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PRELIMINARY TESTS ON MODIFIED CLAYS FOR ELECTROLYTE CONTAMINATED DRILLING FLUIDS.

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Summary

The quality of a bentonite suspension declines in aggressive systems like brackish or saline pore water. An engineered clay (HYPER clay) was developed for sealing materials with enhanced resistance to aggressive conditions. The modified clay is produced by treating a sodium activated bentonite with a cellulose polymer following the HYPER clay process method.

This study investigates the suitability of the modified clay for electrolyte contaminated drilling fluids. Drilling fluids become contaminated with saline pore water, e.g. pick up an electrolyte contamination, while drilling a formation at for example an estuary or near the coast.

Preliminary laboratory tests were performed to study drilling fluid resistance to electrolytes. Therefore the drilling fluids were contaminated with sea water. Subsequently drilling fluid functionality was characterized by its filtration performance, thixotropic behavior, rheology (gel strength, yield point and viscosity) and bleeding behavior. Drilling fluid performance was analyzed at various electrolyte concentrations (7.6, 14 and 28 volume percentage sea water by total volume). Filter press tests (API, 13B-I) showed that the filtration performance improved significantly due to polymer treatment. Moreover, results showed that the rheology properties can be controlled using Xanthan Gum as an additive.

Introduction

The essential function of a drilling fluid is to stabilize the wellbore area during drilling and to transport the cuttings to the surface (Darley and Gray, 1998; Hughes et al, 1993; Kelessidis et al, 2007). However, salt water intrusion in delta's increasingly causes problems during drilling activities. Drilling fluids become contaminated with saline or brackish pore water, e.g. pick up an electrolyte contamination, while drilling through a formation near at for example an estuary or the coast. The quality of a water based drilling fluid however declines in the presence of electrolytes. A drilling fluid is in essence a clay suspension. Upon addition of electrolytes the suspension

will start to flocculate and or aggregate, and eventually the solids will settle out. In that case the drilling fluid will lose its functionality completely. In drilling fluid practice a suspension is considered stable if no phase separation is observed after 24 up to 72 hours (Cebo, 2014).

A decline in drilling fluid functionality can be quantified in the laboratory following the recommended practice for field testing of water based drilling fluids as set by the American Petroleum Institute (13B, 2009; 13A, 2010).

Given the improved hydraulic performance of HYPER clay in concentrated systems as geosynthetic clay liner pastes (> 80% w/w), (Di Emidio, 2010; Di Emidio et al., 2011), HYPER clay could have an elevated resistance to electrolytes and maintain optimal filtration performance even in dilute systems as drilling fluids are (d.s. 3.6 – 5 % w/w). For this reason the focus of this work was to evaluate if HYPER clay could be suitable as base clay in electrolyte resistant drilling fluids.

Drilling fluids

Water based drilling fluids consist of suspended clay particles, the continuous phase (water) and optional treating agents for pH adjustment (soda ash), rheology and filtration control (polymers).

Sodium montmorillonite clays, referred to as sodium bentonites, are perfect to use in drilling fluids, given their natural high tendency to swell. The net surface charge of a clay platelet is negative. This negative surface charge is balanced by exchangeable cations, typically Na^+ or Ca^{2+} , in the interlayers, and in the diffuse double layer. Swell indicates the attraction of ions and water molecules to the particle surface to counter balance this interlayer and outer layer negative surface charge. These adsorbed water molecules are essentially immobile and contribute to the low permeability and thixotropic behavior of bentonites (Barshad, 1960).

The formation of a thin and impermeable cake on the wall is required to stabilize the bore hole and limit fluid losses into the formation. The cake is formed by filtration of the drilling fluid which leaves the particles in the fluid on the wellbore surface.

In terms of viscosity – relation between shear rate and shear stress – the suspension should have a low viscosity to prevent high pressure differences along the length of the wellbore. Bentonite suspensions are however considered to be non-Newtonian fluids, which is caused by their thixotropic behavior. Thixotropy is time dependent flow behavior (Barnes, 1997). Thixotropic behavior is related to the buildup and breakdown of a three dimensional network (also referred as the house-of-cards structure) (Huisman, 2001; Luckham et al., 1999). In terms of laboratory analyses thixotropy is defined as the is the gel strength build up after 10 minutes minus the gel strength after 10 seconds (API, 2009). Yield point represents thixotropic behavior in dynamic state (association energies of particles after intensive mixing) and Gel Strength in static state (association energies of particles after a certain period of rest).

