



Field Application Of A Unique Water-Based Drilling Fluid For The Nile Delta

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Abstract

Research has identified a unique water-based fluid for drilling and completing wells with mixed sand and shale formations in the Nile Delta. This fluid has a combination of properties which make it especially suitable for these applications. They include an inhibitive base brine, specifically sized sodium chloride as bridging/weighting material, superior fluid loss control, good filter cake properties, and excellent return permeability. This specialty fluid has been used to drill in excess of 1,200 meters (3,937 feet) in the Kafr El Sheik formation which contains poorly consolidated sands with clay matrix interbeds. Subsequently, production zones are drilled through as much as 500 meters (1,640 feet) of the Abu Madi, which has very coarse to very fine cross bedded sandstone with shale intercalation, and 200 meters (656 feet) of the Qawasim which contains non-calcareous shale's with sandstone layer interbeds. Seventeen wells have been drilled with system densities ranging from 10.5 to 12.3 lbm/gal, with bottom hole temperatures of 104.4 to 107.2°C (220 to 225°F), and up to a 4,000 psi overbalance. The rheological properties of the system were easily maintained and the hole conditions excellent without differential sticking, torque or drag.

Utilization of this system to drill the Kafr El Sheik along with the subsequent production zones has allowed casing programs to be re-designed with larger diameter tubular, and elimination of a casing string, resulting in a savings of approximately \$1,000,000 per well. Production data with the new casing/tubing configurations indicates the wells are producing at 5 to 6 times the rate per day of the previous wells.

Introduction

The West Manzala Field is located in the Nile Delta of Egypt, 200 miles northeast of Cairo. The field was discovered in 2004 and is presently operated by Dana Gas. Generally, wells are vertical or slightly deviated up to a maximum of 35°, with the surface hole drilled and 13-3/8 inch casing set at approximately 1200 m meters (3940) feet. Prior to 2008, drilling the 12.25 inch hole below the 13-3/8 inch casing was accomplished with higher weight 11-12.5 lbm/gal silicate fluid systems to control shale swelling and sloughing in the Kafr El Sheik formation (pore pressure 10.8-10.9 lbm/gal) .

Due to the increased hydrostatic pressure overbalance, the silicate systems have been associated with problems such as hole gauge, differential sticking, loss of tools, fluid losses And subsequent formation damage (+6) in the lower pore pressure Abu Madi (8.5-9.8 lbm/gal) and Qawasim (9.4 -10 lbm/gal) production zones below the Kafr El Sheik formation.

After drilling the Kafr El Sheik with the silicate system, a 9-5/8 inch casing was placed and cemented then the Abu-Madi formation was drilled thru a 8.5" open hole using a lower weight 9 to 9.8 lbm/gal KCl/polymer system. 7" casing was then run to bottom before putting well on completion.

That has made a Huge extra cost to the company associated with the rig time and personnel cost to run and cement two different casing sizes, the cost for changing into a new mud and for keeping in storage two different casing sizes

The Company had selected a distinguished completion and workover fluid system that has been adapted to meet all demands necessary for drilling. , Completion and work over fluids and designed to control fluid loss and minimize formation damage.

The selected fluid system is based on a sized NaCl/polymer formulation which has been very successful in the drilling and completion of numerous horizontal and highly deviated wells world-wide. This unique system meets drilling and completion requirements by providing desirable rheological properties for hole cleaning, cuttings transport, and contains an optimized particle size distribution of soluble bridging/weighting solids to enhance well bore stability and protect the formation even in high overbalance conditions.

The Beginning

The Idea came through one day when The late Usama Shalash was ask how can we drill a well with a mud system that could colloid with salt and create a somewhat of a glass sheath across our formation and hold a differential pressure of 4000 psi to minimize and/or avoid any reservoir damage. The Idea was then studied and after several trials in 9 months the rest is history.

The Process begins

FLUID REQUIREMENTS LABORATORY EVALUATION

The criteria established for building a fluid system to successfully drill the Kafr El Sheik, Abu Madi, and Qawasim formations include:

- Improved rheological characteristics for hole cleaning and cuttings transport
- Optimum filter cake design and inhibition for formation protection and well bore stability
- High differential pressure/temperature stability

A. Rheological Characteristics

The rheological properties and flow profile of xanthan gum biopolymer are well documented. Fluid compositions containing this polymer provide lower pressure drops across mud motors and drill bits, thereby generating more available hydraulic horsepower for improved down hole motor performance and greater penetration rates (Ref 1) Under dynamic conditions, biopolymer fluids improve suspension and transport, minimize radial slip of drilled and suspended solids and promote cuttings bed erosion. Under static conditions in vertical, high-angle or horizontal well bores, the rheological characteristics of xanthan gum contribute to improved suspension, reduced particle settling and less potential for the formation of cutting beds (Ref 2)

