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Nanotechnology Based Shale Inhibitor

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Abstract

Shale inhibitors that are commonly used in water-based fluid systems are not universally applicable in all formation types or regions. For example, kaolinite rich shales, can lose strength when exposed to KCl through cation exchange with potassium. In the United States, government regulations prohibit the disposal of greater than 3,000 ppm chloride on lease or 1,000 ppm chloride off lease. The hazardous nature of choline chloride restricts its use as shale inhibitor for water-based fluids.

NanoSilica Based Shale Inhibitor (NSBSI) has been developed to mitigate clay destabilization in particularly challenging formations. NSBSI is used when drilling with low solids, non-dispersed (LSND) muds, such as polymer and PAC muds. It can be used as an alternative to polyamine-based shale inhibitors and silicate-based shale inhibitors. Field trials were conducted in three wells. Commonly used shale inhibitor (poly-amine based) were replaced by NSBSI in mud formulations in order to complete the field trials. Trouble-free drilling through problematic shale sections with no changes in mud properties, and no indications of lack of inhibition were experienced.

The novel amine functionalized nano-silica (NSBSI) we have used in this study has a mean particle size distribution of 30-50 nm. In addition to making an adsorption layer on the rock surface, chemically being SiO_2, it can get involved in the cementation on formation surface thereby forming impervious Calcium-Silicate-Hydrate type of layer. In the dispersion test it showed >90% with Pierre II Shales and outperformed the commercial materials. Linear swell meter results demonstrated NSBSI performs very well in comparison to the three commercial products tested herein. This amine functionalized nanosilica inhibitor not only provide lower overall swelling after 72 hours, but also provide very low % swelling until 24 hours. Early stage of swelling is very detrimental for drilling operation, lower swelling at 24hours indicate the slower swelling kinetics, therefore, better inhibiting layer formation. Laboratory based concept was scaled up to bulk quantities and went through successful field trials.

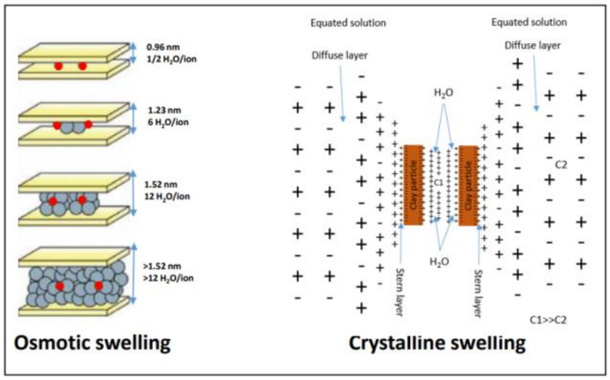
The newly developed inhibitor in the current study has outperformed conventional shale inhibitors wherein the presence of inorganic constituents aids stronger film formation compared to solely organic inhibitors. Comparative studies have been carried out against commercially used shale inhibitors using linear swell meter, dispersion test and pore pressure penetration test and the results will be presented.

Introduction

Water based muds (WBM) are much attractive options when it comes to environmental sustainability, cost and ease of disposal, however, conventional WBM consistently fail to match the drilling performance of Oil based mud (OBM) and synthetic based mud (SBM). Today about 50% of the drilling fluids are water based with rest being non-aqueous type. Non-aqueous drilling fluids come with inherent advantages like rheological, fluid loss control and non-interactive to clay-rich formation. It is well known that formation rocks consist of water sensitive clay minerals are susceptible to swelling in presence of water-based fluids [1–9], wherein, wellbore stability issues like borehole collapse and stuck pipe events lead to increased non-productive time (NPT), contributing towards higher cost of drilling during wellbore construction process. Formation rocks containing higher amount of smectite type clays like montmorillonite (a layered aluminosilicates with high cationic exchange capacity) contributes to its troublesome water swelling nature. On the other hand, clays like Kaolinite, Illite or Chlorite are less prone to swelling due to their low cation exchange capacity (Figure 1).

