient windows by not only measuring return fluid density and flow rates, but also giving early indication of mass flow discrepancies in gallons rather than barrels.

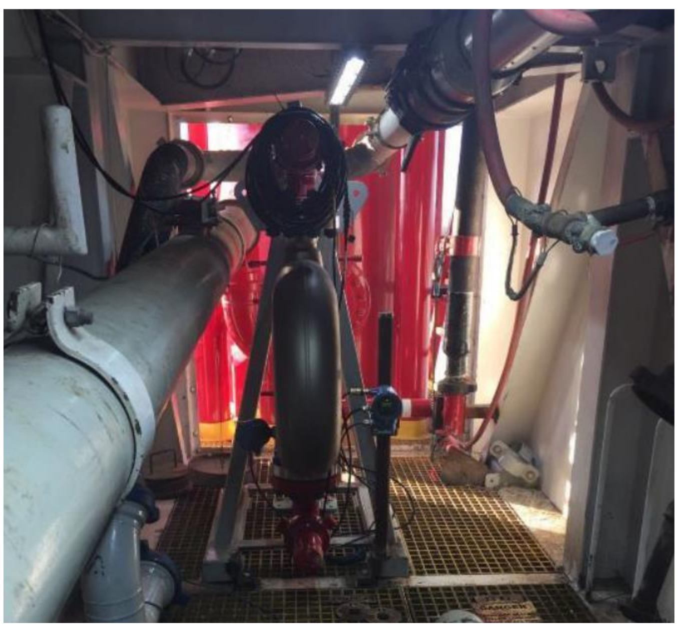

Figure 6 - *An alternate configuration for an MPD-READY rig is having the Coriolis meter installed to the sub flow box to minimize footprint and the amount of piping needed to integrate to the rig. This also benefits rig moves as it reduces the amount of loads that need to be transported from well to well.*

Advanced software coding is able to harness this newer and more powerful equipment in order to optimize the way we are drilling today. With MPD integrated to the drilling contractor's rig, rigs will be outfitted with the ability to perform dynamic pore pressure tests, FIT's, LOT's, and general reservoir characterization.

MPD-READY Case Study Results

Wyoming MPD-READY Rig Drilling

After successful introductions of MPD-READY rigs in the Permian Basin (west Texas) and Eagle Ford (south Texas) with performance and benefits clearly identified, the same approach was implemented in a Wyoming field with narrow drilling windows and several complexities. Typical conventional drilling challenges in this field included full loss of returns, well control situations, stuck pipe, expensive sidetracks, excessive torque and drag, and not being able to run casing to bottom. Increasing MW to maintain overbalanced conditions results in a loss of all returns, which proves costly when oil-based mud (OBM) is utilized to reduce torque and drag. Not increasing MW, however, increases the risk of repeated well control incidents.

The strategy for these wells when implementing MPD was to utilize mud densities that were consistently hydrostatically underbalanced but maintain constant bottomhole pressure (CBHP) with MPD in order to remain overbalanced. The narrow window, as illustrated in **Figure 7**, conveys the tight margin within which static EMW must remain underneath upper formations' fracture pressures but above lower formations' pore pressures while static equivalent mud weight (EMW) must achieve the opposite.

The effects of ECD in the 8.5" intermediate section were moderate, enough to reconsider the MW curve in order to achieve the aforementioned goals simultaneously, while the effects of ECD in the 6" production section due to frictional pressure loss were very significant, increasing EMW as much as 1.5 ppg circulating at just 300 gpm conventionally. In order to drill each section successfully, the SBP required to maintain CBHP while not circulating needed to be considered concurrently with the changing parameters of the well's kick tolerance as it was drilled further. Per each well's FIT achieved, a maximum recommended static underbalance was given to each MW in order to remain within a safety margin of kick tolerance as well as surface equipment pressure ratings, shoe pressure limitations, and drilling window range. MW was increased accordingly per each well's specific criteria.

This case study describes the results of drilling ten wells in this area with MPD-READY rigs without incident.

Reduction in Casing Strings

Because of the narrow pore pressure and fracture pressure margin, wells were originally drilled with a 4-string casing design as it was not possible to continue drilling deeper conventionally. With the use of MPD, 3-string casing designs are now regularly performed for each well with success.