The foundation of the sized NaCl/polymer drilling and completion system is a combination of xanthan gum biopolymer and a proprietary cross linked hydroxypropylated starch derivative. (Ref 3) These two work in a synergistic manner to provide enhanced static suspension and generate a higher degree of shear-thinning than would result from a standard mixture containing the same

biopolymer concentration with a conventional filtrate reducer. In fact, the polymer blend mixed in a saturated saline solution yields a more thermally stable low shear rate viscosity than the biopolymer alone. Therefore, with less primary viscosifier, fluid mixtures are more shear-thinning with reduced viscosity at higher shear rates. The dramatic change across operating shear rates, summarized in Table 1, demonstrates the shear-thinning properties for a standard 10.7 lbm/gal composition. (Table 2)

B. Formation Protection and Well Bore Stability

1. Filter Cake Design

Application of a specialty completion fluid for drilling a highly overbalanced pressure well provides distinct advantages for maximizing production. The system is designed to prevent liquid and solid invasion into a permeable formation by bridging and sealing with a readily removable ultra-low permeability filter cake.

These characteristics are achieved by selecting a suitable size range and particle distribution of soluble solids for bridging the pore openings between formation sand grains. (Table 3) An optimum concentration of these solids must be determined and properly balanced with sufficient sub colloidal-sized components.

The result of this optimized composition is a stable filter cake with low filtrate under specific conditions of temperature and pressure. (Table 4) The low permeability cake is deposited quickly and prevents excessive filtrate from entering the formation. Also, this film of polymer and salt allows the column of fluid to transmit the necessary hydrostatic pressure to keep the well bore open, stable and in-gauge with minimum washout.

2. Inhibition/Shale Stabilization

The sand/shale interfaces to be drilled required a 1.0 lbm/gal over the max pore pressure or higher density to mechanically stabilize the well bore. Chemical stabilization of the shale resulted mainly from the high salinity of the saturated sodium chloride/potassium chloride brine, but further enhancements were achieved by the addition of a low molecular weight polyglycol into the base system. Shale stability index (SSI) values were determined to define the surface conditions of shale specimens before and after exposure to test fluids. The lower the SSI

value, the higher the water uptake into the shale. (Ref 4) Relatively high values are demonstrated for the sized NaCl/polymer system as shown in Table 5. The SSI test procedure is found in Table 6.

3. Density Increase

Several methods were evaluated to increase the fluid density. Additions of sodium chloride particles, calcium carbonate particles, or a combination of these were successfully utilized without adversely affecting the rheological properties, or fluid loss control efficiency.

4. Low Gravity Solids Build-Up

Based upon prior field applications, a significant amount of shale was anticipated while drilling the Kafr El Sheik formation. A methylene blue test value of 17.5 lbm/bbl was established as the maximum concentration of solids before dilution of the whole system was to be conducted.

C. High Differential Pressure/ Temperature Stability

Due to the anticipated high differential pressure in the well bore, controlled filtrate loss for the system was extremely important. Test samples were hot rolled and static aged at 107.2°C (225°F) for 16 hours and then tested for rheological characteristics and fluid loss control. (Table 7) Filtrate loss for laboratory samples of a 10.7 lbm/gal, sized NaCl/polymer system was less than 13.0 mL of total volume in 30 minutes at 107.2°C (225°F) with 4,000 psi of differential pressure on an 850 mD disk. High differential pressure testing was conducted on a Permeability Plugging Apparatus (PPA) with the following features.

- Test pressures up to 5,000 psi (34,474 kPa) and 260°C (500°F)
- Provides more realistic well bore static filtration measurements
- Aids in predicting how a fluid system will seal depleted under-pressured intervals
- Filtration medium is above the fluid sample to prevent particles that settle during the static test from contributing to the build-up of filter cake

DRILLING OPERATIONS

The 16 inch surface hole of the Salma Delta N-1 exploratory well (Table 8) was drilled with a conventional mud system to a total measured depth of 905 meters (2,969 feet), where a 13-3/8 inch casing was placed and cemented. The mud system was used to drill the cement plugs, float collar, cement, and float shoe, and was displaced with a high viscosity spacer pill followed by a standard 10.7 lbm/gal sized NaCl/polymer system. The drilling operation can be summarized as follows:

- Drilled 12-1/4 inch hole trouble-free to a depth of 1,225 meters (4,019 feet)
- Increased system density to 11.9 lbm/gal with calcium carbonate (Table 9) to control formation pressure, and continued drilling to 2,115 meters (6,939 feet)
- Encountered numerous tight spots while POOH with the 12-1/4 inch drill bit to retrieve an 8-1/2 inch coring assembly
- Attempted to core but failed due to mechanical issues
- POOH with the 8-1/2 inch core assembly
- Reamed through tight spots with a 12-1/4 inch bit and continued drilling to 2,273 meters (7,457 feet)
- POOH without problems, changed the bit, and continued drilling 12-1/4 inch hole to a total depth of 2,310 meters (7,579 feet)
- POOH with drilling assembly
- Completed two consecutive logging trips
- Placed 9-5/8 inch casing to total depth without fluid losses, or tight spots
- Cemented casing without fluid losses
- Cleaned casing and displaced well with a 9.7 lbm/gal filtered KCl/ NaCl brine

DRILLING FLUID PERFORMANCE

Typical drilling fluid properties for the 20 days required to drill the Salma Delta N-1 are listed in Table 10.

1. Solids Control/Dilution

The solids content of the fluid was continually monitored to ensure an excessive amount of drill cuttings were not being re-circulated. The drill solids were kept to a minimum with two Brandt shale shakers (180 mesh screens) in

order to control rheological properties, and to minimize formation damage. Periodic fluid checks were conducted to determine if any chemical additions were required, and whole fluid dilutions were added as needed during the drilling process.

2. Rate of Penetration

The average rate of penetration per hour while drilling the Kafr El Sheik formation was 25 meters (82 feet), 15 meters (49 feet) for the Abu Madi, and 20 meters (66 feet) for the Qawasim.

3. Hole Cleaning

There were no problems encountered with hole cleaning, and a wiper trip at total depth produced no sign of cuttings build-up in the well.

4. Torque/Drag

Torque and drag figures were consistent with those expected from drilling the three sections with a typical water-based mud. Lubricant additions were not required.

5. Formation Damage

It has also been proven that the skin damage or reservoir damage in 16 wells drilled with new mud system was highly protective and as per the below table was in most cases negative damage.

Well	Target Formation	Reservoir Pressure	Permeability	Skin
		Psi	md	
EW-14	IAM (II)	4088	13	-4
EW-14	IAM	2545	-	-
EW-14	UAM	4080	-	-
ENE 2ST	UAM	2000	-	-
ENE 2ST Horizontal	IAM	4147	0.5 - 1	-
ABU-GARAL 1	Qawasim + IAM	4250	0.1 - 0.5	-
EL-BASENT-1	Qawasim (1)	4426	80	-5
EL-BASENT-2	Qawasim (2)	4595	10 - 20	5
EL-BASENT-4	Qawasim (1)	4036	80	-
SONDOS-1	KES	2100	1420	-2
SONDOS-2	KES	2100	1300	-1
ZINIA 1	Abu Madi	-	-	-
ZINIA-1St	Abu Madi	-	-	-
VERBENTIA-1	Abu Madi	-	-	-
Faraskur-3	IAM (II)	4060	250	0
NW Abu Monkar-1	Wastani	-	-	-
Salma Delta North-1	IAM	3200	180	6.5
Salma Delta-3	IAM	3160	130	0
Same-2	Abu Madi	1500	-	-
South Abu El Naga-1	IAM	3150	320	-5
South Abu El Naga-2	Wastani	1360	1450	0

CONCLUSION

Unique requirements necessary for drilling mixed sand and shale formations in the Nile Delta have generated the demand for a new type of water-based drilling/completion fluid with inhibitive base brine, specifically sized soluble bridging/weighting material, outstanding fluid loss control, good filter cake properties, and excellent return permeability. The stabilized sized NaCl/polymer and mixed sized NaCl/CaCO₃/polymer systems have met field application requirements for seventeen wells (Table 11) by:

- Having excellent rheological properties and thermal stability for extended periods,
- Providing superior fluid loss control with high differential pressure,
- Depositing a nominal, ultra-low permeability filter cake,
- Providing good shale stabilization, well bore stability, gauge hole, and
- Being non-damaging.

