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Using Nanotechnology for Enhancing Cement Properties in Gas Wells

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Abstract: *This paper is a summary for an experimental work which was done to prove the efficiency of nano calcium carbonatesin enhancing cement properties in gas wells.*

Keywords—nanotechnology, cementing, gas wells; nanocement.

1. INTRODUCTION

Nano particles are considered the most up-to-date technology used in petroleum engineering. Such technology is used for production enhancement through obtaining the required reservoir and fluid properties. Nanotechnology is the use of very small pieces of material, with dimensions among approximately 1 and 100 nanometers. By themselves or by their manipulation, a new, large-scale materials can be created to get the objective application. In simple terms, Nanotechnology is the science, engineering, and technology executed at the Nano-scale. Richard Feynman was the first scientist to suggest (in 1959) that such materials could someday be designed to atomic specifications.

The tiny nature of nanoparticles results in very useful characteristics, such as an increased surface area to volume ratio, leading for stronger or more lightweight materials. Suspensions of nanoparticles are designed easily because the interaction of the nanoparticle's surface with the solvent is strong enough to overcome differences in density, which usually result in a perfect 'Nanofluid'.

Nanoparticles can be used in drilling, completion and production stages. Nanoparticles can be added to the drilling fluid to minimize shale permeability through physically plugging the nanometer-sized pores and shut off water loss. Hence, Nanoparticles can provide potential solution for environmentally sensitive areas where Oil-based muds used as a solution to shale instability problems. Due to high surface area to volume ratio and very low concentration requirement compared to macro and micromaterial-based fluids, nano-based fluid could be the fluid of choice for drilling in shale which is very reactive, highly pliable, and tenacious and thus can stick easily to the bit, stabilizers, tool joints, etc. as it prevents the reduction in ROP and in total operating cost.

Recently, viscoelastic surfactant (VES) fluids composed of low-molecular-weight surfactants have been used as hydraulic fracturing and frac-packing fluids. The surfactants structurally arrange in brine to form rod-like micelles that exhibit viscoelastic fluid behavior. VES fluids, once broken, leave very little residue or production damage. However, excessive fluid leak-off and poor thermal stability has significantly limited their use.

Hatia and Chacko, suggested the injection of air-suspended self-heating Ni-Fe nanoparticles (50 nm) in the hydrate formation through horizontal well. These particles will penetrate deep into the class I, II and H hydrate reservoir by passing through the cavities (86-95 nm). The self-heating of Ni-Fe particles in a magnetic field is caused by hysteresis loss and relaxation losses. These particles cause a temperature rise up to 42 0C in the formation leading to disturbance in thermodynamic equilibrium and causing the water cage to decompose and release methane. In this technique, the pressure of the fluids in contact with hydrate is lowered, pushing the hydrate out of its stability region and leading to its decomposition.

Nanoparticles are small enough to pass through pore throats in typical reservoirs, but they nevertheless can be retained by the rock. Rodriguez, injected concentrated (up to ~20 wt. %) aqueous suspensions of surface-treated silica nanoparticles (D = 5 nm and 20 nm) into sedimentary rocks of different lithologies and permeabilities. The particles generally undergo little ultimate retention, nearly all being eluted by a lengthy post flush. The Nanoparticles in an aqueous dispersion will assemble themselves into structural arrays at a discontinuous phase such as oil, gas, paraffin, or polymer. The particles that are present in this three-phase contact region tend to form a wedge-like structure and force themselves between the discontinuous phase and the substrate.

According to the use of nanoparticles in cementing gas wells, firstly we need to know the special considerations required to cement a gas well which are different from an oil well cementing.

2 LITERATURE REVIEW

In 2012, When R. De La Roige et al added nano calcium silicates to Portland cement, the form of the microscopic hydration process changes. The binding mechanism changes from glue to wrapping as shown in the figure and the cement slurry produces a crystalline structure that is able to partially block capillary pores. Because of the fibre like structure it becomes flexible and prevents micro cracking to occur. Thus enhanced the compressive strength and prevented oil seepages.

