

Silica Dispersion for HT Oil Well Cement

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Abstract

Micronized-crystalline silica, commonly called silica flour (SF), is an indispensable additive for HT oil-well cement >110°C, since it prevents strength retrogression. Our industry uses more than ½ million tons of crystalline silica annually for HT cementing.

Workers exposed to inhalable & respirable crystalline silica are likely to suffer from silicosis and other associated diseases. The threshold limit value for respirable crystalline silica is 0.025 mg/m³ (time weighted average) according to ACGIH TLV. In addition to HSE concerns, the dry blending of silica & cement, has other disadvantages such as inhomogeneity, needing to dispose of the unused volume etc. Sometimes liquid additives are preferred because they are easy to handle, more accurate to add and take up less space on the rig.

Recently, a heavyweight silica dispersion was developed as an alternative & safer solution to the silica/cement dry blend. This silica dispersion complies with the restricted North Sea offshore regulation. On top of controlling strength retrogression and solving the silicosis risk silica dispersion offers additional benefits such as preventing gas migration, improving early compressive strength, and controlling filtration & rheology. Such benefits reduce the overall cost, since fewer additives will be used.

This paper will highlight some recent case histories regarding the use of liquid silica for both offshore & onshore applications. We optimized the concentration of silica needed to prevent strength retrogression up to 175°C. The use of liquid silica in various cement slurries at various densities will be presented. The cement properties were evaluated using an HPHT consistometer & curing chamber, XRD, HPHT fluid loss system, UCA, Fann-viscometer and SEM.

Introduction

Calcium silicate cement, commonly called Portland cement in particular classes G and H, is widely used to cement oil & gas wells. The global demand for oil-well cement is around 11MMt/yr, and it is forecasted to increase to 13.7MMt/yr by 2020. Cement is used to form a permanent seal between the steel pipe and the formation. The durability of oil well cement should be assured during the entire life of the well, which is at least *ca.* 30-50 years prospective. Particular precautions are taken in designing & testing cements for HPHT applications, because of the severity of such environments.

In 1954, Swayze was the first one to report on the effect of high temperatures on the strength of oil-well cements. At elevated temperatures >110°C, the strength of calcium silicate cement deteriorates rapidly due to the metamorphosis of calcium silicate hydrate gel (C-S-H), a phenomenon known as strength retrogression. Many research efforts have been undertaken to study how strength retrogression occurs when cement is exposed to high temperatures. At elevated temperatures, the Ca-rich phase crystalizes to denser phases such as α -C₂SH [Ca₂(HSiO₄)OH] or hillebrandite [Ca₂SiO₃(OH)₂], which shrink, causing an increase in cement permeability and subsequently the cement loses its integrity.

To prevent strength retrogression the use of crystalline silica to lower the CaO/SiO₂ (C/S) molar ratio in Portland cement to less than 1.5 was suggested and successfully implemented. The addition of silica flour, 35-40% BWOC assures stable compressive strength and low permeability for temperatures up to 250°C. As shown in Figure 1, at low C/S ratio <1.5 crystalline phases such as tobermorite, xonotlite and other phases are formed, but they do not cause any strength retrogression or increase in the permeability of cement. It is worth mentioning that the various phases shown in Figure 1 are the most common phases, however there are many other phases which may exist, depending on the cement design, curing conditions, pressure, temperature, and surrounding environments such as formation water, CO₂ gas, etc. Silica sand is also used on its own or blended with silica flour for strength retrogression. The optimal size of SF was found to be *ca.* 20µm. However, such a small size may cause mixing problems in high density cement slurries, and coarser grades with sizes between 45-150µm are also used. It is worth mentioning that other solutions than silica flour were suggested such as the use of bismuth salts like bismuth trioxide [Bi₂O₃] (*ca.* 2-5 %BWOC) to prevent strength retrogression (Di & Rae 2006). However, the use of bismuth salts seems not to have been commercialized probably because it is costly compared to silica additives.

Considering the growing number of high-temperature wells drilled nowadays, our industry uses more than ½ million tons of crystalline silica annually. The common practice for using silica flour is dry blending with Portland cement. The handling of dry blend of SF/cement may pose a health risk to anyone involved in such operation such as drillers and rig crews. Silicosis and other associated lung diseases caused by inhalation of crystalline silica is the hot topic for a number of

research works. Many silica workers lost their lives because of exposure to crystalline silica dust. As a recognition of the severity of silicosis, the American Conference of Governmental Industrial Hygienists (ACGIH) set the threshold limit value for respirable crystalline silica to 0.025 mg/m³ (time weighted average) TLV. The American Occupational Safety and Health Administration (OSHA) has proposed a new permissible exposure limit, calculated as an 8-hour time-weighted average of 50 micrograms of respirable crystalline silica per cubic meter of air (50 µg/m³).

