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Development of a New Reservoir-Friendly Drilling Fluid for Higher Gas Production

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Research Article

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ABSTRACT

Drilling gas reservoir requires high mud density to balance the reservoir pressure. To formulate such fluids, calcium carbonate ($CaCO_3$) was used because of its high acid solubility. However, due to the high concentration of $CaCO_3$ required for high density drilling fluid, sticking might occur which might result in fishing and/or sidetracks operations. To minimize sticking problems, barite ($BaSO_4$) is added with $CaCO_3$ to reduce the amount of solids needed to formulate the drilling fluid. However, barite can cause potential damage because it does not dissolve in commonly used acids. Drilling fluids were developed at a wide range of densities using $CaCl_2$ salt with Manganese Tetroxide (Mn_3O_4). No similar formulations were developed before to the best of the authors' knowledge. The properties of small particle size (D_{50}=1 microns), spherical shape and high specific gravity (4.9 g/cm^3) of Mn_3O_4 make it good weighting material to reduce solids loading and settling compared to $CaCO_3$ (2.78 g/cm^3 and D_{50}=10 microns) and $BaSO_4$ (4.20 g/cm^3 and D_{50}=20 microns). The objective of this study is to show the lab work involved in designing water-based drilling fluids using $CaCl_2$ / Mn_3O_4. The experimental work in this paper involved rheological properties, thermal stability, API and HT/HP filtration. The data generated from this study showed that Lignite and Vinyl amide/vinyl sulfonate copolymer are recommended to provide good rheological stability and filtration control for $CaCl_2$/Mn_3O_4 drilling fluid. Polyanionic cellulose polymer and starch can used to formulate KCl/Mn_3O_4 drilling fluid with good properties at 300 ° F.

INTRODUCTION

The use of drilling fluids is an inevitable need in oil and gas drilling operations. Selection of the most suitable drilling fluid leads to maximize productivity and minimize cost without harming the environment and field equipment [1]. Choosing the right drilling mud is generally evaluated based on two factors:

1) Achieving well technical requirements, and 2) satisfying the environmental regulations [2]. Moreover, the chemistry of drilling fluids is a top consideration since it directly controls the drilling performance, and most importantly the extent of formation damage across the pay zone.

Formation damage mitigation across producing reservoir is essential. Drilling fluid design optimization is the primary approach to reach borehole stability and, minimize well expenditure while improving production rates. Previous studies show that formation damage could occur due to the following: (1) extent of solid invasion, (2) clays swelling, (3) emulsion between oil-based mud and formation water [3], (4) bacteria effect [4], (5) and fine migration of clay particles [5]. Mud invasion solids and filtrate are capable of reducing the permeability of the formation, especially when the mud particles have smaller diameter than pore throats, which lead to further migration of mud particles into the formation [6]. One of the characterizations of suitable drilling fluids is forming a very thin mud cake which it can form very fast and which is easy to remove.

In order to optimize the drilling and well operations, choosing the most effective weighting material in such a water-based mud formulation is required. Barite is considered one of the most popular weighting materials since it has high specific gravity, low cost and less environmental effect [7]. However, it has considerable disadvantages, where it is prone to severe sagging and insoluble in acids, which means that the barite removal process is difficult and expensive [8].

Another well-known weighting material is potassium formate. There are many advantages of potassium formate as well. It can dissolve in water, form high-density fluid [9], create very thin filter cake, stabilize shale, and minimize the potential of differential sticking. On the other hand, potassium formate can cause corrosion since it is reactive with CO_2 forming more formic acid and precipitation of potassium chloride which damages the formation by plugging the pores [10].