Typically swelling issues while drilling with water-based fluids has been reduced by the use of shale inhibitors or clay stabilizers. Swelling of clay happens due to water-clay interaction - a hydration phenomenon of smectite clays leading to spatial separation (also known as house of cards effects) of the aluminosilicate's layers wherein (1) Osmotic swelling: due to osmotic pressure difference and (2) Crystalline swelling: due to electrical double-layer effects are the two major driving forces behind it.

One of the mechanisms of shale stabilization is due to adsorption of inhibitor molecules on the clay surfaces through electrostatic attraction forces [10-29] leading to formation of a hydrophobic barrier that inhibits/delay the penetration/diffusion of water molecules. Second mechanism utilizing potassium chloride (KCl) at higher concentrations providing inhibition via cation exchange method. Use of large amount of KCl (>3%) is an environmentally sensitive issue in terms of disposal. Researchers have proposed polyamines, quaternary ammonium salts, dendrimers, graphene oxide derivatives, functionalized carbon nanotubes, polyethyleneimines, functionalized nano-silica, laponite, biopolymer derivatives for shale inhibitors applications. In this work we demonstrate performance of our novel functionalize nano-silica based shale inhibitors (NSBSI) in comparison with commercially available products.



Materials:
The novel amine functionalized nano-silica (NSBSI) we have developed in this study is spherical in shape (Figure 2) and has a mean particle size distribution of 30-50 nm. In addition to making an adsorption layer on the rock surface, chemically being SiO_2, it can get involved in the cementation on formation surface thereby forming impervious Calcium-Silicate-Hydrate type of layer. For comparison, we have also tested 3 commercially used materials.

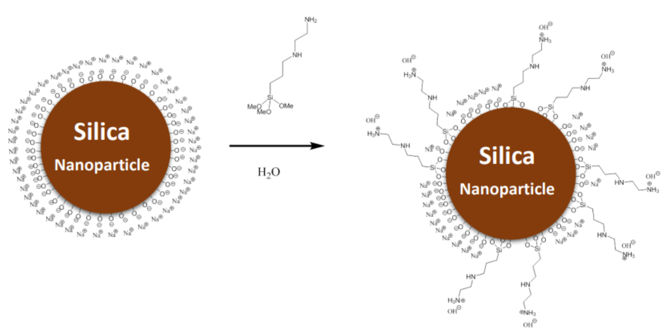


Figure 2: Shape and structure of the amine functionalized Nanosilica inhibitor (NSBSI)

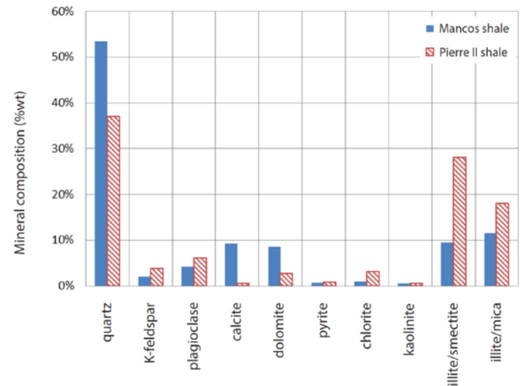


Figure 1: Rietveld analysis of Mancos shale (blue) and Pierre II shale (red). The Illite/smectite mixed layer in the Pierre II shale is estimated to be 70% smectite. The Illite/smectite mixed layer in Mancos shale is estimated as containing 50% smectite.

Dispersion test:
The dispersion tests were conducted on Pierre II Shales. Mineralogical composition of Pierre II both in fresh water (de-ionized water) and seawater. Fresh water-based and seawater-based fluids containing inhibitors, xanthan gum (0.2ppb), and de-ionized or seawater were formulated. Pierre II shale was added to the fluids and the dispersion in glass jars was rolled at 25C for 16 h in an oven. Commercial shale inhibitors (Choline Chloride, Commercial A, and KCl) were used to prepare fresh water-based and seawater-based fluids to compare the shale recovery in the dispersion tests. After 16 h of dispersion tests, the dispersion was passed through #8 mesh to recover shales that remained unaffected from hydration and swelling. Table 1 summarizes the % shale recovery for each test. Amine functionalized Nanosilica inhibitor performed very well compared to the commercially used materials.