In addition to this low level of inhalable silica, it is recommended to use any tools/ solutions such as using less hazardous substitute materials when feasible to reduce the airborne levels as low as possible.

In addition to HSE concerns, the dry blending of silica & cement has other disadvantages, such as inhomogeneity, waste and disposal of the unused volumes, etc. Sometimes liquid additives are preferred because they are easier to handle, more accurate to add & take less space on the rig.

A novel liquid silica dispersion has been developed to replace the use of dry silica flour for oil well cement. It is in line with the regulation’s recommendations for using less hazardous materials.

This paper will discuss the optimal concentration of the silica dispersion needed to prevent the strength retrogression. This paper will highlight some recent case histories regarding the use of liquid silica for offshore & onshore applications. The use of liquid silica in various cement slurries at various densities will be presented. The cement properties were evaluated using an HPHT consistometer & curing chamber, XRD, HPHT fluid loss system, UCA, Fann-viscometer and SEM.

HPHT polymeric fluid loss additives, dispersant and retarder were used. Silica flour, Milisil M10 (23µm & 2.65sg) supplied by Sibelco and microsilica slurry were used to produce silica dispersions.

Table 1: Properties of cement and various silica’s used

Metal oxide	G-cement	Microsilica	Silica flour	Silica dispersion	3gps (26,5LHK)
CaO	64,50	0,22	0,02	0,09	47,63
SiO ₂	21,70	95,00	99,50	97,62	41,65
Al ₂ O ₃	4,10	0,90	0,20	0,44	3,14
Fe ₂ O ₃	5,20	0,45	0,03	0,17	3,88
MgO	0,70	0,45	0,36	0,61
SO ₃	2,70	0,17	0,17	2,04
C/S W ratio	2,97	0,00	0,00	0,001	1,14
C/S mol ratio	3,18	0,00	0,00	0,001	1,23
Particle size [D50] (µm)	ca. 30	0,15	23,0	15,5	
Density (gm/cm ³)	3,15	2,20	2,65	2,5	2,98
BET (m ² /gm)	0,09	21,0	0,90	7,5	2,04

Equipment

Standard oil well cementing equipment was used: a constant speed mixer, static HPHT fluid loss system used at temperature of 300°F with a differential pressure of 1000 psi., Fann 35 viscometer, HPHT consistometer & curing chamber, XRD, UCA & SGSA, and SEM.

Results and Discussion

High Solid Silica Dispersion

The liquid strength retrogression prevention additive (LSRPA) discussed in this paper is a mixture of crystalline and amorphous silica. Table 1 shows the chemical composition determined by using XRF method. The main element is SiO₂ >97%. Those remaining’s are minor associated metal oxides such as CaO, Al₂O₃ and MgO. The density of silica dispersion (A) is 1.8sg (15ppg) and the solid content is 75%. The amorphous silica part with particle size of 150nm provides the typical advantages of a pozzolanic material such as early compressive strength, avoidance of settling (no free water), reduction in the fluid loss, and gas migration control. Therefore, any cement slurry designed with this silica dispersion (LSRPA) does not need additional microsilica for gas migration control. Oil well cements containing this silica dispersion were tested in the lab up to 175°C for a one year period.

Portland cement phases as a function of temperature

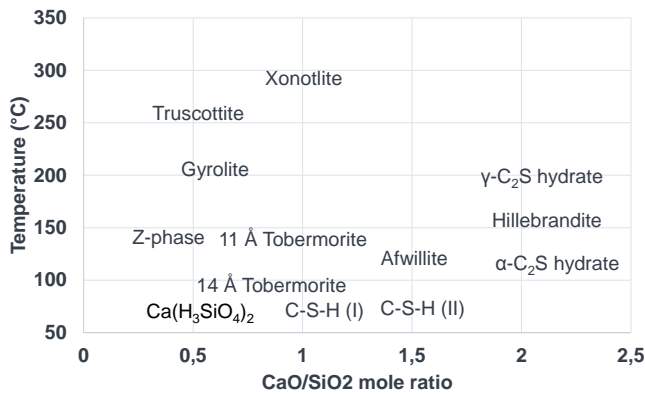


Figure 1. Calcium silicate cement phases at different temperature (Taylor, 1964).

