

Comparing the Effect of Saline Water and Fresh Water on Oil Well Cementing Properties

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ABSTRACT: The success of oil field cementing operations, whether for completion or for remedial purposes, is a vital factor in determining the well's future productive life and eventually return on the well owner's investment. The general purposes for any well cementing job are zonal isolation and segregation, corrosion control, formation stability and pipe strength improvement, and to fully achieve these purposes, specialised cement formulations with critical solid-to-water ratios, slurry density and other cement properties must be closely controlled. The most significant effect on cement performance is caused by the presence of sodium chloride in sea water. With increased offshore drilling activities and also in some instances due to difficulty and expense in bringing fresh water to the job, the use of sea water for mixing cement slurries for down-hole cementing applications has increased significantly. Also in locations where the wellbore extends through a salt dome, large amounts of sodium chloride are sometimes added to the mixing water to minimise the action of the cement slurry dissolving salt from the formation. In this work, experiments were conducted by preparing the cement samples with both the fresh water and saline water and cement properties like the consistency which determines the volume of water to be added to cement, the setting time, the compressive strength, the viscosity, the density, the percentage of free water and specific gravity were determined for both fresh water and saline water slurry. The results were obtained with slight variations between the property of cement mixed with fresh water and the other one mixed with saline water. This study shows that, if saline water is used in place of fresh water for mixing water in cementing systems, setting time and consistency for the cement slurry are reduced which shows that, saline water should be used to quickly confine abnormal pore pressure formation. The density, viscosity, specific gravity and percentage of free water of the cement slurry are increased which also shows that, saline water should be used for a cementing system to fully support the vertical and radial loads applied to the casing.

KEYWORDS: (Saline water, Fresh water, Slurry density, Consistency, Compressive strength, Sodium chloride, Setting

I. INTRODUCTION

Well cementing can be seen as the process of introducing cement to the annular space between the well-bore and casing or to the annular space between two successive casing strings[1]. Cementing is one of the most critical steps in well completion. Sadly, coming at the end of drilling and in the haste to put a well on production, rarely is the time and commitment taken to get a good job. We then spend significantly more time correcting it or battling the effects of a bad cement job.

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Not all cements, even those made from the same components, will react in the same manner when mixed with water. Basically, the differences are in the fineness of the grind of the cement, impurities in the water and in some minor additives added during the cement manufacturing process[2]. The properties of the cement slurry and its behaviour depend on the components and the additives in the cement slurry; these properties can be density, viscosity, setting or thickening time, strength, water content, etc.

Most cements used in the oil industry are a type of portland cement. The name portland was taken from an English channel island with a limestone quarry that was used as source of stone for the development of portland cement. Portland cement is produced from limestone and either clay or shale by roasting at 2600 to 3000°F. The final size of the cement particles has a direct relationship with how much water is required to make a slurry without producing an excess of water at the top of the cement or in pockets as the cement hardens. The crystals seen in set cement include; C3S - tricalcium silicate, C2S – dicalcium silicate, C4AIF - tetracalciumaluminoferrite, C3A - tricalcium aluminate, MgO - periclase or magnesium oxide, and CaO - free lime[2].

Salt is sometimes present in relatively high concentrations in the water used as mixing water in oil fields especially in the off-shore locations where fresh water is difficult to obtain or where the wellbore extends through a salt dome, and if sea water is used in place of freshwater for mix water in cementing systems, density, specific gravity, viscosity, thickening time, the water content and other cement properties will be affected.³

Uses of oil well cementing

Oil well cementing system has a whole range of benefits to the oil and gas production as follows:-

- i To support the vertical and radial loads applied to the casing
- ii To isolate porous formations from the producing zone formations
- iii To confine abnormal pore pressure
- iv To protect casing from corrosion
- v To exclude unwanted sub-surface fluids from the producing intervals
- vi To increase the possibility to hit the target
- vii To resist chemical deterioration of cement[4].

Oil well cementing classification

Oil and gas company classified cement based on the API standard as follows:-

Class A: For use from surface to 6000 ft (1830 m) depth*, when special properties are not required.

Class B: For use from surface to 6000 ft (1830) depth, when conditions require moderate to high sulfate resistance.

Class C: For use from surface to 6000 ft (1830 m) depth, when conditions require high early strength.

Class D: For use from 6000 ft to 10,000 ft depth (1830 m to 3050 m), under conditions of high temperatures and pressures.

Class E: For use from 10,000 ft to 14,000 ft depth (3050 m to 4270 m), under conditions of high temperature and pressures.

Class F: For use from 10,000 ft to 16,000 ft depth (3050 m to 4880 m), under conditions of extremely high temperatures and pressures.

