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Drilling Fluids for ERD: Rheology Requires More Than a Quick Look

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Abstract

Invert emulsions fluids are the preferred system for extended-reach drilling (ERD). They provide superior wellbore stabilization of shale and salt intervals, lubrication, corrosion control, tolerance to contaminants, and yield preferentially oil-wet cuttings with good integrity. In ERD wells, the cuttings may be difficult to remove from the wellbore when fluids with inappropriate viscosity are used.

Rheological properties such as yield point (YP) and FANN® 35 viscometer 6-rpm dial reading (6-rpm reading) are still considered good indicators for hole cleaning capability of the drilling fluid. Many operators have ERD hole cleaning guidelines that call for minimum values for YP and 6-rpm reading. However, the temperature and pressure effects on rheological properties of the fluid are sometimes overlooked and rheological properties at only one temperature (either 120°F or 150°F) are measured and evaluated.

Low-clay and clay-free invert systems relying on polymeric additives and rheology modifiers provide better rheological profile and improved hole cleaning when compared to conventional emulsion fluids. Nevertheless, using thermally or shear-activated polymeric additives and rheology modifiers to reach the required values for YP and 6-rpm reading sometimes leads to overtreatment with unfavorable effects on hole cleaning.

This paper provides a case history where managing drilling fluid rheological properties led to a record well being drilled trouble free in record time.

Introduction

Removal of cuttings from the wellbore is crucial for a successful drilling operation. Improper hole cleaning can result in a number of drilling problems including over-pull on trips, high rotary torque, hole packoffs and stuck pipe.

Optimizing hole cleaning in ERD wells involves integrating a good well plan, with good fluid properties, and good drilling practices followed by careful rig site monitoring.

Rheological properties such as yield point (YP) and the 6-rpm reading are still considered good indicators for the hole cleaning capability of the drilling fluid. Multiple operators have ERD hole cleaning guidelines that call for minimum values for 6-rpm reading of 1.0 – 1.2 times the hole size in inches.

The common approach to reach the required properties in a fresh mixed fluid is treatment with additions of traditional fatty acid or polymeric rheology modifiers.

Mark Politte[1] concluded several decades ago that for invert oil-based drilling fluids “the yield value is only weakly affected by pressure while the temperature dependence depends upon the amount of solids and organophillic clay present and the temperature/shear history.”

During the same period, models that describe the rheology of invert emulsions under downhole conditions were developed.[2] The models require rheological properties measured with a conventional rheometer at two or more different temperatures. However, the temperature and pressure effects on rheological properties of the fluid are sometimes overlooked and rheological properties at only one temperature (either 120 or 150°F) are measured and evaluated.[3]

Oil-Based Drilling Fluid Rheological Modifiers

The two rheological modifiers most commonly used in drilling fluids are based on polyamides or fatty acids. The polyamide-type of modifier is used mainly for temporary viscosifying purposes, while the fatty acid rheological modifiers are used to increase the fluid’s shear-thinning and thixotropic characteristics with minimum clay-based additions while drilling.

When used at proper concentrations in large-diameter, high-angle, horizontal and extended-reach wells, the fatty acid rheology modifier, increases low-shear-rate viscosity (LSRV), gel strengths and cuttings-carrying capacity. This allows higher rates of penetration and improved hole cleaning while maintaining wellbore stability.

Unlike the polyamide gelling agents that require organophilic clays, the fatty acid modifiers interact with the emulsified water phase. Higher water content (lower OWR) improves the performance of fatty acid modifiers resulting in lower concentrations needed to achieve the desired effect. The fatty acid modifiers must be subjected to high shear conditions or increased temperature to reach maximum effectiveness.

Under the effect of drilling, activity fatty acid modifiers readily yield when sheared through the bit and exposed to temperature, producing excessive rheological properties of the overtreated fluids.

Field Application

In a recent ERD application, a freshly mixed fluid was employed. The rheological properties required for good hole cleaning while building the directional section are presented in Table 1.

Table 1 – Desired Drilling Fluid Properties For Interval from 8,000 to 35,000 ft

Property	Desired Range	
	Low	High
PV (cP)	15	24
YP (lb/100 ft^2)	12	20
6-rpm Dial Reading (Fann 35)	12	18

Rheological properties were measured while drilling as per clause 6.3 of the API Recommended Practice 13B-2 with a FANN® 35 viscometer at 120°F (Figure 1). However, HTHP rheology measurements (Table 2) revealed that 6-rpm and YP evaluated at the downhole temperature and pressure conditions were very different from the specified properties. Figure 2 shows the effect of temperature and pressure on the 6-rpm, PV and YP of the fluid which was overtreated with shear and temperature-activated rheology modifiers.