Experiments

Chemicals

G-cement is supplied by Dyckerhoff (fineness (Blaine) is 326 m²/kg). Manganese tetraoxide (Mn₃O₄) was used as a weight material. Various commercially available

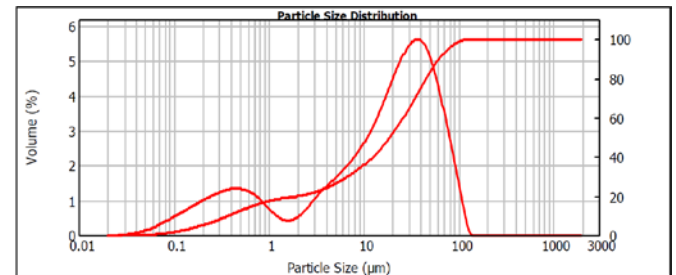


Figure 2: Particle size distribution of silica dispersion.

Table 2 shows the properties of various silica dispersions. To suspend the large & heavy silica flour, stabilizers are added. The concentration and the type of stabilizers were carefully selected to: 1) provide sufficient suspension for at least 6 months, 2) avoid any negative impact on the cement slurry such as difficulty in mixing or excessive viscosity, particularly for high density cement, and 3) retain the green profile for the product. Figure 2 shows the particle size distribution of the silica dispersion. The dispersion shows bimodal distribution with a large peak at 20 μm representing the silica flour part and a small peak at 0.15 μm representing microsilica part.

Use of Silica to prevent strength retrogression

The type of silica (amorphous or crystalline), the particle size and the concentration of silica are important parameters that affect the performance in HT cement. A typical HPHT cement slurry would contain 35-40% BWOC silica flour to lower the molar ratio CaO/SiO_2 to less than 1.5 as shown in Table 1 & Figure 1. This amount is sufficient for maximum temperature of 250 $^{\circ}\text{C}$. Recent research shows that the bottom-hole temperature has a profound effect on the strength retrogression and therefore, an adequate amount of silica is required to retain the strength and the low permeability. A new study by Iverson (2010) suggests that for geothermal cementing at elevated temperatures of 500-650 $^{\circ}\text{F}$, the amount of 35-40% silica flour might be insufficient, as some cement samples showed an increase in permeability over time at such high temperatures. The author tested higher silica concentrations up to 80% BWOC and found out that 60-70% was deemed to be sufficient to produce cement with low permeability and high compressive strength without any deterioration over time. The phase's transition, which causes strength retrogression varies as function of temperature. Therefore, the amount of silica added is somehow correlated to the downhole temperature.

Use of Less Silica

There have been some attempts to use less silica flour than 35% BWOC for HT cement. Bezerra et al (2011) reported that the addition of silica flour of 18% BWOC would be sufficient to prevent strength retrogression if in a temperature range of 110-180 $^{\circ}\text{C}$. As will be shown below, we also investigated the use of low silica concentrations.

Milestone et al (2012) demonstrated that in CO_2 environment a geothermal cement made with low amount of silica flour of ca. 20% BWOC exhibits better stability to carbonation compared to cement made with 40% silica. Low C/S phases such as tobermorite, xonotlite react with CO_2 faster than high C/S phases such as α -CSH or hillebrandite. A silica flour concentration of 15-20% BWOC was recommended to be used as a compromise between strength degradation and rate of carbonation. So from technical and environment point of views using less silica is preferred under certain conditions.

Based on the previous studies on the strength retrogression of calcium silicate cement, an empirical linear relation

between the temperature and the required silica flour can be drawn as shown in Figure 3.

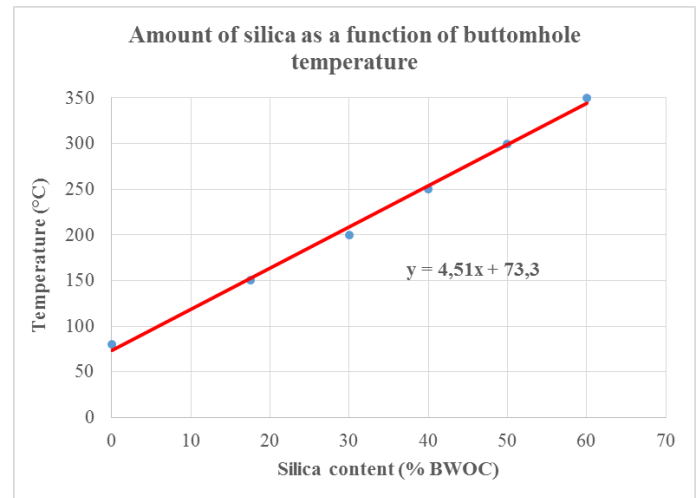


Figure 3: Amount of silica required to stabilize the compressive strength of Portland cement as a function of bottomhole temperature.