Class G: Intended for use as a basic cement from surface to 8000 ft (2440 m) depth. Can be used with accelerators and retarders to cover a wide range of well depths and temperatures.

Class H: A basic cement for use from surface to 8000 ft (2440 m) depth as manufactured. Can be used with accelerators and retarders to cover a wider range of well depths and temperatures.

Class J: Intended for use as manufactured from 12,000 ft to 16,000 ft (3600 m to 4880 m) depth under conditions of extremely high temperatures and pressures. It can be used with accelerators and retarders to cover a range of well depths and temperatures[1].

II. PROBLEM STATEMENT

Fresh water availability in the offshore drilling field is highly economical and so saline/sea water is then used instead. This study intends to show the effect done to cementing properties by the salt content in the sea water and the salt in contact with cement when drilling through the salt dome.

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III. AIM AND OBJECTIVES OF STUDY

The main aim of this research work is to show the effect of saline water and that of fresh water on the oil well cementing properties

Objectives of study

The objectives of the study includes:

To perform cement slurry with both fresh water and saline water.

To determine the density, viscosity, consistency, initial and final setting time, compressive strength and percentage of free water difference between them by experimental procedures.

To formulate the specific gravity difference between them.

IV. SIGNIFICANCE OF THE STUDY

The significance of the study is:

To see how saline water affects the density and viscosity of the cement slurry with time

To see how saline water which contains sodium chloride reduces concentrations of sulphate ions in the cement thereby altering the cement consistency.

To see how saline water can also be used to minimise the action of the cement slurry in dissolving salt from the formations.

V. MATERIALS AND METHODS

Reagents

The reagents used are as follows:-

Dangote Portland cement

Sodium chloride salt

Fresh water

Equipments

The equipments used were as follows:-

Weighing balance for mass measurement

Measuring cylinder for volumetric measurement

Viscometer for viscosity measurement

Stirrer

Plastic containers

Vicat's apparatus for setting time and consistency test

Plunger for consistency test

Needle for setting time test

Trowel for smoothening the surface of mould

A mud balance for density test

A strength testing machine for compressive strength.

Operational Parameters

The parameters that were determined are as follows:-

Slurry density

Slurry viscosity

Slurry specific gravity

Slurry consistency

Slurry initial setting time

Slurry final setting time

Slurry percentage of free water

Slurry compressive strength.

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Procedures

The procedures followed in order to determine the above parameters are as follows and are dependent on each parameter obtained.

To determine the slurry density

The density variation between the slurry made with fresh water and that made with saline water was determined using the steps below:-

A sample of Dangote cement was obtained.

400g each of Dangote cement was measured and placed into two different plastic containers

170ml of water was measured and poured into container A and was stirred gently to obtain a slurry

Another 170ml of water was measured and 6g of salt was added to it, and then poured into container B and was stirred gently to obtain a slurry

The slurry made with fresh water was placed inside the mud balance cup and the density was determined by adjusting the mud balance until it reached a balanced position

The other slurry made with saline water was also placed into the mud balance cup and the density was also determined by adjusting the mud balance till it reached a balanced position

The densities for both the slurries were recorded.

A slight difference in the density between the slurry made with fresh water and that made with saline water was observed at the end of the experiment.

To determine the viscosity

The viscosity variation between the slurry made with fresh water and that made with saline water was determined using the steps below:-

A sample of dangote cement was obtained

300g each was measured and placed into two different plastic containers

150ml of water was measured and poured into container A and was stirred gently to obtain a slurry

Another 150ml of water was measured and 5.5g of salt was added to it, and then poured in to container B and was stirred gently to obtain a slurry

The thermal cup was filled with approximately two-third of the slurry made with fresh water and later the one filled with saline water

The thermal cup was placed on the viscometer stand

The cup and the stand were raised until the rotary sleeve was immersed to scribe lie on the sleeve

The thermometer was placed in the thermal cup to record the temperature

The VG meter toggle switch located on the right side of the VG meter was flipped to high position by pulling forward

The red knob on the top of the VG meter was positioned to 60rpm speed. When the red knob is in the bottom position and the toggle switch is in the forward(high) position, this is termed as the 60rpm speed

With the sleeves rotating at 60rpm, a minimum of ten seconds was waited and the dial reading on the top stabilizer was obtained

The viscosities for both the slurries were recorded.

A slight difference in the viscosities between the slurry made with fresh water and that made with saline water was noticed.

To determine the specific gravity

The specific gravity of both the fresh water slurry and saline water slurry was determined using the equation below:-

$$\text{Specific gravity for fresh water slurry} = \frac{\text{density of the slurry}}{\text{density of water}}$$
$$\text{Specific gravity for saline water slurry} = \frac{\text{density of the slurry}}{\text{density of water}}$$

The equation was used in the appendix and their specific gravity difference was calculated.

