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Wellbore Stabilization for Unconsolidated Formations in the Greater Permian Basin

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Abstract

Specialized drilling fluid treatments have greatly improved the stabilization of unconsolidated formations in the greater Permian Basin. This paper reviews several successful case studies for four typical unconsolidated formations, which are the hydratable Santa Rosa "red bed" formation, the San Andres formation containing high porosity and problematic sands, the Clearfork formation that may have natural and drilling-induced fractures, and the Spraberry formation that is frequently depleted and plagued with pressure-sensitive natural fractures.

A multi-functional deformable inhibitor (MDI) was introduced to enhance the drilling performance in combination with conventional drilling fluids. This paper illustrates its properties, supported by laboratory testing results, leading to the successful protection of the San Andres formation in Andrews County, the Clearfork formation in Martin County, and the Spraberry formation in Howard County by reducing fluid invasion.

After the Santa Rosa "red bed" interval of the wellbore in Cochran County was severely hydrated, a modified fluid system containing MDI restabilized the formation under a combined action of mechanical plugging and chemical inhibition. It blocked pore throats and encapsulated the clay particles to prevent them from dispersion into fluids. These successful cases provide an efficient and environmentally friendly solution to stabilize the unconsolidated formations in the Permian Basin.

Introduction

Unconsolidated formations are mainly caused by the existence of sand grains. Insufficient natural cohesion (Stephens and Bruton, 1992) between the sand grains may result in wellbore instability, which is a principal challenge when drilling in the unconsolidated formations.

Unconsolidated formations are one of the typical problems resulting in lost circulation that prevents a filter cake from forming. Certain number of unconsolidated particles in the annulus may also lead to stuck pipe. As a consequence, mud systems with outstanding walling capacity are desirable, which should contain adequate and appropriate-sized bridging materials.

Drilling fluid system selection is essential to provide sufficient borehole wall support and to overcome the challenges in the depleted sand formations. Density, rheology, fluid loss control, economy, and simplicity are the principal selection criteria for drilling fluids in the unconsolidated formations (Payne et al. 1993).

Table 1 presents a generalized stratigraphic column of the Permian age system in the Permian Basin. The San Andres, Clearfork, and Spraberry formations are often beset with wellbore instability and lost circulation. The shallower zone of the Permian Basin contains surface sand, the "red bed", which is a reddish-colored, clay-like shale stratum. Circulation losses are also frequent in the Santa Rosa sands. Drilling through red bed formations is complex and time-sensitive due to red beds' swelling, threatening the process of running casing.

Table 1-Stratigraphy in Permian Age System

Series	Delaware Basin	Central Basin Platform	Midland Basin
Ochoa	Santa Rosa Rustler Salado Castile	Santa Rosa Rustler Salado	Santa Rosa Rustler Salado
Guadalupe	Lamarbell Canyon Cherry Canyon Brushy Canyon	Tansill Yates Seven Rivers Queen Grayburg San Andres	Tansill Yates Seven Rivers Queen Grayburg San Andres
Leonard	Avalon Shale 1st Bone Spring 2nd Bone Spring 3rd Bone Spring	Clearfork Wichita Albany	Clearfork Upper Spraberry Lower Spraberry Dean
Wolfcamp	Wolfcamp	Wolfcamp	Wolfcamp

This paper presents several field cases utilizing a proprietary multi-functional deformable inhibitor (MDI) to enhance the drilling performance of the unconsolidated formations in the Permian Basin. After traditional solutions had proven to be ineffective, cost-prohibitive, or time-consuming, fluid systems containing the environmentally-friendly MDI have successfully minimized lost circulation and strengthened the wellbore in unconsolidated Santa Rosa, San Andres, Clearfork, and Spraberry formations.

