Application of Nano-Particles in Cementing Applications

Associated With: B.tech Project (VI Semester)

Department: Petroleum Engineering & Geo-Engineering

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This project has added a lot of knowledge and has provided the best exposure to knowing the cementing operation and their application in oil and gas field.

Sincerely,

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1. Introduction:

One of the most important activities is cementing wells during the discovery and completion of oil wells. The primary goal of cementation in hydrocarbon wells is to have isolation of various zones, providing mechanical integrity and support to the wellbore casing and protecting the casing from corrosive fluids attacks. The inclusion of nano-particles in the cement enhances fresh and hardened cement's properties and characteristics, such as strength, promotes hydration reaction, reduces leaching of calcium, resistance to water penetration, induces self-cleaning properties etc.

1.1. Chemical Composition of Class G Cement:

In Standard Cases:

S.No.	Component	Conc.(%)
1	CaO	63.76
2	SiO_2	18.36
3	Al_2O_3	4.86
4	SO_3	3.08
5	MgO	2.86
6	Fe_2O_3	1.74
7	Na_2O	1.27
8	K_2O	0.26

1.2. Objective of the study:

The main objective of the study and experimentation part of this study to increase the compressive strength of oil well cement and reduce the filter loss by applying different nano-particles (mainly oxide) and compare its effect.

Other objective is to study is working of cementing equipment that are:

1. **Autoclave**
2. **HPHT Filter Press**
3. **Cement Slurry Mixer**
4. **Unconfined Compressive Strength (UCS) Equipment**

Our secondary aim for this study is understand the effect of different additives (nano-particles) on cement slurry. For our project, we have used:

1. **Anhy. $CaCl_2$ (As Cement Accelerator)**
2. **PAC-R (To reduce spurt loss)**
3. **Oxides (Zinc Oxide and Silicon Di-Oxide)**

2. About Previous Work:

(Aug 2022 – Nov 2022)

We started our study and research work in the month of August,2022. First, we tried with cement available in our lab with cement additives and saw the result and it was showing very high spurt loss (47 mL). That was too high. So, we decided to start our research work with cuttle fish bone. Cuttle fish bone is the normal source of Calcium. It is referred as Bi-calcium (higher amount of Calcium Carbonate is present). It is used for early strengthen the oil well cement.

But still we were getting the similar kinds of results. The spurt loss was not reducing (With cuttle fish bone, we got 45mL spurt loss). And the economical and availability factor is also associated with cuttle fish bone.

We also changed the cement to see the changes in our results. But there was no significant difference in it. So, we decided to add PAC-R (Polyanionic Cellulose) to reduce spurt loss.

2.1. What we Learn:

We learnt about the working of autoclave and HPHT filter press. We learnt about the role of nano-particles in cementing application. It was our first-time experience on cementing equipment after studying Drilling Technology Course. We also learnt about cementing additives and fundamentals of slurry preparation.

The results were not promising, so our next task was to overcome these challenges and select new additives that can reduce the spurt loss and strengthen the cement as desired.

With this, our BTP-1 get ended and we decided to continue the same research work in BTP-2.

3. Slurry Preparation:

Cement slurry was made in the laboratory according to the API recommended practice for testing well cements API RP 10 B [27]. Firstly, the base cement slurry was prepared using class G cement. The required amount of cement was weighed using a weighing machine (Mettler Toledo, model ME204).

3.1. The composition of Base Slurry:

S. No.	Component	Amount
1	CLASS G Cement	300 gm
2	Anhy. $CaCl_2$	0.2% (0.6 gm BWOC)
3	PAC-R	0.5% (1.5 gm BWOC)
4	Water	44% (132 gm BWOC)

The amount of nano-particle will vary according to requirement in Nano-Particle based Cement Slurry NPCS.

3.2. Purpose of Cement Additives:

We have used the following cement additives in preparation of cement slurries:

3.2.1 Calcium chloride:

Calcium Chloride is undoubtedly the most efficient and economical accelerator. It is available in regular grade (77% calcium chloride) and anhydrous grade (96% Calcium Chloride). The anhydrous calcium chloride is in more general use because it absorbs moisture less readily.

3.2.2. Zinc Oxide:

Zinc oxide/eugenol cement are mixtures of zinc oxide (powder) and eugenol (liquid). They are mainly used as a lining or base under amalgam restorations and as temporary luting cement or filling materials.

3.2.3. Silicon Di-Oxide:

The usage of particles of nano-silica in hydrocarbon well cementing process is a very effective method of altering the characteristics and properties of cement in order to achieve good ring sealing, and considering the fact that the amount of nano-silica needed in often less.

3.2.4. PAC-R:

(Polyanionic Cellulose)

It is a water-based filtration control agent which also provides viscosity and controls fluid loss. PAC R is a cost-effective means of controlling fluid loss and increasing viscosity and it improves the quality of the filter cake in water-based drilling systems. It is a high-performance product ideal in low solid mud, designed for fast penetration.