To determine the Percentage of Free Water

The percentage of free water for both the fresh water slurry and saline water slurry was determined using the steps below:-

A sample of Dangote cement was obtained

400g each of cement was measured and placed in to two different plastic containers

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170ml of water was measured and placed inside a plastic container containing 400g of cement, and was stirred gently and allowed to settle for two hours

5.25g of salt was measured and added to the other container containing 400g of cement, then 170ml of water was poured to it and was stirred vigorously to obtain a slurry, and then allowed to settle for two hours also

The retention of free water from both two samples was observed, decanted and measured

The percentage of free water was calculated in the appendix using the equation below:-

$$\% \text{ of free water} = \frac{\text{volume of decanted water}}{\text{volume of water added to cement}} * 100\%$$

A slight variation of free water percentage between the samples was determined.

To Determine the Water Content or Consistency

The below steps were used to obtain the consistency for both samples:-

A sample of Dangote cement was obtained

300g each of cement was measured and placed into two different plastic containers

5.5g of salt was measured and added to a container containing 300g of cement

A predetermined volume of water was measured and poured into each of the samples above to obtain a partial slurry by stirring, and the time at which water was added was recorded as T1

The Vicat's mould was filled with the prepared slurry and the surface was smoothed with a trowel

The prepared samples were placed one after the other under the Vicat's apparatus bear the plunger

The plunger was lowered until it was just about touching the surface then released totally so that it sunk in to the slurry

The reading on the Vicat's apparatus was recorded anytime the plunger was released until a penetration depth 5-7mm was reached

The normal consistency was calculated. The penetration depth was not reached, then the volume of water was added and the above procedures were repeated

The normal consistency was calculated in the appendix using the equation below:-

$$\text{Normal consistency} = \frac{\text{volume of water used}}{\text{mass of sample}} * 100\%$$

Some variations between the consistency of saline slurry and that of fresh water slurry was obtained.

To Determine the Initial Setting Time

The initial setting time for both the slurries was obtained using the below steps:-

The slurries obtained above for the consistency test were used

The Vicat's apparatus was also used but this time, the plunger was replaced with needle.

The needle was lowered until it was about touching the surface, and then released totally on the centred surface of the sample and the penetration depth on the Vicat's apparatus was checked

The time at which the depth reached 5-7mm was recorded as T2

The initial setting time was calculated in the appendix as (T2-T1).

A slight change between the initial setting times for both the slurries was noticed.

To Determine the Final Setting Time

The final setting time for both the slurries was obtained using the steps below:-

The above steps for the consistency test was used to prepare the slurries

This time, the mould was turned up-side down and the needle was replaced with the 5mm OD round pin

The steps above for the initial setting time were used until a depth of 5-7mm was reached

The time was recorded as T3

The final setting time was calculated in the appendix as (T3-T1)

A slight change in final setting time for both the slurries was determined.

To Determine the Compressive Strength

The compressive strength for both the slurries was determined by the below procedures:-

450g of cement was placed in to container A

450g of cement was also placed in to container B

225ml of water and 1350g of sand were placed in to container A and were mixed vigorously

Also 225ml of water, 1350g of sand and 8g of salt were placed to container 2 and mixed vigorously

Both the samples were place in a mould of 100x100x100 each and kept in a controlled environment at temperature 250C and humidity of 90

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The samples were unmoulded after 24hours and the compressive strength test was carried out using the compression machine and the readings on the machine were recorded.

A slight variation between the compressive strength for saline water slurry and fresh water slurry was experienced.



Fig1 A Compressive Strength Test Machine

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Fig 2 An Unattached Vicat's Apparatus

The Apparatus shown above is designed for the measurement of setting time and consistency test.



Fig.3 Vicats Apparatus with a Plunger

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VI. EXPERIMENTAL RESULTS

The results of the above procedures are written below and are based on each parameter obtained.

TABLE 1: CONSISTENCY TEST

Slurry	Time(minutes)	Volume of water added(ml)
Fresh water	5	75
	10	10
	15	20
	20	3
		Total vol. 108
Saline water	5	75
	10	10
	15	15
	20	3
		Total vol. 103

TABLE 2: INITIAL SETTING TIME TEST

Slurry	Time(minutes)	Length (mm)
Fresh water	30	30
	60	23
	90	15
	120	9
	150	7.6
	165	6
Initial setting time = 165		
Saline water	45	26
	90	17
	135	10
	145	6.2
Initial setting time = 145		

TABLE 3: FINAL SETTING TIME TEST

Slurry	Time(minutes)	Length (mm)
Fresh water	60	27
	120	20
	180	16
	240	10
	300	9
	317	6.1
Final setting time = 317		
Saline water	60	29
	120	21
	180	15
	240	8
	293	6.4
Final setting time = 293		

