SPE/IADC-221428-MS

Management of Cross-Flow Events in High pressure, Deep Disposal Wells Using MPD Techniques

Gerald D. Yao-Dablu and Scott Hoekstra, Beyond Energy Services and Technology Corp, Calgary, Alberta, Canada

This paper was prepared for presentation at the SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition held in Rio de Janeiro, Brazil, USA, 17 – 18 September, 2024.

Abstract

Drilling wells with Managed Pressure Drilling (MPD) technology allows Operators to drill and complete wells that would be otherwise un-drillable or uneconomical when done conventionally. The use of a mud density below the pore pressure can significantly reduce the likelihood of partial or complete loss of circulation especially when drilling through possible fracture or weak zones for Deep Disposal well projects.

While drilling a Deep Disposal well, pore pressure was encountered and confirmed through fingerprinting with the use of surface-applied pressure on connections. Drilling deeper into a different formation, total loss of circulation was experienced. The loss of mud in this scenario, without returns to the surface, can cause the fluid level to drop over time indicating an imminent wellbore influx, threatening a surface well control event. However, due to cross-flow between the pore pressure zone and the loss zone, gas from the pore pressure zone was not seen on surface. Managing these losses involved the successful placement of Loss Circulation Material (LCM) to re-instate circulation and the use of Managed Pressure Cementing procedures to set cement plugs to heal the loss.

This paper delves into this unique instance of how MPD techniques were utilized to manage this cross-flow event in the Deep Disposal well in Alberta while highlighting the safety considerations employed when deciding between changing wellbore fluid to Brine or maintaining Invert as wellbore fluid.

Introduction and Background

The Operator planned to drill a deep disposal well into the Leduc/ Beaverhill Lake Formations while taking into consideration the possibility of encountering both overpressure in the Pekisko to Leduc formations as well as losses. Initial plans after drilling the intermediate I section through the rig flowline and landing casing in the Debolt formation were to; drill and cement the intermediate II section leveraging the advantages of utilizing Beyond's Managed Pressure Drilling services to manage the possible overpressure while minimizing losses; and drill the Production section. See Fig. 1 for a schematic of the initial plans for drilling the disposal well. Target Intermediate II casing landing depth was 4378mMD/4135mTVD and that for the Production Section was 4675mMD/4432mTVD.