Previous studies and lab experiments show that manganese tetroxide (Mn_3O_4) is a better weighting agent and represents an excellent alternative to barite and potassium formate. Manganese tetroxide retains relatively high specific gravity and small particle size, which reduces particle settling and sagging in high mud weight formulations. Manganese tetroxide particles have a spherical shape of (4 μm) in size and specific gravity of (4.8 g/cm^3) which leads to lower contact in particle-to-particle interactions [11,12]. Field studies show that when Manganese tetroxide is used in oil-based drilling fluids, there was less formation damage and high amount of productivity. Al-Yami designed KCl water-based drilling fluid utilizing manganese tetraoxide and $CaCO_3$. The $CaCO_3$ materials were used to improve the filtration control. The aim of this study is to discuss lab work that was performed to design water-based drill-in fluids using $CaCl_2/Mn_3O_4$ at 95 pcf and 300°F.

EXPERIMENTAL STUDIES

Materials

All additives used in this study are conventional additives used in drilling fluids such as Polyanionic cellulose polymer, starch, and Lignite.

Starch is used as filtration control additive, which is the primary component of the seeds of cereal grains or tubers such as rice, wheat, corn, and potato. It has a formula of ($C_6H_{10}O_5H_2O$) n. Starch is degraded at temperatures of maximum 250°F with concentrations of 2 to 10 lb/bbl.

Xanthan is a polysaccharide water soluble polymer produced by bacterial action. XC-polymer has excellent suspension properties and is used in concentration of 0.2 to 2 lb/bbl.

Polyanionic cellulose polymer can be used to control filtrion and build up viscosty. It can be used in fresh water, sea water and salt saturated fluids in concentration of 0.2 to 5 lb/bbl.

Hydrated lime $Ca(OH)_2$ is made by adding calcium oxide to water. It is used in high calcium content drilling fluids to increase the pH in concentration of 0.5 to 20 lb/bbl.

For potassium chloride drilling fluids, KOH is used to increase the pH in concentration of 0.5 to 3 lb/bbl. Lignite is used to provide filtration control and enhance rheological stability at high temperature upto 400°F in water based fluids. It is notably effective in high density mud. Typical dosages are 2 to 6 lb/bbl depending on the degree of filtration control desired. In addition to that, it shows good filtrate control and rheological stability for high density fluids.

Vinyl amide/vinyl sulfonate copolymer are terpolymers of N-methyl-N-vinylacetamide, monomer acrylamide and vinyl sulfonate monomer 2-acrylamide-2-methyl-1-propanesulfonic acid used for high temperature environment. It is used as fluid loss additive for water based fluids.

Vinyl amide/Acrylic Polymer is a low viscosity synthetic polymer to enhance filtration control in water based fluids which can work in high calcium chloride concentrations up to 100,000 ppm. The polymer can be used in brines containing Na, K^+, and Mg^{++} concentration up to saturation and still shows stable performance in a wide range of pH environment.

$CaCO_3$ is a good acid soluble weighting material for productive formation since it can be removed by treatment with hydrochloric acid. It can be used to formulate drilling fluids with a maximum density of 12 lb/gal due to its low specific gravity (2.6 to 2.8).

Mn_3O_4 is manufactured from heating manganese dioxide in air at 1000 °C. Their properties of higher specific gravity (4.8), spherical shape, and solubility in different types of acids make them more attractive weighting material compared to $CaCO_3$ (2.78 g/cm^3) and $BaSO_4$ (4.25 g/cm^3).

$CaCl_2$ can be used in combination with gypsum (calcium sulfate) when drilling evaporates sections. If the drilling fluid is not saturated, it will be washed out **(Table 1)**. In this formulation HEC (hydroxyl ethyl cellulose) is used to build up viscosity. HEC polymers are nonionic derivatives of the cellulose polymer modified to impart water solubility to the cellulose molecule. The nonionic substitution in HEC polymers makes them very tolerant to high salt environments, including divalent calcium and magnesium. However, HEC Polymers alone are considered nonthixotropic. XC polymer functions quite well in $CaCl_2$ fluids as long as the polymer is properly sheared in the initial mix. XC-polymer is one of a very few polymers which will build gel structure. This, therefore, makes XC-polymer the key ingredient when solids suspension is required **(Table 2)**.