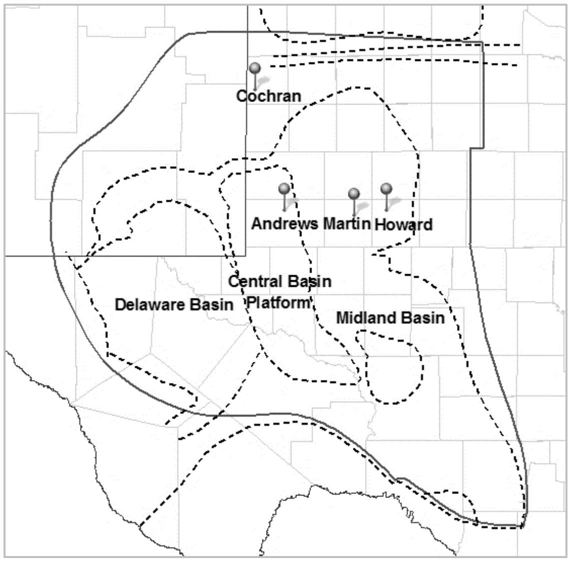

Figure 1– Typical MDI-applied wells in the Permian Basin

Multi-functional Deformable Inhibitor (MDI)

The proprietary MDI is a white powder with a 0.66-0.75 specific gravity. MDI significantly retards water hydration on clay particles, which enable drilling through the swellable formations like Santa Rosa red bed. Besides the outstanding clay inhibition capacity, it also maintains excellent performance in low pH environments, as well as fluid loss control capacity while maintaining a low-viscosity fluid.

A series of laboratory experiments were conducted to prove the outstanding fluid loss control and wellbore strengthening capacity of MDI contained in Fluid D and E. The rheological properties showed in **Table 3** present that MDI provides excellent solids-carrying capacity without eroding the wellbore.

Table 2-Drilling fluid groups designed for testing	
Fluid A	Base Fluid
Fluid B	Base Fluid + 4 ppb Sulfonated Asphalt
Fluid C	Base Fluid + 4 ppb Treated Gilsonite
Fluid D	Base Fluid + 2 ppb Treated Gilsonite + 2 ppb MDI
Fluid E	Base Fluid + 4 ppb MDI

Table 3-Rheological properties					
Fluid	A	B	C	D	E
600 RPM	26	27	37	46	30
300 RPM	19	22	30	31	20
200 RPM	5	14	28	28	15
100 RPM	13	12	25	25	13
6 RPM	8	7	15	14	8
3 RPM	7	6	14	13	7
PV @ 120 °F	7	5	7	15	10
YP	12	17	23	16	10
Gel Strength (10s /10 min)	13/28	11/25	11/27	14/25	11/23

Results of high-pressure high-temperature (HPHT) and dynamic filtration proved that MDI can help minimize mud spurt and fluid loss while constructing a thin protective wall cake. HPHT filtrations were performed at 250 °F and 500 psi. Dynamic filtrations were performed at 250 °F, 1000 psi, and 600 RPM, with 5-Darcy 20-micron filter media.

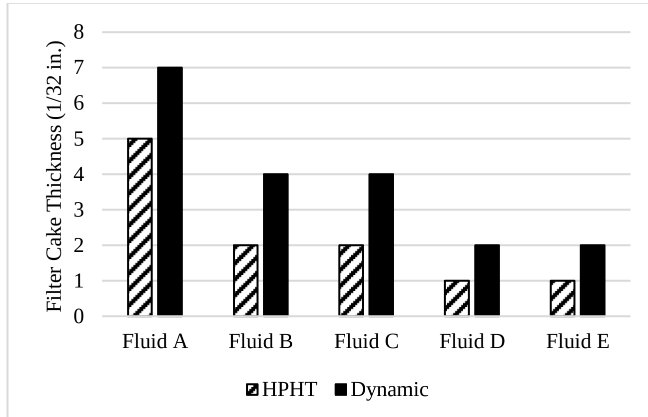

Figure 2- Performance of MDI on filter cake thickness

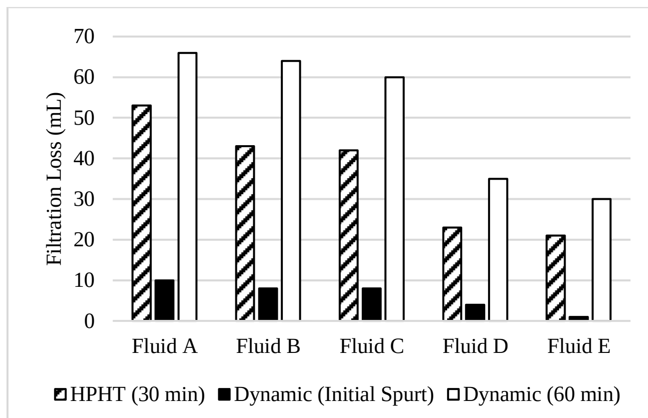

Figure 3-Performance of MDI on filtration loss

MDI is able to provide two different inhibition mechanisms: chemical inhibition which capsulizes the clay particles to prevent coagulation, and mechanical plugging. From **figure 3**, decreasing initial spurt loss volumes with the increasing percentages of MDI proved its capacity of plugging. Appropriate-sized MDI particles are able to block pore throats and encapsulated the clay particles to prevent them from dispersion into fluids.