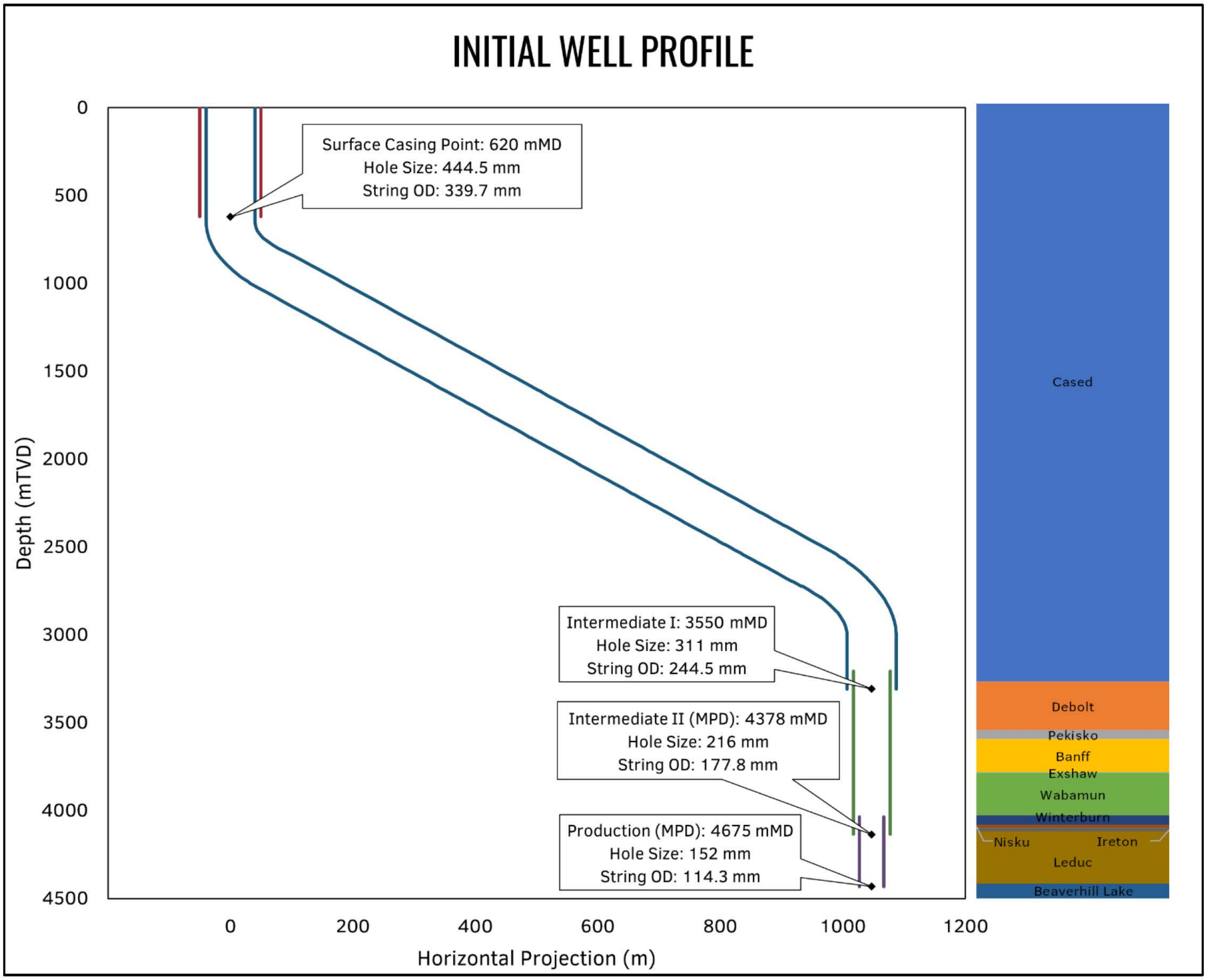

Figure 1—Initial Well Profile

As popularly known in the oil/gas industry, all plans are subject to change based on real-time well conditions and behavior while drilling, of which this well is an example. While drilling the Intermediate II section, an estimated Pore Pressure of ~1740kg/m³ was encountered at ~3879mMD (Banff/Wabanum formation), and with MPD already integrated, EMW was maintained above Pore Pressure by applying Surface Backpressure using Beyond's backpressure System. At ~4210mMD, total loss of circulation was encountered. See Fig. 2 and Fig. 3. Pumping was continued as Loss Circulation Material to be used to heal the losses was being prepared. There is a risk of gas from the pore pressure zone migrating to surface and causing a well control event if the wellbore fluid column is not maintained as fluid is being lost into the loss zone at 4210mMD. As a result of formation cross-flow between the Pore Pressure zone and Loss zone, gas migration to surface was not realized. LCM, once ready, was pumped, shut-in tests were performed to evaluate its effectiveness at healing losses which proved barely effective. Open-hole cement plugs were pumped and squeezed into formation leveraging Beyond's Managed Pressure Cementing expertise after performing a bit trip and running slick BHA. After the plugs were set, gas was observed on the surface which was managed expertly utilizing MPD techniques. Two more attempts to continue drilling after pumping cement plug were unsuccessful. Given this, the intermediate II casing was run and cemented using MPD to isolate the Pore Pressure zone.

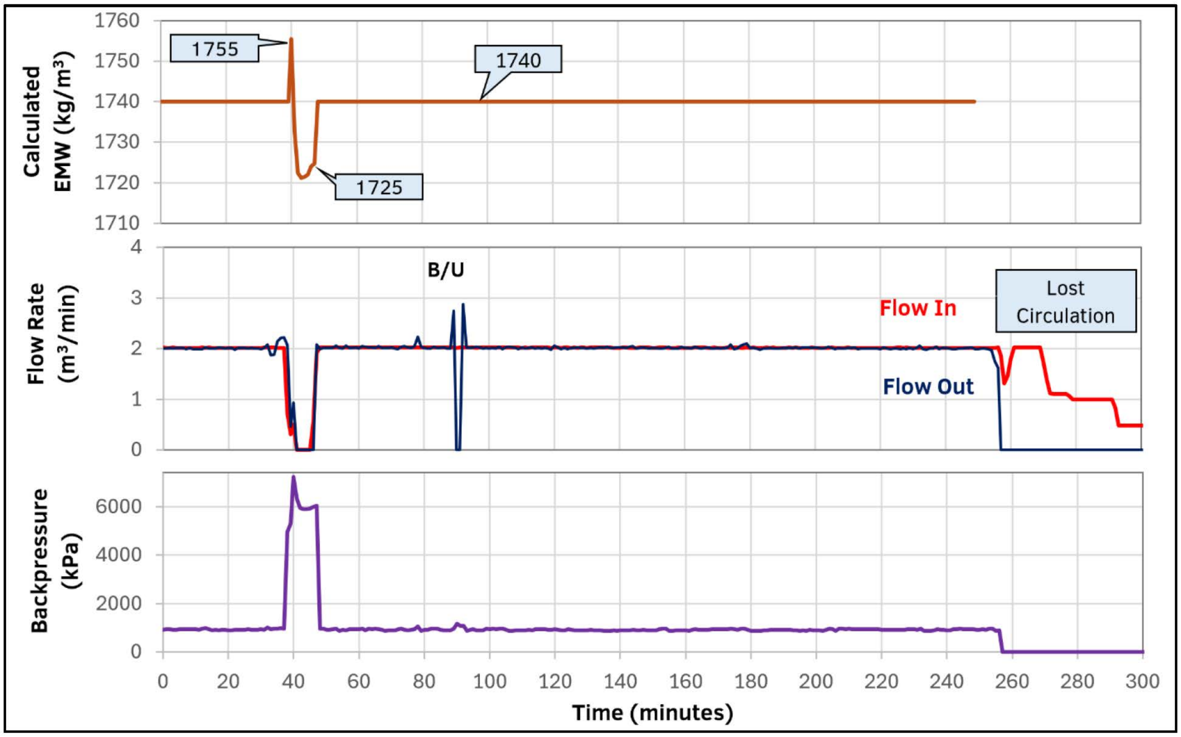

Figure 2—Connection and Lost Circulation (Drilling with 1570kg/m³ OBM)

