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Engineered Lost Circulation Combinations with Reticulated Foam Yields Unprecedented Results in the Powder River Basin

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Abstract

Lost circulation management can often help increase the profitability of prolific oil and gas targets in the Rocky Mountains. The southern part of the Powder River Basin is known for its potential as a prolific oil and gas play. Reaching these high potential reservoirs can be costly because of lost circulation, which contributes to excessive non-productive time (NPT), safety concerns, and potential production impairment caused by poor cement operations. Total losses can range up to 40,000 bbl of fluid, with averages in the 10,000-bbl loss range.

The primary loss zone has been identified as an unconformity in the transition from the Lance to the Fox Hills formation. This unconformity is not present in all areas of the Powder River Basin but when present can significantly increase costs because of drilling NPT.

By applying a new and unique material, reticulated foam, in combination with engineered particle-sized lost circulation material (LCM), we can overcome this challenge. Results show this combination is successful at strengthening the loss zone and curing the losses while drilling, running, and cementing casing. Sweeps comprising 60-ppb multi-modal particulate material (MMPM) and 0.75-ppb reticulated foam pumped through the bottomhole assembly (BHA) provided short-term resolution of losses. For permanent wellbore strengthening, 100-ppb MMPM and 1.0-ppb reticulated foam pumped through a treating sub or open ended should be squeezed across the loss zone. These successful field applications are now a best practice for an area operator.

Introduction

General Mud Loss Mechanisms and Typical Solutions

Lost circulation is caused by various sources **(Figure 1).** The primary cause is mud losses into permeable formations. The loss flow paths are typically large pores in unconsolidated sandstone formations comprising large grains of sand. This is typically a seepage loss with a relatively low loss rate, and drilling can continue. The typical drilling solution is to pretreat the mud with a MMPM LCM. In less severe situations, sweeps of a MMPM LCM might suffice when pretreating the entire mud system.

Flow into existing large voids, such as natural fractures or vugs, is another source of lost circulation, and the mud losses tend to be severe/complete. Because the size and shape of the voids are unknown, stopping the losses typically necessitates some trial and error to help determine the optimal particle size and application. When conventional particulate LCM cannot mitigate the lost circulation, other solutions might be necessary, such as cement and chemical squeezes.

Induced fractures can also cause mud losses, which occur unintentionally during the hydraulic fracturing process when wellbore pressure is higher than the pressure necessary to initiate and propagate a fracture in a formation without near-wellbore pressure barriers. This cause of mud losses is typically difficult to address. During normal drilling operations, experience has shown it is preferable to prevent inducing fractures rather than cure them later. Pretreating mud with sealing particulate LCM can help ensure the near-wellbore pressure barrier is present to help prevent wellbore fracturing. Experience in a specific area might suggest a concentration sufficient to tighten the spurt loss to stop the fracture propagation in time. However, the concentration might be better assessed using a rock mechanics approach **(Ref. 1).**

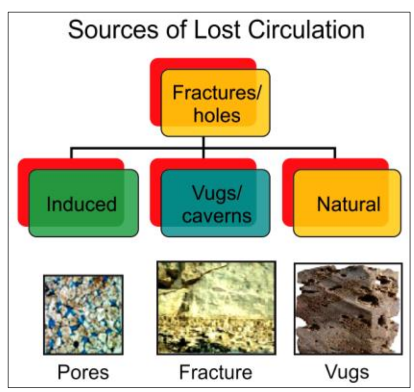

Figure 1—Sources of lost circulation.

Offset Well Lost Circulation

The Fox Hills formation in the southern Powder River

Basin is well known for severe to total lost circulation. It is typically encountered in the intermediate interval and can hinder reaching the planned casing point, as well as compromise cementation of the casing string. Historically, losses in this section range from 10,000 to 25,000 bbl of mud. Attempts to stop the losses using third-party particulate materials have been unsuccessful.

In previous wells, the operators attempted to drill with no returns, periodically suspending drilling activity to build sufficient fluid volume to continue drilling. This accounted for up to 2 days of drilling NPT as well as wellbore instability issues associated with pumping insufficiently inhibited fluid downhole while trying to maintain a safe fluid volume in the pits.

Table 1 shows typical intermediate formations in the southern Powder River Basin, with approximate depths **(Ref. 2).**

Table 1—Typical Powder River formations depths.

