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Elimination of Wellbore Instability and Water Influx with Fluid Technology Used in Over 60 Wells in the Bakken

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Abstract

Wellbore instability and fluid loss to downhole formations are frequent and costly drilling issues. Stress caging and pumping of lost circulation material are two methods used to lessen the impact of these events; this paper presents another solution. To address the issue of wellbore instability within challenging shale and sand formations, several operators in North Dakota have adopted drilling fluid technologies that have significantly improved their drilling programs. The operators drilled nearly 60 wells without incident in a region characterized by catastrophic hole instability.

Offset wells typically address wellbore instability after the fact. The operators of the wells discussed in this paper proactively utilized a unique drilling fluid technology to prevent instability. When drilling, this technology forms a barrier over mechanically weak, depleted, and fragile formations. As a result, the operator avoids drilling fluid losses, stuck pipe, and other wellbore instability issues that typically increase NPT and add unplanned costs associated with lost circulation.

In this region, new operational drilling practices were adopted by multiple operators to eliminate wellbore instability, lost circulation, and water influx from nearby saltwater injection wells while extending mud weights in mechanically weak formations. In the wells documented in this paper, the results demonstrated minimal whole mud losses with extended mud weights in the 17½-in. surface hole section and 12¼-in. intermediate section.

By limiting fluid and pressure invasion into matrix pores and microfractures, this drilling fluid technology can stabilize difficult zones and prevent loss-inducing fracture propagation. When applied properly in the field, this drilling fluid technology can help to reduce wellbore instability and operational costs, while ensuring safe and cost-effective performance when drilling near saltwater disposal wells.

Introduction

Drilling in the maturing Williston Basin of North Dakota, presents challenges due to nearby salt-water disposal wells. Drilling near these pressurized Dakota Sand salt-water disposal wells requires higher mud densities to control the saltwater inflow. The higher mud densities typically result in breakdown of the fragile upper Greenhorn and the Mowry formations causing lost circulation, destabilization of the wellbore, and leading to issues achieving adequate cement jobs on subsequent casing strings.

The Bakken Formation and Dakota Sands

Many wells drilled in Williams and McKenzie Counties in the Williston Basin (Fig. 1) are frequently designed with four casing strings to account for wellbore instability. One of these casing strings, termed the "water string", is used to isolate the over-pressured Dakota Sand group as well as the fragile Greenhorn and Mowry formations. This paper focuses on several operators' experiences drilling on multi-well pads in McKenzie and Williams counties, and how a shift in their operational strategies has led to the elimination of wellbore instability and NPT.

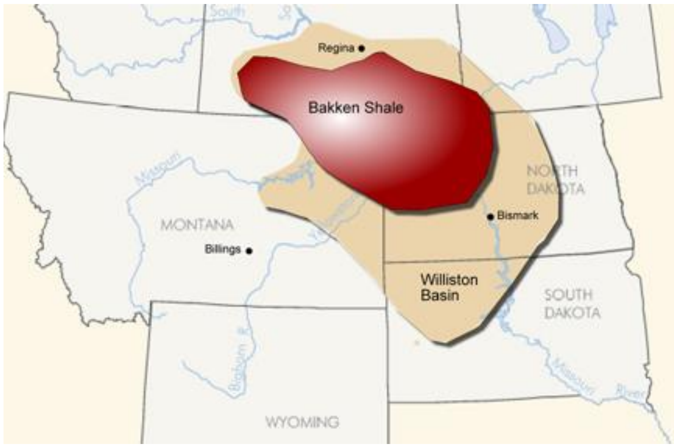


Figure 1 – The Bakken formation in North Dakota and Montana (*Bakken Oil Business Journal*).

According to the U.S. Geologic Survey (USGS 2021), Williams and McKenzie Counties, in northwestern North Dakota are located near the center of the structural and sedimentary Williston Basin (Fig. 2). The preglacial sedimentary formations beneath the county are as thick as 14,828 feet. These beds mainly dip to the south, except along the sides of the north-south Nesson anticline in the counties eastern section. With the exception of a few scattered areas along the Missouri River, Williams County is entirely covered by late Wisconsinan glacial deposits.