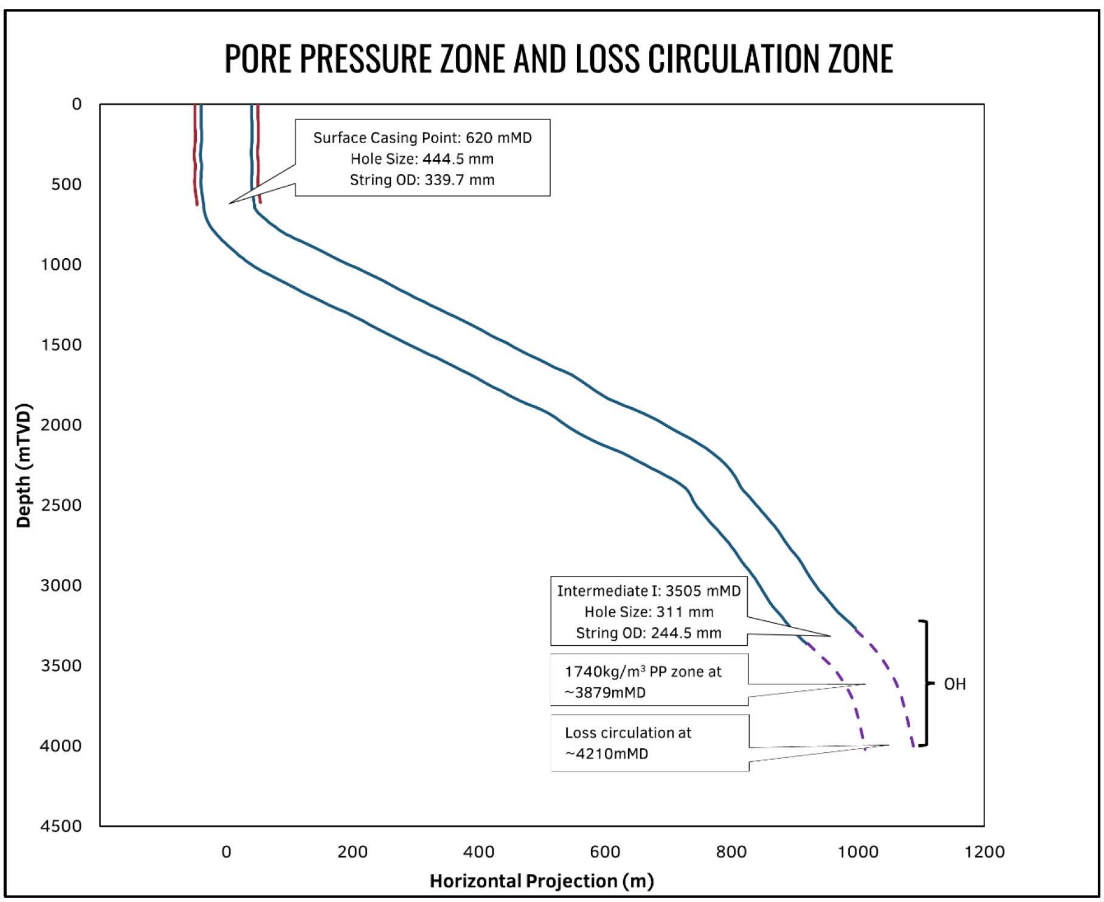

Figure 3—Pore Pressure Zone and Loss Circulation Zone Before First Cement Plug

A new plan was drawn, considering the Loss zone before drilling the production zone. See Fig. 4 for initial wellbore conditions before drilling the production section. Utilizing MPD, drilling commenced, however at ~4335mMD, in response to the presence of H_2S, a sour gas scrubber unit was integrated into the rig to treat sour fluid to prevent exposure to the environment as this exposure will cause safety concerns to personnel present and the environment. At this same depth, losses were also experienced. Two cement plugs were pumped and squeezed into the formation utilizing MPC. Drilling to TD then commenced while simultaneously maintaining overbalanced conditions in the wellbore and an acceptable loss rate while drilling. Following a series of Open Hole logging events, a production liner was run and was managed pressure cemented.