SI Metric Conversion Factors

bbl	x	1.589873	E-01 = m ³
gal	x	3.785412	E-03 = m ³
lbm/gal (ppg)	x	1.198264	E+02 = kg/m ³
lbm/bbl (ppb)	x	2.853010	E+00 = kg/m ³
lbm	x	4.535924	E-01 = kg
in	x	2.54	E-02 = m
in ³	x	1.638706	E-05 = m ³
ft	x	3.048*	E-01 = m
ft ²	x	9.290304	E-02 = m ²
mD	x	9.869233	E-04 = mm ²
cP	x	1.0*	E-03 = Pa*s
psi	x	6.894757	E+00 = kPa
°F	x	(°F-32)/1.8	= °C

*conversion factor is exact

TABLE 2 – COMPOSITION FOR A 10.7 lbm/gal SYSTEM

0.847	bbl	9% KCl brine saturated
0.65	lbm/bbl	with NaCl
7.4	lbm/bbl	Xanthan gum biopolymer
4.0	lbm/bbl	Hydroxypropylated starch
2.1	gal/bbl	derivative
64.0	lbm/bbl	Magnesium oxide
		Polyglycol
		Sized NaCl (D-50/5, 10, 20)

REFERENCES

1. Seheult, J.M., Grebe, E.L., Traweck, J.E. and Dudley M., "Biopolymer Fluids Eliminate Horizontal Well Problems", World Oil, January 1990.

TABLE 3 – SODIUM CHLORIDE PARTICLE SIZE DISTRIBUTIONS

<u>Microns</u>					
<u>Grind</u>	<u>Min</u>	<u>D-10</u>	<u>D-50</u>	<u>D-90</u>	<u>Max</u>
1	0.07	2	5	11	20
2	0.25	2	10	27	45
3	1.2	5	20	58	120

2. Powell, J.W., Parks, C.F. and Seheult, J.M., "Xanthan and Welan: The Effects of Critical Polymer Concentration on Rheology and Fluid Performance", SPE 22066 presented at the Arctic Technology Conference, Anchorage, Alaska, May 29-31, 1991.

3. Dobson, J.W. and Mondshine, T.C. "Unique Completion Fluid Suits Horizontal Wells", Petroleum Engineer International, September 1990.

4. Mondshine, T.C. "Tests Show Potassium-Mud Versatility", Oil and Gas Journal, April 1974.

TABLE 4 – FLUID LOSS OF A 10.7 lbm/gal SIZED NaCl/ POLYMER SYSTEM

<u>Time</u>	<u>Initial, mL</u>	<u>Hot Roll, mL</u>	<u>Static Age, mL</u>
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Spurt	4	4	6
30 min	8	9	9
1 hr	11	11	9
2 hr	13	11	10
3 hr	14	12	10
4 hr	15	13	11
5 hr	16	14	11
6 hr	17	15	12
7 hr	18	17	12
8 hr	19	19	12
24 hr	27	29	15
48 hr	36	38	15

1. Hot roll and static tests were aged at 107.2°C (225°F) for 16 hours
2. Filtrates were conducted at 500 psi and 107.2°C (225°F) on an 850 mD saturated disk (mercury standard)
3. Disks contain approximately 13.0 mL of volume in the pore spaces

TABLE 1 – SHEAR RATE VERSUS VISCOSITY FOR A 10.7 lbm/gal SIZED NaCl/POLYMER SYSTEM

<u>Shear Rate, sec⁻¹</u>	<u>Viscosity, cP</u>
1,020	51
510	71
340	102
170	123
10.2	650
5.1	1,000
0.0636	26,700
1. Test Temperature 76°F	

TABLE 5 - SHALE STABILITY INDEX (SSI) OF VARIOUS FLUIDS

<u>Drilling Fluid</u>	<u>SSI</u>
Oil mud	100
Biopolymer/starch derivative/ sized NaCl / 5%	97
polyglycol in 9% KCl saturated with NaCl	90
KCl/polysaccharide mud	85
Biopolymer/starch derivative/ sized NaCl in saturated NaCl brine	74 65
Lime/starch mud	
Lignosulfonate mud	

TABLE 6 - PREPARATION OF SHALE SAMPLES AND SSI TEST PROCEDURE

A. Shale Preparation

4. Hydrated Pierre shale with 3.3% sodium chloride brine
5. De-watered sample with 1,000 psi of pressure
6. Mounted the de-watered specimens in holders
7. Dried to a water activity of 60-63% in a desiccators containing saturated sodium formate brine
8. Tested dry samples for hardness using a Precision Universal Penetrometer

B. Test Procedure

1. Attached shale holders to jar lids containing the fluid to be tested
2. Rolled jars containing shale and fluid for 16 hours at 150°F
3. Removed containers from roller oven after 16 hours and blotted dry
4. Re-measured hardness of each shale with the penetrometer
5. Calculated with shale stability index value using the following equation:

$$SSI = \frac{DP_w - DP_a}{DP_w - DP_b}$$

Where:

DP_w = Depth of penetration after exposure to water

DP_a = Depth of penetration after exposure to test fluid

DP_b = Depth of penetration before exposure to test fluid

TABLE 7 – SYSTEM PROPERTIES FOR LABORATORY SAMPLES			
<u>Shear Rate, sec⁻¹</u>	<u>Initi al</u>	<u>Hot Roll</u>	<u>Viscosity, cP</u>
			<u>Static Age</u>
1,020	52	58	55
510	71	81	78
340	102	99	95
170	123	138	138
10.2	650	750	800
5.1	1,00	1,10	1,300
0.0636	0	0	43,200
	26,7	29,6	
PV, cP	00	00	22
YP, lb/100 ft ²			56
10 sec gel, lb/ 100 ft ²	32	35	13
	39	46	14
10 min gel, lb/100 ft ²	10	12	9.6
	13	13	
pH	9.9	9.4	
			<u>PPA Filtrate</u>
Spurt, mL	14	8	9
30 min, mL	22	13	13
1. Viscosities were recorded at 24.4°C (76°F) 2. Hot roll and static tests aged at 107.2°C (225°F) for 16 hours 3. Filtrates were conducted at 4,000 psi and 107.2°C (225°F) on an 850 mD saturated disk (mercury standard) 4. Disks contain approximately 13.0 mL of volume in the pore spaces			
TABLE 8 – SALMA DELTA N-1 WELL DATA			

TVD	2,310 meters (7,579 feet)
TMD	2,310 meters (7,579 feet)
Angle of deviation	0°
BHT	104.4°C (220°F)
Well bore diameter	12-1/4 inches
Non-	
Production zone length	221 meters (725 feet) with 22.5 m (net pay length
Kafr El Sheik	(70 mD)
Production zone length	Sandstone/shale Gas
Abu Madi	10.7 – 11.9 lbm/gal
	9.7 lbm/gal KCl/NaCl brine
Permeability	Perforated/gravel pack
Type of formation	
Type of production	
System density range	
Density/type of completion fluid	
Type of completion	

TABLE 9 – CALCIUM CARBONATE PARTICLE SIZE DISTRIBUTION

<u>Min</u>	<u>D-10</u>	<u>Microns</u>		<u>Max</u>
		<u>D-50</u>	<u>D-90</u>	
0.7	3	9	26	69

TABLE 10 – TYPICAL DRILLING FLUID PROPERTIES		
System weight, lbm/gal	10.	11.
Funnel viscosity, sec/qt	7	9
PV,cP	50	70
YP, lb/100 ft ²	23	33
10 sec gel, lb/100 ft ²	25	32
10 min gel, lb/100 ft ²	5	11
API filtrate, mL (30 min)	8	25
HTHP filtrate, mL (30 min)	2	3.6
Solids, % vol	8	10
Water, % vol	8	15
Sand, % vol	92	85
MBT, lbm/bbl equivalent	Tra	Tra
pH	ce	ce
Alkalinity, mud (Pm)	5	12.
Alkalinity, filtrate (Pf/Mf)	9.3	5
Chlorides, mg/L	0.4	9.9
Hardness Ca ⁺⁺ , mg/L	5	0.8
KCl, % wt	0.1	0.2
Polyglycol, % vol	/0.	/0.
	25	45
	18	18
	9,0	9,0
	00	00
	28	44
	0	0
	9	10
	5	6

1. Properties recorded at 48.9°C (120°F)
2. HTHP filtrates were conducted at 500 psi and 104.4°C (220°F) on filter paper

TABLE 11 - WELL DATA SUMMARY	
Number of wells	17
TVD	1,225 – 3,162 meters (4,019 – 10,374 feet)
TMD	1,225 – 3,447 meters (4,019 – 11,309 feet)
Angle of deviation	0.25 – 78°
BHT	104.4 – 107.2°C (220 – 225°F)
Well bore diameter	8-1/2 – 12-1/4 inches
Non-production zone length	500 – 1,200 meters (1,640 – 3,937 feet)
Kafr El Sheik	65 – 500 meters (213 – 1,640 feet)
Production zone length	100 – 200 meters (328 – 656 feet)
Abu Madi	(50 – 300 mD)
Qawasim	Sandstone/shale
Permeability	Gas
Type of formation	10.5 – 12.3 lbm/gal (9.3 – 9.6 lbm/gal KCl/NaCl brine)
Type of production system	Perforated/frac pack/gravel pack
Densities of completion fluid	
Type of completion	