Figure 2 – USGS Map of Nesson Anticline and Williston Basin ([USGS 2021](#)).

The Dakota Sands are a sedimentary geologic formation in midwestern North America. Dakota units are formed mostly of sandstones, mudstones, clays, and shales that were deposited with the opening of the Western Interior Seaway in the mid-Cretaceous Era (USGS 2021).

The drilling operators plan upcoming wells by analyzing data from nearby offset wells to determine if the "water string" in the four-casing string well design is required.

Shielding Technology Solves Saltwater Flow Losses

While drilling the vertical section on the first well of a multi-well pad, a Bakken operator encountered a salt-water influx from a nearby saltwater disposal (SWD) well. The operator increased the mud density to 11.6 lb/gal to stop the saltwater flow which created a lost circulation event in the Greenhorn and Mowry formations. The operator was unsuccessful in achieving returns using conventional lost circulation materials (LCM). Due to losing massive and costly amounts of oil-based drilling fluid (OBF), the operator displaced the drilling fluid system to a water-based drilling fluid (WBF). The operator attempted to stop the loses with several types of LCM, but was unable to regain circulation. After several days of non-productive time (NPT), the operator made the decision to plug and abandon this well.

The operator moved the rig to the next well on the same pad. As soon as the operator finished drilling out of the pre-set surface casing, they displaced the drilling fluid system to an OBF that had been treated with 8 lb/bbl of a proprietary wellbore stabilization technology (WST).

The operator increased the mud density to 12.8 lb/gal (**1.2 lb/gal heavier** than the previous well) prior to drilling into the Dakota Sand formations. Increasing the mud weight and using the WST, prevented the influx of saltwater from the nearby disposal well and allowed the operator to successfully drill this well to casing point (5,900 ft). The casing was successfully run to bottom without issue, however lost circulation was encountered during the cementing of the casing. A two-stage cement job was performed to achieve the appropriate zonal isolation required by federal regulations from the Bureau of Land Management (BLM). The BLM requires operators drilling in the state of North Dakota to provide evidence of casing being set and cemented in a competent formation by evidence of a compliant Cement Bond Log (CBL) as well as returns of cement to surface.

Prior to drilling out the pre-set surface casing on the following well on the same pad, the operator treated their active drilling fluid system with 8 lb/bbl of the same WST additive as they had on the previous well. Prior to drilling into the Dakota Sand group, the mud weight was increased to 12.8 lb/gal and the interval was drilled to casing point while achieving full returns. Before pulling out of the hole to run casing, the operator spotted a pill consisting of 30 lb/bbl WST additive with capabilities of sealing the 500-µm fractures across the mechanically weak Greenhorn Shale formation. A single stage cementing application was completed by running and cementing the casing, successfully lifting cement to the surface, and complying with regulations.

The operator attributes the successful application of the WST additive to the stabilization of the overlying, mechanically weak Greenhorn and Mowry formations. Use of the WST allowed the operator to successfully drill the remaining wells on this pad without experiencing any further issues.

The oil company subsequently held a round-table discussion with nearby operators who were experiencing similar problems with saltwater flows while drilling near SWD injection wells, which had similarly resulted in catastrophic lost circulation events and made achieving cement-to-surface problematic.

Following the round-table discussion, other operators adopted and successfully implemented this paper's wellbore shielding technology into their drilling operations.

Over-Pressured Dakota Sand

While operating in Williams County, another oil company was experiencing similar issues when drilling through the over-pressured Dakota Sand group formations on their first two wells of a proposed four-well pad site. Catastrophic hole instability and lost circulation events while attempting to drill through these challenging formations led to the abandonment of these wells.

On the subsequent wells on this pad, this operator adopted the use of a wellbore shielding technology used to create a barrier that can minimize the fluid and pressure invasion into these mechanically weak formations. The active drilling fluid system was pre-treated with an 8-lb/bbl concentration of the WST additive prior to drilling through the mechanically weak Greenhorn shale formation. This 8-lb/bbl concentration of the WST product was maintained as a background material in the circulating system while drilling to the programmed casing point without incident. After completing a successful wiper trip, a 30-lb/bbl pill treated with the WST additive capable of sealing up to 500-µm fractures was spotted across the fragile Greenhorn formation. Casing was successfully run to bottom and cemented while achieving the planned cement to surface returns, isolating the problematic Greenhorn shale formation.