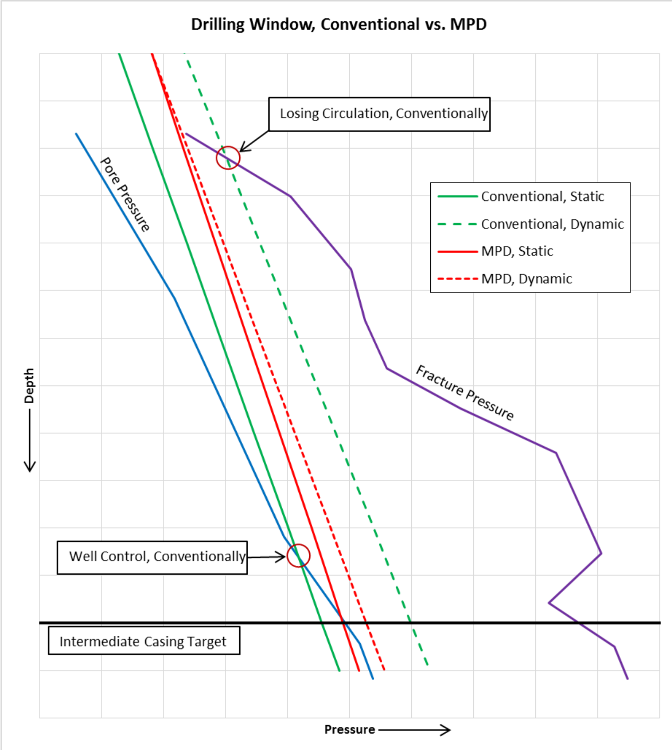

Figure 7 – *Real data from the case study: The narrow window at the top of the graph creates a scenario where drilling conventionally either results in underbalanced conditions or loss of returns. With MPD utilized, the MW and SBP can be successfully engineered in order to avoid both situations and reach the target depth for the next casing string.*

This resulted in eliminating costs of capital equipment for casing tubulars, intermediary BHA, OBM costs, and drilling time while also reducing risk while drilling due to dynamic control of downhole pressure conditions.

Mitigation of Lost Circulation

A chief concern plaguing the particular area was total loss of circulation. As shown above in **Figure 7**, not only can MPD provide the benefit of being able to eliminate a casing string by using lower mud densities and maintaining constant EMW, both statically and dynamically, but MPD-READY rigs have an advantage of mitigating losses during drilling by utilizing the additional capabilities available by integration.

Originally, the MPD-READY application was trialed on the production section only where the loss zone was believed to be in the upper part of the section while controlling unexpected overpressure formations underneath. As conservative utilization began on the intermediate section, it was noted that the intermediate section could be extended further such that its casing point isolated the majority of the loss zone in the production section, therefore mitigating losses and allowing the focus to be drilling the well at balance to stave underbalanced conditions. From there, taking advantage of integrated MPD in the intermediate section has begun to eliminate losses further.

Because of the new casing design as well as the implementation of the integrated MPD, a learning curve for all parties was set in motion, tuning each well's aspects for optimization moving forward. Target mud curve densities have since lowered (**Figure 8**) and the MPD-READY is being utilized for a multitude of the drilling operations.

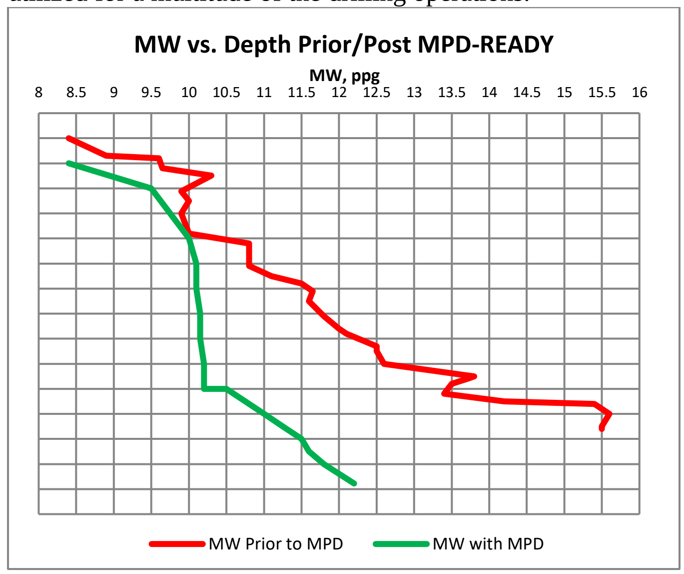

Figure 8 - *While the production section losses were mitigated quickly by lowering MW and replacing ECD with SBP, the intermediate loss zone occurs near the bottom of the section. Therefore, MW begins in a similar trend but remains lower for the remainder of the section.*