3.3. Precaution required during preparation of cement slurry:

- Make sure that cement slurry doesn't spill out of the cement mixer.
- Always wash the cement mixer equipment after making a cement slurry.
- Always use a stabilizer for a steady power supply to prevent damage to equipment.

Stabilizer

Mixer

The real time image of our laboratory work

4. Autoclave:

It is one of the important equipment that is used to check the soundness of cement and make cement blocks. We can use these cement blocks to check the compressive strength of cement with UCS.

4.1. Construction:

The construction of autoclave can be considered within these points:

- **Temperature probe**- for measuring the temperature.
- **Pressure equipment**- used to apply pressure.
- **Jar**- a cylindrical jar of steel in which cubes filled with cement slurry are kept. It is more than half filled with crude oil.

Autoclave

4.2. Working:

To check the soundness, we put our slurry sample in a 2*2*2 in^3 cubic block and put these blocks in a cylinder filled with crude oil and then put that cylinder in an autoclave with temperature of 80°F & pressure of 500 Psi and retrieve the cement block next day.

5. HPHT Filter Press:

Filter Press is the one of most important equipment for cementing operation. It is used to know the filter loss (spurt loss) in cement slurry at applied pressure and temperature condition.

5.1. Construction:

The filter press consists of a heating jacket, Safe Cell, Type J thermocouple probe, pressurizing assemblies, and two power cables. The test cell with slurry will be heated to a temperature of 500°F and pressure of 500 Psi.

HPHT Filter Press

5.2.Working :

To determine the amount of spurt loss, first we assemble the cell properly. Then pour cement slurry in the cell and put filter paper above it and close the cell using screws. Now we apply temperature of 80°F to HPHT setup and then connect pressure line of 500 Psi to the cell and wait for 30 minutes to complete the test.
To achive the pressure, we require pressure cylinder containing N_2 gas and pressure regulator to control the flow of gas from cylinder to HPHT cell. Continous monitoring arre required to determine the data of HPHT filteration test.

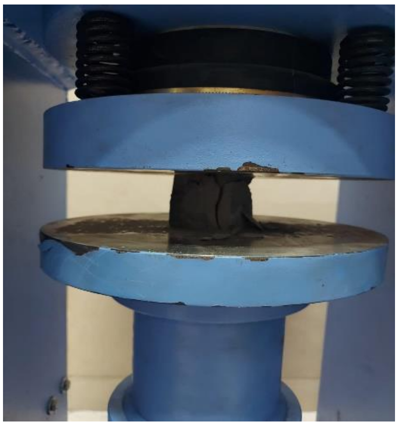
6. Unconfined Compressive Strength Testing Machine:

The unconfined compressive strength (UCS) is an important mechanical property used to quantify the capacity of oil and gas well cement to withstand failure due to downhole stresses and maintain long term zonal isolation. Therefore, it is crucial that UCS measurement is as accurate as possible to ensure that reliable simulations and predictions can be made with regards to cement mechanical response under downhole conditions.

6.1. Construction:

This equipment has two separate parts. One is used to fix the sample and apply compressive load and second is used to operate it. It has a screen that will show the results.

UCS



Applying compressive load to cement block

6.2.Working :

It works on the principle of normal stress. Cement block is fixed in the equipment and we already know the dimensions of cement block. Then we will apply compressive load and determine the peak value that is required for destructive loading.

$$\sigma = \frac{F}{A}$$

Where,

- σ is the compressive stress
- F is the compressive force

7. Result:

7.1. Cuttle Fish Bone: (BTP-1 Result)

7.1.1. Slurry Composition:

S.No.	Component	Amount
1	CLASS G Cement	300 gm
2	Anhy. $CaCl_2$	0.2% (0.6 gm BWOC)
3	Cuttle Fish Bone	0 to 1% BWOC
4	Water	44% (132 gm BWOC)

7.1.2. Autoclave Result:

Cuttle fish bone is not able to disperse due to its higher amount. So, when we increase the conc. of cuttle fish bone, the block formation got affected and its shape got distorted.

7.1.3. HPHT Result:

S. No.	Conc. Of Cuttle fish bone	Spurt Loss (mL)
1	0% BWOC (Base)	47
2	0.5% BWOC (1.5 gm)	43
3	1% BWOC (3 gm)	42

- HPHT results confirms that the filter loss is in quite higher amount. This is clear case of channeling.
- Only cuttle fish bone is not sufficient for our main objective. We have to add some more additive to reduce the filter loss.
- The economy is also associated with cuttle fish bone, so we had to stop our study with cuttle fish bone until we are not sure with rest of the additives that were used in slurry preparation.

7.1.4. UCS Results:

S. No.	Cuttlefish Bone Conc. (BWOC)	Load Applied (kN)	Compressive Strength (Mpa)
1	0% (Base)	36	14.4
2	0.50%	41	16.4
3	1.00%	48	19.2

- Compressive strength is increased by 33% from base by applying 1% Cuttlefish bone.

