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Improving Zonal Isolation in Casing Annuli Susceptible to Shallow Water Flows (Case Study)

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***Abstract*—The essential factor in cement setting is the transition of cement slurry to a solid phase and invasion of fluid during this time period intercepts in achieving a proper cement job. Shallow and highly pressurized water zones have been identified in the area of study. The water flows from these zones through the cement to the surface, thus addressing well control hazards and environmental issues. There are various characteristics that define a baseline for a cement to have, to prevent the water percolation through it while setting. The key role resides in thickening time and static gel strength development of the cement slurry.**

The foamed cement, particle size distribution (PSD) cement and microsphere cements have been known to have successfully mitigated the water percolation problem. Each solution has its own merits and demerits thus cost is a crucial factor in selecting one of these solutions.

Two cement slurries were proposed named A-Slurry#1 and A-Slurry#2, these slurries have transition time 2 minutes and 1 minutes respectively as compared to the 13 minutes transition time of case study slurry. The short transition time of the proposed slurries and other characteristics establishes this slurry as a potential candidate to overcome the shallow water flow problems concurrent in the field.

I. INTRODUCTION

Cementing a well is the basic and one of foremost operations in drilling and completing a well. Primarily a well cementing is applied to restrict inter-zonal flows and aiding the well casing by providing necessary support. Some problems concurrent due to an improper cement operation are casing corrosions, casing-cement interface flow, cement defect and mud channels, cement-formation interface flows, fracture flows, micro annuli in cement sheath, thread leaks as shown below[1]:

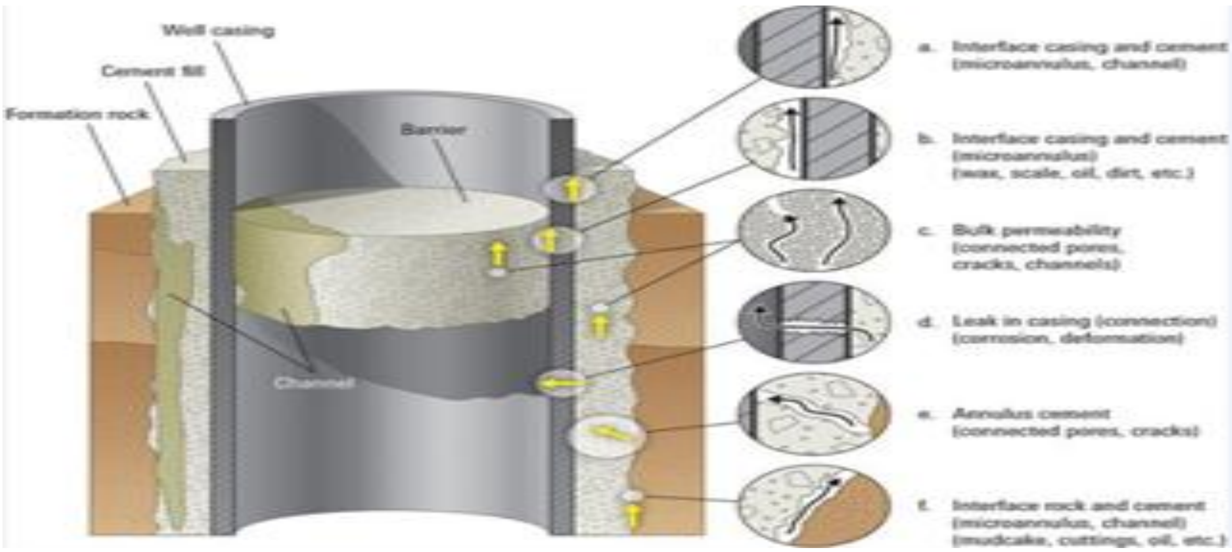

Figure 1 Improper cement outcomes [1]

These problems arise due to improper cement design or challenging formation properties and conditions, such as low fracture gradient formations, shallow water flow zones, loss of circulation zones, thief zones, unstable shale, shallow gas formations and many more. The area of study named “CASE-X” consists of shallow water flow (SWF) zones that are highly pressurized due to connection with an outcrop source and geological complexity of the formations present. The troublesome SWF zones are present at various depths.