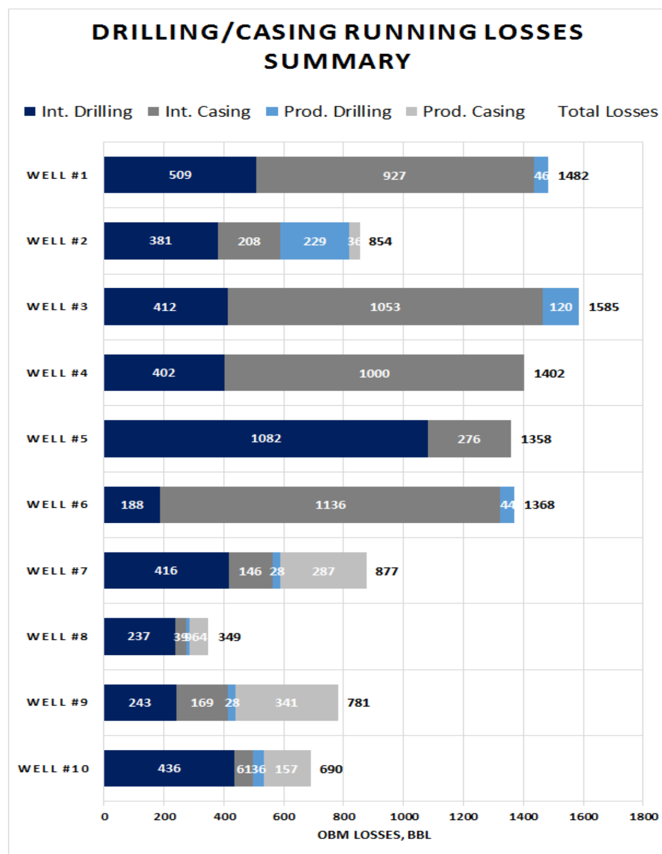

Figure 9 - *Chronological order of OBM losses per well. Notice first as production section losses begin to diminish. Then as MPD was*

utilized earlier in the drilling program the intermediate section losses began to dwindle as well. The wells correspondingly progress with lower MW's in order to utilize MPD more for drilling and tripping, ECD and surge/swab management synergies between MPD/Rig Crew and the mud provider continue to show the overall reduction per well.

This refinement of the well engineering and additional execution of MPD in the intermediate section yielded an average 65% reduction of OBM losses in the intermediate section and 50% reduction of OBM losses overall.

Gas Management & Pore Pressure Characterization

With MPD integrated to the rig, return fluids can make a seamless transition from flowing down the conventional flow line to the rig's MGS in the event of gas breakout at surface.