Both dynamic and static gel strength hold the cuttings into suspension, particularly important during long distance horizontal direction drilling and/ or when operations are interrupted (Yaln, 2002). The gel strength should be minimized though, to prevent

high pump pressures when restarting. Furthermore, the gel strength should be non-progressive. Interparticle bond formation in static conditions should be established after 10 minutes.

Target values

The requirements values set for a drilling fluid depend on the design of the borehole, pipeline dimensions and the formation drilled (Kabell, 1999). The minimum requirements are set by OCMA standard (API, 2010). Optimum filtration performance is expressed in a slick and thin filter cake of about 1 to 2 mm (Cebo, 2014; Rugang, 2014), and filtration losses of no more than 16 ml in 30 minutes (API, 2010). Regarding the rheology of the drilling fluid, the viscosity should be low, in the order of 20 cP. Besides this, the ratio between yield point and plastic viscosity should not exceed 6 (API, 2010).

An absolute minimum yield strength of 15 lb/ 100 ft² (7.2 Pa) is recommended to transport cuttings (from practice, Cebo 2014). Preferably it should be around (8.6 to 12 Pa) 18 to 25 lb/ 100 ft² in order to transport also larger and heavier cuttings (from practice Cebo 2014). In terms of gel strength it is important that the gel strength is not progressive after 10 minutes and that it remains lower than 30 lb/100 ft² (14.4 Pa) (Rugang, 2014).

Inhibitory effect of electrolytes and calcium

For water based drilling mud the continuous phase is most often fresh groundwater or surface water. A local deficiency of fresh water, could result in the use of saline or brackish water as process water. Furthermore, a fresh drilling fluid could become contaminated during the drilling process by mixing with local pore water containing elevated concentration of calcium (calcite rock formations) or electrolytes (sea water beddings). Such water will contaminate the continuous phase with ions like sodium, calcium and chloride, in general referred to as electrolytes.

Water is considered to be fresh if it contains a chloride concentration less than 150 mg/l. Water is considered to be brackish if it contains a chloride concentration of 150 mg/l up to 1000 mg/l (De Vries, 2007). For untreated bentonites it is advised to use fresh process water (EC < 1 mS/cm) (Cebo, 2014). Already a chloride concentration of 165 mg/l has an inhibitory effect on the hydration and dispersion for untreated bentonite (Rugang et al., 2014). Furthermore, it is advised to use process water with a calcium concentration lower than 100 mg/L. If not available treatment with soda ash is prescribed (Cebo, 2014).

In a stable clay suspension, there is an energy barrier between the dispersed clay platelets that prevents the collision of platelets and the subsequent formation and growth of particles. This energy barrier originates from the total energy of interaction. The total energy of interaction is a function of interparticle attractive and repulsive forces. Depending on the balance between attractive forces (van der Waals forces, electrostatic attraction between positive and negative charges, hydrogen bonds, and shared cations) and repulsive forces (electrochemical repulsion, ζ potential) between the clay platelets, four different structures can arise (Huisman, 2001). These

structures are (see Figure 1): dispersed and deflocculated, dispersed and flocculated, aggregated and deflocculated, aggregated and flocculated.

Upon addition of electrolytes flocculation is initiated and subsequent aggregation of clay particles is accelerated. As a result, platelets associate in the form of a loose, open network (Rugang et al., 2014; Caenn et al, 2011). This structure persists to a limited extent in filter cakes, causing a considerable increase in permeability (Stamatakis and Tien, 1991). Moreover, aggregation and particle growth will cause the clay suspension to be unstable and phase separation will occur. The rheology of the drilling fluid changes dramatically and the fluid loses its functionality (Yaln et al., 2002). Therefore, it is necessary to develop drilling fluids that are compatible with electrolytes.