An excessive rheology fluid adversely influences the ECD management especially in ERD wells.[5, 6]

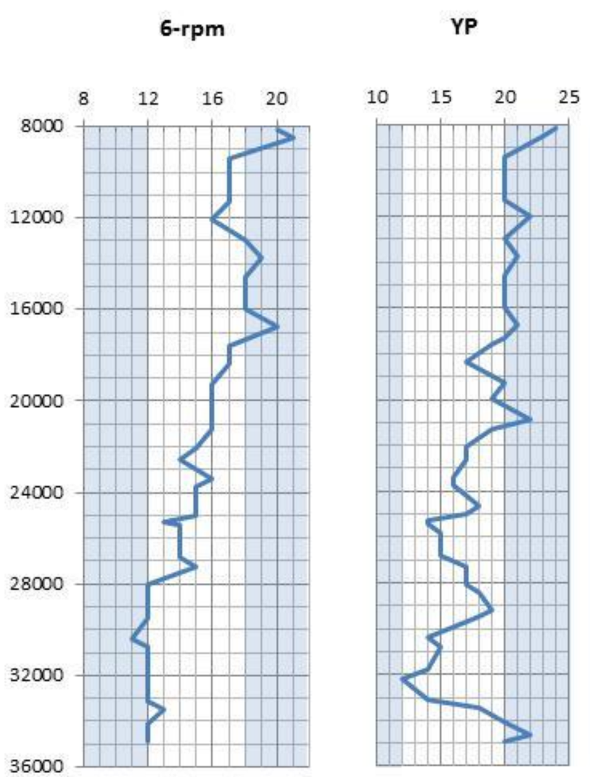

Figure 1. Rheological Properties of the fluid recorded while drilling: 6-rpm (dial readings) and YP (lb/100 ft^2)

Table 2 - HTHP Rheological Properties of the Drilling Fluid Pre-Optimization

Test Num	Temp (°F)	Pressure (psi)	6 rpm	Gel Strength (lb/100 ft^2)		PV (cP)	YP (lb/100 ft^2)
				10-sec	10-min		
1	120	0	13	28	52	25	16
2	120	1000	16	26	56	23	25
3	120	2000	19	25	60	22	33
4	150	0	19	37	41	20	19
5	150	1000	23	35	44	19	25
6	150	2000	27	33	46	17	33
7	150	3000	32	32	49	15	41
8	150	4000	38	30	52	12	51
9	200	0	26	42	32	15	24
10	200	1000	29	40	33	14	29
11	200	2000	33	39	35	13	34
12	200	3000	38	38	36	12	39
13	200	4000	44	36	38	10	46
14	200	5000	50	35	40	7	55
15	250	1000	29	36	28	12	33
16	250	2000	32	35	29	11	37
17	250	3000	36	34	30	9	43
18	250	4000	40	33	31	8	48
19	250	5000	44	32	33	6	54
20	300	1000	23	28	25	11	38
21	300	2000	26	27	26	10	42
22	300	3000	28	26	27	9	46
23	300	4000	31	26	28	8	50
24	300	5000	34	25	29	6	56

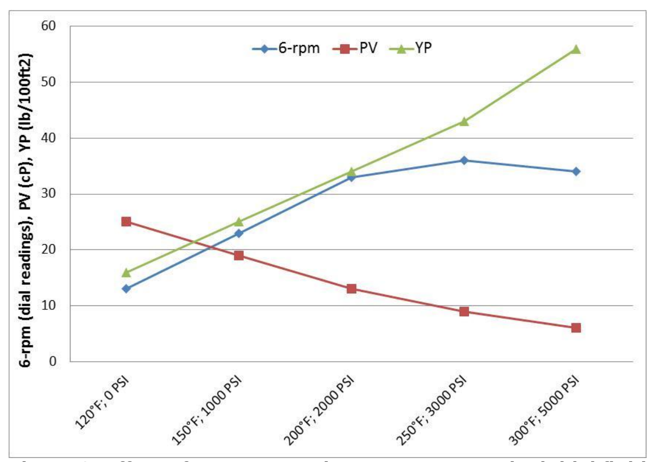

Figure 2. Effect of Pressure and Temperature on the initial fluid

Surging 6-rpm and YP revealed the overtreatment with fatty acid rheology modifiers would have been noticed by measuring the fluid's rheology at a minimum of two temperatures even at atmospheric pressure (Figure 3).