Amorphous & crystalline silica mixture for strength retrogression

Microsilica or silica fume, which consists of amorphous & spherical microfine silica particles, is widely used in oil-well cement primarily as an anti-gas migration additive. We tested the use of microsilica for strength retrogression and found it is suitable for such application on its own for a temperature up to 140 $^{\circ}\text{C}$. Above such temperature a blend of silica flour and microsilica can be used. Microsilica has high specific surface area in the range of 15-25 m^2/g and can react very quickly with cement. It is consumed completely after a few days, depending on the temperature.

Grabowski and Gillott (1989) were probably the first, who tested the use of silica fume (microsilica) at HPHT conditions. They studied the effect of substitution of silica flour with varying proportions of silica fume on the strength and permeability of the cement after hydrothermal treatment at 230 $^{\circ}\text{C}$. They concluded that the addition of microsilica slightly lowered the compressive strength however the water permeability decreased favorably with the increasing amount of microsilica.

Luke (2004) tested the stability of Portland cement Class H at 180 $^{\circ}\text{C}$ and 20.7MP for 28 days using various pozzolanic materials such as silica fume, and fly ash, in addition to silica flour. At such an elevated temperature, none of the utilized pozzolanic materials with a concentration of 35% BWOC were capable of preventing strength retrogression on their own. Only in combination with silica flour was it possible to obtain stable cement. After heating a Class H cement with the addition 35% microsilica for 28 days at 180 $^{\circ}\text{C}$, it was found

that α -C₂SH was the main crystalline phase and other minor phases indicating weak cement structure. However, with the addition of 35% silica flour to a blend of G-cement: microsilica (70:30), tobermorite was the main crystalline phase formed, with traces of quartz.

Since the silica dispersion is a mixture of crystalline and amorphous silica with 2/3 being crystalline silica, it was important to run a long-term durability test for one year. Two oil-well cements with Class G and silica dispersion concentration of 1.5 and 3gps respectively, were prepared. These are equivalent to 17.5 and 35% BWOC dry silica. The tests were conducted at temperatures of 150 and 175°C and pressure of 20.7MPa. At temperatures up to 175°C, cements with 3gps silica were stable. Presumably, those cements with silica dosage of 3gps are suitable for higher temperature than 175°C, but this has not been tested. Currently, we are running stability tests at 200 and 230°C.

We investigated the long-term durability of oil well cement using silica concentration of 1.5gps (17.5% BWOC), which is half the typical concentration, for one year at a temperature of 150°C. After 6 months, the compressive strength was 6230psi and the permeability of 0.00036mD, indicating the suitability of such cement. XRD and SEM indicated the formation of α -C₂SH, which is responsible for strength retrogression, but the content seems to be too low to cause cement failure. The microstructure analyses show that all microsilica and almost all silica flour and cement have been reacted after 3 weeks. There was still a minor amount of silica flour present after 1 year. The water permeability of the cement samples cured up to one year at 150°C was found to be <0.1mD. This low permeability and high strength are fulfilling the API criteria for stable cement at HPHT conditions.

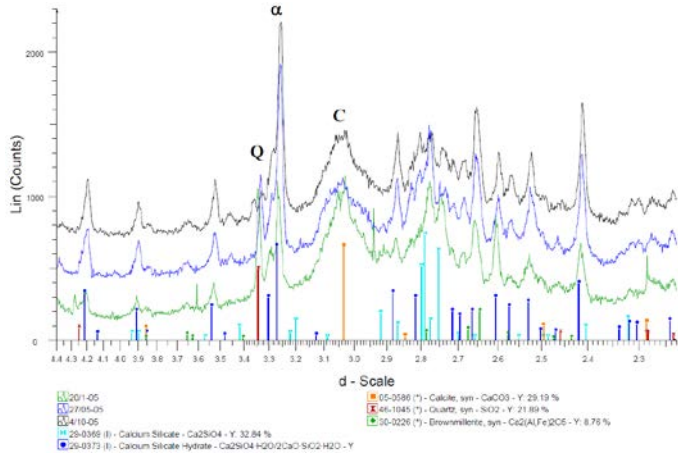


Figure 4: XRD of an oil-well cement slurry cured at pressure of 3000 psi and 150°C for 3 weeks (green curve), 3 months (blue curve) and 6 months (black curve).