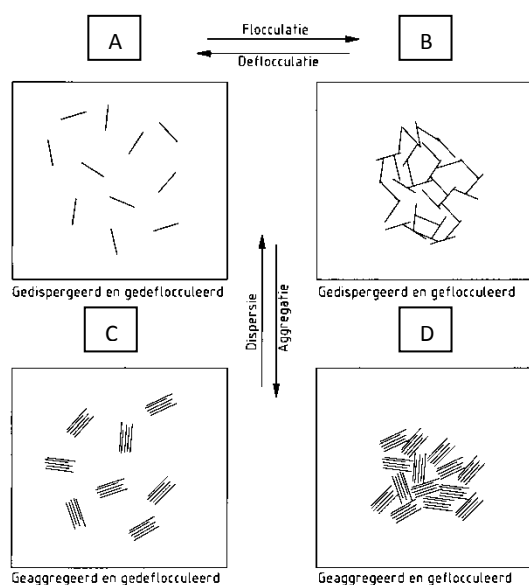


Figure 1: Orientation of clay platelets in four different structures (Huisman, 2001): dispersed and deflocculated (A, upper left), dispersed and flocculated (B, upper right), aggregated and deflocculated (C, lower left), aggregated and flocculated (D, lower right).

HYPER clay elevated resistance to electrolytes

HYPER clay is a carboxymethyl cellulose treated bentonite as introduced by Di Emidio (2010) for use in sealing materials (such as e.g. geosynthetic clay liners). With the HYPER clay procedure the polymer is intercalated between the clay sheets and is irreversibly adsorbed due to a dehydration step. Thereby HYPER clay platelets maintain their long range repulsive energies even in electrolyte systems.

Preceding research on HYPER clay based drilling fluids (den Hamer et al. 2014, in press) showed that the suspension remained stable and the filtration performance optimal in presence of electrolytes. However it also showed that the yield strength was low and decreased with increasing polymer concentration. The relatively low yield and gel strengths for HYPER clay based drilling fluids indicate that indeed the total energy of interaction is dominated by long range repulsive forces; even in an electrolyte contaminated system. This repulsive force is however so strong that the clay platelets hardly link in an edge-edge or edge-face orientation and thus hardly form a three dimensional network (house-of-cards structure, see Figure 1b). Explaining the low association energy between clay platelets, i.e. the low yield point (Figure 1a).

Present research investigates the addition of a nonionic biopolymer (Xanthan Gum) to HYPER clay suspensions and its impact on the yield point and gel strength. The presence of nonionic polymers induces steric bonds, however it does not cause cross linkage (as for cationic polymers) or further reducing bond energies by repulsion (as for ionic polymers) (Hiemenz and Rajagopalan, 1997).

Materials

Syntheses of HYPER clay

The base clay is an activated sodium montmorillonite, (Product name Absorben). Physical and chemical composition of Absorben can be requested at Cebo Holland BV.

A polyanionic carboxymethyl cellulose (PAC; brand name: Gabroil PAC HiVis, product of Akzo Nobel) is used to treat the clay. PAC is a highly charged anionic polyelectrolyte with carboxylic acid groups located on its cellulosic backbone. The counter ion for the anionic groups is sodium. The degree of substitution is > 0.9 . The indicated apparent viscosity (API HV purified) ≥ 37 mPa.s.

To produce HYPER clay (HC), Absorben was treated with PAC at various dosages (4%, 8% and 14% dry weight clay). For a detailed description of HYPER clay production method we refer to Di Emidio (2010). Di Emidio (2010) used polymer dosages of 2% up to 10% dry weight clay, and a water to clay ratio of 10 (W/C). To compensate for the elevated viscosity of the PAC polymer, more water was used to dissolve the polymer. Therefore, W/C in this study was 15.

To assess the quality of the HYPER clays produced, the swelling potential was determined in accordance with ASTM D5890. The swell index test gives an indication of the maximum swell capacity of a clay. The swell capacity of Absorben was elevated due to polymer treatment and increased with polymer dosage. The swell indexes observed were 24, 35, 38 and 50 ml per 2 gram, at a polymer dosage of 0%, 4%, 8% and 14% respectively. Following economical reasoning a HYPER clay containing 4% PAC was selected for drilling fluid testing.

Drilling fluid formulation

Drilling fluids were prepared containing 5% solids by weight using tap water (Ghent Municipality) and left to hydrate for 30 minutes. The period of hydration was set at 30

minutes instead of 16 hours as prescribed by API (2010) to compensate for the use of a high shear pump in practice (Cebo, 2014). Subsequently, these fluids were diluted, i.e. contaminated, with sea water. The drilling fluids formulated are presented in Table 3.

The volume ratio between pore water and drilling fluid water is set at 0.39 by dilution from 50 kg/m³ to 36 kg/m³ solids. A ratio of 0.39 corresponds to a sea water vol.% (on total volume) of 28% for a 36 kg/m³ concentrated drilling fluid. To obtain a relation between drilling fluid quality (at 36 kg/m³) and the degree of contamination the final sea water percentage was varied from 0%, 7.6%, 14% to 28%.