The drilling fluid system was then displaced to a 12.5-lb/gal OBF and again pre-treated with an 8-lb/bbl concentration of the WST additive. A successful Formation Integrity Test (FIT) was performed and the mud weight was increased to 13.2 lb/gal before drilling into the over-pressured Dakota Sand formations. The interval was drilled to the programmed casing point without incident and a sweep consisting of 60 lb/bbl of conventional LCM was circulated. Casing was run and cemented on bottom with partial returns.

On the final well of this 4-well pad, the operator treated their active drilling fluid system with an 8-lb/bbl concentration of the WST product before drilling into the fragile Greenhorn shale formation. The interval was drilled to casing point without incident and a pill consisting of 30-lb/bbl WST additive capable of sealing up to 500-µm fractures was then spotted across the Greenhorn formation. The casing was run and cemented on bottom with over 300 bbl of excess cement returned to surface.

The well was then displaced with the same OBF system used on the previous well on this pad already consisting of an 8-lb/bbl concentration WST product. Upon the completion of a successful FIT, the mud weight was again increased to 13.2 lb/gal and the Dakota formation was drilled through to the programmed casing point without incident. The casing was run and cemented on bottom while again achieving cement to surface.

WST Stabilizes Fragile Formations

The WST additive is a proprietary organic cellulosic technology that is designed to form a thin, flexible layer, or "shield" when added to a drilling fluid system (Herdes, 2017; Brassette et al., 2018; Devadass et al., 2019; Haddad et al., 2019; Jordan, et al., 2019). Once introduced into an active drilling fluid system, these particles produce an extremely low permeability boundary at the fluid-rock interface, delivering an equally low invasion area across a broad range of porosity and microfracture sizes (1 to 250 µm). Additives are available to extend the basic particle size distribution of the WST to cover fractures up to 3,000 µm.

Specifically, when a fracture begins to develop, a low permeability seal instantly forms over the face of the fracture, preventing continuous invasion of fluid into the fracture and eliminating ongoing fracture propagation (Fig. 3). Through the application of this impermeable barrier over pores and microfractures, the technology effectively limits the transfer of destabilizing wellbore pressure to the pore fluid as well as the intrusion of filtrate into the matrix permeability and microfractures. As a result, the fracture initiation pressure is increased and the fracture propagation process is inhibited as a direct consequence of the surrounding formation being isolated from the drilling fluid pressure in the wellbore (Fig. 4).