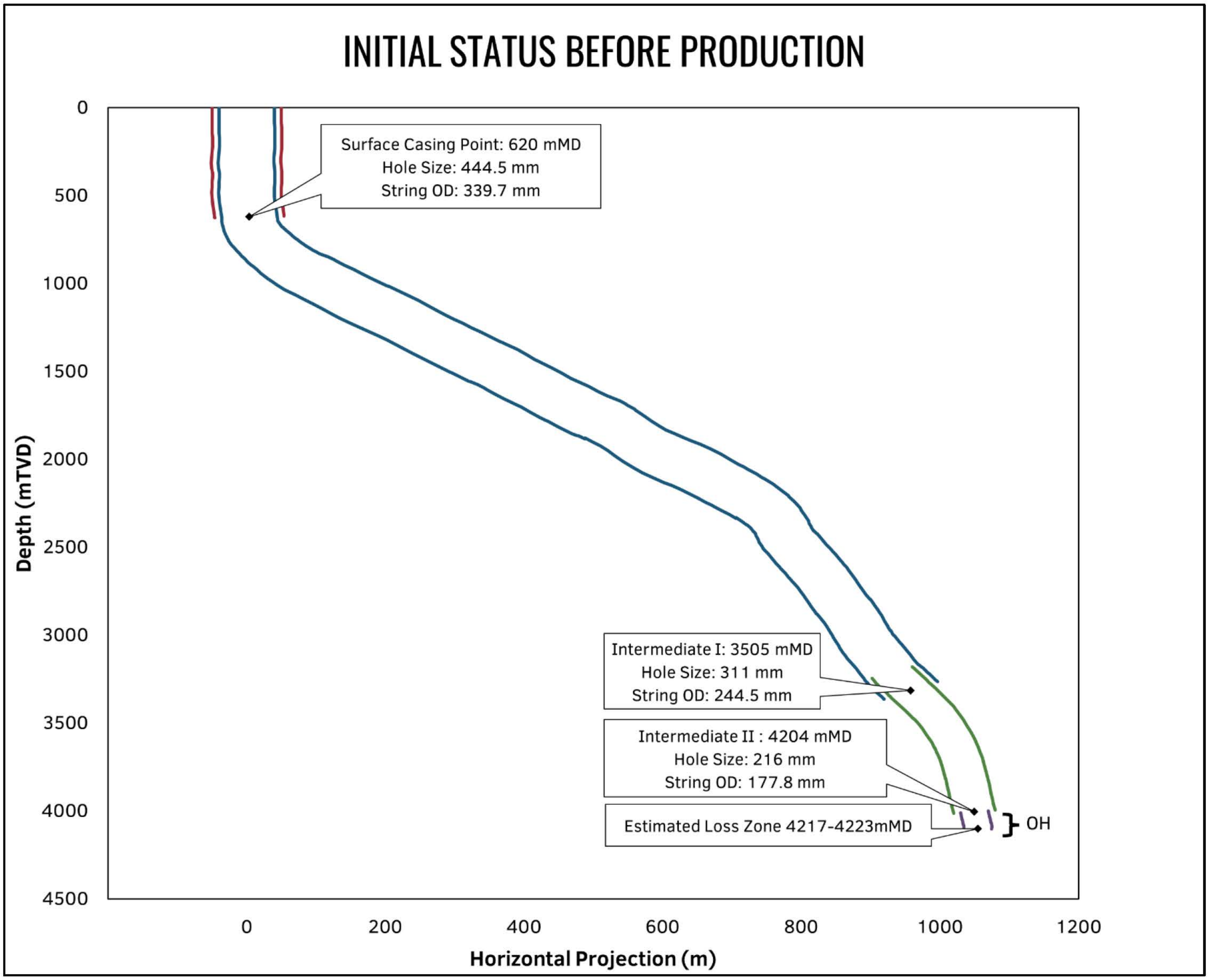

Figure 4—Initial Wellbore Status Before Drilling Production Section

The purpose of this paper is to highlight how Pore Pressure was determined using Beyond's MPD services, how the cement plug was pumped and squeezed using MPC, how the liner was Managed Pressure cemented, Safety considerations made including the importance of proper Mud Weight Selection and importance of Sour Gas management.

Pore Pressure Test

The objective of managed pressure drilling is to maintain ECD at or slightly above Pore Pressure or as close to near-balance as possible while drilling an entire section, during connection and trips (Balanza, Justiniano and Poletzky 2015).

It is imperative to accurately determine pore pressure while performing drilling operations, especially in areas with Offset wells showing high pore pressure with the possibility of encountering a fracture zone. With the emergence of MPD and its growing popularity over the years, different ways of determining Pore Pressure have been developed. Leveraging the ability to control Bottomhole Pressure by adjusting Surface Applied Pressure made possible by the automatic opening or closing of the chokes by the required percentage, operators can pinpoint the exact balance point where Pore Pressure is equal to the Bottom Hole Pressure.

One way of fingerprinting Pore Pressure is by performing Dynamic Flow Checks or Dynamic Pore Pressure Tests. These tests are possible due to the accurate measurement of flow out recorded, using a Coriolis Flow Meter in the MPD System. For this test, the SBP pressure was decreased in steps, and compared the flow in and flow out, until a gain trend was detected in the system (Zhang, Muhammad and Alhajri 2023). This test can be performed at any point during the drilling process, as long as the flow meter is calibrated, i.e. matching the flow behavior as seen in the initial stages in Fig. 5. In Fig. 5, the behavior of the EMW (Equivalent Mud Weight) graph is directly proportional to changes on the Backpressure graph. To identify the Pore Pressure, starting from a reasonably high backpressure, this backpressure is reduced in steps causing the EMW to also reduce accordingly. This process is carried out while monitoring Flow In vs Flow Out in the wellbore to the point where there is a divergence of flow as seen in Fig. 5, indicating the pore pressure, i.e. the corresponding EMW at that divergence. Once the test is completed, over balance is reinstated by re-applying back pressure.