II. CASE-X CEMENTING PROBLEMS

The SWF zones have their effects in the exploration and production phases. These can result during the drilling and even at the time of abandonment of the well. There are two major problems faced when encountering an SWF zone consists of cement zonal isolation and surface casing vent flows and sustained Casing Pressures. The surface casing vent flows and sustained casing pressures are emanates of poor zonal isolation subjected under shallow water or gas flows. The problems occurred are further explained as following:

2.1 CEMENT ZONAL ISOLATION

The hydration of slurry with respect to time results in phase transition from soft gel like material to a solid hard material known as Transition time. Transition time is the measure of time from which cement goes from 100 lbf/100 sq. ft (48 Pa) to 500 lbf/100 sq.ft (240 Pa). During the liquid phase of the cement slurry the hydrostatic pressure exerted by this slurry is higher than that of the pore pressure of the adjacent formation. The critical wall shear stress (CWSS) defined as the point where critical hydration period (CHP) begins. At this point cement starts hardening to provide a self-support and the slurry column can no longer transmit hydrostatic pressure. The hydrostatic pressure of the remaining water in the porous and permeable cement must balance with the pore pressure from the formation.

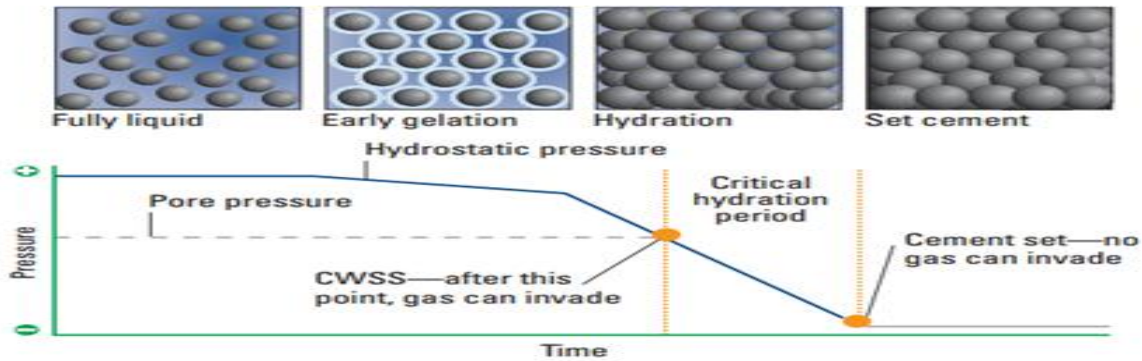

Figure 2 Cement setting process [4]

Since SWF zones have a very high pore pressure, at this point (CHP) the water encroaches into the cement sheath because it has lost its hydrostatic pressure due to hardening and also is not hard enough to resist the water flow. This water flow creates microannuli's and percolates through the cement sheath.

2.2 SURFACE CASING VENT FLOW AND SUSTAINED CASING PRESSURE

Surface casing vent flows are the flow of gas or any liquid or their combinations out of the casing annulus and often referred to as internal migration. Surface casing vent flows are a result of improper zonal isolation of cementing process, which has induced various flows through the systems. The flow can be through the interface of casing –cement, cement-formation, casing leaks, formation fractures, microannuli in cement sheath.

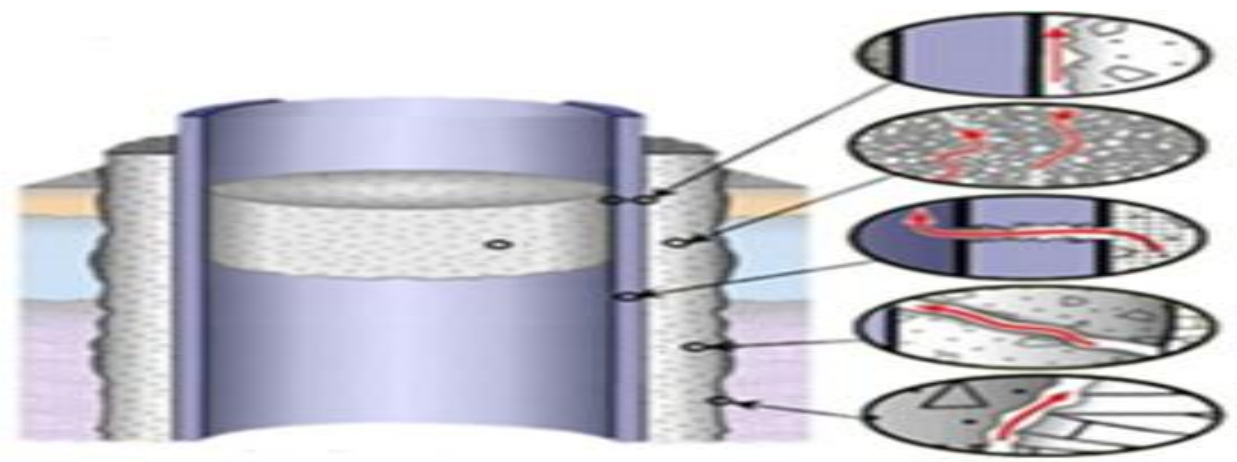

Figure 3 Interface flows [6]