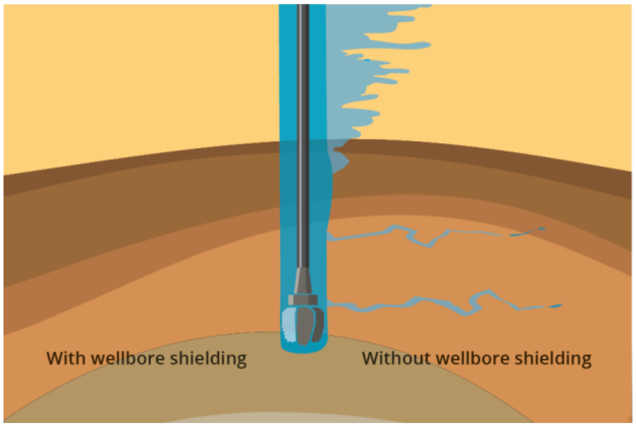
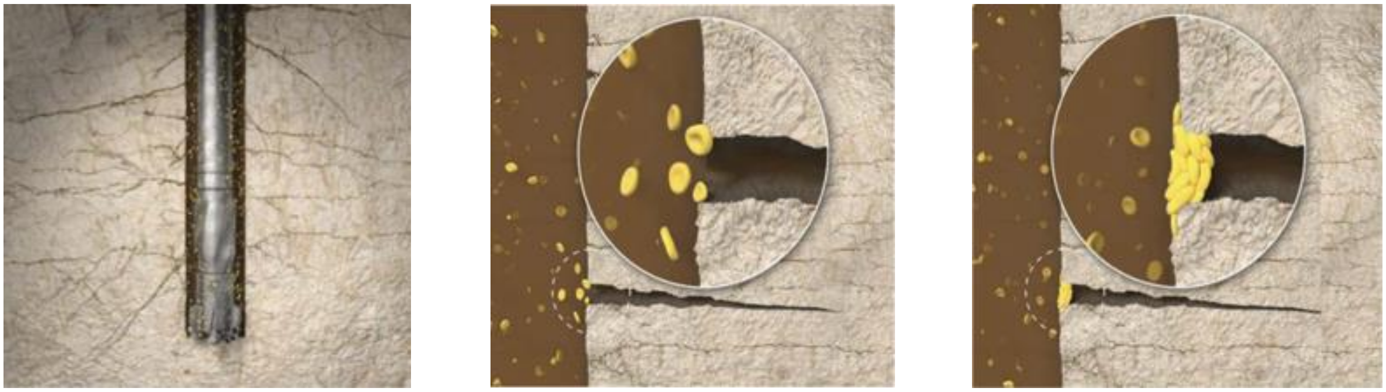


Figure 4 – Left: the protective nature of the wellbore shield that prevents drilling fluid from penetrating into the formations. Right: fluid lost to the fragile formations without the use of the WST.

The WST additive does not adversely impact the rheology of the drilling fluid and can be used in all WSF, OBF, and synthetic-based drilling fluids. The versatility of the WST product to isolate the drilling fluid pressure from the formation pressure is especially important in situations such as the saltwater flows (Fig. 5). Use of the WST product allowed the drilling fluid density to be increased slightly and thus control the increased pressure from the saltwater flow.



Initially, the WST particles are free-floating in the drilling fluid.

As the differential pressure increases, the shielding particles form a protective layer over the fracture mouth.

Finally, the shielding particles form a nearly impenetrable barrier against fluid and pressure invasion.

Figure 3 – WST particles isolate the formation from drilling fluid invasion.

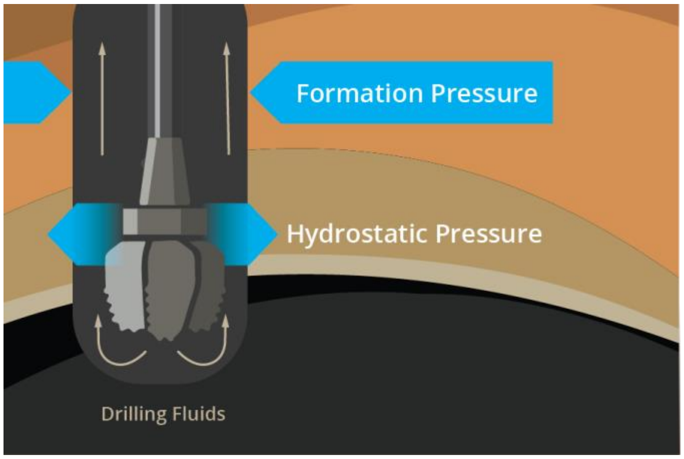


Figure 5 – Along with the isolating the wellbore from region's weak or over-pressured formations, the drilling fluid must be tailored to control hydrostatic pressure from the saltwater flow.

The WST barrier is designed with low flow initiation pressure characteristics. In most circumstances, the shield is removed easily by simply flowing the well. Specifically, the WST particles deposit themselves along the wellbore wall due to differential pressure between the drilling fluid and the formation fluids. Once production is initiated, the inflow of fluid into the well lifts the shield particles from the formation wall with minimal flow required to achieve exceptional return permeability (Fig. 6).