Formation	Measured Depth (ft)	Subsea (ft)	True Vertical Depth (ft)	Description
Fort Union	24	5,098	24	Fort Union at surface
Shale marker	1,249	3,873	1,249	Low-resistivity shale near base Fort Union
Top Lance	1,375	3,747	1,375	Top Lance
Lance marker	3,020	2,102	3,020	Middle Lance marker
Fox Hills	4,216	906	4,216	Fox Hills sandstone
Lewis	4,340	782	4,340	Lewis shale
Pierre	4,571	551	4,571	Pierre shale
Teckla	5,276	-154	5,276	Teckla B sandstone
Teapot	6,108	-986	6,108	Teapot sandstone
Parkman	6,693	-1,571	6,693	Parkman (shaley)
Steele	7,216	-2,094	7,216	Steele shale

The Fox Hills formation is located at 4,216 ft where there is an unconformity zone that might contain channels of unknown size **(Ref. 3).** This unconformity can extend to the Parkman formation. The mud losses are generally significant and difficult to mitigate using the normal particulate LCM for the area.

When mud weights are minimized and continuous background LCM is applied during drilling through the Fox Hills formation, losses are sometimes avoided. When present, losses treated with conventional LCM solutions can be 10,000 bbl of mud for each well with losses as high as 40,000 bbl at times.

If losses in this interval are not mitigated, drilling operations could be hampered by continuous mud losses and unacceptable cementing quality. Curing losses in the loss zone is always preferred before drilling ahead into deeper zones that are also potential loss zones.

New Engineering Solution for Effectively Sealing Large Voids of Unknown Sizes

To address the challenge of mitigating lost circulation from the unconformity loss flow paths of unknown sizes, a new LCM was selected. This new LCM solution contains sized reticulated foam (SRF). Three SRF sizes (fine, medium, and coarse) are available and can be selected based on the assessment of the loss rate and potential size of the void to be sealed off. Fine SRF is ±3 mm, medium SRF is approximately 10 mm, and coarse SRF is approximately 1 in. **Figure 2** shows an example of the SRF materials.

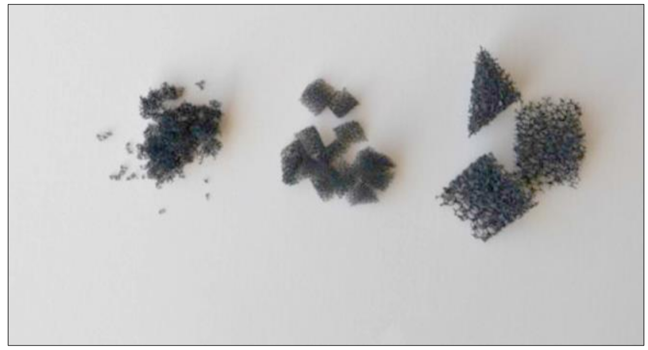

Figure 2—Fine, medium, and coarse SRF.

The reticulated foam is not the actual LCM but is the enabler that increases the efficiency and effectiveness of LCM combinations to which it is added. The foam LCM is typically mixed with other particulate solid LCMs in a carrying fluid, such as mud, to be pumped together as a pill. This unique foam material has interconnected pores to allow mud to pass through, but solid LCM accumulating on it forms an immobile mass—the seal. Additionally, the foam material is highly compressible and deformable. The foam LCM can be pumped through downhole tools and bit nozzles easily and into fractures or vugs substantially smaller than the foam when a pump rate of 5 bpm or higher is maintained. Because of these unique properties, placing the combination containing the SRF is most efficient when applied using a hesitation squeeze technique. To seal a void with the foam already inside, the operator simply stops the pump to allow the deformed reticulated foam to restore its size and shape and engage the side of the voids, such as the fracture walls. When the foam LCM enters the voids, forming a permeable layer, a low pump rate of approximately 0.25 bpm slowly squeezes the carrying mud through the SRF while screening out the mud solids and LCM. Over time, a significant amount of immobile solids accumulate and seal off the voids. Thus, knowing the precise size and shape of the voids is no longer necessary as long as the selected foam is larger than the void dimensions. Laboratory tests indicate this foam can work at temperatures up to 300°F.