Sustained Casing Pressure (SCP) is an aftereffect of surface casing vent flow that occurs when the flowing fluid doesn't find a flow path towards surface and due to high source pressure it accumulates in the casing annulus. The accumulation of such fluid results in pressure buildup that results in a pressurized annulus. The buildup pressures are bleed-off routinely but have to be permanently shut off prior to well plug and abandonment.

III. CEMENT SOLUTIONS ACROSS THE GLOBE

There have been various SWF zones related problem reported and mitigated with cement slurries by addition of different kinds of additives, but each solution has been constrained towards the situation and conditions present. From all those studies an understanding has been developed for cement slurry to have the following characteristics to mitigate a shallow water zone.

Table 1 Requisite characteristics

PROPERTY	PRESCRIPTION
Free water	Zero free water
Transition time	As low as possible and inversely dependent on pressure of SWF zone
Density	Sufficient to induce overbalanced hydrostatic pressure
Compresive strength	Adequate to support wellbore
Rheology	Sufficient for effective annular displacement

The cements that are widely accepted to have the potential to mitigate SWF zones are as following:

3.1 MICROSPHERE CEMENT

This cement is a strong and lightweight cement containing microspheres composed of silica, flashy shell or other water-soluble substances. These microspheres consist of nitrogen or CO2 or another specified chemical. These slurries are typically used for cementing intermediate casing where low permeability cements are mandatory due to weak formations containing any migrating fluid.

To mitigate SWF zones microsphere cement consists of microspheres filled with super absorbent polymers (SAP) that swell in contact with water and help in plugging the microannuli's created due to percolation of water in the cement sheath [11].

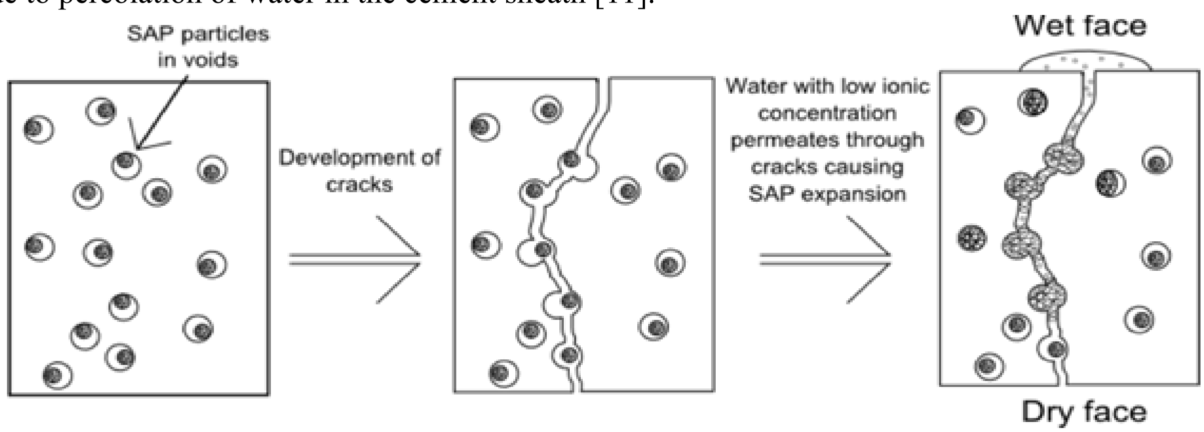

Figure 4 SAP swelling mechanism [10]

3.2 FOAM CEMENT

The foam cements consist of base cement mixed with a gas by compressors and Nitrogen gas is often used to form the foam slurry. The foam slurry is applicable when the density of conventional cement cannot be reduced without deferring the required properties. The cement is utilized in fields of low fracture gradients, low temperatures and Shallow water/gas flow zones.

The mechanism of the foam cement in preventing the migration of fluids during critical hydration period is similar to that of Microsphere cement using pressured microspheres. The compressible property of the cement allow slight compensate for volumetric changes due to cement hydration and leak-off. The viscous nature of the foam resists the flow of annular fluids. These properties combined are used to prevent migration of shallow flows into the cement sheath.