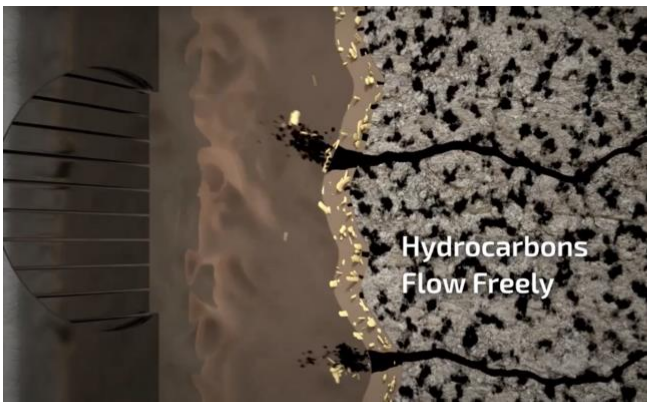


Figure 6 – Illustration of hydrocarbons flowing freely once production is initiated.

Since the unique sealing mechanism limits the transmission of wellbore pressure into the formation, the dramatic reduction of fluid influx in the microfractures minimizes the risks of formation breakdown and effectively stabilizes weak shales.

The WST approach differs from conventional LCM, such as calcium carbonate and graphite, in that these materials are ineffective until the wellbore destabilization has already started. i.e., losses are occurring. The approach used operationally with the shielding technology is to protect the wellbore from destabilizing. In addition, typical LCM products are much more difficult to remove from the deep fractures and usually require a cleanup process to initiate production flow (Fig 7).

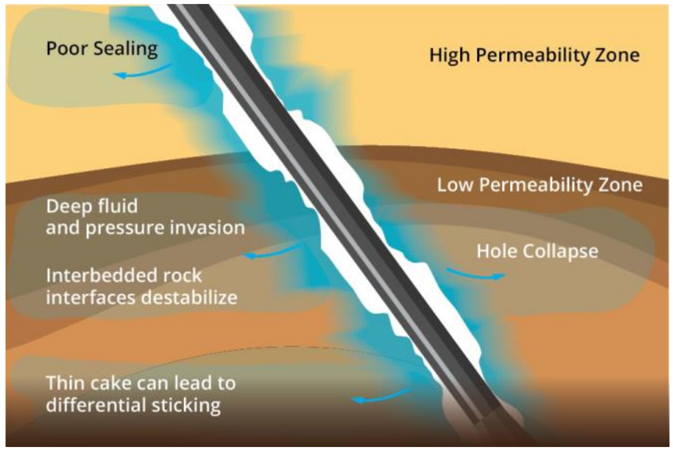


Figure 7 – Issues using conventional LCM with poor sealing in multiple formation types.

As field proven in this paper, the WST containing drilling fluid can be reused, on a different well. The addition of WST does not adversely affect drilling fluid flow properties and thus does not contribute to elevated equivalent circulating densities (ECD).

Conclusions

Repeated wellbore instability, including instability caused by water influx from nearby saltwater injection wells, was eliminated by a number of operators in the Williston Basin as a result of new operational drilling procedures using wellbore shielding technology.

Using a wellbore shielding additive prior to drilling through the problematic zones helped to stabilize weak formations while also allowing for the extension of mud weights with several active operators.

From an operational perspective, the usage of the fluid additive technique described in this paper has been extremely successful with local operators in the vicinity of saltwater disposal wells, and it has now been successfully implemented in other drilling regions as well.

In addition to the elimination of wellbore instability and the resultant NPT that had previously increased operators' costs, operators achieved cement-to-surface returns, as required by the BLM, saving additional cement costs and time.

Acknowledgments

Impact Fluid Solutions would like to express its appreciation to the Operators who have continued to rely on our technology in the Williston Basin. Thank you, AADE, for providing us with the chance to demonstrate our technology.

Nomenclature

BLM = *Bureau of Land Management*
CBL = *Cement Bond Log*
ECD = *Equivalent Circulating Density*
FIT = *Formation Integrity Test*
HSE = *Health, Safety, and Environment*
LCM = *Lost Circulation Materials*

NPT = *Non-Productive Time*
OBF = *Oil Based Drilling Fluid*
SWD = *Saltwater Disposal*
WBF = *Water Based Drilling Fluid*

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