As nonionic biopolymer the additive Xanthan Gum was added. Xanthan gum is a polysaccharide, a common product in drilling industry to increase drilling fluid carrying capacity (API, 2010, 19.1.2).

Table 1: Composition of process waters used in present research

Parameter	Tap Water (Ghent)
Origen	Ghent
Composition	100 % tap water
EC	0.640
Ca ²⁺	132.3

Table 2: Composition of seawater from Oostende, Belgium.

Parameter	unit	Sea water
Origen		Oostende
Composition	vol.% process water	100% sea water
EC	[mS/cm]	49.5
Ca ²⁺	[mg/L]	481
Na ⁺	[mg/L]	10460
K ⁺	[mg/L]	469
Mg ²⁺	[mg/L]	1288
Cl ⁻	[mg/L]	19889
SO ₄ ²⁻	[mg/L]	2306
HCO ₃ ⁻	[mg/L]	183

* Sea water from Oostende, Belgium was collected and filtered before use. Detailed composition analyses of Oostende seawater can be found in Di Emidio et al, 2011.

Methods

Drilling fluid performance was characterized by suspension stability, its thixotropic and rheological properties (gel strength, yield point and viscosity), and filtration performance; tested in accordance with API 13-b Recommended Practice for Water Based Drilling Fluids (API, 2009). Each sample was stirred for 5 minutes before rheological and filtration properties were measured.

The degree of suspension stability was quantified by measuring the volume of 'free water' after 24 hours of incubation at constant temperature 20 °C ± 1. After 24 hours the final temperature and suspended solids height were registered. The volume of free water was calculated as volume clear water over total volume. Using this method the electrolyte concentration at which aggregation and phase separation starts is determined.

Table 3: Drilling fluids formulated

No	HYPER clay		Additive		Sea water	EC	[Ca ²⁺] ¹
#	conc., type polymer	wt.% process water	type	wt.% process water	% v/v	mS/cm	mg/l
0 ⁴	0% PAC	3.6%	-	0.00%	7.5%	14.2	132.3
0 ⁴	0% PAC	3.6%	Xanthan gum	0.21%	28%	0.64	132.3
1 ²	4%PAC	3.6%	-	0.00%	0%	0.64	132.3
2 ²	4%PAC	3.6%	Xanthan gum	0.10%	0%	0.64	132.3
3 ²	4%PAC	3.6%	Xanthan gum	0.21%	0%	0.64	132.3
4 ³	4%PAC	3.6%	Xanthan gum	0.21%	7.5%	14.2 ⁴	129.9 ⁴
5 ³	4%PAC	3.6%	Xanthan gum	0.21%	14%	26.2 ⁴	240.5 ⁴
6 ³	4%PAC	3.6%	Xanthan gum	0.21%	28%	49.5 ⁴	481.0 ⁴
7 ⁵	4%PAC	3.6%	-	0.00%	28%	0.64	132.3
8 ⁵	4%PAC	3.6%	Xanthan gum	0.10%	28%	0.64	132.3
9 ⁵	4%PAC	3.6%	Xanthan gum	0.21%	28%	0.64	132.3
10 ⁶	4%PAC	3.6%	Xanthan gum	0.21%	28%	0.05	<detection limit

Filtration performance was determined by following the API Fluid Loss Test, the standard static filtration test used in the industry (API 13B, 2009). With the addition that in present tests the weight of filtrate was recorded continuously (6 times per second).

¹ Calculation based on dilution factor and measured total calcium content of sea water and tap water using a cuvette test.

² Diluted from drilling fluid containing 5% solids. The process water used for this 5% solids drilling fluid was tap water from Ghent municipality (EC = 0.64 mS/cm, Calcium concentration = 132.26 mg/l). Subsequently the 5% drilling fluid was diluted to a solid concentration of 3.6% using tap water.

³ Diluted from drilling fluid containing 5% solids. The process water used for this 5% solids drilling fluid was tap water from Ghent municipality (EC = 0.64 mS/cm, Calcium concentration = 132.26 mg/l). Subsequently the 5% drilling fluid was diluted to a solid concentration of 3.6% using a only sea water (28 vol.% SW) or a mixture of fresh water and sea water (7.5 vol.% and 14 vol.%).

⁴ Properties of 'pore water' added upon dilution of the drilling fluid.