Multi-Modal Particulate Material

The SRF can be used with any combination of LCMs, but the most efficient combination is to use it with an MMPM. During drilling, the SRF can be applied in sweeps with the MMPM but should not be a part of the background material because it will be shear degraded when exposed to multiple trips through the BHA and solids removal equipment. MMPM use effectively seals pores and smaller fractures during drilling. The MMPM is more than a broad distribution of particle sizes. It also contains material that is sized to have several concentration peaks at different size ranges **(Figure 3).**

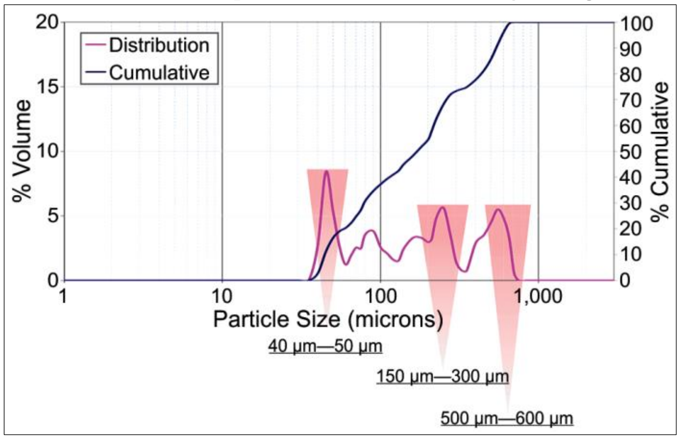

Figure 3—MMPM particle size distribution (PSD) example.

If the particulate LCM has a fast-sealing property (FSP) enhanced by the multi-modal PSD when mixed together with the SRF, the mixture pill has an FSP over a wide fracture and/or large vug size range. The FSP is determined by testing the sealing particulate LCM over a slot simulating a fracture entrance. The spurt loss of the test is converted to milliliters per foot of slot. When this spurt loss is low, a seal can form in a few seconds. Because of the particulate LCM's FSP, the mixture pill can be used as a sealing sweep pill to quickly seal off multiple natural fractures during drilling. **Figure 4** shows a fast-sealing multi-modal particulate (FSMMP) LCM that produces only 46 mL or less spurt loss over a 1-ft slot length of an 850-micron wide slot when tested at a concentration of only 20 ppb. This fast sealing performance is a quality assurance standard maintained at the factory to help ensure a truly high-performance product.

When SRF is mixed with a high-fluid-loss LCM formulation, laboratory tests show that it can enable such a pill to seal a slot as wide as 10 mm with a 4,000-psi pressure differential **(Ref. 4).**

Figure 4—FSMMP LCM.

Field Applications and Results

Specific criteria for the most efficient and effective lost circulation prevention and mitigation are presented in Appendix 1. A general description of the applications is presented here.

For the first well in the Powder River Basin, field personnel worked closely with the operator to develop a strategy for reducing the loss severity and NPT incurred while addressing these losses. They reviewed offset well data and collaborated with the service company's global technology group to determine the best practices and LCM options for this specific set of conditions. This treatment protocol has also been applied to subsequent wells successfully, reducing losses by 47% on average (Figure 3).

Sweeps formulated with FSP LCM and medium and coarse SRF were pumped at various intervals, with pill concentrations ranging from 30 to 120 ppb, depending on the downhole loss severity. Soft squeezes were applied to help ensure proper pill placement.

The sweep and squeeze protocol helped save 1 to 2 days of rig time valued at USD 100,000 to 200,000. The operator also saved more than USD 400,000 associated with drilling fluid costs and significantly reduced downtime during LCM treatments. Cement reached higher in the annulus than on any previous well, helping ensure good casing integrity and fewer workover interventions in the future.

Summary

In the southern Powder River Basin, on every well in which SRF, multi-modal particulate LCM, and an engineered application method was applied, the circulation loss was remediated. This allowed the operator to drill to target depth (TD) without losing any additional fluid downhole. This is the first time these losses have been remediated in an area where previous LCM materials were unsuccessful.

Such results answer the question presented by many operators as to whether this loss zone could be remediated. The LCM success is attributed not only to the unique material type but also the collaborative engineering work performed to develop the best application method.

Ultimately, a solution has been developed for an issue that has impacted a prolific Wyoming basin for many years, with unprecedented results.

Acknowledgment

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Appendix 1: Application Procedures

This section presents the recommended lost circulation prevention methods and procedures followed during operations in the Powder River Basin.