Table 1. $CaCl_2$ used to drill evaporates sections.

Water	bbl	0.85		Density	pcf	77	
Defoamer	gal	0.01		Plastic viscosity	cp	16-24	24

$CaCl_2$ (78%)	lb	112		Yield point	lb/100 ft^2	24-26	26
XC-polymer	lb	0.5	1	10 sec gel	lb/100 ft^2	04-Jun	6
HEC	lb	0.5	1	10 min gel	lb/100 ft^2	Dec-14	14
Starch	lb	3	6	Filtrate	ml/30 min	04-May	5
Lime	lb	0.15	1	pH		09-Oct	10
$CaSO_4.2H_2O$	lb	5	6	Chlorides	mg/l	1,60,000	
$CaCO_3$ ‘fine’	1b	9					
$CaCO_3$	1b	16					
‘Medium’							

Table 2. $CaCl_2$ used to drill a reservoir section.

Formulation and Material concentration (One barrel) Average fluid properties						
Density Freshwater	pcf bbl		75			
			0.89	Density	lb/ft^3	75
		:				
Defoamer	gal	:	0.01	Plastic Viscosity	cp	16-24
						ALAP
XC-Polymer	lb	:	0.50 – 1.0	Yield Point	lb/100 ft^2	24-26
Starch	lb	:	4.0 – 6.0	10 sec gel	lb/100 ft^2	04-Jun
Lime	lb	:	0.25 – 0.50	10 min gel	lb/100 ft^2	08-Dec
$CaCl_2$ (78%)	lb	:	8	Filtrate	ml/30 min	04-May
$CaCO_3$ “fine”	1b		99	Cake thickness	32nd in API	01-Feb
				pH		9 – 10
				Chloride	mg/l × 1000	12

Procedure

Many attempts and tests were done to formulate Mn_3O_4 water based drilling fluids formulations in order to achieve the final formulations suitable for deep drilling. The tests needed are:

1.Rheological properties

2.API and HP/HT standard filtration, and 3-Thermal stability

Intensive lab work was done using API RP 13B-1 procedure to design $CaCl_2/Mn_3O_4$ water based drill-in fluids at a density of 95 pcf at 300°F.

RESULTS AND DISCUSSION

The presence of oxygen in drilling fluids can accelerate corrosion rates and degradation of water-soluble polymers. An oxygen scavenger can be used to remove the oxygen. Sodium sulfite is an example of oxygen scavenger as shown in Equation 1:

$$O_2 + 2Na_2SO_3 \rightarrow 2Na_2SO_4 \qquad (1)$$

The drilling fluid properties including PV, YP, Filtration (API and HT/HP), filter cake thickness, and drill-in fluid pH were measured. To evaluate thermal stability, the drill-in fluid was aged for 16 hours at 300°F and the properties mentioned earlier were measured again.

Polyanionic cellulose polymer was used to formulate $Mn_3O_4/CaCl_2$ drilling fluid. Good rheology properties were obtained but having controlled fluid loss was the concern **(Table 3)**. High concentration of $CaCl_2$ was used so calcium bromide was added to minimize recrystallization.

Table 3. Formulation utilizing XC polymer and PAC-R and CaBr.