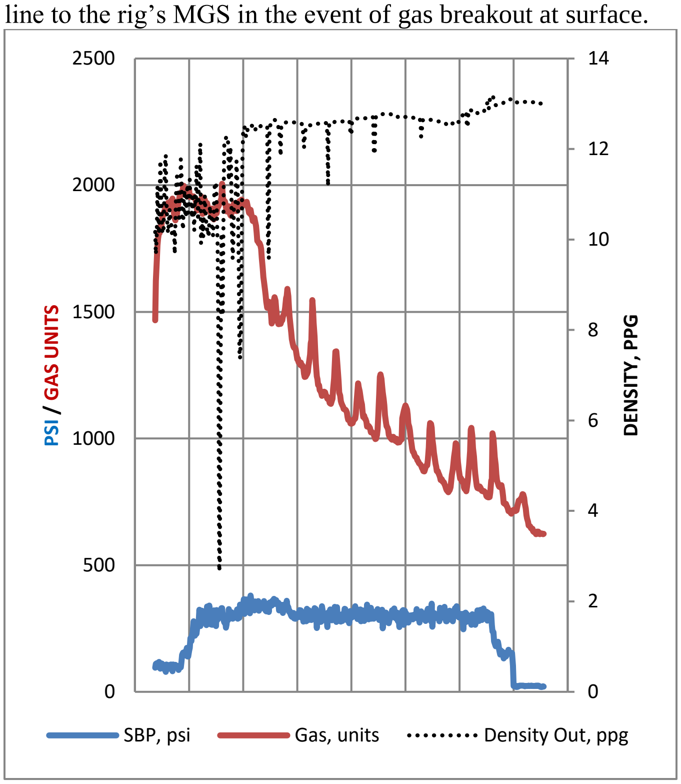

Figure 10 - *As gas is seen breaking out at surface, fluids are redirected to the MGS and the MPD manifold increases SBP in order to mitigate the gas. Density appears erratic as the gas cut mud makes its way out of the well, however, as the proper MW is found to bring the well back to balanced conditions, the density reading begins to become consistent—another confirmation that the pore pressure has been correctly found.*

Not only can MPD-READY rigs see redundancy on fluid flow metering, but also encompass the ability to characterize the pore pressure of the underground formations and successfully keep the well at balance until the proper mud density has been circulated around the annulus and operations are ready to continue.

Well Control

With comparisons to offset wells, the MPD-READY rig electrically actuated servomotor chokes perform at a superior level than conventional MPD systems, but the most differentiating factor between MPD integration and traditional call-out services is the close-proximity pipeline integration and system data-sharing.

Out of 10 wells, only one well control event has occurred with the MPD-READY rig after a hardline in the standpipe washed out unexpectedly and all flow into the drillstring was ceased.

Table 1 - *Offset well analysis of well control events.*

Well Name	Pit Gain / Casing Pressure	NPT	Notes
Offset Well #1	20 bbl / 357 psi	1.5 hours	Noticed increase in CP, MPD choke control failure, shut in and circulated out conventionally
Offset Well #2	37 bbl / 2796 psi (initial)	86 hours	Multiple influxes/losses subsequent of initial well control due to loss of MPD choke control - resulted in bullhead and running casing at depth
Offset Well #3	18 bbl / 782 psi	2 hours	Tripping out, swabbed in an influx and then incurred losses. Circulated out conventionally
MPD-READY Well	< 1 bbl / 1177 psi	3 hours	Mud line washed out, MPD choke shut in immediately, annular closed additionally, repaired mud line and circulated out gas breakout

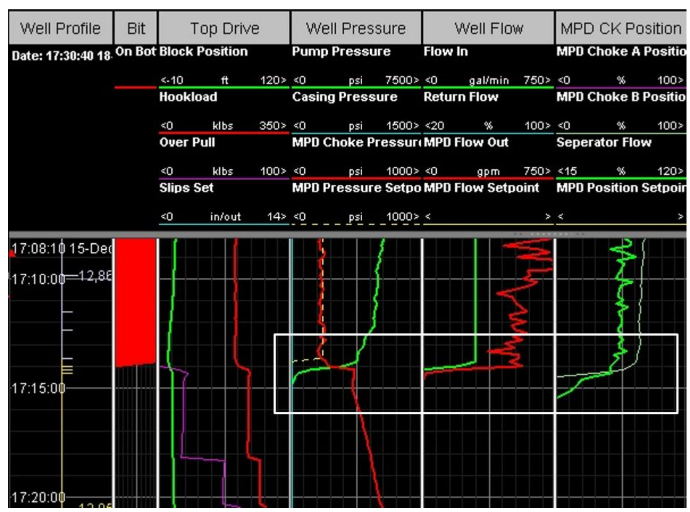

Figure 11 - *Because both the MPD system and the rig's control system were integrated together, the MPD system was able to react instantaneously and close the MPD chokes, trapping pressure and mitigating the size of the influx.*

As part of the standard procedure for MPD integration, an Influx Management Matrix (IMM) is created and agreed upon by both the Operator and Drilling Contractor before operations begin. The purpose of the IMM is to clearly define which limits are acceptable, which are not, and what actions to take upon reaching any of the trigger points. It is created via hydraulics analysis concerning Kick Tolerance based on Kick Intensity and Kick Volume. After acceptance by both parties, the rig crew is thoroughly trained on its use such that when operating conditions prompt a change in drilling activity, the driller takes immediate and appropriate action without delay.