In 2019, When Mariam E. et al used Nano-Graphite (0.2% by volume) in class G cement, this led to more reduction in cement viscosity with increasing shear rate. This explains the behavior of shear thinning fluid, which makes this additive an attractive solution for squeeze jobs. As indicated in the following figures, the Herschel-Buckly model is the best to describe this behavior.

In 2015, C. Vip et al studied the effect of adding 1 % Nano Calcium Carbonate to prevent effect of cement contamination with oil base mud. Density, Rhyological properties and Electrical resistivity was measured before and after adding NPs.

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The average density of smart cement was 16.47 ppg and the density of OBM was 7.34 ppg. As cement was contaminated with OBM, the density of cement slurry reduced due to lower density of OBM. As summarized in Table 1, 0.1 % of OBM contamination reduced the density by 0.5 % to 16.39 ppg and 3% of OBM contamination reduced it to 15.53 ppg which means 5.7 % decrement. Adding 1 % of NC as a modification reduced the density slightly to 16.3 ppg that is 1 %. 0.1 % and 3% of OBM contamination also reduced the density of modified cement slurry with 1 % of NCC by 0.5 % and 5.2 % respectively to 16.23 ppg and 15.46 ppg.

a- Smart cement : for the smart cement after 10 sec the gel strength was 10 lb/100 ft2, and after 10 minutes it was 13/100 ft2

b- NCC Modified Smart Cement: Adding 1 % of NCC Increased the Rhyological properties of cement slurry due to its higher surface energy as a Nanoparticle. The gel strength with the modified cement slurry with NPs 1% increased by 10 % and 15 % respectively to 11 lb/100 ft2 and 15 lb/100 ft2 after 10 sec and 10 min respectively.

c- Contaminated Smart Cement: 3% of OBM contamination filled up the pores of loose net structure around the cement particles which resulted in increasing the rhyological properties of cement slurry. The gel strength of the 3% OBM contaminated cement slurry increased to 16 lb/100ft2 after 10 seconds, a 60% increase and to 19 lb/100 ft2, after 10 minutes, a 46% increase.

d- Contaminated NCC Modified Smart Cement : As we mentioned, adding 1% NCC to the cement slurry increased the rhyological properties of cement slurry. Adding 1% NCC increased the gel strength of 3% OBM contaminated cement slurry to 18 lb/100 ft2 after 10 sec, a 13% increase and to 22 lb/100ft2 after 10 min, 16% inc.

Resistivity:

a. Smart Cement : the average initial resistivity of cement slurry was 1.07 ohm.m
b. NCC modified smart cement : Adding 1% NCC to cement reduced the initial resistivity from 1.07 to 0.85 ohm.m, a 21% reduction. This may be due to the changes in the pore fluid composition due to adding 1% NCC. As shown in table 1, adding 1% NCC caused 1% Change in density of cement slurry, while the changes of initial resistivity was 21 times more sensitive to the modification of cement slurry.
c. Contaminated Smart Cement: Contamination of the cement by 0.1% and 3% OBM resulted in an increase in initial resistivity to 1.13 ohm.m and 1.42 ohm.m respectively. Contamination of the cement by 0.1% and 3% OBM resulted an increase of 6% and 33% respectively. As shown in table 1, the changes in density of smart cement slurryby OBM contamination Contamination by 0.1% and 3% OBM, were 0.5% and 5.7% respectively. Hence Comparing the changes in the density of OBM contaminated cement slurry and the changes in the initial resistivity. So, the changes in resistivity were 6-12 times more than in density.
d. Contaminated NCC Smart Cement: As shown in figure 3, adding 1% NCC reduced the resistivity of 0.1% OBM contaminated cement from 1.13 to 0.94 ohm.m, a 17% reduction. Adding 1% NCC reduced the resistivity of 3% OBM contaminated cement from 1.42 to 1.06 ohm.m, a 25% reduction.

3 METHODOLOGY

1st Experimental work

A simple cement was made by the following process:

CaCO3 was heated to 800 °c, Then CaO was formed

$$CaCO_3 \longrightarrow CaO + CO_2$$

When 0.05 Liter of H2O was added to 100 gm of CaO, Ca(OH)2 was formed, before getting dried, a 200 gm of sand was added in three stages, then a simple cement was formed. It got dried within 2 days and held 2 bricks strongly.