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TABLE 4: COMPRESSIVE STRENGTH TEST

Slurry	Compressive strength(KN)	Mass of sample(Kg)
Fresh water	50.6	1.73
Saline water	71.5	1.81

TABLE 5: VISCOSITY TEST

Slurry	Time (minutes)	Viscosity (poises)
Fresh water	30	10.8
	60	11.9
	90	15.3
	120	18.5
Saline water	30	10.5
	60	15.6
	90	18
	120	26

TABLE 6: DENSITY TEST

Slurry	Density (ppg)
Fresh water	19.6
Saline water	19.8

TABLE 7: PERCENTAGE OF FREE WATER TEST

Slurry	Volume of free water(ml)	% of free water (100%)
Fresh water	20	11.76
Saline water	23	13.53

TABLE 8: SPECIFIC GRAVITY TEST

Slurry	Density (ppg)	Specific gravity
Fresh water	19.6	2.36
Saline water	19.8	2.39

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VII. DISCUSSION OF RESULT

The results obtained above can be discussed one after the other below Table 1 for the consistency test showed that, smaller amount of water is needed to make slurry with saline than with fresh water and as such, saline water should be used in a place where there is water scarcity especially onshore. As observed by Slagle and Smith⁶ that, most well cement salt saturate the water phase of the slurry they intended should best bond casing to a salt formation where a saturated slurry dissolves little salt and form an adequate interface with it on hardening but saturation makes the slurry mixing difficult and excessively delays initial set. This indicates that the water needed for a salted formation cement is lower than that of carbonate formations which means that the result for consistency test is on the right way.

Table 2 and table 3 for the initial and final setting time test respectively showed that, use of saline water reduces the initial and final setting time than the use of fresh water and so, to quickly confine an abnormal pore pressure formation, saline water should be used. As indicated by Smith and Calvert⁴ that, during his study, the thickening time obtained for the sea water slurry reduces by 35.7% to that obtained using fresh water. This means that the setting time test is accurate

Table 4 for the compressive strength test showed that, use of saline water increases the compressive strength of cement than fresh water and as such, to fully support the vertical and radial loads applied to the casing, saline water should be used instead of fresh water. According to Ludwig,⁵ the addition of sodium chloride changes the physical properties of cement, it increases the early strength in the range of 0 to 100,000ppm of the salt. Smith and Calvert⁴ also observed that using sea water increases the early strength development at lower temperatures by as much as 50%. This indicates that the result obtained for the compressive strength test is remarkably right.

Table 7 for the percentage of free water test showed that, percentage of free water in saline water slurry is higher than that with fresh water slurry when same amount of water was used. In order to fully protect casing from corrosion, fresh water slurry should be used since large amount of water indicates high possibility of corrosion and also contributes the addition of water production in the wellbore.

VIII. CONCLUSION

At the end of the study, the below points were achieved

The aim of the work was achieved since all the parameters listed in the objective were determined

The study has showed that saline water reduces the consistency and cement setting time.

It also showed that sea water increases the cement compressive strength, viscosity, density, specific gravity and percentage of free water.

IX. RECOMMENDATION

At the end of the study, the following are the recommendations:-

Consistometer should be used in carrying out the thickening time test because it is the standard apparatus used in the oil and gas industry for consistency and thickening time test determination

The test should also be carried out at an increasing temperature to match with the reservoir varying temperatures.

Other cementing properties should also be considered like the reactivity, compositional changes, tensile strength test, freezing point depression, fluid loss e.t.c

APPENDIX

$$\text{Specific gravity for fresh water slurry} = \frac{\text{density of slurry}}{\text{density of water}} = \frac{19.6}{8.3} = 2.36$$

$$\text{Specific gravity for saline water slurry} = \frac{\text{density of slurry}}{\text{density of water}} = \frac{19.8}{8.3} = 2.39$$

$$\% \text{ of free water for fresh water slurry} = \frac{\text{vol.of dacanted water}}{\text{vol.of water added to cement}} \times 100 = \frac{20}{170} \times 100 = 11.76\%$$

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$$\% \text{ of free water for saline slurry} = \frac{\text{vol. of decanted water}}{\text{vol. of water added to cement}} \times 100 = \frac{23}{170} = 13.53\%$$

$$\text{Normal consistency for fresh water slurry} = \frac{\text{vol. of water used}}{\text{mass of the sample}} \times 100 = \frac{108}{300} \times 100 = 36\%$$

$$\text{Normal consistency for saline water slurry} = \frac{\text{vol. of water used}}{\text{mass of the sample}} \times 100 = \frac{103}{305.5} \times 100 = 33\%$$

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