		Influx Management Matrix			
		Zone A			
Influx Indicator: Flow Rate Out > Flow Rate In **AND** Pit Gain	**Influx Circulation System**	**At planned SBP while Drilling 0-400 psi RPM ≤ 120**	**At planned Connection SBP 0-1000 psi RPM = 0**	**Above planned Drilling SBP & under SBP limit 400 psi < SBP < 600 psi RPM ≤ 10 rpm**	**Above SBP Limit SBP ≥ 1200 psi RPM = 0**
No Influx	**No Influx**	Continue Drilling if background gas trend is stable	Resume circulation and continue drilling. Monitor background gas trend. Evaluate condition if background gas is affecting coriolis reading.	Stop Drilling, increase MW in and reduce SBP to planned or contingency levels	Stop Drilling, Pick up off bottom stop pumps and shut in well on MPD system. Close BOP evaluate SIDPP and SICP for corrective action
Normal Operating Limit: Background gas increasing trend	**IF influx ≤ 12 bbl then circulate through MPD system and SMGS**	Continue drilling, increase SBP to stop influx. Divert returns to MGS and circulate influx out.	Continue drilling, increase SBP and circulate influx out w/returns through MGS. Evaluate SBP requirement. Resume drilling with increased BHCP	Stop Drilling P/U off bottom (space out) Increase SBP to stop influx. Divert returns to MGS and circulate influx out. Increase MW to reduce SBP to planned or contingency levels	Stop Drilling, Pick up off bottom stop pumps and shut in well on MPD system. Close BOP evaluate SIDPP and SICP for corrective action
Well Control	**IF influx > 12 bbl then circulate through rig well control system**	Stop Drilling, Pick up off bottom stop pumps and shut in well on MPD system. Close BOP evaluate SIDPP and SICP for corrective action	Stop Drilling, Pick up off bottom stop pumps and shut in well on MPD system. Close BOP evaluate SIDPP and SICP for corrective action	Stop Drilling, Pick up off bottom stop pumps and shut in well on MPD system. Close BOP evaluate SIDPP and SICP for corrective action	Stop Drilling, Pick up off bottom stop pumps and shut in well on MPD system. Close BOP evaluate SIDPP and SICP for corrective action

Figure 12 - *The Influx Management Matrix is a reliable resource for the Operator's wellsite leaders on location to ensure operating conditions are clearly reviewed and understood by the MPD/rig crew members. In the event of an unexpected overpressure formation, this serves as the insurance plan to mitigate surprises.*

Stripping with SBP and with Casing

Even with MPD, stripping operations can prove rather difficult when threading a narrow drilling window, especially if the data is parsed between companies, communication is hindered by operating location at the rig, and most importantly hardware configuration allows for separate, simultaneous operations. With MPD-READY rigs, personnel are working side-by-side, constantly communicating during the same operation while being able to view all of the same data, together. Furthermore, MPD integration to the Drilling Contractor's rig allows for using the existing rig pumps for stripping operations, eliminating the need for additional capital equipment costs and rig up of auxiliary pump(s) typically needed by traditional MPD call-out services.

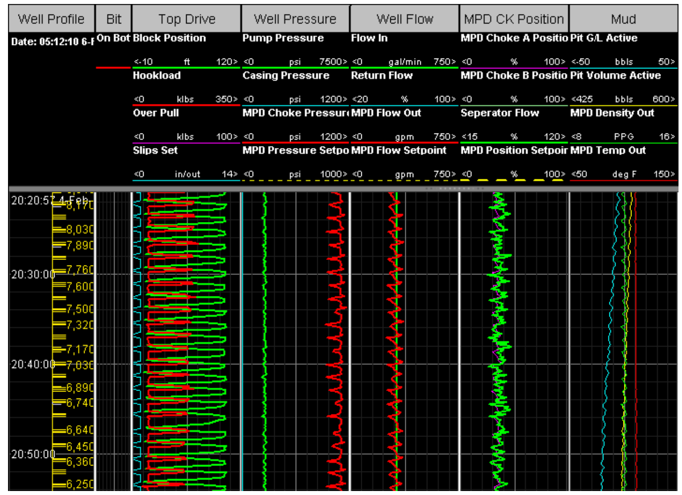

Figure 13 - *All channels being monitored simultaneously and redundancy with certain sensors (e.g. flow out) results in advanced, consistent, and successful MPD performance.*