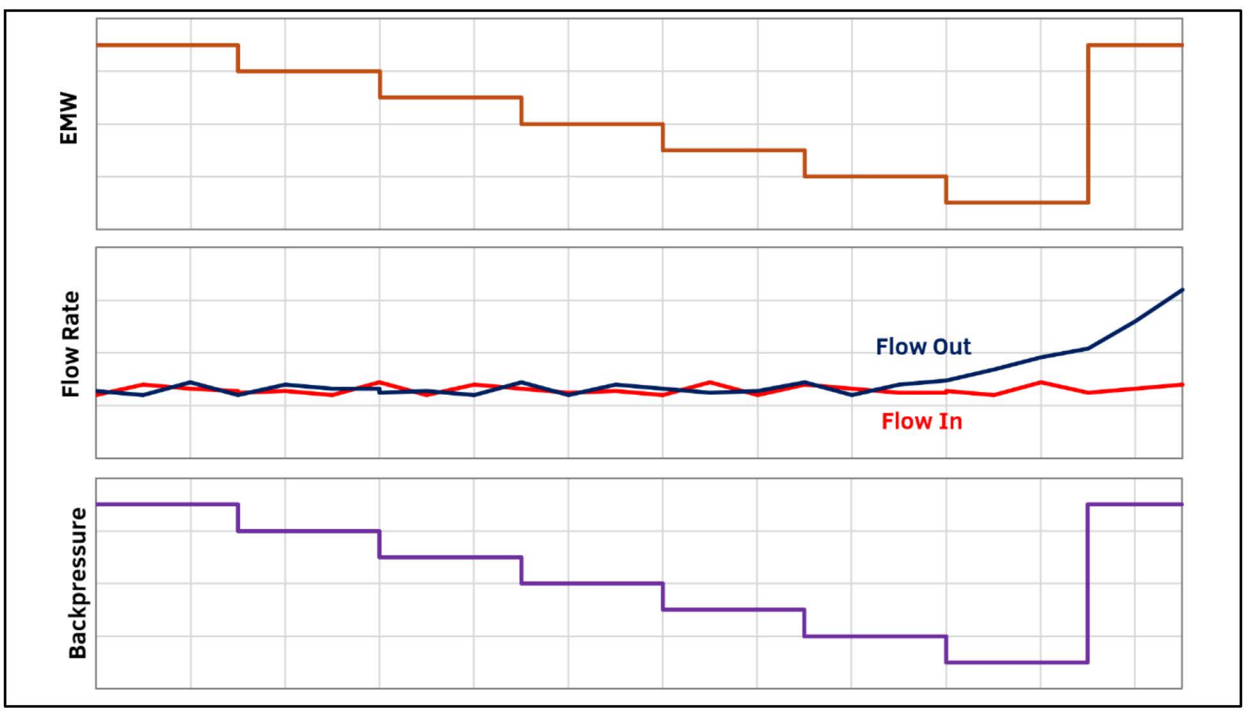

Figure 5—Dynamic Pore Pressure Test

Another way to determine the pore pressure is to assess the bottoms-up gas rate after holding a specific static back pressure on connections. This method involves holding different Equivalent Static Density (ESD) by adjusting the static back pressure on each connection while drilling ahead and evaluating the bottoms-up gas rate generated with the particular ESD. ESD is slightly adjusted for the subsequent connections while evaluating the B/U gas. This process helps determine when the ESD is nearing the balance point of the wellbore, thereby facilitating the estimation of pore pressure. This was the exact method employed while drilling the Intermediate II section with 1570 kg/m³ OBM. As seen in Fig. 6 (showing the last three connections before lost circulation), different backpressures were held on each connection corresponding to different EMW as well as bottoms up gas. Connection 1, EMW 1743 kg/m³ ≡ 4.3 kscm/day B/U Gas, Connection 2, EMW 1726 kg/m³ ≡ 5.8 kscm/day B/U Gas and Connection 3, EMW 1721 kg/m³ ≡ 11.8 kscm/day B/U Gas, Connection 4, EMW 1725 kg/m³ ≡ 6.1 kscm/day B/U Gas. With these deductions, Pore Pressure was determined to be ~1740 kg/m³.

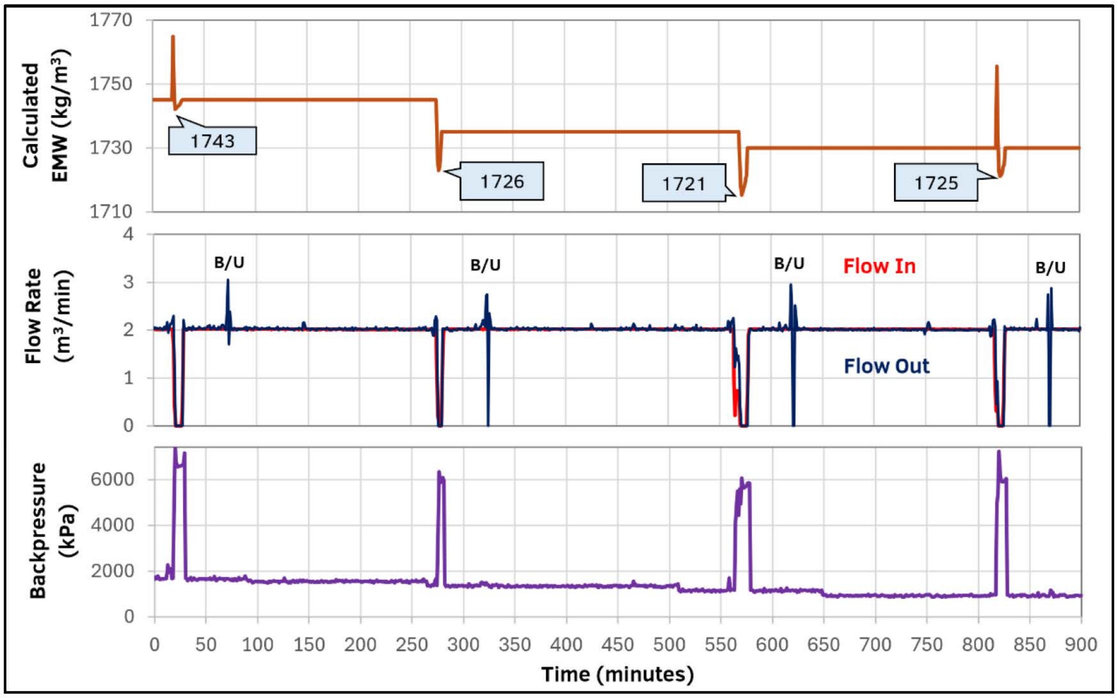

Figure 6—ESD on Connections before Lost Circulation

On this well, which was faced with both severe losses in one zone and a Pore Pressure in another zone accompanied by sour gas, it became imperative that Pore pressure should be determined. However, performing a Dynamic Pore Pressure Test just as explained previously, poses a risk of the release of Sour Gas when flow divergence occurs. Because of this, while drilling the production section with 1100kg/m³ Brine, a modified method of this test was employed, where the balance point of the wellbore was determined. As shown in Fig. 7, backpressure was reduced in steps with losses recorded for each pressure step reducing until losses were zero. At this point, it is believed that a balance point has been found in the wellbore where the EMW (1165kg/m³) associated with it was just higher than the Pore Pressure.