⁵ Diluted from drilling fluid containing 5% solids. The process water used for this 5% solids drilling fluid was tap water from Ghent municipality (EC = 0.64 mS/cm, Calcium concentration = 132.26 mg/l). Subsequently the 5% drilling fluid was diluted to a solid concentration of 3.6% using sea water.

⁶ Diluted from drilling fluid containing 5% solids. The process water used for this 5% solids drilling fluid was decalcified tap water using a Purelab Prima Elga purifier system (EC = 0.052 mS/cm, Calcium concentration was below the detection limit). Subsequently the 5% drilling fluid was diluted to a solid concentration of 3.6% using sea water.

Rheology properties were determined using a Fann (model 35 SA) viscometer. A so called consistency curve displays the relationship between shear rate and shear stress. The apparent viscosity (AV), plastic viscosity (PV), yield point (YP) and Gel strength after 10 seconds and 10 minutes were derived from this consistency curve in accordance with API 13B (2009).

Results and Discussion

Suspension Stability

Bentonite treatment following the HYPER clay procedure in combination with xanthan gum addition resulted in the creation of a stable suspension in the presence of sea water. No phase separation was observed 24 h and even 72 h after addition of the electrolyte contamination (up to 28% SW by total volume drilling fluid after dilution). Opposed to the untreated clay for which a (free water volume of 17.7 ml / 1000 ml was measured at 7.5 vol.% sea water. These results indicate that aggregation and subsequent settlement of aggregates – in presence of 28 vol.% SW - is prevented due to the HYPER clay treatment in combination with the nonionic additive.

Filtration Performance

Influence of electrolyte contamination on drilling fluid quality

Filtration performances of electrolyte contaminated drilling fluids are compared based on the results shown in Figure 2. The relation between sea water % on total volume (unit presented on the x-axis), sea water mixing ratio ($V_{\text{pore water}} / V_{\text{process water fresh drilling fluid}} = 0.39$), and EC is presented in Table 3.

Treatment according to the HYPER clay procedure results in a filtration loss well below the limit of 16 gr/30 minutes (API, 2010), even if the drilling fluid is diluted up to 28 vol.% with sea water (Figure 2). As expected the filtration performance decreases with increasing vol.% sea water, i.e. electrical conductivity (Figure 2). Filtrate loss increases from 8.8, 9.4, 9.9 to 12.4 gr/ 30 minutes with 7.6%, 0%, 14% up to 28% sea water.

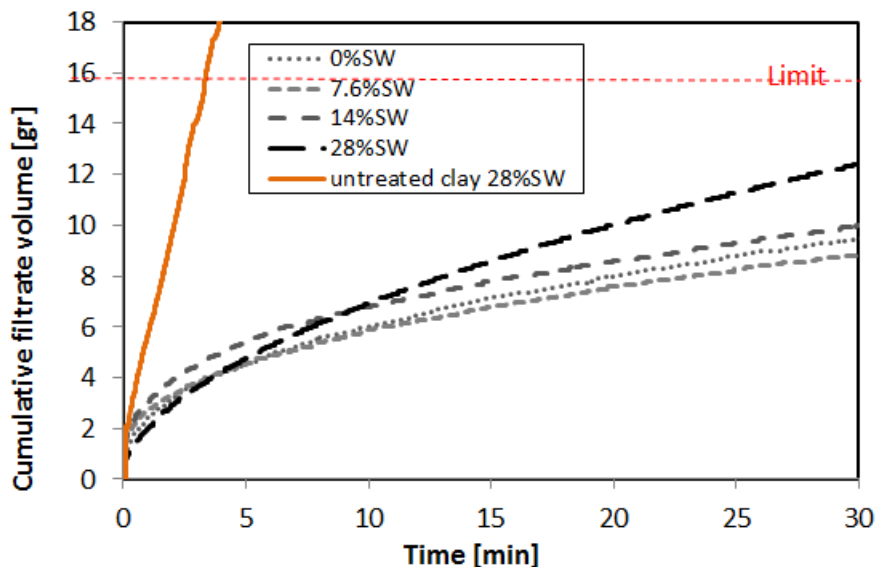


Figure 2: Influence of drilling fluid contamination with sea water on filtrate performance. Filtrate loss over 30 minutes at various electrolyte concentrations for a drilling fluid diluted to 3.6% solids (plus 0.2% Xanthan Gum). All drilling fluids presented are based on HYPER clay except for the untreated clay.