The result is a more streamlined, natural way to conduct stripping with pressure operations. Notice in **Figure 13** the accuracy of measuring flow out and how swabbing affects downhole conditions. While steadily pumping 318 GPM at surface directly to the MPD manifold with the rig pumps and stripping out of hole (STOOH) at ~3,800 ft/hr, return flow to the Coriolis meter was oscillating between 260 GPM and 360 GPM. Coupled with the rig's data acquisition system, it can be observed that this fluctuation circumscribes the rig's flow in calculation, swaying more to the low flow rate side, which indicates the drillstring is moving out of the hole rather than to bottom. Using this method, the swab effects can not only be identified, but quantified. In order to mitigate the influence of swabbing the well and maintain a constant EMW at well bottom, a SBP of 947 psi was applied while the pipe was not reciprocating and 1100 psi while the pipe was being pulled out of the well.

Measuring and considering mechanically dynamic parameters by viewing all available data as a single acquisition system is an integral part of engineering operational procedures effectively. This is also important in monitoring active kick/loss scenarios as well control events commonly occur during tripping operations.

During the case study, the production casing was also stripped to bottom for each well, resulting in being able to reach TD consistently throughout the pads, eliminating earlier difficulties of getting casing to bottom. Casing while drilling (CWD) was trialed during one well with MPD online. No stuck pipe incidents or losses were observed, revealing additional opportunities for both technologies to be used in tandem in the future.

Managed Pressure Cementing

The MPD-READY system was also used to hold SBP while cementing the production casing in order to maintain EMW at TD at or above the desired pressure.

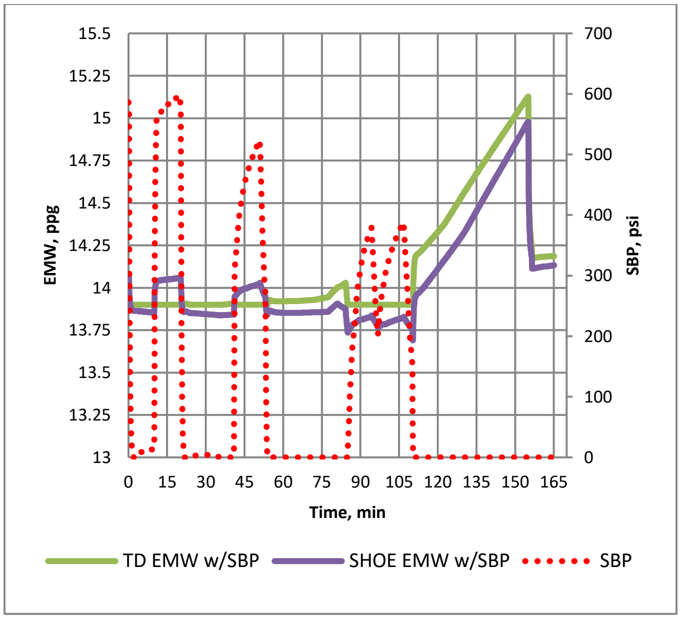

Figure 14 - *Production cement job while holding SBP with MPD-READY rig. While pumping, ECD was greater than the desired 13.9 ppg but SBP was used to compensate while pumps were off.*

Maintaining constant EMW while circulating cement is particularly crucial in order to ensure a proper cement job takes place. MPD cementing mitigates inconsistency in the cement column due to formation fluids while also condensing slurries to fortify the setting process, increasing its integrity.

Remote / Onsite Engineering

With the consolidation of live-streaming data enhanced by the MPD-READY system, remote and onsite engineering played a key role in developing future well plans. Upon reaching unexpected pore pressure or pushing behind the section's planned TD, the MPD-READY system not only was able to maintain proper downhole parameters per impulsive well conditions, but also timely characterize the conditions such that the proper pressures and MW was utilized in order to maintain the appropriate EMW at bit.