Case Study

Cochran County – Santa Rosa "Red Bed" Formation

The following is a case study of a well where the MDI stabilized the red bed after becoming problematic in the Santa Rosa and Rustler formations. This allowed for successful casing run after the "red bed" was exposed 20 days.

Surface casing was set at 480', leaving the problematic red bed exposed. A partially saturated sodium chloride brine system, in which pre-hydrated lime was added for pH control, was used to drill out under the surface casing. At 1,500', approximately 1% by volume liquid partially hydrolyzed polyacrylamide (PHPA) was added to the system. Then, a brief stuck pipe incident was observed. The hole was then conditioned with salt gel (attapulgite clay) and yellow starch (corn starch), followed by 1% by volume field oil to achieve a 45 sec/qt apparent viscosity, 15 mL/30 min API filtrate, 8.0 pH with a 9.4 ppg mud weight.

The drilling was continued over the next 3 days, but solids were not adequately controlled. Low gravity solids (LGS) ranged from 4.0-7.5%, apparent viscosity ranged from 45-70 sec/qt, mud weight ranged from 9.4-11.0 ppg, and API filtrate ranged from 20-45 mL/30 minutes. Drilling ahead without any problems was being reported until approximately 3,200' when rate of penetration (ROP) dropped to less than 10 ft/hr, which leading to a bit trip. It was recorded that the trip out of the hole went smoothly, but tripping back in the hole then hit a bridge at approximately 1,500'.

Over the next 4 days, there were several attempts for hole cleaning, such as lowering the LGS to less than 3%, increasing oil content to 2% by volume, raising the funnel viscosity to 75 sec/qt, lowering the API filtrate to 4 mL/30 min., and adding in a liquid asphaltic material turning the system into an asphaltene based oil (ABO). However, no progress was made when the well in the red bed interval was severely hydrated for 9 days.

Crucially, 2 ppb of MDI was added to the system at this point. Within 2 hours of the MDI being applied, torque and drag started to decrease. The hole was able to be cleaned while reaming back into the hole. After 4 hours of reaming, to approximately 2,200', tripped in the remaining 1,000' and continue drilling a new hole.

Over the next 10 days viscosity ranged from 65-75 sec/qt, mud weight ranged from 10.1-10.9 ppg, API filtrate range from 4-6 sec/30 min, LGS ranged from 4.0-6.5% by volume, oil content and asphaltenes were no longer added dropping the oil content from 2% to 1% due to dilution but the MDI continued to be maintained between 2-4 ppb. The ROP averaged 7 ft/hr over the next 10 days due to high solids content but the well was drilled to planned total depth. Casing was cemented on the bottom performing as if no instability issue had occurred. MDI restabilized the formation when the red bed had been exposed for 20 days.

Andrews County – San Andres Formation

The following surveys three horizontal wells in chronological progression.

Andrews Well #1

The lateral was drilled with a cut brine system at a 28 sec/qt apparent viscosity utilizing pre-hydrated bentonite and xanthan sweeps, circulating the reserve with reported rates of penetration averaging 105 ft/hr. Severe losses were seen at a fluid weight of 9.5 ppg with ensuing differential sticking and torque creating further impediments to drilling. Heavy losses continued to total depth of the well with fluid weights ranging from 9.0-9.8ppg. Total days on well were 21 days with the majority being non-productive time due to stuck pipe and losses.

Andrews Well #2

The next well utilized a xanthan gum and starch fluid system with a 40 sec/qt apparent viscosity circulating the rig's pit system and utilizing surface solids control. There were losses seen, however, not nearly as severe as the aforementioned well. Due to the plugging effect of the fluid the weight tolerance of the formation was as high as 10.5 ppg. Additional cost was added due to whole mud dilutions to combat solids accumulation. The major impediment to drilling using this system was a 40-50% reduction in penetration at 65 ft/hr versus previous wells.