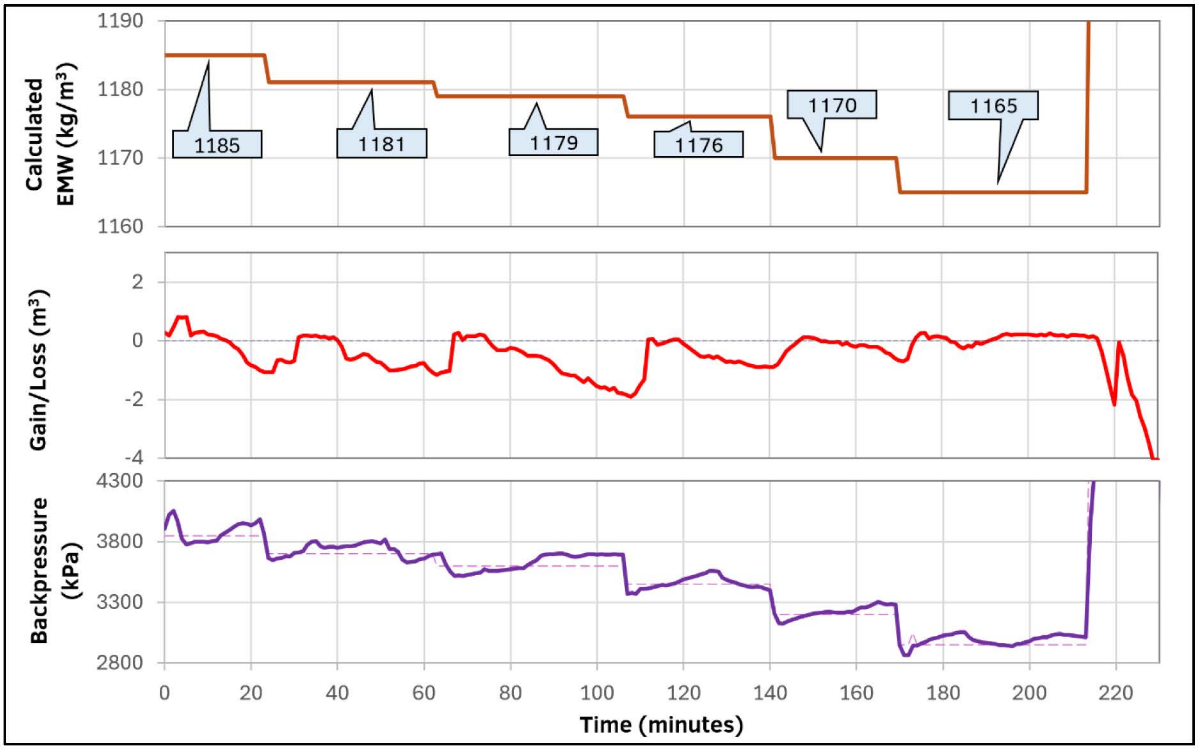

Figure 7—Modified Dynamic Pore Pressure Test

Managed Pressure Cementing

Managed Pressure Cementing, with its increasing popularity in Alberta, Canada, adopts the same concepts used in Managed Pressure Drilling with all its advantages. Before performing cementing operations, it is important to maintain overbalanced conditions. Conventional cementing includes the use of an overbalanced fluid system as an initial fluid to satisfy these conditions. In situations such as this well where both Pore Pressure and Losses in different zones are being experienced simultaneously, we ran the risk of significant mud/cement losses to formation because of high Initial Equivalent Circulating Density even before the cementing sequence is completed. Enter MPC, where this Initial ECD can be reduced and maintained at a reasonable point above the determined Pore Pressure by using a lighter mud in conjunction with backpressure to control the loss rate.

It is crucial to properly design a program based on real-time conditions in the well, cement and fluid properties, pump rates, well geometry, and equipment specifications to maintain desired ECD within the determined drilling window (Balanza, Justiniano and Poletzky 2015). To attempt to heal losses experienced at ~4335mMD, after pumping Loss circulation materials (LCM), cement plugs were pumped and squeezed into the formation at ~4335mMD employing the use of Managed Pressure Cementing Techniques. This operation followed the following procedure:

1. Follow MPC schedule until Cement top hits the bit.
2. Continue to apply 1500kPa (or squeeze pressure stated in schedule), squeezing cement ($4m^3$) into formation while monitoring loss rate (~$3m^3$/hr)
3. Shut down pumps and apply squeeze pressure (2000kPa) as per Cement Provider Cement Program, while maintaining the desired loss rate until the volume of PreFlush fluid ($8m^3$) and Cement ($4m^3$) have been pumped away.
4. Wait on Cement for 4 hours while maintaining 2000kPa as per Program provided by the Cement Provider.
5. Strip out 3-5 stands and circulate at $1.2m^3$/min while holding ~1000kPa as per MPC schedule.