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

But, when 100 gm CaCO3 was ground while heated to 800 °c, Then CaO was formed and. 0.05 Liter of H2O was added which was a strong exothermic reaction, within 15 seconds the 200 gm sand was added, the resulting cement was stronger after dried between bricks. This is because grinding while heating the calcium carbonate led to getting the smallest particle size of it. And the getting Ca (OH)2 by an exothermic reaction led to forming nano size of particles that formed due to emitting heat between its particles.

$$\mathrm{CaCO3} \xrightarrow{heat} \mathrm{CaO} + \mathrm{CO2}$$

$$\mathrm{CaO} + \mathrm{H2O} \longrightarrow \mathrm{Ca\ (OH)2}$$

So, it is concluded that stronger cement is formed using nanolime.

2nd Experimental work

A modification was made for 500 gm of cement before mixing it to water and drying it. when 50 gm CaCO3 was ground while heated to 800 °c, Then CaO was formed and. 0.1 Liter of H2O was added which was a strong exothermic reaction, within 10 seconds the 500 gm of cement was added, the resulting cement was stronger after being dried between bricks. The resulting cement is stronger than the normal cement (before adding nanolime), this is because of nanolime effect.

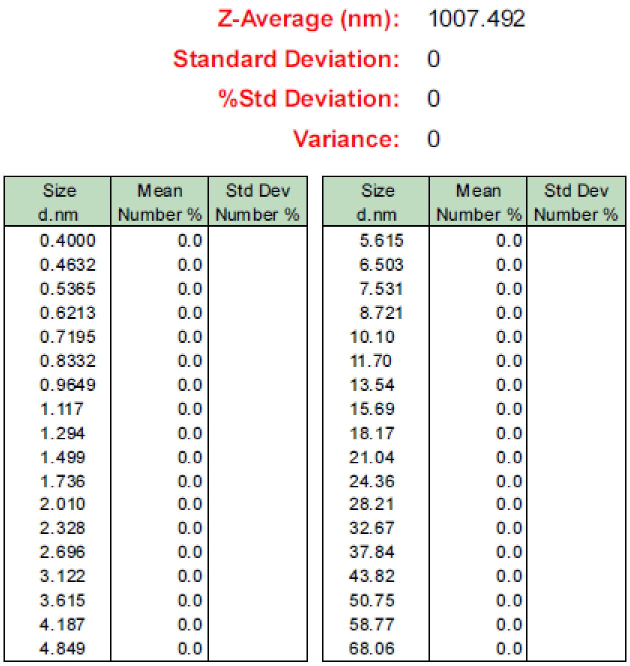
$$\mathrm{CaCO3} \xrightarrow{heat} \mathrm{CaO} + \mathrm{CO2}$$