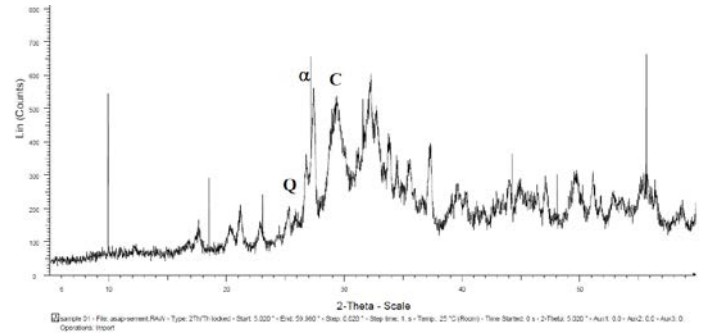


Figure 5: XRD of one year cement sample containing 1.5gps silica dispersion (17.5% BWOC). Q represents quartz, α for α -C₂SH [Ca₂(HSiO₄)OH] and C is calcite.

Silica dispersion in high density cement slurry

Silica dispersion with a density of 1.8sg was used industrially with total concentration of 3gps (26.5 LHK) in cement slurry with a density of 2.15sg (15ppg) at 175°C, as it will be shown in case history # 1 below. Silica dispersion was tested in the lab in high density cement slurry up to 2.3sg. As shown in Table 2, this high density slurry exhibits low viscosity (PV=78cP & YP=8 lbs/100ft²). In order to achieve such low viscosity & high density cement slurry, the following impact factors should be considered:

- A) Use of weight material (60% BWOC) such as manganese tetraoxide (Mn₃O₄)
- B) Use of enough amount of dispersant
- C) Use of fluid-loss additives, which don't have a viscosifying effect

It can be anticipated that cement slurries with higher density than 2.3sg can be formulated using silica dispersion.

Table 2: Design & properties of a 2.3sg HPHT oil-well cement containing silica dispersion

Density	2.30 sg
Fann readings at BHCT or maximum 88°C (API 10RB) 300/200/100/60/30/6/3	86/62/34/25/15/6/4
PV (cP)	78
YP (lbs/100ft ²)	8
Fluid loss (ml/30 min, 1000 psi)	40
Slurry Yield	106.97
Mix Water	Fresh
Product	Concentration (LHK)
Neat Class G Cement	
Liquid Silica	26.5 LHK
Cement Dispersant	2.0
Fluid Loss Control Agent	3.0
High Temperature Retarder	2.5
Cement Defoamer	0.2
Weight Material (Mn ₃ O ₄)	60% BWOC
Mix Water Requirement	29.22
Total Mix-water Requirement	75.92

While a large amount of microsilica is beneficial in terms of reducing the cement permeability, improving the compressive strength and the cement bonding, mixing silica dispersion in high density cement slurry may become difficult. Therefore, we tried a new silica dispersion composition with less microsilica.

Table 3: Silica dispersion with different compositions.

Dispersion	Silica flour	Microsilica	Density	PV	YP
	wt.%	wt.-%	Kg/L (sg)	cP	lbs/100ft ²
Silica dispersion A	67	33	1,8	40,5	14,5
Silica dispersion B	75	25	1,95	100,5	65,5
Silica dispersion C	79	21	2,01	129	26

Table 3 show the properties of 3 dispersions with various silica ratios. As the silica flour content increases from dispersion A to dispersion C, the density of the dispersion increases. In addition, the plastic viscosity increases as function of silica flour as shown in Table 3 & Figure 5. However, using high-density silica dispersion (sg>2) at low dosage of 2 – 2.5gps provides cement slurry with fairly good viscosity. Table 4 shows cement slurry with density of 2.3sg with the use of silica dispersion C. So, by optimizing the silica ratio in the dispersion, it is possible to use the liquid additive in HPHT cement with density up to 2.4sg at low dosage of 2.5gps. This is beneficial from the handling point of view. It was noticed that the silica dispersion greatly reduces the fluid loss even at low concentrations of FLA, compared to the use of dry silica flour.