Volume Preparation Before Drilling Out of Casing

- Begin the interval with all storage capacity topped off (mud tanks, KCl spike fluid, premixes, and reserve storage tanks).
  - If the rig's mud pumps cannot pull straight from the premix, it is recommended to isolate a rig tank that can pump straight downhole and prepare an LCM pill in that tank before drilling out.
  - LCM should not be added to the pill tank until the fluid has a 6-RPM reading of 8 to help ensure all LCM remains suspended in the tank.
- Add 60-ppb FSP LCM to the pill tank. Have sacks of lost circulation additive on the tanks and ready to mix. If material has compacted, break up the material in the sack and have ready to mix. Material should be mixed over the top of the tank. Guard rails should be set up to help ensure safety on the tank.
  - Mix two additional sacks more than the calculated reticulated foam sacks because some material is wasted during mixing and lost to rig grates.
- Use dilution rates of 25 BPH to maintain the rig's pit volumes as high as possible while drilling. This dilution rate will help ensure the pit volume remains at the highest safe operational level and make up for fluid lost to cuttings while drilling.
- Test all transfer pumps to help ensure they are in good working order before transfers are necessary.

Rig and Solids Control Preparation During LCM Mixing

- The drillpipe screen might need to be removed for 60 ppb or greater concentration sweeps, if it is allowed by the directional company.
- Drying shakers used on the intermediate section are recommended to help reduce the volume of fluid lost to cuttings.
  - Fluid from the drying shakers should be run through a centrifuge before being pumped back to the active system.
- One centrifuge should be continuously run on the active system to help manage mud weight at <9.0 ppg.
- Gun lines should be turned off when continuous LCM treatments occur. Hopper lines should discharge directly into the suction tank to prevent diluting the LCM being added to the system.
- If trips are necessary, it is recommended to pump the drillstring fluid capacity with clean fluid to help prevent plugging the BHA with LCM in the drillstring.

LCM Procedure with N_2 Contingency

- A base fluid system of 3.0% KCl polymer (beginning outside the surface casing shoe) should be used.
  - Background concentration of LCM containing 10-ppb 50-micron bridging agent and 10-ppb ground marble.
  - Maintain continuous treatment while drilling.
- Drilling fluid additive sweeps should be considered during drilling to assist in hole cleaning. Mud engineer recommendations for mixing the drilling fluid additive should be followed. A wiper trip is recommended before entering the Fox Hills formation.
- After the wiper trip, adjust the continuous treatment to one ground walnut LCM, one 600-micron bridging agent, and one 150-micron bridging agent per 15-minute treatment until through the Parkman formation.
- At the first sign of losses, pump the previously prepared LCM pill that contains 60-ppb FSP LCM, 0.5-ppb medium-grade reticulated foam, and 0.25-ppb fine-grade reticulated foam. This pill should be timed to the bit, and the shakers should be monitored for returns.
  - Exact depth and pumped volume should be recorded on the mud report.
- A second pill should be prepared and immediately pumped behind the first sweep.
- *If no returns are achieved after pumping three 60- to 70-bbl sweeps, it is recommended to perform a wiper trip to the shoe, observe if the hole remains full, and attempt to break circulation before turning on N_2 for drilling.*
  - *If the hole is not full and returns are not achievable at the shoe, the rig should wash and ream to bottom on fluid, then drill two stands down with low N_2 air at 200 to 250 ft^3/min before spotting and soft squeezing an LCM pill.*
- If returns are achieved with the sweeps, drill ahead at 600 to 650 gpm and 100 ft/hr, closely monitoring for losses while drilling. If returns are lost again, defer to the previous underlined italicized bullets regarding short tripping and preparing for air.

Soft Squeeze Recommendation

- The squeeze pill should consist of well-blended LCM and pumped through an open BHA and bit with no jets or open ended.

- The LCM pill should contain 140 bbl of 90-ppb FSP LCM, 0.5-ppb coarse SRF, 0.25-ppb medium SRF, and 0.5-ppb swellable LCM.
  - The 140 bbl cover approximately 1,000 ft of the 12.25-in. openhole volume.
- The LCM pill should be displaced such that 1,000 ft of LCM pill remains in the drillstring to avoid diluting the pill in the annulus.
- The drillstring should be picked up into the casing for the squeeze operation, if possible.
- Squeeze pressure is determined by the operator, but 1.0 ppg greater than the actual mud weight is recommended for the depth being squeezed.
  - If the loss zone is at 6,500 ft with an 8.8-ppg fluid, then 338 psi should be slowly targeted.
- If 60 bbl is squeezed away and zero pressure is achieved, a second pill of 140 bbl should be spot and squeezed again.
  - If pressure builds, it should be held and the pumps bumped as needed to maintain target pressure for 2 hours.
  - After 2 hours of holding pressure, the rig should trip out and pick up a new drilling BHA.
- The previously spot and squeezed LCM pill should be reamed through while adding LCM to the system.