A case study of foam cementing by waheed et.al 2002 [14], a field consisted of many wells but five of them in the vicinity that were prone to shallow water flows The wells are named as V,W,X,Y,Z. Due to water flow problems encountered on well V and W the other wells sharing the same problem were foam cemented and no water flows were encountered. The casing cement design summary is given below:

Well Name	Lead Cement	Tail Cement	Spacer
V	12 ppg gel cement	15 ppg neat cement	Sea water
W	12 ppg gel cement	15 ppg neat cement	Sea water
X	12.1 to 13.4 ppg foam cement	15 ppg neat cement	Sea water
Y	10.8 to 12.6 ppg foam cement	15 ppg neat cement	Sea water
Z	9.8 to 11.8 ppg foam cement	15 ppg neat cement	Sea water

Table 2 Foam cement case

3.3 PARTICLE SIZE DISTRIBUTION (PSD)

Particle size distribution (PSD) cements are based on the concept of solid particle size adjustment. The proper particle size distribution increases the compressive strength of the cement and reduces its porosity and permeability independent to the slurry density

The PSD cement was successfully applied to a field facing SWF zone problems as reported by Landbo T. et.a[32]. The properties of slurry consisted of zero free water, fluid loss 18mL/30min and transition time of 19.6 minutes.

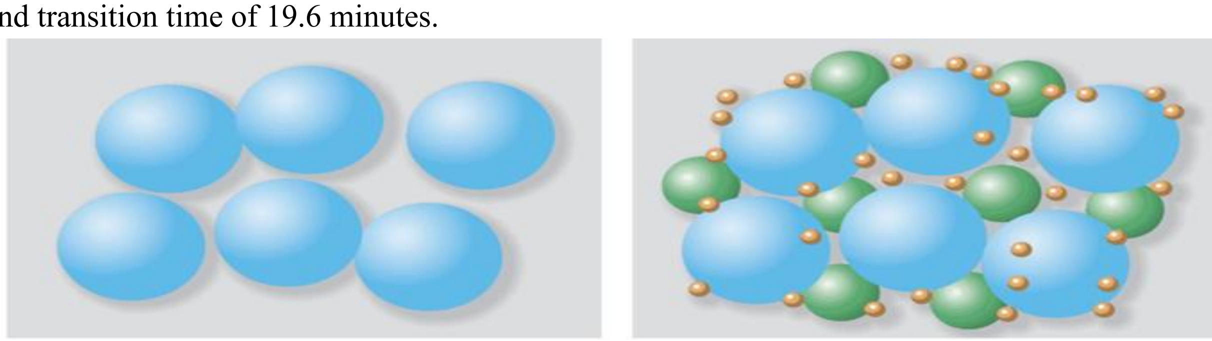

Figure 5 PSD cement structure [14]

IV. METHODOLOGY

In this study, a series of various cement design with their additives would be compared with the cement design applied in the SWF zone from case study. The properties to be compared are enlisted below density, plastic viscosity, yield point, thickening time and free fluid.
The cement designs to be compared consist of Case-X slurry, PSD slurry from a field test[1] and a proposed slurry named A-Slurry. The additives of PSD and Case-X slurry are subject to proprietary matter, but the additives of A-slurry are given below:

Table 3 A-slurry composition

ADDITIVES	A-SLURRY	
	#1	#2
Fresh Water (L)	47.5	43.8
Defoamer (L)	0.01	0.01
Fumed Silica suspension (L)	-	10
Synthetic Fluid loss additives (Kg)	0.6	0.6
Synthetic retarder (Kg)	0.3	0.7
Expansion aid (dry blended) (Kg)	5	7.5
Class G (Kg)	100	100

The A-slurry basically focuses on preventing fluid migration by addition of expansive agents and latent hydraulic materials. These materials form a dense matrix that reduces the permeability and has a higher resistance to fluid percolations

V. PROPERTIES OF CEMENT SLURRIES

The properties measured of the A-slurry are given in the table below:

Table 4 A-Slurry properties

Property	A-SLURRY	
	#1	#2
Density (ppg)	15.8	15.8
Thickening Time (hrs:min) 30 Bc 70 Bc	2:54	6:03