The observed improved performance in high electrolyte systems is explained by the extended basal spacing (Di Emidio, 2010) upon polymer intercalation. This effect cultivates a preserved swelling capacity of the HYPER clays in electrolytes. The observations of Rugang et al. (2014) support these postulations. Based on SEM analyses of filter cakes, Rugang et al. (2014) relates an increase in filter cake permeability, in the presence of electrolytes, to an increase of pore size and decrease in pore wall thickness. In absence of the adsorbed polymer, electrolyte contamination causes coagulation of clay particles to such an extent that an open pore network is formed (Rugang et al., 2014).

Rheology

Influence of electrolyte contamination on drilling fluid quality

Figure 3 and Figure 5 present the relation between viscosity, yield point and the degree of sea water contamination.

For a drilling fluid based on untreated bentonite (0%PAC) and contaminated with 28 vol.% SW a yield point of 38 lb/100 ft² was observed using a XG concentration of 0.2%. Reducing the XG concentration to 0.1% and 0.0%, the yield point reduced accordingly to a value of 29 lb/100 ft² and 15 lb/100 ft² respectively (results not presented in Figure 5).

For drilling fluids based on HYPER clay (4%PAC) the added amount of XG was set at 0.2% to obtain a yield point of 21 lb/100 ft² in the absence of sea water contamination (0%SW). The amount of XG to be added was fixed at 0.2% XG for all levels of contamination (7.6%, 14% and 28% SW).

From Figure 5 it becomes clear that a XG addition of 0.2% was however not required in the presence of electrolytes. This is indicated by the relatively high yield point values for drilling fluids contaminated with 7.6%, 14% and 28% of sea water.

Furthermore, it was observed that both dynamic (yield point) and static gel strength increase with increasing concentration of electrolytes i.e. with increasing degree of sea water contamination. The gel strength was not progressive after 10 minutes of rest (results at 30 and 60 minutes not presented here).

Figure 4 illustrates the thixotropic properties of the drilling fluid at increasing sea water contamination. The build up of gel strength in static conditions in 10 minutes was relatively high, in the order of 25 to 35 lb/100 ft² at sea water contamination of 0%, 7.6% and 14% (Figure 4). These values are just below or above the set limit of 30 lb/100 ft². At 28% sea water the gel strength did not fulfill the requirements; it increased to 68 lb/100 ft².

To study the effect of XG concentration on yield point and gel strength at a sea water contamination of 28% more drilling fluids were prepared. The results are presented in Figure 6. Figure 6 shows that by reducing the XG concentration the yield point will decrease accordingly. The yield point drops from 43 lb/100 ft² to 19 lb/100 ft² reducing the XG concentration from 0.2% to 0.0%. However, the static gel strength is only effected limited by a decrease in XG concentration.

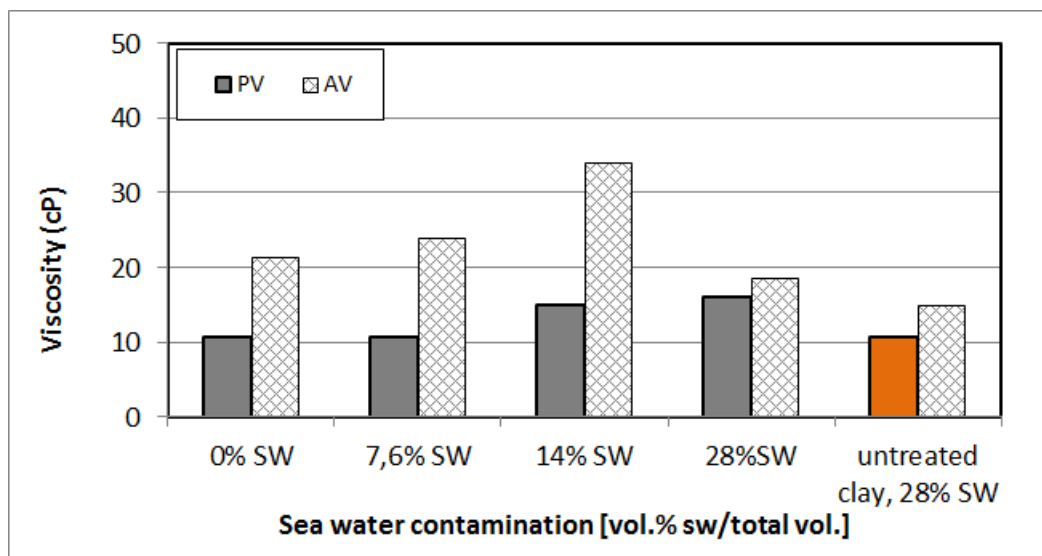


Figure 3: Apparent Viscosity (AV), Plastic Viscosity (PV) and Yield Point (YP) as a function of electrolyte concentration of a drilling fluid diluted to 3.6% solids (plus 0.2% Xanthan Gum).