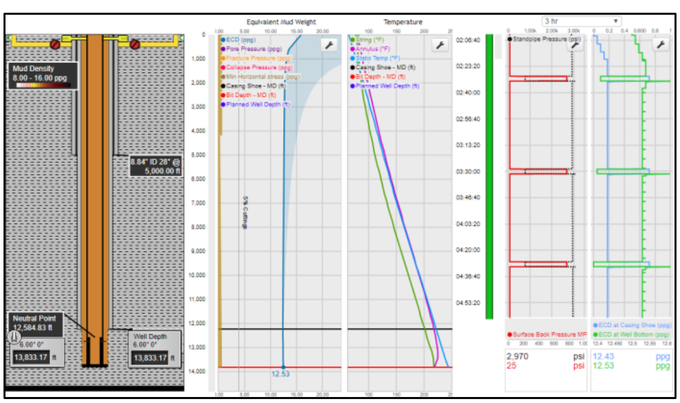

Figure 15 - *Remote and onsite engineering can be interchanged via modern networking technology and plays a key role in communicating live well conditions and updating drilling parameters.*

Dynamic pore pressure tests and gas trend monitoring coupled with remote and onsite engineering were key to updating drilling parameters accordingly and aiding in completing a successful project.

Summary and Conclusions

With the price of oil mired for three years, the cost of drilling has inflated and constrained investments in conventional projects. Drilling efficiency is again paramount to not only sustain business, but also prepare for the market's turnaround. Despite the downturn, technology and innovation continues to progress, offering drilling techniques that tackle top priorities such as eliminating non-productive time, unlocking unconventional plays, and reducing drilling costs through integration and automation. A paragon to these values is MPD-READY rigs – drilling rigs with integrated Managed Pressure Drilling technology in order to not only optimize drilling projects, but also steer the industry toward better communication and cooperation between drilling contractors and the end user.

The benefits of MPD are well known, including but not limited to drilling in previously undrillable zones, higher ROP, improved influx and losses management, reduction in rheology costs, reservoir characterization, lower wellbore fatigue, and improving HSE. However, integrating this capability into the rig contractor unlocks new advantages not before realized including personnel optimization, consolidated service providers, bundling costs, and tangible capabilities such as the ability to remotely divert fluids to multiple avenues, skidding without rig down and rig up, cutting-edge data acquisition and visibility, and access to advanced MPD techniques which normally require additional rig-up and personnel costs.

A case study performed by MPD-READY rigs yielded the following results:

1. Cost optimization with equipment permanently installed, eliminating the need for repeated rig down/up
2. Installation plan engineering by drilling contractor allowed for efficient installation and low footprint
3. Drilling operations enhanced by remote and onsite engineering with live updates from the rig
4. A single source provider for the rig and MPD service facilitated collaboration between both groups as well as communication with the customer
5. Eliminated a casing string, optimizing wells to 3-string designs
6. Reduction of cumulative losses per well
7. Effective gas management and pore pressure estimation
8. Efficient influx mitigation and reduction of risk
9. Stripping with the rig's mud pumps possible with the drillstring as well as the casing
10. Managed pressure cementing successful for mitigating losses and influxes
11. Sharing of data and integration of sensor monitoring optimizes drilling operations for conventional systems as well as MPD system

Drilling wells quickly should not be the only shared interest between operators and contractors, but rather providing a quality wellbore through the implementation of technologies, partnering together to align goals, optimize the industry, and take away the market's power over progress.

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Nomenclature

BHA = *Bottomhole assembly*
BHP = *Bottomhole Pressure*
BOP = *Blow out preventer*
CBHP = *Constant bottomhole pressure*
CWD = *Casing while drilling*
ECD = *Equivalent Circulating Density*
EMW = *Equivalent Mud Weight*
FIT = *Formation integrity test*
GPM = *Gallons per minute*
IMM = *Influx management matrix*
LOT = *Leak-off test*
MGS = *Mud-gas separator*
MPD = *Managed Pressure Drilling*
MW = *Mud Weight*
NPT = *Non-productive time*
OBD = *Overbalanced Drilling*
OBM = *Oil-based mud*
PPG = *Pounds per gallon*
PVT = *Pit volume totalizer*
RCD = *Rotating Control Device*
ROP = *Rate of penetration*
SBP = *Surface Backpressure*
STOOH = *Stripping out of hole*
TCP/IP = *Transmission Control Protocol/Internet Protocol*
TD = *Total depth*
UBD = *Underbalanced Drilling*
WITS = *Wellsite Information Transfer Specification*

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