$$\mathrm{CaO} + \mathrm{H2O} \longrightarrow \mathrm{Ca\ (OH)2}$$

4. RESULTS AND DISCUSSION

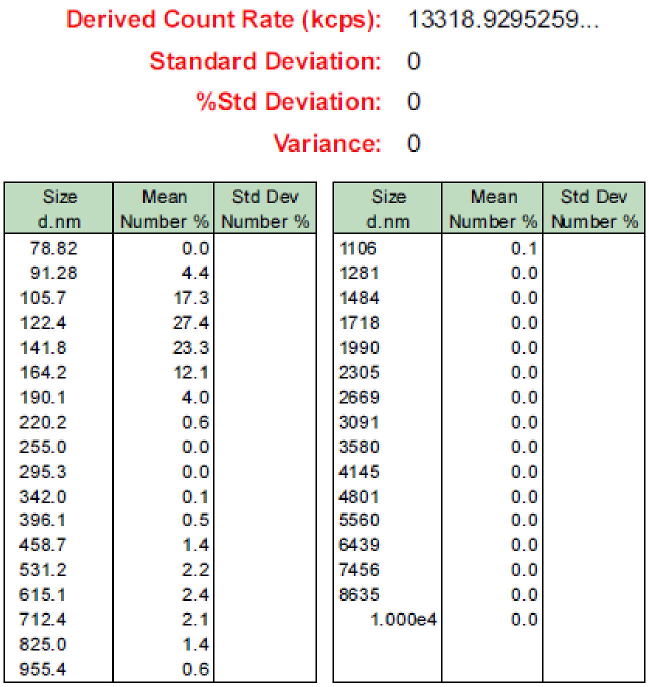
Dynamic light scattering (DLS) is a technique in physics that can be used to determine the size distribution profile of small particles in suspension or polymers in solution.[1] In the scope of DLS, temporal fluctuations are usually analyzed by means of the intensity or photon auto-correlation function (also known as photon correlation spectroscopy or quasi-elastic light scattering). In the time domain analysis, the autocorrelation function (ACF) usually decays starting from zero delay time, and faster dynamics due to smaller particles lead to faster decorrelation of scattered intensity trace. It has been shown that the intensity ACF is the Fourier transformation of the power spectrum, and therefore the DLS measurements can be equally well performed in the spectral domain.[2][3] DLS can also be used to probe the behavior of complex fluids such as concentrated polymer solutions.

Device showed the following results:



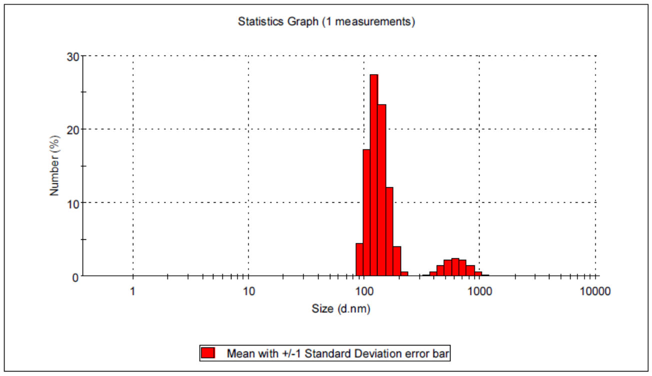
Z-Average (nm): 1007.492
Standard Deviation: 0
%Std Deviation: 0
Variance: 0

Size d.nm	Mean Number %	Std Dev Number %	Size d.nm	Mean Number %	Std Dev Number %
0.4000	0.0		5.615	0.0	
0.4632	0.0		6.503	0.0	
0.5365	0.0		7.531	0.0	
0.6213	0.0		8.721	0.0	
0.7195	0.0		10.10	0.0	
0.8332	0.0		11.70	0.0	
0.9649	0.0		13.54	0.0	
1.117	0.0		15.69	0.0	
1.294	0.0		18.17	0.0	
1.499	0.0		21.04	0.0	
1.736	0.0		24.36	0.0	
2.010	0.0		28.21	0.0	
2.328	0.0		32.67	0.0	
2.696	0.0		37.84	0.0	
3.122	0.0		43.82	0.0	
3.615	0.0		50.75	0.0	
4.187	0.0		58.77	0.0	
4.849	0.0		68.06	0.0	



Derived Count Rate (kcps): 13318.9295259...
Standard Deviation: 0
%Std Deviation: 0
Variance: 0

Size d.nm	Mean Number %	Std Dev Number %	Size d.nm	Mean Number %	Std Dev Number %
78.82	0.0		1106	0.1	
91.28	4.4		1281	0.0	
105.7	17.3		1484	0.0	
122.4	27.4		1718	0.0	
141.8	23.3		1990	0.0	
164.2	12.1		2305	0.0	
190.1	4.0		2669	0.0	
220.2	0.6		3091	0.0	
255.0	0.0		3580	0.0	
295.3	0.0		4145	0.0	
342.0	0.1		4801	0.0	
396.1	0.5		5560	0.0	
458.7	1.4		6439	0.0	
531.2	2.2		7456	0.0	
615.1	2.4		8635	0.0	
712.4	2.1		1.000e4	0.0	
825.0	1.4				
955.4	0.6				



The results are represented in the following figure

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