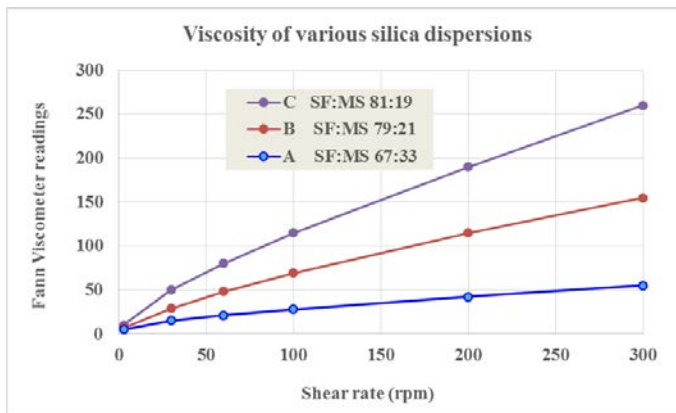


Figure 6: Viscosity measurement of silica dispersions using Fann viscometer at 50°C.

Table 4: 2.3 cement slurry with 2.5gps silica dispersion C. Total silica is 36% BWOC.

Temp.	Readings on Fann viscometer in rpm						PV	YP	Density	FL at 150C	Filter cake
	300	200	100	60	30	3	cP	lbs/100ft ²	SG	ml	mm
20	195	138	79	54	33	11	174	21	2,3	61	50
85	188	143	85	60	39	12	154,5	33,5			

Field applications

The liquid strength retrogression prevention additive (LSRPA) is particularly fit for cementing operations with

restricted blending or bulk plant facilities or whenever space on the rig is limited or costly (Gibson, 2011). Typical main application areas for silica dispersion, both offshore and onshore, requiring silica dispersion to prevent strength retrogression would be:

- Casing strings
- Liners
- P&A Plugs

To reduce logistics and ease the bulk management on board the rig, the silica dispersion enhances flexibility as it does not require pre-blended silica in bulk cement. For low and medium slurry volumes, the silica dispersion will be economically and logistically preferred.

While having answered most of the time logistics issues, the LSRPA also provides a better quality slurry when compared to conventional G-cement + silica. The additive is liquid and as such the required amount of total silica by weight of cement is guaranteed while this is not the case with inhomogeneous dry-blends.

Most applications so far have taken place in highly regulated markets like the North Sea and Norwegian sectors, and also in remote places like Africa. The LSRPA has proven versatile, being used on primary cementing, squeezes and cementing plugs operations. LSRPA was used in medium and high-density slurries. Most benefits were observed on plug and abandonment operations when the logistics operations were made easier by handling only neat cement and a few IBC tote tanks in place of managing multiple dry-blends on and around the rig. Overall cost savings on improved logistics e.g. shipping offshore or remote places, absence of dedicated blending plant, less waste on product use and others has not been quantified, but amounts easily to more than the extra cost of the additive alone. In all applications the excess additive was easily moved to another location or kept on the rig for a future application. The LSRPA has proven robust with storing time more than 18 months and counting.

Regarding the mixing of LSRPA in cement slurry, for pre-mixed mix waters (containing weighting agent), it is added to the mixing tank when preparing the mix water. For the LAS operation, LSRPA is added directly to the displacement tank through a separate line or using 2 chambers of the LAS depending on the available set-up on the cement unit. A 2" hose combined with a membrane pump was used to feed the LSRPA. The product is easy to empty from IBCs and normally would take 5-10 minutes.

Case histories

Case #1:

During an HPHT plug and abandonment operation, 240m of 8 ½" open hole was cemented with 10.5 m³ of gas migration controlled slurry to isolate the 8 ½" section.

A 20% open hole excess was applied to the pumped volume. To separate the cement slurry from the OBM, 7 m³ of weighted spacer with water-wetting spacer were pumped ahead of the cement with balanced volume behind. The cement was displaced with 1.92 sg OBM at 1500 lpm.

As the plug was part of a multiple plug P&A, it was not

required to tag or pressure test the plug.

The operator was using the rig under a sub-leasing agreement, part of which stated that any remaining bulk cement from the previous customer was to stay onboard.

Liquid silica was added to the pre-mixed mix-water without any problems. To account for high solids content, the product was agitated directly ahead of the job to ensure all active ingredients were captured.