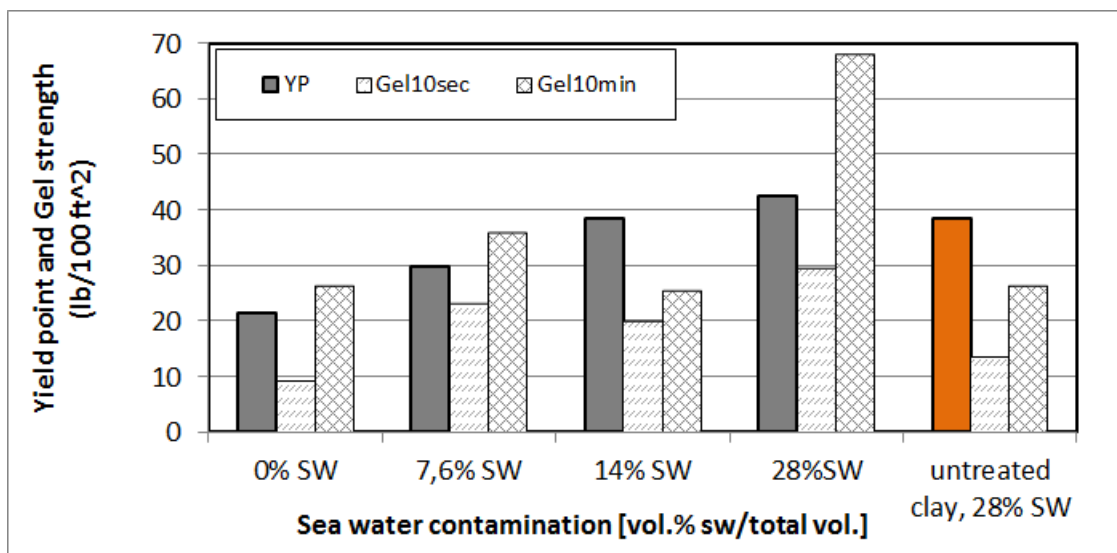


Figure 4: Dynamic (YP) and static Gel Strength (GS) build up as a function of electrolyte concentration of a drilling fluid diluted to 3.6% solids (plus 0.2% Xanthan Gum).

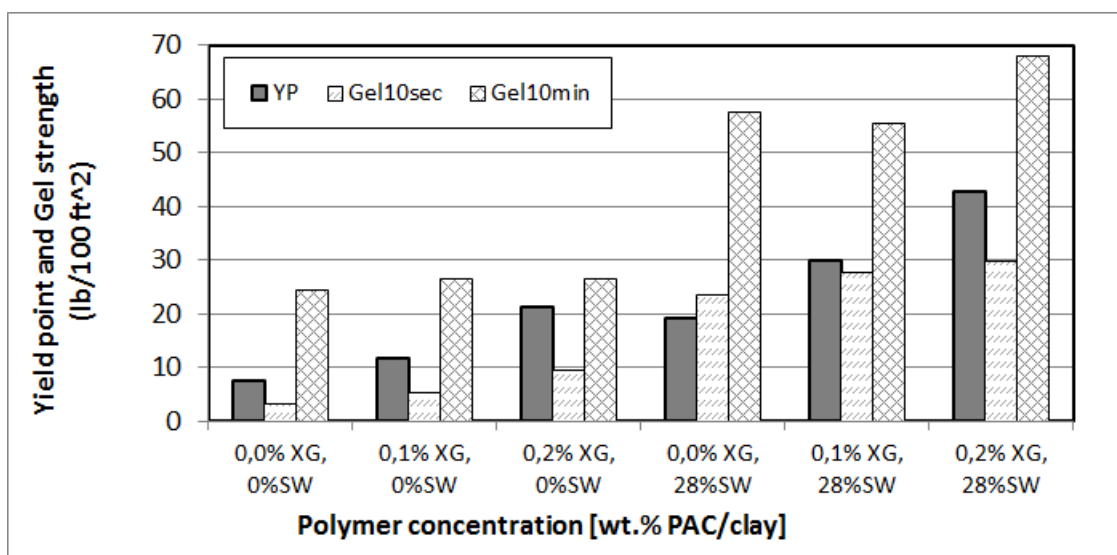


Figure 6: Dynamic (YP) and static Gel Strength (GS) build up as a function of Xanthan Gum concentration and electrolyte concentration of a drilling fluid diluted to 3.6% solids.