7.2. Zinc Oxide: (BTP-2 Results)

7.2.1. Slurry Composition:

S.No.	Component	Amount
1	CLASS G Cement	300 gm
2	Anhy. $CaCl_2$	0.2% (0.6 gm BWOC)
3	ZnO	0 to 0.3% BWOC
4	Water	44% (132 gm BWOC)
5	PAC-R	0.5% (1.5 gm BWOC)

7.2.2 Autoclave Result:

Autoclave results are better than previous case. The shape of retrieved cement blocks are perfect.

7.2.3 HPHT Results:

S. No.	Conc. Of ZnO	Spurt Loss (mL)
1	0% BWOC (Base)	25
2	0.10% BWOC (0.3 gm)	23
3	0.15% BWOC (0.45 gm)	23
4	0.20% BWOC (0.6 gm)	22
5	0.30% BWOC (0.9 gm)	20

- Spurt loss got reduced by 20% w.r.t. base (for maximum conc. of commercial ZnO).

- Commercial ZnO is not cost-effective.

- We also tried to perform the same experiment with synthesized ZnO (Using Zinc Nitrate), but neither the amount we received after batch process is enough nor the blocks formed are in well-shaped.

- PAC-R gave expecting results and reduce the spurt loss.

7.2.4. UCS Results:

S. No.	ZnO Conc. (BWOC)	Load Applied (kN)	Compressive Strength (Mpa)
1	0% (Base)	36	14.4
2	0.10%	38	15.2
3	0.15%	41	16.4
4	0.20%	43	17.2
5	0.30%	51.5	20.6

- Compressive strength is increased by 43% from base by applying 0.3% ZnO BWOC.

- The strength gets increased with increment in conc. of zinc oxide.

7.3. Silicon Di-Oxide: (BTP-2 Results)

7.3.1. Slurry Composition:

S. No.	Component	Amount
1	CLASS G Cement	300 gm
2	Anhy. $CaCl_2$	0.2% (0.6 gm BWOC)
3	SiO_2	0 to 0.5% BWOC
4	Water	44% (132 gm BWOC)
5	PAC-R	0.5% (1.5 gm BWOC)

7.3.2. Autoclave Result:

Autoclave results are better than previous case. The shape of retrieved cement blocks are perfect.

7.3.3 HPHT Results:

S. No.	Conc. Of SiO_2	Spurt Loss (mL)
1	0% BWOC (Base)	25
2	0.10% BWOC (0.3 gm)	20
3	0.20% BWOC (0.60 gm)	20
4	0.30% BWOC (0.90 gm)	19
5	0.40% BWOC (1.2 gm)	18
6	0.50% BWOC (1.5 gm)	17.8

- Spurt loss got reduced by 28.8% w.r.t. base (for maximum conc. of SiO_2).
- SiO_2 is cost-effective than ZnO.

7.3.4. UCS Results:

S. No.	SiO_2 Conc. (BWOC)	Load Applied (kN)	Compressive Strength (Mpa)
1	0% (Base)	36	14.4
2	0.10%	40.2	16.08
3	0.20%	41.2	16.48
4	0.30%	43	17.2
5	0.40%	45	18
6	0.50%	47.2	18.88

- Compressive strength is increased by 31% from base by applying 0.5% SiO_2 BWOC.

8. Future Plans:

The results we achieved by using ZnO and SiO_2 are promising. We are planning to use Ultrasonic Cement Analyzer for strength determination in future. We are also thinking about the rheology of cement slurry and characterization of filer cake.

We are also planning to check the consistency of cement slurry using atmospheric consistometer.

$$B_c = \frac{T - 78.2}{20.02}$$

Where T = the torque on the paddle in g-cm
B_c = the slurry consistency in API consistency units.

Cement Testing Specification:

API Spec. 10A (2002), RP 10B-2 (2005)/ISO 10426-2 (2003), RP 10B-3 (2004)/ISO 10426-3 (2003), and RP 10B-4 (2004)/ISO 10426-4 (2004)


UCA

Atmospheric Consistometer

9. Conclusion:

- ZnO and SiO_2 are providing promising result.
- PAC-R is able to reduce the spurt loss.
- SiO_2 is providing better HPHT test results in comparasion to ZnO.
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- Higher conc. of SiO_2 is also can be used due to its low cost in comparasion to ZnO and avaliability.

- By adding nano-silica particles into the cement suspension, the water content cement is intensified. This lessens the settling process and increase the tolerance of the cement at early stage of cementation.

- ZnO is providing better compressive strength than SiO_2. Now the selection of nano-particle is dependent on the objective of the operation. If we want to increase the compressive strength then we will prefer ZnO or if we want to reduce spurt loss then we will prefer SiO_2.

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