Andrews Well #3 – MDI Solution

Saturated sodium chloride brine was used to drill the lateral circulating the reserve pit with an apparent viscosity of 28 sec/qt. The hole was swept with high-viscosity sweeps comprised of xanthan gum and 5 ppb of MDI. Minimal seepage was seen through the length of the well with reported fluid weights ranging from 10.0-10.1 ppg. Reported penetration rates averaged at 110 ft/hr with some variation above and below. The drilling days (spud to TD) of the three wells are summarized in **Figure 4**.

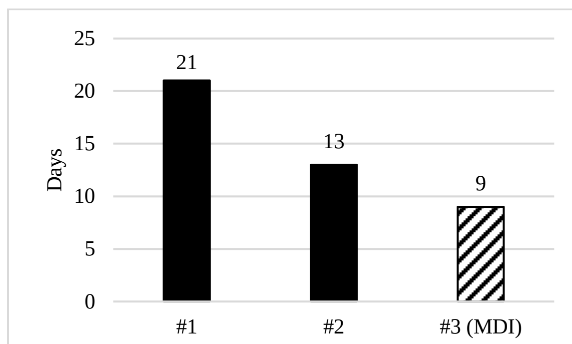

Figure 4-Drilling days (spud to TD) of Andrews Well #1-3

Martin County – Clearfork Formation

In Martin County, three example wells in Block 36 T-2-N are presented, generalizing the typical problems in this area and illustrating how MDI addressed the problems.

Martin Well #1

The Clearfork formation was drilled with fresh water utilizing a surfactant at 0.1% by volume and frequent high-viscosity gel sweeps were pumped. The average annular velocity (AV) was raised to around 250 ft/min and the average ROP was increased to around 60 ft/hr initially. Minor seepage was observed while entering the Clearfork formation, however, heavy seepage was detected about 300 ft into the Clearfork formation. Fiberous and granular lost circulation material (LCM) were utilized to address the losses. The LCM was only temporarily effective after being pumped. Observed temporary increase of torque and drag followed by enlarged cuttings. Average ROP after seepage began was around 25 ft/hr. Drilling operations were stopped on multiple occasions due to the heavy seepage.

Martin Well #2

The Clearfork formation was still drilled with fresh water utilizing a surfactant at 0.1% by volume. Only occasional high-viscosity gel sweeps were pumped to aid in hole cleaning. The average AV was increased to 300 ft/min and the average ROP was increased to just over 140 ft/hr initially. Minor seepage was observed initially entering the Clearfork and heavy seepage to no returns was observed about 350 ft into the Clearfork. Pump rates were decreased to an average AV around 250 ft/min and granular and fibrous LCM sweep were pumped. After decreasing the pump output the ROP decreased to around 70 ft/hr. After the LCM sweep started covering the Clearfork formation losses decreased temporarily but began increasing within the hour. Decision was made to pump aggressive LCM sweeps but increase AV to 300 ft/min. The average ROP increased to around 140 ft/hr while drilling the remaining Clearfork formation, as well as over 100 ft/hr for the remaining wellbore interval.

Martin Well #3 – MDI Solution

200 ft of the Clearfork formation was drilled with a 9.6-10.0 ppg NaCl brine. Initially entering the Clearfork formation heavy seepage were observed. MDI sweeps with fiberous and granular LCM was pumped and losses were reduced to minimal seepage. After successfully setting casing into the top of the Clearfork, the problematic area of the Clearfork was drilled with fresh water treated with 0.06% by volume surfactant an average AV of around 250 ft/min and frequent low volume high viscosity sweeps with gel and MDI were pumped. The ROP averaged over 100 ft/hr, and more importantly, no losses were observed again while drilling the Clearfork formation.

Howard County – Spraberry Formation

The following surveys a grouping of horizontal wells in the same field with progressive fluid applications to mitigate issues common to the area such as an over-pressured San Andres and losses in deeper, weight-sensitive formations. Modification of casing designs and fluid systems were necessary for the overall success and economics of the wells.

The wells all have a three-string casing design but vary in the type of mud system used and the intermediate casing point. The progression of intermediate casing points and fluid systems depends largely on the effects of an over-pressured San Andres, the need for adequate mud weight to balance the San Andres and losses in weight sensitive formations below, namely the Clearfork, Spraberry and Dean.