6. Repeat steps 1-5 for subsequent cement plugs/squeezes.

This procedure was developed and adopted to ensure cement plugs are squeezed into formation at a desired rate preventing the cement pumped from migrating up the annulus.

After successfully drilling to the Target Depth (~4607mMD) utilizing MPD to control the loss rate, 114.3mm Drill Pipe conveyed 114.3mm liner was run and cemented using MPC techniques. During the first stages of the liner cementing, surface backpressure was applied to maintain a desired ECD above the Pore Pressure since the initial mud system and Preflush densities were below the Pore Pressure. The backpressure was removed in stages as the cement was circulated up the annulus. Since losses were expected during cementing, an excess volume of cement slurry was designed to ensure proper cementing of the liner in the open hole which was confirmed by the execution of bond logs after the completion of the liner cementing.

Safety Considerations

Drill Mud Selection

Water- or oil-based fluid circulated down the drill pipe into the well and back up to the rig for purposes including containment of formation pressure, the removal of cuttings, bit lubrication and cooling, treating the wall of the well and providing a source for well data (ISO 13624-1:2009 2009). Given that drilling mud serves as the primary well control barrier alongside Managed Pressure Drilling (MPD), it is crucial to determine the appropriate density and properties while considering the pressure limitations of the MPD equipment. Bearing assembly provided for this project by Beyond Energy Services and Technologies has a Static (Pipe Static) pressure rating of 10250kPa and a Dynamic (Pipe moving) pressure rating of 7000kPa after safety margins have been applied.

While drilling the Intermediate II section, a high Pore Pressure zone (estimated to be ~1740kg/m^3, bled down to 1650kg/m^3 by the time casing was run) was encountered at ~3879mMD/ 3681mTVD (Banff/ Wabanum formation) while drilling with 1570kg/m^3 Oil-based mud. This means that the minimum static backpressure required to maintain overbalance was ~6150kPa. Considering the above MPD Pressure rating and the 1570kg/m^3 drilling mud, overbalance can be maintained for Pore Pressures up to ~1850kg/m^3. If a 1100kg/m^3 Brine was the selected mud choice for that section, overbalance can be maintained for Pore Pressures up to 1380kg/m^3 which is lower than the encountered Pore Pressure of 1750kg/m^3, therefore, maintaining 1570kg/m^3 oil-based mud for the Intermediate II section was a good Drill mud selection.

After isolating the high pore pressure zone by running and cementing the Intermediate II casing, drilling with 1100kg/m^3 Brine was then employed since the pore pressure encountered in the Production section was 1165kg/m^3, much lower than what was experienced in the intermediate II section. Since the highest EMW that can be applied to the well with 1100kg/m^3 Brine is 1380kg/m^3 (as per equipment limitations), the selection of this mud weight for this section proved to be a safe choice.

MPD Equipment

MPD techniques are carried out using equipment that provides a closed-loop system. i.e. mud returns while drilling or circulating are not directly open to the atmosphere. Some MPD equipment provided for the project included the following:

1. Rotating Control Device (RCD)
2. Bearing Assembly
3. Choke Manifold Building
4. Coriolis Meter
5. Mud Gas Separator
6. Flare Stack

Rotating Control Device (RCD). A drill-through device with a rotating seal that contacts and seals against the drill string (drill pipe, casing, kelly, etc.) for the purpose of controlling the pressure or fluid flow to surface (American Petroleum Institute Specificatin 16 RCD 2005). This device, as seen in Fig. 8, also being sour gas rated, diverts mud returns away from the floor which is critical when it comes to Sour gas operations such as this one. Here, Sour gas/fluid was diverted by the RCD to H_2S scrubbers where it was treated.

Figure 8—Beyond ARES 1578 RCD

Bearing Assembly. The bearing assembly, also sour gas rated, as shown in Fig. 9, houses the RCD with clamps fitted to hold it in place, pressure-rated to 34.5MPa to handle high pressures from the well.

Figure 9—Beyond Titan 5 Body with ARES 1578 inserted

Choke Manifold Building. The Choke Manifold Building houses the Surface backpressure system, the Pressure Relief Valve (PRV) and the MPD Control System. The Surface backpressure system which is controlled by the MPD control system, has chokes that restrict the flow of fluid through it thereby generating backpressure on the well during dynamic and static conditions. The PRV installed prevents the over-pressurization of the wellbore.

Coriolis Meter. The Coriolis meter measures the density, temperature, and flow rate of fluid flowing through it which is important while drilling. It promotes early kick detection which allows the operator to react quickly, hence preventing the likelihood of a well-control event.

Mud Gas Separator. The self-erecting Gas Buster as seen in Fig. 10 specifically designed for MPD drilling applications, where gas needs to be removed from the drilling fluid and cuttings mixture. It is also equipped with a walking system, providing operators the ease of re-positioning without the need for secondary equipment. The gas that is separated from the mixture is then diverted to the flare stack.

Figure 10—Beyond Mus Gas Separator (Big-B) with Manifold Building behind

Flare Stack. The self-erecting Flare Stack in Fig. 11 complements the MPD system by offering a safe a reliable way to flare gas returns from the wellbore. It is designed to contain an advanced ignition system and a flame arrestor with a bypass for emergencies.