An increase of static and dynamic gel strength indicates an increase in association energies between particles (Huisman, 2001, Luckham, 1999). So, more and/or stronger bonds are formed between clay platelets, with increasing sea water contamination. This observation could be explained by a reduced zeta potential and compressed energy barrier (due to increasing chemical stress, i.e. conductivity). Therefore, face to edge orientation of dispersed clay particles starts to exist and flocculation is initiated (Huisman, 2001, Luckham, 1999; Figure 1b).

It is postulated that in the presence of xanthan gum a 'secondary minimum' is created where a much weaker and potentially reversible adhesion between particles exists (Heimenz and Rajagopalan, 1997). See an illustration of the diagram of free energy with particle separation in Figure 5. These weak flocks are sufficiently stable not to be broken up by Brownian motion when the suspension is in rest, although

sufficiently small not to settle down, and may disperse under an externally applied force such as vigorous agitation. Since no phase separation is observed (free water is 0 ml/1000 ml) at all levels of sea water contamination there are no aggregates formed yet heavy enough to settle out within a window of 72 h.

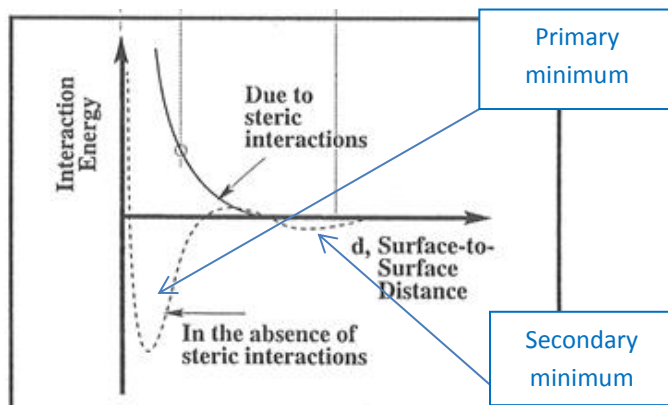


Figure 5: Adjusted from Heimanz and Rajagopalan, 1997, page 608. Depending on the nature of the particles, a strong van der Waals attraction and electrostatic repulsion. Steric repulsion could stabilize the dispersion against coagulation in the primary minimum in the interaction potential.

Conclusion

Polymer treatment according to the HYPER clay process method improved the filtration performance of sodium activated bentonite in drilling fluids that become contaminated with electrolytes during drilling. Xanthan Gum is a suitable additive to correct for the rheological requirements.

During drilling through formations with brackish or saline pore water the drilling fluid will be more and more diluted with electrolyte contaminated pore water. To simulate this a HYPER clay (4% PAC) based drilling fluid of 5% solids was diluted to 3.6% solids using sea water.

Based on the research results it is concluded that a HYPER clay based drilling fluid is resistant to sea water contamination up to 28 vol.% sea water. The filtrate loss is well below the limit set by API standard at a pore water to drilling fluid water volume ratio of 0.39, using sea water (EC of 49.5 mS/cm and calcium concentration of 481 mg/l). Using HYPER clay, the filtration performance will remain as required and will only be affected minimally as a function of the electrolyte concentration.

In terms of rheology, more specifically the dynamic gel strength, HYPER clay based drilling fluids fulfill the set requirements up to 28 vol.% sea water contamination. The observed gel strength build up in static conditions was however above the advised limit of 30 lb/100 ft² at 28% SW contamination. Both static and dynamic gel strength depend on the degree of sea water contamination of the drilling fluid. Xanthan gum or the addition of fresh drilling fluid can be used to fine-tune the dynamic gel strength (yield point) while drilling. Ongoing research focuses on the aspect of static gel strength specifically, regarding HYPER clay performance in drilling fluids contaminated with a lower volume ratio of pore water to drilling fluid water (< 0.39).

Besides, research focuses in particular on the various characteristics of nonionic polymers to be used as additive, and its relation to HYPER clay performance.

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