Formulation		
Additive		**Concentration**
Water		0.815 bbl
XC-Polymer		1.0 ppb
Polyanionic Cellulose Polymer		2.0 ppb
Lime		0.5 ppb
$CaBr_2$		0.0255 bbl
$CaCl_2$ (78%)		235.54 ppb
Mn_3O_4		69.549 ppb
Results		
Parameter	**Before Hot Rolling**	**After Hot Rolling**

600 rpm	71	62
300 rpm	47	40
200 rpm	36	30
100 rpm	24	21
6 rpm	7	9
3 rpm	5	7
10 sec gel, lb/100 ft^2	4	7
10 min gel, lb/100 ft^2	12	10
Plastic viscosity, cp	24	22
Yield point, lb/100 ft^2	23	18
HTHP filtration, ml/30 min	No Control	No Control

$CaCl_2$ concetration was reduced and Mn_3O_4 amount was increased to investigate the compatibility of Polyanionic cellulose polymer with Mn_3O_4/$CaCl_2$ drilling fluid **(Table 4)**. Starch and $CaCO_3$ fine and medium were added to improve the fluid loss control. However, no control was observed even before hot rolling.

Table 4. Formulation utilizing XC polymer and PAC-R and Starch and $CaCO_3$ fine and $CaCO_3$ medium.

Formulation	
Additive	**Concentration**
Water	269.5 bbl
XC-Polymer	1.75 ppb
Polyanionic Cellulose Polymer	3 ppb
starch	6 ppb
lime	0.5 ppb
$CaCl_2$ (78%)	101 ppb
Mn_3O_4	110 ppb
$CaCO_3$ (Fine)	10 ppb
$CaCO_3$ (Medium)	15 ppb
Sodium Sulfite	0.5 ppb
Results	
Parameter	**Before Hot Rolling**
600 rpm	137
300 rpm	86.5
200 rpm	62.3
100 rpm	37.6
6 rpm	4.1
3 rpm	3.7
10 sec gel, lb/100 ft^2	2.3
10 min gel, lb/100 ft^2	2.6
Plastic viscosity, cp	45.5
Yield point, lb/100 ft^2	35.1
HTHP filtration, ml/30 min	No Control

Vinylamide/Acrylic Polymer was used to replace starch to control the fluid loss **(Table 5)**. Good rheology properties were obtained but no fluid loss control was achieved even after adding more solids ($CaCO_3$ and Mn_3O_4) and reducing $CaCl_2$ salt concentration. Vinylamide/Acrylic Polymer was not compatible with Mn_3O_4/$CaCl_2$ drilling fluid.

Table 5. Formulation utilizing Vinylamide/Acrylic Polymer.

Formulation		
Additive	**Concentration**	**Concentration**
water	294 bbl	289.8 bbl
XC polymer	1.75 ppb	1.75 ppb
Vinylamide/Acrylic Polymer	6 ppb	6 ppb
Polyanionic Cellulose Polymer	7 ppb	7 ppb
$CaCl_2$ (78%)	70 ppb	64 ppb
Mn_3O_4	50 ppb	60 ppb
$CaCO_3$ (Fine)	23 ppb	25 ppb
$CaCO_3$ (Medium)	15 ppb	17 ppb
Sodium Sulfite	2 ppb	2 ppb

Lime	0.5 ppb	0.5 ppb
Results		
Parameter	**Before Hot Rolling**	**Before Hot Rolling**
600 rpm	44.5	75.3
300 rpm	31.5	49.7
200 rpm	24.5	42.2
100 rpm	18.4	33.1
6 rpm	8.4	18.2
3 rpm	7.8	13.5
10 sec gel, lb/100 ft^2	7.8	13.2
10 min gel, lb/100 ft^2	7.9	14.6
Plastic viscosity, cp		
Yield point, lb/100 ft^2		
HTHP filtration,		
ml/30 min	No Control	No Control

Lignite was used in $Mn_3O_4/CaCl_2$ drilling fluid in attempt to control fluid loss. Manganese Tetraoxide was used only in the formula without $CaCO_3$ to evaluate its filtration performance in combination with lignite. XC- polymer, Polyanionic cellulose polymer were used to evaluate their rheological performance. Exposure of drilling fluids to temperature might change the fluid's rheology and filtration. Good fluid loss control was observed before and after hot rolling at 300°F and 300 psi for 16 hours **(Table 6)**.

Table 6. Formulation utilizing XC polymer and Resinex and CaBr.