With regard to requirements for P&A operations, operators in Norway are normally referring to NORSOK D-010, rev 04. As a rule of thumb, a minimum 500 psi compressive strength is required for tagging and 1500 psi for pressure testing.

Table 5: Technical parameters and cement design of case#1

RKB to Seabed Depth	267m
Plug Measured/True Vertical Depth	5330mMD/4970mTVD
Bottom Hole Static Temperature	174°C
Bottom Hole Circulating Temperature	139°C
Density	2.15 sg
PV (cP)	73.5
YP (lbs/100ft ²)	8.5
Fluid loss (ml/30 min, 1000 psi)	32
CS 12/24 hrs (psi)	5475/5630
Slurry Yield	100.15
Mix Water	Fresh
Product	Concentration (LHK)
Neat Class G Cement	
Liquid Silica	26.5 LHK
Cement Dispersant	1.5
Fluid Loss Control Agent	3.0
High Temperature Retarder	2.3
Cement Defoamer	0.2
Weight Material (Mn ₃ O ₄)	30% BWOC
Mix Water Requirement	29.29
Total Mix-water Requirement	69.09

isolate upper formations prior to entering the reservoir and provide a competent casing shoe.

A 30% open-hole excess was applied to the pumped volume. To separate the cement slurry from the OBM, 20 m³ of weighted spacer with water-wetting spacer were pumped ahead of the cement. The cement was displaced with 1.70 sg OBM at 2000 lpm. No issues/problems during the job.

Casing was pressure tested on set cement to 640 bar.

Liquid silica was added directly to the displacement tanks through the liquid additive system using a separate line from storage tanks without any problems. To account for high solids content, the product was agitated directly ahead of the job to ensure all active ingredients were captured.

Table 6: Technical parameters and cement design of case#2

RKB to Seabed Depth	267m
Casing Shoe Measured/True Vertical Depth	4488mMD/4465mTVD
Bottom Hole Static Temperature	151°C
Bottom Hole Circulating Temperature	120°C
Density	1.90 sg
PV (cP)	49.5
YP (lbs/100ft ²)	8.5
Fluid loss (ml/30 min, 1000 psi)	38
CS 12/24 hrs (psi)	3004/4787
Slurry Yield	101.34
Mix Water	Fresh
Product	Concentration (LHK)
Neat Class G Cement	
Liquid Silica	26.5 LHK
Cement Dispersant	1.0
Fluid Loss Control Agent	2.75
High Temperature Retarder	2.05
Cement Defoamer	0.2
Mix Water Requirement	37.78
Total Mix-water Requirement	70.28

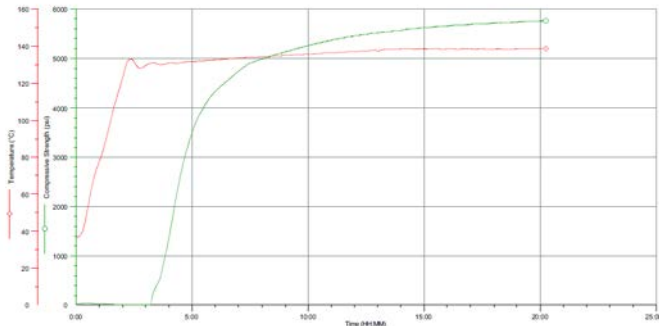


Figure 7: Compressive strength curve of case#1 cement

Case #2:

During an HPHT 9 5/8" casing operation, a 377m interval was cemented with 12.7 m³ of gas migration controlled slurry to

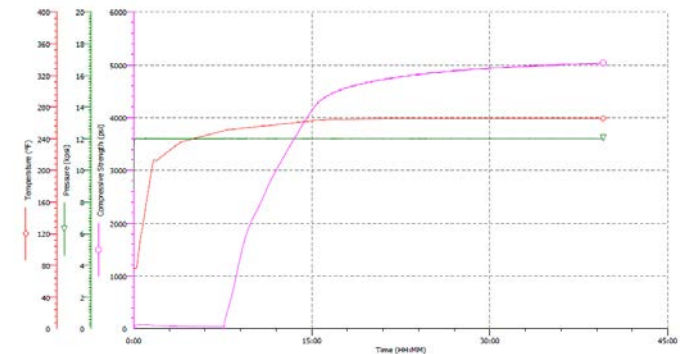


Figure 8: Compressive strength curve of case#2 cement

Case #3:

During an HPHT plug and abandonment operation, 394m of 6" open hole to inside a 7" liner was cemented with 7.75 m³ of gas migration controlled slurry to isolate the 6" section.