[1] Malakai Deepwater, Block G, Offshore Sabah, Malaysia

100 Bc	3:02 3:04	6:04 6:05
Rheology at mix 300 200 100 60 30 6 3	 218 150 78 48 26 7 4	 107 78 45 30 18 6 5
Plastic viscosity	210	93
Yield Point (lbf/100ft^2)	8	14
Free Water %	0	0
API Fluid Loss (ml/30min)	52	48
UCA at 81.6^{O}C 3000 psi Time to 50 psi Time to 500 psi 24 hrs 48 hrs 72 hrs	 6:38 8:09 2205 2900 3200	 15:02 16:21 2650 3075 3282

The properties of Case-X slurry are given below:

Table 5 Case-X slurry properties

Properties	Case X Slurry
Density (ppg)	15.8
Plastic Viscosity (cp)	40.5
Yield point (lbf/100ft^2)	20.1
Thickening Time @70 Bc	5:45
Transition time from 70 to 100Bc	13 minutes
Free fluid (mL/250mL)	0

The properties of PSD slurry are given as below:

Properties	PSD Cement
Density (ppg)	12.0
Plastic Viscosity (cp)	233.2
Yield point (lbf/100ft^2)	12.1
Thickening Time (hr:mm) @70Bc	12:24
Free fluid (mL/250mL)	0
24-hour compressive strength (psi)	516

Table 6 PSD slurry properties

VI. COMPARISON OF CEMENT SLURRIES

The properties of the Case-X slurry with the PSD slurry and with A-Slurry#1 and A-Slurry#2 are compared as following:

Table 7 Comparison of all slurries

Properties	PSD Cement	Cement A slurry#1	Cement A slurry#1	Case X slurry
Density (ppg)	12.0	15.8	15.8	15.8
Plastic Viscosity (cp)	233.2	210	93	40.5
Yield point (lbf/100ft^2)	12.1	8	14	11.6
Thickening Time (hr:mm) @70 (Bc)	12:24	3:02	6:04	5:45
Transition time 70 to 100 (Bc)	NA	2 minutes	1 minute	13 minute
Free fluid (mL/250mL)	0	0	0	0
24-hour compressive strength psi	516	2205	2650	NA

The discussion for each property is given as following:

- Plastic viscosity: The plastic viscosity of Cement-A slurries and PSD are greater than that of Case-X cement, it determines that they are enough viscous to prevent water percolation when the cement is in liquid phase.
- Yield point: The yield point of all the slurries in the table compared have similar yield point except for slurry 2 that has a lower yield point.
- Thickening Time: The thickening time of Cement A-Slurry#1 is lower than others, which can help in setting the cement earlier than others because it has lower critical hydration period than others. The transition time of Cement Slurry A is very low as compared to Case X slurry that defines how lower its critical hydration period would be, lower critical hydration period means that the slurry forms a solid sheath faster to prevent percolation of water.
- Free Fluid: There was no free fluid in all the slurries compared being a requisite factor for any cement slurry to mitigate shallow water flow zones requires.
- Compressive Strength: The compressive strength development for Cement slurry A-Slurry#1 and A-Slurry#2 are greater than that of PSD cement ensuring a good structural support.

VII. CONCLUSION

The Cement Slurry A shows prominent results that are necessary for a cement system to mitigate shallow water flows to allow a proper cement job execution. The conclusion for the topic considering the requirement and slurry properties analyzed are given as following:

- Shorter thickening time transitions allow the cement to hydrate fast such that it has a minimum critical hydration period.
- The cement slurry has a rapid compressive strength build thus it can be concluded that the transition of slurry from liquid phase to solid is fast resulting in lower critical hydration period.
- The results indicate that the cement is quick setting cement and the slurry is very economic as compared to the foam cement and PSD cement.
- In contrast to PSD cement and foamed cement, the experimental slurry has no technical complexity or any high cost job executions.

The A-Slurry#1 and A-Slurry#2 showcased more prominent results in comparison to the PSD slurry and Case-X slurry.

VIII. RECOMMENDATIONS

The cement slurry proposed has prominent results but there is still room for improvement and advancements. Due to unavailability of some results the permeability and static gel strength development could not be discussed thus questioning the credibility of the cement to be used for mitigating for SWF zones in real field scenarios.

But the results from thickening time of cement seem that the use of cement slurry is provident for preventing shallow water flows.

ABBREVIATIONS

CHP	Critical hydration period
CWSS	Critical wall shear stress
PSD	Particle size distribution
SCP	Sustained casing pressure
SCVF	Surface casing vent flow
SWF	Sallow water flow zones

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