Formulation		
Additive		**Concentration**
Water		0.815 bbl
XC-Polymer		1.75 ppb
Lignite		4.0 ppb
Lime		0.5 ppb
$CaBr_2$		0.0255 bbl
$CaCl_2$ (78%)		235.54 ppb
Mn_3O_4		69.549 ppb
Results		
Parameter	**Before Hot Rolling**	**After Hot Rolling**
600 rpm	64	77
300 rpm	44	47
200 rpm	35	36
100 rpm	25	25
6 rpm	9	7
3 rpm	7	5
10 sec gel, lb/100 ft^2	7	5
10 min gel, lb/100 ft^2	12	8
Plastic viscosity, cp	20	30
Yield point, lb/100 ft^2	24	17
HTHP filtration, ml/30 min	25 ml	26 ml

Lignite was used again but with lower concentration of $CaCl_2$ salt and with higher concentration of Mn_3O_4 and only 5 lb/bbl of $CaCO_3$ **(Table 7)**. An earlier study by Al-Yami at el., showed that 5 lb/bbl of $CaCO_3$ with Mn_3O_4 can provide acceptable fluid loss control and thin filter cake when combined with good fluid loss additives **(Figure 1)**. Good rheology and fluid loss control before and after hot rolling was observed from this formulation.

Table 7. Formulation utilizing XC polymer and Resinex Formulation.

Additive		**Concentration**
Water		0.756 bbl
XC-Polymer		1.5 ppb
Lignite		6 ppb
Lime		0.5 ppb
$CaCl_2$ (78%)		202.9 ppb
Mn_3O_4		72.326 ppb
$CaCO_3$ (Fine)		5 ppb
Results		
Parameter	**Before Hot Rolling**	**After Hot Rolling**

600 rpm	80	48
300 rpm	53	30
200 rpm	42	22
100 rpm	30	14
6 rpm	13	3
3 rpm	10	2
10 sec gel, lb/100 ft^2	10	2
10 min gel, lb/100 ft^2	12	7
Plastic viscosity, cp	27	18
Yield point, lb/100 ft^2	26	12
HTHP filtration, ml/30 min	32 ml	32 ml

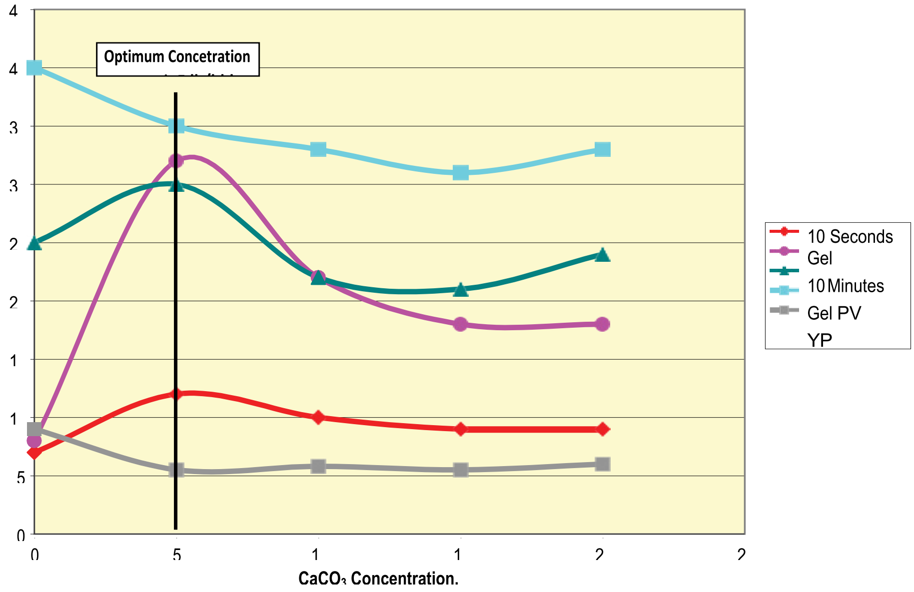

Figure 1. Effect of $CaCO_3$ concentration on properties of Mn_3O_4 drilling fluid.