A 10% open hole excess was applied to the pumped volume. To separate the cement slurry from the OBM, 7 m³ of weighted spacer with water wetting spacer were pumped ahead of the cement with balanced volume behind. The cement was displaced with 2.15 sg OBM at 1300 lpm. No issues/problems during the job.

The plug was tagged and pressure tested to 160 bar after 24 hrs.

Liquid silica was added to the pre-mixed mix-water without any problems. To account for high solids content, the product was agitated directly ahead of the job to ensure all active ingredients were captured.

Table 7: Technical parameters and cement design of case#3

RKB to Seabed Depth	361m
Plug Measured/True Vertical Depth	4444mMD/4200mTVD
Bottom Hole Static Temperature	140°C
Bottom Hole Circulating Temperature	124°C
Density	2.15 sg
PV (cP)	70.5
YP (lbs/100ft ²)	7.5
Fluid loss (ml/30 min, 1000 psi)	46
CS 12/24 hrs (psi)	3805/4315
Slurry Yield	100.15
Mix Water	Fresh
Product	Concentration (LHK)
Neat Class G Cement	
Liquid Silica	26.5 LHK
Cement Dispersant	0.5
Fluid Loss Control Agent	3.0
High Temperature Retarder	3.1
Cement Defoamer	0.2
Weight Material (Mn ₃ O ₄)	30% BWOC
Mix Water Requirement	29.55
Total Mix-water Requirement	69.10

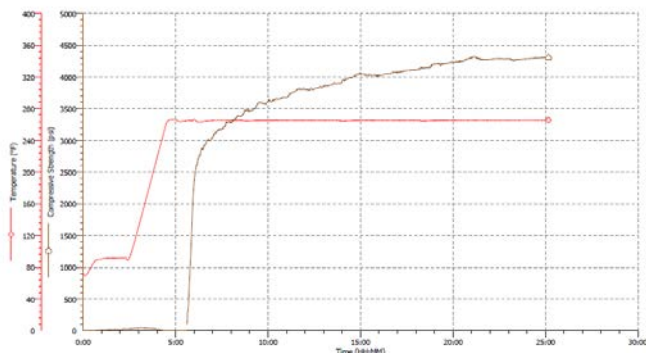


Figure 9: Compressive strength curve of case#3 cement

Conclusions

The use of dry micronized crystalline silica to prevent strength retrogression of oil-well cement at elevated temperatures has potential risks for the people involved in such operations. The use of a silica dispersion can eliminate such risks. The presented silica dispersion, which comprised a mixture of crystalline and amorphous silica is a multi-benefits additive to oil-well cementing. It offers the following advantages:

- 1) Prevents strength retrogression at high temperature >110°C
- 2) Prevents gas migration
- 3) Develops an early high compressive strength
- 4) Forms no free water
- 5) Develops enough viscosity at high temperatures which prevents settling of cement particles

In addition, the study summarized the use of silica flour and microsilica for strength retrogression:

I) Microsilica on its own prevents strength retrogression at high temperatures up to 140°C

II) Silica dispersion comprising a mixture of silica flour and microsilica, with a ratio of 67:33 with a solid content of 75% is used in the field for HT cementing

III) For cementing with a temp from 110-150°C the dosage of 1.5gps (silica=17%BWOC) is sufficient to prevent strength retrogression

IV) For high temperatures >150°C, the dosage of 3gps (silica=35%BWOC) is recommended

V) Silica dispersion is useable for HPHT cementing with a density up to 2.4sg

Silica dispersion is particularly suited for the following cementing applications:

- A) Plug & abandonment jobs where full dry-blending facilities may not be available
- B) Offshore cementing when only silica cement is used in the liner section
- C) Exploration wells and locations with no facility to supply dry-blend of cement + silica flour
- D) Location with strict HSE regulations

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Nomenclature

- gps = gallon per sack. One sack is 94LB (42.2kg)
 BWOC = By Weight of Cement
 CSH = Calcium Silicate Hydrate
 SEM = Scanning Electron Microscopy
 XRD = X-Ray Diffraction
 LHK = Liter per 100kg Cement
 LAS = Liquid Additive System
 LSRPA = liquid Strength Retrogression Prevention Additive
 lpm = liter per minute

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