Howard Well #1

Projected plan was to drill a 12 ¼” hole past the salts using saturated NaCl brine then displace to a slop mud system prior to the loss zones. After displacement, the fluid weight was reduced to 8.8 ppg and a 60 bbl/hr flow was observed when the pumps were shut off. Shortly thereafter when drilling resumed, severe losses began. Pressure testing revealed that a 9.8 ppg mud weight was needed to hold back the water flow but the wellbore would take fluid at an 8.8 ppg mud weight. Abundant amounts of fibrous and granular LCM’s were pumped and circulated in the system to try and plug the depleted zones without success. Total depth was eventually reached with losses present while pumping and flow presents with pumps off.

Howard Well #2

To overcome the water flow problem from the over-pressured San Andres formation, a 9.8 ppg mud with pre-hydrated bentonite and inert wellbore strengthening particles was added. Severe losses were seen in the Clearfork and Spraberry formations. It was then decided to run a modified wellbore strengthening fluid that includes the MDI to increase the weight tolerance of the loss zones and decrease the equivalent circulating density (ECD) with a much lower viscosity. Seepage losses and water flows were successfully minimized at a 9.4 ppg fluid weight. However, the losses increased whenever the weight rose above 9.5 ppg. The intermediate casing was successfully set without issue and the lateral interval was drilled with the same MDI wellbore strengthening system.

Howard Wells #3-6 – MDI Solution

Given the data collected from the previous wells, a progressive casing design was adopted for these wells. A much shallower intermediate casing point was utilized setting the intermediate casing string past the base of the San Andres formation. This enabled the entire intermediate section to be drilled with a saturated NaCl brine system (9.8-10.0 ppg) which provided an adequate hydrostatic weight to prevent a water flow from occurring in the San Andres formation. For the production interval, modified wellbore strengthening fluid from Well #2 was utilized given its ability to increase the weight tolerance of the now exposed Clearfork, Spraberry, and Dean formations. Because of the lower mud weight and the wellbore strengthening property of this fluid, all four wells were drilled with negligible losses and no indications of wellbore instability from drill out to casing of the production interval. The drilling days (spud to TD) of the six wells are summarized in **Figure 5**.

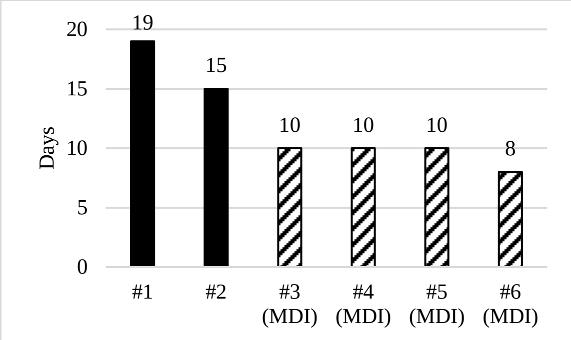

Figure 5-Drilling days (spud to TD) of Howard Well #1-6

The modified wellbore strengthening fluid system in use is a binary system comprised of traditional wellbore strengthening components (various-sized inert particles) and the proprietary MDI that provided inhibition as well as innovative wellbore strengthening properties. The combined actions provided the means to increase the weight tolerance of the Clearfork, Spraberry, and Dean formations.

Conclusions

- This paper reviews several case studies utilizing MDI that successfully addressed the unconsolidated formation problems in the greater Permian Basin.
- The laboratory tests proved MDI's outstanding fluid loss control and wellbore strengthening capacity.
- In San Andres, Clearfork, and Spraberry formations, the field cases showed the successful protection by reducing fluid invasion.
- A modified wellbore strengthening fluid system containing MDI restabilized the severely hydrated Santa Rosa "red bed" interval under a combined action of mechanical plugging and chemical inhibition.

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Nomenclature

ABO = *Asphaltene based oil*
AV = *Annular velocity*
ECD = *Equivalent circulating density*
HPHT = *High-pressure high-temperature*
LCM = *Lost circulation material*
LGS = *Low gravity solids*
MDI = *Multi-functional deformable inhibitor*
PHPA = *Partially hydrolyzed polyacrylamide*
ppb = *pounds per barrel*
ROP = *Rate of penetration*
TD = *Total depth*

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