Materials	Test conditions	% Recovery
NSBSI (3ppb)	Sea water	91%
Choline Chloride (3ppb)	Sea water	82%
None	Sea water	25%
None	Fresh water	0.4%
Choline Chloride (3ppb)	Fresh water	57.9%
Commercial A (3ppb)	Fresh water	53.4%
KCl (3%)	Fresh water	50.3%
Choline Chloride (3ppb)	Sea water	81.6%
Commercial A (3ppb)	Sea water	72.2%

Linear Swellmeter Test: (for these tests you need to state concentration of product. The commercial products I would put as recommended by vendor (lb/bbl of product B or C or) for our product lb/bbl active or what would be recommended amount per bbl.

Linear swellmeter measurements, the capacity of inhibitors to prevent hydration and swelling are conducted to quantify the changes in the volume of bentonite pellets/ wafers. The bentonite wafers were prepared by pressing dry bentonite powder at 41.4 MPa for 30 min. The drilling fluids were circulated around the wafers and the changes in the height of compressed wafers with respect to time were used as swelling percentages. The results summary is presented in Figure 4. Results demonstrate both NSBSI and LMS-NH_2 perform very well in comparison to the three commercial products tested herein. Amine functionalized nanosilica inhibitor not only provide lower overall swelling after 72 hours, but also provide very low % swelling after 24 hours. Early stage of swelling is very detrimental for drilling operation, lower swelling at 24hours indicate the slower swelling kinetics, therefore, better inhibiting layer formation.

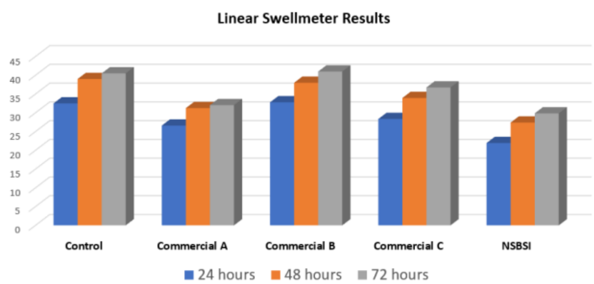


Figure 4: Linear Swellmeter results comparison

Field Deployment:
Novel amine functionalized nanosilica based inhibitor has been successfully field trialed 3 times replacing a commercial additive, trouble-free drilling operation was achieved in each trial.

Field trial 1:

Hole diameter – 16”
Mud density – 76pcf
Other regular additives: Barite, XC polymer, starch, caustic soda, calcium carbonate and NaCl.
NSBSI Concentration – 2-3 volume %
PV = 18 cP
YP = 22 lb/100ft^2
6,3 RPM = 7,5 DR
10sec, 10min gel = 6,8 lbf/100ft^2

Results:

- There was no issue while adding/mixing NSBSI to the active mud system.
- There were no issues while drilling such as hole cleaning was observed.
- The cuttings integrity was good due to inhibition of swelling provided by NSBSI.

Field trial 2:

Hole diameter – 12-1/4”
Mud density – 75-77pcf
Other regular additives: Defoamer, Biocide, Soda Ash, Bentonite, NaCl, XC-Polymer, $CaCO_3$, Barite, NaOH and Oxygen Scavenger .
NSBSI Concentration – 3 volume %
PV = 18 cP
YP = 25 lb/100ft^2
6,3 RPM = 7,6 DR
10sec, 10min gel = 8,16 lbf/100ft^2

Results:

- There was no issue while adding/mixing NSBSI to the active mud system.
- There were no issues while drilling such as hole cleaning observed.
- The cuttings integrity was good due to inhibition of swelling provided by NSBSI

Conclusions:

- Novel nanosilica-based shale inhibitor have been developed.
- Both demonstrated superior performances in laboratory-based dispersion and linear swellmeter test when compared with commercially used materials.
- Both novel inhibitors developed here perform very well in comparison to the commercially used materials.
- Novel amine functionalized nanosilica based inhibitor (NSBSI) has been successfully field trialed.

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