Figure 11—Beyond Flare Stack

Sour Gas management

Confirmed presence of H_2S (Hydrogen Sulfide) gas while drilling produces an added level of complexity to which operators and service providers must pay attention. At ~4335mMD, H_2S alarms were set off during the circulation of mud. This prompted the need for modification to the on-field drilling equipment including the changing of rams to variable pipe rams. An H_2S scrubber was integrated into the flow loop of equipment in the field. Fig. 12 shows how the third-party Scrubber, which includes the P tank, manifold, and flare stack was included in the flow loop. The Scrubber package was rigged into the downstream of the Coriolis and upstream of the Beyond Mud Gas Separated. All Beyond Energy Services and Technologies Corp's equipment is Sour gas-rated and can handle sour fluid flowing through it.

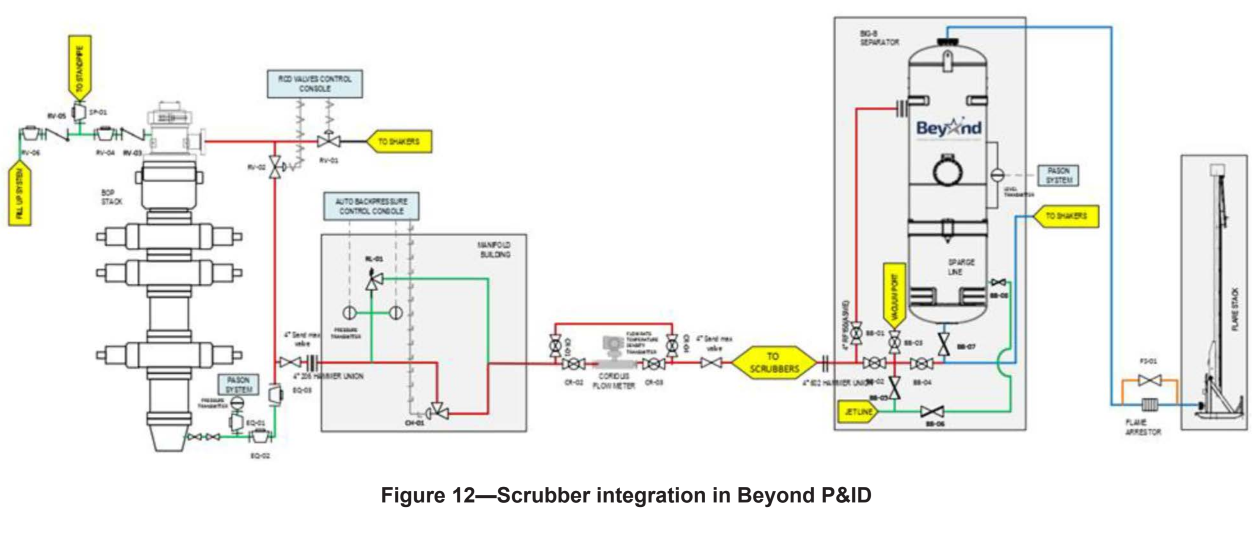

Figure 12—Scrubber integration in Beyond P&ID

Conclusion

Managed Pressure Drilling techniques, as per the above, prove to be an important addition to the drilling operations of this Deep Disposal Well, which otherwise would have been un-drillable and uneconomical. With MPD;

1. Pore Pressure was successfully fingerprinted
2. Cement plugs were successfully pumped and squeezed into formation under pressure
3. Casing and liners were cemented using Managed Pressure Drilling techniques which reduced the amount of fluid that would have been lost if done conventionally
4. The well was completed considering and applying all safety precautions while following industry regulations and guidelines.

Beyond Energy Services and Technologies Corp provides industry-leading equipment, services, and flexible solutions to a wide range of complex drilling operations.

Nomenclature

MPD	Managed Pressure Drilling
MPC	Managed Pressure Cementing
DD	Deep Disposal
LCM	Loss Circulation Material
Beyond	Beyond Energy Services and Technologies Corp
EMW	Equivalent Mud Weight
PP	Pore Pressure
FG	Fracture Gradient
BP	Back Pressure
SBP	Surface Back Pressure
BHP	Bottom Hole Pressure
SAP	Surface Applied Pressure
ESD	Equivalent Static Density
ECD	Equivalent Circulating Density
RCD	Rotating Control Device
PRV	Pressure Relief Valve
MGS	Mud Gas Separator
OBM	Oil-Based Mud
B/U Gas	Bottoms Up Gas
H_2S	Hydrogen Sulfide
OH	Open Hole
TD	Target Depth
Strip	Tripping with surface applied back pressure

References

Balanza, Jose Antonio, Luis Carlos Justiniano, and Isabel Poletzky. 2015. "Implementation of Managed Pressure Casing Drilling and Managed Pressure Cementing Techniques in Unconventional Reservoirs." London: SPE/IADC Drilling Conference and Exhibition, March 17–19. 1–16. doi:https://doi.org/10.2118/173080-MS.

American Petroleum Institute Specificatin 16 RCD. 2005. Oil & Gas Drilling Glossary. February. Accessed May 24, 2024. https://iadclexicon.org/rotating-control-device-rcd/.

ISO 13624-1:2009, Petroleum and natural gas industies. 2009. Oil & Gas Drilling Glossary. Accessed May 24, 2024. https://iadclexicon.org/mud/.

Zhang, Hua, Jamal uddin Muhammad, and Naif Mutlaq Alhajri. 2023. "Successful Managed Pressure Drilling Application in a Challenging Well With Crossflow in Unconventional Field." SPE-213441-MS. Manama: Middle East Oil, *Gas and Geosciences Show*, February 19-21. 1–15. doi:10.2118/213441-MS.