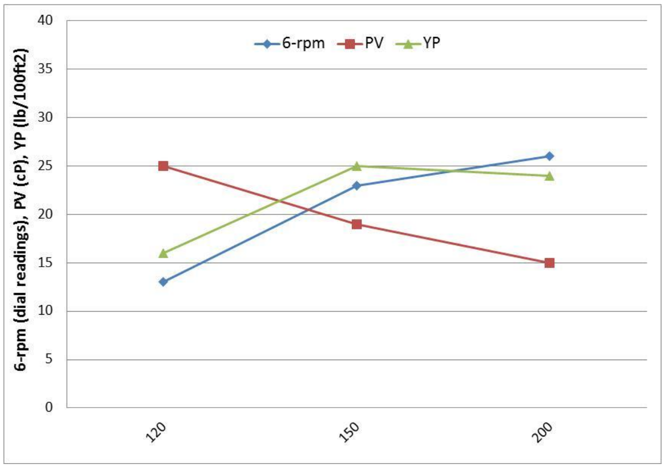

Figure 3. Effect of temperature on the rheological properties of the initial fluid measured at 0 psi.

For proper ECD management, the rheology measured at both downhole and surface conditions was targeted to be in the same range. A flatter profile was demonstrated to contribute to lower ECD and minimize the surge and swab pressures while maintaining the hole cleaning potential of the fluid.[5, 6, 7]

An optimization process to adjust the rheological properties required fatty acid rheology modifier additions to be stopped and their concentration allowed decreasing. Rigsite testing of the viscosity under multiple temperatures became mandatory and were supplemented by multiple HTHP rheology tests.

The effect of pressure and temperature on the optimized fluid is presented in Figure 4. Similar indications may be achieved through multiple temperature viscosity checks at atmospheric pressure (Figure 5).

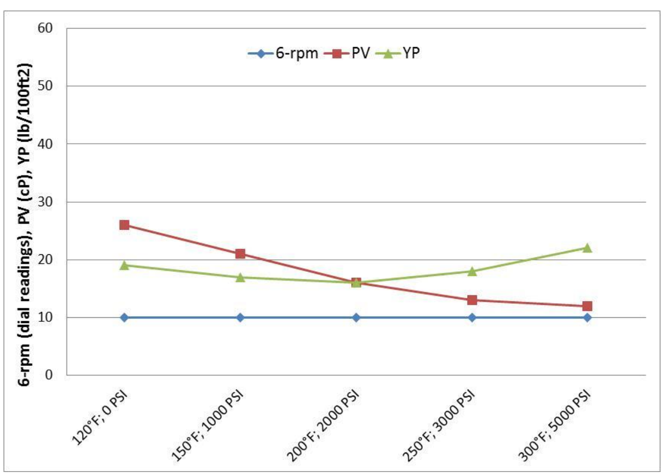

Figure 4. Effect of Pressure and Temperature on the optimized fluid

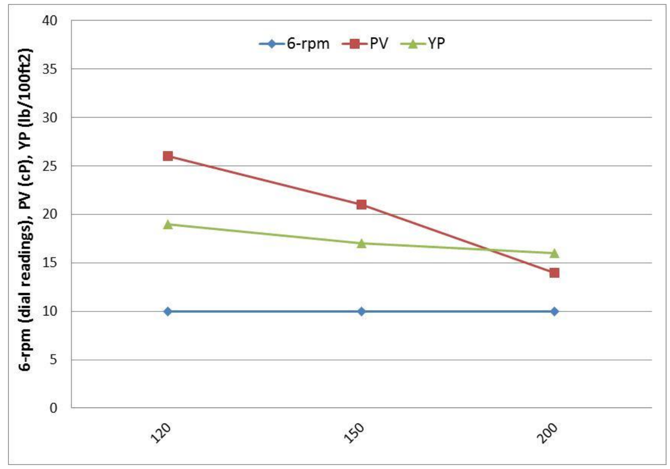

Figure 5. Effect of Temperature on Rheological properties of the optimized fluid measured at 0 PSI.

Table 3 - HTHP Rheological Properties of the Drilling Fluid at the End of the Interval

Test Num	Temp (°F)	Pressure (psi)	6 rpm	Gel Strength (lb/100 ft²) 10-sec	10-min	PV (cP)	YP (lb/100 ft²)
1	120	0	10	22	47	26	19
2	120	1000	10	17	37	27	20
3	120	2000	11	13	30	30	18
4	150	0	10	19	37	20	17
5	150	1000	10	15	31	21	17
6	150	2000	11	12	26	23	16
7	150	3000	11	10	22	23	18
8	150	4000	11	8	18	25	17
9	200	0	10	16	28	14	16
10	200	1000	10	14	24	15	16
11	200	2000	10	12	21	16	16
12	200	3000	11	10	19	17	16
13	200	4000	11	8	16	18	16
14	200	5000	11	7	14	19	16
15	250	1000	9	12	20	11	18
16	250	2000	10	11	18	12	18
17	250	3000	10	9	16	13	18
18	250	4000	10	8	14	14	18
19	250	5000	11	7	13	15	18
20	300	1000	9	11	17	9	21
21	300	2000	9	10	15	10	21
22	300	3000	9	9	14	10	22
23	300	4000	10	8	13	11	22
24	300	5000	10	7	12	12	22