Finally, Vinyl amide/vinyl sulfonate copolymer was tested without $CaCO_3$ and high concentration of $CaCl_2$ **(Table 8)**. The best drilling fluids properties were obtained when using Vinyl amide/vinyl sulfonate copolymer in the $Mn_3O_4/CaCl_2$ drilling fluid even after hot rolling for 300°F and 300 psi for 16 hours.

Table 8. Formulation utilizing XC polymer and Therma Check and CaBr.

Additive	Formulation	Concentration
Water		0.815 bbl
XC-Polymer		1.75 ppb
Vinyl amide/vinyl sulfonate copolymer		2.0 ppb
Lime		0.5 ppb
$CaBr_2$		0.0255 bbl
$CaCl_2$ (78%)		235.54 ppb
Mn_3O_4		69.549 ppb
	Results	
Parameter	**Before Hot Rolling**	**After Hot Rolling**
600 rpm		123
300 rpm		76
200 rpm		57
100 rpm		33
6 rpm		6
3 rpm		3
10 sec gel, lb/100 ft^2		4
10 min gel, lb/100 ft^2		
Plastic viscosity, cp	20	47
Yield point, lb/100 ft^2	25	29
HTHP filtration,		
ml/30 min	14 ml	12 ml

Al-Yami showed that Polyanionic cellulose polymer and starch are better than Lignite and Vinyl amide/vinyl sulfonate copolymer polymers in providing good rheological stability and filtration control for KCl/Mn_3O_4 drilling fluid. In this study, we showed that Lignite and Vinyl amide/vinyl sulfonate copolymer are better than Polyanionic cellulose polymer and starch in providing good rheological stability and filtration control for $CaCl_2$/Mn_3O_4 drilling fluid.

CONCLUSIONS

In this study, Mn_3O_4/$CaCl_2$ drilling fluid (95 pcf) was designed and tested. Based on the testing results, the following conclusions can be drawn:

1. Oxygen scavenger was added to Polyanionic cellulose polymer to extend its stability and provide good rheological properties. However, the filtration control was not good.
2. Adding starch and $CaCO_3$ and Polyanionic cellulose polymer did not solve the fluid loss control problem.
3. Vinylamide/Acrylic Polymer was not compatible with Mn_3O_4/$CaCl_2$ drilling fluid. No fluid loss control was achieved even after reducing $CaCl_2$ concentration.
4. Lignite and Vinyl amide/vinyl sulfonate copolymer are better than Polyanionic cellulose polymer and starch in providing good rheological stability and filtration control for $CaCl_2$/Mn_3O_4 drilling fluid.
5. Polyanionic cellulose polymer and starch are better than Lignite and Vinyl amide/vinyl sulfonate copolymer in providing good rheological stability and filtration control for KCl/Mn_3O_4 drilling fluid.
6. The use of small concentration of $CaCO_3$ (5 lb/bbl) with Mn_3O_4 (203 lb/bbl) improved the filtration and reduced the filter cake compared to using Mn_3O_4 alone.

NOMENCLATURE

BHCT=bottomhole circulating temperature,

°F BHST=bottomhole static temperature, °F

PV=plastic viscosity, cp

YP=yield point, lb/100 ft^2

SI METRIC CONVERSION FACTORS

In × 2.54*	E-02=m
(°F-32)/1.8*	E+00=°C
ft × 3.048*	E-01=m
gal × 3.785 412	E-03=m^3
lbm × 4.535 924	E×01=kg
psi × 6.894 757	E-03=Mpa
lbm/gal × 1.198 26	E-01=S.G
bbl × 1.58987	E-0=m^3

*Conversion factor is exact.

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