Flow regime simulations in a typical section of the well using downhole measured rheological properties for both the initial and optimized fluid are presented in Figures 6 and 7. They show very different flow patterns for both fluids even though the rheology measured at 120°F atmospheric pressure for both fluids is very similar.

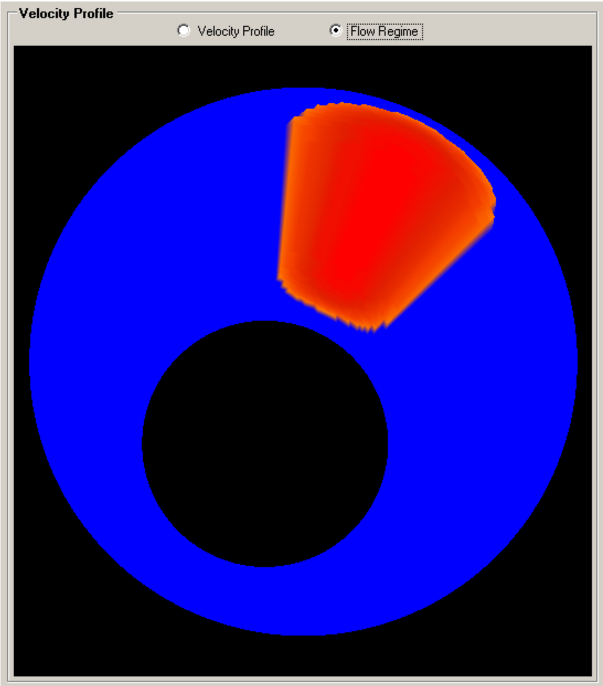

Figure 6. Drilling fluid flow regime simulation in a typical section of the well (blue = laminar and red = turbulent flow) using the pre-optimization HTHP rheological properties at 250°F and 3000 psi.

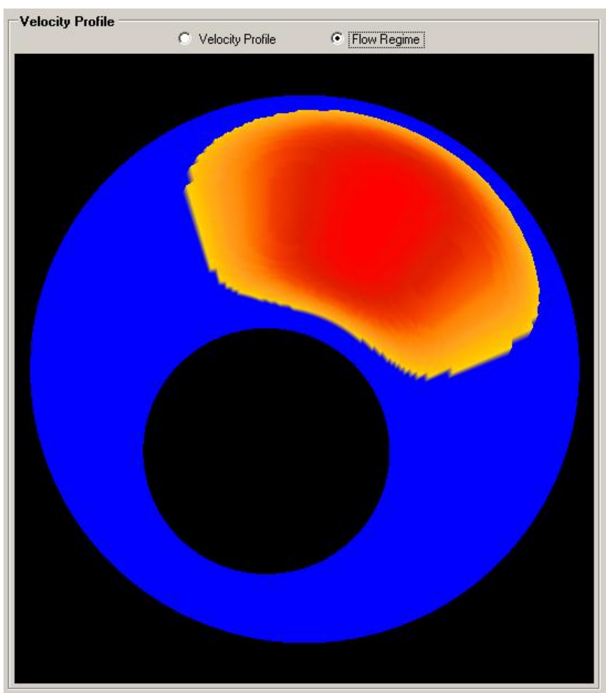

Figure 7. Drilling fluid flow regime simulation in a typical section of the well (blue = laminar and red = turbulent flow) using the end of interval HTHP rheological properties at 250°F and 3000 psi.

Conclusions

Measuring and reporting the rheological properties for oil-based drilling fluids at only one temperature may provide misleading information. Using these values for hydraulics calculations could render a distorted image of the downhole events and flow regimes. Measuring the drilling fluid rheology at multiple temperatures and pressures assists in managing the downhole rheology and ECD.

Acknowledgments

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Nomenclature

ECD = *Equivalent Circulating Density*
ERD = *Extended Reach Drilling*
LSYP = *Low shear yield point,* $lb_f/100\ ft^2$
OWR = *Oil Water Ratio*
PV = *Plastic viscosity, cP*
HTHP = *High Temperature High Pressure*
YP = *Yield point,* $lb_f/100\ ft^2$

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